Object-Oriented Software Engineering
Using UML, Patterns, and Java

Chapter 7, System Design: Addressing Design Goals

Overview ▷

System Design I

- ✓ 0. Overview of System Design
- ✓ 1. Design Goals
- ✓ 2. Subsystem Decomposition
  - ✓ Architectural Styles

System Design II

3. Concurrency
4. Hardware/Software Mapping
5. Persistent Data Management
6. Global Resource Handling and Access Control
7. Software Control
8. Boundary Conditions

System Design

✓1. Design Goals
- Definition
- Trade-offs

✓2. Subsystem Decomposition
- Layers vs Partitions
- Coherence/Coupling

3. Concurrency
- Identification of Threads

4. Hardware/ Software Mapping
- Special Purpose
- Buy vs Build
- Allocation of Resources
- Connectivity

5. Data Management
- Persistent Objects
- File system vs Database

6. Global Resource Handling
- Access Control List vs Capabilities
- Security

7. Software Control
- Monolithic
- Event-Driven
- Conc. Processes

8. Boundary Conditions
- Initialization
- Termination
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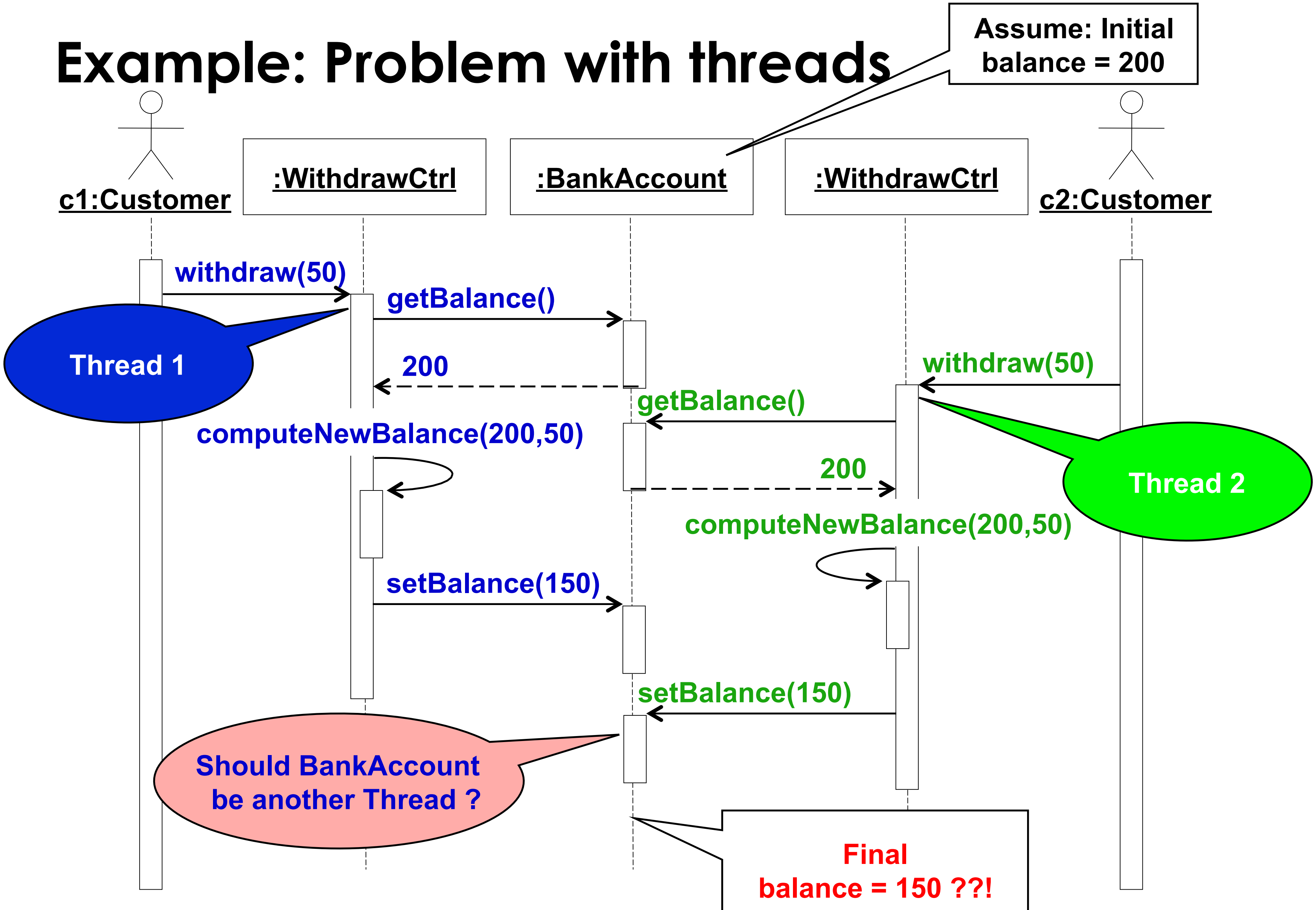
Concurrency

- Nonfunctional Requirements to be addressed: Performance, Response time, latency, availability.
- Two objects are inherently concurrent if they can receive events at the same time without interacting
    - Source for identification: Objects in a sequence diagram that can simultaneously receive events
        - Unrelated events, instances of the same event
- Inherently concurrent objects can be assigned to different **threads of control**
- Objects with mutual exclusive activity could be folded into a single **thread of control**

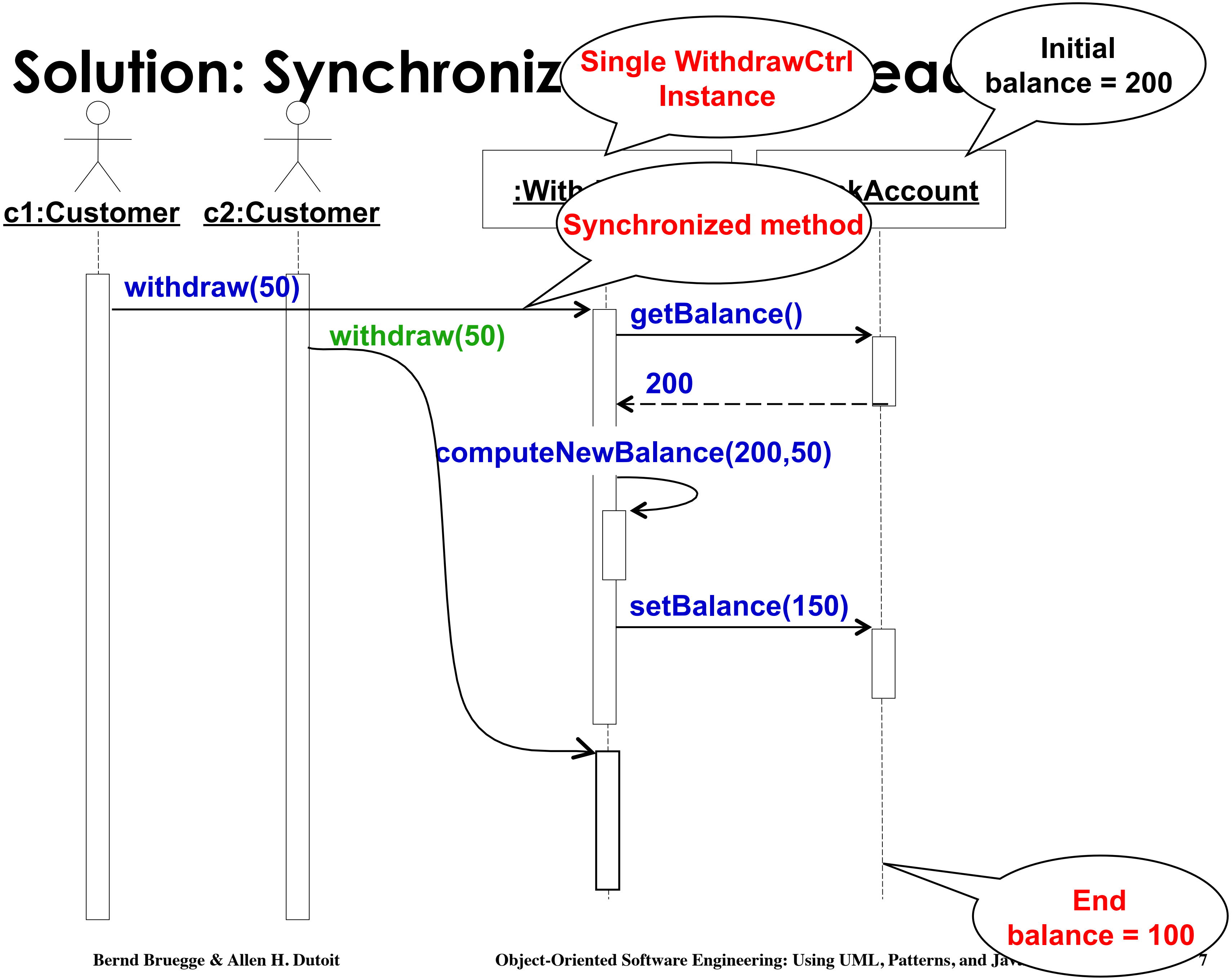
Thread of Control

- A thread of control is a path through a set of state diagrams on which a single object (different from time to time) is active at a time
  - A thread remains within a state diagram until an object sends an event to different object and waits for another event
  - Thread splitting: Object does a non-blocking send of an event to another object.
- Concurrent threads can lead to race conditions.
- A race condition (also race hazard) is a design flaw where the output of a process depends on the specific sequence of other events.
  - The name originated in digital circuit design: Two signals racing each other to influence the output.

Example: Problem with threads



Solution: Synchroniz[…]eac[…]



Concurrency Questions

- To identify threads for concurrency we ask the following questions:
  - Does the system provide access to multiple users?
  - Which entity objects of the object model can be executed independently from each other?
  - What kinds of control objects are identifiable?
  - Can a single request to the system be decomposed into multiple requests? Can these requests be handled in parallel? (Example: a distributed query)

Implementing Concurrency

- Concurrent systems can be implemented on any system that provides
  - Physical concurrency: Threads are provided by hardware

  or

  - Logical concurrency: Threads are provided by software
- Physical concurrency is provided by multiprocessors and computer networks
- Logical concurrency is provided by threads packages.

Implementing Concurrency (2)

- In both cases, - physical concurrency as well as logical concurrency - we have to solve the scheduling of these threads:
  - Which thread runs when?
- Today's operating systems provide a variety of scheduling mechanisms:
  - Round robin, time slicing, collaborating processes, interrupt handling
- General question addresses starvation, deadlocks, fairness -> Topic for researchers in operating systems
- Sometimes we have to solve the scheduling problem ourselves
  - Topic addressed by software control (system design topic 7).

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4. Hardware Software Mapping

- This system design activity addresses two questions:
  - How shall we realize the subsystems: With hardware or with software?
    - If hardware is chosen, how to proceed is out of the scope of the current course
  - How do we map the object model onto the chosen hardware and/or software?
    - Mapping the Objects:
      - Processor, Memory, Input/Output
    - Mapping the Associations:
      - Network connections

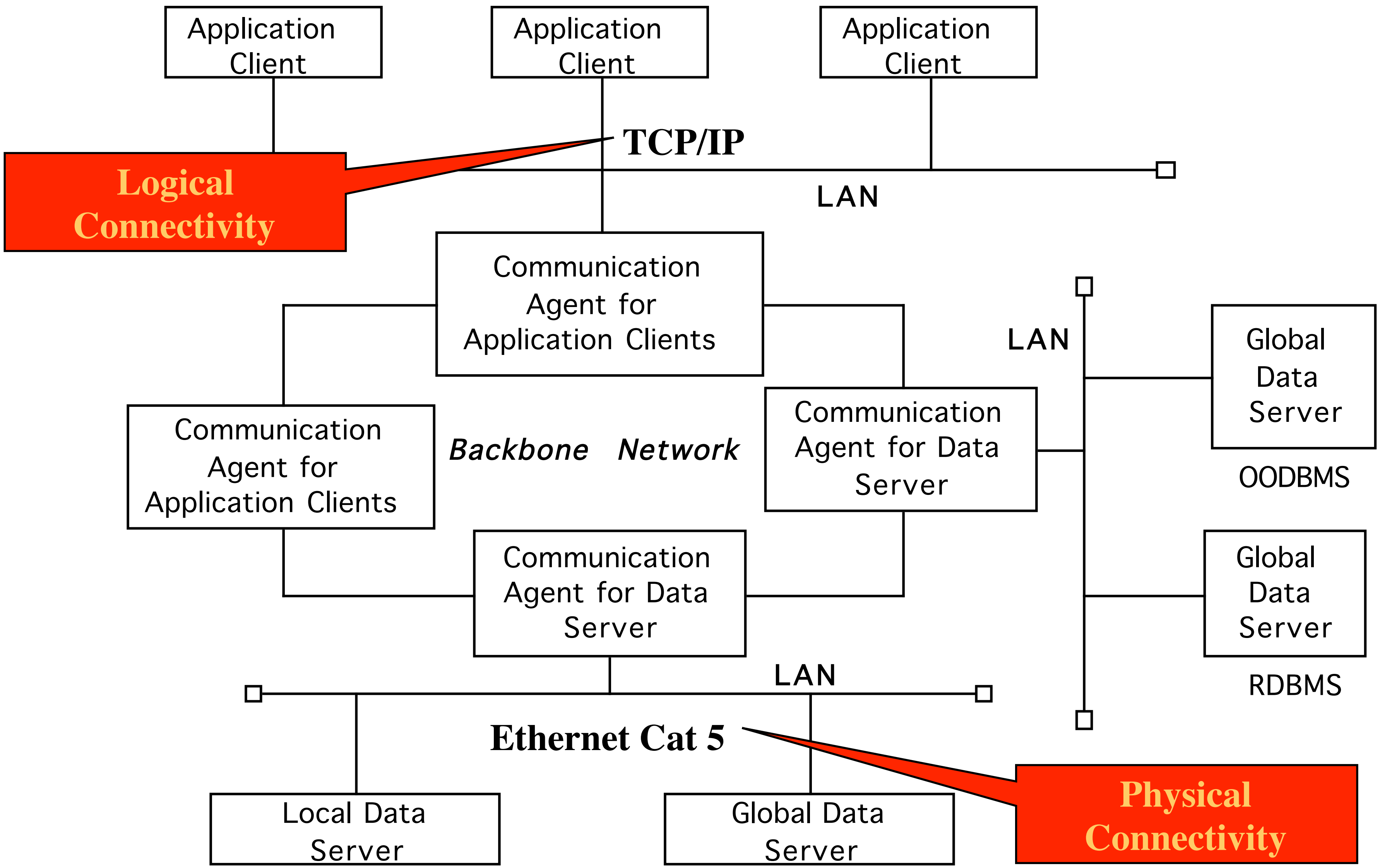
Mapping Objects onto Hardware

- Control Objects -> Processor
  - Is the computation rate too demanding for a single processor?
  - Can we get a speedup by distributing objects across several processors?
  - How many processors are required to maintain a steady state load?
- Entity Objects -> Memory
  - Is there enough memory to buffer bursts of requests?
- Boundary Objects -> Input/Output Devices
  - Do we need an extra piece of hardware to handle the data generation rates?
  - Can the desired response time be realized with the available communication bandwidth between subsystems?

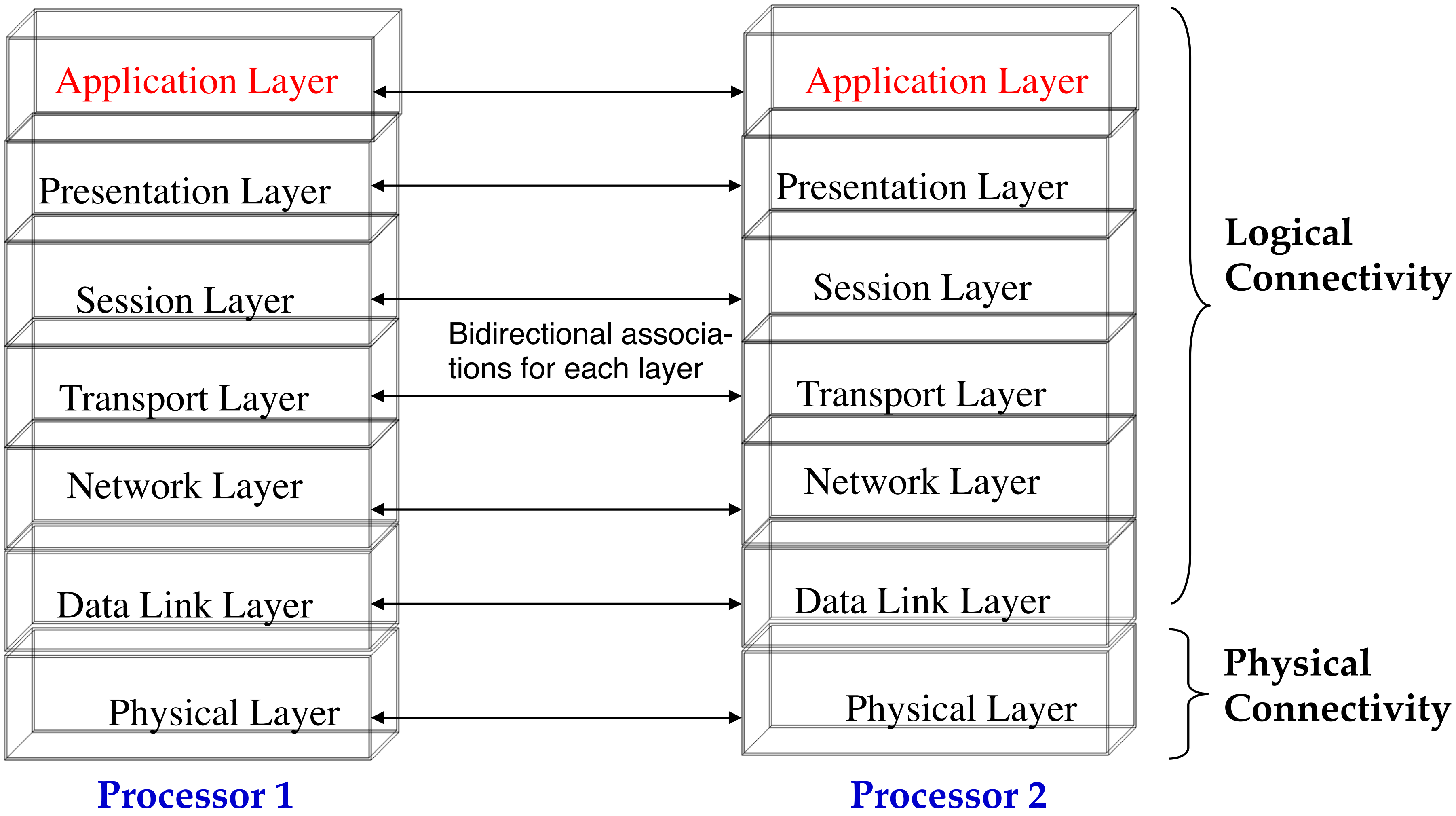
Mapping the Associations: Connectivity

- Describe the physical connectivity
  - ("Physical layer in the OSI reference model")
    - Describes **which associations** in the object model **are mapped to physical connections**
- Describe the logical connectivity (subsystem associations)
  - Associations that do not directly map into physical connections
  - In which layer should these associations be implemented?
- Informal connectivity drawings often contain both types of connectivity
  - Practiced by many developers, sometimes confusing.

Example: Informal Connectivity Drawing



Logical vs Physical Connectivity and the relationship to Subsystem Layering



Hardware-Software Mapping Difficulties

- Much of the difficulty of designing a system comes from addressing externally-imposed hardware and software constraints
  - Certain tasks have to be at specific locations
    - Example: Withdrawing money from an ATM machine
  - Some hardware components have to be used from a specific manufacturer

Hardware/Software Mappings in UML

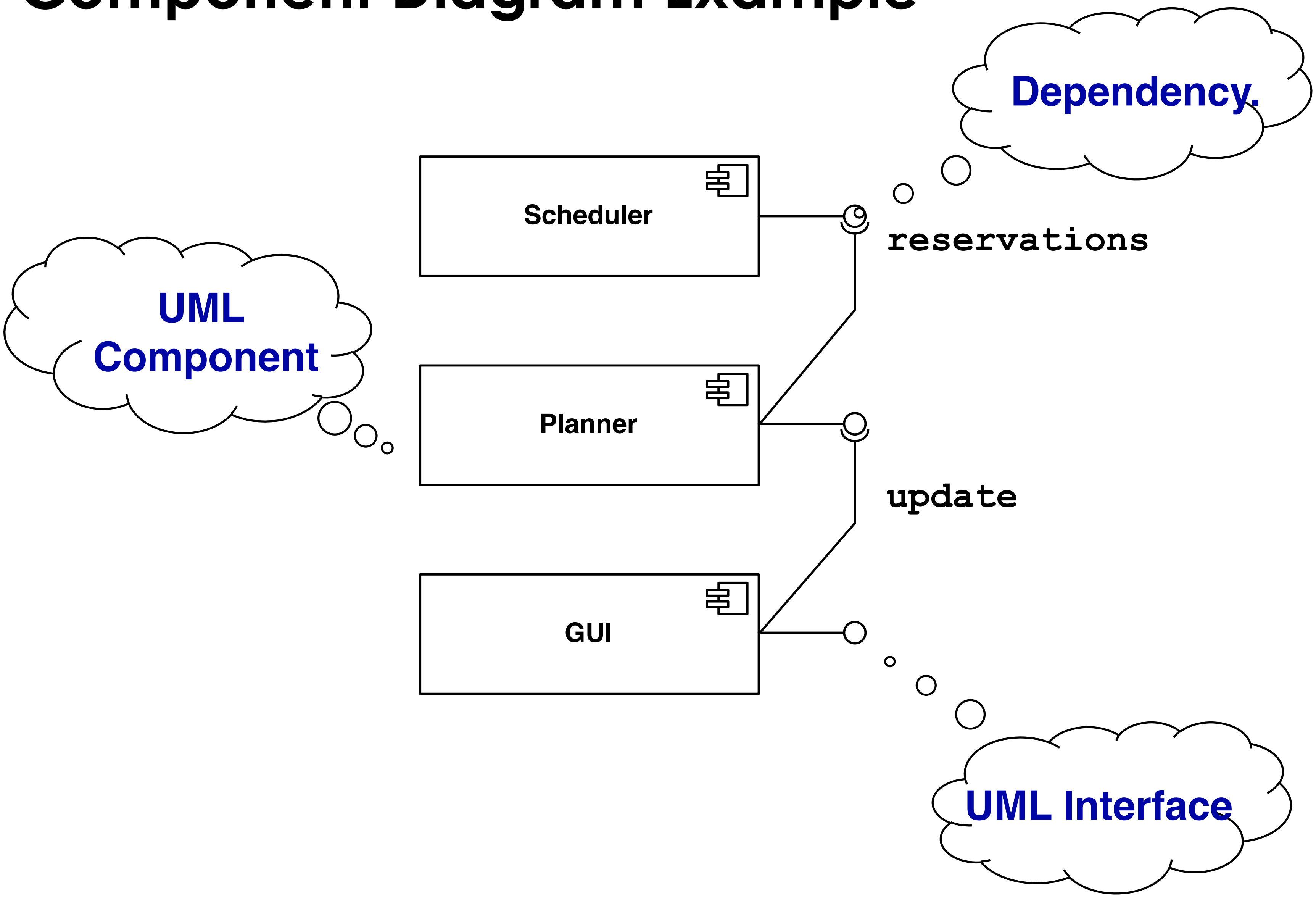
- A UML component is a building block of the system. It is represented as a rectangle with a tabbed rectangle symbol inside

- The Hardware/Software Mapping addresses dependencies and distribution issues of UML components during system design.

Two New UML Diagram Types

- Deployment Diagram:
  - Illustrates the distribution of components at run-time.
  - Deployment diagrams use nodes and connections to depict the physical resources in the system.
- Component Diagram:
  - Illustrates dependencies between components at design time, compilation time and runtime

Component Diagram Example



UML Component Diagram

- Used to model the top-level view of the system design in terms of components and dependencies among the components. Components can be
  - source code, linkable libraries, executables
- The dependencies (edges in the graph) are shown as dashed lines with arrows from the client component to the supplier component:
  - The lines are often also called connectors
  - The types of dependencies are implementation language specific

UML Interfaces: Lollipops and Sockets

- A UML interface describes a group of operations used or created by UML components.
  - There are two types of interfaces: provided and required interfaces.
    - A provided interface is modeled using the lollipop notation
    - A required interface is modeled using the socket notation.
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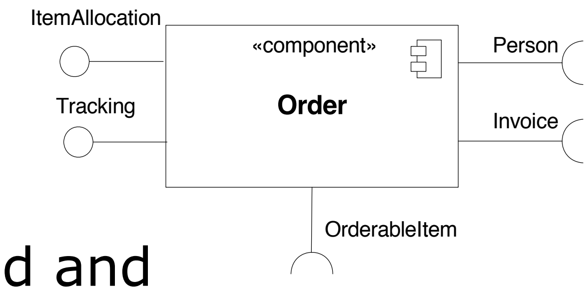
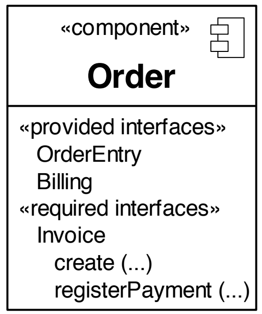




Component diagram – details from UML 2.4.1

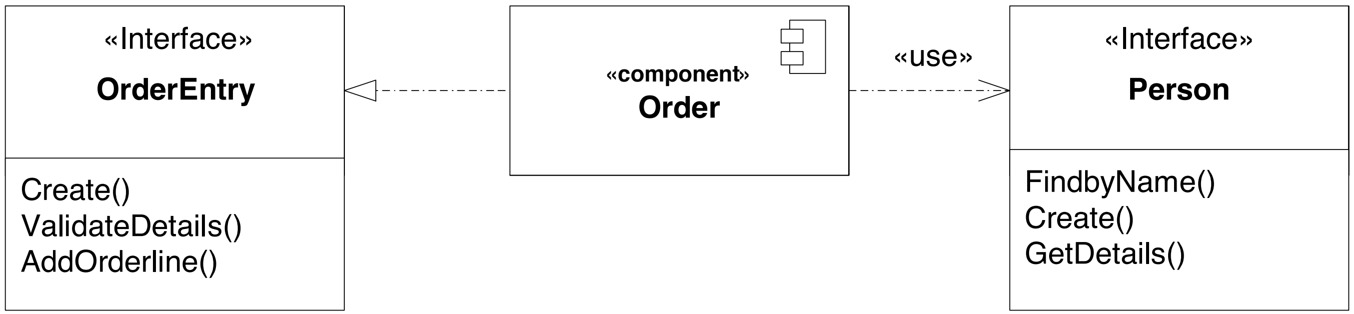
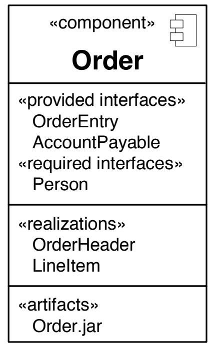


Figure 8.8 - Explicit representation of the provided and required interfaces, allowing interface details such as operation to be displayed (when desired).



A white-box representation of a component

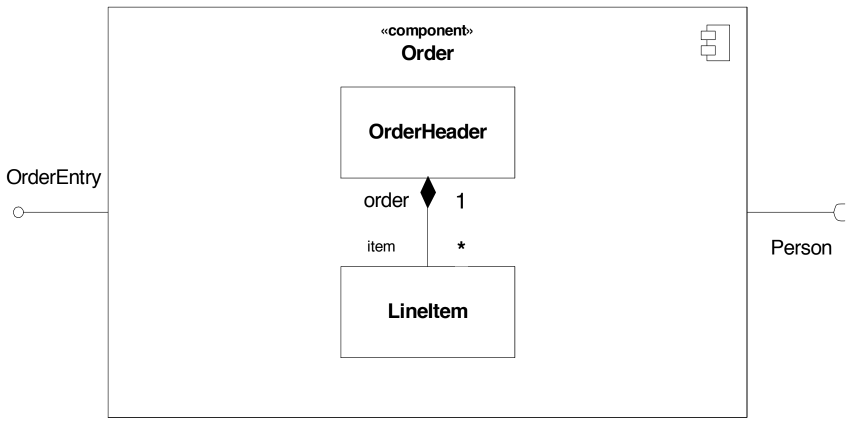


Figure 8.11 - An alternative nested representation of a complex component

Component diagram – details from UML 2.4.1 / 2

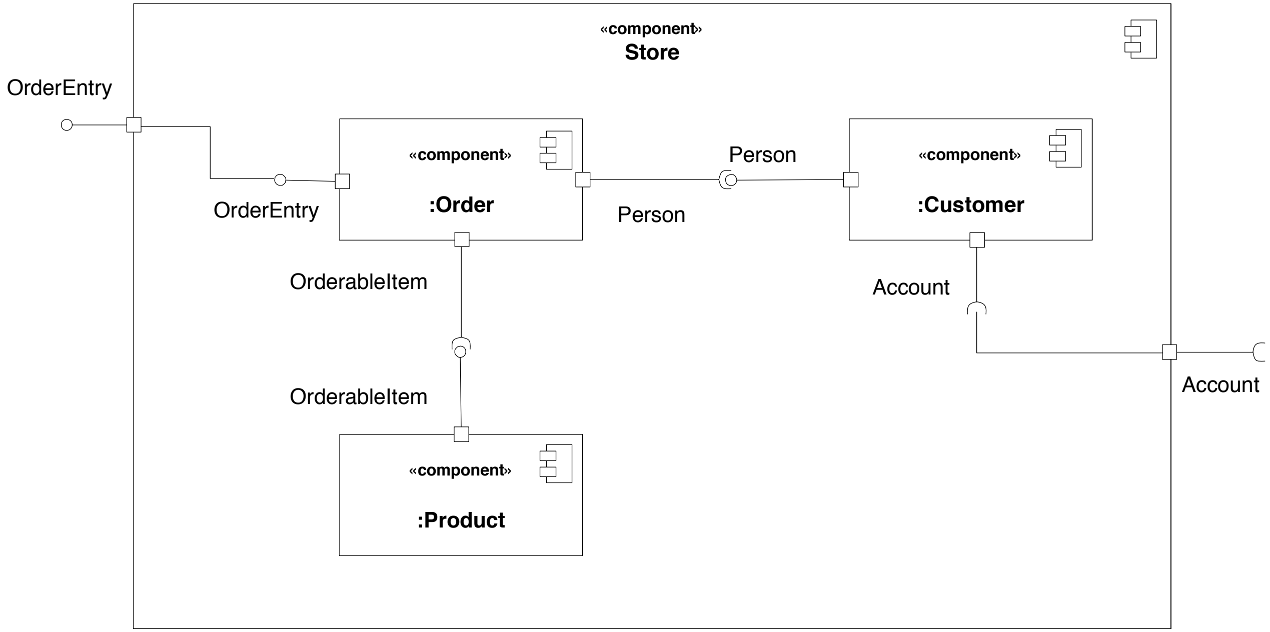


Figure 8.12 - An internal or white-box view of the internal structure of a component that contains other components with simple ports as parts of its internal assembly

- A port specifies a distinct interaction point between the component and its environment.
  - Ports are depicted as small squares on the sides of classifiers.
  - The interfaces associated with a port specify the nature of the interactions that may occur over a port.

Component diagram – details from UML 2.4.1 / 3

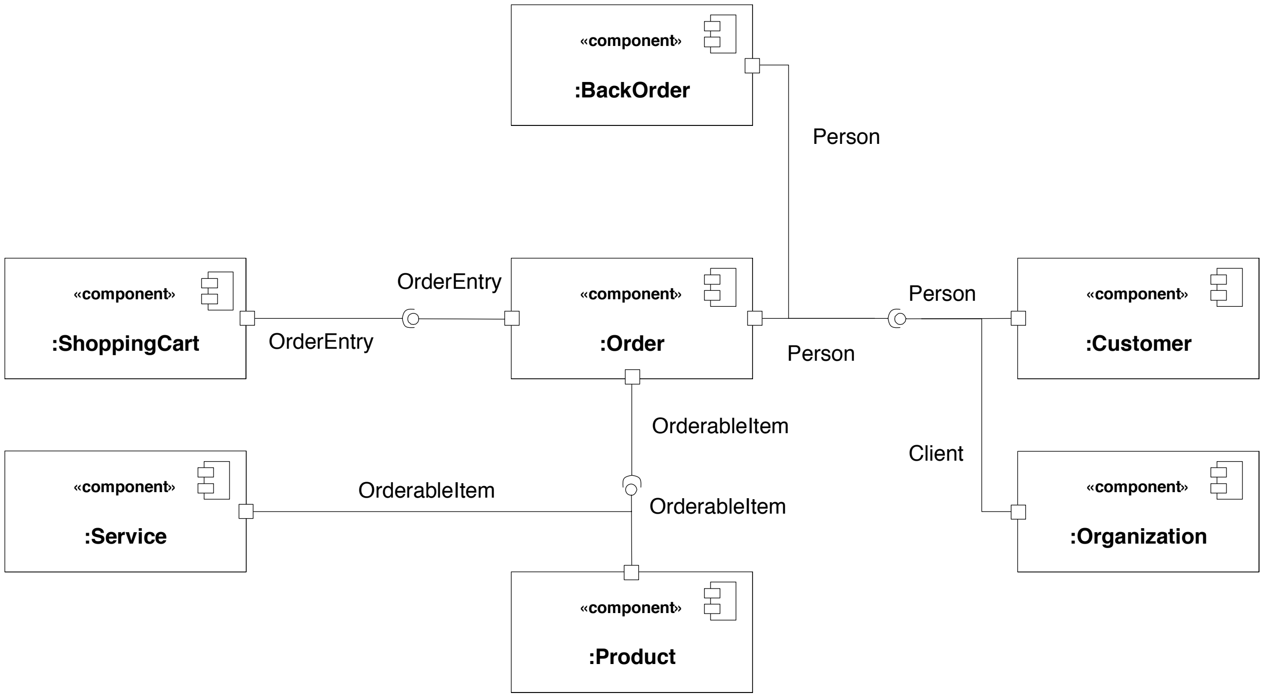
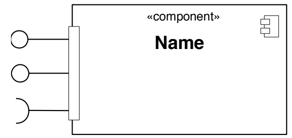


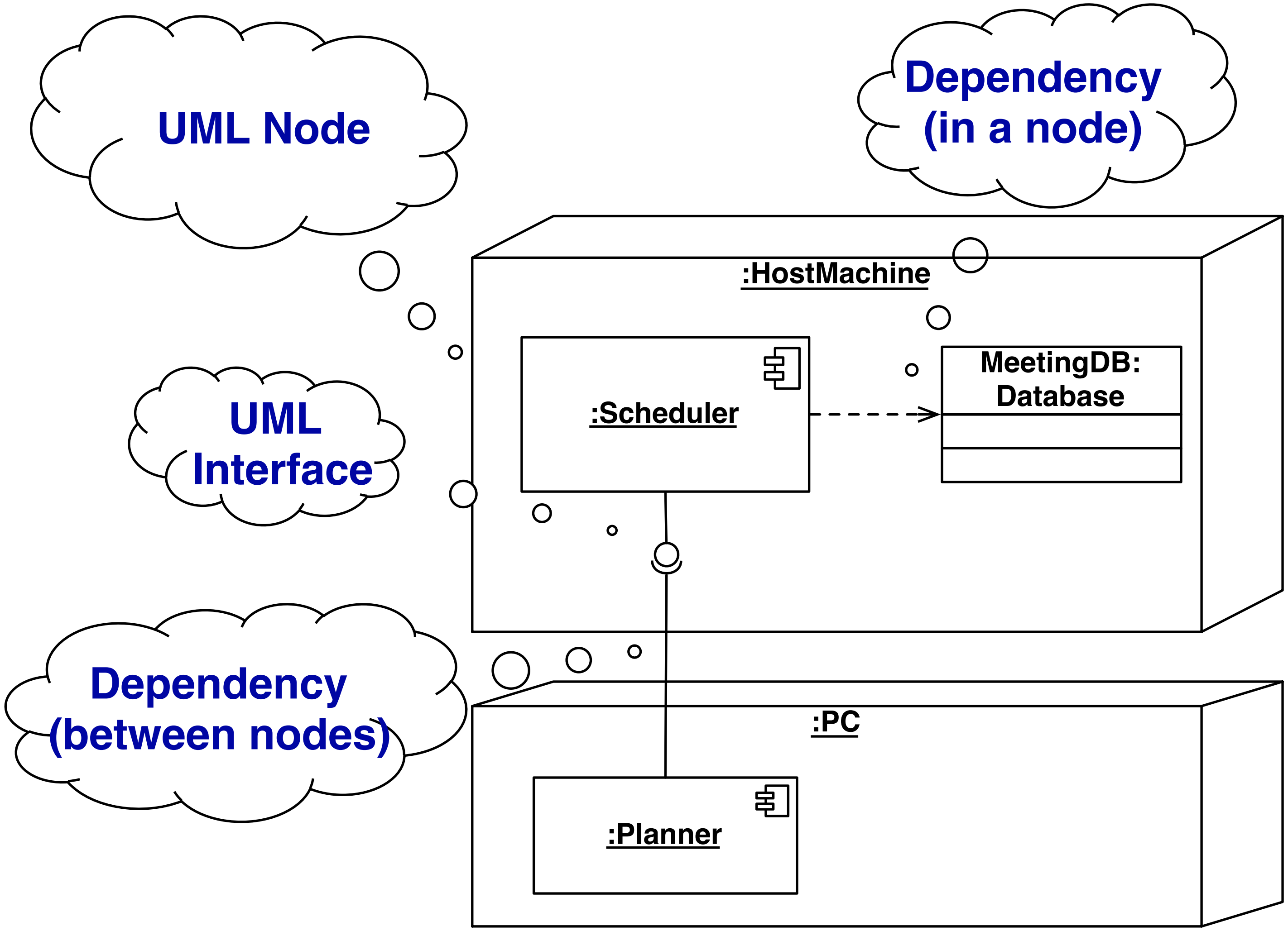
Figure 8.15 -Example of a composite structure of components, with connector wiring between simple ports on parts (Note: "Client" interface is a subtype of "Person").



Component with a complex port

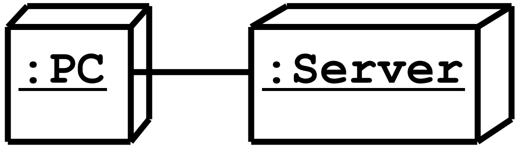
Where multiple components have simple ports that provide or require the same interface, a single symbol representing the interface can be shown, and lines from the components can be drawn to that symbol

Deployment Diagram Example



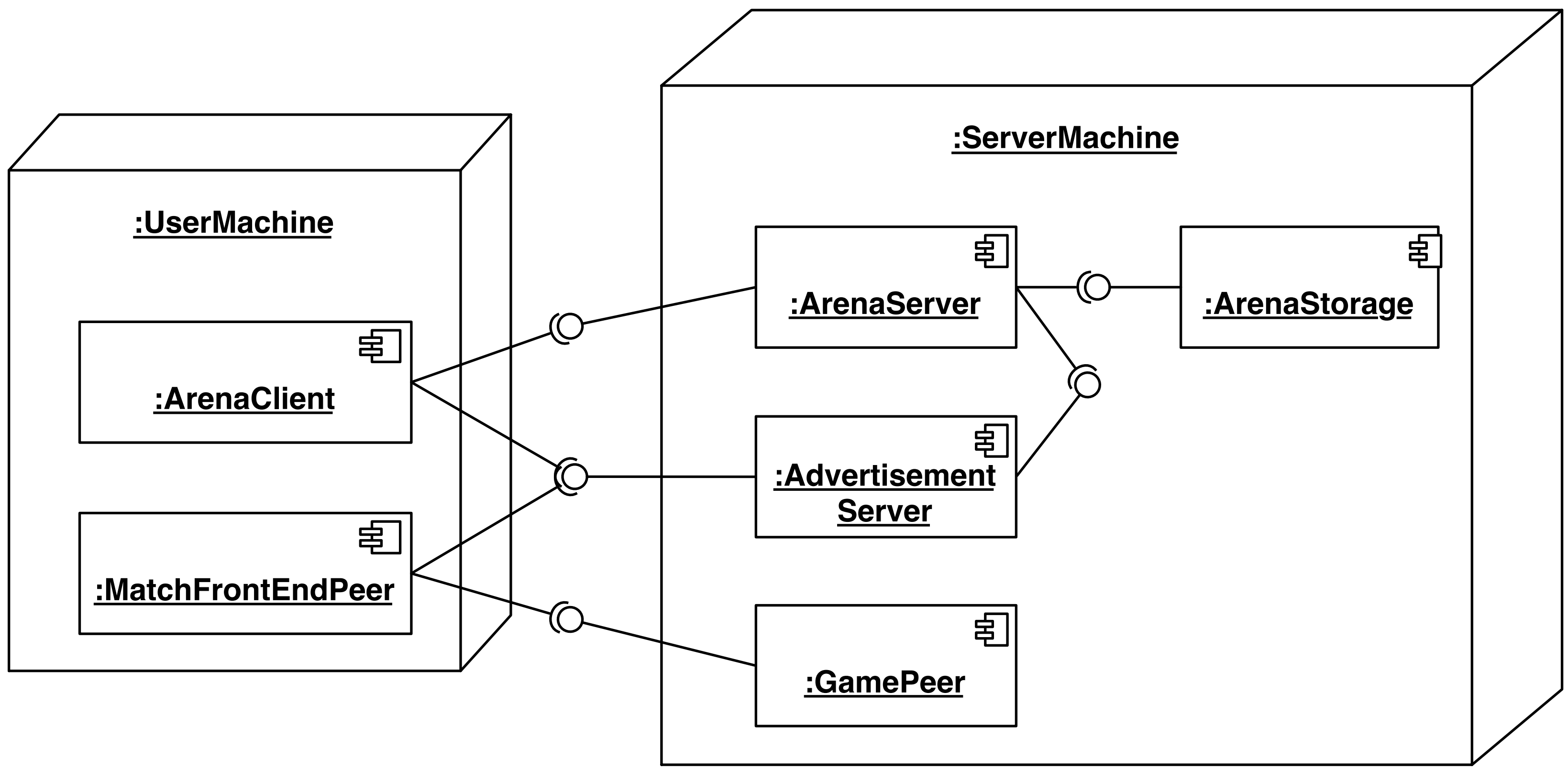
Deployment Diagram

- Deployment diagrams are useful for showing a system design after these system design decisions have been made:
  - Subsystem decomposition
  - Concurrency
  - Hardware/Software Mapping



- A deployment diagram is a graph of nodes and connections ("communication associations")
  - Nodes are shown as 3-D boxes
  - Connections between nodes are shown as solid lines
  - Nodes may contain components
    - Components can be connected by "lollipops" and "grabbers"
    - Components may contain objects (indicating that the object is part of the component).

ARENA Deployment Diagram



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5. Data Management

- Some objects in the system model need to be persistent:
  - Values for their attributes have a lifetime longer than a single execution
- A persistent object can be realized with one of the following mechanisms:
  - Filesystem:
    - If the data are used by multiple readers but a single writer
  - Database:
    - If the data are used by concurrent writers and readers.

Data Management Questions

- How often is the database accessed?
  - What is the expected request (query) rate? The worst case?
  - What is the size of typical and worst case requests?
- Do the data need to be archived?
- Should the data be distributed?
  - Does the system design try to hide the location of the databases (location transparency)?
- Is there a need for a single interface to access the data?
  - What is the query format?

Mapping Object Models

- UML object models can be mapped to relational databases
- The mapping:
  - Each class is mapped to its own table
  - Each class attribute is mapped to a column in the table
  - An instance of a class represents a row in the table
  - One-to-many associations are implemented with a buried foreign key
  - Many-to-many associations are mapped to their own tables
- Methods are not mapped

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6. Global Resource Handling

- Discusses access control
- Describes access rights for different classes of actors
- Describes how object guard against unauthorized access.

Defining Access Control

- In multi-user systems different actors usually have different access rights to different functionality and data
- How do we model these accesses?
  - During analysis we model them by associating different use cases with different actors
  - During system design we model them determining which objects are shared among actors.

Access Matrix

- We model access on classes with an access matrix:
  - The rows of the matrix represents the actors of the system
  - The column represent classes whose access we want to control
- Access Right: An entry in the access matrix. It lists the operations that can be executed on instances of the class by the actor.

	Class 1	Class 2	Class 3
Actor 1	methodX() methodZ()	methodW()	
Actor 2	MethodY()		methodV()

Access Matrix Example

Classes

Access Rights

Actors

	Arena	League	Tournament	Match
Operator	<<create>> createUser() view ()	<<create>> archive()		
LeagueOwner	view ()	edit ()	<<create>> archive() schedule() view()	<<create>> end()
Player	view() applyForOwner()	view() subscribe()	applyFor() view()	play() forfeit()
Spectator	view() applyForPlayer()	view() subscribe()	view()	view() replay()

Access Matrix Implementations (1 of 2)

- Global access table: Represents explicitly every cell in the matrix as a triple (actor,class, operation)

LeagueOwner, **Arena**, view()
LeagueOwner, League, edit()
LeagueOwner, **Tournament**, <<create>>
LeagueOwner, **Tournament**, view()
LeagueOwner, **Tournament**, schedule()
LeagueOwner, **Tournament**, archive()
LeagueOwner, **Match**, <<create>>
LeagueOwner, **Match**, end()

.

Access Matrix Implementations (2 of 2)

- Access control list
  - Associates a list of (actor,operation) pairs with each class to be accessed.
  - Every time an instance of this class is accessed, the access list is checked for the corresponding actor and operation.
- Capability
  - Associates a (class,operation) pair with an actor.
  - A capability provides an actor to gain control access to an object of the class described in the capability.

Global Resource Questions

- Does the system need authentication?
- If yes, what is the authentication scheme?
  - User name and password? Access control list
  - Tickets? Capability-based
- What is the user interface for authentication?
- Does the system need a network-wide name server?
- How is a service known to the rest of the system?
  - At runtime? At compile time?
  - By Port?
  - By Name?

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7. Decide on Software Control

Two major design choices:

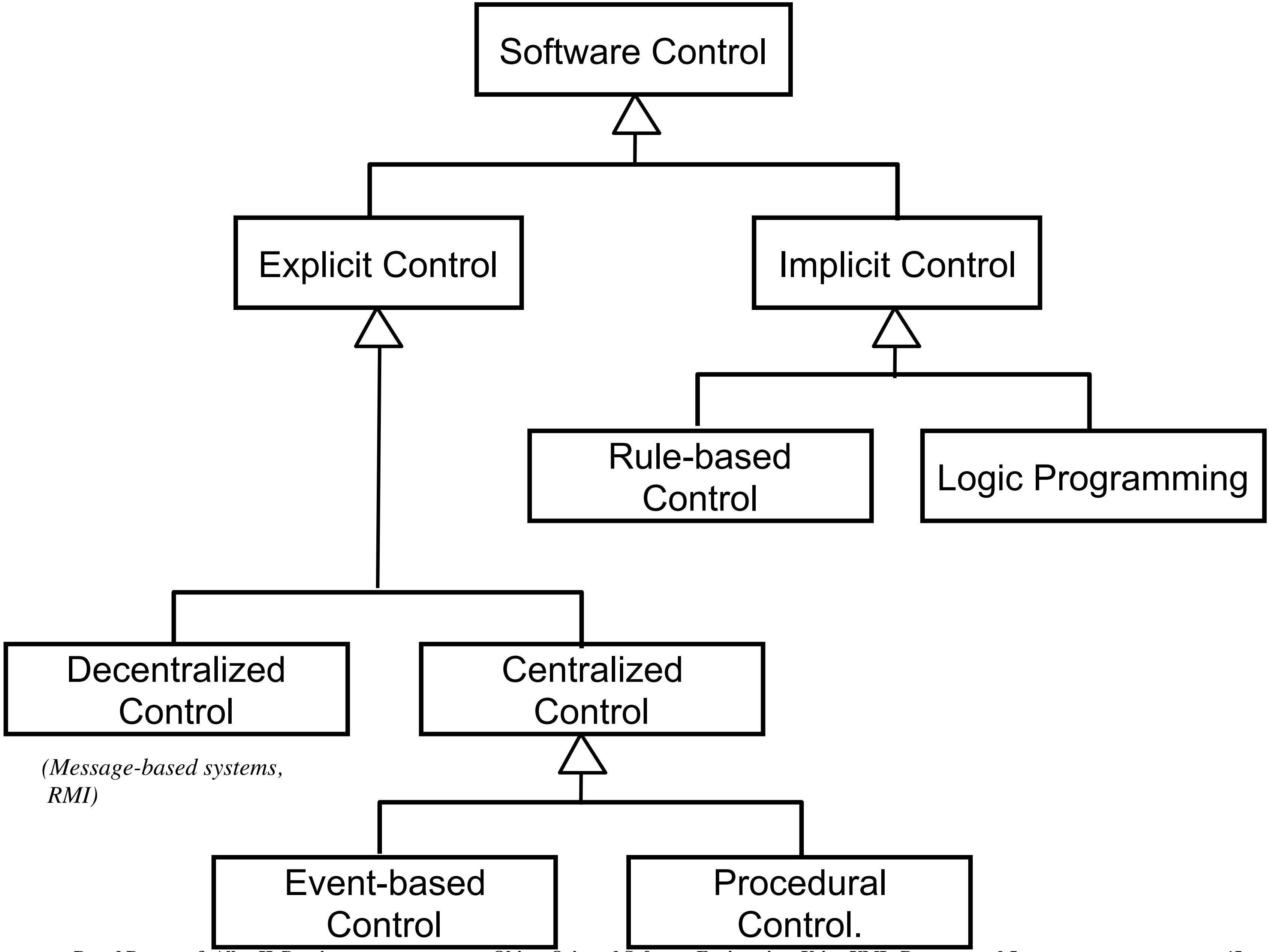
1. Choose implicit control
   - Rule-based systems, Logic programming
2. Choose explicit control
   - Procedural languages: Centralized or decentralized

Centralized vs. Decentralized Designs

- (Explicit) Centralized Design
  - One control object or subsystem ("spider") controls everything
    - Pro: Change in the control structure is very easy
    - Con: The single control object is a possible performance bottleneck
- (Explicit) Decentralized Design
  - Not a single object is in control, control is distributed; That means, there is more than one control object
    - Con: The responsibility is spread out
    - Pro: Fits nicely into object-oriented development

Centralized vs Decentralized Design/2

- (Explicit) Centralized control:
  - Procedure-driven: Control resides within program code.
  - Event-driven: Control resides within a dispatcher calling functions via callbacks.
- (Explicit) Decentralized control
  - Control resides in several independent objects.
    - Examples: Message based system, RMI
  - Possible speedup by mapping the objects on different processors, increased communication overhead.


Software Control
Explicit Control
Implicit Control
Rule-based Control
Logic Programming
Decentralized Control
Centralized Control
(Message-based systems, RMI)
Event-based Control
Procedural Control.

Centralized vs. Decentralized Designs (2)

- Should you use a centralized or decentralized design?
- Take the sequence diagrams and control objects from the analysis model
- Check the participation of the control objects in the sequence diagrams
  - If the sequence diagram looks like a fork => Centralized design
  - If the sequence diagram looks like a stair => Decentralized design.

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8. Boundary Conditions

- Initialization
  - The system is brought from a non-initialized state to steady-state
- Termination
  - Resources are cleaned up and other systems are notified upon termination
- Failure
  - Possible failures: Bugs, errors, external problems

- Good system design foresees fatal failures and provides mechanisms to deal with them.

Boundary Condition Questions

- Initialization
  - What data need to be accessed at startup time?
  - What services have to be registered?
  - What does the user interface do at start up time?
- Termination
  - Are single subsystems allowed to terminate?
  - Are subsystems notified if a single subsystem terminates?
  - How are updates communicated to the database?
- Failure
  - How does the system behave when a node or communication link fails?
  - How does the system recover from failure?.

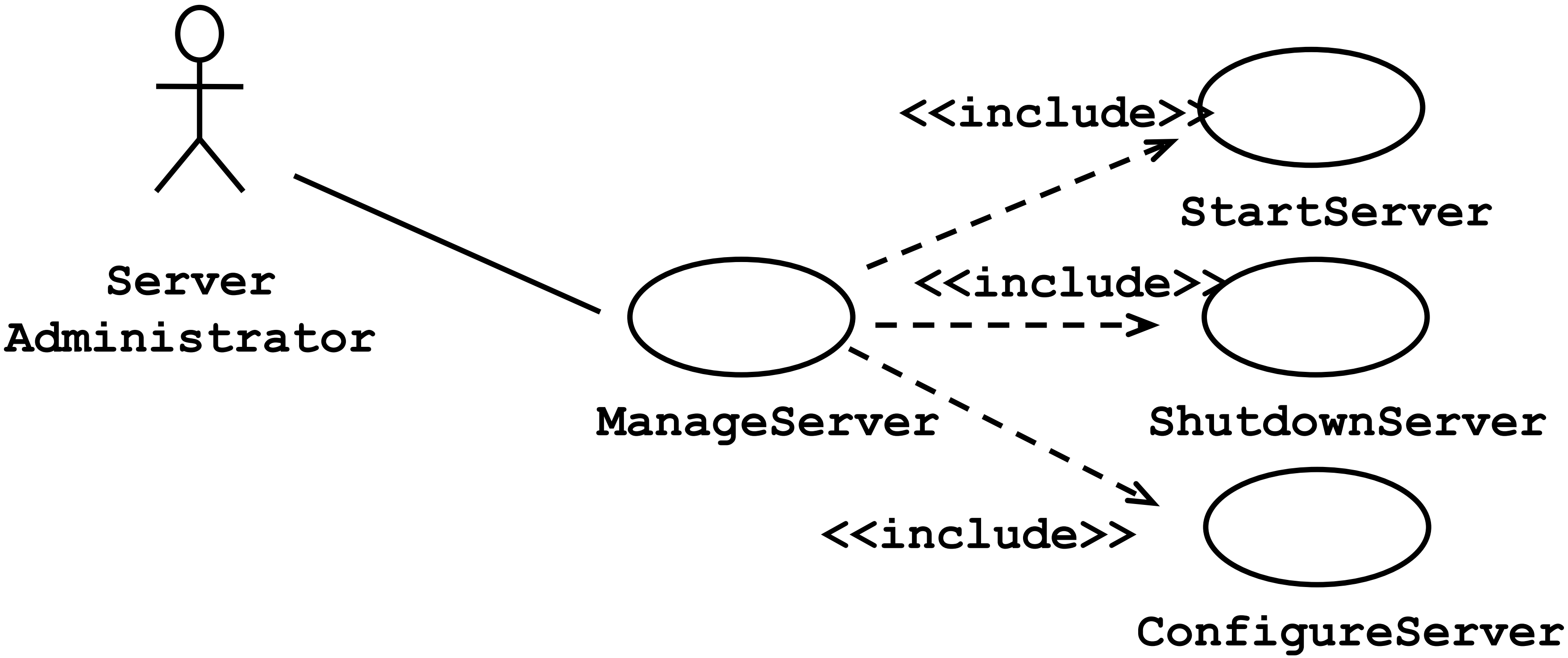
Modeling Boundary Conditions as use cases

- Boundary conditions are best modeled as use cases with actors and objects
- We call them boundary use cases or administrative use cases
- Actor: often the system administrator
- Interesting use cases:
  - Start up of a subsystem
  - Start up of the full system
  - Termination of a subsystem
  - Error in a subsystem or component, failure of a subsystem or component.

Example: Boundary Use Case for ARENA

- Let us assume, we identified the subsystem `AdvertisementServer` during system design
- This server takes a big load during the holiday season
- During hardware software mapping we decide to dedicate a special node for this server
- For this node we define a new boundary use case `ManageServer`
- `ManageServer` includes all the functions necessary to start up and shutdown the `AdvertisementServer`.

ManageServer Boundary Use Case



Summary

- System design activities:
  - Concurrency identification
  - Hardware/Software mapping
  - Persistent data management
  - Global resource handling
  - Software control selection
  - Boundary conditions
- Each of these activities may affect the subsystem decomposition
- Two new UML Notations
  - UML Component Diagram: Showing compile time and runtime dependencies between subsystems
  - UML Deployment Diagram: Drawing the runtime configuration of the system.