Modeling Real-Time System Architectures with UML 2.0

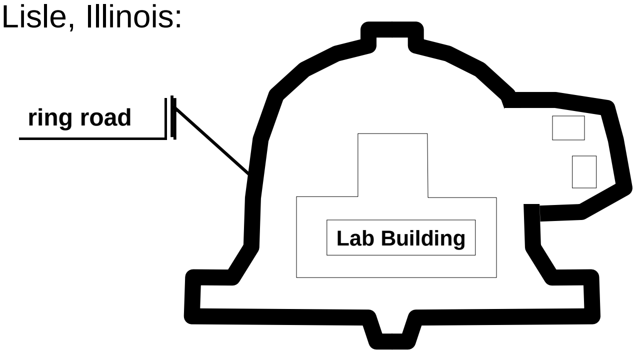
Bran Selic
Principal Engineer
IBM Software Group –
Rational Software
bselic@ca.ibm.com

Objectives

- Define architecture and its role in software design
- Identify requirements for modeling software architectures
- Describe how UML 2 and MDA can be used for modeling software architectures of embedded systems

A Parable

Lisle, Illinois:



- “Architectural” decay, caused by:
  - Lack of high-level (architectural) view (“the forest vs the trees”)
  - Difficulties in enforcing architectural decisions

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Presentation Overview

- Software architecture and its role
- Requirements for architectural modeling
- The role of UML 2 and MDA in architectural modeling
- Example system
- Architectural patterns for embedded software

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(Run-Time) Architecture

- An abstract view of a system that identifies only the important elements and relationships
- We will focus only on run-time architectures:

  The run-time organization of <u>significant</u> software components interacting through interfaces, those components being composed of successively smaller components and interfaces

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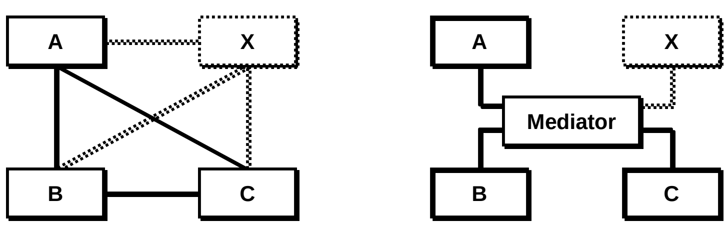
Why Architecture is Important

- Enables communication between stakeholders
  - exposes how individual requirements are handled
- Drives system construction
  - decomposition into units of responsibility and parallel development
- Determines a system's capacity for evolutionary growth



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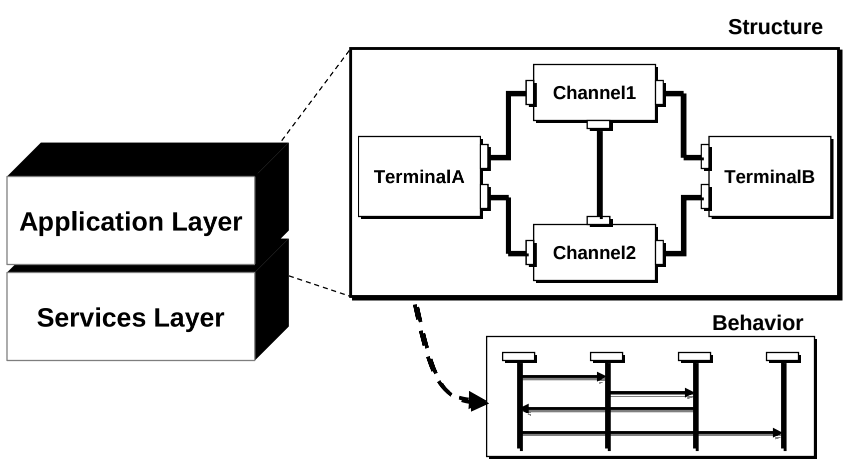
Example Complex Architecture Spec

- ♦ Example telecom system architecture



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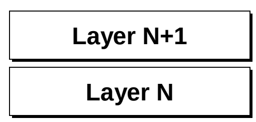
Basic Run-Time Architectural Patterns

- Peer-to-peer communication:

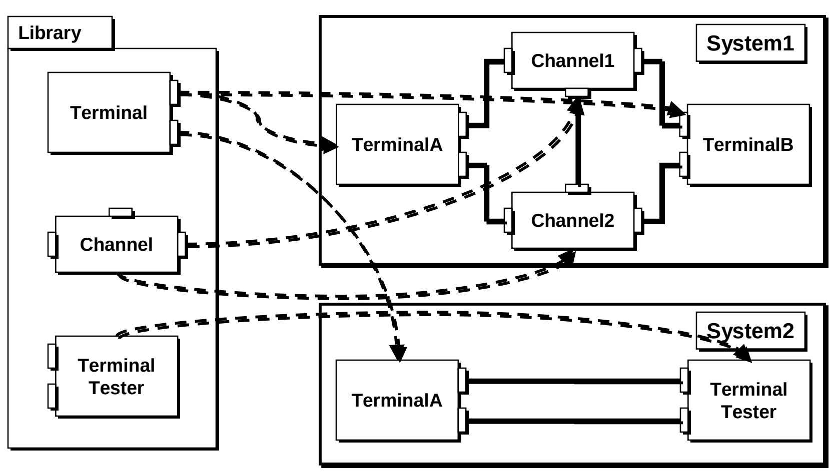
- Containment:

aggregation (information hiding)

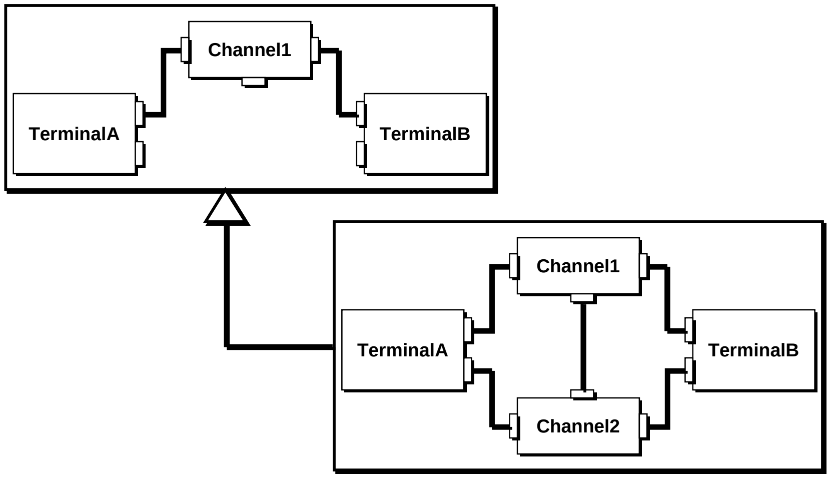
- Layering



Architectural Component Design



Refining Architectures (Reuse)



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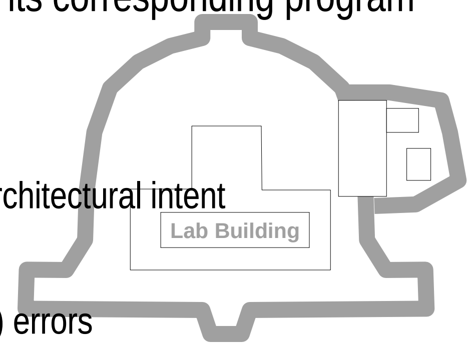
Architectural Decay

- The (usually) gradual divergence between an architectural model and its corresponding program implementation
- Caused by:
  - Misunderstandings of architectural intent
  - Design disagreements
  - Implementation (coding) errors
- Often occurs during low-level maintenance work



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Summary of Requirements

- Need the ability to specify software architectural patterns in a direct and and expressive way
- Need to provide reuse of architectural-level components
- Need to prevent architectural decay

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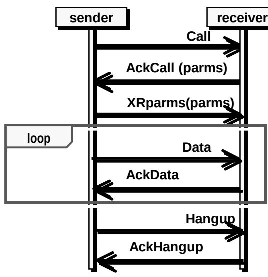
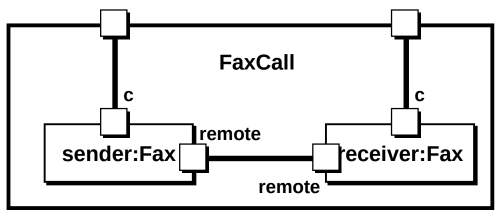
UML 2.0 and Architectural Modeling

- UML 2.0 adds two fundamental capabilities for modeling software architectures
  - *Structured classes* for modeling structural aspects:
    - parts, ports, and connectors
    - reusable architectural components
  - *(Complex) interactions* for modeling behavior





What About Architectural Decay?

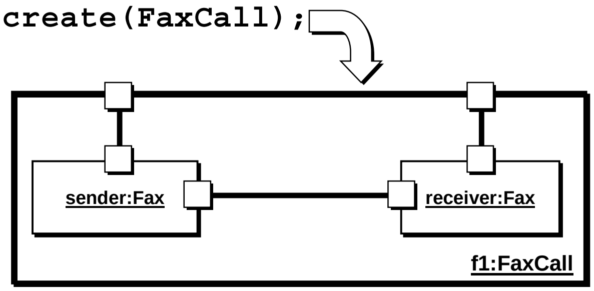
- Ensure visibility and enforcement of architectural intent
- Achieved by:
  - Requiring that *all* design work to take place at the model level
  - Automatically generating implementations directly from models

…i.e., use *model-driven development*

Structured Object Semantics

- Run-time assertion: the complete internal structure of a composite is automatically created (recursively, if necessary) when the object is created

```
f1 := create(FaxCall);
```



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Benefits of Run-Time Assertion

- *Architectural enforcement:* only explicitly prescribed architectural structures can be instantiated
  - it is not possible to bypass (corrupt) the architecture by low-level programming
- *Simplification:* low-level program code that dynamically creates (destroys) components and the connections between them is eliminated
  - in some systems this can be as much as 35% of all code
- Major net gain in productivity and reliability

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Summary: UML as an ADL

- UML 2.0 seems to have the necessary level of expressive power to specify software architectures directly (= architectural description language)
- By supporting the class/object paradigm at the architectural level it enables definition of reusable architectural components
- Combined with Model-Driven Development (MDD) methods, it can also ensure architectural enforcement

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Design Patterns

- *A **design pattern** is a proven generalized solution to a generalized problem that can be used to derive a specific solution to a specific problem*
- Represent distilled reusable experience
- Major benefits of using patterns:
  - Simplify and speed-up design
  - Reduce risk
  - Facilitate communications between designers

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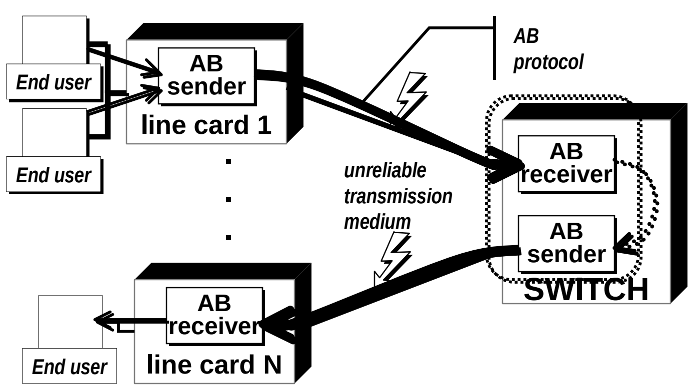
Example System

- A multi-line packet switch that uses the alternating-bit protocol as its link protocol



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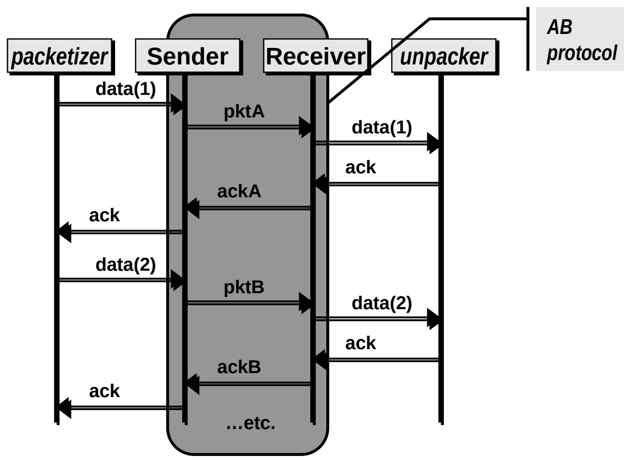
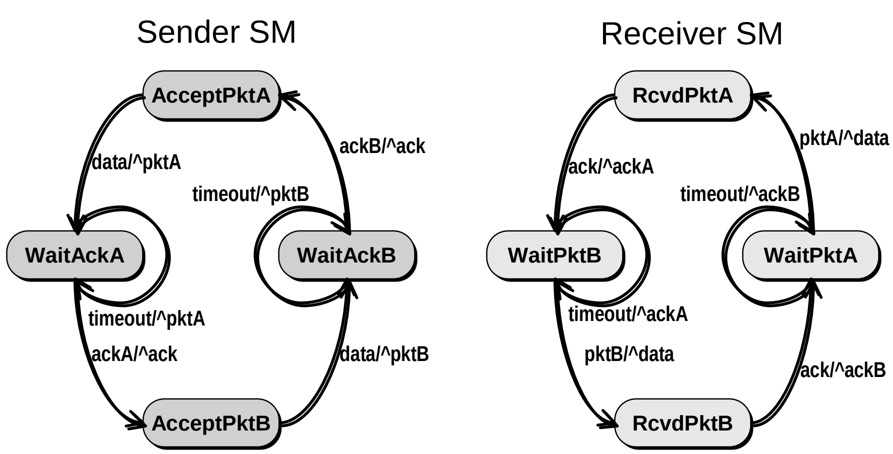
Alternating Bit Protocol (1)

♦ A simple one-way point-to-point packet protocol



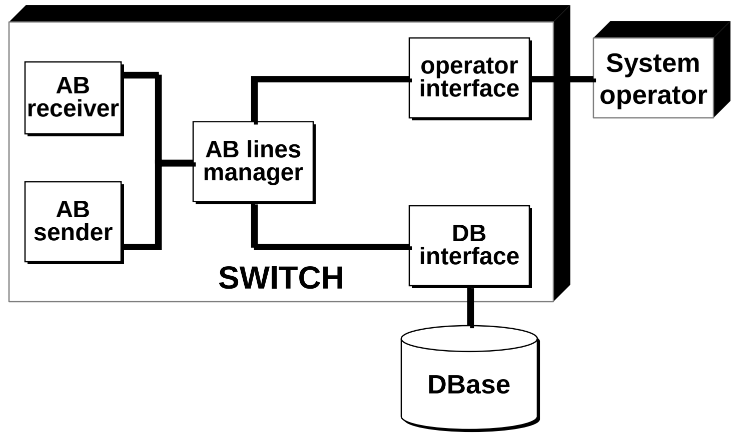
Alternating Bit Protocol (2)

♦ State machine specification



Additional Considerations

- Support infrastructure



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Control

The set of (additional) mechanisms and actions required to bring a system into the desired operational state and to maintain it in that state in the face of various planned and unplanned disruptions

- For software systems this includes:
  - system/component start-up and shut-down
  - failure detection/reporting/recovery
  - system administration, maintenance, and provisioning
  - (on-line) software upgrade

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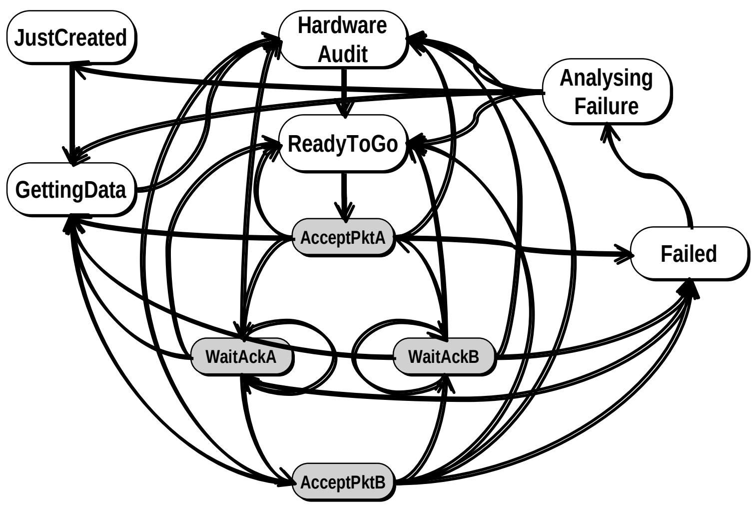
Retrofitting Control Behavior



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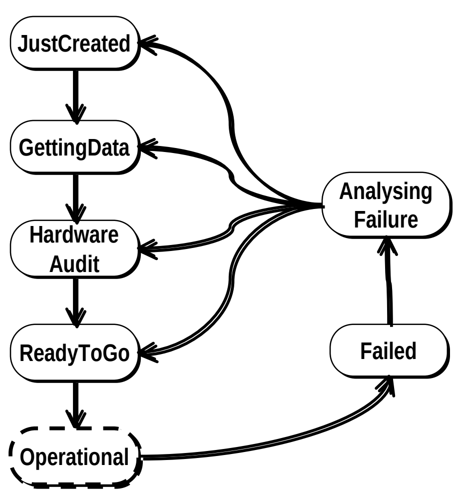
The Control Automaton

- In isolation, the same control behavior appears much simpler



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Control versus Function

- Control behavior is often treated in an ad hoc manner, since it is not part of the primary system functionality
  - typically retrofitted into the framework optimized for the functional behavior
  - leads to controllability and stability problems
- *However, in highly-dependable systems as much as 80% of the system code is dedicated to control behavior!*

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Some Important Observations

- *Control predicates function*
  - before a system can perform its primary function, it first has to reach its operational state
- *Control behavior is often independent of functional behavior*
  - the process by which a system reaches its operational state is often the same regardless of the specific functionality of the component

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The Recursive Control Architectural Pattern

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Basic Design Principles

- *Separate control from function*
  - separate control components from functional components
  - separate control interfaces from functional interfaces
  - imbed functional behavior within control behavior
- *Centralize control (decision making)*
  - if possible, focus control in one component
  - place control policies in the control components and control mechanisms inside the controlled components

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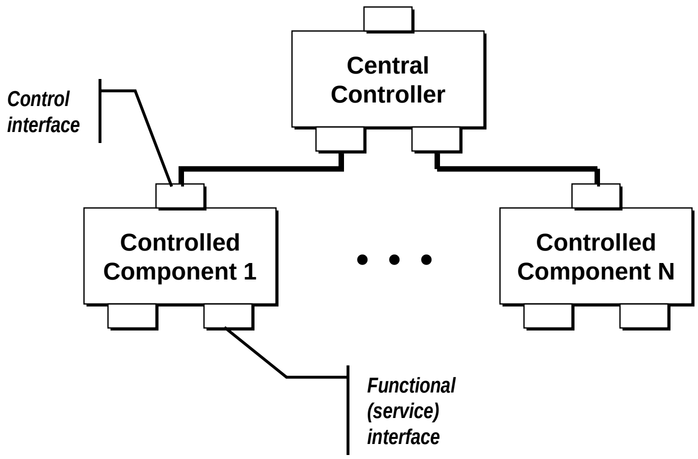
The Basic Structural Pattern

- Set of components that need to be controlled in a coordinated fashion



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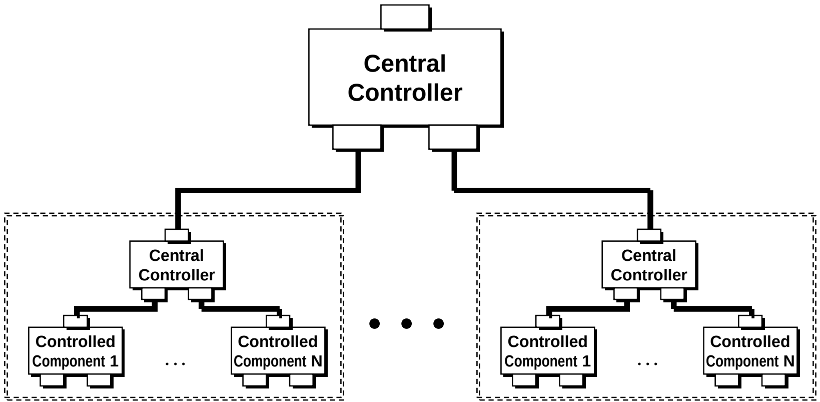
Recursive Application

- Hierarchical control
  - scales up to arbitrary number of levels



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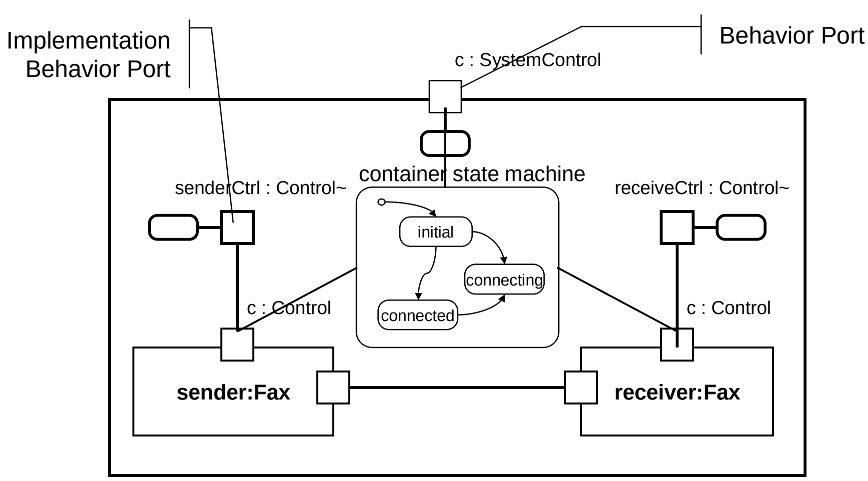
Behavior Ports

- Ports directly connected to the state machine



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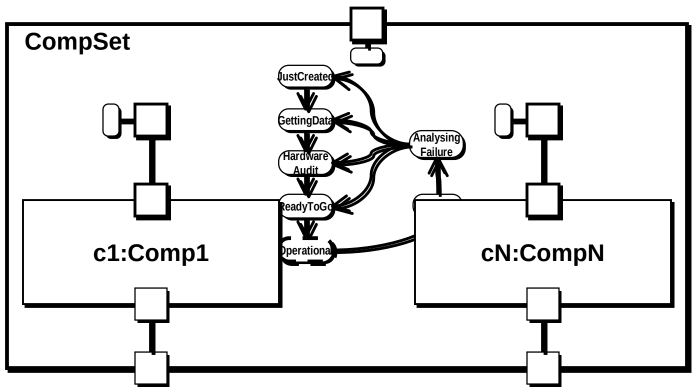
Realization with Ports and Objects

- Composite plays role of centralized controller



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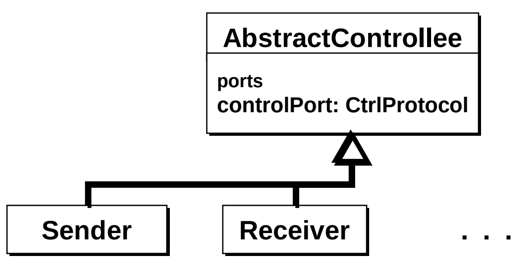
Exploiting Inheritance

- Abstract control classes can capture common control behavior and structure
- Different subclasses capture function-specific behavior



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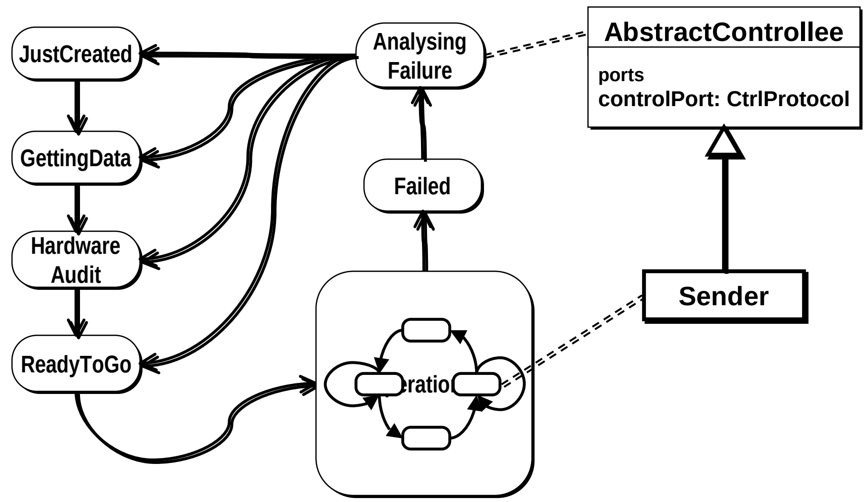
Exploiting Hierarchical States



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The Run-Time Layering Architectural Pattern

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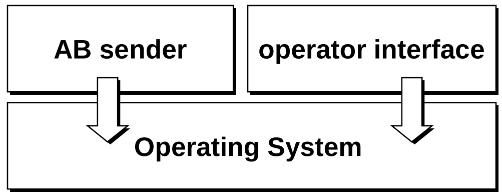
Semantics of Layering (1)

- A fundamentally different type of structural relationship



- Layering is different from containment
  - Higher-layers do not contain lower layers
  - Formally, the lower layers "contain" the higher layers (existence dependency) but they do not encapsulate them

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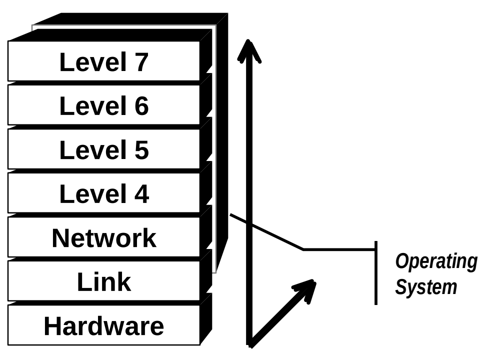
Semantics of Layering (2)

- In complex systems, layering is a complex multidimensional relationship
  - e.g., 7-layer model of Open System Interconnection (OSI)



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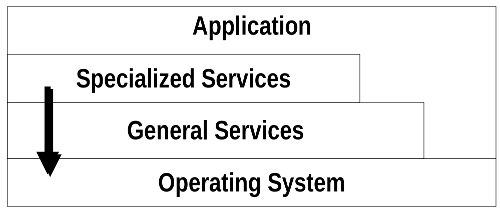
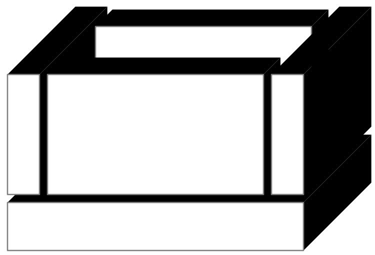
Inadequate Representations of Layering

- Staircase model



- Toaster model



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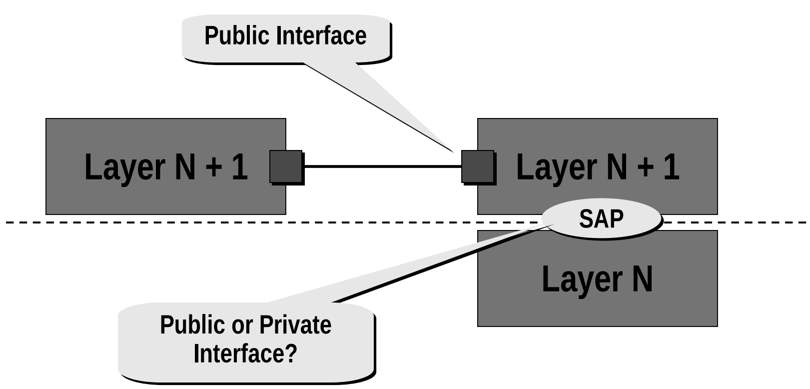
More on the OSI Model

- Two distinct kinds of interfaces: peer and SAP



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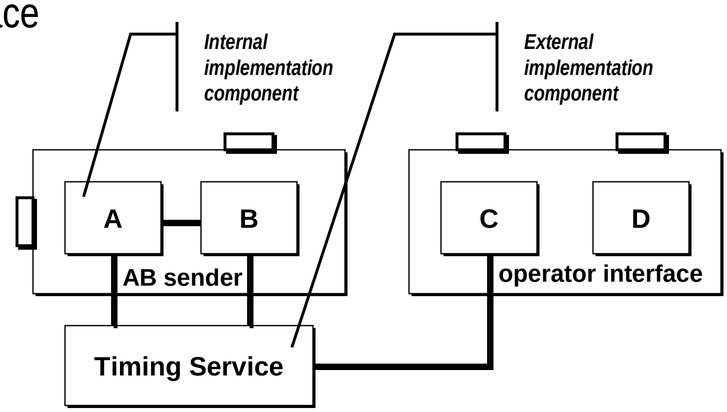
Implementation Components

- Private sub-components required to realize the functionality offered by component through its public interface



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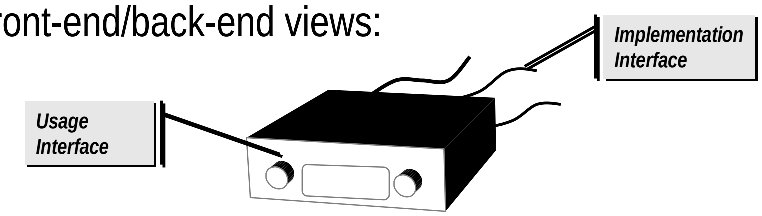
Interface Types for Layering

- Need to differentiate two interface types:
  - *Usage interface*: implementation-independent interface through which a component provides its services (function and control)
  - *Implementation interface* (service access point): implementation-specific interface through which a component accesses an external service
- Front-end/back-end views:



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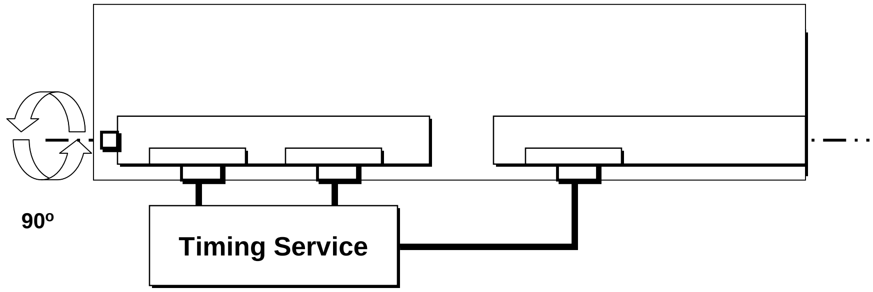
Implementation Interfaces

- Implementation interfaces are public interfaces but can be viewed as being in a different "plane" (dimension) from service interfaces



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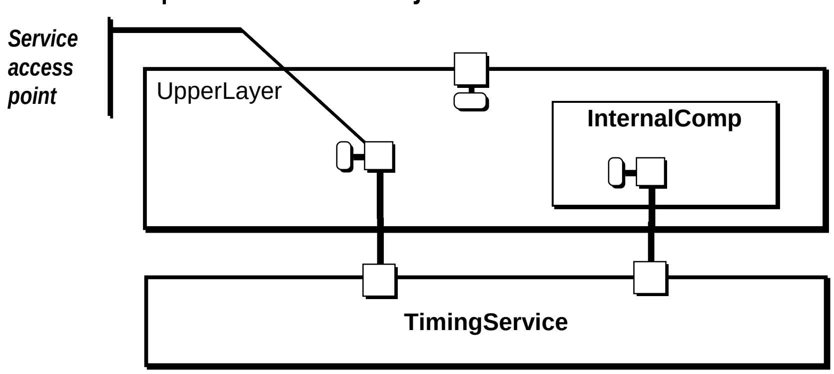
Modeling Layers with Ports and Objects

- Implementation interfaces are modeled by implementation end ports that can be connected directly to service ports of other objects



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Summary: Architectural Patterns

- Architecture plays a fundamental role in software design and evolution
- To prevent architectural decay we need to
  - Specify architectures directly, clearly, and easily
  - Enforce architectural specifications
- The combination of UML 2 and MDA enables us to meet these objectives
- We have demonstrated this ability by showing how these concepts can be used to model two high-level architectural patterns common in embedded system design

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