UML Tutorials

Using UML Part Two – Behavioral Modeling Diagrams

by Sparx Systems

http://www.sparxsystems.com

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Introduction

The Unified Modeling Language (UML) has become the de-facto standard for building Object-Oriented software. UML 2.1 builds on the already highly successful UML 2.0 standard, which has become an industry standard for modeling, design and construction of software systems as well as more generalized business and scientific processes. UML 2.1 defines thirteen basic diagram types, divided into two general sets: structural modeling diagrams and behavioral modeling diagrams. Part two will deal with behavioral modeling diagrams.

The Object Management Group (OMG) specification states:

> *"The Unified Modeling Language (UML) is a graphical language for visualizing, specifying, constructing, and documenting the artifacts of a software-intensive system. The UML offers a standard way to write a system's blueprints, including conceptual things such as business processes and system functions as well as concrete things such as programming language statements, database schemas, and reusable software components."*

The important point to note here is UML is a "language" for specifying and not a method or procedure. The UML is used to define a software system – to detail the artifacts in the systems, to document and construct; it is the language the blueprint is written in. The UML may be used in a variety of ways to support a software development methodology (such as the Rational Unified Process), but in itself does not specify that methodology or process.

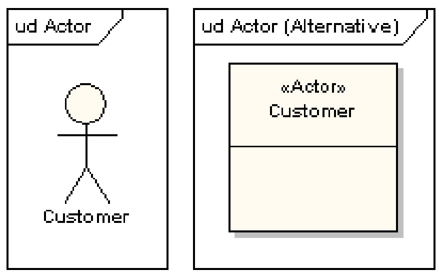
Behavior diagrams capture the varieties of interaction and instantaneous state within a model as it "executes" over time.

Use Case Model

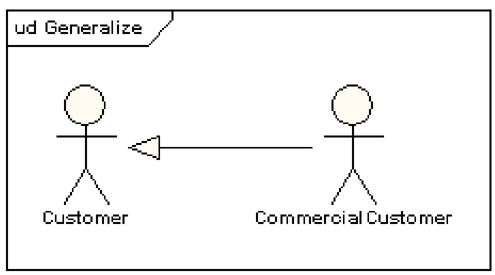
The use case model captures the requirements of a system. Use cases are a means of communicating with users and other stakeholders what the system is intended to do.

Actors

A use case diagram shows the interaction between the system and entities external to the system. These external entities are referred to as actors. Actors represent roles which may include human users, external hardware or other systems. An actor is usually drawn as a named stick figure, or alternatively as a class rectangle with the «actor» keyword.

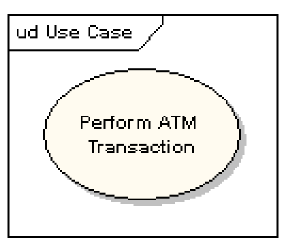


Actors can generalize other actors as detailed in the following diagram:

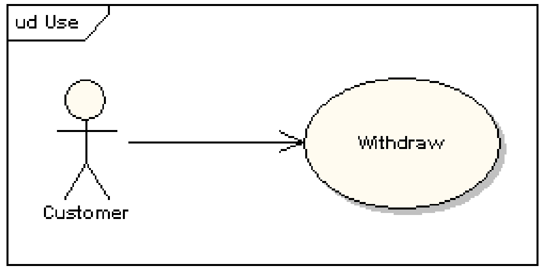


Use Cases

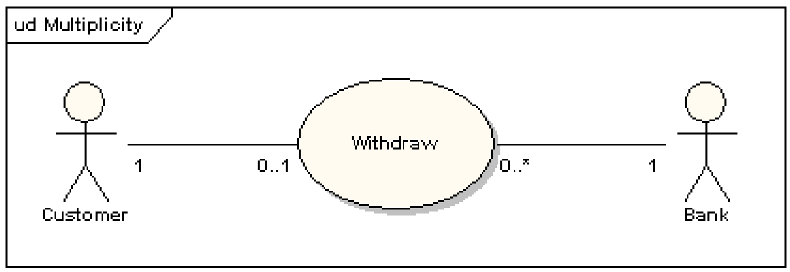
A use case is a single unit of meaningful work. It provides a high-level view of behavior observable to someone or something outside the system. The notation for a use case is an ellipse.



The notation for using a use case is a connecting line with an optional arrowhead showing the direction of control. The following diagram indicates that the actor "Customer" uses the "Withdraw" use case.



The uses connector can optionally have multiplicity values at each end, as in the following diagram, which shows that a customer may only have one withdrawal session at a time, but a bank may have any number of customers making withdrawals concurrently.



Use Case Definition

A use case typically includes:

- Name and description
- Requirements
- Constraints
- Scenarios
- Scenario diagrams
- Additional information.

Name and Description

A use case is normally named as a verb-phrase and given a brief informal textual description.

Requirements

The requirements define the formal functional requirements that a use case must supply to the end user. They correspond to the functional specifications found in structured methodologies. A requirement is a contract or promise that the use case will perform an action or provide some value to the system.

Constraints

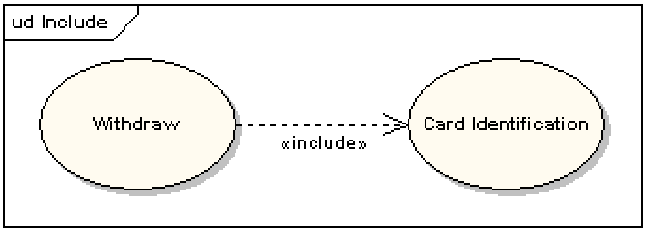
A constraint is a condition or restriction that a use case operates under, and includes pre-, post- and invariant conditions. A precondition specifies the conditions that need to be met before the use case can proceed. A post-condition is used to document the change in conditions that must be true after the execution of the use case. An invariant condition specifies the conditions that are true throughout the execution of the use case.

Scenarios

A scenario is a formal description of the flow of events that occur during the execution of a use case instance. It defines the specific sequence of events between the system and the external actors. It is normally described in text and corresponds to the textual representation of the sequence diagram.

Including Use Cases

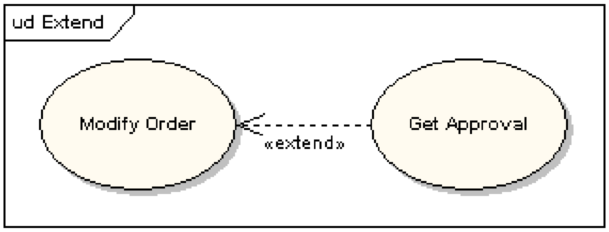
Use cases may contain the functionality of another use case as part of their normal processing. In general it is assumed that any included use case will be called every time the basic path is run. An example of this is to have the execution of the use case <Card Identification> to be run as part of a use case <Withdraw>.



Use Cases may be included by one or more Use Case, helping to reduce the level of duplication of functionality by factoring out common behavior into Use Cases that are re-used many times.

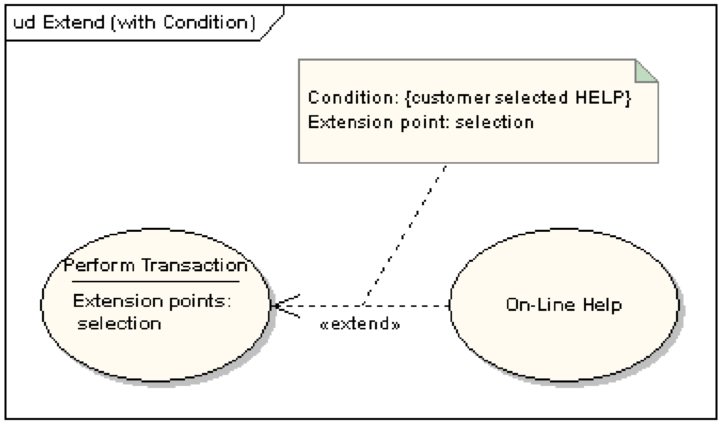
Extending Use Cases

One use case may be used to extend the behavior of another; this is typically used in exceptional circumstances. For example, if before modifying a particular type of customer order, a user must get approval from some higher authority, then the <Get Approval> use case may optionally extend the regular <Modify Order> use case.



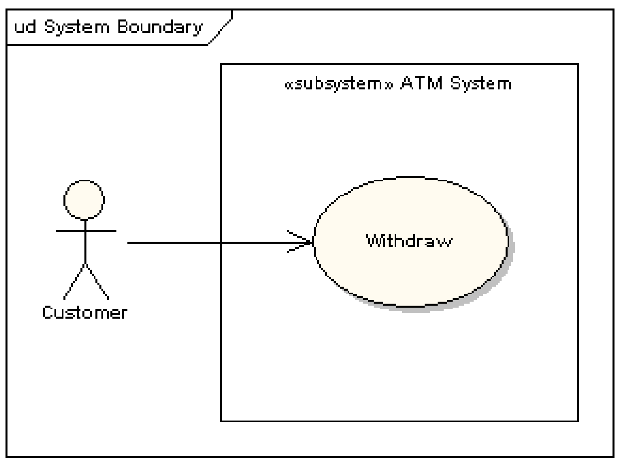
Extension Points

The point at which an extending use case is added can be defined by means of an extension point.



System Boundary

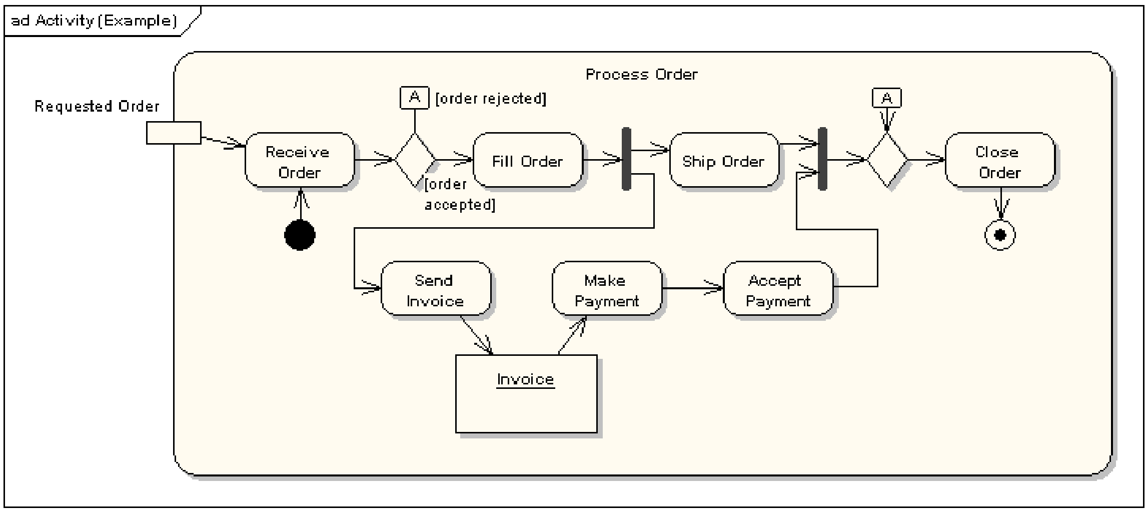
It is usual to display use cases as being inside the system and actors as being outside the system.



Activity Diagrams

In UML an activity diagram is used to display the sequence of activities. Activity diagrams show the workflow from a start point to the finish point detailing the many decision paths that exist in the progression of events contained in the activity. They may be used to detail situations where parallel processing may occur in the execution of some activities. Activity diagrams are useful for business modeling where they are used for detailing the processes involved in business activities.

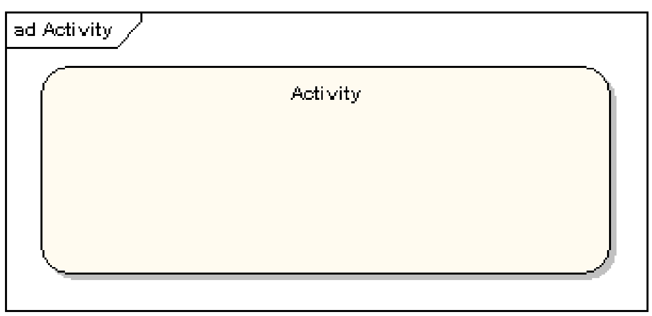
An example of an activity diagram is shown below.



The following sections describe the elements that constitute an Activity diagram.

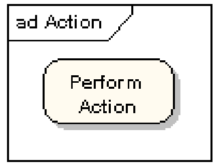
Activities

An activity is the specification of a parameterized sequence of behavior. An activity is shown as a round-cornered rectangle enclosing all the actions, control flows and other elements that make up the activity.



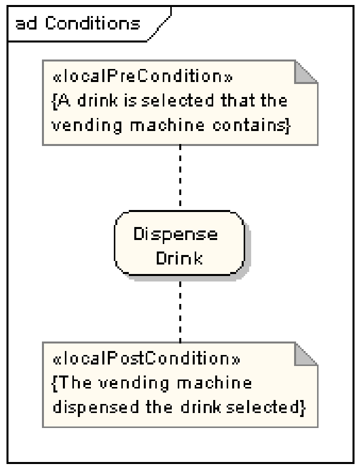
Actions

An action represents a single step within an activity. Actions are denoted by round-cornered rectangles.



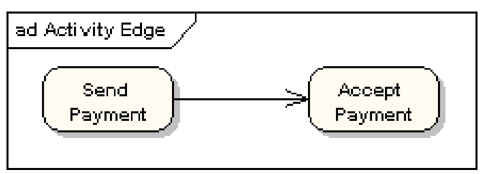
Action Constraints

Constraints can be attached to an action. The following diagram shows an action with local pre- and post-conditions.



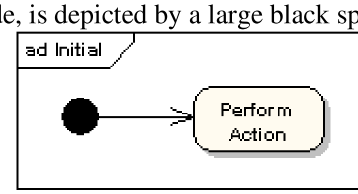
Control Flow

A control flow shows the flow of control from one action to the next. Its notation is a line with an arrowhead.



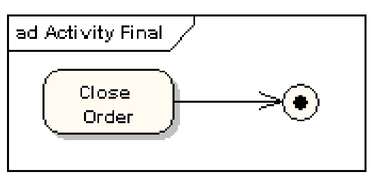
Initial Node

An initial, or start node, is depicted by a large black spot, as shown below.

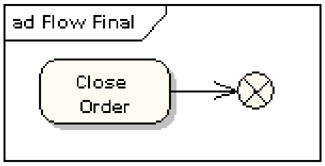


Final Node

There are two types of final node: activity and flow final nodes. The activity final node is depicted as a circle with a dot inside.



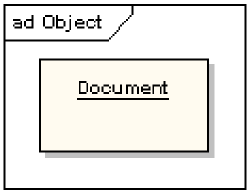
The flow final node is depicted as a circle with a cross inside.



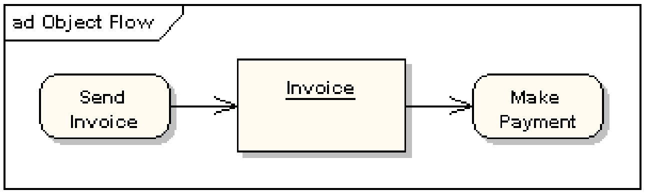
The difference between the two node types is that the flow final node denotes the end of a single control flow; the activity final node denotes the end of all control flows within the activity.

Objects and Object Flows

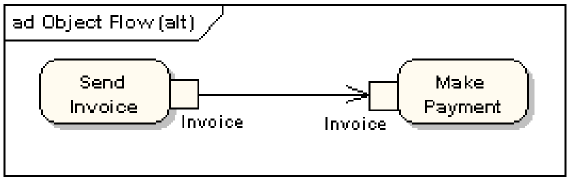
An object flow is a path along which objects or data can pass. An object is shown as a rectangle.



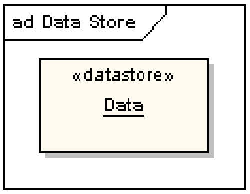
An object flow is shown as a connector with an arrowhead denoting the direction the object is being passed.



An object flow must have an object on at least one of its ends. A shorthand notation for the above diagram would be to use input and output pins.

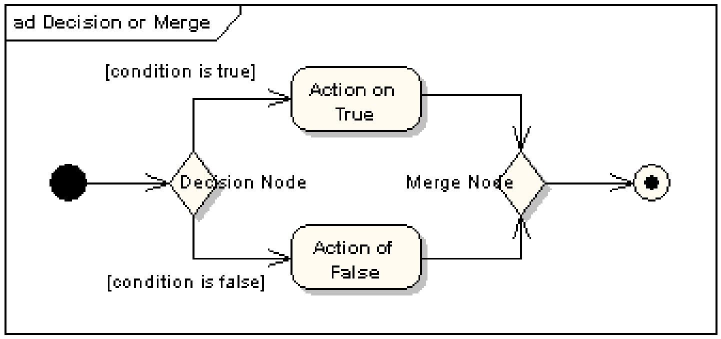


A data store is shown as an object with the «datastore» keyword.



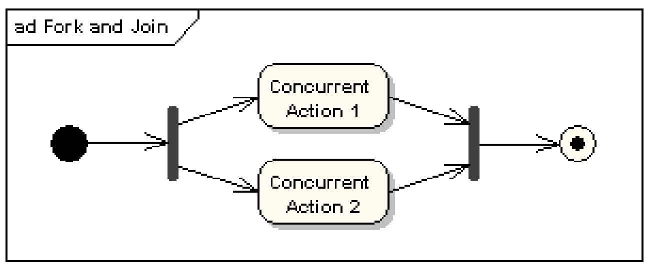
Decision and Merge Nodes

Decision nodes and merge nodes have the same notation: a diamond shape. They can both be named. The control flows coming away from a decision node will have guard conditions which will allow control to flow if the guard condition is met. The following diagram shows use of a decision node and a merge node.



Fork and Join Nodes

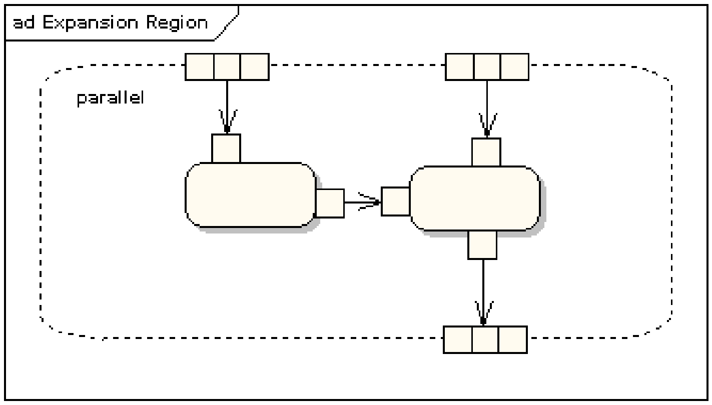
Forks and joins have the same notation: either a horizontal or vertical bar (the orientation is dependent on whether the control flow is running left to right or top to bottom). They indicate the start and end of concurrent threads of control. The following diagram shows an example of their use.



A join is different from a merge, in that the join synchronizes two inflows and produces a single outflow. The outflow from a join cannot execute until all inflows have been received. A merge passes any control flows straight through it. If two or more inflows are received by a merge symbol, the action pointed to by its outflow is executed two or more times.

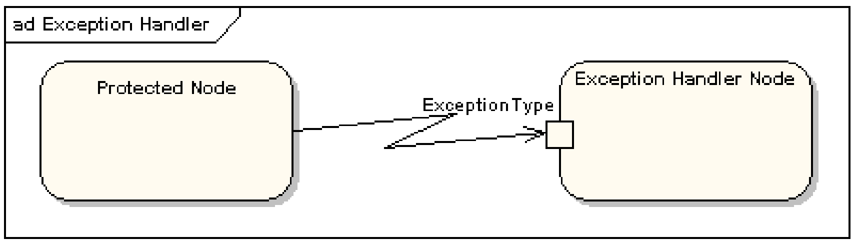
Expansion Region

An expansion region is a structured activity region that executes multiple times. Input and output expansion nodes are drawn as a group of three boxes representing a multiple selection of items. The keyword iterative, parallel or stream is shown in the top left corner of the region.



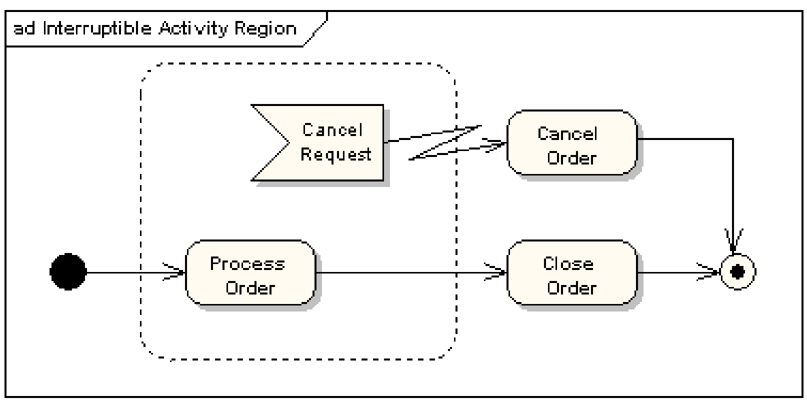
Exception Handlers

Exception handlers can be modeled on activity diagrams, as in the example below.



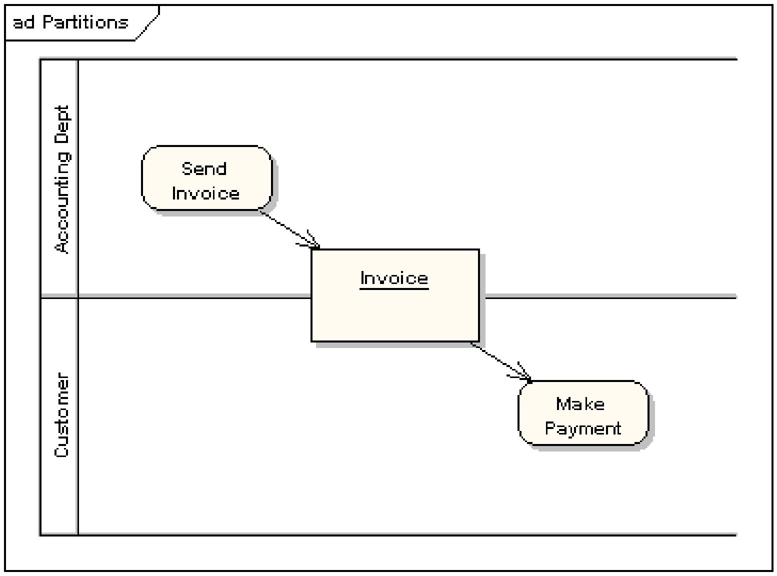
Interruptible Activity Region

An interruptible activity region surrounds a group of actions that can be interrupted. In the very simple example below, the "Process Order" action will execute until completion, when it will pass control to the "Close Order" action, unless a "Cancel Request" interrupt is received, which will pass control to the "Cancel Order" action.



Partition

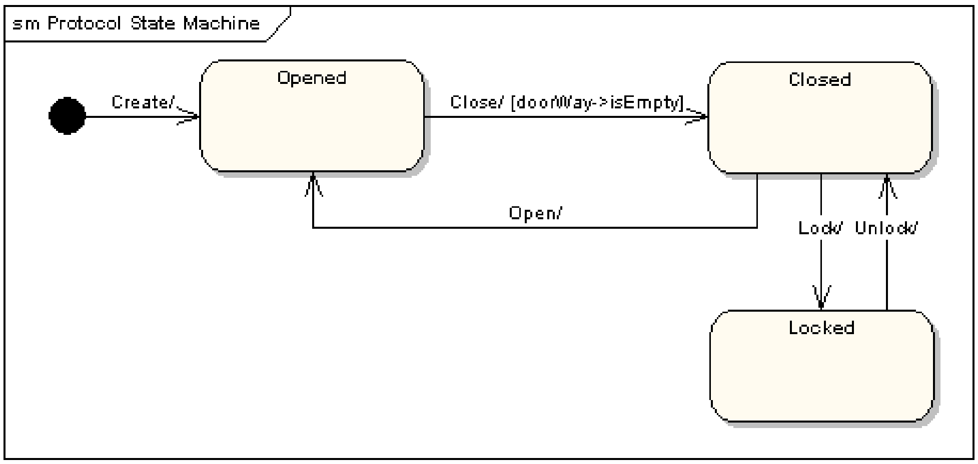
An activity partition is shown as either a horizontal or vertical swimlane
. In the following diagram, the partitions are used to separate actions within an activity into those performed by the accounting department and those performed by the customer.


ad Partitions
Accounting Dept
Customer
Send Invoice
Invoice
Make Payment

State Machine Diagrams

A state machine diagram models the behavior of a single object, specifying the sequence of events an object goes through during its lifetime in response to events.

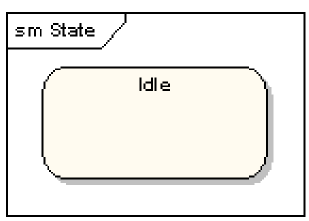
As an example, the following state machine diagram shows the states that a door goes through during its lifetime.



The door can be in one of three states: "Opened", "Closed" or "Locked". It can respond to the events Open, Close, Lock and Unlock. Not all events are valid in all states; for example, if a door is opened, you cannot lock it until you close it. Also notice that a state transition can have a guard condition attached: if the door is opened, it can only respond to the Close event if the condition doorWay->isEmpty is fulfilled. The syntax and conventions used in state machine diagrams will be discussed in full in the following sections.

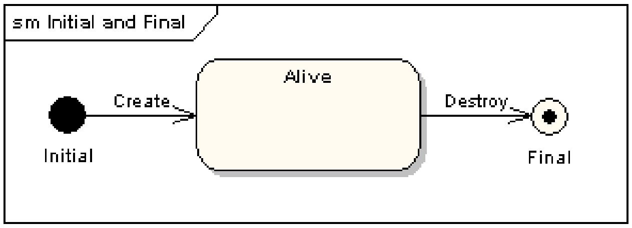
States

A State is denoted by a round-cornered rectangle with the name of the state written inside it.



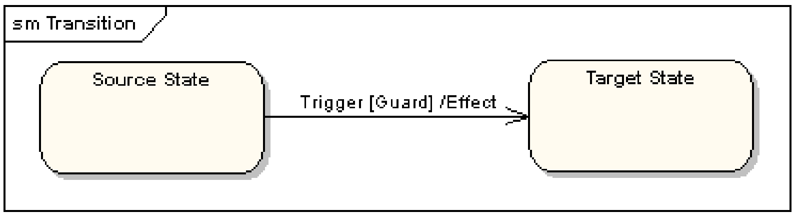
Initial and Final States

The initial state is denoted by a filled black circle and may be labeled with a name. The final state is denoted by a circle with a dot inside, and may also be labeled with a name.



Transitions

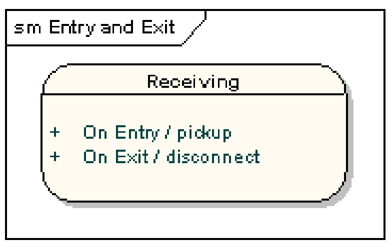
Transitions from one state to the next are denoted by lines with arrowheads. A transition may have a trigger, a guard and an effect, as below.



"Trigger" is the cause of the transition, which could be a signal, an event, a change in some condition, or the passage of time. "Guard" is a condition which must be true in order for the trigger to cause the transition. "Effect" is an action which will be invoked directly on the object that owns the state machine as a result of the transition.

State Actions

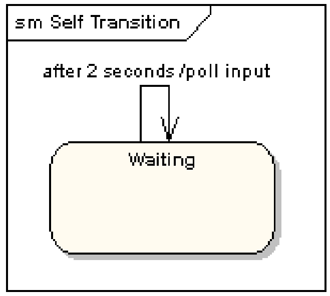
In the transition example above, an effect was associated with the transition. If the target state had many transitions arriving at it, and each transition had the same effect associated with it, it would be better to associate the effect with the target state rather than the transitions. This can be done by defining an entry action for the state. The diagram below shows a state with an entry action and an exit action.



It is also possible to define actions that occur on events, or actions that always occur. It is possible to define any number of actions of each type.

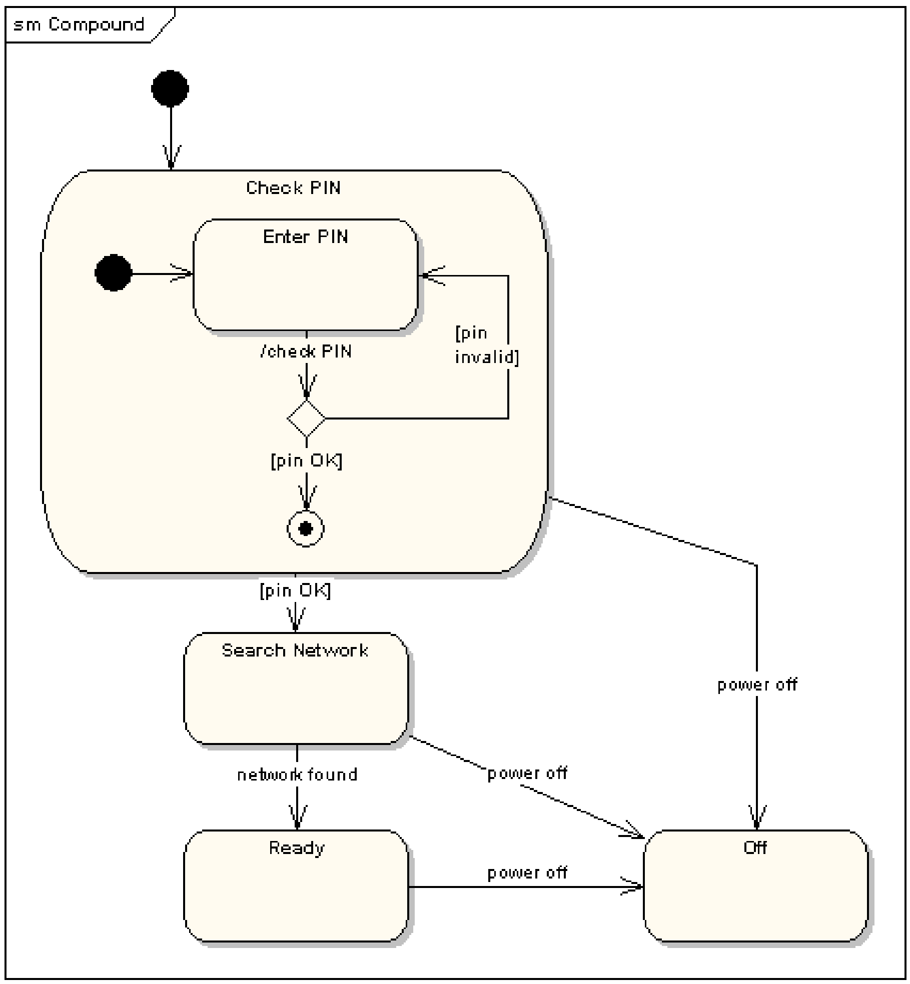
Self-Transitions

A state can have a transition that returns to itself, as in the following diagram. This is most useful when an effect is associated with the transition.

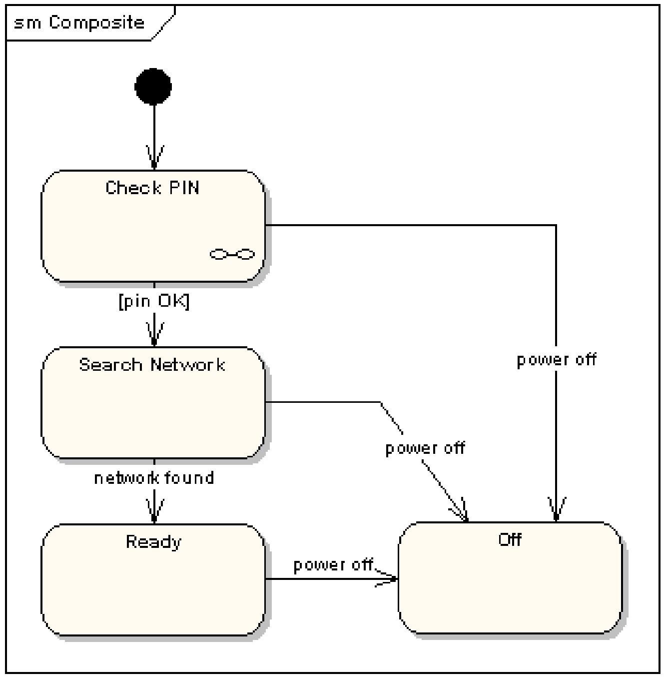


Compound States

A state machine diagram may include sub-machine diagrams, as in the example below.



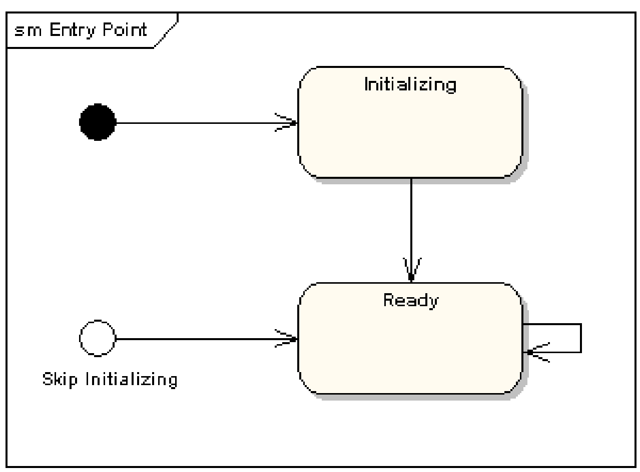
The alternative way to show the same information is as follows.



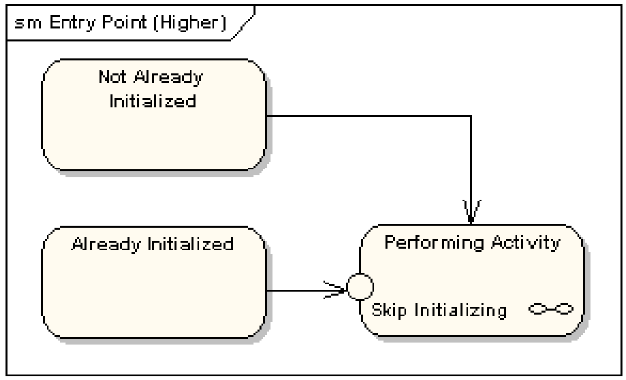
The notation in the above version indicates that the details of the Check PIN sub-machine are shown in a separate diagram.

Entry Point

Sometimes you won't want to enter a sub-machine at the normal Initial State. For example, in the following sub-machine it would be normal to begin in the Initializing state, but if for some reason it wasn't necessary to perform the initialization, it would be possible to begin in the Ready state by transitioning to the named Entry Point.

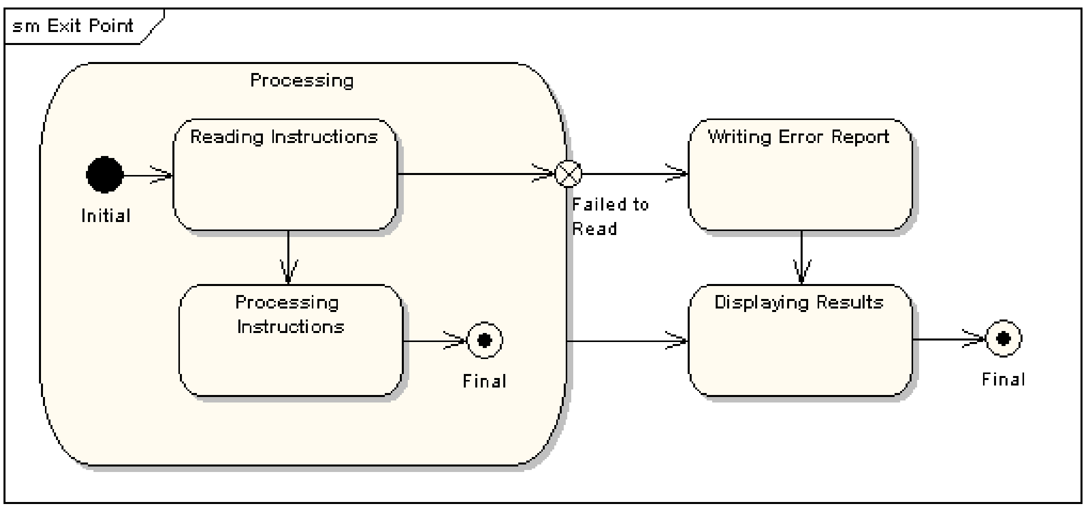


The following diagram shows the state machine one level up.



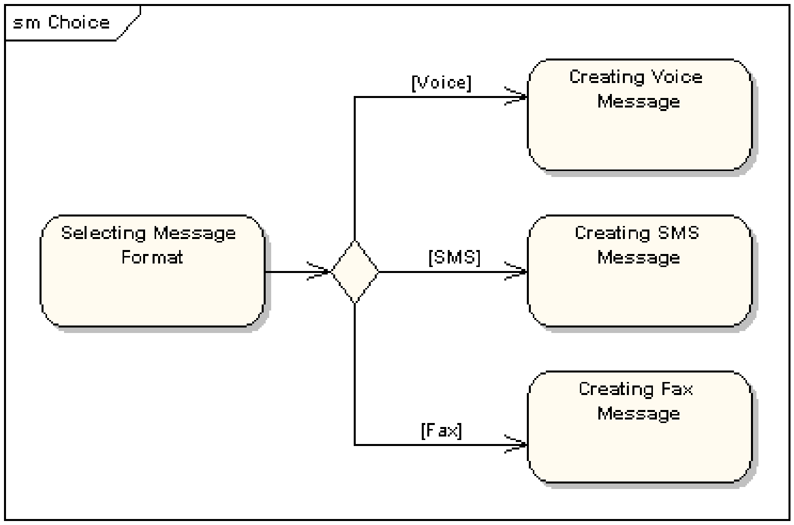
Exit Point

In a similar manner to entry points, it is possible to have named alternative exit points. The following diagram gives an example where the state executed after the main processing state depends on which route is used to transition out of the state.



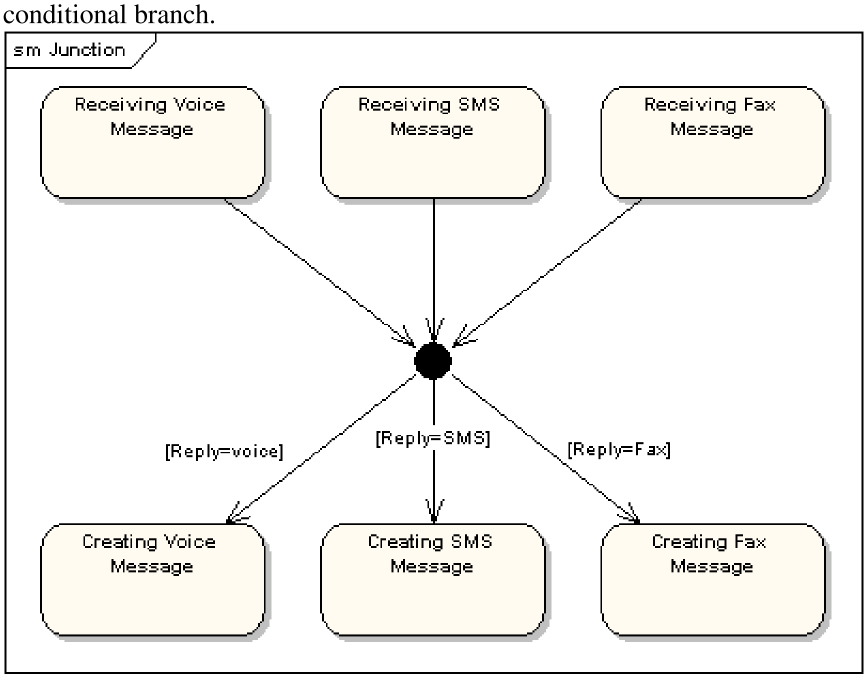
Choice Pseudo-State

A choice pseudo-state is shown as a diamond with one transition arriving and two or more transitions leaving. The following diagram shows that whichever state arrived at, after the choice pseudo-state, is dependent on the message format selected during execution of the previous state.



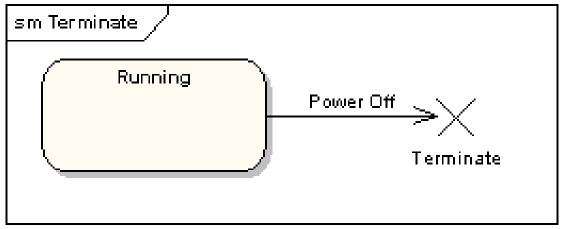
Junction Pseudo-State

Junction pseudo-states are used to chain together multiple transitions. A single junction can have one or more incoming, and one or more outgoing, transitions; a guard can be applied to each transition. Junctions are semantic-free; a junction that splits an incoming transition into multiple outgoing transitions realizes a static conditional branch, as opposed to a choice pseudo-state which realizes a dynamic conditional branch.



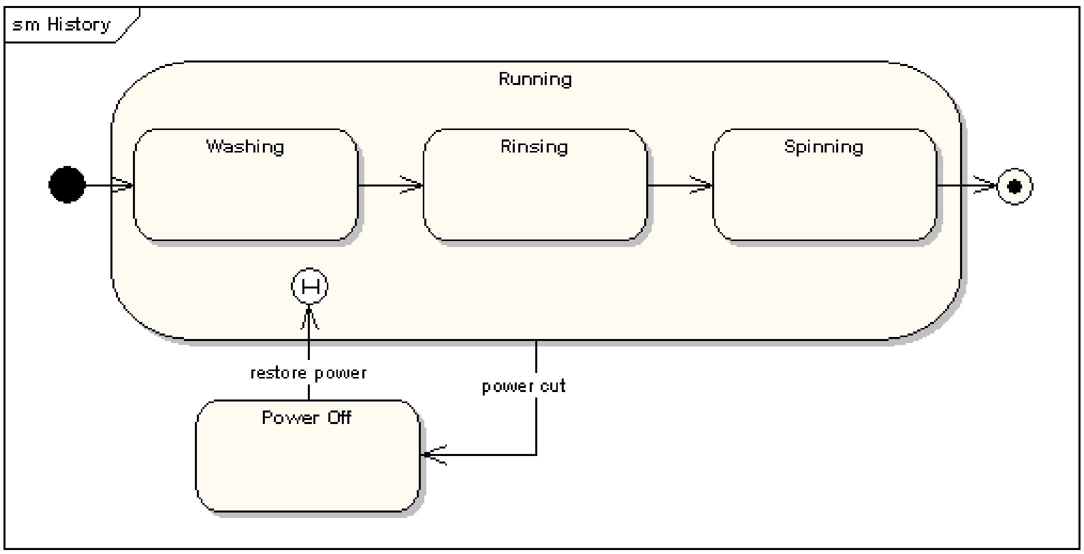
Terminate Pseudo-State

Entering a terminate pseudo-state indicates that the lifeline of the state machine has ended. A terminate pseudo-state is notated as a cross.



History States

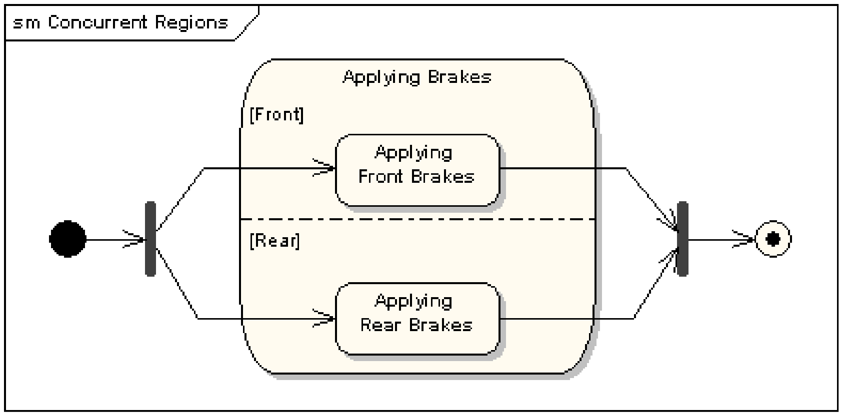
A History State is used to remember the previous state of a state machine when it was interrupted. The following diagram illustrates the use of history states. The example is a state machine belonging to a washing machine.



In this state machine, when a washing machine is running, it will progress from "Washing" through "Rinsing" to "Spinning". If there is a power cut, the washing machine will stop running and will go to the "Power Off" state. When the power is restored, the running state is entered at the "History State" symbol meaning that it should resume where it last left-off.

Concurrent Regions

A state may be divided into regions containing sub-states that exist and execute concurrently. The example below shows that within the state "Applying Brakes", the front and rear brakes will be operating simultaneously and independently. Notice the use of fork and join pseudo-states, rather than choice and merge pseudo-states. These symbols are used to synchronize the concurrent threads.

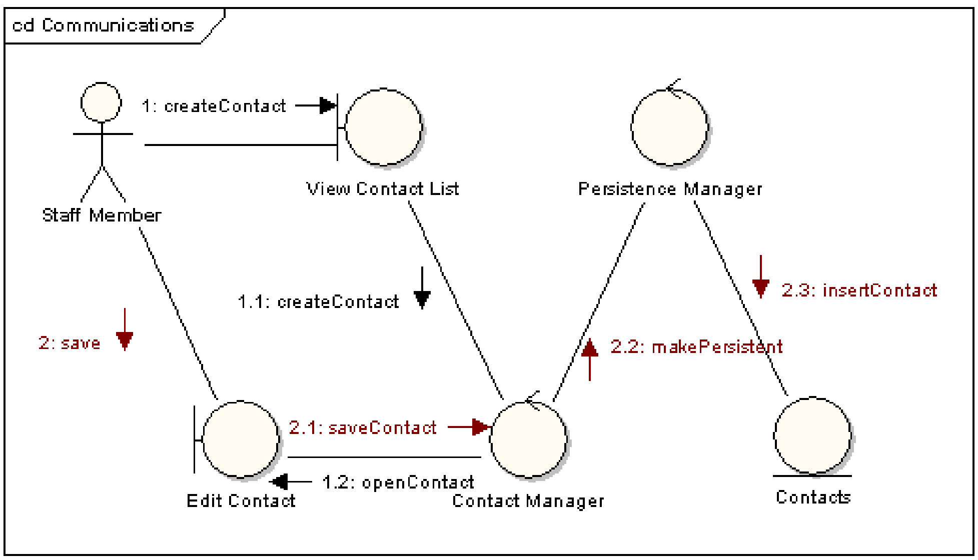

sm Concurrent Regions
Applying Brakes
[Front]
Applying Front Brakes
[Rear]
Applying Rear Brakes

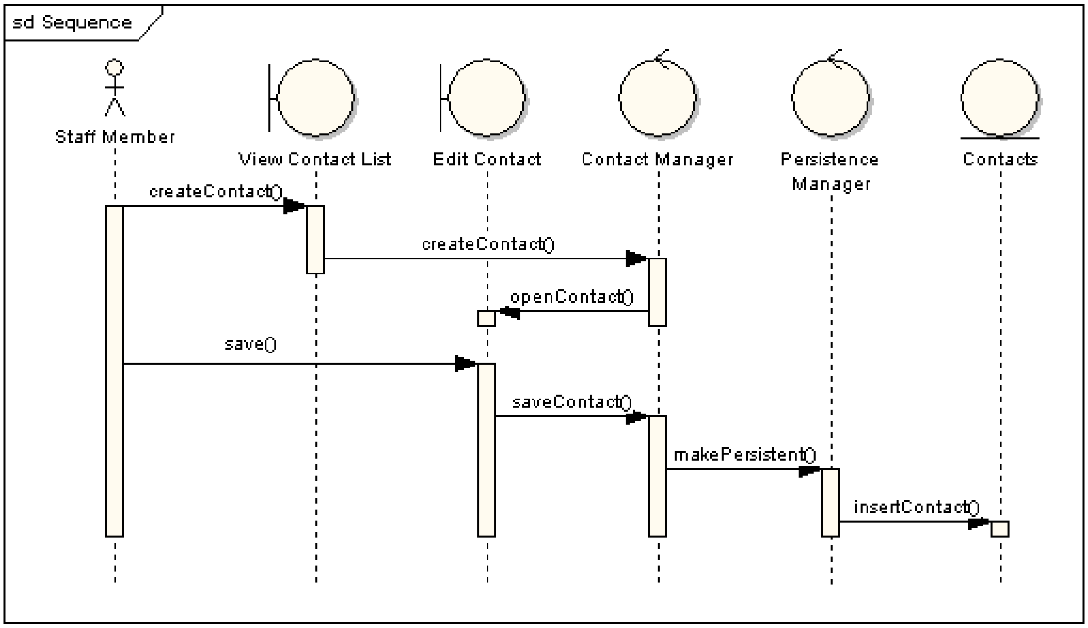
Communication Diagrams

A communication diagram, formerly called a collaboration diagram, is an interaction diagram that shows similar information to sequence diagrams but its primary focus is on object relationships.

On communication diagrams, objects are shown with association connectors between them. Messages are added to the associations and show as short arrows pointing in the direction of the message flow. The sequence of messages is shown through a numbering scheme.

The following two diagrams show a communication diagram and the sequence diagram that shows the same information. Although it is possible to derive the sequencing of messages in the communication diagram from the numbering scheme, it isn't immediately visible. What the communication diagram does show quite clearly though, is the full set of messages passed between adjacent objects.



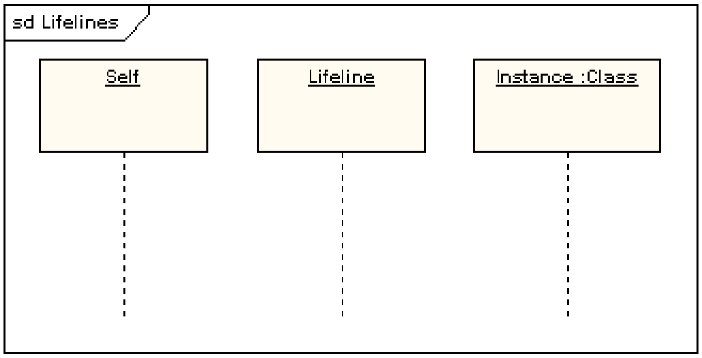

sd Sequence
Staff Member
View Contact List
Edit Contact
Contact Manager
Persistence Manager
Contacts
createContact()
createContact()
openContact()
save()
saveContact()
makePersistent()
insertContact()

Sequence Diagrams

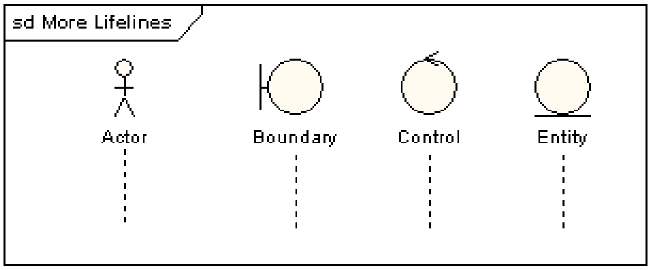
A sequence diagram is a form of interaction diagram that shows objects as lifelines running down the page, with their interactions over time represented as messages drawn as arrows from the source lifeline to the target lifeline. Sequence diagrams are good for showing which objects communicate with which other objects, and what messages trigger those communications. Sequence diagrams are not intended for showing complex procedural logic.

Lifelines

A lifeline represents an individual participant in a sequence diagram. A lifeline will usually have a rectangle containing its object name. If its name is "self", that indicates the lifeline represents the classifier which owns the sequence diagram.

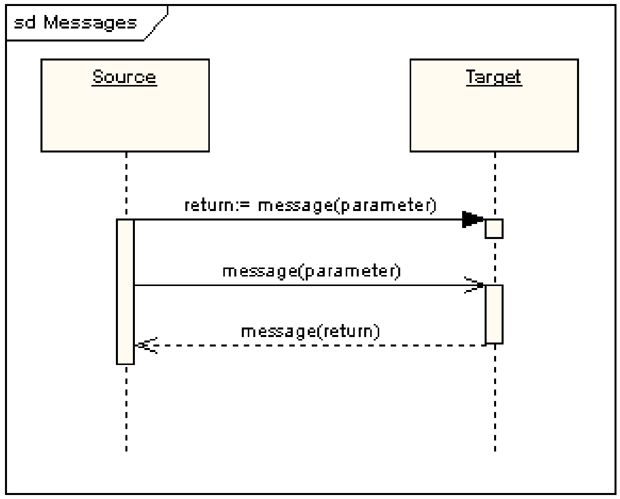


Sometimes a sequence diagram will have a lifeline with an actor element symbol at its head. This will usually be the case if the sequence diagram is owned by a use case. Boundary, control and entity elements from robustness diagrams can also own lifelines.



Messages

Messages are displayed as arrows. Messages can be complete, lost or found; synchronous or asynchronous; call or signal. In the following diagram, the first message is a synchronous message (denoted by the solid arrowhead) complete with an implicit return message; the second message is asynchronous (denoted by line arrowhead), and the third is the asynchronous return message (denoted by the dashed line).

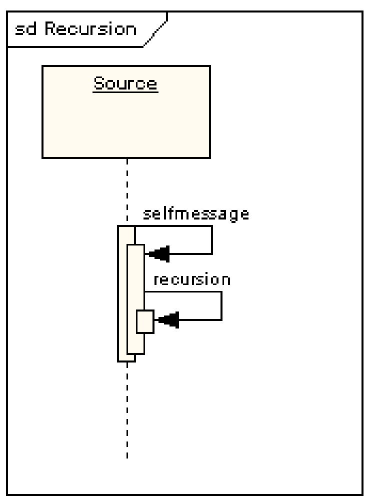


Execution Occurrence

A thin rectangle running down the lifeline denotes the execution occurrence, or activation of a focus of control. In the previous diagram, there are three execution occurrences. The first is the source object sending two messages and receiving two replies; the second is the target object receiving a synchronous message and returning a reply; and the third is the target object receiving an asynchronous message and returning a reply.

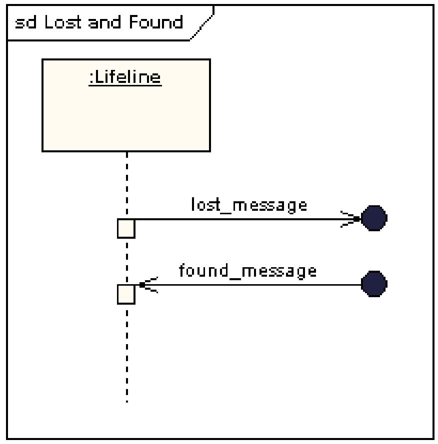
Self Message

A self message can represent a recursive call of an operation, or one method calling another method belonging to the same object. It is shown as creating a nested focus of control in the lifeline's execution occurrence.



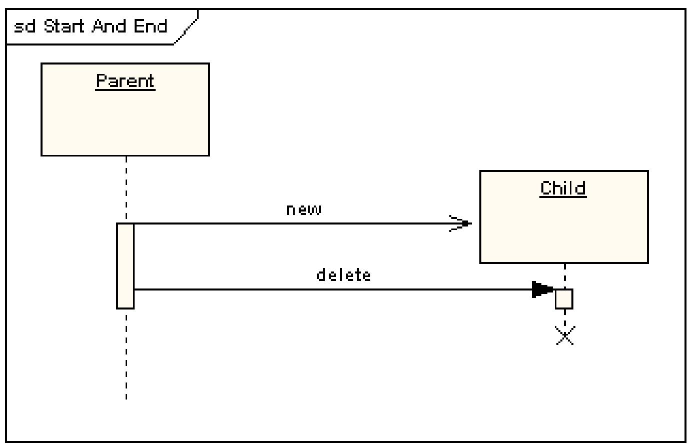
Lost and Found Messages

Lost messages are those that are either sent but do not arrive at the intended recipient, or which go to a recipient not shown on the current diagram. Found messages are those that arrive from an unknown sender, or from a sender not shown on the current diagram. They are denoted going to or coming from an endpoint element.



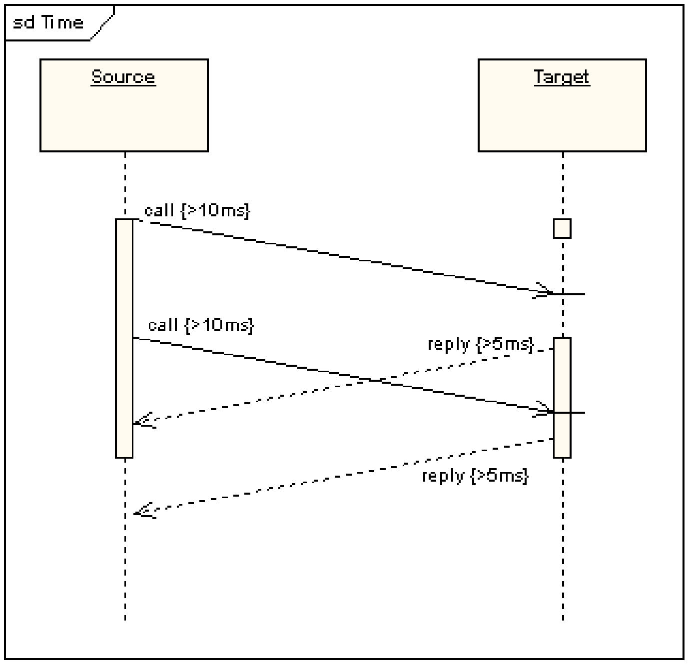
Lifeline Start and End

A lifeline may be created or destroyed during the timescale represented by a sequence diagram. In the latter case, the lifeline is terminated by a stop symbol, represented as a cross. In the former case, the symbol at the head of the lifeline is shown at a lower level down the page than the symbol of the object that caused the creation. The following diagram shows an object being created and destroyed.



Duration and Time Constraints

By default, a message is shown as a horizontal line. Since the lifeline represents the passage of time down the screen, when modeling a real-time system, or even a time-bound business process, it can be important to consider the length of time it takes to perform actions. By setting a duration constraint for a message, the message will be shown as a sloping line.



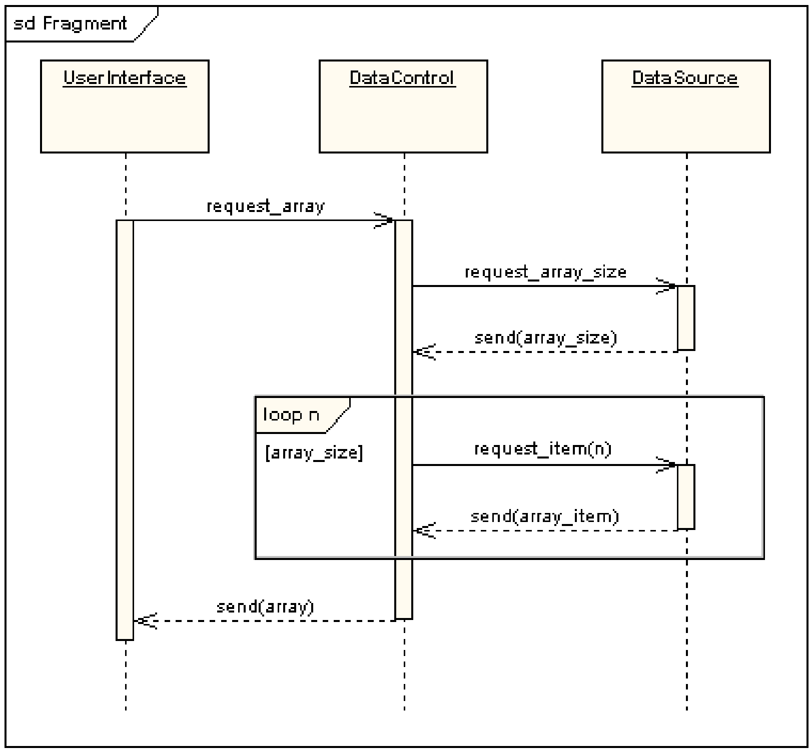
Combined Fragments

It was stated earlier that Sequence diagrams are not intended for showing complex procedural logic. While this is the case, there are a number of mechanisms that do allow for adding a degree of procedural logic to diagrams and which come under the heading of combined fragments. A combined fragment is one or more processing sequence enclosed in a frame and executed under specific named circumstances. The fragments available are:

- Alternative fragment (denoted “alt”) models if…then…else constructs.
- Option fragment (denoted “opt”) models switch constructs.
- Break fragment models an alternative sequence of events that is processed instead of the whole of the rest of the diagram.
- Parallel fragment (denoted “par”) models concurrent processing.
- Weak sequencing fragment (denoted “seq”) encloses a number of sequences for which all the messages must be processed in a preceding segment before the following segment can start, but which does not impose any sequencing within a segment on messages that don’t share a lifeline.
- Strict sequencing fragment (denoted “strict”) encloses a series of messages which must be processed in the given order.
- Negative fragment (denoted “neg”) encloses an invalid series of messages.
- Critical fragment encloses a critical section.
- Ignore fragment declares a message or message to be of no interest if it appears in the current context.
- Consider fragment is in effect the opposite of the ignore fragment: any message not included in the consider fragment should be ignored.

- Assertion fragment (denoted "assert") designates that any sequence not shown as an operand of the assertion is invalid.
- Loop fragment encloses a series of messages which are repeated.

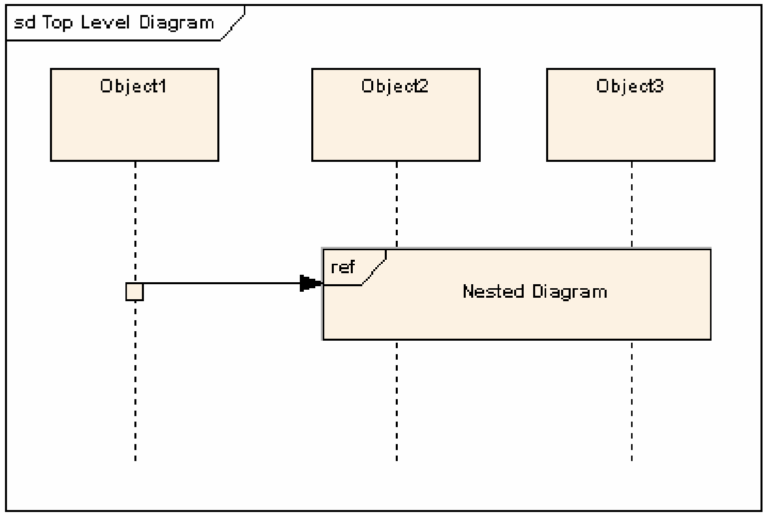
The following diagram shows a loop fragment.

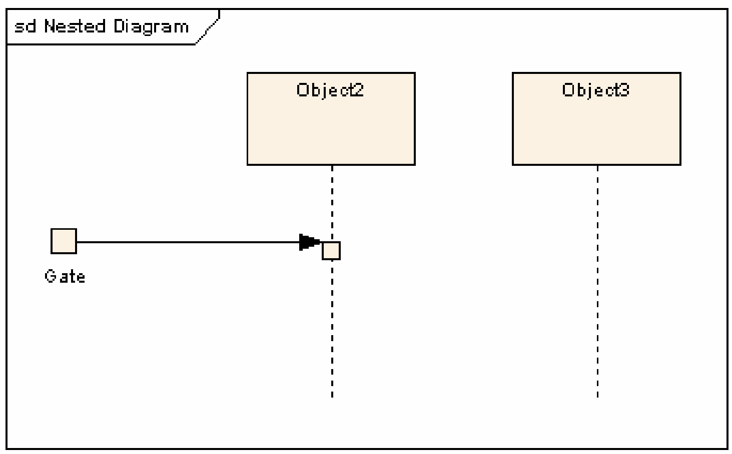


There is also an interaction occurrence, which is similar to a combined fragment. An interaction occurrence is a reference to another diagram which has the word "ref" in the top left corner of the frame, and has the name of the referenced diagram shown in the middle of the frame.

Gate

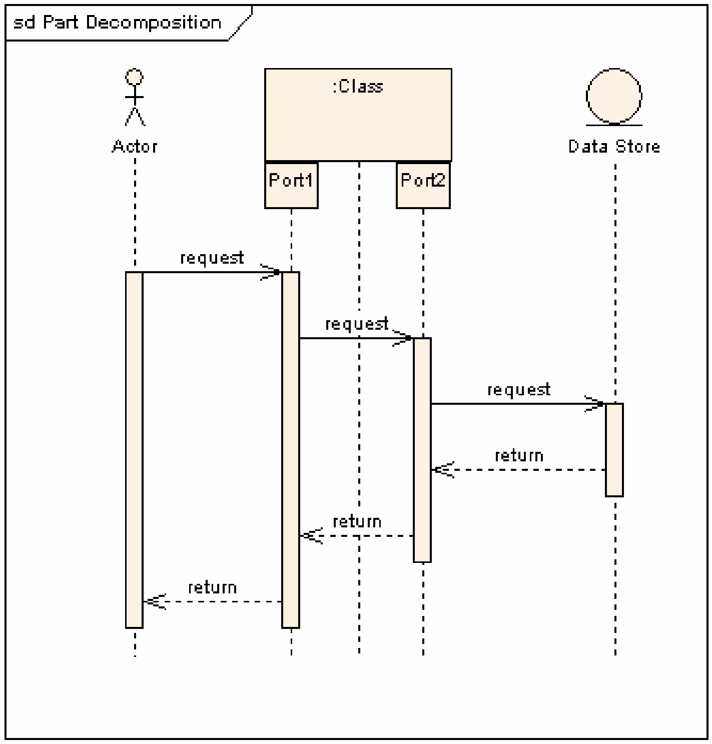
A gate is a connection point for connecting a message inside a fragment with a message outside a fragment. EA shows a gate as a small square on a fragment frame. Diagram gates act as off-page connectors for sequence diagrams, representing the source of incoming messages or the target of outgoing messages. The following two diagrams show how they might be used in practice. Note that the gate on the top level diagram is the point at which the message arrowhead touches the reference fragment - there is no need to render it as a box shape.





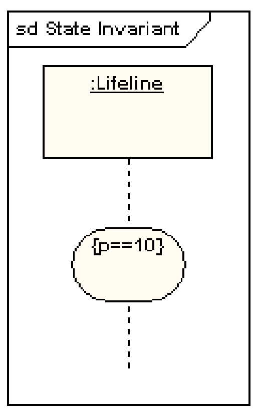
Part Decomposition

An object can have more than one lifeline coming from it. This allows for inter- and intra-object messages to be displayed on the same diagram.



State Invariant / Continuations

A state invariant is a constraint placed on a lifeline that must be true at run-time. It is shown as a rectangle with semi-circular ends.



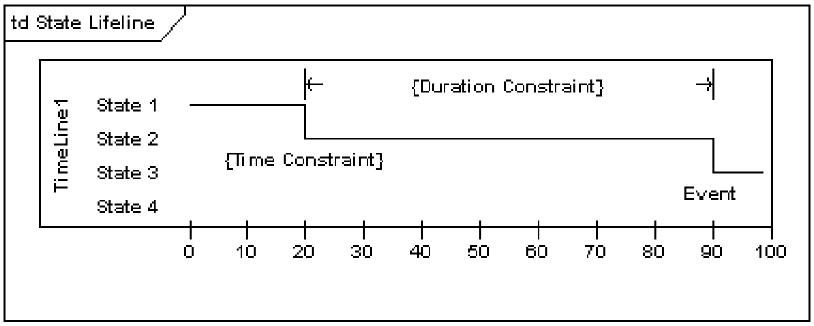
A continuation has the same notation as a state invariant, but is used in combined fragments and can stretch across more than one lifeline.

Timing Diagrams

UML timing diagrams are used to display the change in state or value of one or more elements over time. It can also show the interaction between timed events and the time and duration constraints that govern them.

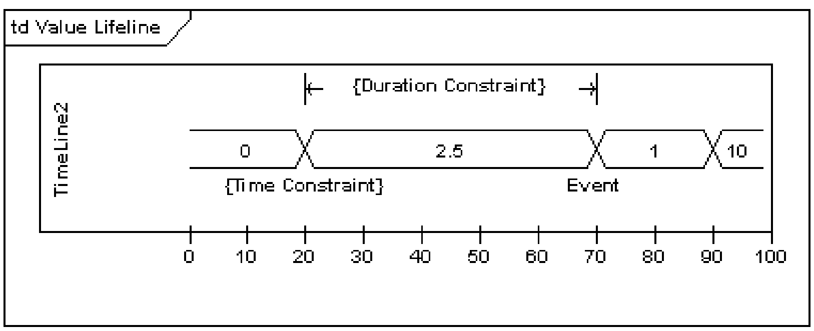
State Lifeline

A state lifeline shows the change of state of an item over time. The X-axis displays elapsed time in whatever units are chosen, while the Y-axis is labeled with a given list of states. A state lifeline is shown below.



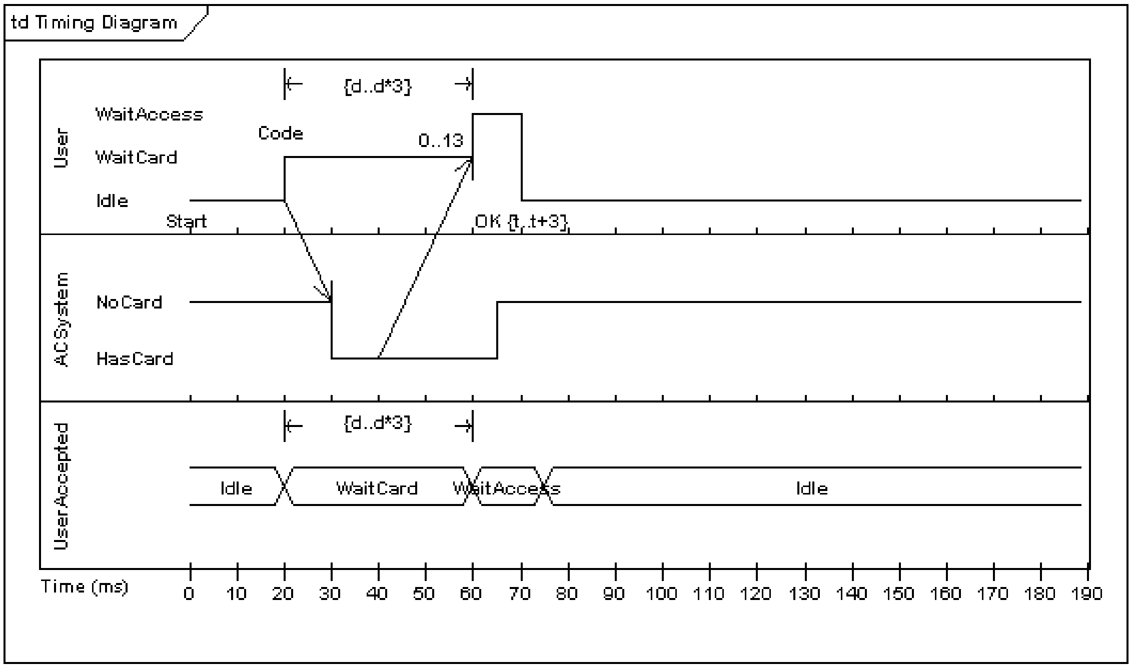
Value Lifeline

A value lifeline shows the change of value of an item over time. The X-axis displays elapsed time in whatever units are chosen, the same as for the state lifeline. The value is shown between the pair of horizontal lines which crosses over at each change in value. A value lifeline is shown below.



Putting it all together

State and value lifelines can be stacked one on top of another in any combination. They must have the same X-axis. Messages can be passed from one lifeline to another. Each state or value transition can have a defined event, a time constraint which indicates when an event must occur, and a duration constraint which indicates how long a state or value must be in effect for. Once these have all been applied, a timing diagram may look like the following.

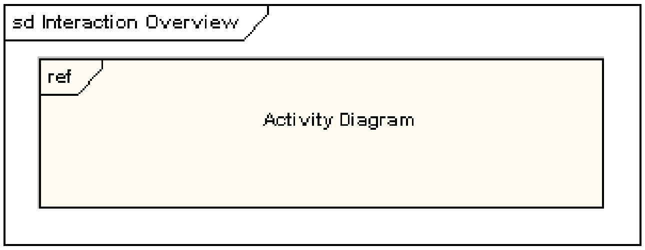

td Timing Diagram
User
WaitAccess
WaitCard
Idle
{d..d*3}
Code
0..13
Start
OK {t..t+3}
ACSystem
NoCard
HasCard
UserAccepted
{d..d*3}
Idle
WaitCard
WaitAccess
Idle
Time (ms)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190

Interaction Overview Diagrams

An interaction overview diagram is a form of activity diagram in which the nodes represent interaction diagrams. Interaction diagrams can include sequence, communication, interaction overview, and timing diagrams. Most of the notation for interaction overview diagrams is the same for activity diagrams. For example initial, final, decision, merge, fork and join nodes are all the same. However, interaction overview diagrams introduce two new elements: interaction occurrences and interaction elements.

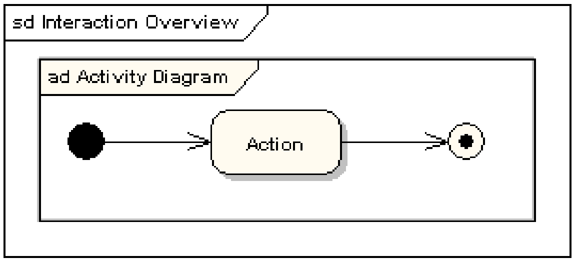
Interaction Occurrence

Interaction occurrences are references to existing interaction diagrams. An interaction occurrence is shown as a reference frame, that is, a frame with “ref” in the top-left corner. The name of the diagram being referenced is shown in the center of the frame.



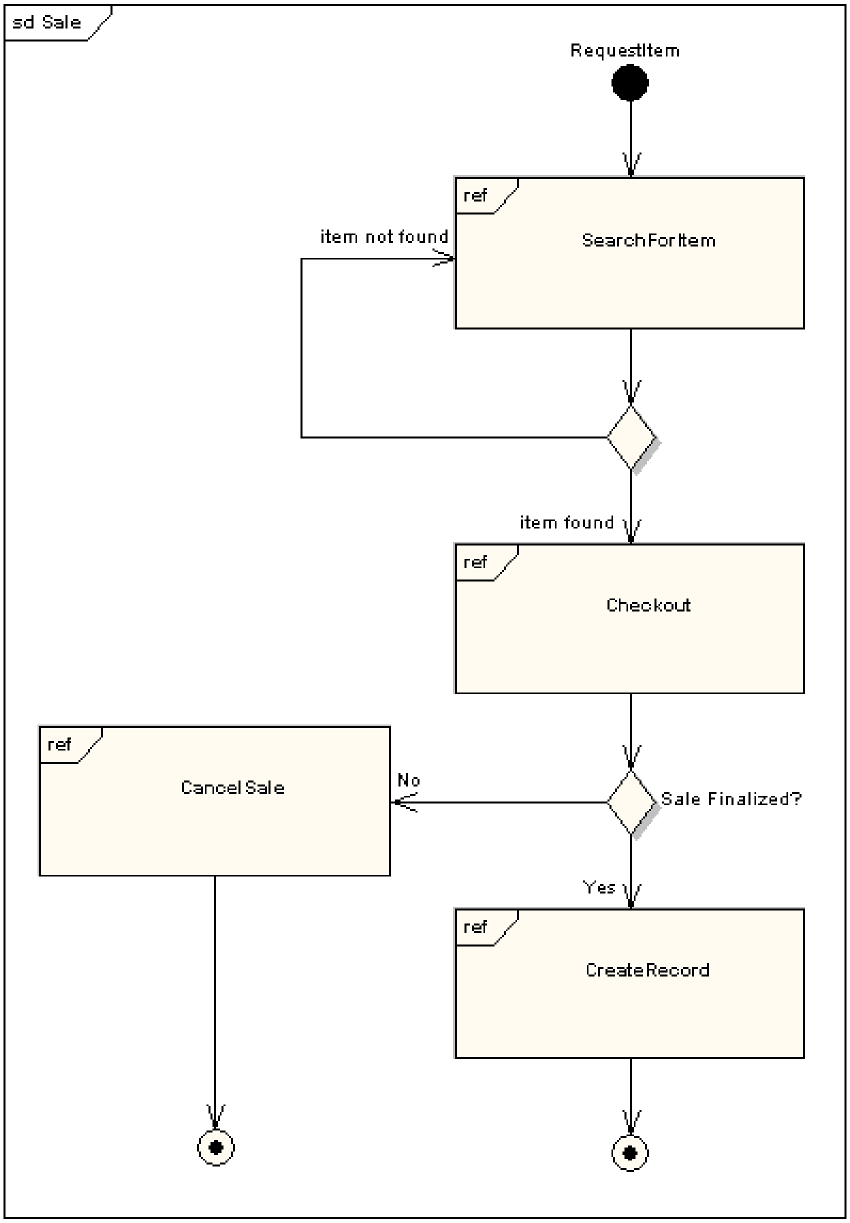
Interaction Element

Interaction elements are similar to interaction occurrences, in that they display a representation of existing interaction diagrams within a rectangular frame. They differ in that they display the contents of the references diagram inline.



Putting it all together

All the same controls from activity diagrams (fork, join, merge, etc.) can be used on interaction overview diagrams to put the control logic around the lower level diagrams. The following example depicts a sample sale process, with sub-processes abstracted within interaction occurrences.


sd Sale
RequestItem
ref
SearchForItem
item not found
item found
ref
Checkout
ref
Cancel Sale
No
Sale Finalized?
Yes
ref
CreateRecord

Recommended Reading

For more information, please refer to:

Sparx Systems' Web Site:	www.sparxsystems.com
Object Management Group's Web Site:	www.omg.com
Object Management Group's UML pages:	www.uml.org