Introduction to Software Engineering Methods

System Design

Literature used

- Text Book

  Chapters 6 and 7

Content

Overview of System Design Activities:

1. Design Goals
2. Subsystem Decomposition
3. Other activities

   Hardware/Software Mapping

   Persistent Data Management

   Global Resource Handling and Access Control

   Software Control

   Boundary Conditions

Design

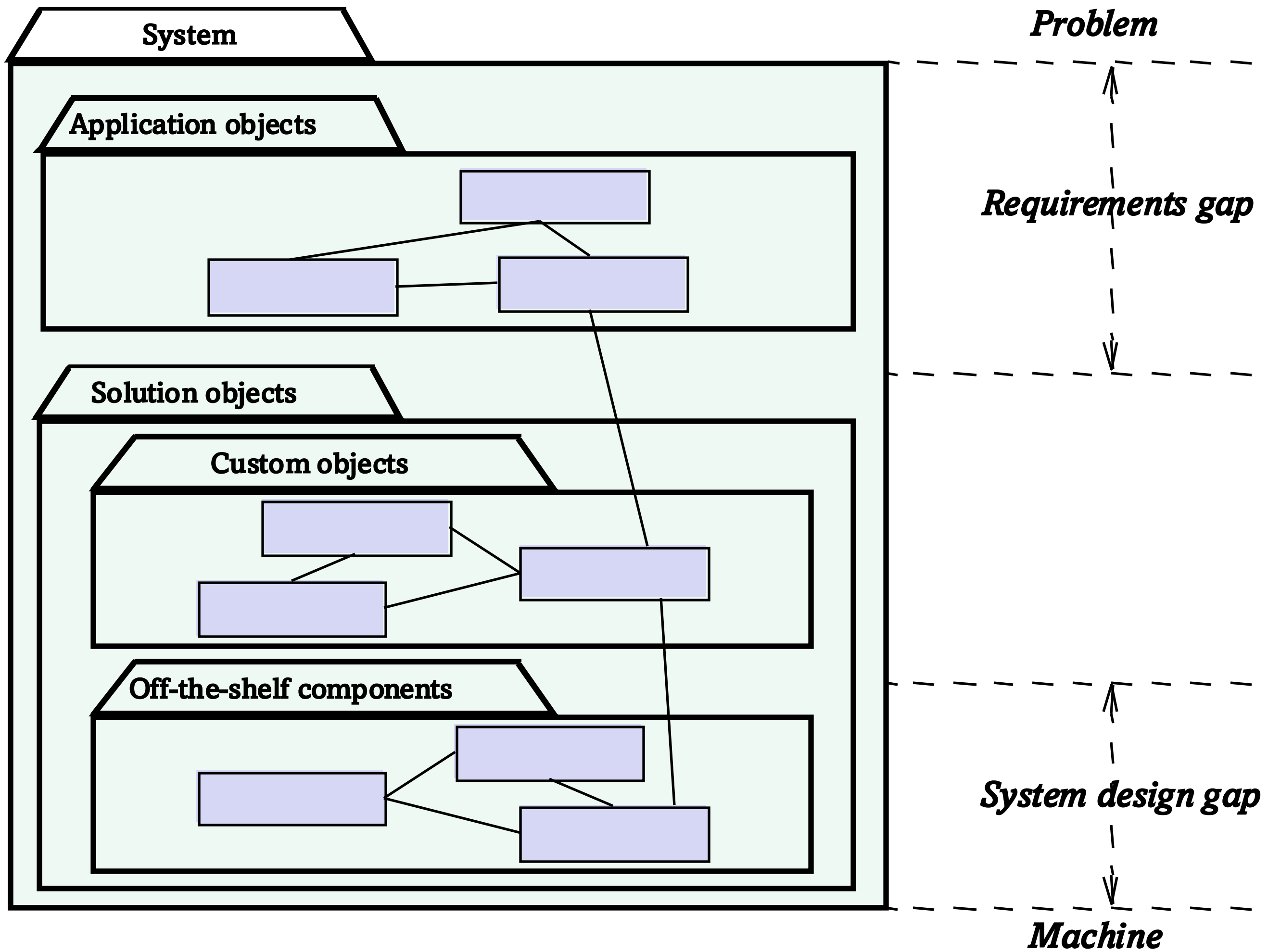
“There are two ways of constructing a software design: One way is to make it so simple that there are obviously no deficiencies, and the other way is to make it so complicated that there are no obvious deficiencies.”

- C.A.R. Hoare

Analysis & Design

- *Analysis:* Focuses on the application domain
- *Design:* Focuses on the solution domain
  - Design knowledge is a moving target
  - Design decisions are changing very rapidly
    - Technology changes rapidly
    - Cost of hardware rapidly sinking
- "*Design window*":
  - Time window in which design decisions must be made

System Design:



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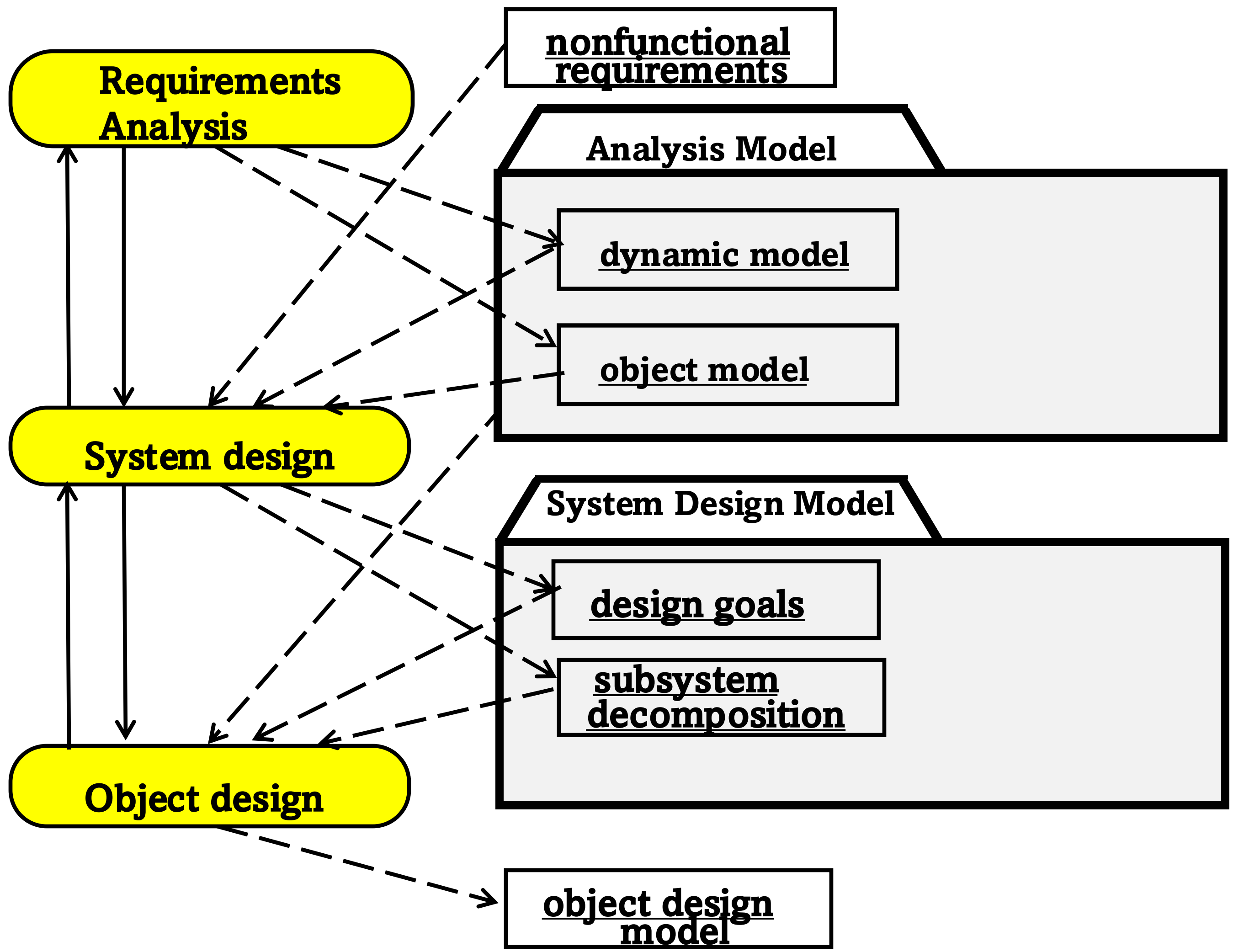
System Design Activities



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System Design Activitiies

1. Design Goals
- Definition
- Trade-offs

2. System Decomposition
- Layers/Partitions
- Cohesion/Coupling

3. Concurrency
- Identification of Threads of control

4. Hardware/ Software Mapping
- Special purpose
- Buy or Build Trade-off
- Allocation
- Connectivity

5. Data Management
- Persistent Objects
- Databases
- Data structure

6. Global Resource Handling
- Access control
- Security

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

8. Boundary Conditions
- Initialization
- Termination
- Failure

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How to use the results from the Requirements Analysis for System Design

- **Nonfunctional requirements =>**
  - Activity 1: Design Goals Definition
- **Functional model =>**
  - Activity 2: System decomposition (Selection of subsystems based on functional requirements, cohesion, and coupling)
- **Object model =>**
  - Activity 4: Hardware/software mapping
  - Activity 5: Persistent data management
- **Dynamic model =>**
  - Activity 3: Concurrency
  - Activity 6: Global resource handling
  - Activity 7: Software control
  - Activity 8: Boundary conditions

Example: Current Desktop Development

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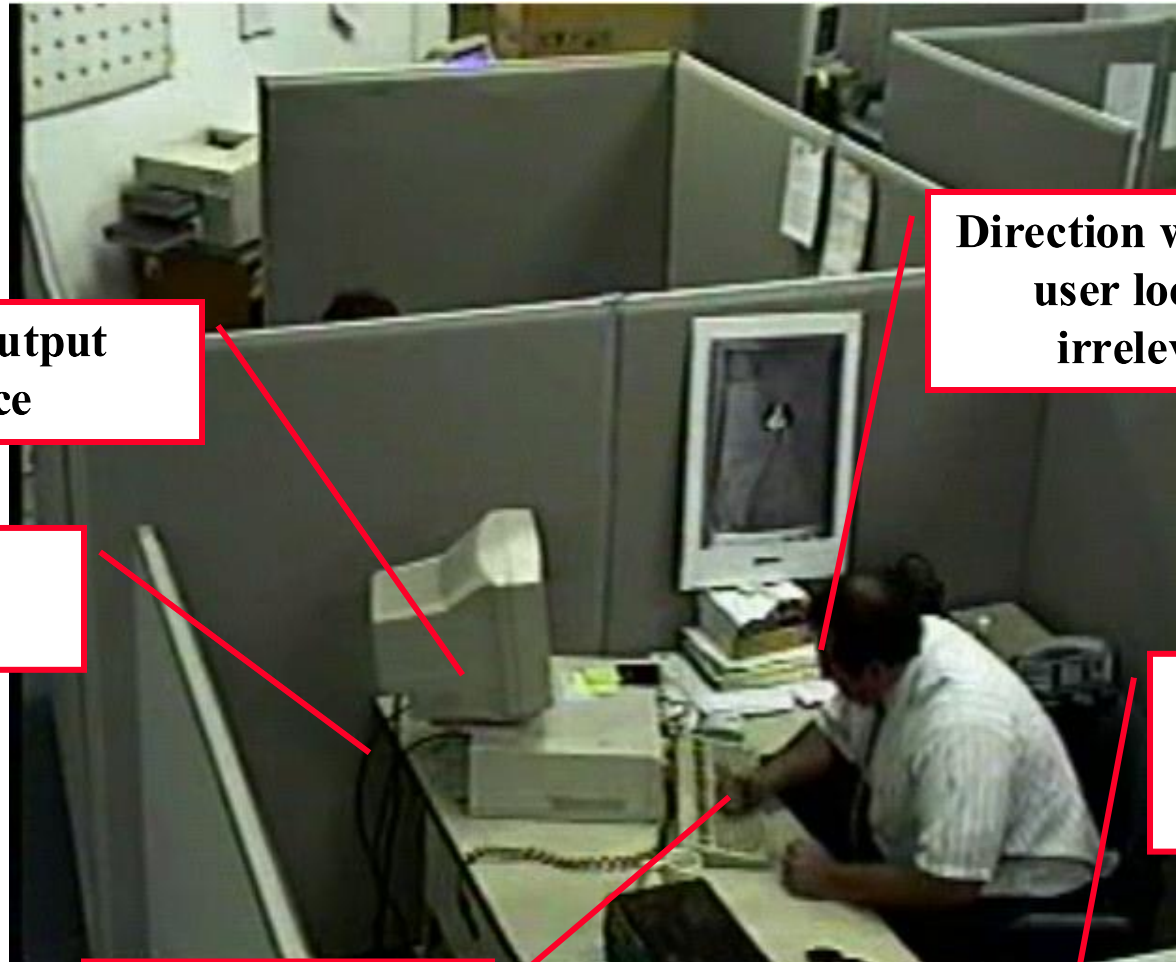
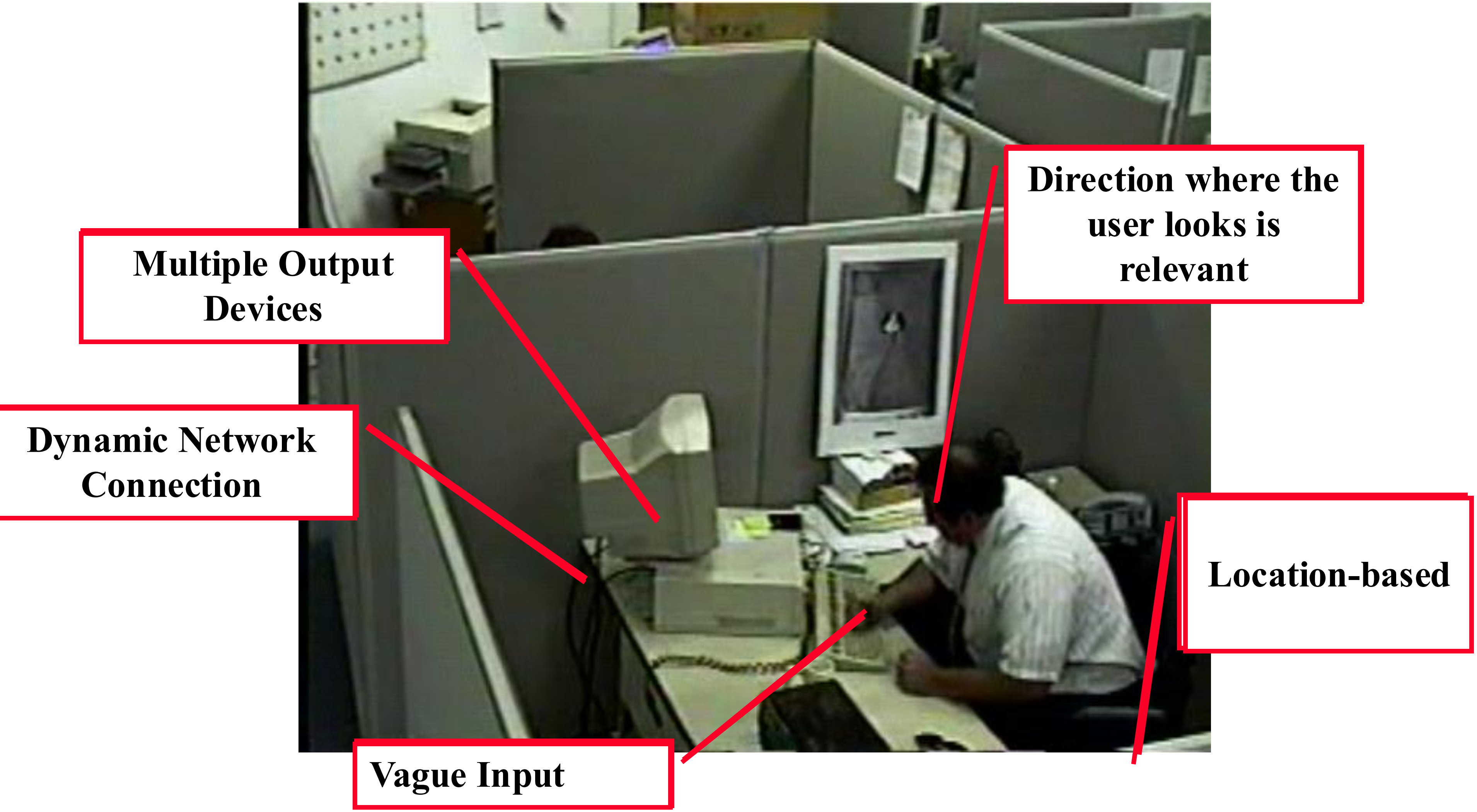
Identify Current Technology Constraints



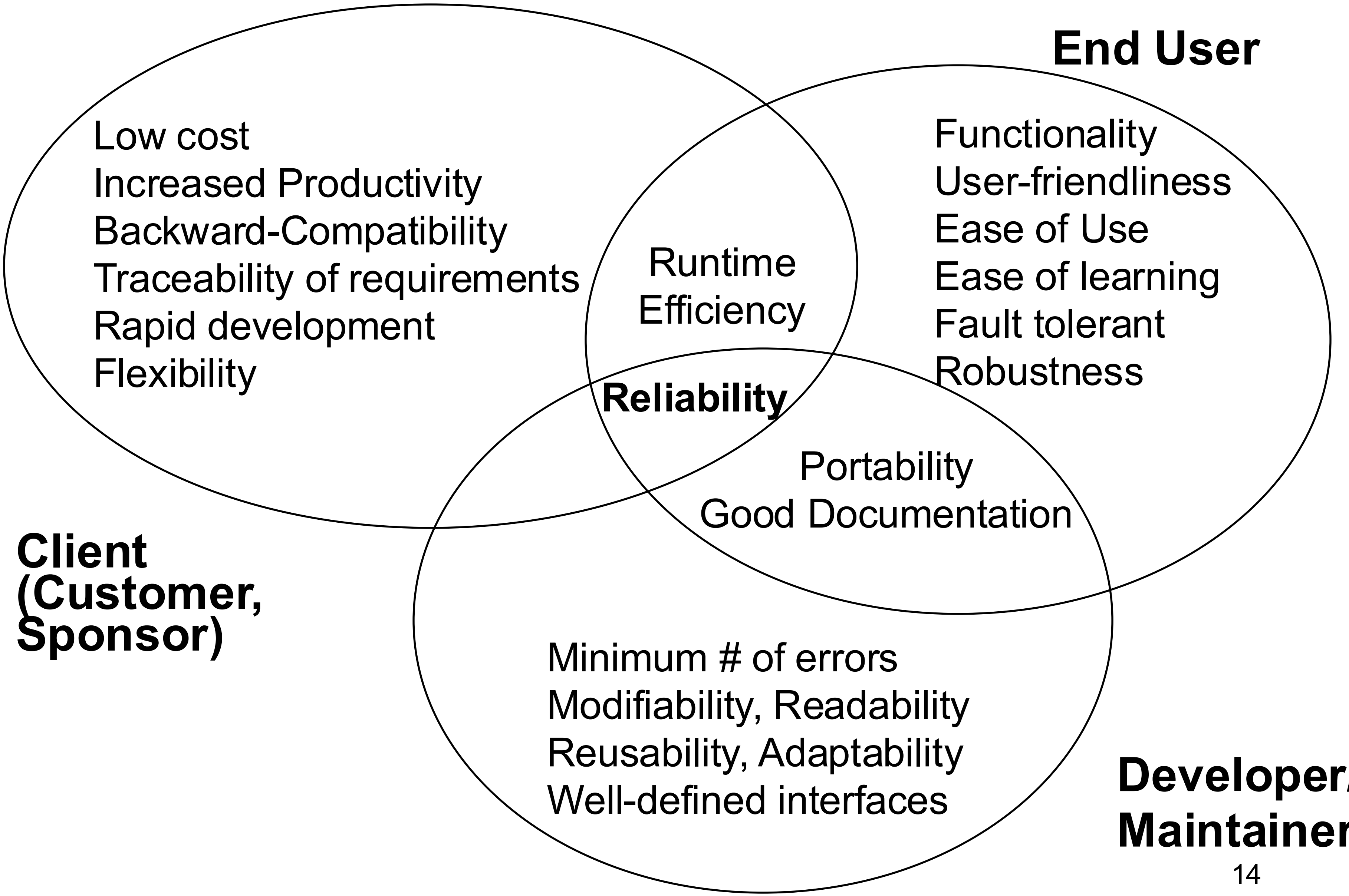
Generalize Constraints using Technology Enablers



Map Generalized Constraints into Design Goals

- Reliability
- Modifiability
- Maintainability
- Understandability
- Adaptability
- Reusability
- Efficiency
- Portability
- Traceability of requirements
- Fault tolerance
- Backward-compatibility
- Cost-effectiveness
- Robustness
- High-performance
- Good documentation
- Well-defined interfaces
- User-friendliness
- Reuse of components
- Rapid development
- Minimum # of errors
- Readability
- Ease of learning
- Ease of remembering
- Ease of use
- Increased productivity
- Low-cost
- Flexibility

Structuring Design Goals



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Design goals from non-functional requirements

- **Performance**
  - Response time
  - Throughput
  - Memory
- **Dependability**
  - Robustness
  - Reliability
  - Availability
  - Fault tolerance
  - Security
  - Safety
- **End-user criteria**
  - Utility
  - Usability
- **Cost**
  - Development cost
  - Deployment cost
  - Upgrade cost
  - Maintenance cost
  - Administration cost
- **Maintenance**
  - Extensibility
  - Modifiability
  - Adaptability
  - Portability
  - Readability
  - Traceability of requirements

Design Trade-offs

- Space vs. Speed
- Efficiency vs. Portability
- Rapid development vs. Functionality
- Cost vs. Reusability
- Backward Compatibility vs. Readability
- Delivery time vs. Quality
- Delivery time vs. Functionality
- …

System Decomposition

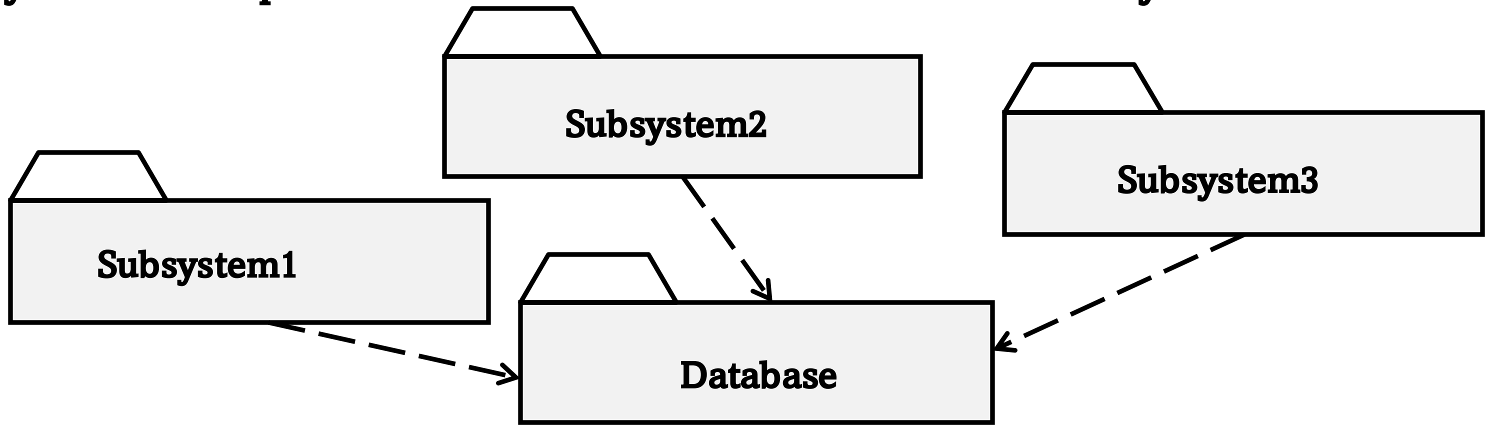
- **Subsystem:**
  – Collection of classes, associations, operations, events and constraints that are interrelated
  – Sources for subsystems: UML Use cases, Objects and Classes.
- **Service**:
  – Group of operations provided by the subsystem (a set of related operations that share a common purpose)
  – Sources for services: Subsystem use cases
- **Service is specified by Subsystem interface**:
  – Specifies interaction and information flow from/to subsystem boundaries, but not inside the subsystem.

Coupling and Cohesion

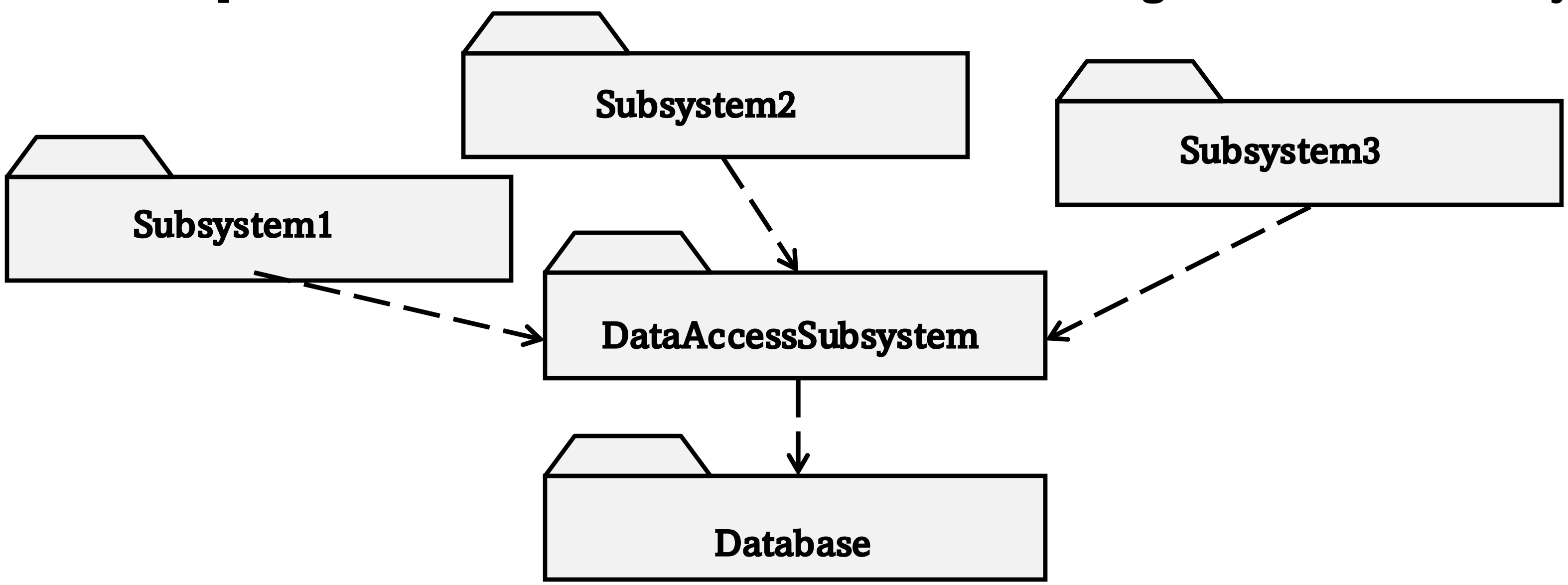
- Goal: Reduction of ***complexity while change occurs***
- **Coupling** measures dependencies between subsystems
  – High coupling: Changes to one subsystem will have high impact on the other subsystem (change of model, massive recompilation, etc.)
  – Low coupling: A change in one subsystem does not affect any other subsystem
- **Cohesion** measures the dependence within the system
  – High cohesion: The classes in the subsystem perform similar tasks and are related to each other (via associations)
  – Low cohesion: Lots of miscellaneous and auxiliary classes, no associations
- Subsystems should have as maximum cohesion and minimum coupling as possible:
  – How can we achieve high cohesion?
  – How can we achieve loose coupling?

Reducing coupling

System decomposition 1: Direct access to the Database subsystem

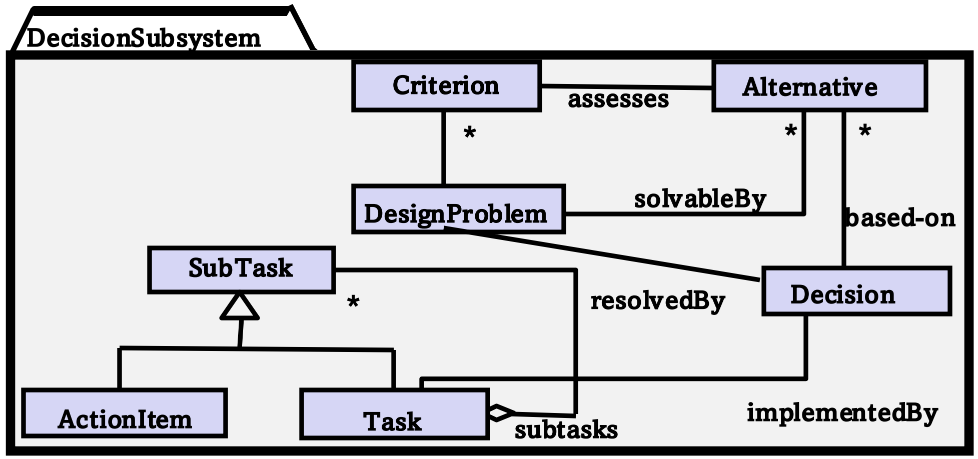


System decomposition 2: Indirect access to the Database through a DataAccessSubsystem

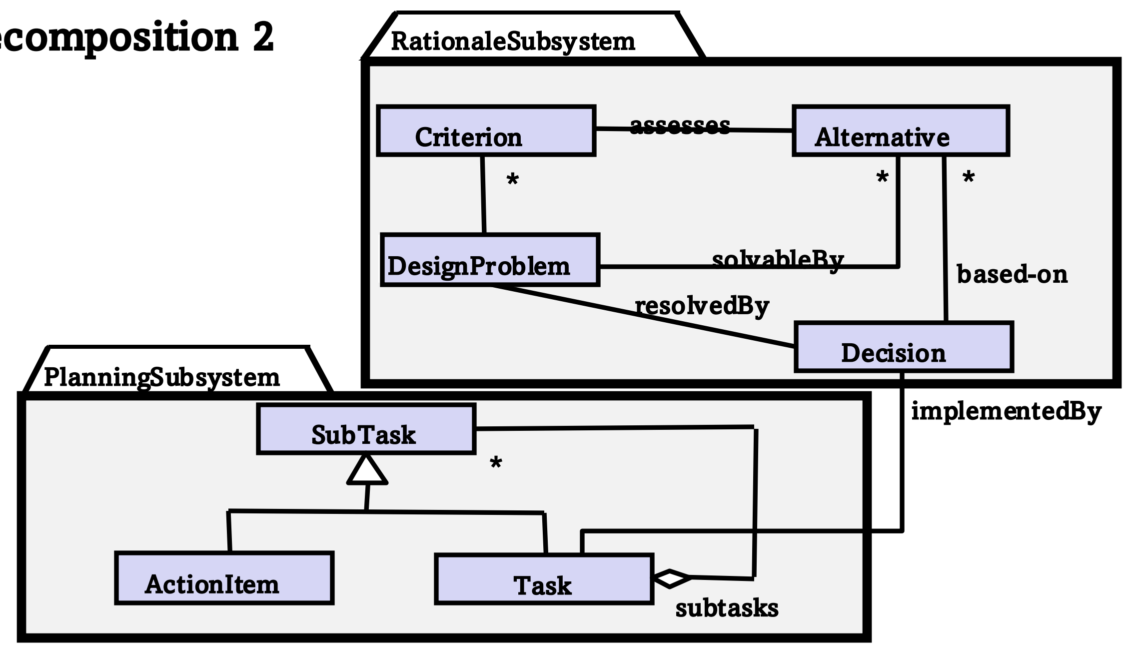


Increasing cohesion

System decomposition 1



System decomposition 2



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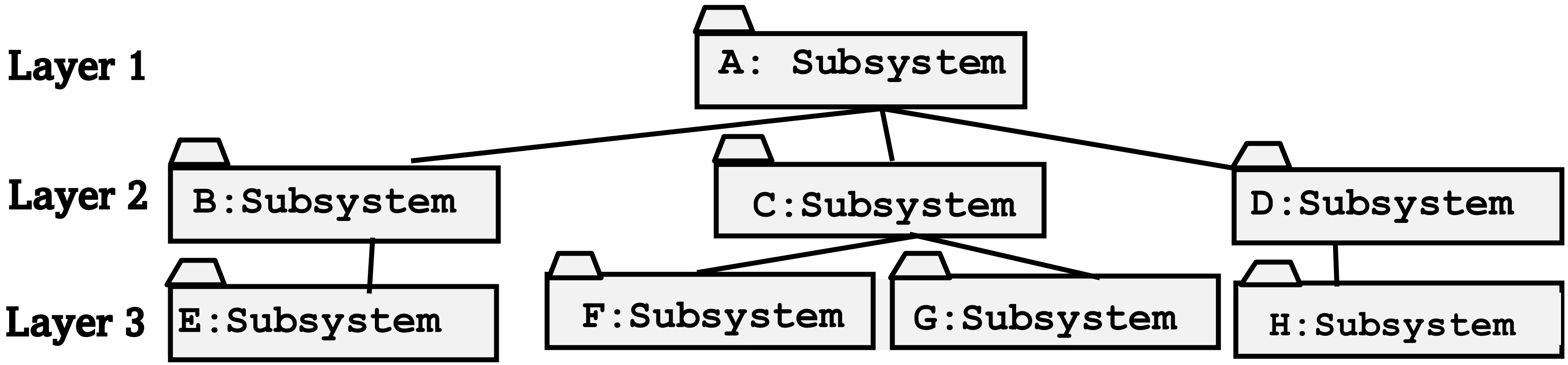
Partitions and Layers

Partitioning and layering are techniques to achieve low coupling.

A large system is usually decomposed into subsystems using both, layers and partitions.

- **Partitions** vertically divide a system into several independent (or weakly-coupled) subsystems that provide services on the same level of abstraction.
- A **layer** is a subsystem that provides subsystem services to a higher layers (level of abstraction)
  - A layer can only depend on lower layers
  - A layer has no knowledge of higher layers

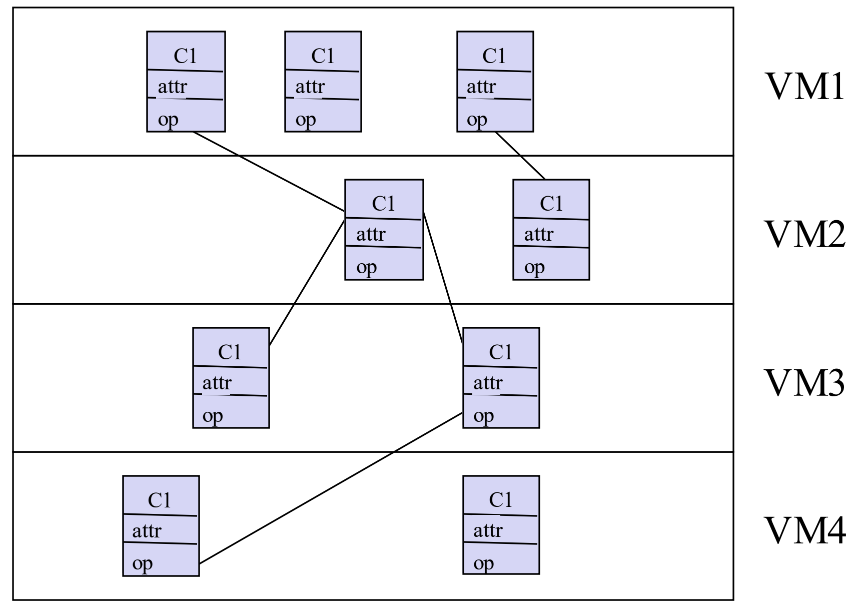
Subsystem Decomposition into Layers



- Subsystem Decomposition Heuristics:
  - No more than 7+/-2 subsystems at any layer
    - More subsystems increase cohesion but also complexity (more services)
  - No more than 7+/-2 layers, use 3 layers (good)

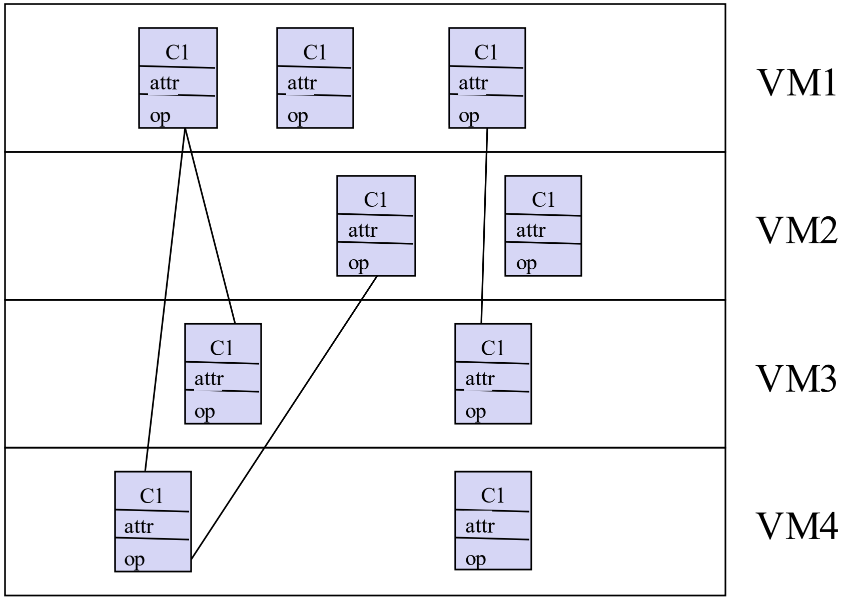
Closed Architecture (Opaque Layering)

- Any layer can only invoke operations from the immediate layer below
- Design goal: **High maintainability, flexibility**



Open Architecture (Transparent Layering)

- Any layer can invoke operations from any layers below
- Design goal: **Runtime efficiency**



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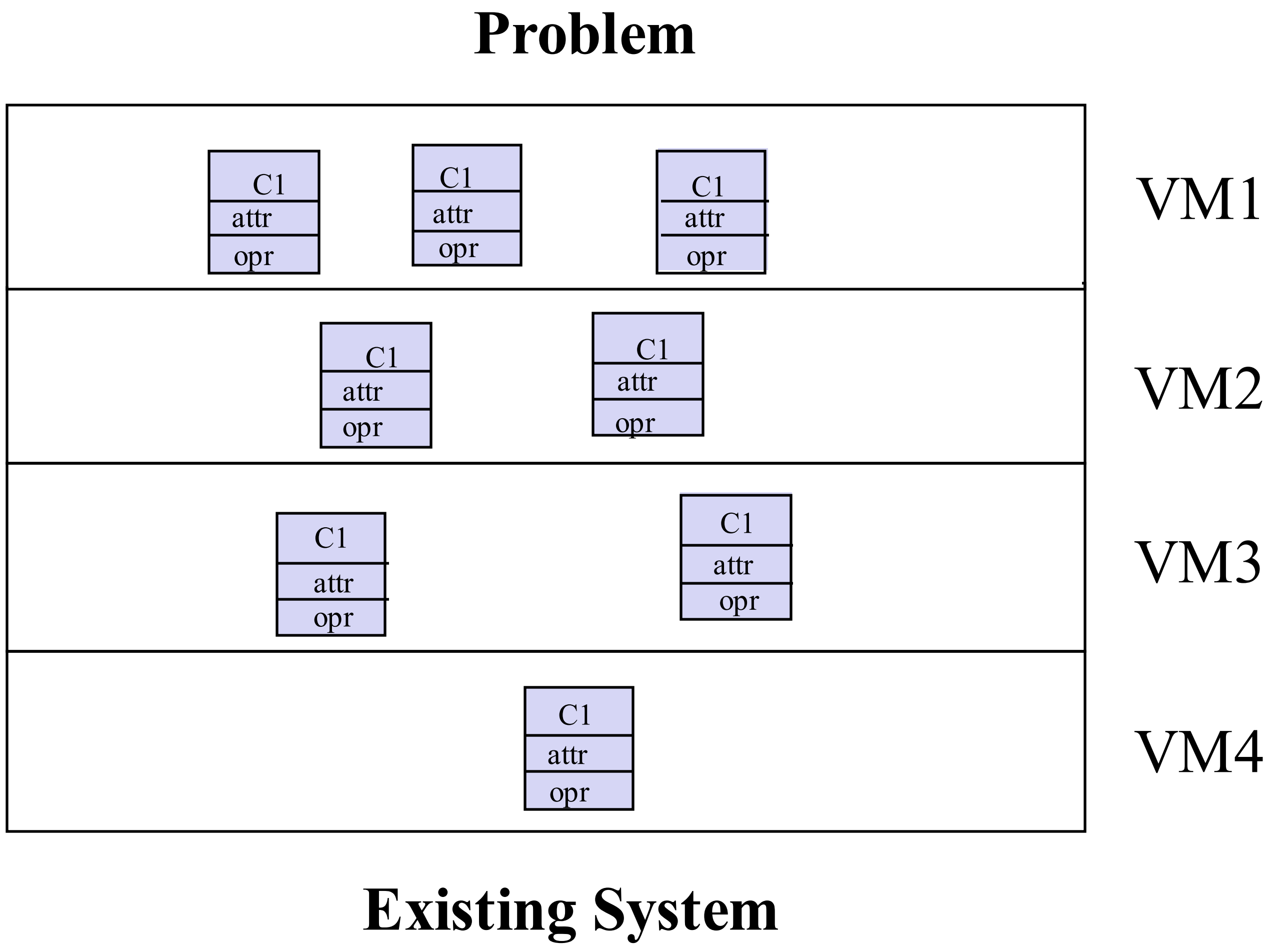
Example of layer Architecture: Virtual Machine



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Properties of Layered Systems

- Layered systems are ***hierarchical***. They are desirable because hierarchy reduces complexity (by low coupling).
- Closed architectures are more portable.
- Open architectures are more efficient.
- Layered systems often have a chicken-and egg problem
  – Example: Debugger
    - Debugger opening the symbol table when the file system needs to be debugged

Choosing Subsystems

- Criteria for subsystem selection:
  – Most of the interaction should be within subsystems (High cohesion), rather than across subsystem boundaries (Low coupling).

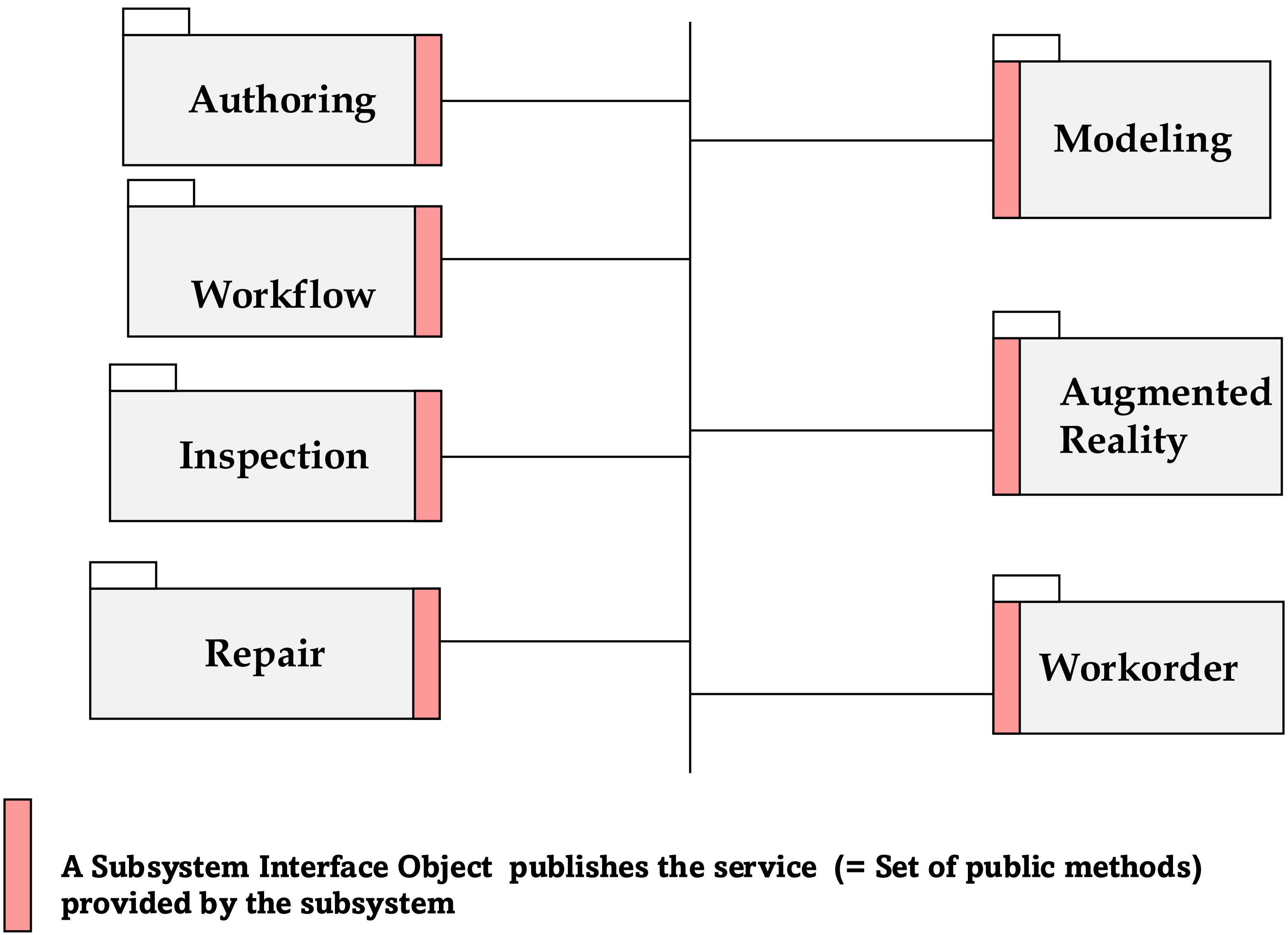
Some heuristics for grouping objects into subsystems

- Assign objects identified in one use case into the same subsystem
- Minimize the number of associations crossing subsystem boundaries
- All objects in the same subsystem should be functionally related
- …

Software Architectural Styles

- Subsystem decomposition
  – Identification of subsystems, services, and their relationship to each other.
- Specification of the system decomposition is critical.
- Patterns for software architecture
  – Client/Server
  – Peer-To-Peer
  – Repository
  – Model/View/Controller
  – Pipes and Filters
  – …

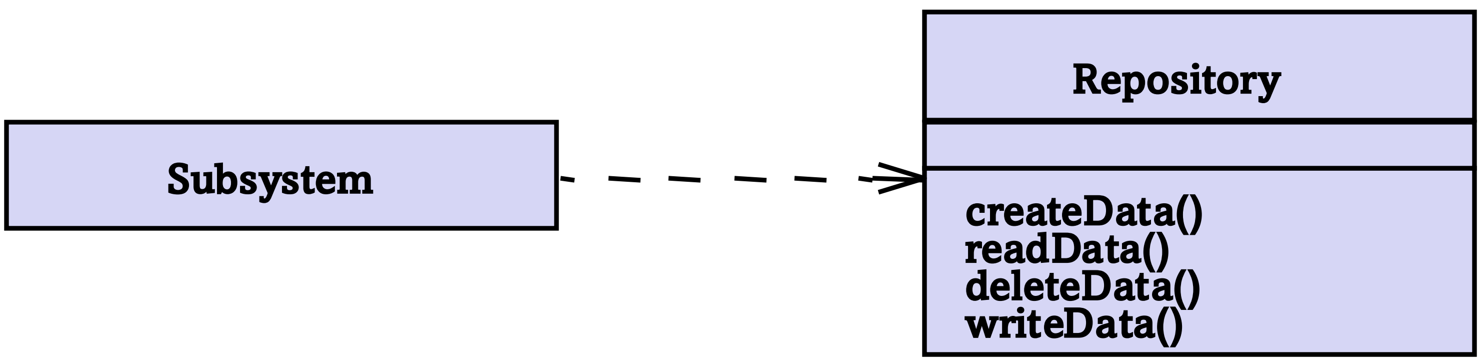
System as a set of subsystems communicating via a software bus



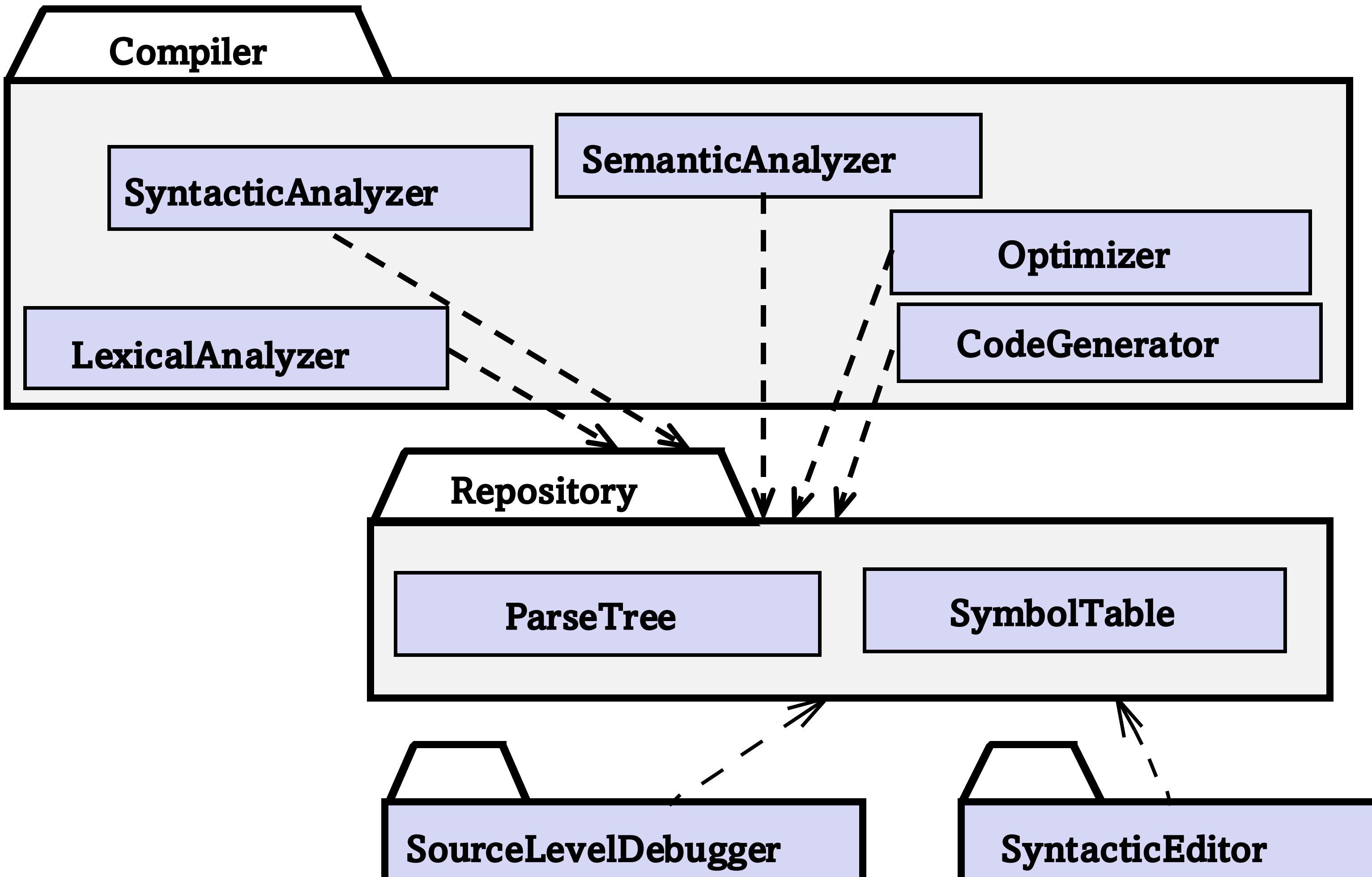
A Subsystem Interface Object publishes the service (= Set of public methods) provided by the subsystem

Repository Architectural Style

- Subsystems access and modify data from a single data structure
- Subsystems are loosely coupled (interact only through the repository)
- Control flow is dictated by central repository (triggers) or by the subsystems (locks, synchronization primitives)



Repository Architectural Style



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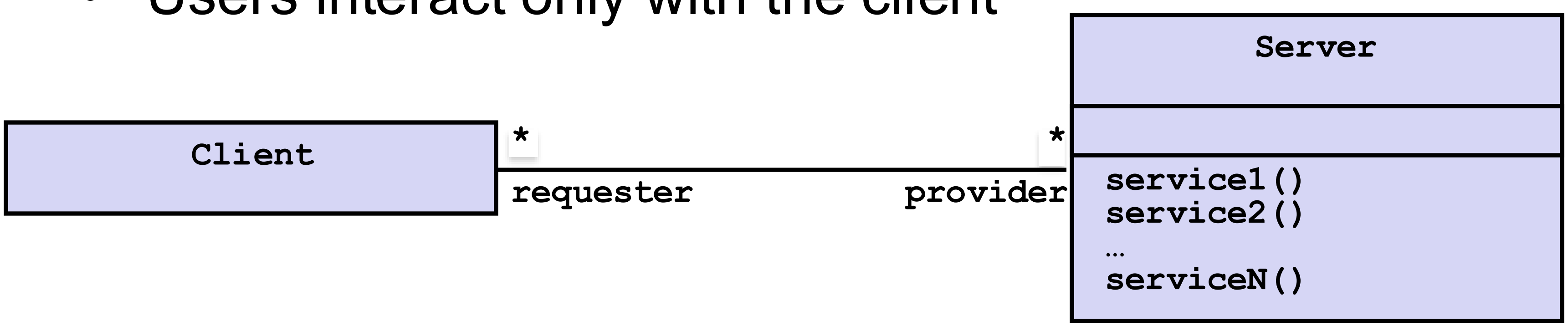
Client/Server Architectural Style

- One or many servers provide services to instances of subsystems, called clients.
- Client calls on the server, which performs some service and returns the result
  - Client knows the *interface* of the server *(its service)*
  - Server does not need to know the interface of the client
- Response in general immediate
- Users interact only with the client



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Example of Client/Server Architectural Style

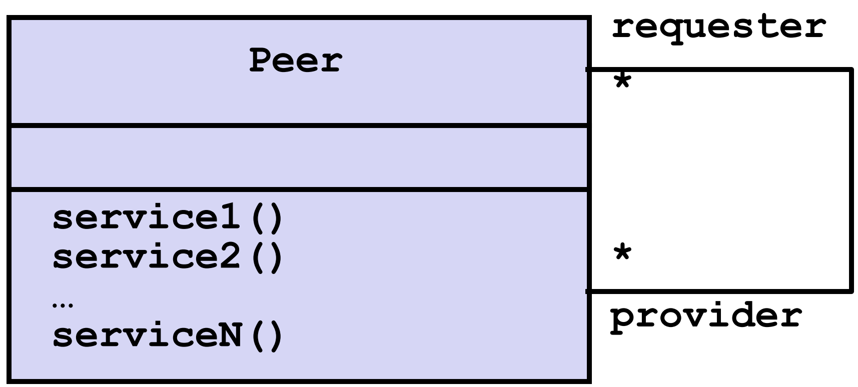
- Often used in database systems:
  - Front-end: User application (client)
  - Back end: Database access and manipulation (server)
- Functions performed by client:
  - Customized user interface
  - Front-end processing of data
  - Initiation of server remote procedure calls
  - Access to database server across the network
- Functions performed by the database server:
  - Centralized data management
  - Data integrity and database consistency
  - Database security
  - Concurrent operations (multiple user access)
  - Centralized processing (for example archiving)

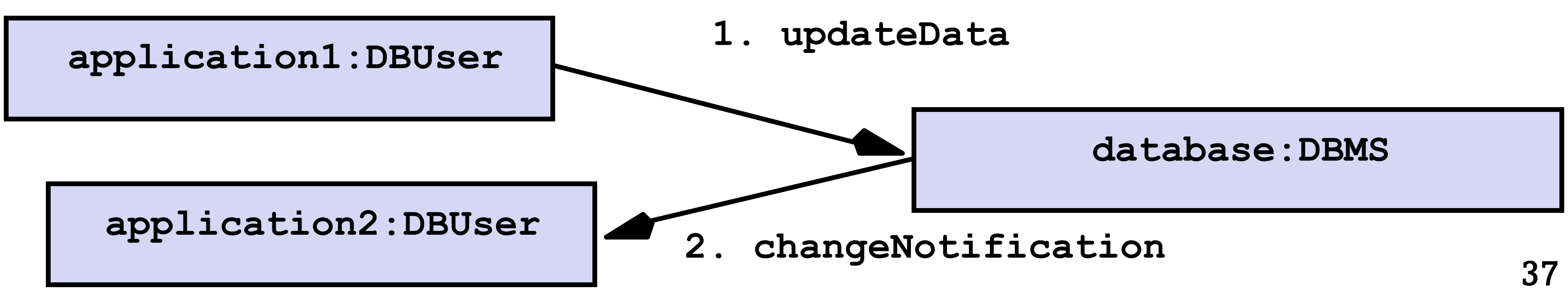
Example of Design Goals for Client/Server Architectural Style

- *Service Portability*
  - Service can be installed on a variety of machines and operating systems and functions in a variety of networking environments
- *Transparency, Location-Transparency*
  - The server might itself be distributed, but should provide a single "logical" service to the user
- *Performance*
  - Client should be customized for interactive display-intensive tasks
  - Server should provide CPU-intensive operations
- *Scalability*
  - Server should have spare capacity to handle larger number of clients
- *Flexibility*
  - The system should be usable for a variety of user interfaces and end devices (eg. wearable computer, desktop)
- *Reliability*
  - System should survive node or communication link problems

Peer-to-Peer Architectural Style

- Generalization of Client/Server Architecture
- Clients can be servers and servers can be clients
- More difficult because of possibility of deadlocks





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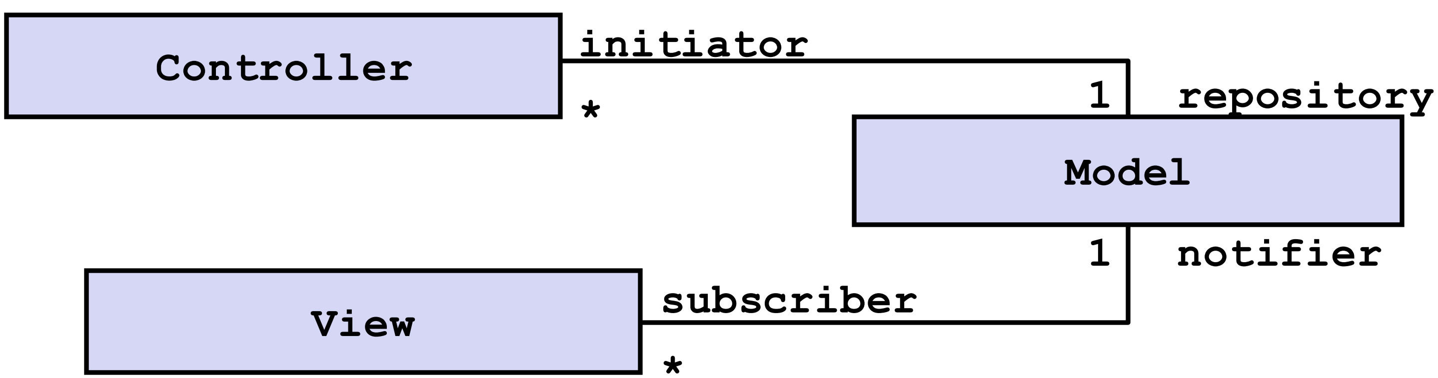
Model/View/Controller

- Subsystems are classified into 3 different types
  - Model subsystem: **Responsible for application domain knowledge**
  - View subsystem: **Responsible for displaying application domain objects to the user**
  - Controller subsystem: **Responsible for sequence of interactions with the user**
- MVC is a special case of a repository architecture:
  - Model subsystem implements the central datastructure, the Controller subsystem explicitly dictate the control flow



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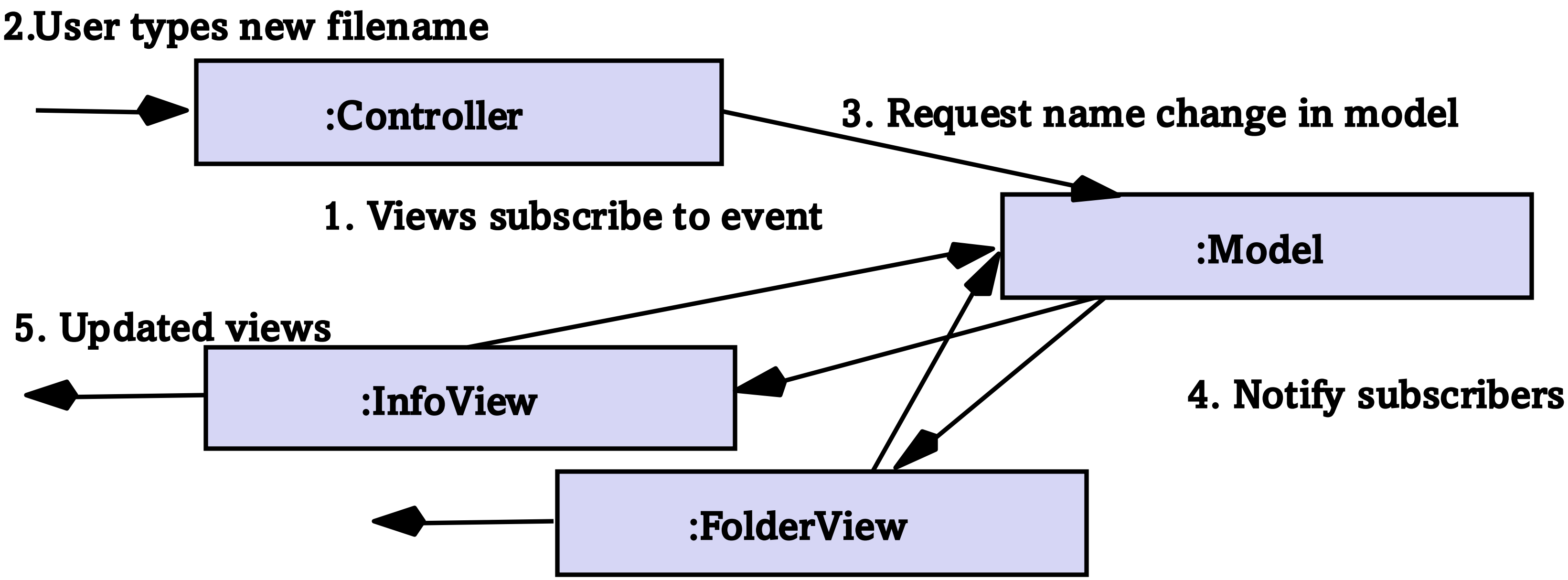
Example of MVC: Sequence of Events



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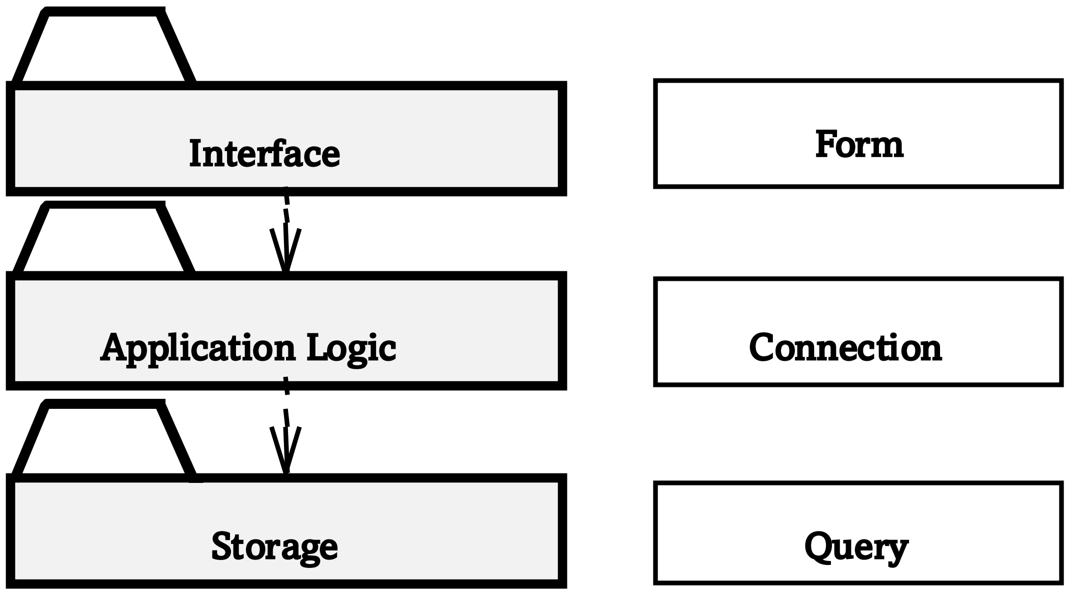
Three-tier architectural style.



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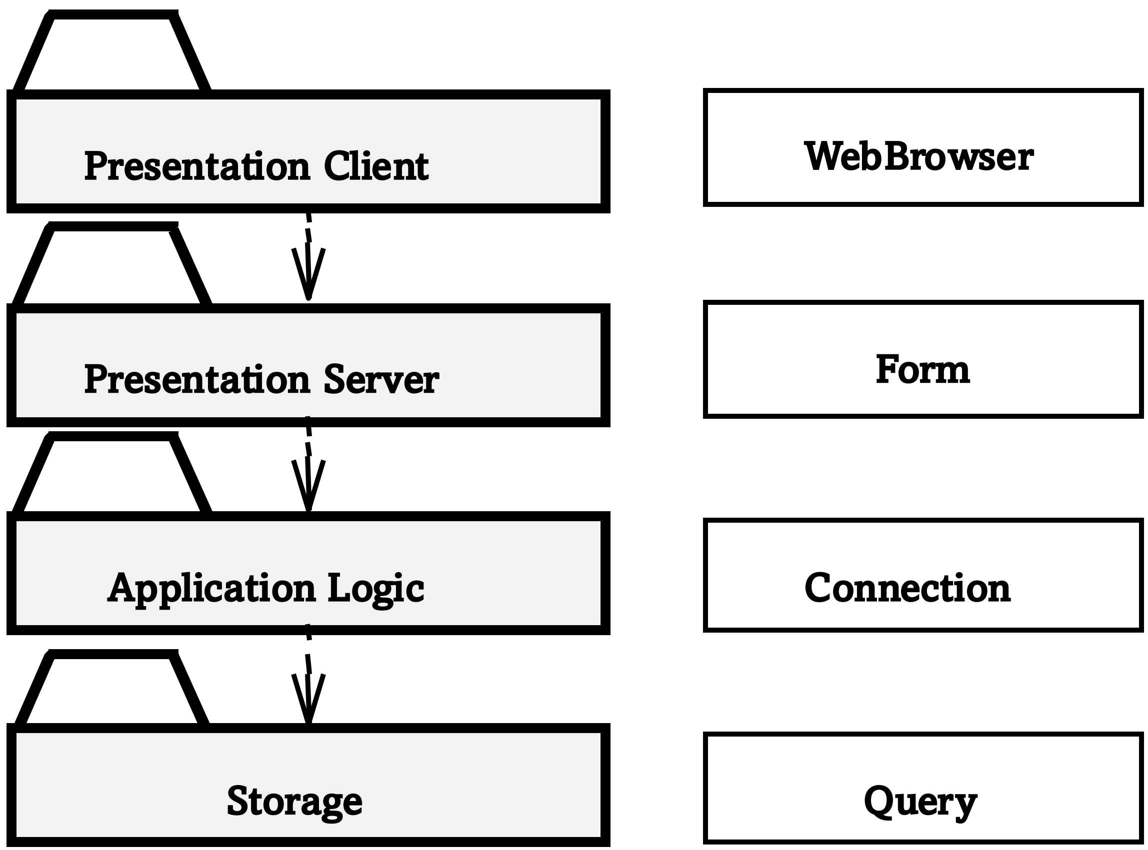
Four-tier architectural style.



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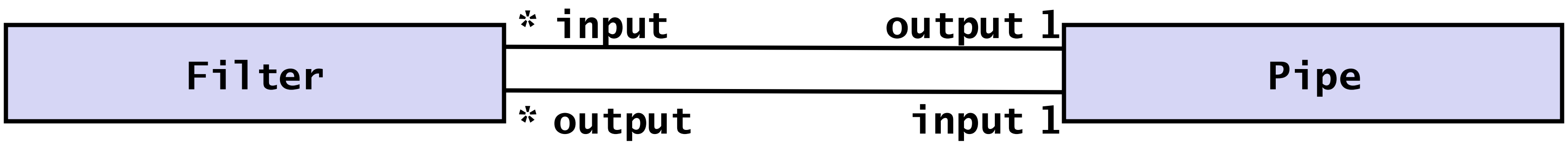
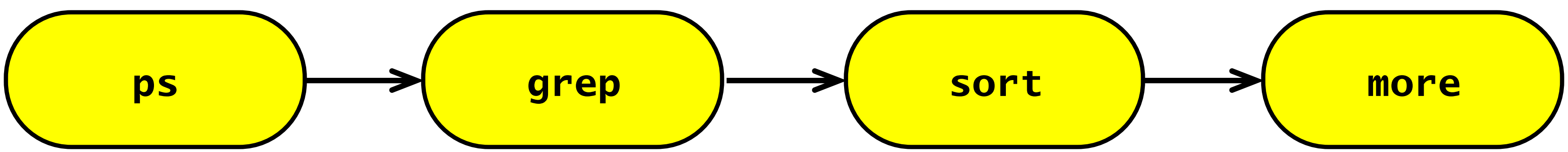
Pipe and filter architectural style.




```
% ps auxwww | grep dutoit | sort | more

dutoit   19737  0.2  1.6 1908 1500 pts/6    O 15:24:36  0:00 -tcsh
dutoit   19858  0.2  0.7  816  580 pts/6    S 15:38:46  0:00 grep dutoit
dutoit   19859  0.2  0.6  812  540 pts/6    O 15:38:47  0:00 sort
```



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Intermediate Summary

- System Design
  - Reduces the gap between requirements and the (virtual) machine
  - Decomposes the overall system into manageable parts
- Design Goals Definition
  - Describes and prioritizes the qualities that are important for the system
  - Defines the value system against which options are evaluated
- Subsystem Decomposition
  - Results into a set of loosely dependent parts which make up the system

System Design

1. Design Goals
- Definition
- Trade-offs

2. System Decomposition
- Layers/Partitions
- Cohesion/Coupling

3. Concurrency
- Identification of Threads of control

4. Hardware/ Software Mapping
- Special purpose
- Buy or Build Trade-off
- Allocation
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5. Data Management
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8. Boundary Conditions
- Initialization
- Termination
- Failure

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System Design Activities (continue)

- Hardware/Software Mapping
- Persistent Data Management
- Global Resource Handling and Access Control
- Software Control
- Boundary Conditions

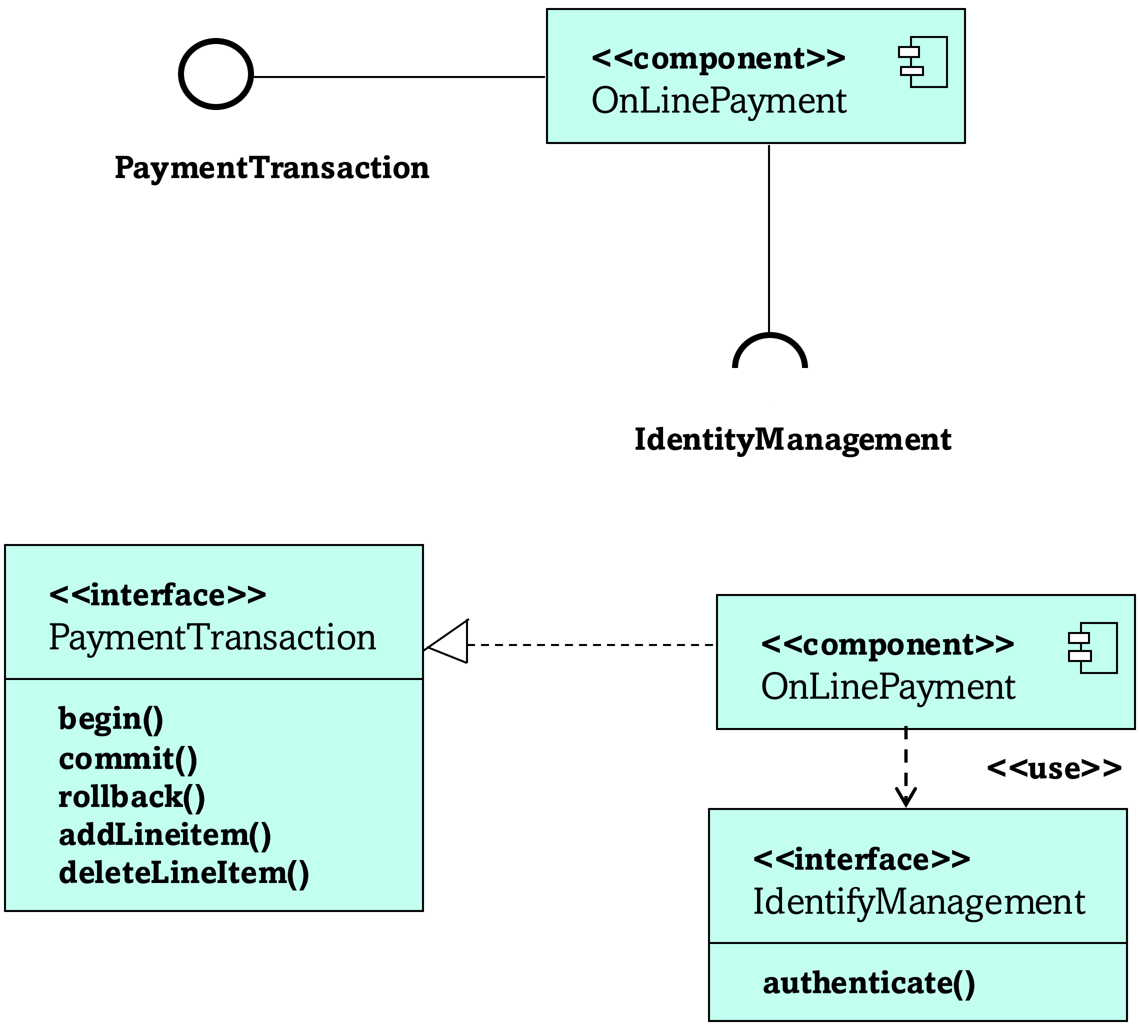
Hardware/Software Mapping

- This activity addresses two questions:
  - How shall we realize the subsystems?
    - Hardware or Software?
  - How is the object model mapped on the chosen hardware & software?
    - Mapping Objects onto Reality: Processor, Memory, Input/Output
    - Mapping Associations onto Reality: Connectivity
- Much of the difficulty of designing a system comes from meeting externally-imposed hardware and software constraints.
  - Certain tasks have to be at specific locations

Component and Deployment diagrams

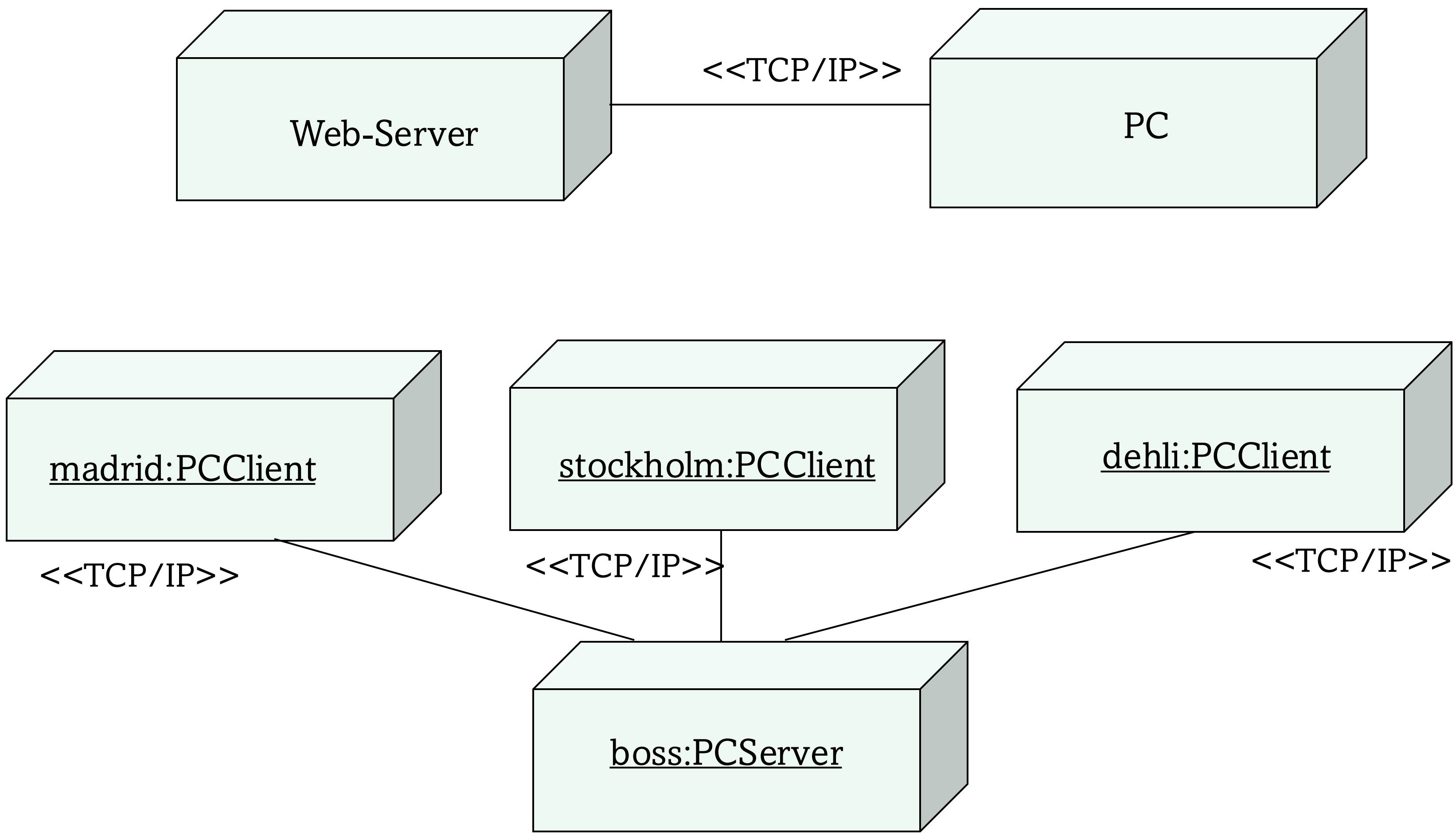
- Models for physical implementation of the system
- Show system components, their structure and dependencies and how they are deployed on computer nodes
- Two kinds of diagrams:
  - component diagrams
  - deployment diagrams
- Component diagrams show structure of components, including their interface and implementation dependencies
- Deployment diagrams show the runtime deployment of the system on computer nodes

Component Diagrams (component interface)



Adopted from Shaum

Deployment diagrams



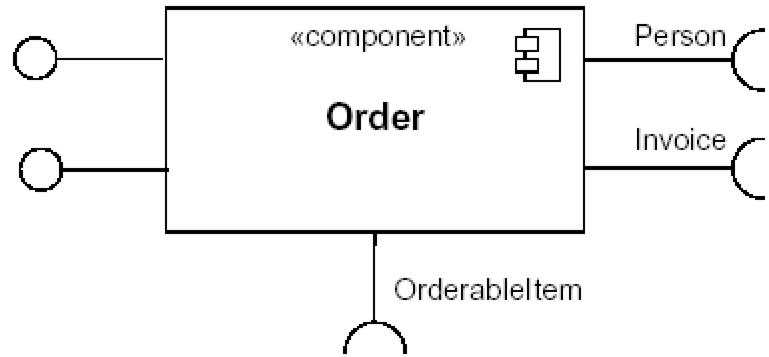
Adopted from Shaum

Drawing Hardware/Software Mappings in UML

- System design must model static and dynamic structures:
  - Component Diagrams for static structures
    - show the structure at design time or compilation time
  - Deployment Diagram for dynamic structures
    - show the structure of the run-time system

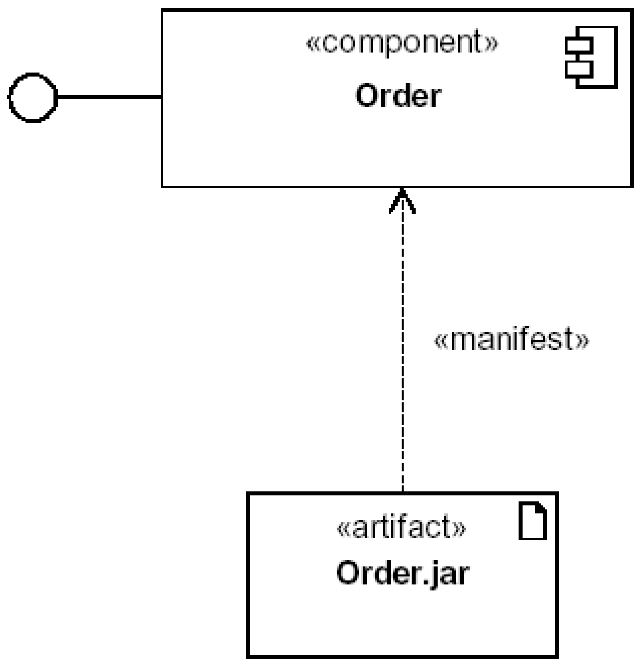
Deployment Diagrams (artifact)

- Component

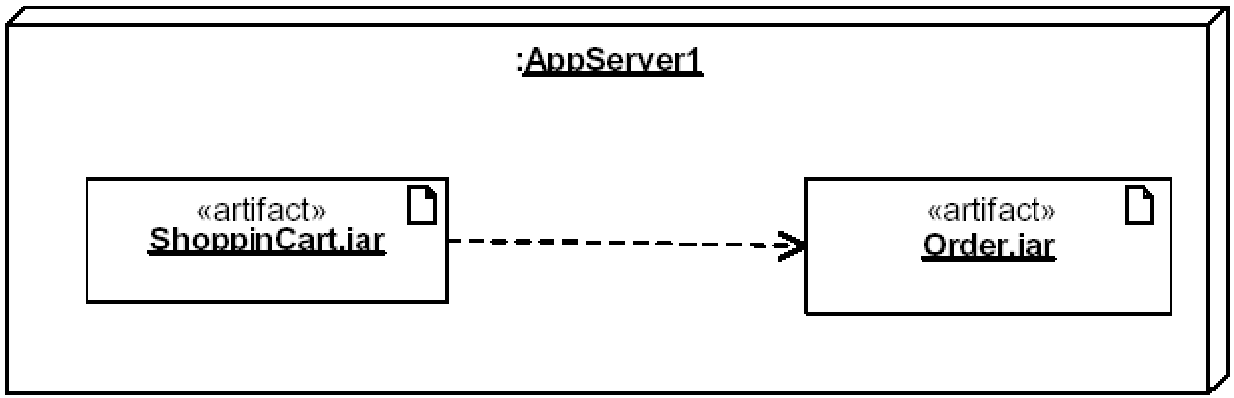


- Artifact - Artifacts represent concrete elements in the physical world (physical piece of information) that are the result of a development process.

Manifestation relationship between artifacts and components



Location of Artifacts on the node



Data Management

- Some objects in the models need to be persistent
- A persistent object can be realized with one of the following
  - Files
    - Cheap, simple, permanent storage
    - Low level (Read, Write)
    - Applications must add code to provide suitable level of abstraction
  - Database
    - Powerful, easy to port
    - Supports multiple writers and readers

File or DB?

When should you choose flat files?

- Voluminous data (e.g., images)
- Temporary data (e.g., core file)
- Low information density (e.g., archival files, history logs)

When should you choose a database?

- Concurrent accesses
- Access at finer levels of detail
- Multiple platforms or applications for the same data

When should you choose a relational database?

- Complex queries over attributes
- Large data set

Adopted from Bernd Bruegge & Allen H. Dutoit Object-Oriented Software Engineering: Using UML, Patterns, and Java

Global Resource Handling

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

Access Matrix Implementations

- Global access table: Represents explicitly every cell in the matrix as a (actor,class, operation) tuple.
  - Determining if an actor has access to a specific object requires looking up the corresponding tuple. If no such tuple is found, access is denied.
- Access control list associates a list of (actor, operation) pairs with each class to be accessed.
  - Every time an object is accessed, its access list is checked for the corresponding actor and operation.
  - Example: guest list for a party.
- A 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.
  - Example: An invitation card for a party.
- Which is the right implementation?

Decide on Software Control

Choose implicit control (non-procedural, declarative languages)
- Rule-based systems
- Logic programming

Choose explicit control (procedural languages):

- Procedure-driven control
  - Control resides within program code. Operations wait for input whenever they need data from an actor.
    - Example: Main program calling procedures of subsystems.
  - Simple, easy to build, hard to maintain (high recompilation costs)
- Event-driven control
  - Control resides within a dispatcher calling functions via callbacks.
  - Very flexible, good for the design of graphical user interfaces, easy to extend

Centralized vs. Decentralized Designs

- 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 sequence diagram looks more like a fork: Centralized design
    - The sequence diagram looks more like a stair: Decentralized design
- Centralized Design
  - One control object or subsystem ("spider") controls everything
    - Pro: Change in the control structure is very easy
    - Cons: The single control object is a possible performance bottleneck
- Decentralized Design
  - Not a single object is in control, control is distributed, that means, there is more than one control object
    - Cons: The responsibility is spread out – changes are not obvious
    - Pro: Fits nicely into object-oriented development

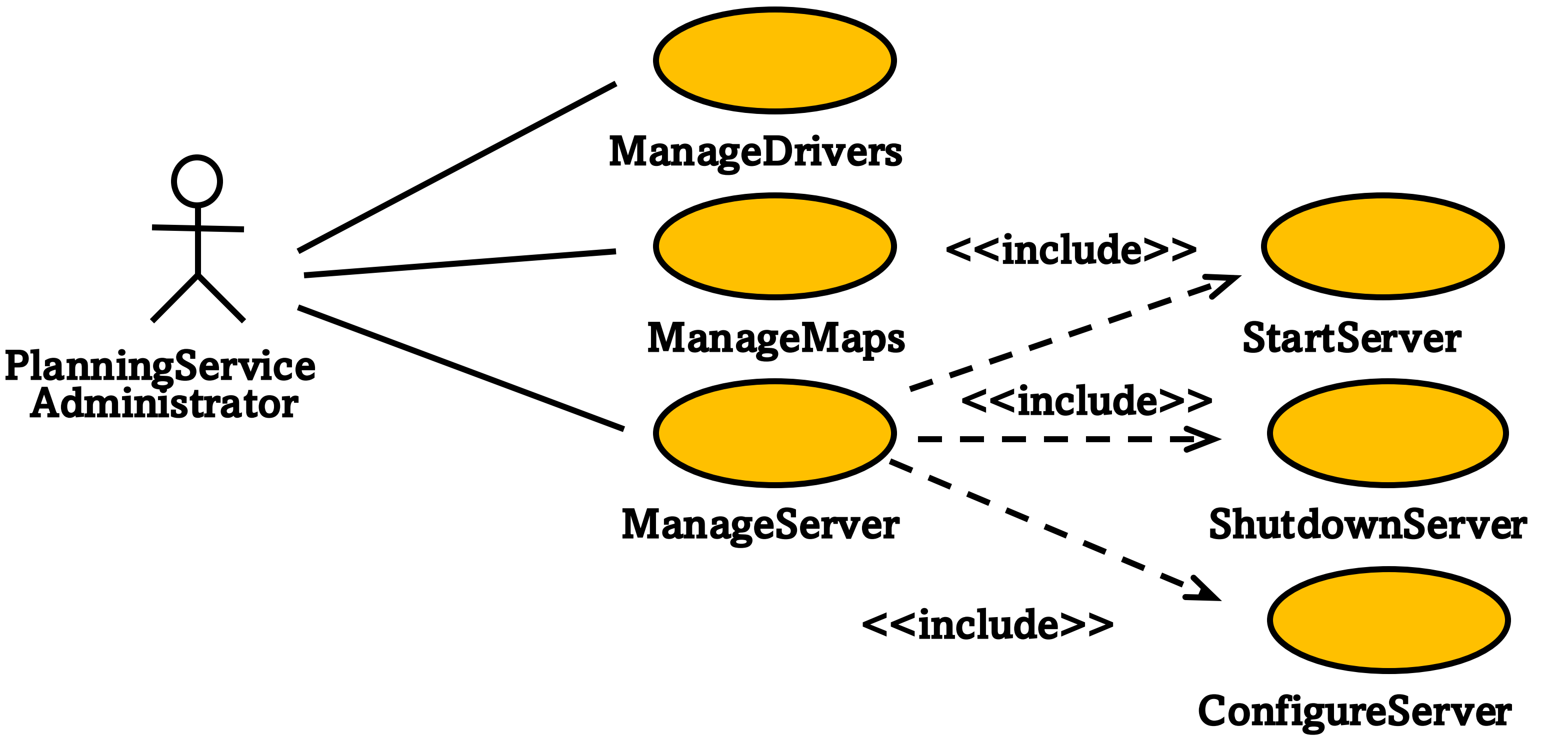
Boundary Condition

- Initialization
  - How does the system start up?
    - 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?
    - How does it present itself to the user?
- Termination
  - Are single subsystems allowed to terminate?
  - Are other subsystems notified if a single subsystem terminates?
  - How are local updates communicated to the database?
- Failure
  - How does the system behave when a node or communication link fails? Are there backup communication links?
  - How does the system recover from failure? Is this different from initialization?

Modeling Boundary Conditions

- Boundary conditions are best modeled as use cases with actors and objects.
- 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 subystem or component, failure of a subsystem or component

ManageServer Use Case



Adopted from Bernd Bruegge & Allen H. Dutoit Object-Oriented Software Engineering: Using UML, Patterns, and Java

Summary

In this lecture, we reviewed the activities of system design :

- Design goals identification
- System decomposition
- Concurrency identification
- Hardware/Software mapping
- Persistent data management
- Global resource handling
- Software control selection
- Boundary conditions

Each of these activities revises the subsystem decomposition to address a specific issue. Once these activities are completed, the interface of the subsystems can be defined.

Next lecture

- Object design

Chapters 8 & 9