Real-Time Object-Oriented Modeling

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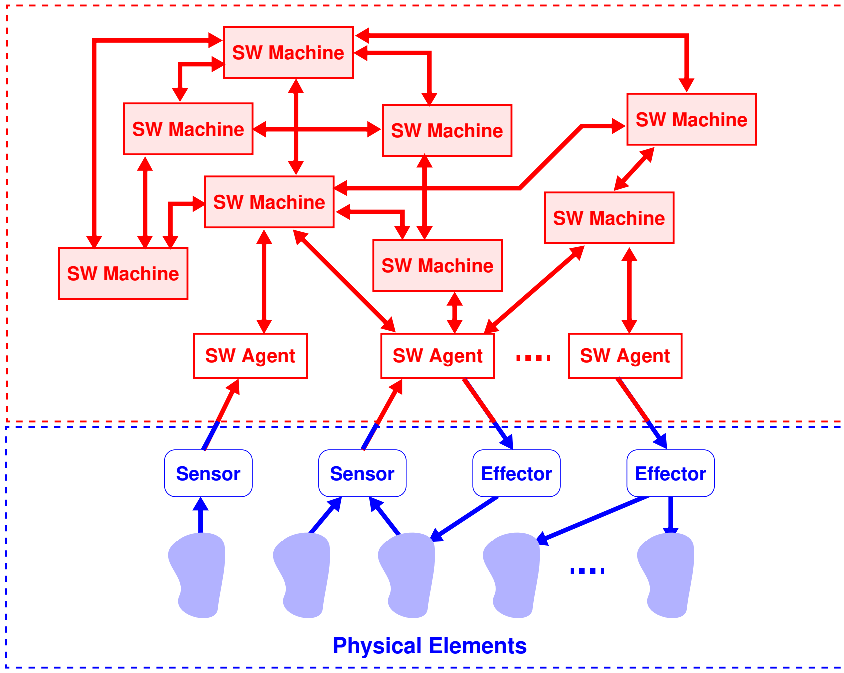
Tutorial Structure

- **Real-Time Systems and Architecture**
- **The ROOM Modeling Concepts**
- **Development Process**
- **Summary**

General Real-Time System



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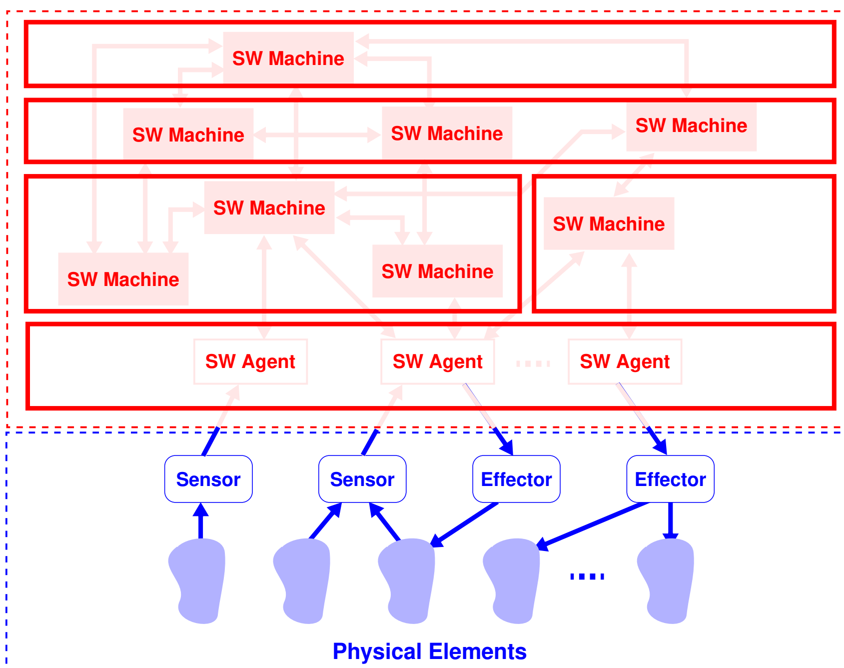
Software Architectures



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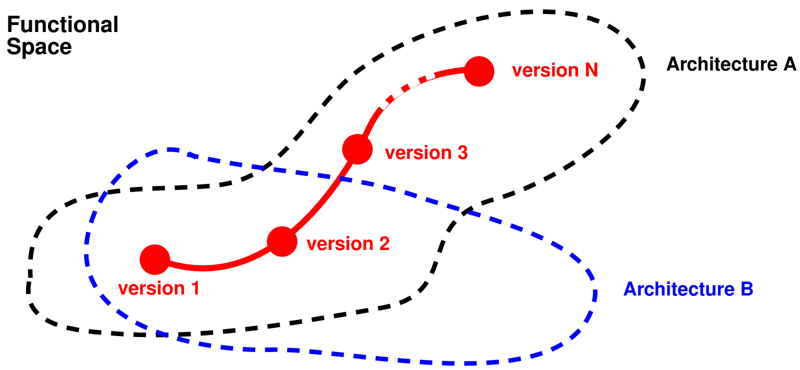
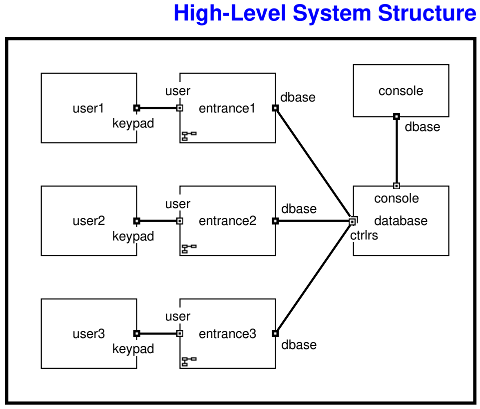
What is an Architecture?

- ***Architecture:*** **an abstract specification that constrains the *structural* and *behavioral* patterns of all system components**
- **Key to proper construction and evolution**

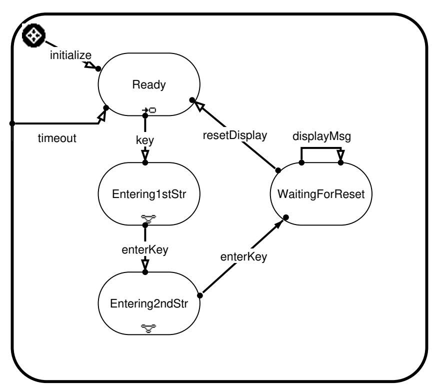


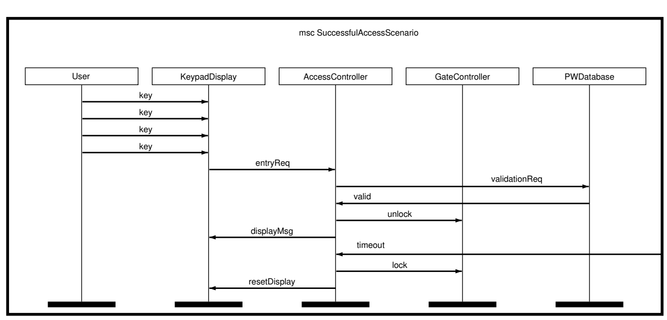
An Example Architectural Specification

High-Level System Structure



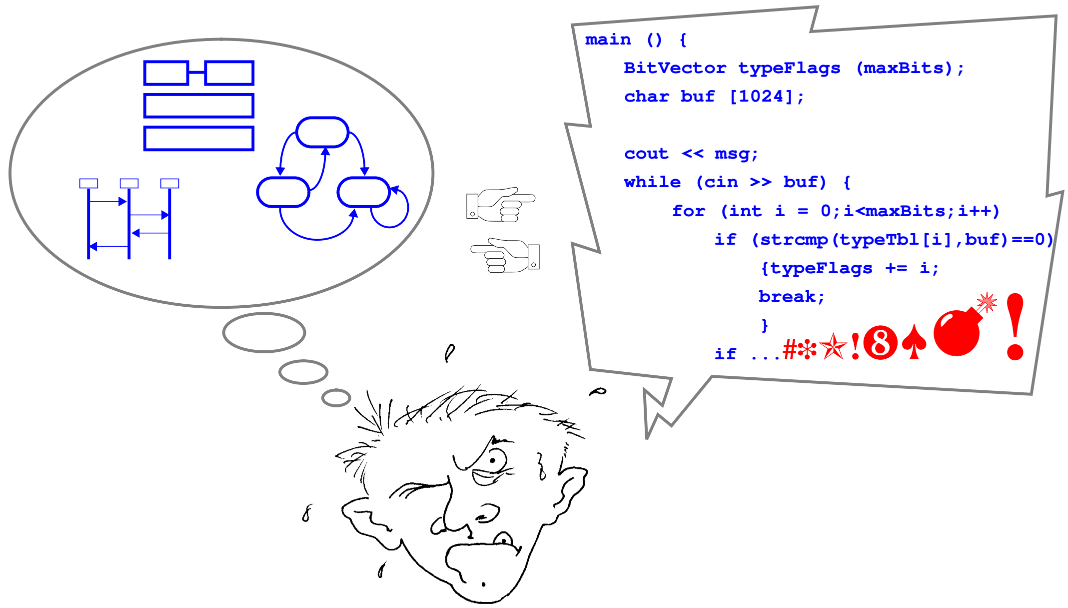
Behavior





Scenarios (Use Cases)

The Fate of Most Architectures...

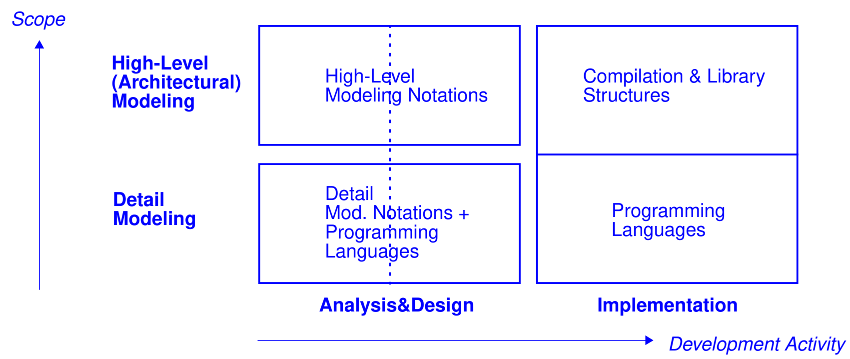


Why Architectures Fail

- **Interpretation errors**
  - *"Hmm, I wonder what that bubble means?"*
- **Feasibility (technological) limitations**
  - *"And, here, a miracle occurs..."*
  - *"To simplify analysis, we will assume..."*
- **Translation errors**
  - *"Oops!"*
- **Design changes**
  - *"I'll show those ivory-tower types how to do it right..."*

Modeling and the Development Cycle

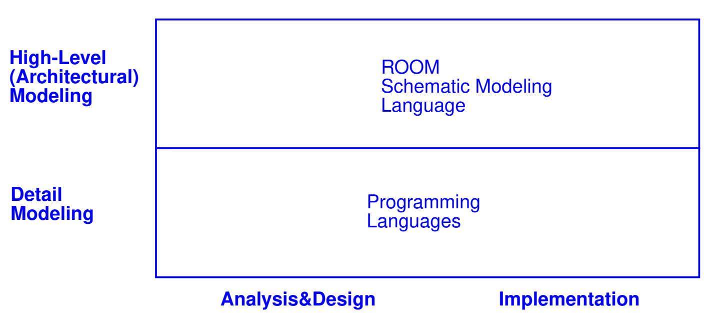
- **Traditional view**



- **Characterized by *semantic gaps* that discourage recursion and introduce errors**

The ROOM Approach

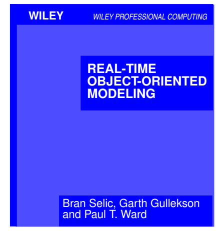
- ***R*eal-Time *O*bject-*O*riented *M*odeling**
- **Two level scheme with formally defined relationships between levels**



- **Incorporate standard programming languages (e.g., C++) for detail modeling**

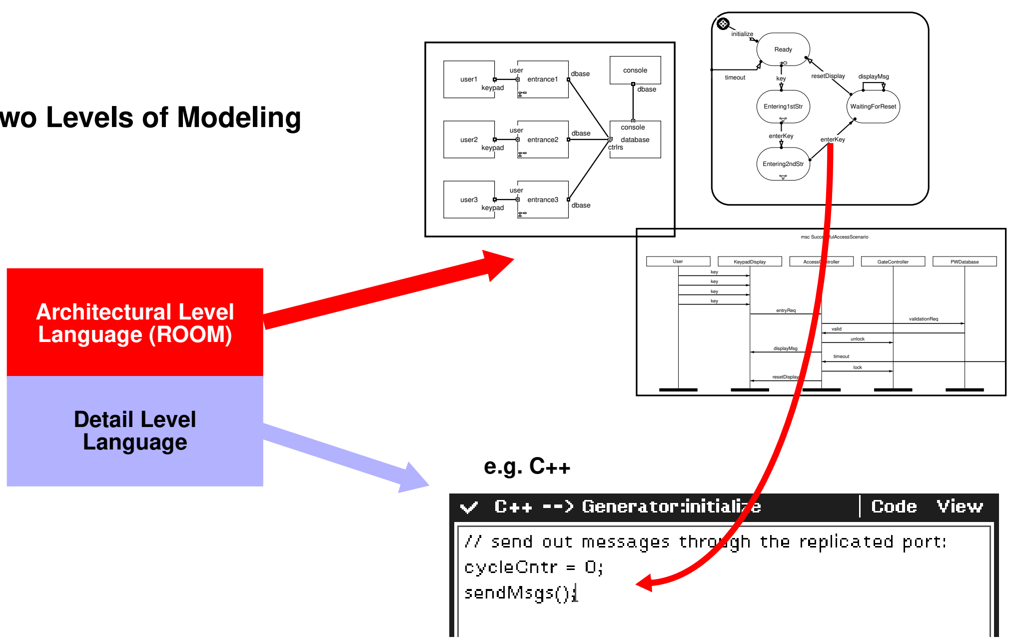
ROOM

- A method for developing software for real-time distributed systems
  - suited for event-driven systems
  - full-cycle method (A → D → I)
  - uses a formal graphical modeling language
  - suited for computer-based automation:
    - executable models
    - automatic code generation
- Originated in Bell-Northern Research



Modeling in ROOM

Two Levels of Modeling



Why Object-Oriented?

- The structural aspect of architectures tends to be *object-based*
- The object paradigm is a synergistic combination of proven, useful concepts
  - encapsulation, polymorphism, inheritance...
- The potential for re-use
  - formally supported only in implementation-level programming languages
  - can it be used at the architectural level?
    - e.g., can an architecture be inherited?

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- **The ROOM Modeling Concepts**
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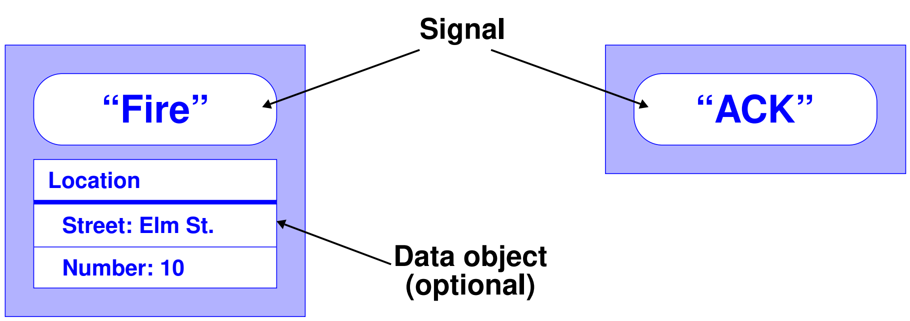
The Question of Notation...

> *"By relieving the mind of all unnecessary work, a good notation sets it free to concentrate on more advanced problems, and in effect increases the mental power of the race"*
>
> *- Alfred N. Whitehead*

Messages

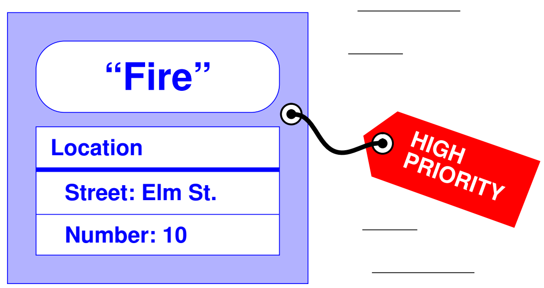
- **Objects that carry information about some event**



- **Message-based communication is well-suited to distributed systems**

Message Priorities

- A message in transit is assigned a *priority* that identifies the significance of its event



- Required to support timely responses

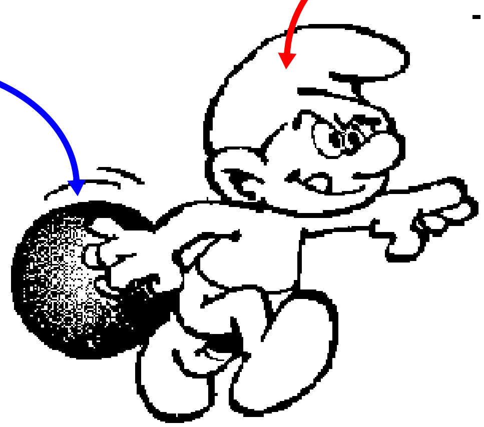
Object Types

ACTIVE

- actors
- own execution thread (concurrent)

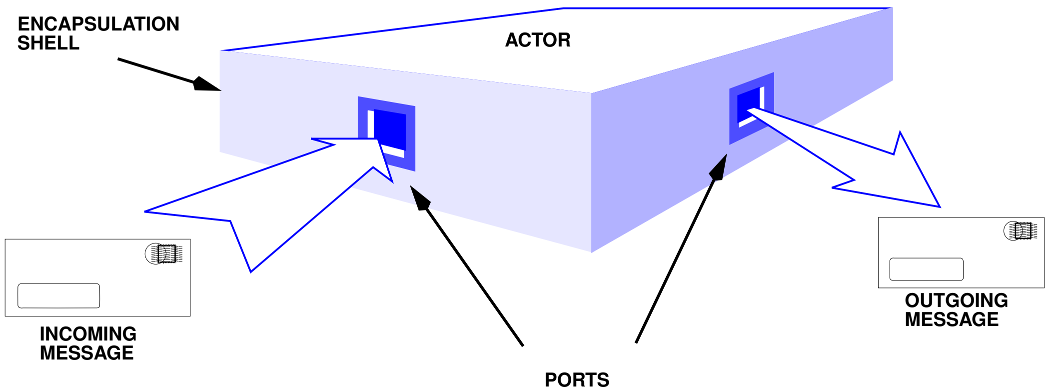
PASSIVE

- messages
- Detail Level data



Actors

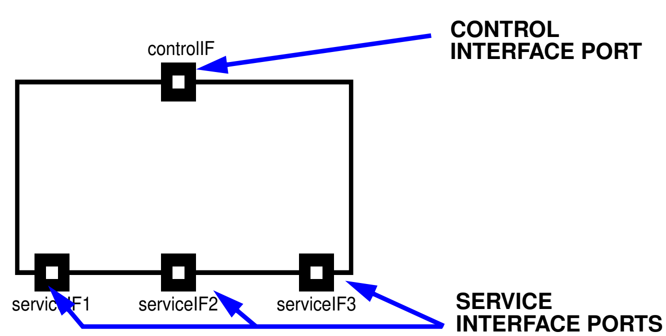
- The active objects of ROOM are called *actors*



- Actors can send and receive messages through distinct interfaces called *ports*

Actor Interfaces

- Each interface of an actor has a unique name and an associated *protocol*
- Different interfaces can use different protocols
- An actor can present different “views” of itself to different collaborators; e.g.:



Protocols

- An extension of conventional interface concept based on message exchange sequences

- A protocol is defined by:

  - a set of valid *message types* and their *directions* of flow

JokeProtocol — Protocol View

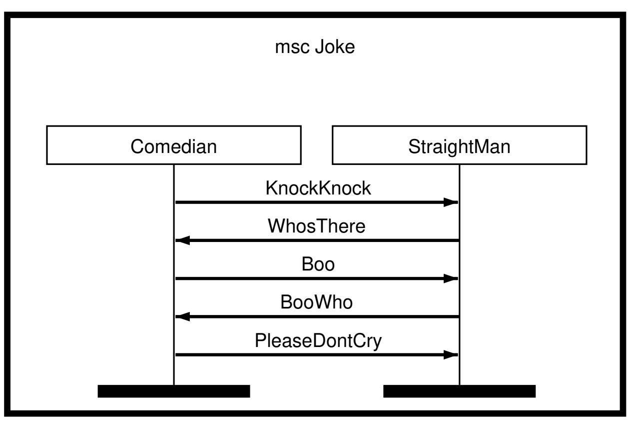
In Signals	Data Class
KnockKnock	Null
Boo	Null
PleaseDontCry	Null

Out Signals	Data Class
WhosThere	Null
BooWho	Null

  - a set of valid message sequences (future extension)

Message Sequence Charts

- Message sequences are expressed by *Message Sequence Charts* (MSCs)



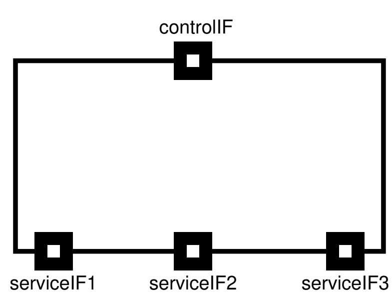
- Defined by ITU standard Z.120

Protocol Classes

- Sometimes different actors use the same protocol definitions
- It is convenient to define protocols independently of the actors that use them through *protocol class* specifications
- Each port (actor interface) has a *type* that is defined by its protocol class
- Protocol classes represent reusable interface specifications; this is the basis for a type of polymorphism available in ROOM

Actor Types

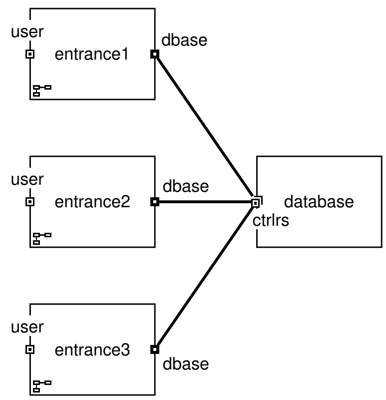
- The collection of all interface types of an actor defines its type



- This is a basis for a form of *genericity*

Combining Actors — Actor Structures

- **The object paradigm allows us to combine objects to create more complex systems**



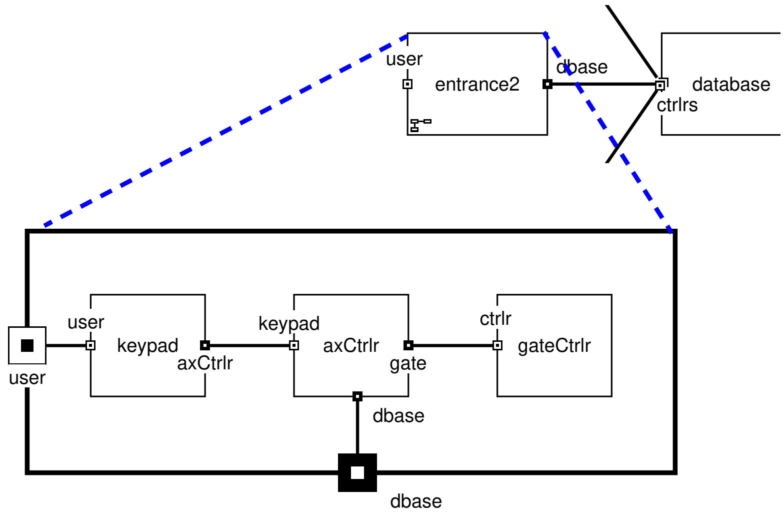
- **The connections between ports are called *bindings***

Bindings

- **Abstract representations of established communication channels for exchanging messages between actors**
- **Only ports with compatible protocols can be bound**
    - **Usually, a protocol class and its conjugate**
- **Bindings explicitly identify all valid causal linkages between actors**
- **Semantics of bindings are defined by the protocol classes of the ports**

Looking Inside Actors

- If the functionality of an actor is complex, it may be useful to break it down into simpler components



- Actors can be defined ***recursively!***

Reusing Specifications — Actor Classes

- As with protocols, it is often useful for multiple actors to share a common specification

- This is achieved through actor classes

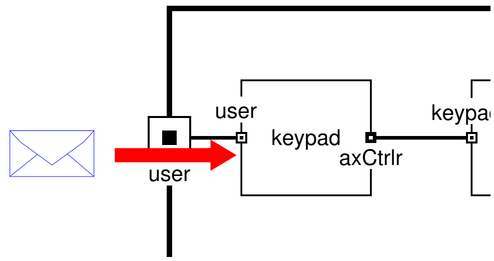
- ROOM distinguishes between the class and the type of an actor

  actor class = actor type + actor implementation

Handling Messages and Port Types

- **Actors can either relay messages to internal components or handle them directly**

- **All messages arriving on *relay ports* are forwarded automatically**

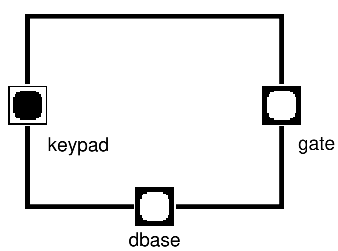


- **Alternatively, messages arriving on an *end port* are processed by the actor**

End Ports and Behavior

- **End ports are the access points to the *behavior* (component) of an actor**

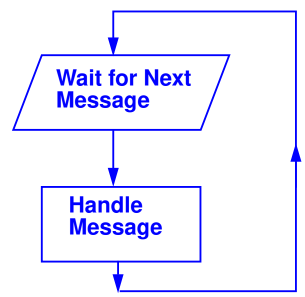
- **Identified by a distinct graphical notation**



- **The behavior component is implicit; i.e., it is not explicitly rendered in a diagram**

The Behavior of Reactive Systems

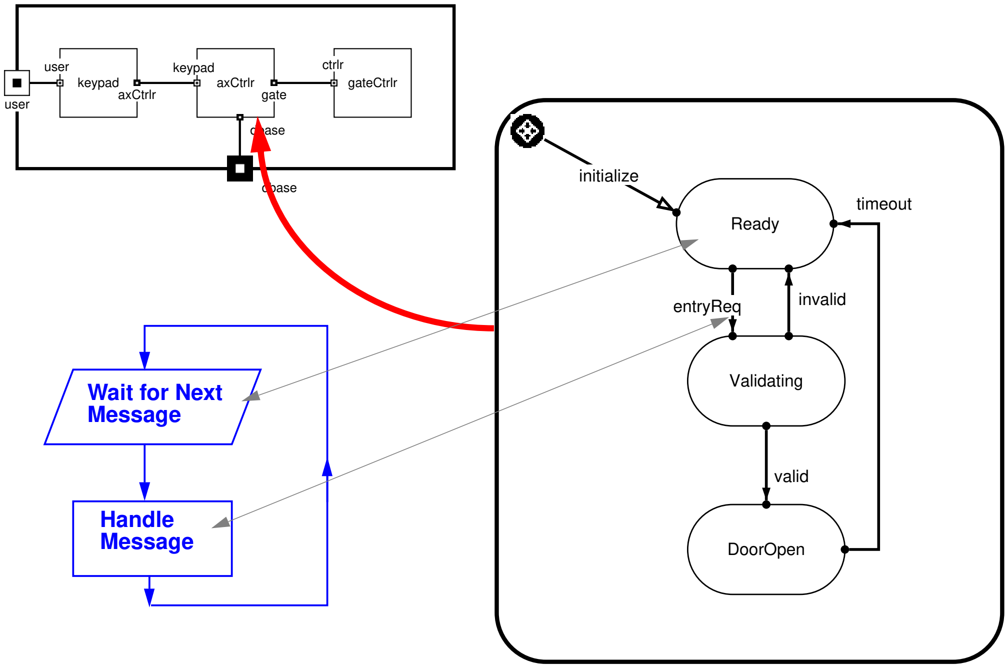
- Between successive events, the behavior is quiescent, “listening” for incoming messages
- When a message arrives, the behavior is activated and may respond by sending one or more messages of its own through its ports



Execution Paradigms

- *What happens if a new higher priority event arrives while the previous event is being processed?*
- Two options:
  - *preemptive* paradigm interrupts current event handling
  - *run-to-completion* paradigm finishes handling the current event handling before moving on to the new event
- ROOM uses the run-to-completion paradigm

ROOMcharts



Events, Triggers, and Actions

- Each transition has

  - a *trigger* which specifies the message arrival event(s) that causes the transition

entryReq Events

Ports/SAPs	Signals	Guard
keypad	entryReq	true

  - optionally, an *action* that specifies how the event is handled

C++ --> AccessController:entryReq | Code View

```
dbase.send (validationReq, *(msg->data));
```

- The action specification belongs to the Detail Level and uses the programming level of choice (e.g., C++)

Extended State Variables

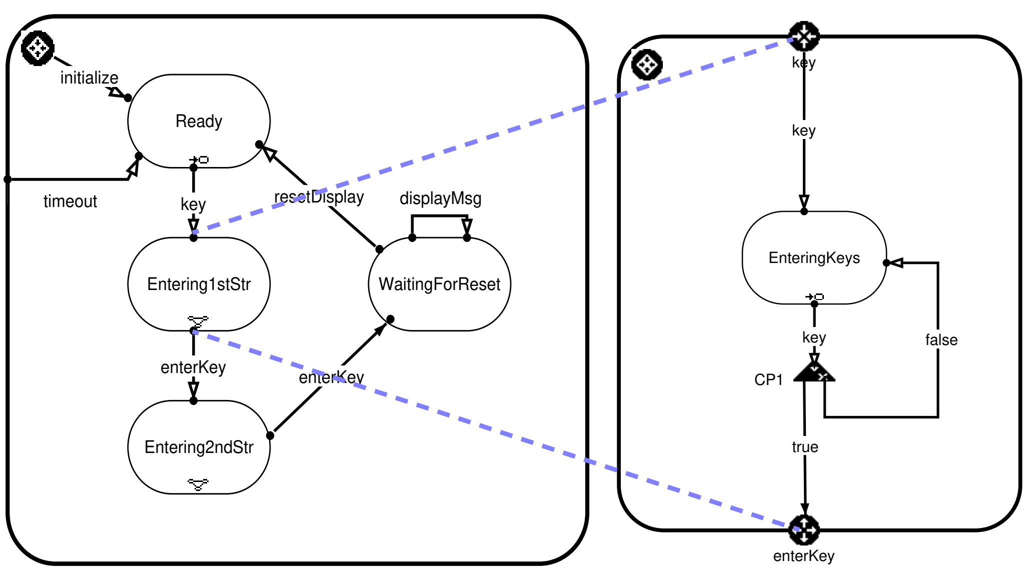
- In addition to temporary variables that may be associated with an action, ROOMcharts also allow the definition of *extended state variables*

- Variables are passive objects used to store Detail Level information that needs to be retained between transitions

  - for example, instances of C++ object classes

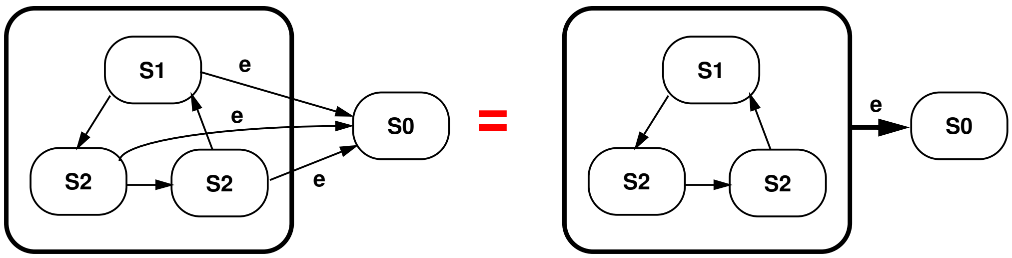
Hierarchical States

- Hierarchy is a means of dealing with complexity by focussing on only a manageable chunk at a time



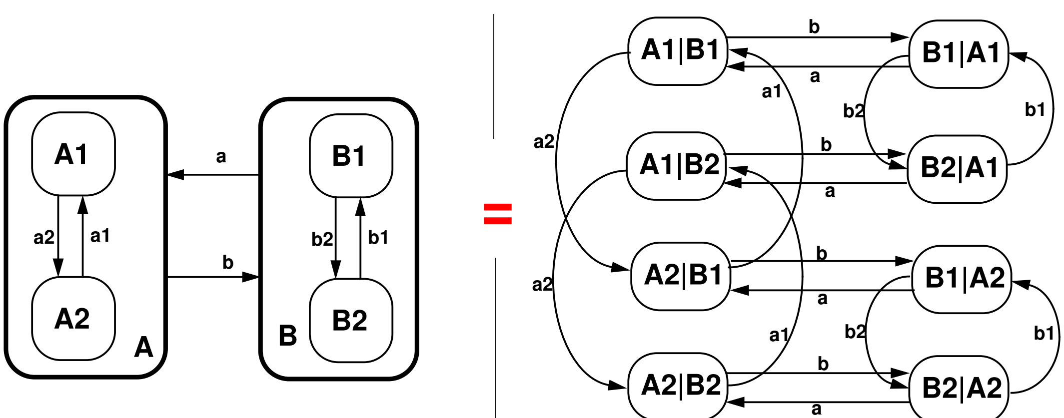
Behavior — Group Transitions

- A "shorthand" form for equivalent transitions that emanate from a common state



- Group transitions not only reduce visual clutter but often also identify "higher-order" events and provide hints about potential state aggregations

The Effectiveness of ROOMcharts



ROOMCHART:
(6 states, 6 transitions)

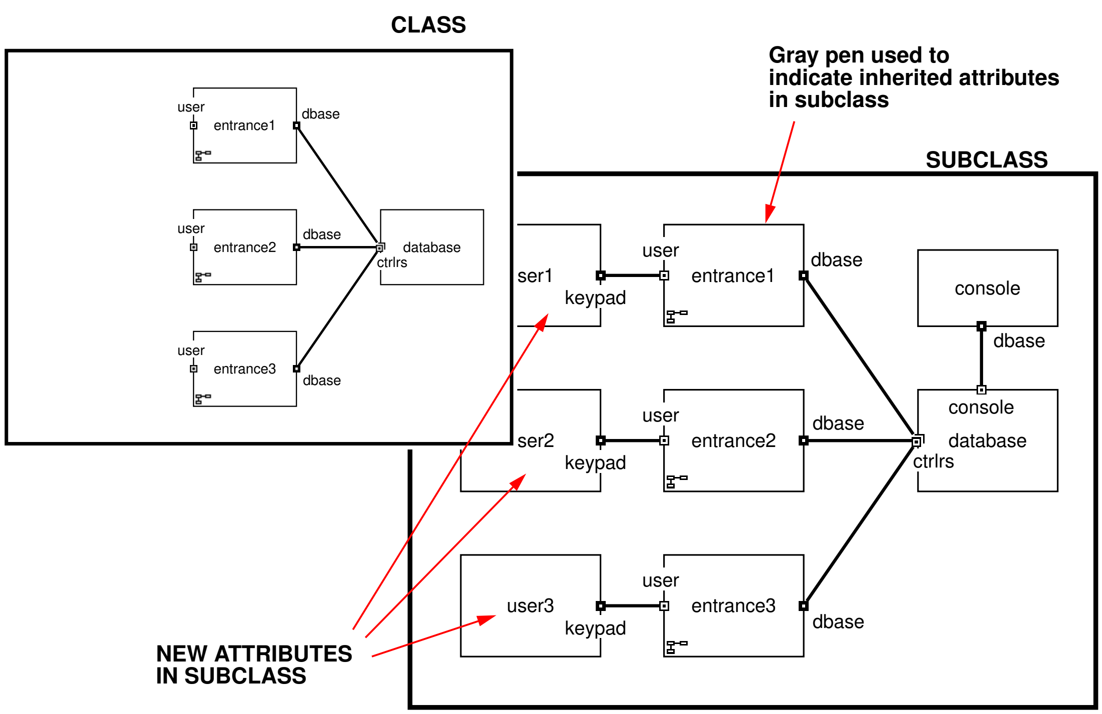
"FLAT" STATE MACHINE EQUIVALENT:
(8 states, 16 transitions)

For a 3-state equivalent: 9 states and 12 transitions (vs. 24 and 72)!

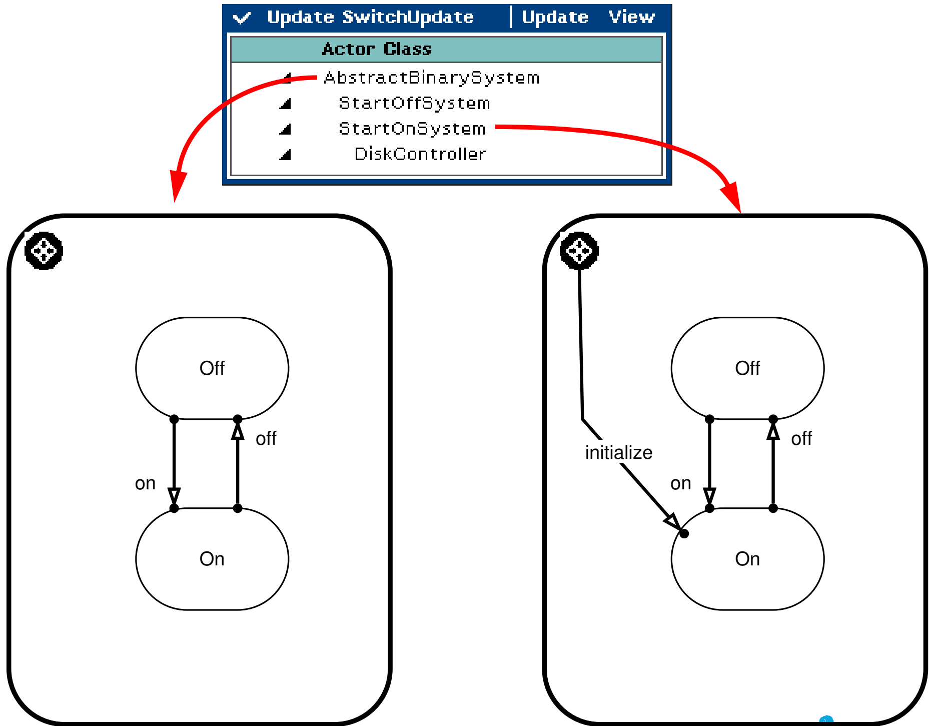
Inheritance Hierarchies in ROOM

- Each of the following class types has a distinct class hierarchy
  - Actor classes
  - Protocol classes
  - Data classes
- The rules of inheritance are not uniform in the three different hierarchies

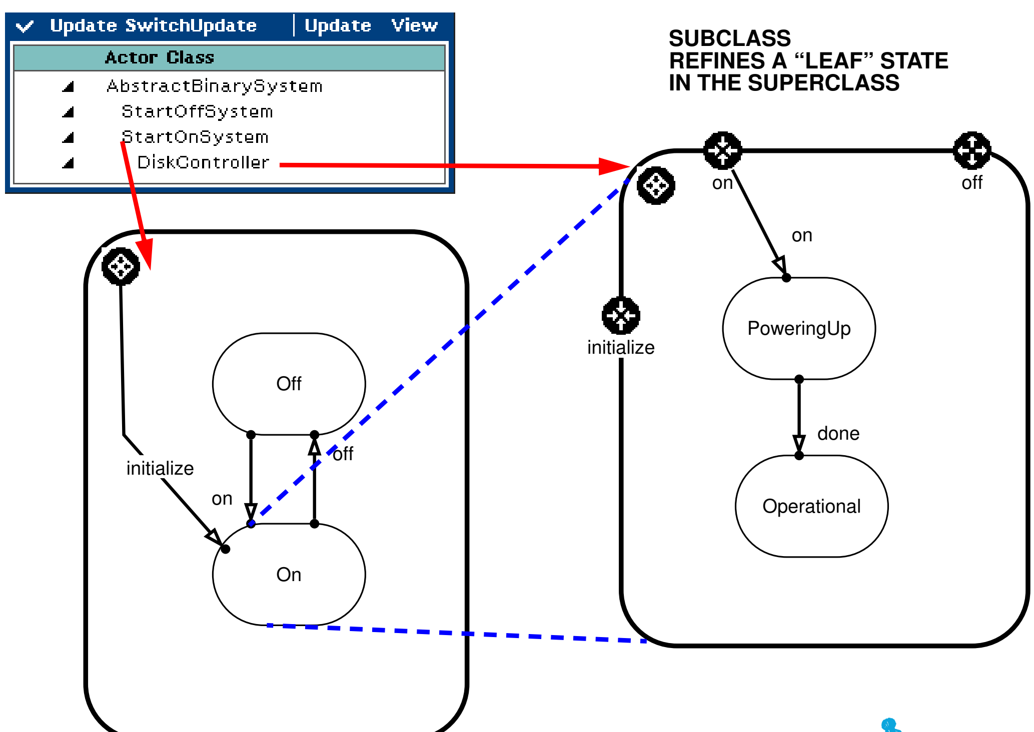
Actor Class Inheritance — Structure



Actor Class Inheritance — Behavior

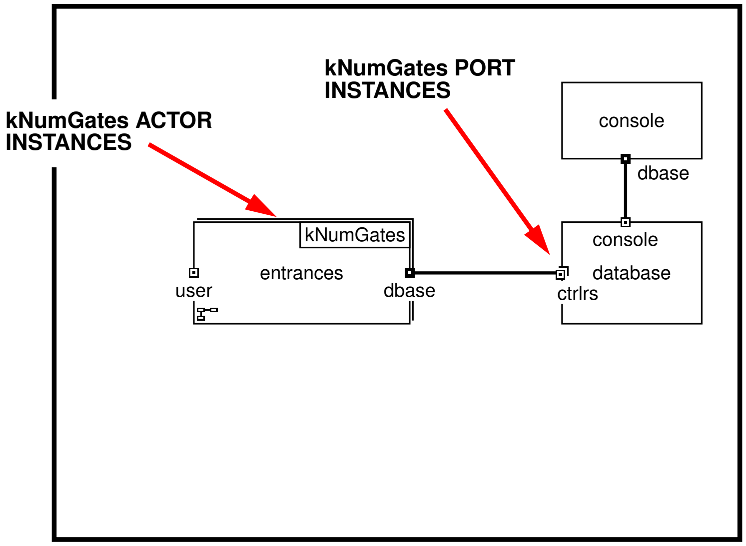


Refinement of Behavior in Subclasses



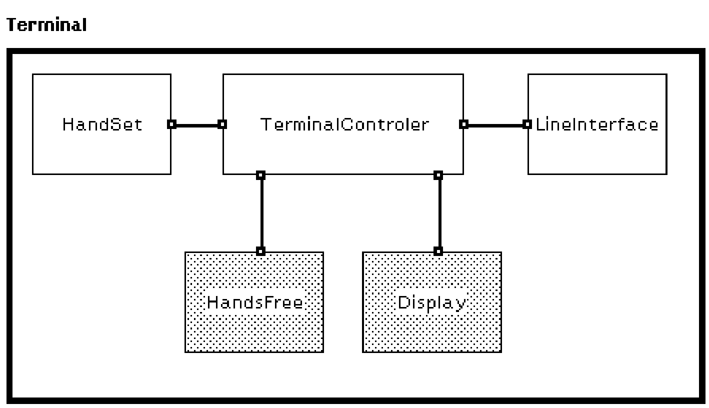
Replicated Structures

- Useful for dealing with regular repeating structures



Dynamic Structure — Optional Actors

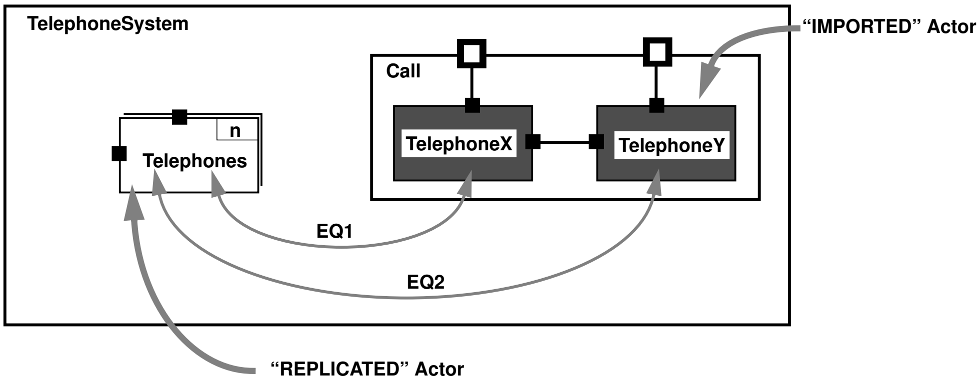
- Components may be created *after* their container as needed



- Creation/destruction controlled by the container

Multiple Containment and Importing

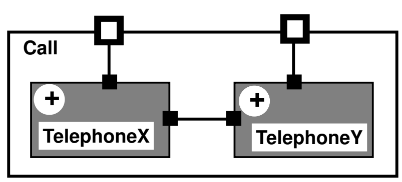
- **Captures components that are simultaneously part of two or more container actors**



- **Component actors are "slots" to be filled as needed**

Generic Structures

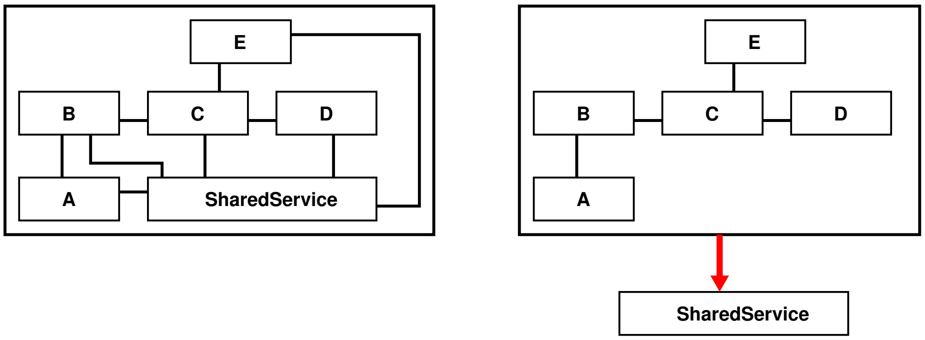
- **Ability to define a component as "generic"**



- **Any actor with a compatible type can be imported into the generic "slot"**
- **A single model represents a collection of possible variants**

Layering

- **Layer relationships:**
  - **Directed hierarchical relationship**
  - **For modeling widely-shared implementation services**



- **Reduces apparent complexity**
- **Communication model also based on protocols and port-like interfaces (Service Access Points (SAPs))**

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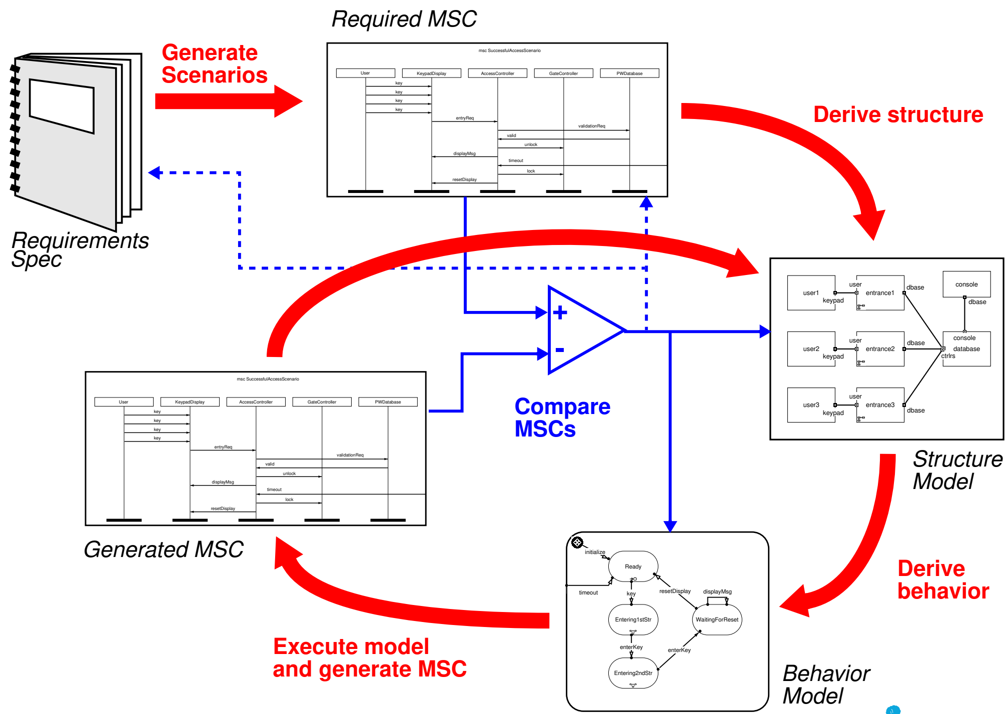
Typical Current Development Micro-Cycle



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Why Use ROOM?

- The essential complexity of reactive systems is sufficiently high to require specialized modeling concepts

- ROOM takes advantage of many recent developments in computer technology (formal methods, the object paradigm, graphical user interfaces)

- Also, ROOM was explicitly designed to take advantage of computer-based automation of many of the more mechanical activities of development

- This gives it a unique potential for significant gains in productivity and quality

Modeling Structure

- Use of graphical syntax for easier comprehension

- Abstractions for dealing with high-level (architectural) phenomena of large real-time systems

  - Protocol-based multiple interfaces

  - Concurrent objects (actors)

  - Dynamic structures

  - Replicated structures

Modeling Behavior

- High-level based on graphical syntax
- Uses hierarchical state machines
  - Chosen to allow powerful modeling capabilities while allowing for straightforward and efficient (automated) implementations
- Priority-based event handling for dealing with real-time requirements
- Incorporates industry standard programming languages (e.g., C++) for detailed specs

Experience

- Over a hundred different industrial projects have used ROOM
  - including complete automatic code generation
- Various application domains:
  - telecom
  - defense/aerospace
  - manufacturing
- ROOM and ObjecTime are being used as a basis for teaching real-time systems in a number of undergraduate and graduate courses