Umbra's System Representation

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Abstract

This document describes the Umbra System representation. Umbra System representation, initially developed in the spring of 2003, is implemented in Incr/Tcl using concepts borrowed from Carnegie Mellon University's Architecture Description Language (ADL) called Acme. In the spring of 2004 through January 2005, System was converted to Umbra 4, extended slightly, and adopted as the underlying software system for a variety of Umbra applications that support Complex Systems Engineering (CSE) and Complex Adaptive Systems Engineering (CASE). System is now a standard part of Umbra 4. While Umbra 4 also includes an XML parser for System, the XML parser and Schema are not described in this document.
1 Introduction

Umbra’s System.tcl library implements a System class definition. The need for a System representation grew from the need to represent or model a variety of complex systems in support of System of Systems analytics as well as CSE and CASE at Sandia. The design and specification of System closely follows design concepts borrowed from Carnegie Mellon University’s Architecture Description Language (ADL) called Acme. This paper provides an overview of the relevant pieces of Acme, compares it with concepts in Umbra, then describes and provides examples of the Umbra System class.

It is noteworthy that Acme, like other ADLs, was developed to provide a formal basis for description and analysis of the architectures of component-based systems. Typically, the focus is upon software system architectures. By contrast, Umbra simulations include working models of complex component-based systems which can, in turn, often be described using ADLs. Unlike mainstream ADL work, the focus of Umbra simulations is not typically constrained to software systems. In particular, Systems typically analyzed using Umbra include physical elements or components that are not typically discussed in the ADL literature.

1.1 Acme Overview

Acme is an ADL developed at CMU for modeling complex software architectures. Acme is built on an ontology of seven types of entities for architectural representation: components, connectors, systems, ports, roles, representations, and rep-maps. Of the seven types, the most basic elements of architectural description are components, connectors, and systems.

- **Components** represent the primary computational elements and data stores of a system. Intuitively, they correspond to the boxes in box-and-line descriptions of software architectures. Typical examples of components include such things as clients, servers, filters, objects, blackboards, and databases.

- **Connectors** represent interactions among components. Computationally speaking, connectors mediate the communication and coordination activities among components. Informally they provide the “glue” for architectural designs, and intuitively, they correspond to the lines in box-and-line descriptions. Examples include simple forms of interaction, such as pipes, procedure call, and event broadcast. But connectors may also represent more complex interactions, such as a client-server protocol or a SQL link between a database and an application.

- **Systems** represent configurations of components and connectors.

Components’ interfaces are defined by a set of ports. Each port identifies a point of interaction between the component and its environment. A component may provide multiple interfaces by using different types of ports. A port can represent an interface as simple as a single procedure signature, or more complex interfaces, such as a collection of procedure calls that must be invoked in certain specified orders, or an event multi-cast interface point.

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1 This section is strongly based upon documents available at [http://www-2.cs.cmu.edu/~acme/](http://www-2.cs.cmu.edu/~acme/)
Connectors also have interfaces that are defined by a set of roles. Each role of a connector defines a participant of the interaction represented by the connector. Binary connectors have two roles such as the caller and called roles of an RPC connector, the reading and writing roles of a pipe, or the sender and receiver roles of a message passing connector. Other kinds of connectors may have more than two roles. For example an event broadcast connector might have a single event-announcer role and an arbitrary number of event-receiver roles.

Acme supports the hierarchical description of architectures. Specifically, any component or connector can be represented by one or more detailed, lower-level descriptions. Each such description is termed a representation in Acme. The use of multiple representations allows Acme to encode multiple views of architectural entities. It also supports the description of encapsulation boundaries, as well as multiple refinement levels.

### 1.2 Acme and Umbra Compared

Umbra applications can be readily modeled using the Acme representation. With a few notable exceptions most Umbra features directly correlate to key Acme concepts. The most notable exception is the use of the term connector which is elaborated below.

Figure 1 shows how a typical two-module Acme system might be illustrated for the purpose of these discussions. The interior components drawn encapsulate some functionality and are interfaced through ports. Components are associated through connectors. These connectors may have two or more roles, with each roll associating a particular port to the connector. Together the components are drawn in a representation. A system is formed by instancing this representation and encapsulating it as a component by its own right. To hide interior detail, this component’s ports are bound to various internal ports through a binding process.

![Figure 1: Illustration of an Acme System and its key attributes.](image)

Figure 2 shows a conceptual Umbra System. Key attributes shown in the diagram are the Umbra modules, which encapsulate computation, the Umbra input and output connectors, the connections made between modules, and the Tcl interface points.
Umbra modules are analogous to elemental Acme components. (Typically, they are implemented as C++ classes and instanced through the interpreter.) Umbra modules have four interfaces that would be modeled as Ports in Acme. These are the input and output connectors (which support continuous data flow) and the Tcl method and callback interfaces (which serve as input and output messaging interfaces).

It is easy to confuse Umbra and Acme’s respective uses of the word connector. In Umbra, the connector is the interface point. Connections are made between connectors. In Acme, Ports are the interface points, connectors are used to generally implement the connections. Acme’s richer representation allows Acme connectors themselves to have computational roles and can be modeled in a hierarchical fashion. Presently, Umbra does not implement features that use this abstraction.

Umbra has three features that would be modeled in Acme as connectors. These are normal (feed forward) and feedback connections between Umbra connectors and the Tcl, procedures that get used to implement application features that use the module’s messaging interfaces. In the case of connections, no computation is performed and the connection nearly approximates an Acme association. In the case of the messaging interface, a substantial amount of local computation is performed. This computation can be thought of as the computation within an Acme connection. It is noteworthy that in the case of event callbacks, Umbra uses the term associate to link various callback interface points to specific Tcl procedure calls.

Figure 2: Conceptual illustration of an Umbra module pair combined to simulate a system

1.3 Umbra’s System Class

Umbra’s System class tries to strike a balance between the very general representations within Acme and the special needs in Umbra. In its implementation, Systems are
represented as incrTcl\textsuperscript{2} classes. System classes can also be thought of as Acme System representations. Likewise, System class instances are components that can be treated like any other component.

Table 1 below groups and compares interface methods in the System class against those from Umbra modules. In cases where there is strong overlap, the System class supports methods with the same behavior and syntax as those of the Umbra module interface. It is noteworthy that many Umbra applications and the Umbra user community’s discussions are tied to Umbra’s use of the word connector to refer to a specific type of port. The System design preserves this preference but also introduces the use of port where it has distinguishing characteristics. In some minor cases, syntax used within Umbra collides with Tcl namespaces. In particular, the set method is problematic when used as an incrTcl class method. In this case, the term port (as in portValue) is introduced to move System closer to the Acme representation.

Table 1) Functional Grouping of Umbra’s module and System interface elements

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Umbra Module Method</th>
<th>System Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Instantiation &amp; Maintenance</td>
<td>classType</td>
<td>classType</td>
</tr>
<tr>
<td></td>
<td>delete</td>
<td>itcl::delete instance</td>
</tr>
<tr>
<td></td>
<td>cleanupClass</td>
<td></td>
</tr>
<tr>
<td>Port, Connector, and Parameter</td>
<td>connectors</td>
<td>portNames</td>
</tr>
<tr>
<td>Query and Management</td>
<td>connections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>binding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>get / set</td>
<td>portValue</td>
</tr>
<tr>
<td></td>
<td>connected</td>
<td>connected</td>
</tr>
<tr>
<td></td>
<td>parameters</td>
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<td></td>
<td>connect</td>
<td>connect</td>
</tr>
<tr>
<td></td>
<td>feedback</td>
<td>feedback</td>
</tr>
<tr>
<td></td>
<td>unconnect</td>
<td>unconnect</td>
</tr>
<tr>
<td>Component Queries and Manipulation</td>
<td>componentNames</td>
<td></td>
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<tr>
<td></td>
<td>component</td>
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<td></td>
<td>componentP</td>
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<tr>
<td></td>
<td>bind</td>
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<tr>
<td></td>
<td>component</td>
<td></td>
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<tr>
<td></td>
<td>sendComponent</td>
<td></td>
</tr>
<tr>
<td>Condition and Event Handling</td>
<td>offChange</td>
<td></td>
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<tr>
<td></td>
<td>offConnect</td>
<td></td>
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<td></td>
<td>offSet</td>
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<td></td>
<td>offUpdate</td>
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<td></td>
<td>onChange</td>
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<td>onConnect</td>
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<td>onSet</td>
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<td>onUpdate</td>
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<tr>
<td></td>
<td>offChange</td>
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</tr>
</tbody>
</table>

\textsuperscript{2} incrTcl is a lightweight object oriented extension to Tcl. Current Tcl releases include incrTcl as a standard component. As a result, documentation for incrTcl can be found within Tcl documentation sets.
1.3.1 Example System
As an example system, we consider ClockSystem which is included with the basic Umbra installation and defined in ClockSystem.tcl. ClockSystem is diagrammed in Figure 3. This System’s ports include a dtIn and a dtOut. The dtIn port is bound to a SimClock modules’s scale input connector while the dtOut port is bound to the same module’s dt output connector. A pair of System methods are defined for ClockSystem, realTime and simTime can connect and disconnect the system’s DigitalFilter module as shown in Figure 3. (Note, the switch is shown for conceptual purposes. Typically connectors or associations are not described using this convention.)

Figure 3: ClockSystem Diagram (from example ClockSystem.tcl)

1.4 System Instantiation & Maintenance
As with typical Umbra modules, systems are instantiated by following the name of the system with the name of the instance. In this case, the system name is actually an incrTcl class and the instance is an incrTcl instance. In some cases, a variety of messages may be printed during module creation. The instantiation command then returns the name of the module just created.

1.4.1 Instantiating and Deleting System Instances and Classes
System instanceName
   Creates an instance of a base system

itcl::delete instanceName
   Note: this is different than the standard way Umbra modules are deleted. Here, the itcl system is responsible for initiating the deletion whereas Umbra modules have a method to delete themselves.

deleClassInstances System
   This procedure deletes all modules within a class (but leaves the class defined).

cleanupClass className
This procedure deletes all modules within a class as well as the class itself. This method is particularly useful for clearing memory prior to redefining a system class.

1.4.2 Example Conventions
The examples that follow were generated by copying output from the Umbra console window. Commands are indicated using the percent sign prompt (characters leading up to the percent key are deleted). Values are offset and colored blue for clarity. System messages, which may not be part of the release version of Umbra, are retained and colored red. Comments about the example are offset and italicized.

1.4.3 Examples of System Instantiation and Deletion

*This example constructs a basic System*

```
% System foo
foo
```

*This example constructs several ClockSystems*

```
% ClockSystem cs
  Constructing System instance cs

% ClockSystem cs2
  Constructing System instance cs2

% ClockSystem cs3
  Constructing System instance cs3
```

*This example deletes all System instances and, in the process, deletes all classes derived from System (including the ClockSystems defined above).*

```
% itc1::delete object cs
  Deleting system cs

% deleteClassInstances System 1
```

*After rebuilding the classes*

```
% cleanupClass System
  cleanupClass: Deleting class System
    Deleting system cs3
    Deleting system cs2
```

1.5 Port, Connector, and Parameter Query and Management

In this implementation ports mainly refer to interface elements that correspond to Umbra module connectors. Within Umbra, Systems have input and output ports. These ports are bound to the connectors and subsystem ports.

In its implementation, ports are not actually connected to Umbra module connectors or other system ports. Rather, the connect and feedback methods use the port bindings to find and connect individual modules to one another. In the case of hierarchically defined systems, these methods recursively search downward until they can individually reach and connect each Umbra module. The unconnect method uses an inverse process to unconnect each module.
1.5.1 Basic System Methods

*attribute attName*

Queries the System to determine whether attName is a defined attribute of the System. Returns the attribute value or null if the attribute isn’t defined (or if its value is null).

*attribute attName attValue*

Sets the System attribute attName to attValue. attValue can be any Tcl atom, list, or string.

*attributes*

*portNames*

Returns a list of the names of the ports as they are defined at the system interface.

*connectors*

Returns a discriminated list of port names. This method corresponds to the default Umbra module connectors method.

*connections portName*

Returns a list of connections (as opposed to bindings) associated with the given port name. This method corresponds to the default Umbra module connections method.

**Caveat:** As this command returns the actual connections, the modules named within the return value are names of actual Umbra modules, as opposed to names of the systems within which the modules are contained.

*connected portName*

*Not implemented.* This method will return 1 if the port is connected and 0 if it is not connected.

*binding portName*

Returns the internal binding for portName. For further elaboration, see the section on System Modification and Manipulation.

*portValue portName*

Returns the current value of the connector on any internally bound component.

**Caveat:** When two or more connectors are bound to the same port (only possible with input ports), this method returns the value on the first port. This value can be misleading if the system is not connected at the input.

*portValue portName newValue*

Sets all internally bound connectors at portName to the newValue.

**Caveat:** As with normal Umbra modules, this setting will only take effect if the connectors referenced are not connected to other modules.

*connect portName moduleName portName*

*connect portName moduleName connectorName*

*feedback portName moduleName portName*

*feedback portName moduleName connectorName*
Modules within System instances can be connected to other system instances or normal Umbra modules using the same syntax as the normal Umbra connect method.

Caveat: When connecting a system instance to an Umbra module, the system instance must be listed first. This is because Umbra modules do not know about system modules.

```plaintext
unconnect portName
```

This method, unlike the Umbra module method, disconnects all internal connections found through the port binding hierarchy.

### 1.5.2 Attribute setting and querying

```plaintext
% System s
  s
  % s attributes
  % s attribute foo 1
  1
  % s attribute foo
  1
  % s attributes
  {foo 1}
```

### 1.5.3 Connection Query Examples

In these examples, `cs` is a `ClockSystem` system instance as defined in `ClockSystem.tcl`

```plaintext
% cs portNames
dtIn dtOut
% cs portValue dtIn
  0.0
% cs portValue dtOut
  0.0
% cs connectors
  {Input dtIn} {Output dtOut}
% cs connections dtOut
null
```

The following connections query exposes an internal connection that gets made when the clockSystem is put in realTime mode (the default).

```plaintext
% cs connections dtIn
{connect cs.clockSystem.filter scaleOutput}
% cs simTime
  0.001
% cs connections dtIn
null
```

### 1.5.4 Connection Management Examples

In this example, a normal Umbra module is created and connected to a ClockSystem instance.

```plaintext
% DigitalFilter filter
% cs connect dtOut filter scaleInput
  Making Umbra Connection: filter connect scaleInput cs.ClockSystem.simClock dt
```
This next example connects two ClockSystem instances. Initially, the system produces an error because the internal connector that the port references is in use at the time the connection is attempted. (Specifically, dtIn is being used internally by the wallclock.) See diagram provided above for further elaboration.

```
% cs connect dtOut cs2 dtIn
   Making system connection: cs2 connect dtIn cs.clockSystem.simClock dt
   Making Umbra Connection: cs.clockSystem.simClock connect dt cs2.clockSystem.simClock scale
   unable to connect cs.clockSystem.simClock->dt with cs2.clockSystem.simClock->scale

Putting the clockSystem into simulated time mode disconnects the internal connector and allows it to be used by the external system.
% cs2 simTime 0.001
% cs connect dtOut cs2 dtIn
   Making system connection: cs2 connect dtIn cs.clockSystem.simClock dt
   Making Umbra Connection: cs.clockSystem.simClock connect dt cs2.clockSystem.simClock scale

Here is a similar example using the feedback.
% cs2.clockSystem.simClock connections scale {connect cs2.clockSystem.filter scaleOutput}
% cs2 simTime 0.001
% cs feedback dtOut cs2 dtIn
   Making system feedback connection: cs2 feedback dtIn cs.clockSystem.simClock dt
   Making Umbra Connection: cs.clockSystem.simClock feedback dt cs2.clockSystem.simClock scale
```

1.6 Component Query and Manipulation Functions

For some applications, it’s important to directly interact with or inspect the state of internal modules. A set of component query functions are available for inspecting and interacting with components within a system.

Unlike Umbra modules, System modules can be extended dynamically by adding components and establishing binding. By extension, internal component interfaces are exposed through a system sendComponent command. These capabilities have been implemented to allow systems to be defined and manipulated dynamically. Dynamic system creation is particularly useful for defining systems through XML documents.

In its implementation, Systems store named lists of components. Within Umbra, each module must have a unique name whether it is associated with a system or built as a stand-alone module. Rather than require that user applications be directly exposed to specific module names, query and manipulation functions are available for interacting with internal components by using a standard name. In Acme, this indirection is a form of binding.
1.6.1 Key Limitations
Dynamically created systems cannot have unique methods. This is a limitation of the incrTcl implementation. This limitation is similar to the fact that Umbra modules with specialized methods must be created through a programming language (i.e., C++). By extension, systems that are complex enough to require their own methods should be defined through a programming language (i.e., incrTcl).

1.6.2 Caveats
A careful balance must be struck between creating systems directly (in code) and creating or extending systems dynamically. Applications should not overly rely on system modification and manipulation mechanisms as doing so can negate the benefits of having system definition formalisms in the first place. At the extreme, overuse of these methods could cause the system formalism to be more a barrier to effective programming than a boon in usability.

1.6.3 Methods

**componentNames**

Returns list of component names. These are consistent, easier to remember externally referenced names, as opposed to the names of the internal modules.

```
component componentName
```

Returns name of actual or internal module referred to externally by the high level name. In the case of Umbra modules, these are the actual instance names.

```
component componentModuleName moduleInstanceName
```

Adds moduleInstanceName to the system with and names it componentName for external referencing.

```
component componentName delete
```

Deletes the named component from the system and deletes the Umbra instance for it as well.

```
componentP internalName
```

Returns

1 if the named component is a component of this system

2 if the name is the name of a component in the system

0 if it's neither a component or the name the system uses

```
binding portName
bind portName
```

Returns the internal bindings to portName.

```
bind portName [Input|Output] bindings
```

Creates an input or output port to connector binding to portName.

```
sendComponent componentName message
```

invokeMethod componentName method
This method sends message (Tcl method) to the internal component named
componentName. Note that componentName is the externally referenced name and
not the actual moduleInstanceName. This external referencing allows the same
“sendComponent” command to be sent to several Systems regardless of their
composition.

Note: sendComponent and invokeMethod are just two different wordings of the
same function call. Eventually, we will remove one or the other. Vote your
preference.

Caveat. If the component is a System instance, this method assumes that the System
instance has a message that can receive the same command. If it does not, that call
will likely flag an error. For this reason, sendMessage is more appropriate.

bindMessage portName bindings
Not implemented. Creates message binding named portName. As with connector
ports, message bindings are actually lists of methods. For some systems, the same
method needs to be sent to several internal components. This mechanism will
provide that capability.

sendMessage portName arguments
Not implemented. Sends the message (which in Acme parlay is also a port) with
given arguments to the internal components.

1.6.4 Example 1
In these examples, cs is a ClockSystem system instance as defined in
ClockSystem.tcl
% cs componentNames
wallClock simClock filter
% cs component wallClock
cs.clockSystem.wallClock
% cs componentP wallClock
0
% cs componentP cs.clockSystem.wallClock
1

1.6.5 Example 2
The code for the following example is in AnimateSystem.tcl. The system, diagrammed in
Figure 4, includes a VectorInterpolator and a geometric object (a scene model) with joints
set up to drive it in XYZ. The system is diagrammed below.
The first step is to create the separate modules:

% VectorInterpolator as.vi
% as.vi events 0 "0 0 0" 10 "0 0 3" 20 "0 4 4" 50 "5 5 5" 100 "0 0 0"
0 {0 0 0 } 10 {0 0 3} 20 {0 4 4} 50 {5 5 5} 100 {0 0 0 }
% scene model as.ball
% as.ball sphere 1
% as.ball makePosJoint {0 1 2}
% as.vi connect currentValue as.ball joints

The second step is to create and populate a system with these components and then add the needed bindings:

% System as
% as component replayer as.vi
% as.vi
% as component geom as.ball
% as.ball
% as bind time Input "{as.vi time}"{as.vi time}

Finally, the system is connected to the simClock, the simClock is reset, and (optionally), the system run to see the simple animation.

% as connect time simClock time

Send the geometry (geom) subcomponents a message to change color.
% as sendComponent geom "color {.4 .3 .6}"

Now reset the simClock and watch the system animate by running Umbra (click run button).
% simClock reset

At this point, the system contains several modules that can be discovered through Umbra’s modules command:

% modules as
% as.ball
% as.vi

Because the system owns the modules, the modules will get deleted if the system gets deleted. However, No modules get listed because they are all deleted.

Deleting system as.System

% modules as
2 Conclusion

This document described the Umbra System representation and compared key design elements with Carnegie Mellon University's ADL called Acme. As a compact way to organize system definition code, the Umbra System representation is recommended for all serious System of Systems, CSE, and CASE modeling work. Work is ongoing to convert Sandia legacy models to use the Umbra System representation. Feedback has been favorable. An initial extension to this concept has been an XML Schema and parser which are under development. These developments are expected to further firm up the use of the Umbra System representation.
### Key Words

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADL</td>
<td>Architecture Description Language</td>
</tr>
<tr>
<td>Acme</td>
<td>A simple, generic software architecture description language (ADL) developed at Carnegie Mellon University that can be used as a common interchange format for architecture design tools and/or as a foundation for developing new architectural design and analysis tools.</td>
</tr>
<tr>
<td>Complex Adaptive Systems</td>
<td>A second-order operational model for the complexity paradigm that addresses adaptively or the ability for the system to change its behavior over time in response to evolving system dynamics. Examples include economies, ecologies, weather, traffic and social organizations including military and security organizations.</td>
</tr>
<tr>
<td>Complex Systems</td>
<td>A first-order operational model for the complexity paradigm. Complex Systems is a new field of science studying how parts of a system give rise to the collective behaviors of the system, and how the system interacts with its environment.</td>
</tr>
<tr>
<td>Component</td>
<td>A constituent element, as of a system. In Umbra, the terms module and component are used nearly synonymously. In Acme, the term component dominates.</td>
</tr>
<tr>
<td>Connector</td>
<td>See Port.</td>
</tr>
<tr>
<td>Event</td>
<td>A message (e.g., via a method call) sent to an object (e.g., an Umbra module) that allows the object to execute work.</td>
</tr>
<tr>
<td>IncrTcl</td>
<td>IncrTcl is a lightweight object oriented extension to Tcl. Current Tcl releases include incrTcl as a standard component. Documentation for incrTcl can be found within Tcl documentation sets or from <a href="http://www.activeState.com">http://www.activeState.com</a> which distributes Tcl.</td>
</tr>
<tr>
<td>Module</td>
<td>1. A standardized, often interchangeable component of a system or construction that is designed for easy assembly or flexible use. 2. A portion of a program that carries out a specific function and may be used alone or combined with other modules of the same program.</td>
</tr>
<tr>
<td>Ontology</td>
<td>An explicit formal specification of how to represent the objects, concepts and other entities that are assumed to exist in some area of interest and the relationships that hold among them.</td>
</tr>
<tr>
<td>Parameter</td>
<td>A data value associated with a system or system component. In Umbra, parameters can be values set by the application or can result from computation. Parameter values typically change infrequently.</td>
</tr>
<tr>
<td>Port</td>
<td>An Umbra construct that allows modules to share information in an organized fashion. (Sometimes referred to as connectors.)</td>
</tr>
<tr>
<td><strong>System</strong></td>
<td>A collection of Umbra modules that represents a system function such as a unmanned ground vehicle (UGV), unmanned air vehicle (UAV), and unattended ground sensor (UGS). System is often referred as a meta-module.</td>
</tr>
<tr>
<td><strong>System of Systems</strong></td>
<td>A system where each component is a system (including one or more components) and the sub-systems components behave interdependently. Also, the large-scale integration of many interdependent, self-contained systems in that together satisfies a global need.</td>
</tr>
<tr>
<td><strong>Tcl</strong></td>
<td>Script-level programming language used in Umbra. (Commercially available at <a href="http://www.activeState.com">http://www.activeState.com</a>).</td>
</tr>
<tr>
<td><strong>Umbra</strong></td>
<td>Developed by engineers in the Intelligent Systems and Robotics Center at Sandia National Laboratories in Albuquerque, NM, Umbra is a powerful software framework that engineers and programmers can use to develop simulations and analyses, intelligent system and robot controls, 3-D graphics modeling, and new applications. Umbra supports trade-off analyses of complex robotic systems, device, physics, and component concepts.</td>
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Distribution:
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