Sarasvati - Simple, Capable and Transparent Workflow

Reference Manual

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Sarasvati - Simple, Capable and Transparent Workflow: Reference Manual

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Chapter 1. What is workflow

To help understand what workflow is, we start with definitions of the main components of a workflow system.

Definitions

- *Actor* - A person or program which performs some *action* .
- *Action* - Something to be performed by an *actor* . Once an *actor* is notified that a given *action* is to be completed, they may perform it synchronously or asynchronously. It may take hours or days to complete the *action* .
- *Process Definition* - A set of actions which need to be performed. The actions have a defined order in which they must be performed. Some actions may be performed concurrently with others.
- *Process* - An instantiation of a *process definition* . Each *process definition* may have many processes running at once. A *process definition* can be compared to the on disk image of a program, where the *process* is comparable to an executing program (possibly with multiple threads of execution). Or from an OO perspective, a *process definition* is analogous to a class definition and a *process* is like an instantiated object of that class.
- *Workflow Engine* - A program, library or API which can load *process definitions* and from them, generate and execute a *processes* .
- *Workflow* - A label for systems which enable the building of process definitions and the execution of processes.

Why workflow?

So what is so special about workflow? After all, dependencies can be handled programatically. If action A is followed by action B, then action A can just invoke action B when it is complete. Concurrency can be handed by threads.

What workflow generally provides over a manual implementation is

- Ease of implementation
  - If there are complicated dependencies, these are tracked by the workflow engine. Each action doesn't need to worry about what comes before or after it. This also allows actions to be more easily abstracted and reused.
  - The workflow engine also ideally handles persistence. Processes can be long running, taking weeks or months to complete. The workflow engine will handle persisting the state of the workflow, so if the containing program dies, needs to be update or restarted, the process will not be lost.
- Ease of definition
  - Workflow system generally provide an easier way of designing and/or specifying process definitions than by doing it manually in code.
  - Generally workflow systems can read in process definitions in a human readable file format.
  - Many workflow systems also provide visual editors.

Examples

Example 1: Order Fulfillment

The scenario here is of a small company which sells beach balls. They have a process for servicing an order.

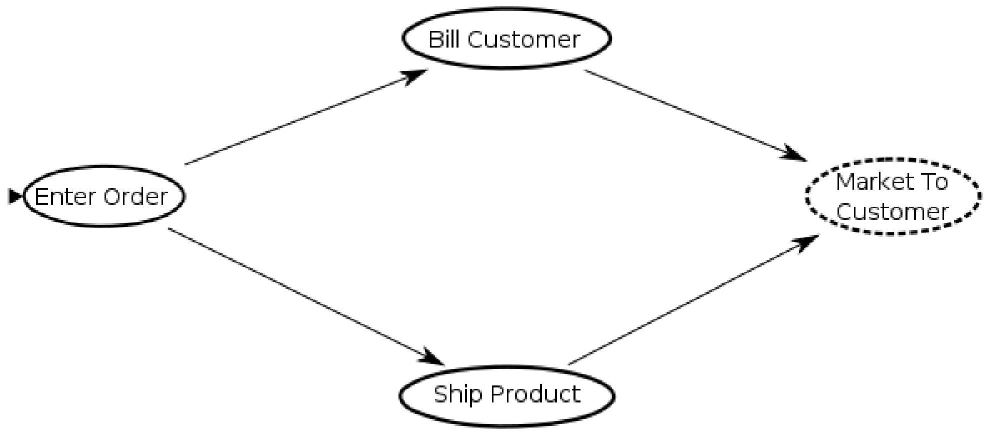
Actors

- Sales (person)
- Billing (program)
- Warehouse (person)
- Marketing (program)

The process

1. The sales person receives an order and enters it into the system.
    a. This includes the type number of products ordered and the payment information.
2. Once this is complete, the order will go to both billing and the warehouse.
3. While the warehouse people package and ship the order, the billing system will perform whatever credit card transactions are necessary.
4. Once the product is both shipped and billed, a marketing system will determine what promotional material and/or special offers to send to the customer, in order to elicit future business.

Graphically, the process could be represented as follows:



Example 2: Document conversion

This scenario concerns a news aggregation company called NewsCO which takes in news from various sources and republishes it in a variety of formats. Here we will look at a simplified workflow which handles two input formats.

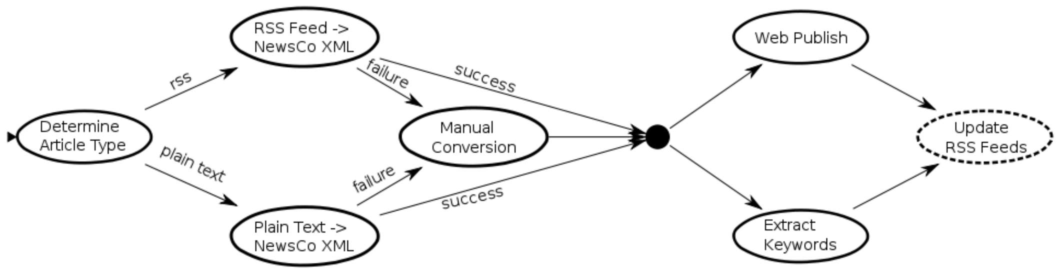
Actors

- RSS -> NewsCO XML format Converter (program)
- Plain text -> NewsCO XML format converter (program)
- Editor (person)
- NewsCO XML web publisher (program)
- NewsCO XML Analyzer (program)
- NewsCO XML RSS publisher (program)

The process

1. The process begins when an article arrives, either from an RSS feed or via a file drop in plain text format.
2. Conversion:
    a. If the article is in RSS format, the RSS XML will be converted to a proprietary XML format (the NewsCO XML format)
    b. If the article is in plain text, it will be parsed and converted to the NewsCO XML format.
    c. If there is an error in the conversion process, the article will be handed to a human editor who will manually do the conversion
3. Publishing
    a. The NewCO XML will be converted to a webpage and posted on a web site for consumption by the public. The web publisher is an asynchronous program which accepts XML and later provides notification when the publishing is complete. This could be a separate workflow.
    b. NewsCO customers receive RSS feeds of articles based on keywords. The article will be scanned for keywords. A database entry will be created.
    c. Each customer who has expressed interest in a keyword found in the article will have their RSS feed updated with a link to the published web article.

Graphically, the process could be represented as follows:



Chapter 2. Why graph based workflow?

Graphs and Processes

Graphs have been used for a long time to visually represent processes. Some examples are:

- Flowcharts [http://en.wikipedia.org/wiki/Flowcharts]
- Unified Modeling Language (UML)
  - Activity diagrams [http://en.wikipedia.org/wiki/Activity_diagram]
  - State Machine Diagram [http://en.wikipedia.org/wiki/State_diagram#UML_state_diagram]
- Finite State Automata [http://en.wikipedia.org/wiki/Finite_state_automata]

Graphs are visual, intuitive and ubiquitous. That finite state machines are graphs shows their expressive power. A graph combined with some storage is roughly equivalent to a Turing Machine, capable of executing any computation.

Alternatives

There are other ways of representing workflows. For example, one could just list out the actions along with their dependencies. The engine could then properly sequence the actions, For example, the simple Order Fulfillment example could be defined as

1. Enter Order for Sales depends on nothing
2. Bill Customer for Billing depends on 1
3. Ship Product for Warehouse depends on 1
4. Market to Customer for Marketing depends on 2, 3

While this would work fine for simple processes, it doesn't offer a way to define cycles. If, for example, the warehouse people determine that they are out of stock, they may need to send the workflow back to the sales department so they can interact with the customer. This mechanism also lacks a clear means of flow control. A single workflow could potentially cover the order fulfillment process for many different product types. It is likely that some sections of the workflow would only apply to specific products.

Chapter 3. Core Concepts

Introduction

Graph based workflow/business process management engines are common. They have areas of commonality, but they also vary greatly in concept and implementation. For example, there are differences in how concurrency and synchronization are modeled and in how modularity and re-use are promoted.

We begin with the some definitions, move on to features likely to be common across most engines, then explain Sarasvati specifics.

Definitions

Graphs come with a set of common terms. To begin with, a graph is made up of a set of things, hereafter referred to as *nodes* and a set of connections between *nodes* , know as *arcs* .

- *Graph* - A set of nodes, with a set of arcs connecting the nodes. While graphs have a wider applicability, graph here is synonymous with process definition.
  - Also know as: Process Definition, Network, Workflow
- *Node* - An element of a graph. A node corresponds roughly to an action as defined previously. Nodes can be thought of as pieces of code, waiting to be executed when their turn comes.
  - Also known as: Vertex, Place
- *Arc* - A directed connection between two nodes. *Directed* means that arcs have a start node and an end node. In some cases, an arc may have a label, or name.
  - Also know as: Edge, Transition
- *Predecessor* - If two nodes are connected by an arc then the node at the beginning of the arc is the *predecessor* of the node at the end of the arc. How nodes are connected by arcs defines the order of execution. Generally a node may not execute until at least one, potentially many or all, of its predecessors have executed. Nodes may have many arcs exiting and entering them.

These definitions cover the parts of a process definition. However, they don't cover how that process definition is actually executed. When a process definition gets executed, the execution is called a *process* . Somehow, a process must track which nodes are being executed. This is generally accomplished by placing markers called *token* on the active nodes.

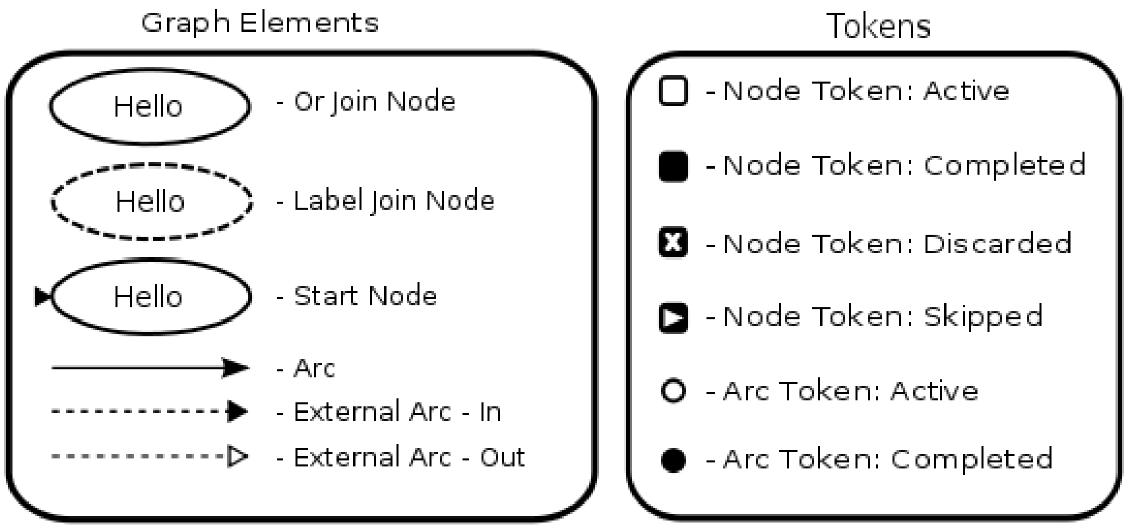
- *Process* - An executing process definition. A process definition may have have zero, one or many processes executing at any given time.
  - Also known as: Case, Instance, Workflow
- *Token* - The set of active tokens marks the current process state. Tokens generally point to a node which is currently executing. Tokens sometimes have associated state, which is a way of passing data from node to node.
  - Also know as: Execution

Sarasvati Graph Execution

Let us start with a simple process definition, the classic 'Hello World'. When executed, this process will print out 'Hello, World!' and then complete.

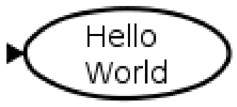
Legend

First, we introduce a graphical notation for process definitions and execution. Not all the symbols will make sense immediately, but they will all be explained.



Single Node

The simplest useful process definition would consist of a simple node. Here is the graphical representation:



How will this process be executed? First the engine needs to determine where to start execution.

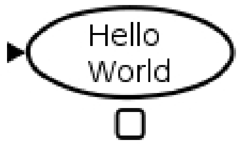
- *Start Node* - A node at which a token will be placed when process execution begins.

There are various ways of handling this. For example, there may be a specific type of node designated for start positions. All nodes of this type will have tokens placed in them at process start. Alternately, nodes may have an attribute which indicates whether or not they are a start node, allowing any node to be a start node. Sarasvati takes this second approach.

Assuming that the 'Hello World' node is a start node, execution would begin by creating a new *node token* at the 'Hello World' node.

- *Node Token* - A token situated at a node. Node tokens track the response of the node guard (see below). They may also have attributes.

With the addition of the node token, the process would now look like:



As you can see, the node now has an active node token stationed on it.

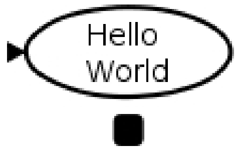
At this point the node has not yet been executed. Before it can be, its *guard* would need to be invoked.

- *Node Guard* - Nodes have functionality associated with them, which will be executed when a node token is accepted into the node. However, before a node is executed, its guard will be executed. The guard is allowed one of three responses:
  - *Accept* - The node will be executed.
  - *Discard* - The node token will be marked as discarded and the node will not be executed.
  - *Skip* - The node will *not* be executed, however, processing will continue as if the node had completed execution normally.

By default, a node's guard will return Accept. The node will then be *executed* . This should cause 'Hello, World!' to be printed out.

- *Node Execution* - When a node is executed, whatever custom logic has been assigned by the developer will run. To complete node execution, the node must inform the engine that that the given node token has been completed. Node completion may happen synchronously as part of the execution of the node function or it may happen later, asynchronously.

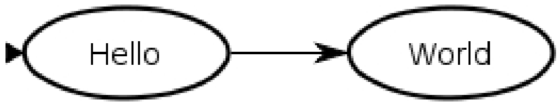
As there are no further steps in the process, it is now *complete* and looks like:



- *Process Completion* - A process with no active tokens is considered complete.

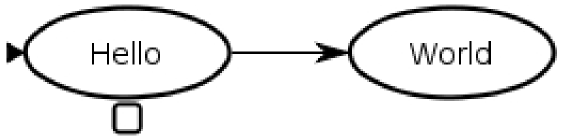
Two Nodes

Let's now example a slightly more complicated example. Instead of a single node, we'll have two, the first of which prints out 'Hello', the second prints out 'World'. It looks as follows:

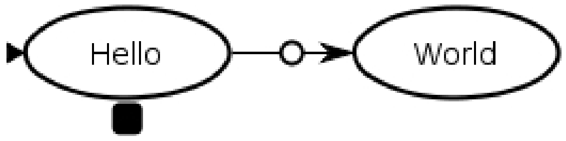


The *Hello* node is a *predecessor* of the *World* node. This dependency is indicated by the directed arc.

As the *Hello* node is marked as a start node, a node token will be placed there when the process begins executing.



When the node token on *Hello* is completed, an *arc token* will be generated on the outgoing arc.



- *Arc Token* - A token situated on an arc. Arc tokens exist so that nodes know when to execute. Arc tokens may not have attributes.

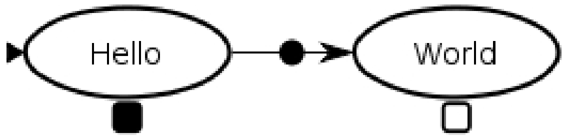
Whenever an arc token is created on an arc, the *join strategy* of the node at the end of the arc is evaluated, to determine if the node is ready to have a node token created at that node. The only time join strategies are not used is when a process is started. At that time all start node will have node tokens created on them.

- *join strategy* - A join strategy determines if a node token should be created on a node. Evaluation of the join strategy is generally initiated by the processing of an arc token on an incoming arc to the node. The join strategy will determine two things:
  - *Is the join complete?* Some join strategies require multiple arc tokens to be present before a node token is created on the node. Others may be satisfied every time an arc token arrives.
  - *Which arc tokens completed the join?* Every arc token that participates in completed the join will be marked complete and will be noted as a parent of the new node token, preserving a history of the flow of execution.

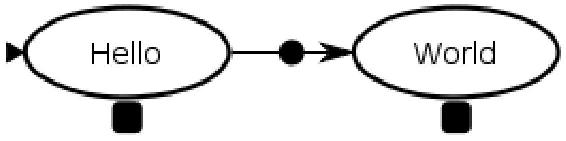
Since the arc on which the arc token is situated goes into a node using the*or join strategy* , a node token will be created on *World* immediately.

- *or join strategy* - The or join strategy will allow a new node token every time an arc token arrives at the node. This stands in contrast to a *label-and join strategy* , where active arc tokens must exist on all incoming arcs with the same name.

The process now looks like:



The *World* node will now run its guard and then execute. Finally the node token will be completed.



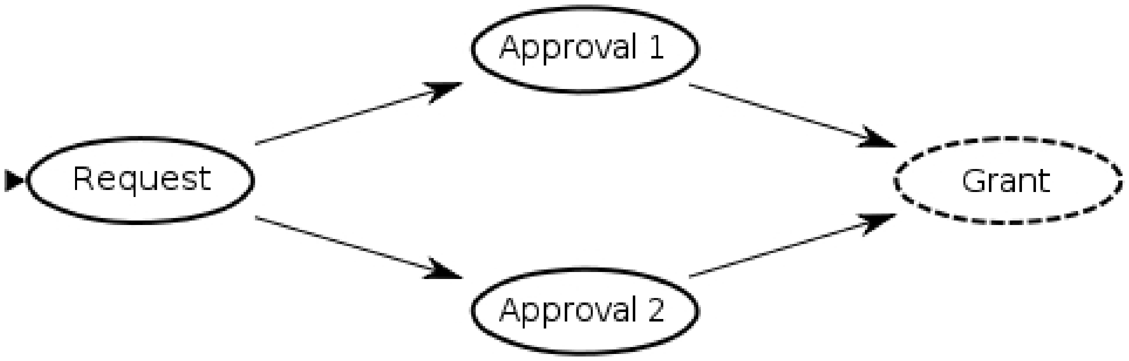
Split and Join with Wait States

Let us now examine an example which contains concurrent execution.

The process describes an approval process.

1. A request is made
2. Two approvals must be obtained
3. The request is granted

The process looks like:



This a simplified system, since it does not allow approvals to be denied.

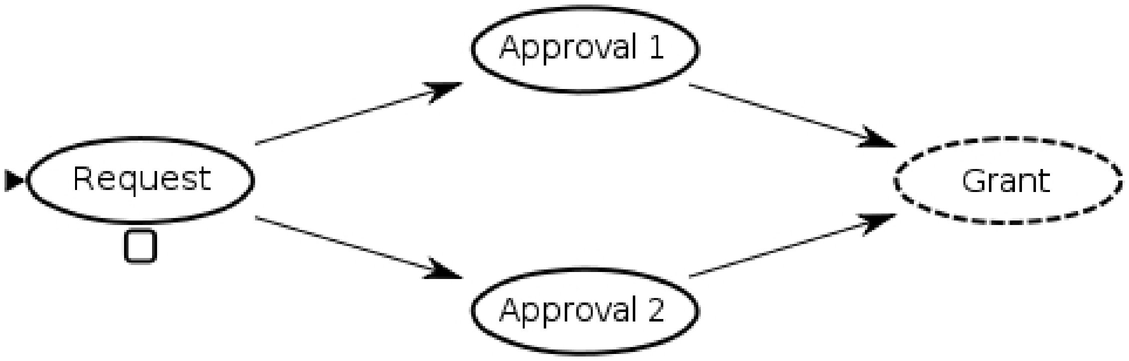
There is more than one way that this process could be executed.

- If the approvals are granted by people, the nodes will almost certainly be executed asynchronously. This means that when a token arrives at *Approval 1* , the node will generate a notification to the user who is to do the approval. The token will then enter a *wait state* . Execution may continue elsewhere in the process, but this token will wait until the user enters the system and grants approval.
- If approvals are done by software which does a check and then returns immediately the tokens will not have enter a *wait state* , but may continue immediately.
- *Wait State* - When a token enters a node and the node is executed, it may choose not to immediately continue process execution at the end of the node method. In this case the token will remain in the node until it is complete asynchronously. While the token is waiting to be completed, it is considered to be in a wait state.

Let us view process execution for both these cases, starting with the case where approvals are done by people and thus tokens will need to enter wait states.

Execution will begin as usual, by placing a node token in the nodes marked as being start nodes.

The *Request* node will be executed. It generates a task for the requester to complete. Until the requester has filled out out the request and completed the task, the token will be in a wait state. During this time the process will look like:



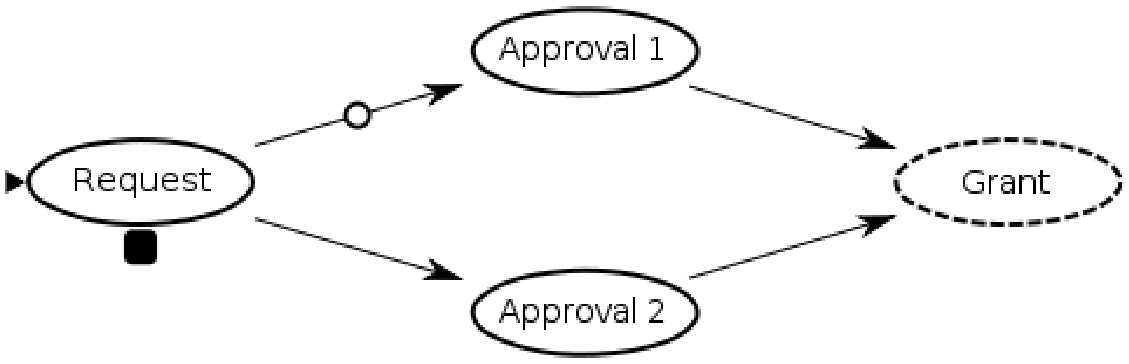
Question: What happens once the *Request* has been completed? Which arc or arcs will arc tokens be generated on?

Answer: Sarasvati requires that an arc name be specified when completing a node token. All arcs with this name will have arc tokens generated on them.

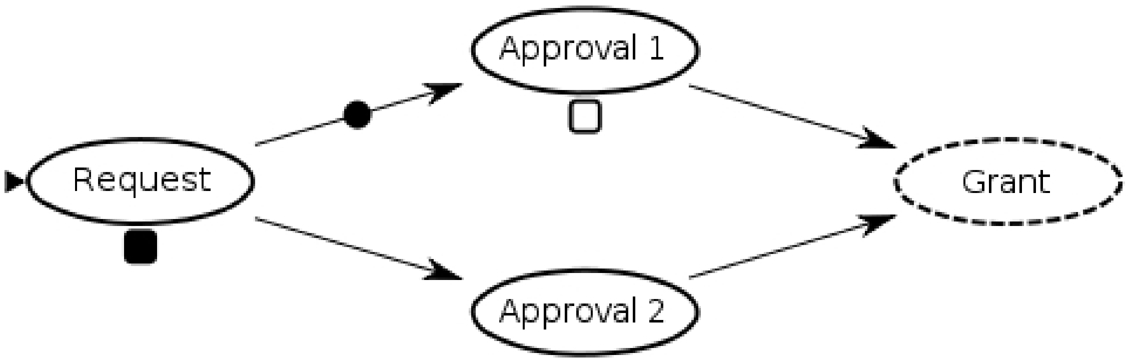
Some things to note:

- Most arcs have no name specified. They are considered to have the 'default' name.
- Usually when completing a node token, the default arc name will be given.
- Each arc will have an arc token placed on it in turn. No specific order is guaranteed
- When an arc token is placed on an arc, it will continue on to its end node immediately and see if the node can be executed.

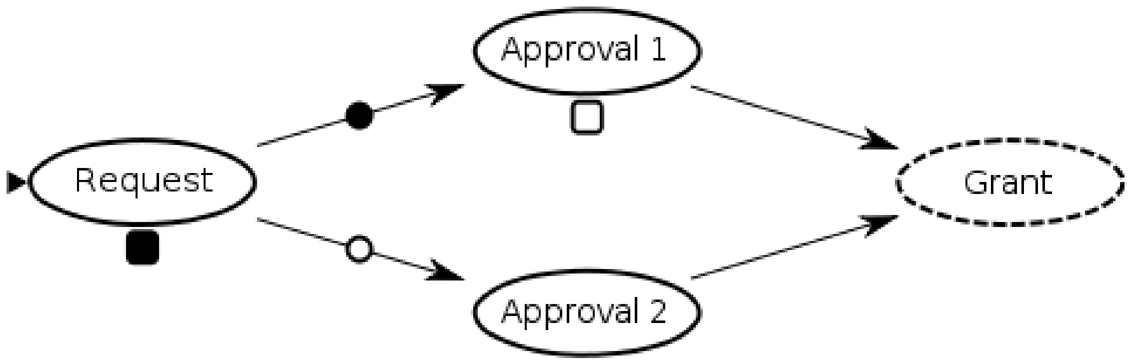
So now the node token on *Request* has been completed and arc tokens will be generated on the outgoing arcs. First a node token will be generated on the upper arc (though order of arc execution is not guaranteed).



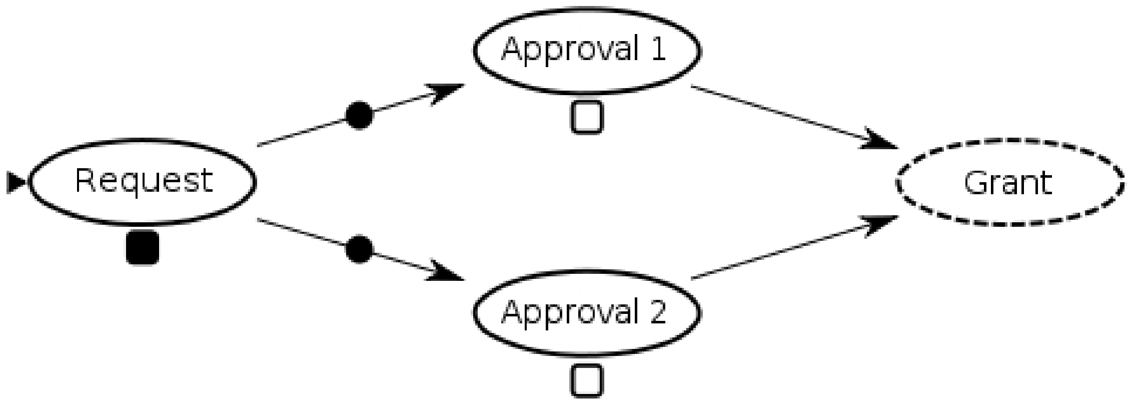
This arc leads to a node which can be executed. The arc token will be completed and a node token will be placed in the *Approval 1* node.



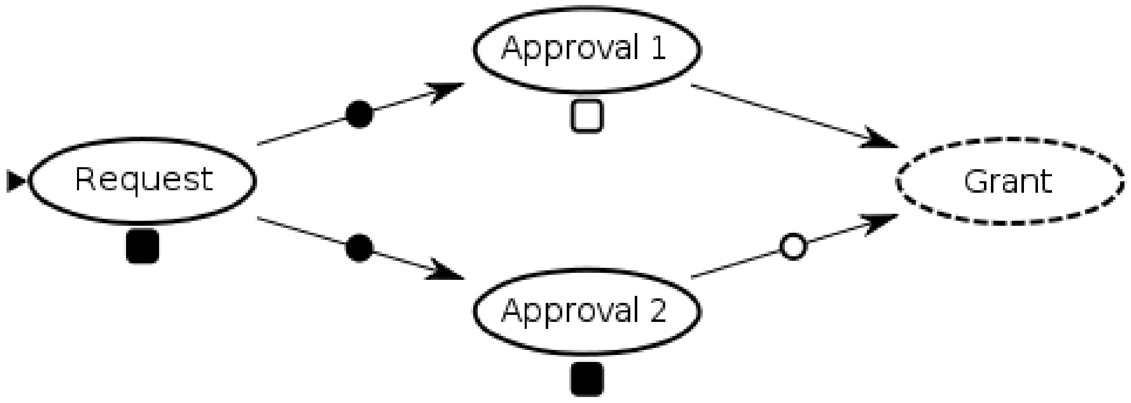
Here the node token will enter a wait state. Since no further execution can take place here, an arc token will now be generated on the second outgoing arc.



Again, since node *Approval 2* can be executed immediately, the arc token will be completed and a node token will be created. It will also enter into a wait state once the notification to the user has been created.



At some point one of the approvals will be completed. Let's say that it's *Approval 2* . This will mark the node token complete and generate an arc token on the outgoing arc.

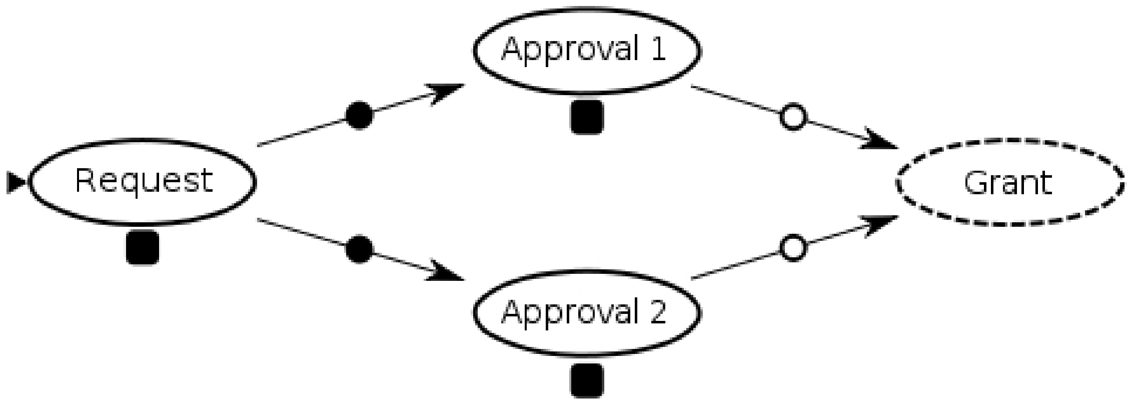


Now the engine will see if the *Grant* node can be executed. However, as the dashed border indicates, the *Grant* node is using the *label-and join strategy*. .

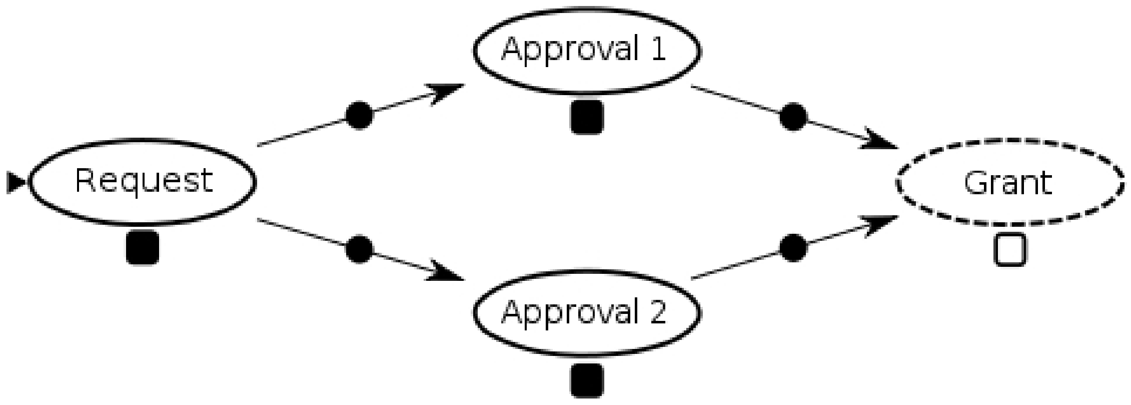
- *label-and join strategy* - When an arc token arrives a node using the label-and join strategy, arc tokens must exist on all other arcs *with the same name* before the node will accept a node token.

Since there are two arcs with the 'default' name coming into *Grant* , and only one of them has an arc token, the node can not be executed at this time. Execution will halt at this point.

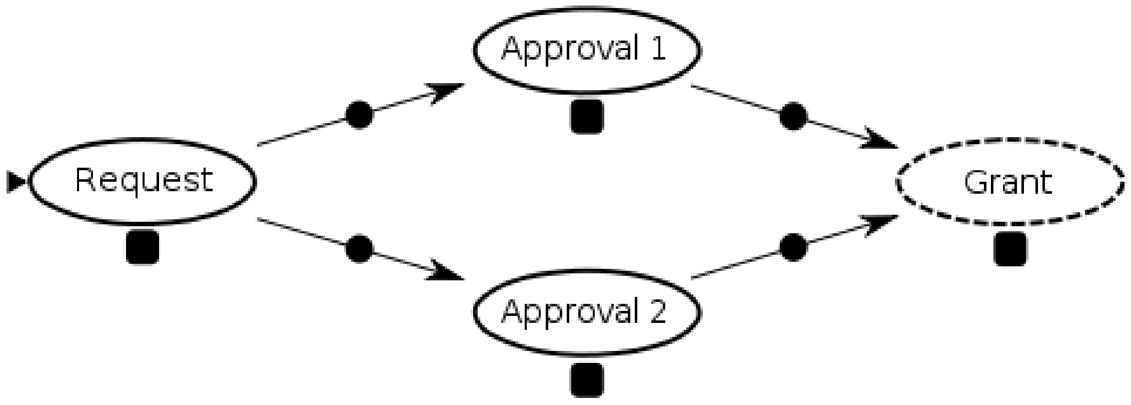
At some point later, the token at *Approval 1* is completed. This generates an arc token on the outgoing node.



Now when the engine tries to execute *Grant* it finds arc tokens on all the incoming 'default' arcs. These arc tokens are marked complete and a node token is generated on *Grant* .



Once the *Grant* task is finished, its node token will also be completed and the process will be complete.



Multithreading

As seen the previous example, a process may have multiple tokens active concurrently. Does this imply that each token executes in a separate thread? No. Concurrency here is like that of multiple programs running on a single chip. Each runs in turns, but may present the appearance of running simultaneously.

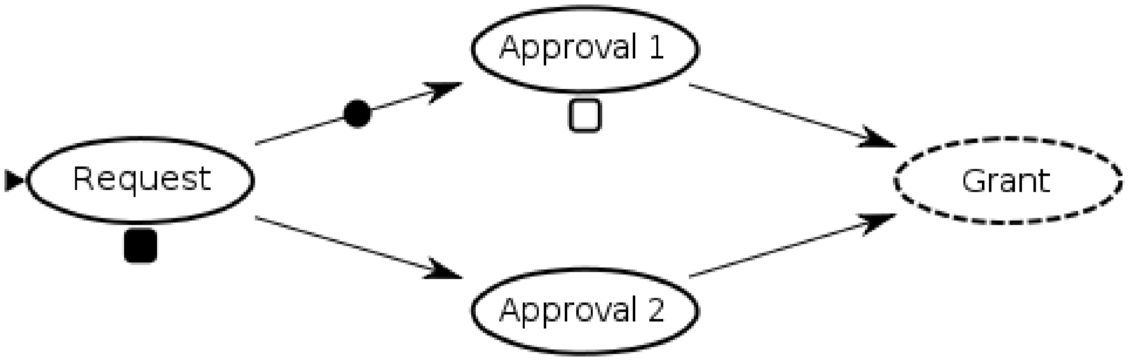
However, true multithreading can be done at the node level. Each node when executed, may hand off its work to a background thread. The node token will then enter a wait state, and other nodes may be executed. When the background task is complete, it may then complete the node token, allowing further execution.

Note that only one thread may safely execute the process at any given time, and care must be taken to serialize access to the process itself.

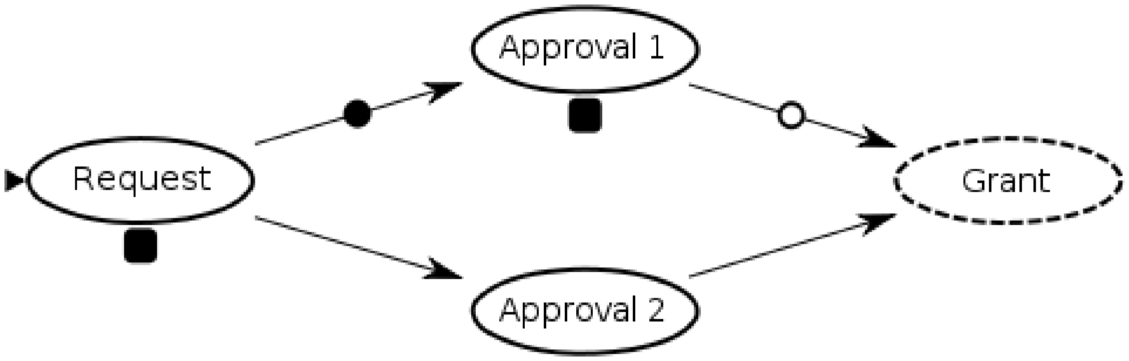
Split and Join without Wait States

Lets now take a look at the same process, except now the approvals will be done by software and will not require a wait state.

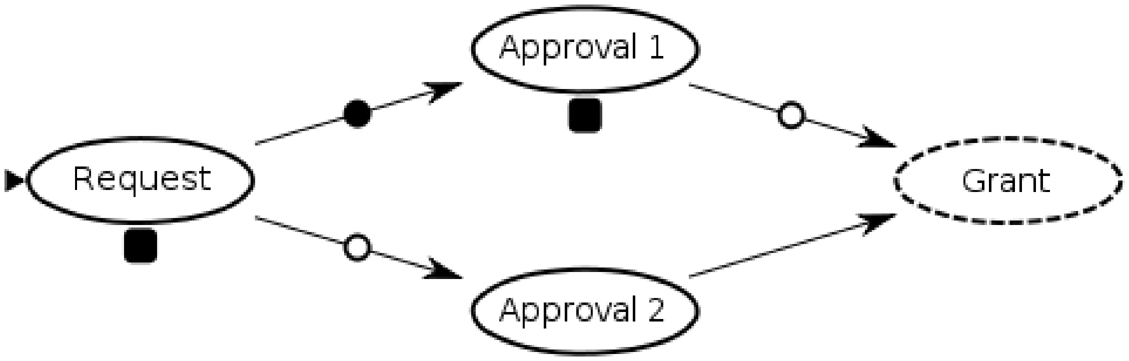
The execution will be the same up to the point where *Approval 1* is executing.



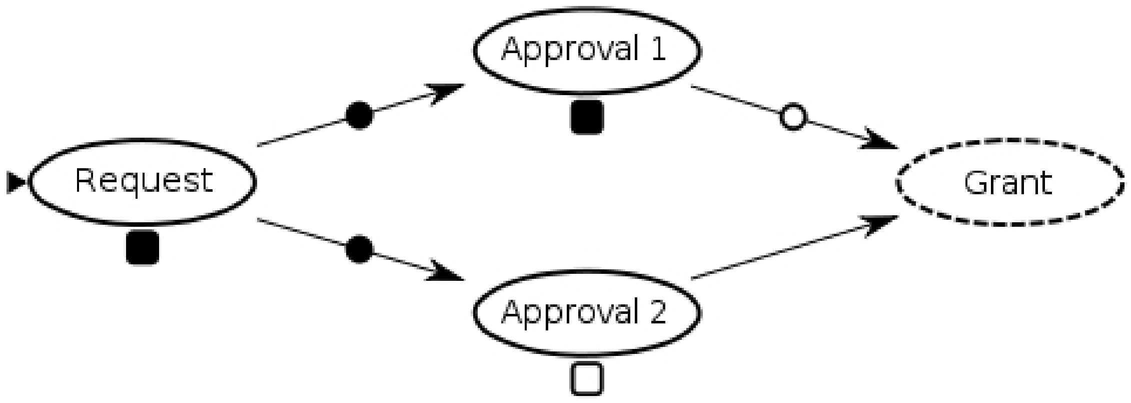
Previously, the node token went into a wait state. This time, the approval is done synchronously and the token will be completed. This will generate an arc token on the outgoing arc.



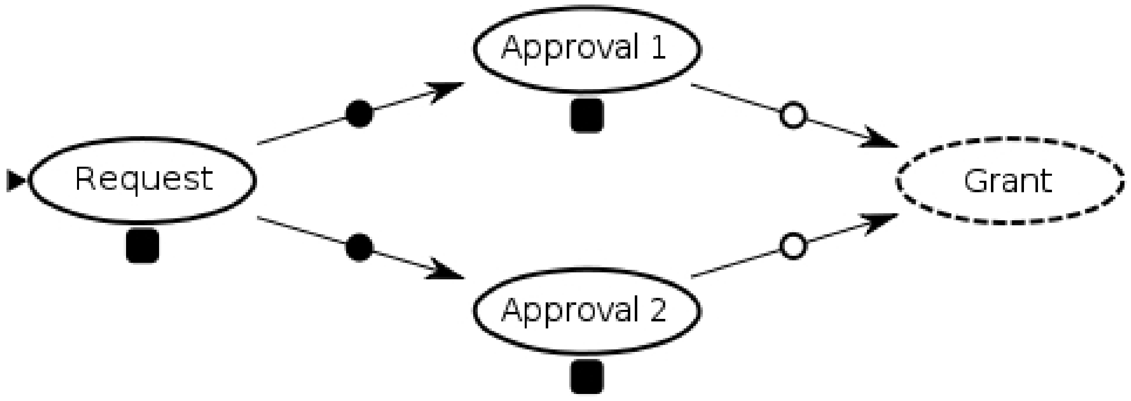
Again, the *Grant* node is using the label-and join strategy, so it will wait for an arc token on the other incoming arc before executing. Execution will continue on the lower outgoing arc of *Request* .



Execution will continue into *Approval 2* .



This execution will also finish synchronously and an arc token will be generated on the outgoing arc.



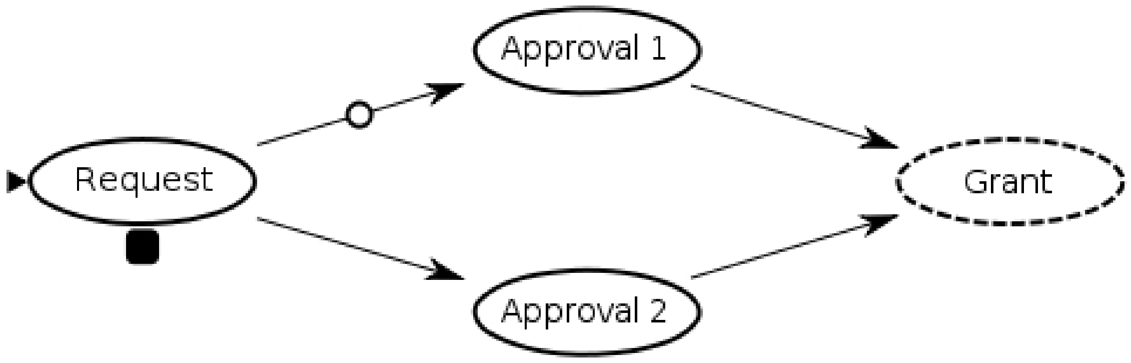
Execution will finish as before now that all required incoming arcs have tokens on them.

Flow Control with Guards using Skip

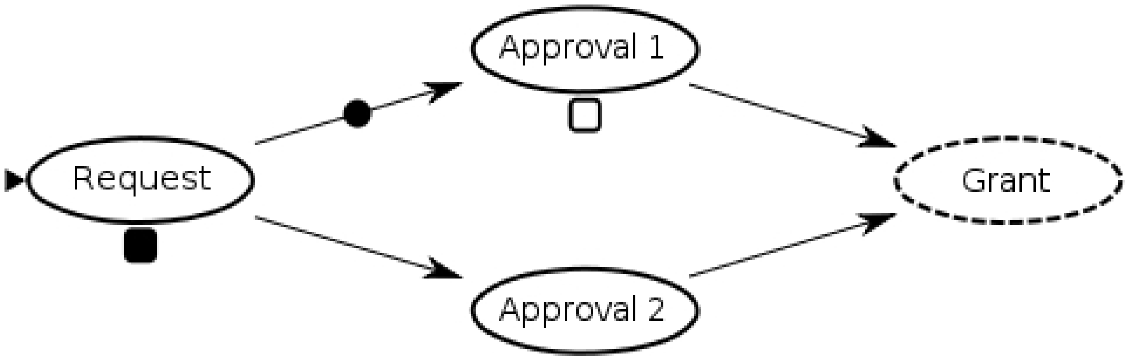
Now that we've seen how execution can split across arcs and join strategies can bring current executions back together, let us examine how to select which outgoing arcs receive tokens and which nodes get executed.

This example uses almost the same process as the previous example. The difference is that either or both approvals may be optional, depending on what is being requested.

Let us pick up execution after the request has been entered and an arc token generated on the upper arc:



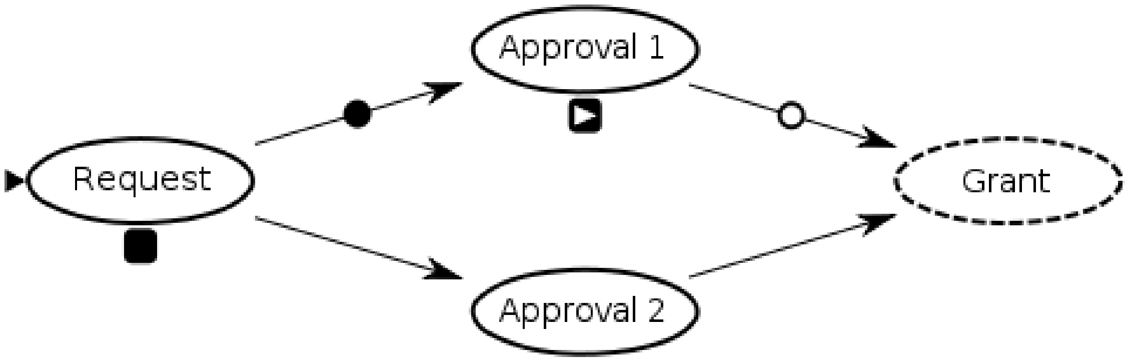
Now the node token will be generated in *Approval 1* .



However, remember that this does *not* mean that the node will immediately execute. First the *guard* must be invoked. Up until now, the guard has always been assumed to just return *Accept* . This time however, the guard is intelligent. It will check to see if this approval is required. If not, it will return a *Skip* response.

- *Skip* - A guard response which indicates that the node should not be executed, but that execution should continue on the outgoing nodes. An arc name may be specifying indicated which arcs should be used. If no arc name is given, arcs with the default name (unnamed arcs) will be used.

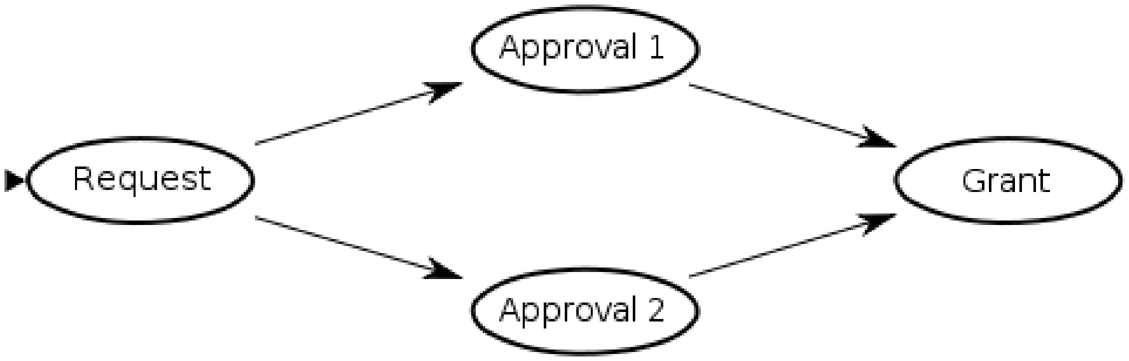
Assume that *Approval 1* is not required. The node token will marked as having skipped the node, and execution will continue on the outgoing arc.



Flow Control with Guards using Discard

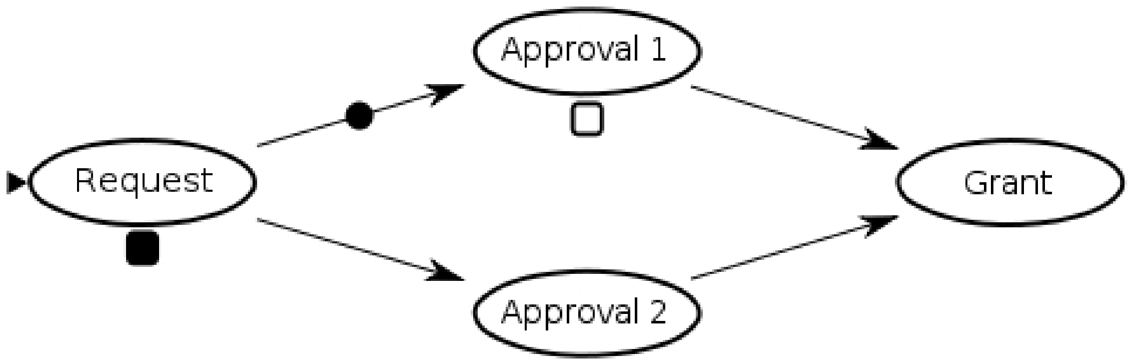
Having seen Skip, let us examine how to use the Discard response from guards. The same basic process definition is used, only this time, the assumption is that only one of the guards is required.

The graph now looks like:



Because we are using discard, only one token will reach *Grant*. This is why the *Grant* node is no longer a *label-and join stragy*.

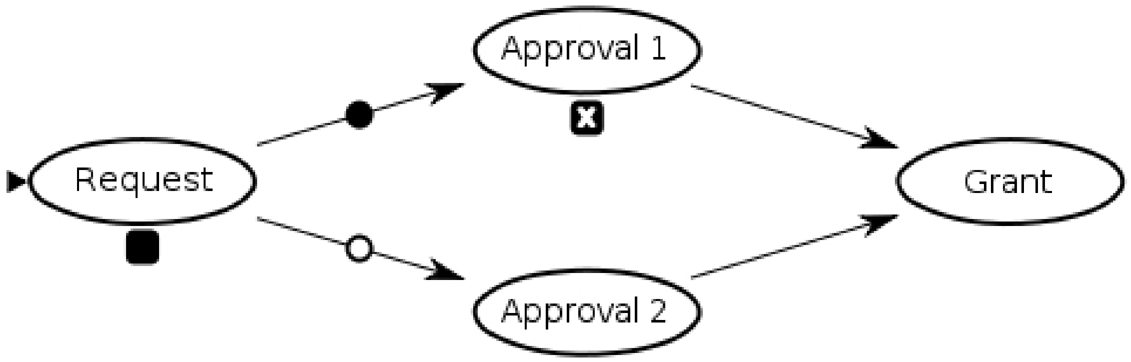
Execution begins as normal. We pick up execution where a node token has been generated in *Approval 1*.



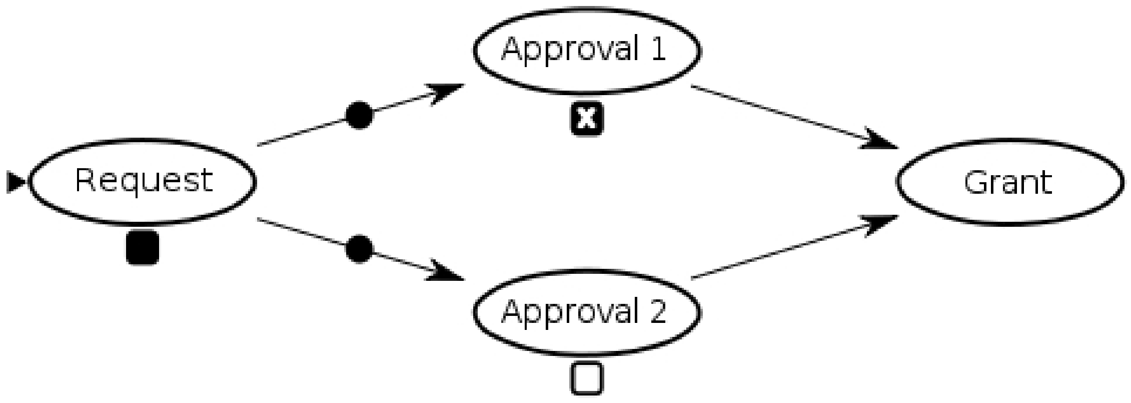
In this case, the guard determines that *Approval 1* is not required, and returns a *Discard* response.

- *Discard* - A guard response indicating that the node token should be marked as discard, the node should *not* be executed and no tokens will be generated on outgoing arcs.

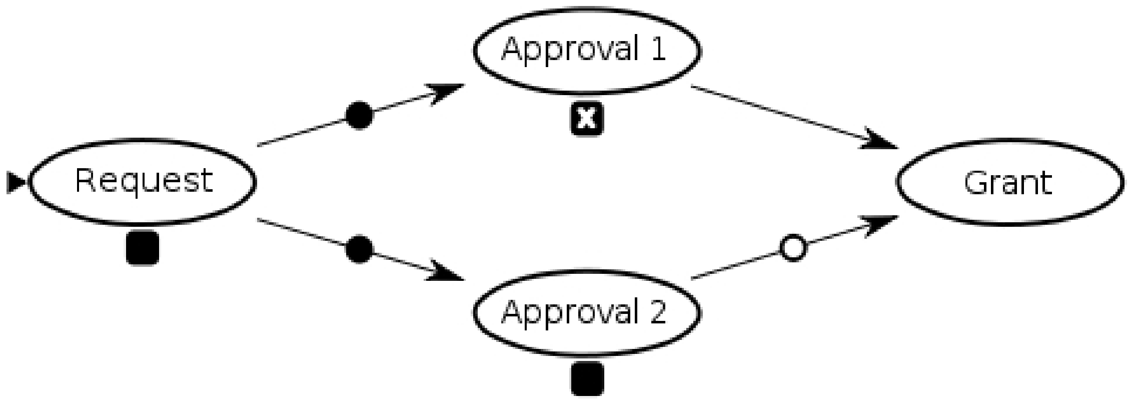
The process now looks like:

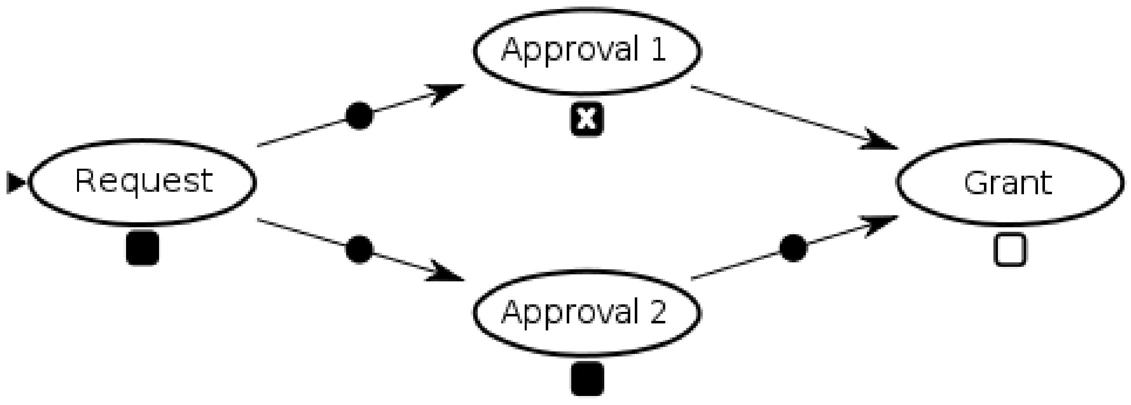


The node token has been discarded, and execution has continued from the completion of *Request* where an arc token has been generated on the lower outgoing arc. Execution will now continue.

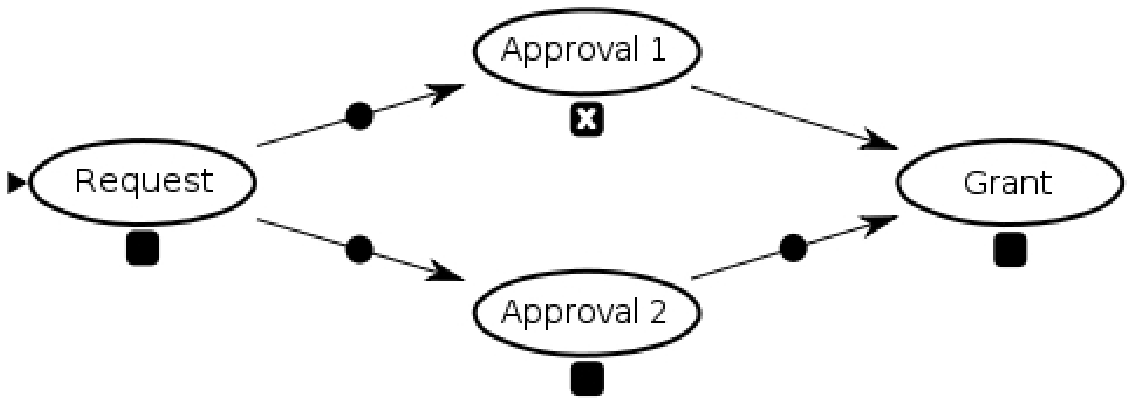


Approval 2 will accept its node token and will continue normally.





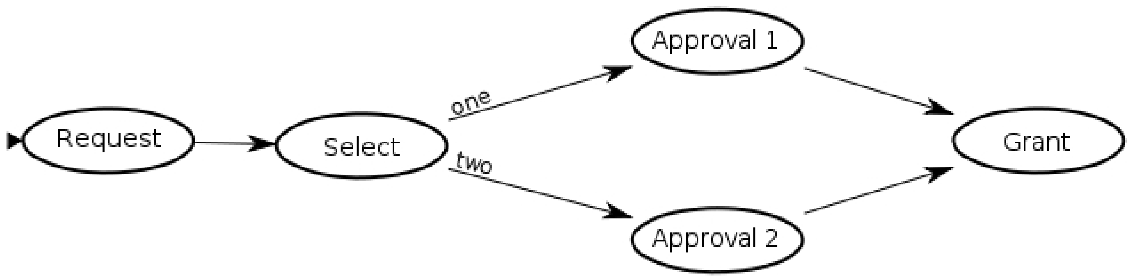
Remember, because *Grant* is using the *or join strategy*, it will have a node token generated on it as soon as any arc tokens arrived.



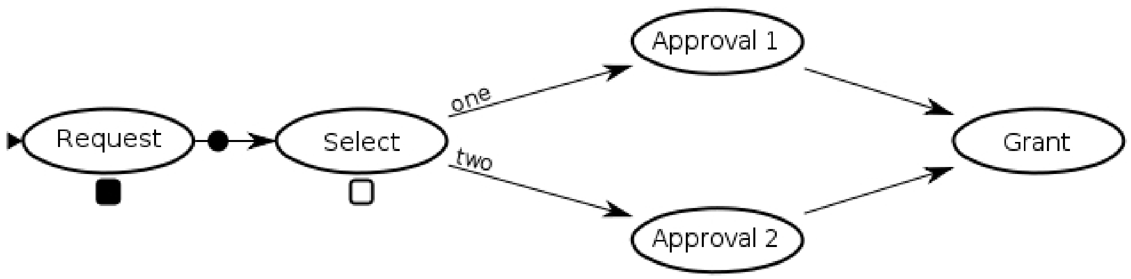
Flow Control with Guards using Named Arcs

This same basic process could be implemented using a guard which returns Skip along with an arc name.

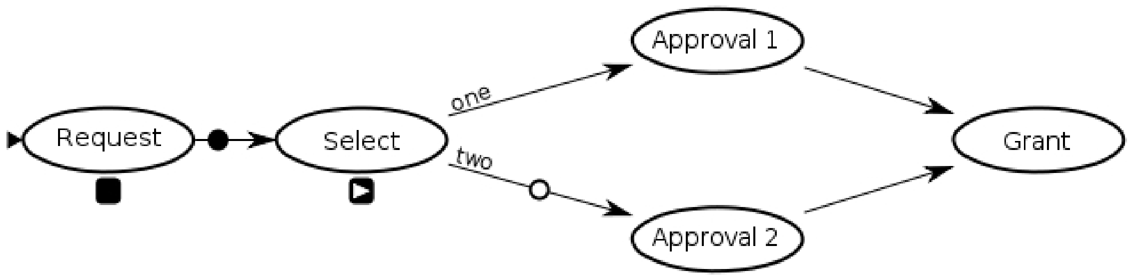
In this variant, a *Select* node has been inserted after *Request* . This node has no functionality, it only exists to give the guard a place to run.



Let us pick it up after process started, as *Select* has a node token generated on it, and its guard is invoked.



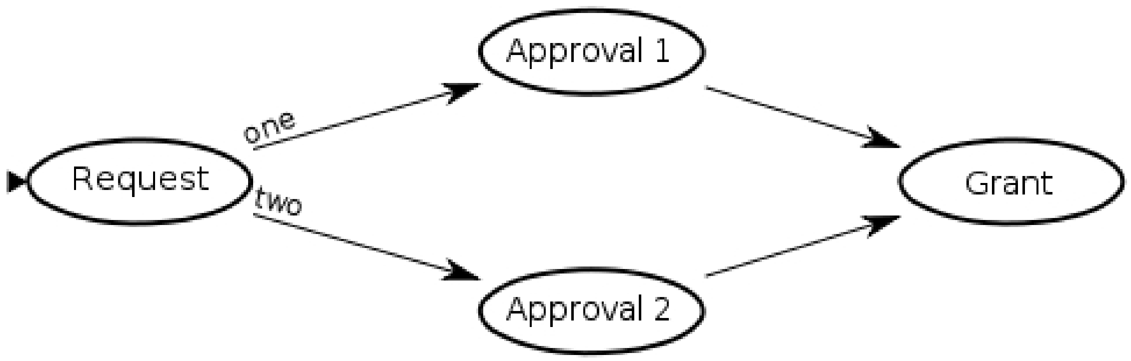
The *Select* guard will return a *Skip* response which includes the arc name on which to exit. *All arcs with this name will have an arc token generated on them* . In this case, let us say the guard determines that *Approval 2* is required. It returns *Skip two* . An arc token is then generated on all arcs named *two* (of which is there only one in this case).



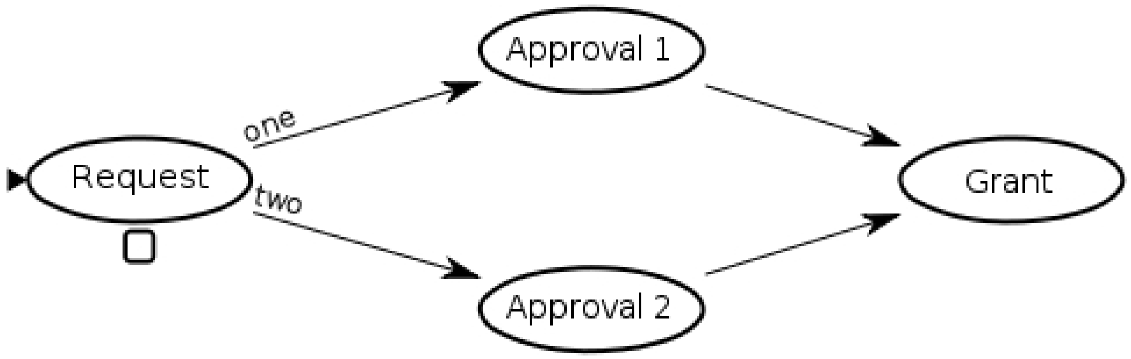
From here execution continues as normal.

Flow Control from Node Completion using Named Arcs

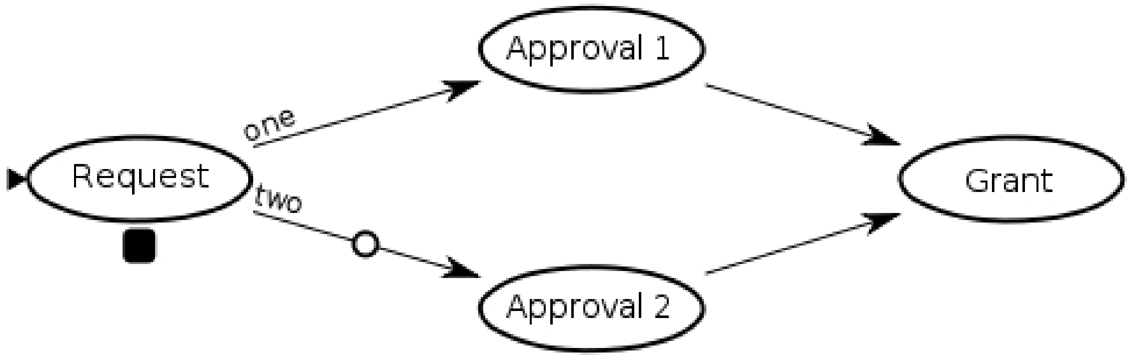
As mentioned previously, when a node token is completed, an arc name must be specified. Arc tokens will be generated on all outgoing arcs with that name. So the previous example could also be implemented like this:



Instead of using the guard on the *Select* node, the *Request* node will specify which arc to exit on.



If we again specify *two* , then an arc token will be generated on that arc.



From there, execution will continue.

Graph Composition and Nested Processes

Much like any software, a set of process definitions can grow larger, more complex and more intertwined as time goes. One solution used in the broader software world is encapsulation. This involves pulling out common functionality and breaking up large pieces into smaller components. These same techniques can be used with a set of process definitions. Rather than using copy/paste, sections of process definitions that are common can be extracted. Large process definitions can be split out into smaller components.

Sarasvati supports two ways of doing encapsulation, each with it's own advantages and disadvantages. The first is *graph composition* , the second is *nested processes* . Both of these techniques allow complete process definitions and components that have been split out to be defined in separately. The difference lies in when they are composed.

- *Load-time composition* - Graph composition brings the disparate elements together at load time. The main definition being loaded may refer to other definitions. These definitions will be loaded as well and they will all be combined into a single definition. This single definition will execute as if it had been defined in a single file.
- *Run-time composition* - Nested processes use composition at runtime. The main definition will be loaded. When this definition is executed, a node may start a nested process. This nested process will execute and when completed, the main process will continue.

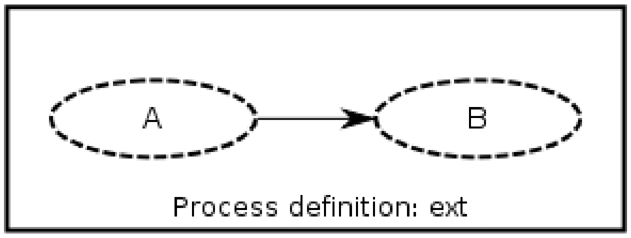
Now that we have general idea of how graph composition and nested processes compare, let us investigate them in more detail.

- *Graph composition* - The set of process definitions may be seen as a single, disconnected graph. A node may contain arcs to nodes in other process definitions. These arcs are referred to as *external arcs* . When the process definition is loaded, referenced external process definitions will be loaded as well. All the process definitions will be composed into a single, larger graph. The external arcs will become regular arcs. The same external processes definition may be embedded more than once. Each *external instance* of an external process definition will be given a unique identifier.
  - Advantages
    - Interactions with external process definitions are not limited to a single node. The connections may be as complicated as within process definition.
    - Since the graph is not nested, execution is simple.
    - All nodes will share a single process variable scope, allowing easy sharing of variables.
  - Restrictions
    - Recursion is not allowed, since this would lead to an infinite loop during loading. *NOTE:* As in regular programing, recursive structures can be implemented using non-recursive techniques.
    - All nodes will share a single process variable scope. Sometimes it is desirable to have shared state for a subset of the nodes in a process definition.
    - The version of an external graph is set when the process definition is loaded, rather than when nodes from that graph are executed. If an external process definition is updated, process definitions referring to it must be reloaded as well to pick up the changes.
- *External Arc* - An arc which has an endpoint in an external process definition. While normal arcs are always specified as originating in the node where they are defined (aka *out arcs*), it is not possible to add arcs to an external process. Therefore external arcs may either be *in arcs* or *out arcs* . Note that external arcs may be *named* just like regular arcs.
  - *Out Arc* - An arc which starts in the defining node and ends in a specified node
  - *In Arc* - An arc which starts in a specified node and ends in the node in which it is defined.
- *External Instance* - A specific external process definition may be referenced multiple times. It may also be imported into the referring process definition multiple times, or just a single time. Each external arc names a specific instance of the external process definition.
- *Nested Process* - A node in an executing process may create a separate, new process (of the same or different process definition). This new process is known a nested process. The new process gets initialized with the process state of the containing process and the current token. When the nested process completes, the token in the containing process will be completed.
  - Advantages
    - The nested process will have it's own process state
    - Processes may nested recursively
    - Nested processes will always use the latest version process definition at the time the node is executed.
  - Restrictions

- The interaction with the nested process must all be contained by a single node. The nested process will execute in isolation. The nodes in the nested process won't interact with the those of the containing process in any way.

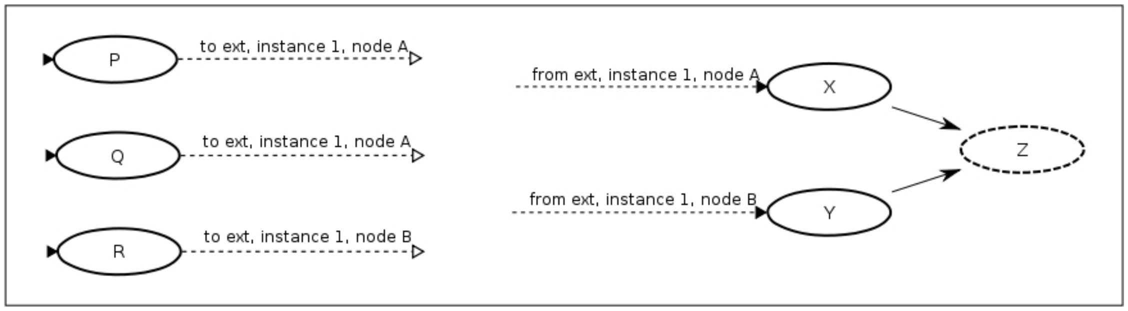
Graph Composition Example One

Let's look at an examples of how this works in practice. Here is a small process definition which we want to embed. This process definition will be named *ext* .



It only has two nodes. Notice that both nodes are using the *label-and* join strategy, even though one node has no inputs and the other only has one. However, in the composed graph these nodes may have more inputs.

Next is the process definition which will be using *ext*.

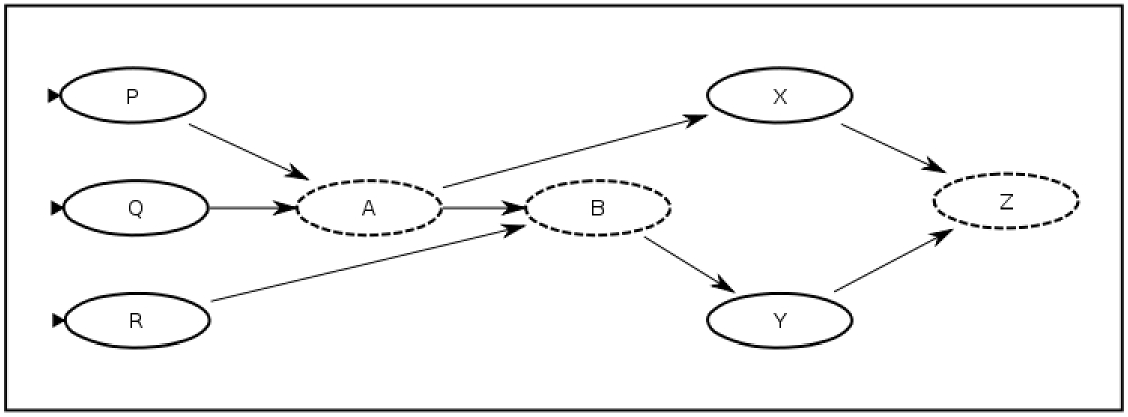

P
to ext, instance 1, node A
Q
to ext, instance 1, node A
R
to ext, instance 1, node B
from ext, instance 1, node A
X
from ext, instance 1, node B
Y
Z

This process definition looks very different from previous examples. It isn't even fully connected.

Some things to note:

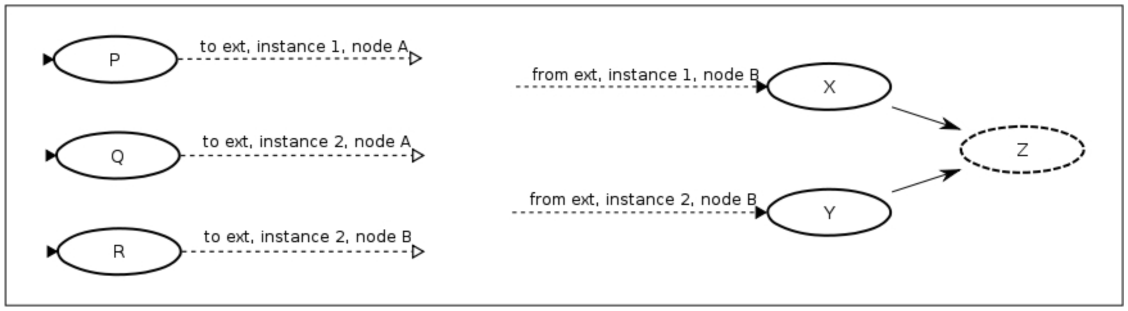
- The external arcs are labeled with the process definition name, instance and node name that they are intended to link to.
- In this case, all the arcs are connecting to the same instance of *ext* , instance 1.
- Both in and out external arcs may connect to any node in the target external. They are not limited to just start nodes, for example.

When the graph is loaded, the composed version will look as follows:

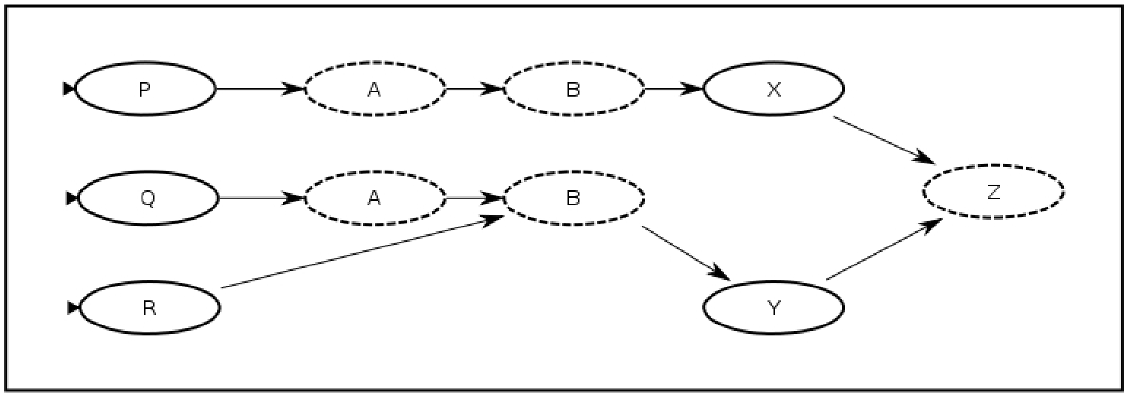


Graph Composition Example Two

The previous example referenced only a single instance. Here is the example using two instances 'ext.


P
to ext, instance 1, node A
Q
to ext, instance 2, node A
R
to ext, instance 2, node B
from ext, instance 1, node B
X
from ext, instance 2, node B
Y
Z

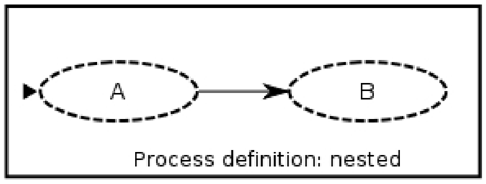
When it is loaded, the composed graph looks like:

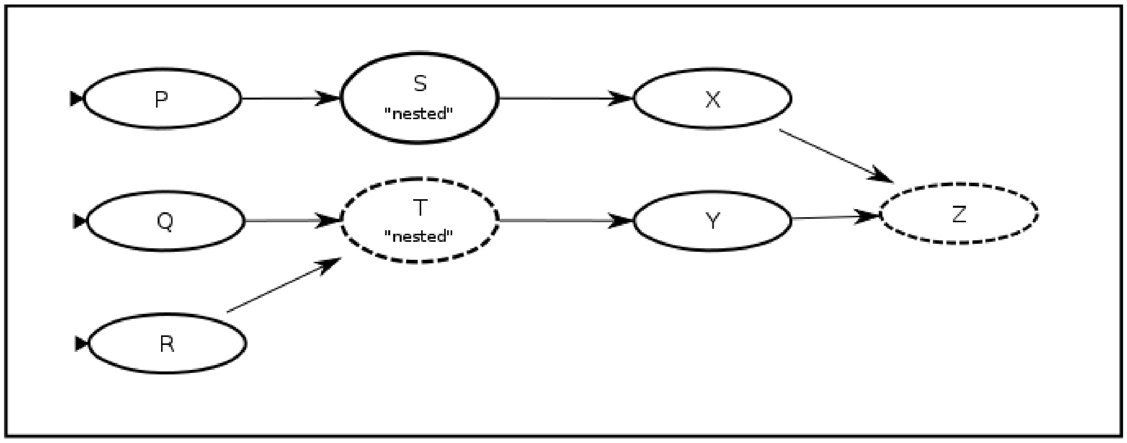


As you can see, we now have two copies of *ext* embedded in the process definition. One copy will be made for each unique instance referenced. A process definition can have references to any number of different external definitions and each external process definition can be imported any number of times.

Nested Processes Example

The above example could not be implemented with nested processes because a nested process must be represented by a single node in the parent process. So, here is a similar, but simpler example using nested processes.





Nodes `S` and `T` both refer to the nested process named `nested` . Note that `nested` is almost the same as `ext` , except that the first node is a start node. This is because `nested` will be executed as a separate process. If it didn't have a start node, it would not execute.

When `S` and `T` execute, each will spawn a separate process. When `S` is executed, it will have an incomplete node token `t` . As part of execution it will start a new `nested` process `P` which have have the token `t` as a parent. When `P` completes, it will check if it has a parent token, and finding that it does, will complete `t` . This will allow execution to continue in the original process.

Execution Environment

While executing your process definitions, it may be desirable to have some shared state or to send data between nodes via the tokens. Sarasvati supports both these things via the execution *environment* . Each process has an environment on which attributes/variables can be set. In addition, each token also has its own environment.

- *Environment* - A set of key/value attributes.

When using a memory backed engine, all environment attributes are stored in memory. However, when using a database backed engine, we may wish to persist only certain attributes. Also, storing objects in the database can be complicated, storing arbitrary objects in memory is easier than doing so in the database. By default, attributes are *persistent* , however, there is a separate set of variables which are *transient* .

- *Persistent Attributes* - These attributes will be stored for the lifetime of the process. There may be restriction on what can be (easily) stored a persistent attribute, since it may need to be stored in a database table.

- *Transient Attributes* - These attributes will be stored in memory, only as long as the process and/or token is in memory. For a memory backed engine, these have the same scope as the persistent attributes. There are no restrictions on what can be stored as a transient attribute.

Process Attributes

If you want state that is accessible from anywhere during process execution, then attributes can be set on the process environment. These attributes are visible and mutable by all nodes.

Token Attributes

Each *node token* also has its own environment. Arc tokens do not have an environment, because they do not execute in the same way that node tokens do, and thus have no need for private state. Node tokens are initialized with the state of their *parent tokens* .

- *Parent token* - Each node tokens has zero to many parents.
  - A node token on a start node has no parents. It will start with an empty environment.
  - A node token on a node with one incoming arc of a given name has a single parent. Its environment will be copied from the parent.
  - A node token on a node using the labe-and join strategy may have multiple parents, one for each arc of the same name. In this case the environments of all the parents must be combined in some way. By default, each environment will be imported into that of the new node. So if more than one parent has an attribute with the same one, the last one imported will overwrite the previous values. This behavior may be overridden, but if this is a concern, then using process level attributes may be advisable.

Chapter 4. Using Sarasvati

Introduction

Using Sarasvati usually involves writing process definition files, along with custom node types. Sarasvati uses an XML file format for process definitions. These files can be loaded into in-memory graph structures and executed, or they can be loaded first into a database, and from there loaded and executed.

We first introduce the file format, then explain how to implement custom behavior. Finally, we discuss how to interact with the Sarasvati engine.

Sarasvati File Format

Introduction

The process definition file format is defined by an XSD, which is available to view in the project SVN [http://code.google.com/p/sarasvati/source/browse/common/ProcessDefinition.xsd].

We'll explore the Sarasvati file format, starting with the root element and working from there, with examples interspersed.

Process Definition

This is the root element. It should indicate the XML namespace, that being: `http://sarasvati.googlecode.com/ProcessDefinition`

Table 4.1. `process-definition` attributes

Attribute Name	Usage	Is Required?	Default Value
`name`	The unique name for this process definition.	Yes	N/A

Table 4.2. `process-definition` nested elements

Element	Description
`node`	Every `process-definition` must have a least one `node` defined.
`external`	An external declares a process definition to be included. More than one external process definition may be included and the same process definition may be included more than once with a different name for each include.

Nodes

Nodes in a process definition are defined by the `node` element. Every node must have a name *unique to that file*.

Table 4.3. `node` attributes

Attribute Name	**Usage**	**Is Required?**	**Default Value**
`name`	The name of this node. The name must be unique within this process definition.	Yes	N/A
`type`	The node type. Determines the node behavior.	No	`node`
`isStart`	Specifies whether a node will be presented with a token when the process is started.	No	`false`
`joinType`	Determines the join strategy the node should use when a token arrives. Some nodes may accept incoming tokens as soon as they arrives, others may act as gates, waiting until a certain number of nodes arrive or token exist on specific incoming arcs before executing. See below for the allowed join types.	No	`or`
`joinParam`	Some join strategies, such as the token set join, may join based on this paramter. Alternately, this can be used by the custom join type as the developer desires.	No	N/A

Table 4.4. `node` nested elements

Element	Description
`guard`	Each node may have a single, optional guard element. The guard is generally defined in the Rubric rules language and will be evaluated when the node's join strategy determines that the node is to be executed. The guard will determine if the node should be executed, skipped or if the newly created node token should be discarded.
`arc`	Nodes may have zero to many arcs, pointing to other nodes in the same process definition. Arcs link together nodes and provide the paths along with the flow of execution proceeds.
`custom`	Each node has a custom section which may contain any user defined elements. How data from these custom elements is loaded is explained in the section on custom node attributes below.

Every node defines a join strategy, which is invoked when tokens arrive at the node and determines when the node is ready to be executed.

Table 4.5. `node` join types

Type	Behavior
`or`	An `or` join will be satisfied any time an arc token arrives at the node.
`and`	An `and` join will be satisfied when an arc token arrives and there are arc tokens waiting at all other incoming arcs to the node. In most cases the `labelAnd` is safer and more flexible.
`labelAnd`	A `labelAnd` join will be satisfied when an arc token arrives and there are arc tokens waiting at all other incoming arcs to the node which share the same name/label as the arc that the arc token is arriving on.
`tokenSetAnd`	A `tokenSetAnd` join will be satisfied when all active arc tokens in the set are on incoming arcs to the same node and there are no active node tokens in the token set. An exception will be raised if a non-token set token arrives.
`tokenSetOr`	A `tokenSetOr` join will be satisfied when all active arc tokens in the set are on incoming arcs to the same node and there are no active node tokens in the token set. The `or` strategy will be used as a fallback if a non-token set token arrives.
`custom`	Users may use custom join strategies. See the API reference for more detail.

Built in Node Types

- `node` - Nodes of this type will complete out on the default arc when they are executed. The node type can be useful if a synchronization point is needed. It can also be used as a choice mechanism, by specifying a guard which skips to selected arcs.
- `wait` - Nodes of this type will enter a wait state when executed. They will continue when completed by external logic. This can be useful when you need to wait on an external event, and no other logic is required.
- `script` - Requires a `script` element which will contain a script to execute when the node is executed.

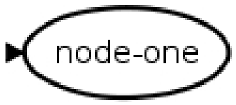
Element guard

A node may contain a GuardLang statement, which will be executed as the node's guard. The guard element has no attributes and may contain no nested elements.

One Node Example

With just `process-definition` and `node` a simple process definition can be built.

The simplest process definition would be a single node. Graphically, it would look like:



The corresponding XML process definition would look like:

```
<?xml version="1.0"?>
<process-definition
  name="simplest"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="node-one" isStart="true"/>

</process-definition>
```

While there can be many nodes declared in a process definition, we have as yet, not defined a way of linking them together.

Node Arcs

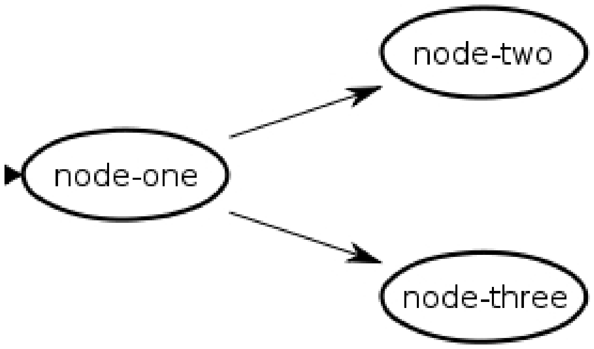
An `arc` element declares an arc from the enclosing node to the node with the name specified in the `to` attribute. An arc is allowed no nested elements.

Table 4.6. `arc` attributes

Attribute Name	Usage	Is Required?	Default Value
`to`	Specifies the name of the node this arc goes to.	Yes	N/A
`name`	Specifies the arc name. This name need not be unique.	No	`null`
`external`	If this arc is linking to an external (see below for more information on externals), the name of the external being linked to. If an `external` attribute is specified then the `to` attribute will refer to a node in the external, not a locally defined node.	No	`null`

Arc Example One

The following example contains three nodes.

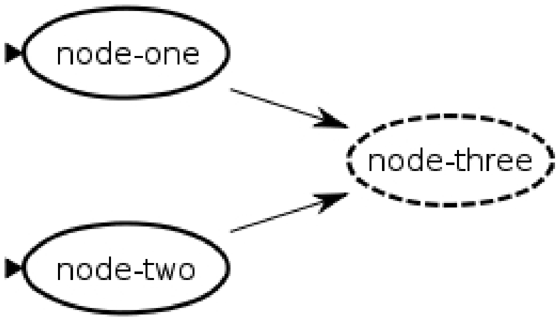


```
<?xml version="1.0"?>
<process-definition
  name="example2"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="node-one" isStart="true">
    <arc to="node-two"/>
    <arc to="node-three"/>
  </node>

  <node name="node-two"/>
  <node name="node-three"/>

</process-definition>
```

To indicate an arc, an `arc` element is added to the start node. The `to` attribute indicates the name of the target node. A node with that name must exist in the same process definition file.

Arc Example Two

Here is an example with two start nodes. They both have arcs to `node-three` , which uses the `labelAnd` join strategy. It will only execute once both `node-one` and `node-two` have completed.



```
<?xml version="1.0"?>
<process-definition
  name="example3"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="node-one" isStart="true">
    <arc to="node-three"/>
  </node>

  <node name="node-two" isStart="true">
    <arc to="node-three"/>
  </node>

  <node name="node-three" joinType="labelAnd"/>

</process-definition>
```

Now that we've seen how to create links between nodes in the same process definition, let us examine how to include external process definitions and create links to them.

Externals

An exernal process definition must have a declaration for each time it is to be included.

Table 4.7. `external` attributes

Attribute Name	Usage	Is Required?	Default Value
`name`	The name by which this external process definition will be referred to. The name must be unique within this process definition.	Yes	N/A
`processDefinition`	The name of the process definition being included. The same process definition may be included more than once.	Yes	N/A

Table 4.8. `external` nested elements

Element	Description
`arc`	Externals may have zero to many arcs. The arcs originate in the extenal process definition. They may end in nodes in the same process definition, in other externals or even in the same external.
`custom`	Each external has a custom section which may contain any user defined elements. How data from these custom elements is made loaded is explained in the section on custom external attributes below.

External arcs

An `arc` element in an `external` declares an arc from a node in the enclosing external to the node with the name specified in the `to` attribute. An arc is allowed no nested elements.

Table 4.9. `arc` attributes

Attribute Name	Usage	Is Required?	Default Value
`from`	Specifies the name of the node in the external that this arc starts from.	Yes	N/A
`to`	Specifies the name of the node this arc goes to.	Yes	N/A
`name`	Specifies the arc name. This name need not be unique.	No	`null`
`external`	If this arc is linking to another external, this specifies the name of the external being linked to. If an `external` attribute is specified then the `to` attribute will refer to a node in the external, not a locally defined node.	No	`null`

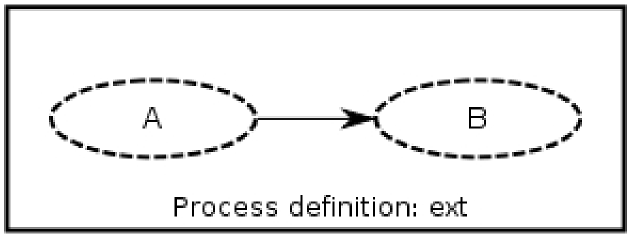
External Arc Example One

To examine external arcs, we'll need at least two process definitions.

This example is from the EngineConcepts section.

```
<?xml version="1.0"?>
<process-definition
  name="ext"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="A" joinType="labelAnd">
    <arc to="B"/>
  </node>

  <node name="B" joinType="labelAnd"/>

</process-definition>
```

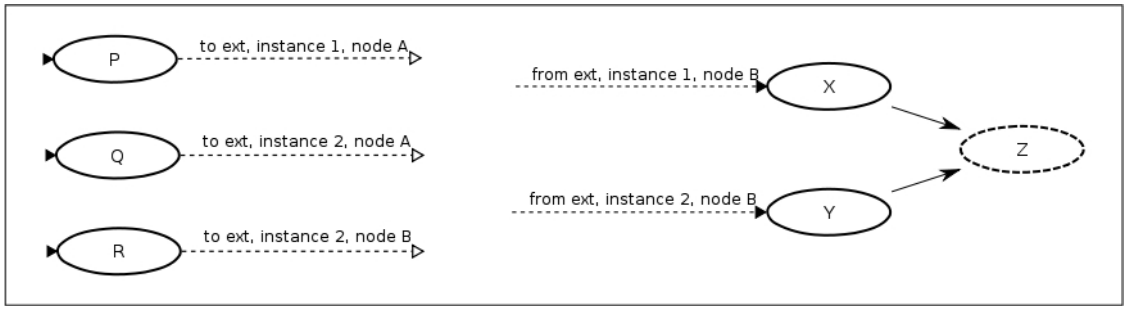
It looks like:



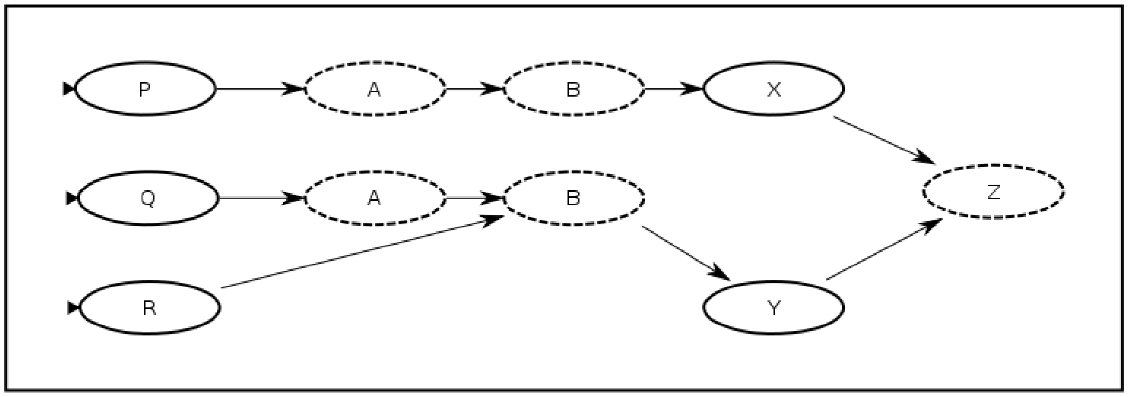
The graph which contains external arcs going to 'ext', is below.

```
<?xml version="1.0"?>
<process-definition
  name="example4"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="P" isStart="true">
    <arc external="1" to="A"/>
  </node>

  <node name="Q" isStart="true">
    <arc external="2" to="A"/>
  </node>

  <node name="R" isStart="true">
    <arc external="2" to="B"/>
  </node>

  <node name="X">
    <arc to="Z"/>
  </node>

  <node name="Y">
    <arc to="Z"/>
  </node>

  <node name="Z" joinType="labelAnd"/>

  <external name="1" processDefinition="ext">
    <arc from="A" to="X"/>
  </external>

  <external name="2" processDefinition="ext">
    <arc from="B" to="Y"/>
  </external>

</process-definition>
```

It looks like:


P
to ext, instance 1, node A
Q
to ext, instance 2, node A
R
to ext, instance 2, node B
from ext, instance 1, node B
X
Z
from ext, instance 2, node B
Y

When the process definition is loaded into memory, it will look like:



Java API

The process definition file format also supports custom elements and attributes, but before we discuss that, the API needs to be introduced.

Interfaces

The main interface for interacting with process definitions and processes is `Engine` :

```
package com.googlecode.sarasvati;

public interface Engine
{
  GraphProcess startProcess (Graph graph);
  void startProcess (GraphProcess process);
  void cancelProcess (GraphProcess process);
  void finalizeComplete (GraphProcess process);
  void finalizeCancel (GraphProcess process);
  void completeExecution (NodeToken token, String arcName);
  void completeAsynchronous (NodeToken token, String arcName );
  void executeQueuedArcTokens (GraphProcess process);
  GraphRepository<? extends Graph> getRepository ();
  GraphFactory<? extends Graph> getFactory ();
  GraphLoader<? extends Graph> getLoader ();
  void addNodeType (String type, Class<? extends Node> nodeClass );
  void fireEvent (ExecutionEvent event);
  void addExecutionListener (ExecutionListener listener, ExecutionEventType...even
  void addExecutionListener (GraphProcess process, ExecutionListener listener, Exe
  void removeExecutionListener (ExecutionListener listener, ExecutionEventType...e
  void removeExecutionListener (GraphProcess process, ExecutionListener listener,
  ExecutionListener getExecutionListenerInstance (String type) throws WorkflowExce
  void setupScriptEnv (ScriptEnv env, NodeToken token);
}
```

Process definitions are stored in classes implementing the `Graph` interface.

```
package com.googlecode.sarasvati;

public interface Graph
{
  String getName ();
  int getVersion ();
  List<? extends Arc> getArcs ();
  List<? extends Arc> getInputArcs (Node node);
  List<? extends Arc> getInputArcs (Node node, String arcName);
  List<? extends Arc> getOutputArcs (Node node);
  List<? extends Arc> getOutputArcs (Node node, String arcName);
  List<? extends Node> getStartNodes ();
  List<? extends Node> getNodes ();
}
```

A `Graph` contains instances of `Node` and `Arc` .

`Node` is where the developer can provide custom functionality, and has the following API:

```
package com.googlecode.sarasvati;
public interface Node extends Adaptable
{
  String getName ();
  String getType ();
  boolean isJoin ();
  boolean isStart ();
  String getGuard ();
  Graph getGraph ();
  boolean isExternal ();
  GuardResponse guard (Engine engine, NodeToken token);
  void execute (Engine engine, NodeToken token);
}
```

Flow of Execution

When the engine determines that a node is ready to execute, it will follow this flow:

1. Generate a `NodeToken` pointing to that node.
2. Execute the `guard` function on the node. This will return a `GuardResponse`.
   - The `GuardResponse` contains a `GuardAction` , which is an enum having values `AcceptToken` , `DiscardToken` and `SkipNode` .
3. If the action is `AcceptToken` , the `execute` method will be called. The process will not continue until the `Engine#completeExecution` method is invoked. It must be invoked with the name of the arcs on which to generate `ArcToken` s.
4. If the action is `DiscardToken` , the token is marked complete and no further execution will take place from this set of tokens.
5. If the action is `SkipNode` , `Engine.completeExecution` will be called with the arc name contained in the `GuardResponse` .

Custom logic for Node Execution

To provide custom behavior to your nodes, you will override the `execute` method on `Node` . Sarasvati currently provides two implementations of the base API, one memory backed and one database backed, implemented using Hibernate. Other implementations could be made using, for example, pure JDBC or some other persistence mechanism. There are three base classes for nodes.

- `com.googlecode.sarasvati.mem.MemNode`
- `com.googlecode.sarasvati.hib.HibNode`
- `com.googlecode.sarasvati.CustomNode`

If using only the memory backed implementation, `MemNode` should be extended. If using only the hibernate backend, nodes should subclass `HibNode`. `CustomNode` can be used with either or both backends. In to store custom attributes in the database, it uses a key/value pair table. `CustomNode` can only be used if the database mapping doesn't need to be explicitly defined.

Example One

To demonstrate use of each implementation, we start with a node that just prints out "Hello, World". We start with the process definition.

Example One: Process Definition

```
<?xml version="1.0"?>
<process-definition
  name="hello-world"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="hello" type="helloWorld" isStart="true"/>

</process-definition>
```

Example One: Node implementation

If using the memory implementation, the subclass would look like:

```
package com.googlecode.sarasvati.example.mem;

import com.googlecode.sarasvati.Arc;
import com.googlecode.sarasvati.Engine;
import com.googlecode.sarasvati.NodeToken;
import com.googlecode.sarasvati.mem.MemNode;

public class HelloNode extends MemNode
{
  @Override
  public void execute (Engine engine, NodeToken token)
  {
    System.out.println( "Hello, world!" );
    engine.completeExecution( token, Arc.DEFAULT_ARC );
  }
}
```

The hibernate version would look like:

```
import javax.persistence.DiscriminatorValue;
import javax.persistence.Entity;

import com.googlecode.sarasvati.Arc;
import com.googlecode.sarasvati.Engine;
import com.googlecode.sarasvati.NodeToken;
import com.googlecode.sarasvati.hib.HibNode;

@Entity
@DiscriminatorValue( "helloWorld" )
public class HelloNode extends HibNode
{
  @Override
  public void execute (Engine engine, NodeToken token)
  {
    System.out.println( "Hello, World!" );
    engine.completeExecution( token, Arc.DEFAULT_ARC );
  }
}
```

The hibernate version would also require an insert into the `wf_node_type` table, with type, description and behaviour.

```
insert into wf_node_type (id, description, behaviour)
 values ( 'helloWorld', 'Says hello to the world', 'helloWorld' )
```

The behaviour column ties the type to a discriminator specified on the subclass. This allows having multiple types with the same implementation class, if that was desired.

The backend independent version would look like:

```
import com.googlecode.sarasvati.Arc;
import com.googlecode.sarasvati.CustomNode;
import com.googlecode.sarasvati.Engine;
import com.googlecode.sarasvati.NodeToken;

public class HelloNode extends CustomNode
{
  @Override
  public void execute (Engine engine, NodeToken token)
  {
    System.out.println( "Hello, World!" );
    engine.completeExecution( token, Arc.DEFAULT_ARC );
  }
}
```

For use with the hibernate backend, a row would still need to be added to the `wf_node_type` table.

```
insert into wf_node_type (id, description, behaviour)
 values ( 'helloWorld', 'Says hello to the world', 'custom' )
```

Example One: Loading and Running

Now we can load the process into memory, or into the database. This is done using a `GraphLoader` , which can be retrieved from the appropriate engine. Before loading the process definition, you will need to tell the engine about your custom node types.

The steps are

1. Create an engine of the appropriate type
2. Register custom node types
3. Load the process definition from XML file
4. Get the loaded graph from the graph repository associated with the engine
5. Start a new GraphProcess using the graph

Here are the steps in code for the memory backed implementation.

```
MemEngine engine = new MemEngine();

// Tell engine about our custom node type
engine.addNodeType( "helloWorld", HelloNode.class );

// Load the process definition (this can throw LoadException or JAXBException
// The graph will be stored in the GraphRepository for this engine
engine.getLoader().load( "/path/to/hello-world.wf.xml" );

// Get the graph from the GraphRepository
Graph graph = engine.getRepository().getLatestGraph( "hello-world" );

// start a graph process
GraphProcess process = engine.startProcess( graph );
```

Here are the steps in code for the hibernate backed implementation. It assumes that you have a means of creating a hibernate `Session` object.

```
Session session = ...; // get hibernate session
HibEngine engine = new HibEngine( session );

// Tell engine about our custom node type
engine.addNodeType( "helloWorld", HelloNode.class );

// Load the process definition (this can throw LoadException or JAXBException
// The graph will be stored in the GraphRepository for this engine
engine.getLoader().load( "/path/to/hello-world.wf.xml" );

// Get the graph from the GraphRepository
Graph graph = engine.getRepository().getLatestGraph( "hello-world" );

// start a graph process
GraphProcess process = engine.startProcess( graph );
```

Here are the steps in code using the backend independent custom type with `MemEngine`.

```
MemEngine engine = new MemEngine();
```

```
    // We can either register the type with the Engine or with the DefaultNodeFact
    // directly.
    // Either tell the engine about our custom node type
    engine.addGlobalCustomNodeType( "helloWorld", HelloNode.class );

    // or tell the DefaultNodeFactory about the node type directly
    DefaultNodeFactory.addGlobalCustomType( "helloWorld", HelloNode.class );

    // Load the process definition (this can throw LoadException or JAXBException
    // The graph will be stored in the GraphRepository for this engine
    engine.getLoader().load( "/path/to/hello-world.wf.xml" );

    // Get the graph from the GraphRepository
    Graph graph = engine.getRepository().getLatestGraph( "hello-world" );

    // start a graph process
    GraphProcess process = engine.startProcess( graph );
```

The call to `startProcess` will create tokens on the start nodes and will continue executing the process until it completes or enters a wait state.

Custom Attributes

Often, custom nodes will need some information with which to do their work. Sarasvati supports this in two ways.

The schema for process definition files has a `<custom>` element which contains an `<xs:any>` element at the end of the node definition. Custom elements may be added here. These can be automatically mapped to properties on custom nodes.

For example, given the following custom node:

```
public class CustomNode extends MemNode
{
  String foo;

  public String getFoo ()
  {
    return foo;
  }

  public void setFoo (String foo)
  {
    this.foo = foo;
  }

  @Override
  public void execute (Engine engine, NodeToken token)
  {
    // do something ...
    engine.completeExecution( token, Arc.DEFAULT_ARC );
  }
}
```

The following process definition would load the value `test` into the `custom` property.

```
<?xml version="1.0"?>
<process-definition
  name="example1"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="test" type="custom" isStart="true">
    <arc to="1"/>

    <custom>
      <foo>test</foo>
    </custom>
  </node>
</process-definition>
```

There several things to note with custom elements.

- All custom elements must be contained within the `<custom>` tag.
- Non-string properties on custom node types are supported.
  - Support for primitive types such as boolean, byte, char, short, int, long, float, double as well as their corresponding object types is built in.
  - Support for non-primitive types can be added
    - Implement `com.googlecode.sarasvati.env.AttributeConverter`
    - Register the new mutator using the `setConverterForType` method (which takes a class and an `AttributeConverter`) on `com.googlecode.sarasvati.env.AttributeConverters`.

Nested objects are supported. For example:

```
  <custom>
    <task>
      <name>test</name>
    </task>
  </custom>
```

The loader would invoke `getTask().setName( ... )` on the custom node.

Attributes are also supported. How they are mapped is based on the contents of the element the attribute is on. If the element has child elements, the attribute will get mapped as a child property. If the element is itself a property, the attribute name will be combined with the element name to get the property name.

```
  <custom>
    <task user="pat">
      <name>test</name>
    </task>
  </custom>
```

This would map the `name` element value to `getTask().setName( ... )` and the `user` attribute to `getTask().setUser( ... )`.

However, the following would be mapped differently:

```
  <custom>
    <task user="pat">
      test
    </task>
  </custom>
```

This would map the text in the `task` element to `setTask( ... )` and the `user` attribute to `setTaskUser( ... )`.

Custom Loader

You may also provide custom loading via a subclass of `NodeFactory`. It has the following interface:

```
public interface NodeFactory
{
  Node newNode (String type) throws LoadException;
  void loadCustom (Node node, Object custom) throws LoadException;
}
```

The custom data may be null, a single object, or a list of objects. The object or objects will either be elements of `org.w3c.dom.Element` or JAXB objects, if you have a JAXB mapping for your custom XML.

Instances of `NodeFactory` may be registered on `GraphLoader`.

Example Two: Process Definition

Here we examine a more complicated example, which uses custom attributes.

```
<?xml version="1.0"?>

<process-definition
  name="example1"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="start" isStart="true">
    <arc to="1"/>
  </node>

  <node name="1" type="task">
    <arc to="2"/>
    <arc to="3"/>

    <custom>
      <taskName>Enter order</taskName>
      <taskDesc>
        Enter order and billing info
      </taskDesc>
    </custom>
  </node>

  <node type="task" name="2">
    <arc to="4"/>

    <custom>
      <taskName>Bill Customer</taskName>
      <taskDesc>
        Bill the Customer
      </taskDesc>
    </custom>
  </node>

  <node type="task" name="3">
    <arc to="4"/>

    <custom>
      <taskName>Ship product</taskName>
      <taskDesc>
        Package and ship product
      </taskDesc>
    </custom>
  </node>

  <node type="task" name="4" joinType="labelAnd">

    <custom>
      <taskName>Market to Customer</taskName>
      <taskDesc>
        Send marketing material to customer
      </taskDesc>
    </custom>

  </node>

</process-definition>
```

Example Two: Node implementation

We will need a couple of classes to represent tasks and their state. First we look at the memory based implementation.

First we have an enum for task states.

```
public enum TaskState { Open, Completed, Rejected }
```

Next is the `Task` class.

```
public class Task
{
  protected NodeToken nodeToken;
  protected String name;
  protected String description;
  protected TaskState state;

  public Task (NodeToken nodeToken, String name, String description, TaskState sta
  {
    this.nodeToken = nodeToken;
    this.name = name;
    this.description = description;
    this.state = state;
  }

  public NodeToken getNodeToken ()
  {
    return nodeToken;
  }

  public void setNodeToken (NodeToken nodeToken)
  {
    this.nodeToken = nodeToken;
  }

  public String getName ()
  {
    return name;
  }

  public String getDescription ()
  {
    return description;
  }

  public TaskState getState ()
  {
    return state;
  }

  public void setState (TaskState state )
  {
    this.state = state;
  }

  public boolean isRejectable ()
  {
    Node node = getNodeToken().getNode();
    return !node.getGraph().getOutputArcs( node, "reject" ).isEmpty();
  }
}
```

In our simple example, we need some way of tracking which tasks have been created.

```
public class TaskList
```

```
{
  protected static List<Task> tasks = new LinkedList<Task>();

  public static List<Task> getTasks ()
  {
    return tasks;
  }
}
```

Finally, the custom node for generating tasks

```
public class TaskNode extends MemNode
{
  protected String taskName;
  protected String taskDesc;

  public String getTaskName ()
  {
    return taskName;
  }

  public void setTaskName (String taskName)
  {
    this.taskName = taskName;
  }

  public String getTaskDesc ()
  {
    return taskDesc;
  }

  public void setTaskDesc (String taskDesc)
  {
    this.taskDesc = taskDesc;
  }

  @Override
  public void execute (Engine engine, NodeToken token)
  {
    Task newTask = new Task( token, getTaskName(), getTaskDesc(), TaskState.Open )
    TaskList.getTasks().add( newTask );
  }
}
```

When a task node is executed, it will create new `Task` instance and add it to a task list. A task can be completed or rejected as seen in the following code snippet:

```
      Task t = ...;

      if ( isCompletion )
      {
        t.setState( TaskState.Completed );
        engine.completeExecution( t.getNodeToken(), Arc.DEFAULT_ARC );
      }
      else if ( isReject && t.isRejectable() )
      {
        t.setState( TaskState.Rejected );
        engine.completeExecution( t.getNodeToken(), "reject" );
      }
```

The primary difference with the database/Hibernate version, is that the node and tasks will require database backing. Let us look at the `TaskNode` class.

```
@Entity
@DiscriminatorValue( "task" )
@SecondaryTable( name="wf_node_task", pkJoinColumns=@PrimaryKeyJoinColumn(name="id
public class TaskNode extends HibNode
{
  @Column (name="name", table="wf_node_task")
  protected String taskName;

  @Column (name="description", table="wf_node_task")
  protected String taskDesc;

  public TaskNode() { /* Default constructor for Hibernate */ }

  public String getTaskName ()
  {
    return taskName;
  }

  public void setTaskName (String taskName)
  {
    this.taskName = taskName;
  }

  public String getTaskDesc ()
  {
    return taskDesc;
  }

  public void setTaskDesc (String taskDesc)
  {
    this.taskDesc = taskDesc;
  }

  @Override
  public void execute (Engine engine, NodeToken token)
  {
    HibEngine hibEngine = (HibEngine)engine;

    Session session = hibEngine.getSession();

    TaskState open = (TaskState)session.load( TaskState.class, 0 );
    Task newTask = new Task( (HibNodeToken)token, getTaskName(), getTaskDesc(), op
    session.save( newTask );
    }
  }
```

Environment

It is often useful to track state associated with a process or tokens. Sarasvati provides several environments in which state can be placed. Some environments are defined solely by the contents of a process definition, and are therefore readonly. Readonly environments are represented by the ReadEnv [../../javadoc/com/googlecode/sarasvati/env/ReadEnv.html] interface. Most environments are read-write and are represented by the Env [../../javadoc/com/googlecode/sarasvati/env/Env.html] interface, which extends from `ReadEnv`.

The Env interface supports both persistent and transient attributes.

Table 4.10. Environment Attribute Types

Type	Behavior
Persistent	Must be serializable to the database. All primitives and object version of the primitives, as well as String and Date are supported by default. Support for other types may be added by defining an AttributeConverter [../../javadoc/com/googlecode/sarasvati/env/AttributeConverter.html], which is then registered with the AttributeConverters [../../javadoc/com/googlecode/sarasvati/env/AttributeConverters.html] class, using the `setConverterForType` method.
Transient	Transient attributes are only stored as long as the process is in memory. They are a convenient places to cache values during process execution. Because they aren't persisted to a database, there is no restriction on what types can be stored.

Process Environment

A process environment is read-write and is shared across an entire process.

```
GraphProcess p = ...;
Env env = p.getEnv();
env.setAttribute( "foo", "test" );
env.setAttribute( "bar", 5 );
String foo = env.getAttribute( "foo" );
int bar = env.getAttribute( "foo", Integer.class );
```

Node Token Environment

The node token environment is read-write. Node token state is only visible to the given token, however tokens inherit the environment of their parents. Token state is initialized using the following rules:

- If a token has no parents, it will start with an empty environment.
- If a token has one parent, it will inherit the environment of its parent.
- When a child token inherits the environment of it's parent, it may point directly to the parent's environment, until the child writes to the environment, at which point the environment will be copied.

This means that if the parents writes to the environment after children have been created, and the children have not written to their environments, these changes will be visible to the children.

- If a token has multiple parents parent, it will inherit the environment of its parent.
- If a token has multiple parents parent with overlapping attribute names, the child environment wil get one the value from one of the parents, generally whichever is merged into the child environment last.

```
NodeToken t = ...;
Env env = t.getEnv();
env.setAttribute( "foo", "test" );
env.setAttribute( "bar", 5 );
String foo = env.getAttribute( "foo" );
int bar = env.getAttribute( "foo", Integer.class );
```

Combining Environment

To read from both the process and node token environments, use the `NodeToken#getFullEnv()` method. It will return an `Env` which will read first from node token environment and, if no attribute is defined there, read from the process environment. All writes will affect the node token environment.

This is implemented using NestedEnv [../../javadoc/com/googlecode/sarasvati/impl/NestedEnv.html], which can be used to stack any combination of environments.

Token Set Environment

When working with token sets, there are two environments available.

1. An environment shared by all tokens in the token set
2. An environment specific to each member index. For example, if a token set is generated with three members, then the first token will have index `0`, the second with have index `1` and the third will have index `2`. Any tokens generated from the first token will also have index `0`, until such point as the token set is joined and is marked complete.

To see how token set environments are used, take as an example an approval process. The token set is generated as follows:

```
Map<String,List<?>> initialMemberEnv = new HashMap<String, List<?>>();
String[] groups = new String[] { "Accounting",
                                 "Security",
                                 "Operations" };
initialMemberEnv.put( "group", Arrays.asList( groups ) );

Env tokenSetEnv = new MapEnv();
tokenSetEnv.setAttribute( "deadline", 3 );

engine.completeWithNewTokenSet(
    token,           // the token being completed
    Arc.DEFAULT_ARC, // the name of the arc(s) to exit on
    "approvals",     // name to give the new token set
    3,               // number of tokens to generate on each arc
                     // with the given name
    true,            // completing asynchronously
    tokenSetEnv,     // initial token set env
    initialMemberEnv // token set member env
  );
```

This generates a token set with three tokens in it. They all share a common `deadline` attribute, but each will see a different value for the `group` attribute. These attributes can be access from the tokens in the token set as follows:

```
// Access the token set environment
Env setEnv = token.getTokenSet( "approvals" ).getEnv();
int deadline = setEnv.getAttribute( "deadline", Integer.class );

// Access the environment specific to this token within the token set
Env env = token.getTokenSetMember( "approvals" ).getEnv();
String group = env.getAttribute( "group" );
```

Externals Environment

When defining an external in a process definition, attributes may be defined for that external. Those attributes will be visible to nodes in the referenced external. In the following process definition, when node `A` is executed, it will print out the values defined for attributes named `foo` and `bar`. If the process definition were executed directly, both values would be undefined.

```
<process-definition
  name="external-env-one"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="A" type="script">
    <custom>
      <execute type="js">
        var env = token.getNode().getExternalEnv();
        System.out.println( "foo: " + env.getAttribute( "foo" ) );
        System.out.println( "bar: " + env.getAttribute( "bar" ) );
      </execute>
    </custom>
  </node>
</process-definition>
```

Process definition `external-env-one` can be included in `external-env-two`, as demonstrated below. If executed, `foo` would now have the value `hello` and `bar` would have the value `world`.

```
<process-definition
  name="external-env-two"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="B">
    <arc external="one" to="A"/>
  </node>

  <external name="one" processDefinition="external-env-one">
    <custom>
      <foo>hello</foo>
      <bar>world</bar>
    </custom>
  </external>

</process-definition>
```

The values defined for externals can be overriden. This can happen when the proces definition which defines the external is itself references as an external, as below. Now, `foo` will have the value `goodbye`, while `bar` will retain the value `world`.

```
<process-definition
  name="external-env-three"
  xmlns="http://sarasvati.googlecode.com/ProcessDefinition">

  <node name="C" isStart="true">
    <arc external="two" to="B"/>
  </node>

  <external name="two" processDefinition="external-env-two">
    <custom>
      <foo>goodbye</foo>
    </custom>
  </external>

</process-definition>
```

Execution Listeners

It is often useful to have a callback mechanism for various events in the execution of the workflow. Sarasvati allows registering listeners either globally or per-process. Support for specifying listeners per-graph will be forthcoming.

Execution listeners must implement the ExecutionListener [../../javadoc/com/googlecode/sarasvati/event/ExecutionListener.html] interface. Because execution listeners may be added to processes that are serialized to a database, there are some rules around how they should be built.

1. Execution listeners are stored in the database simply by classname. They must therefore have a public default constructor.
2. Instances of an execution listeners may be shared across threads and should therefore be thread-safe. For performance reasons, they should ideally be stateless, allowing them to be unsychronized.

Here is an example listener which prints out events as they occur.

```
package com.googlecode.sarasvati.example;

import com.googlecode.sarasvati.event.EventActions;
import com.googlecode.sarasvati.event.ExecutionEvent;
import com.googlecode.sarasvati.event.ExecutionListener;

public class LoggingExecutionListener implements ExecutionListener
{
  @Override
  public EventActions notify (final ExecutionEvent event)
  {
    System.out.println( event.getEventType() + ": " +
                        " Process: " + event.getProcess() +
                        " NodeToken: " + event.getNodeToken() +
                        " ArcToken: " + event.getArcToken() );
    return null;
  }
}
```

This listener could be register for all processes as follows:

```
// Add listener for all event types
engine.addExecutionListener( LoggingExecutionListener.class );

// Add listener for only the arc token and node token completed events
engine.addExecutionListener( LoggingExecutionListener.class,
                             ExecutionEventType.ARC_TOKEN_COMPLETED,
                             ExecutionEventType.NODE_TOKEN_COMPLETED );
```

One can also specify a particular process to listener to.

```
// Add listener for all event types
engine.addExecutionListener( process, LoggingExecutionListener.class );

// Add listener for only the arc token and node token completed events
engine.addExecutionListener( process, LoggingExecutionListener.class,
                             ExecutionEventType.ARC_TOKEN_COMPLETED,
                                            ExecutionEventType.NODE_TOKEN_COMPLETED );
```

Listeners aren't limited to a passive. In some cases they may affect workflow processing by returning a `EventActions` with an appropriate `EventActionType`. The actions that may be taken are:

- An execution listener may prevent a process that is in pending complete state from moving to complete state. This is to allow end of workflow processing to happen asynchronously.
- Similarly, an execution listener may prevent a process that is in pending cancel state from moving to cancelled state.
- An execution listener may prevent a node token that has just been accepted into a node from executing. This may be used to implement delayed node execution based on timer.

Here is a listener that creates and returns `EventActions`.

```
public class DelayExecutionListener implements ExecutionListener
{
  @Override
  public EventActions notify (final ExecutionEvent event)
  {
    if ( event.getEventType() ==
         ExecutionEventType.PROCESS_PENDING_COMPLETE )
    {
      return new EventActions(
        EventActionType.DELAY_PROCESS_FINALIZE_COMPLETE );
    }
    return null;
  }
}
```

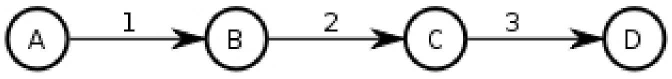
Backtracking

In graph based workflow, execution proceeds forward from node to node along directed arcs. However, it happens that we wish to allow execution to return to nodes where it has already been. Sometimes this is done because some action needs to be performed repeatedly. Other times, it's because something has gone wrong, and we need to go back to an earlier point to fix things and go back through the process. Here we focus primarily on the second case, and look at different ways of accomplishing this.

Linear Backtracking

Here is a simple, linear workflow:

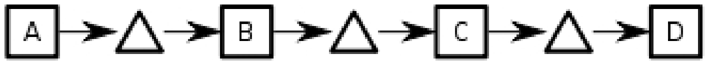
Figure 4.1. Linear Process Definition



$$\begin{tikzcd} A \arrow[r, "1"] & B \arrow[r, "2"] & C \arrow[r, "3"] & D \end{tikzcd}$$

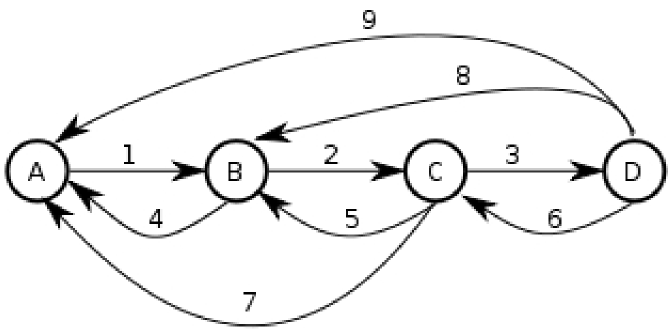
In this case, there is only one progression that can be made. Using squares for node tokens and triangles for arc tokens, the resulting execution looks like:

Figure 4.2.



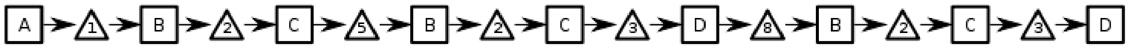
What if we wish to let a user choose to send the workflow backwards, instead of forwards, say to fix a mistake made earlier. If we wanted to be able to go back, we'd have to set up arcs going backwards. Assuming, we want maximum flexibility, we'd end up with a process definition that looked like:

Figure 4.3. Manual Linear Backtracking



Now we could go from A to B to C, back to B to C to D, back to B to C to D and done. The execution would look like:

Figure 4.4. Manual Linear Backtracking: Execution

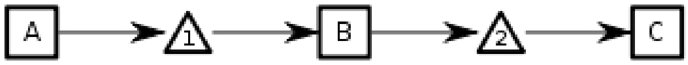


Note that the arc tokens now display the arc name.

We have gained flexibility, but at the cost of making the workflow much more complex. The number of arcs has tripled. What if instead, we could use the existing arcs? After all we know where we've been, and we just wish to go back to a previous good state. So, rather than having to make explicit arcs that go back to all conceivable previous states, we can just *backtrack*. In other words we can just trace our footsteps backwards to where we were.

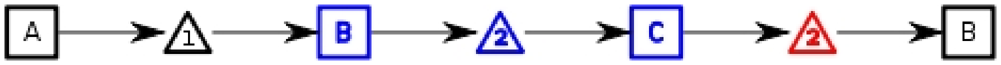
So, lets says we've gotten up to *C*. At this point, the process execution history looks like:

Figure 4.5.



Now we wish to backtrack to *B*. If we retrace our steps, the process history will now look like:

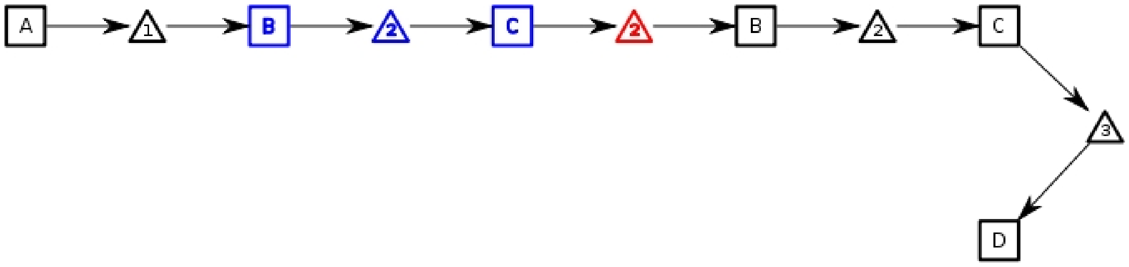
Figure 4.6.



Note that when we traverse arc *2* backward, it's marked in red. This is to mark that we've gone backwards along that arc. The node tokens on *B* and *C*, as well as the forward moving arc token on *2* are also marked, but in blue. This is to note that these actions have been backtracked. When node tokens are backtracked, they are given the opportunity to undo whatever work they did, send out notifications, or do whatever else is required.

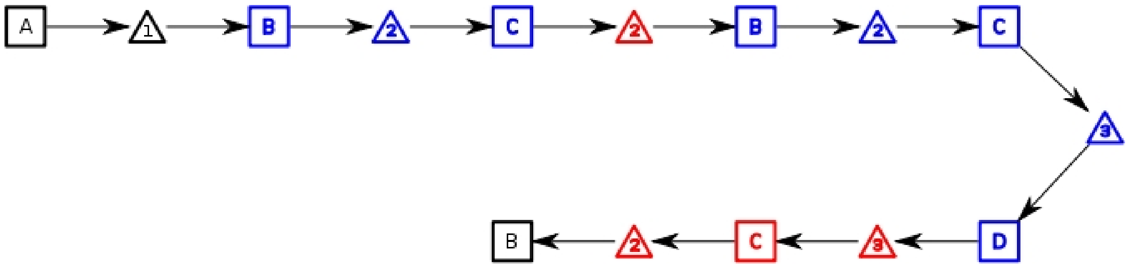
We can now move forward again, this time going up to *D*, where the process execution history looks like:

Figure 4.7.



If from here, we once again wish to return to *B*, the execution history will look like:

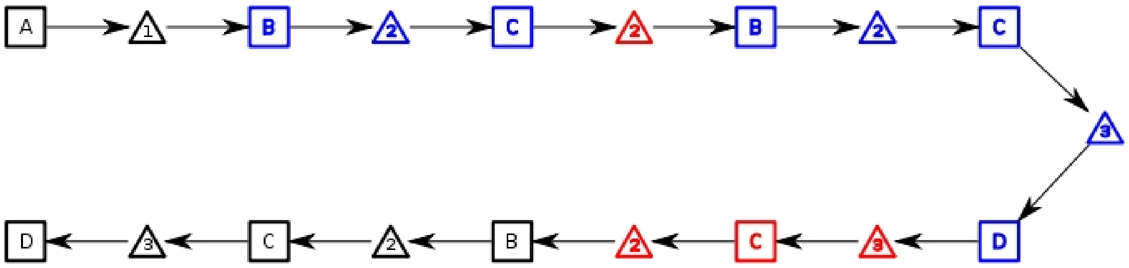
Figure 4.8.



Note that since we are somewhat literally retracing our steps, to get from *D* to *B* we created backwards tokens at arc *3*, node *C* and arc *2*. The corresponding forward tokens have been marked as backtracked.

From here we now finish, and go to the end.

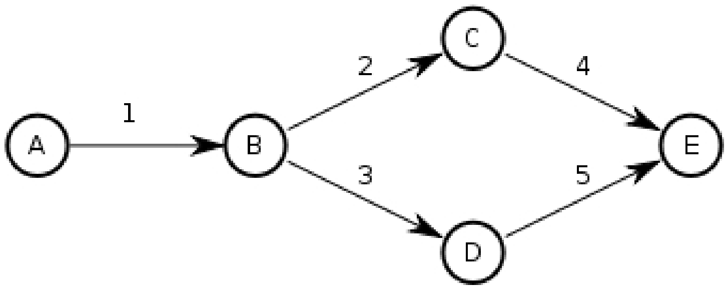
Figure 4.9.



Backtracking Across a Split

Let us now examine a process definition which has splits and joins.

Figure 4.10.



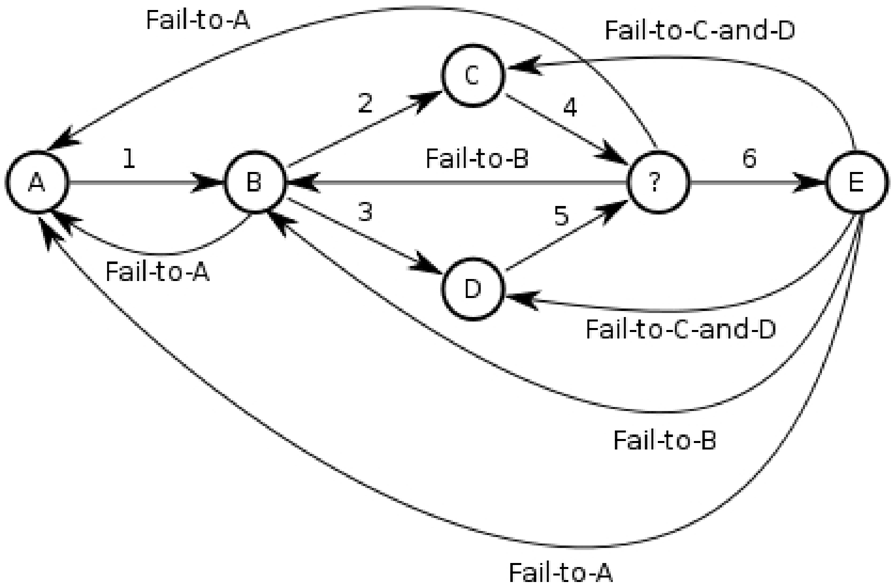
These complicate manual backtracking a great deal.

If one has multiple, concurrent node tokens active after a split, backtracking one of them means that all must be backtracked. The one which has been backtracked must out and find all incomplete concurrent tokens and complete them. It must also set a marker indicating that backtracking should occur. All the tokens must then first be collected by an intermediary node, which will test to see if a backtrack is required. It will then send execution forward or back based on this test.

If all tokens which were generated from the split aren't collected and sent back as a single token then each token sent back to the split will generate a new set of tokens from the split. This could cause many duplicates to be generated.

Here is an example of a graph which would be roughly equivalent to the previous graph, but allows manual backtracking.

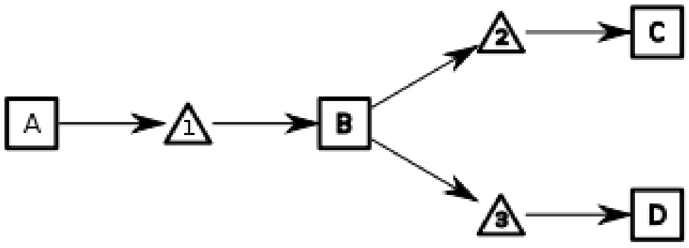
Figure 4.11. Manual Backtracking Split/Join



It has a great deal many more arcs, as well as a more complicated structure, to accommodate backtracking to the split.

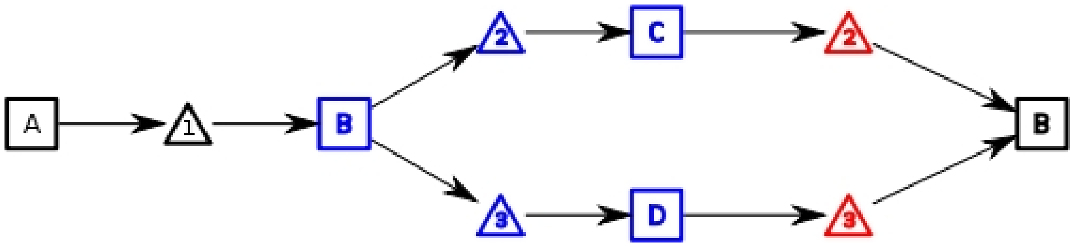
To see how automated backtracking would work, let us first progress from *A* to *B* to where both *C* and *D* are open.

Figure 4.12.



We can now attempt to backtrack to *B*.

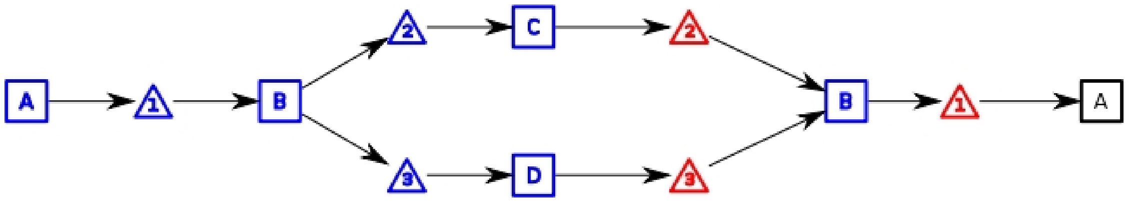
Figure 4.13.



The engine will follow all execution history which emanated from *B* and attempt to reverse it. So we can see that it flows backwards from *C* and *D* backwards to *B*.

If we now attempt to backtrack one more step to *A*, the execution history will look like:

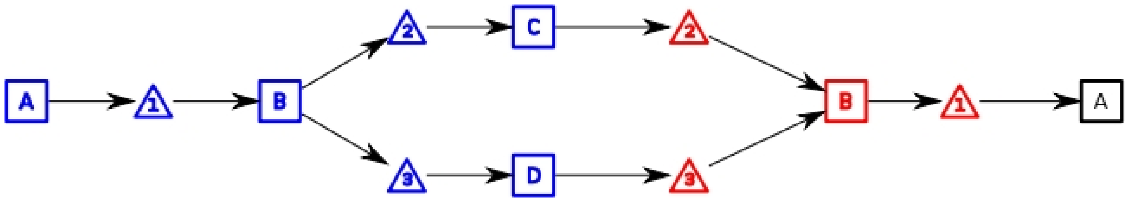
Figure 4.14.



Though this appears to be a simple linear backtrack, it's actually slightly complicated. The history starting from *A* includes the backtracking we just did. So the engine must traverse this to get to the current active tokens and backtrack them.

If instead, we were to backtrack directly from when *C* and *D* were open, back to *A*, the execution history would look as follows:

Figure 4.15.

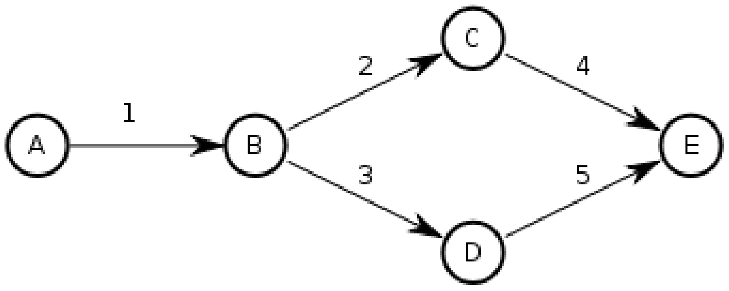


It looks almost the same, except that the second *B* is marked as a backwards execution, since this time, we went straight across it, instead of stopping there, and then continuing backwards.

Backtracking Across a Join

We'll use the same process definition as we used for demonstrating splits.

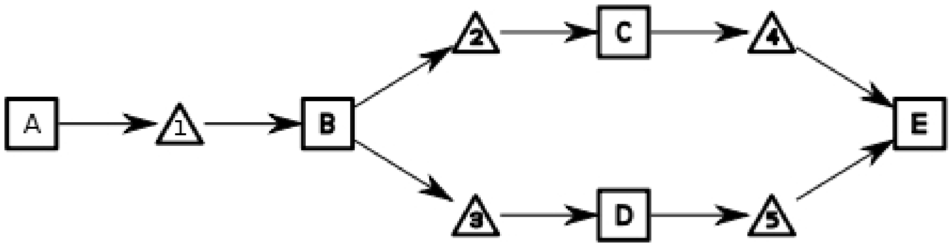
Figure 4.16.



Going back from a join is both more and less problematic than a split. A join can act as a split and send tokens back all of its inputs. However, it is very difficult to go back to just one of the inputs. If only one of the join inputs is reactivated, then the join will never fire, since it won't have all the required inputs available.

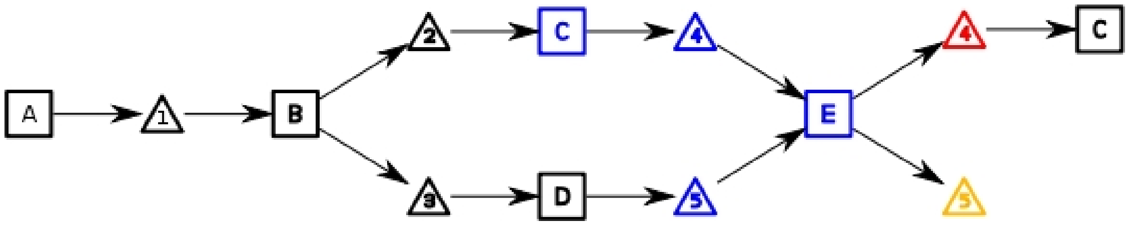
To start off with, assume execution has proceeded to *E* and the execution history looks like:

Figure 4.17.



If we then want to go back to when *C* was open, the process will now look like:

Figure 4.18.

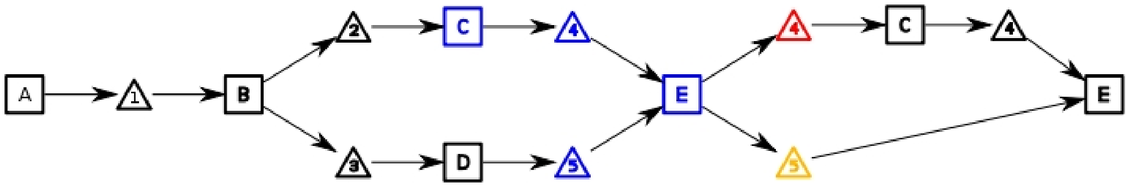


As expected, *C* is now open. To do so, we backtracked across arc *4*. However, *D* is not open but there is an open arc token on *5*. We only wanted *C* open, not *D*. However, when *C* completes, we want *E* to execute again. However, *E* will only execute if there are arc tokens waiting on arcs *4* and *5*. So, we backtrack arc *5*, but the arc token we create on *5* is left active. Now when *C* completes, *E* will execute as it will have arc tokens on all inputs.

The arc token on *5*, marked in yellow, is called a *u-turn* since this is what it does. It backtracks onto an arc, but then turns around and goes right back.

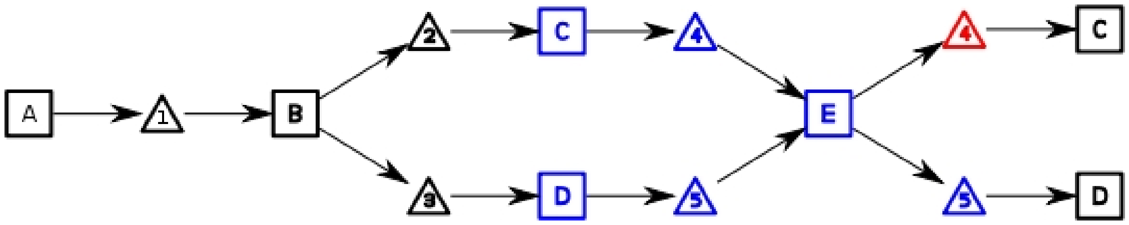
If we complete *C* the process will look like:

Figure 4.19.



If instead of completing *C* we backtracked to *D* as well, the process would now look like:

Figure 4.20.



The u-turn arc token is now marked as backtracked and a node token is now active on *D* .

Using Backtracking

Backtracking is very easy to use in Sarasvati.

To backtrack, invoke the `backtrack(NodeToken token)` method on your `Engine` instance.

```
/**
 * Backtracks execution to the point where the given
 * node token was active. The token must be complete
 * and must not have been backtracked before. If it's
 * not complete, there isn't any point in backtracking
 * to it. If it has already been backtracked, the
 * execution has either returned to a point previous
 * to that token, or there is a newer, non-backtracked
 * token at that node now.
 *
 * @param token The destination token to backtrack to.
 */
void backtrack (NodeToken token);
```

Your custom node classes may override the `isBacktrackable` and `backtrack` methods on `Node` .

`Node#isBacktrackable` will control whether a given invocation of `Engine#backtrack` will succeed. Sometimes, business logic may require that certain actions not be repeated.

`Node#backtrack` gives a place to to undo the the results of your custom node logic, and/or send notifications. This method will not be invoked until after `isBacktrackable` has returned true for all nodes needing to be backtracked.

```
/**
 * Returns true if the specific execution of
 * this Node by the given NodeToken can be
 * backtracked.
 *
 * @param engine The engine doing the backtracking
 * @param token The token being backtracked
 * @return True if the node can be backtracked, false otherwise.
 */
boolean isBacktrackable (Engine engine, NodeToken token);

/**
 * Does whatever work is necessary to backtrack
 * this execution. For example, a task node may
 * send a notification that the task has been
 * backtracked.
 *
 * @param engine The engine doing the backtracking
 * @param token The specific token being backtracked.
 */
void backtrack (Engine engine, NodeToken token);
```

Here is an example of how backtracking might be invoked. This example assumes we want to backtrack to an ancestor of the current token located at a node named *Check Inventory*.

```
String name = "Check Inventory";
NodeToken ancestor =
  FindNodeNamedVisitor.findFirstNamedParent( token, name );
engine.backtrack( ancestor );
```