COMPONENT/CONNECTION/SIGNAL MODELING OF ACCELERATOR SYSTEMS*

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Abstract

This paper presents a pragmatic global approach to data modeling a complex facility such as a particle accelerator. By successively partitioning the facility into collaborating subsystems, one eventually arrives at the component level--the point at which the subsystem is replaceable as a single unit. The fundamental goal of the model is to capture the dynamical relationships (i.e., the connections) that exist among the accelerator components. Components participate in one or more of three connection types: control, housing, and power. These connections are captured in a multi-hierarchical model capable of handling any component of the accelerator, from the macro scale (magnets, power supplies, racks, etc.) to the embedded scale (circuit board components), if desired. The connection approach has been used to model the signal flows between the components via their port connections. The result is a schema for a cable database that provides end-to-end signal tracing throughout the facility. The paper will discuss the multi-hierarchy nature of the model and its success in replacing the "Revision Controlled Drawing" approach to system documentation.

INTRODUCTON

Complex technical systems such as an accelerator facility require the collaborative operation of many thousands of subsystems and their constituent elements. These facilities have high availability standards, while at the same time require continual modification and enhancement. The complex nature of these facilities indicates an approach is needed whereby the documentation can be kept consistent with continually evolving system configuration and can be 'queried' from a variety of viewpoints to elicit information related to the operation and improvement of the facility.

This paper presents a modeling approach to capturing and elucidating the 'as-built' facility configuration. The approach models the system as a set of connected 'components' that interchange and transform 'signals' to effect the system operation. The derived model is designed to encourage the incremental documentation of day-to-day changes in the facility layout, as opposed to the "Revision Controlled Drawing" approach to system documentation.

Attempts in the past to model systems with this degree of complexity have met with limited success. Previous modeling attempts have commonly been carried out from the perspective of the accelerator physicist – a user type who is quite at home with system modeling. The model abstraction is often focused on the effect of the accelerator devices on the beam – usually by assigning 'roles' to devices (e.g., 'horizontal corrector'). While these models serve well the purpose of understanding the behavior of the beam, they often do not address the complex infrastructure required to make these accelerator devices function as a system. This rather subjective role modeling approach does not lend itself well to the myriad of racks, chassis, and components, all of which are part of the facility assembly.

COMPONENTS

In the present context, a component is defined as "a unit replaceable physical entity associated with the accelerator facility." A component is a functional constituent of a working assembly or system. A complex facility may have many thousands of components, but a much smaller number of 'component types' that contain information (manufacturer, description, form factor, etc.) common to the components of a given type. Site-specific tailoring of the model is accomplished by modifying the definitions of the component types to meet the facility requirements.

Components are readily identifiable, familiar elements of any facility. Examples of components are: power supply, chassis, I/O card, magnet, pump, etc. They are defined by their structure as it relates to their removal from or replacement in the system. This pragmatic approach is appealing to the electrical, mechanical, and power supply engineer alike, as well as and the accelerator operator, physicist, and technical assembly staff. With this definition, the 'system' or accelerator facility is defined as a set of collaborating components. The model attempts to capture this collaboration.

A component as defined here has a finer granularity than the more common accelerator 'device,' which may be made up of several components. The common usage of the term device – for example a vacuum pump – often also implicitly refers to its assembly components, power supply, and the set of controllers and readback elements necessary for the functioning of the pump. A device (for example, a magnet) may have different roles, depending on the perspective of the user – the operator, the physicist, or the engineer. In the present context, a magnet is viewed simply as a component that converts an electrical current into a magnetic field; it has no other site-specific role attached to it. This approach substantially reduces the subjectivity in abstracting the device's function. Assignment of roles to components or component assemblies is handled as an extension to the basic model.

CONNECTIONS

Three properties critical to a component's installation in the facility are: a) how and where it is housed, b) its power source, and c) how it is controlled. The present

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model attempts to capture each of these properties in a systematic and searchable way.

Housing

In the model, each installed component maintains a reference (a housing child/parent relationship) to some other component in the facility in which it is housed. The unique child/parent relation of each component implies that the components are members of a simple hierarchy. The underlying concept is that any component is 'connected to' its housing parent and shifts the modeling focus away from the component to that of a connection. The assembly is defined by the connections, not the components - which become attributes of the connections. This housing child/parent reference carries with it the basic system assembly information.

The housing hierarchy provides the ability to physically locate any component – from the macro scale for bulk components (magnets, racks) to the mini scale of removable/replaceable electronic circuit components. Queries such as 'what else is in this rack' or 'what else is nearby' are possible using the hierarchical model. Building, room, and rack component types are required to complete this hierarchy.

Power

Analogous to the housing hierarchy, each active component maintains a reference to an external component that is its power source. Power is distributed through the facility by means of a set of electrically connected components, forming a power hierarchy. Each component in the power hierarchy also retains a reference to its housing parent, thus capturing the power grid assembly information. A typical component power path might be: /switch-gear/circuit-breaker/circuit/ac-panel/ circuit/power-strip/power-supply/chassis/IO module. This hierarchy answers queries such as 'what components will fail if this circuit is opened.'

Control

This connection hierarchy refers to devices that are part of the facility control system. Control from a central processor to an I/O point is effected by a complex set of field buses, switches, links, multiplexors, etc. Any component that is read/write accessible by the control system is also a member of the control hierarchy. Again, the assembly information for these control components is contained in the housing parent reference.

PORTS, PINS, AND SIGNALS

A component receives a set of input signals, manipulates and outputs them to some other component in the system. This adds the abstraction of 'behavior' to the component concept. The component definition is extended to include its 'ports' – the mechanism by which components exchange. Each port is further broken down into its constituent 'pins,' each associated with a distinct signal.

'Signals' represent a flow of information (command/data) or energy (high current, rf, etc.) between two distinct pins associated with component ports. This pin-pin association is captured in the model, broadening the model's connection-oriented approach. The media by which the signals are transported – fiber, coax, wireless, high-current bus bar, waveguide, etc. are attributes of the pin-pin connections. The full component/port/pin model not only provides a powerful basis for documenting the system cabling plant, it also provides an integrated mechanism for capturing the system signal flow as well.

COMPONENT MODEL

Components as Signal Transformers

A component's ports/pins are the mechanism by which a component exchanges signals with the rest of the plant. This concept can be abstracted into a component transfer function where each output signal of the component is a function F of the input set of signals:

$$\mathrm{OUTPUT}_j = \mathrm{F}(\mathrm{INPUT}_i,\ i=1,n) + \mathrm{G},$$

where G is a function of the component itself.

The case of a fanout component is represented simply by:

$$\mathrm{OUTPUT}_j = \mathrm{INPUT}_0\,.$$

For a power supply component, the signal transformer function would be modeled as the supply's excitation curve. Storing the signal transfer function of each component of the system provides the capability of carrying out end-to-end signal tracing. Combined with the connection information outlined above, much of the framework needed for Petri net or other systems analysis is available.

The component model shown in Figure 1 provides a modeling framework into which the facility may capture whatever components are required in the as-built documentation of the system.

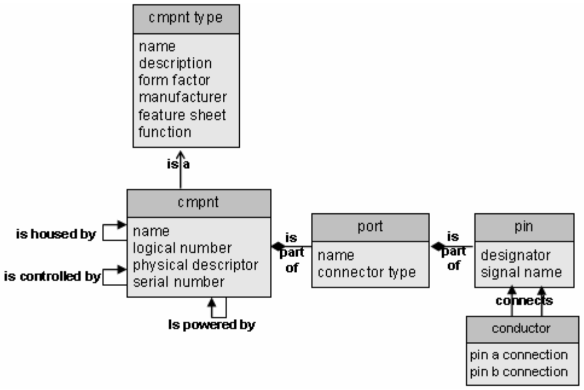

Figure 1: The Component/Connection/Signal Model. The housing, control, and power relationships are captured by references to other components in the. The set of signals in the facility are captured by their association to the component/port/pin elements.

Subassemblies

The hierarchical nature of the model provides the capability to handle component sub-trees as subassemblies. These subassemblies can be treated as single entities (added, replaced, moved, etc.) while retaining their internal connection topologies. At the same time the user retains the capability of manipulating the individual constituents of the subassembly.

ACCELERATOR DEVICES

Devices of interest to the accelerator physicist are assembled from components that either directly affect the beam (magnets, rf cavities, electrostatic deflectors, etc.) or measure some property of the beam (BPM, rf phase detector, etc.). These physics devices, and their effect on the beam, are abstracted into beam physics models in order to simulate the behavior of the beam, to develop new beam capabilities, and to diagnose operational beam-related problems. Establishing relationships, or 'maps' between physics devices and the component model provides a common modeling framework for the accelerator operator or physicist, and the engineering and technical staff. The component model encompasses not only the beam-related components, but also all of the component infrastructure required to assemble (housing hierarchy), manipulate (control hierarchy), or activate (power heriarchy) the as-built system.

For the accelerator physics components, a natural extension of the above three hierarchies would include an accelerator hierarchy. Using this shared accelerator hierarchy in the physics modeling codes would create an opportunity to extend the physics codes to help to locate and diagnose failed or malfunctioning components resulting in errant beam behavior.

DISCUSSION

The present approach provides an integrated global model with powerful querying capability related to the system assembly (the as-built documentation), the power distribution, and control of the system. It is a model of the connections in the facility, where the component instances are handled as attributes of the multi-hierarchical connections. If an installed component (e.g., a power supply) is exchanged with a spare, the stored 'connection' information does not change – only the serial number of the device making up the connection is updated in the model. If a component is substituted by a different but compatible component type, then the component-type attribute of the connection is affected. The system connection information is otherwise unchanged. The failed module remains in the model – its housing parent is changed from the production environment to the repair bench or to a spares cage. The modeling approach naturally lends itself to providing a component fault history, since it allows entry of fault information as it relates to the component behavior within the system.

The model developed here focuses on the housing, control, and power hierarchies common to all modern facilities. An additional accelerator hierarchy would provide a view specific to that type of facility. Additional hierarchies that may be implemented in the model; these include a vacuum hierarchy and component-type hierarchy.

The present model has been implemented in a relational database using the IRMIS Toolkit [1]. The implementation is in routine use at the Advanced Photon Source and is now the primary tool for providing the as-built documentation of the control system. This system is being tested at a number of other accelerator facilities.

ACKNOWLEDGEMENTS

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REFERENCES

[1] IRMIS Toolkit, http://www.aps.anl.gov/epics/irmis