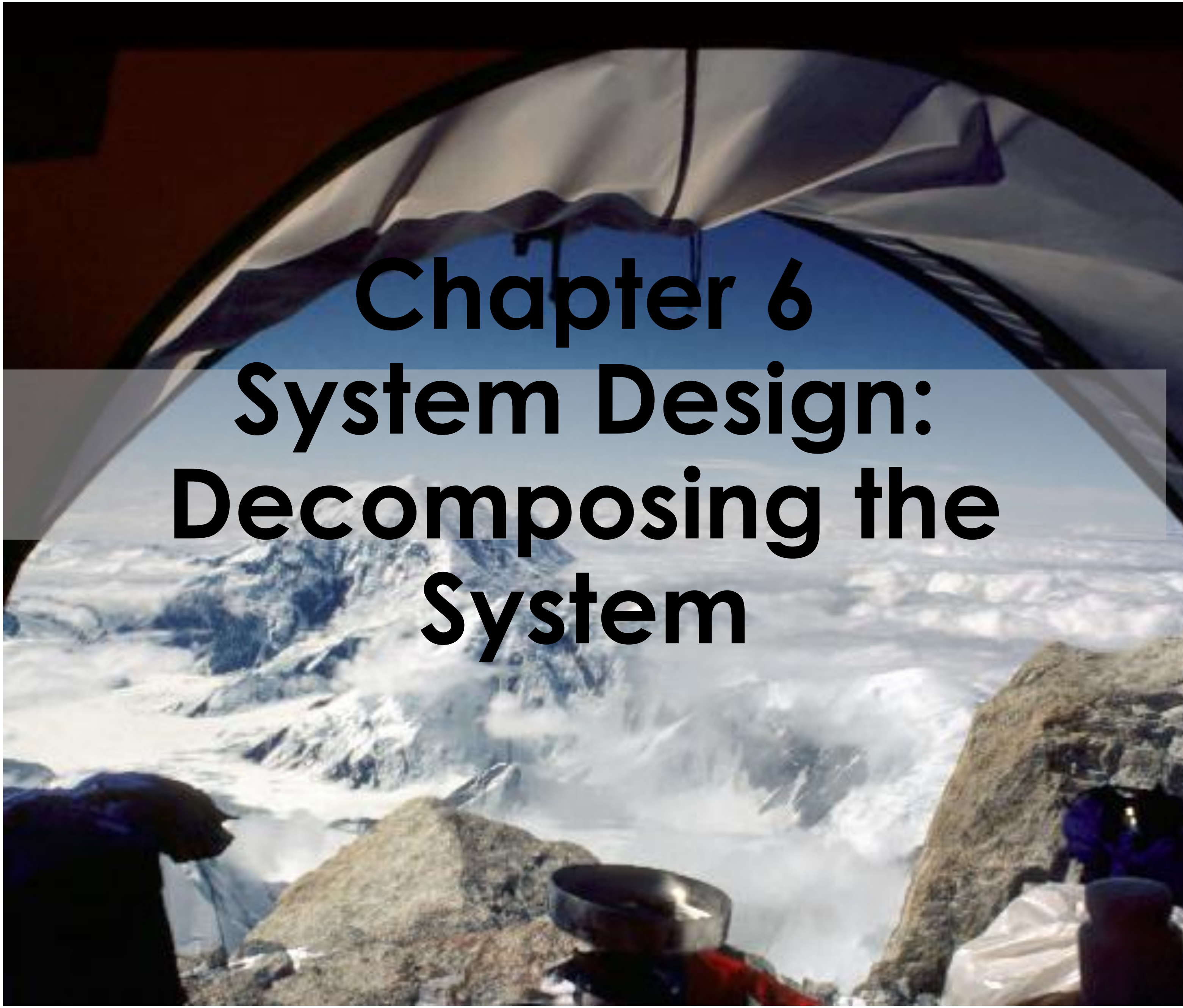
Object-Oriented Software Engineering
Using UML, Patterns, and Java



Chapter 6
System Design: Decomposing the System

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

Why is Design so Difficult?

- *Analysis:* Focuses on the application domain
- *Design:* Focuses on the solution domain
  - Design knowledge is a moving target
  - The reasons for design decisions are changing very rapidly
    - Halftime knowledge in software engineering: About 3-5 years
    - Cost of hardware rapidly sinking
- "Design window":
  - Time in which design decisions have to be made

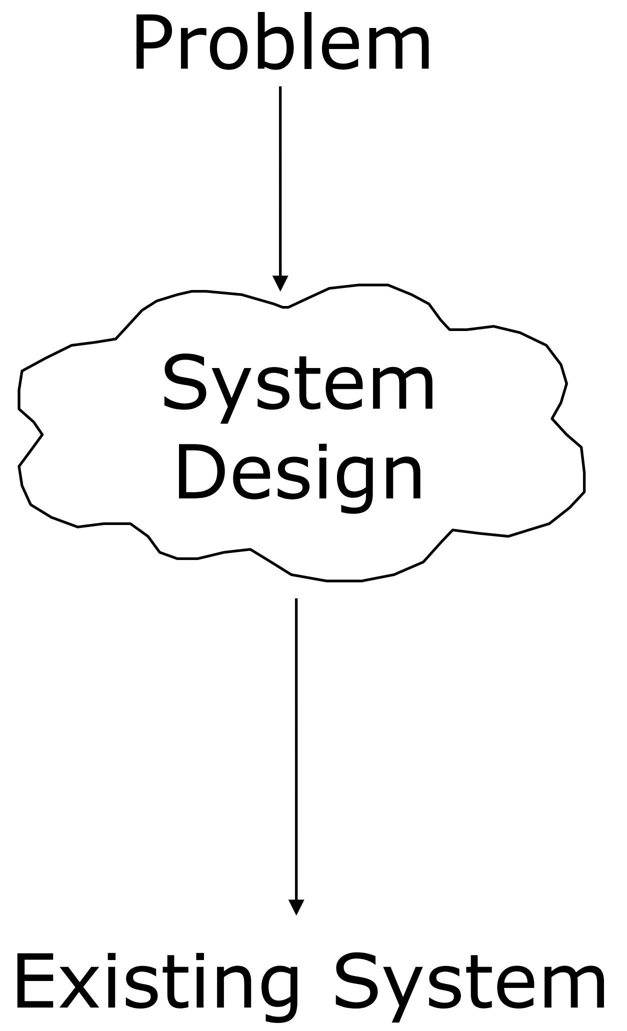
The Scope of System Design

- Bridge the gap
  - between a problem and an existing system in a manageable way
- How?
- Use Divide & Conquer:

  1) Identify design goals

  2) Model the new system design as a set of subsystems

  3-8) Address the major design goals.



System Design: Eight Issues

System Design

1. Identify Design Goals
- Additional NFRs
- Trade-offs

2. Subsystem Decomposition
- Layers vs Partitions
- Coherence & Coupling

3. Identify Concurrency
- Identification of Parallelism (Processes, Threads)

4. Hardware/ Software Mapping
- Identification of Nodes
- Special Purpose Systems
- Buy vs Build
- Network Connectivity

5. Persistent Data Management
- Storing Persistent Objects
- Filesystem vs Database

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

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

8. Boundary Conditions
- Initialization
- Termination
- Failure

How the Analysis Models influence System Design

- Nonfunctional Requirements
  => Definition of Design Goals
- Functional model
  => Subsystem Decomposition
- Object model
  => Hardware/Software Mapping, Persistent Data Management
- Dynamic model
  => Identification of Concurrency, Global Resource Handling, Software Control
- Finally: Subsystem Decomposition
  => Boundary conditions

From Analysis to System Design

Nonfunctional Requirements

1. Design Goals
- Definition
- Trade-offs

Functional Model

2. System Decomposition
- Layers vs Partitions
- Coherence/Coupling

Dynamic Model

3. Concurrency
- Identification of Threads

Object Model

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

5. Data Management
- Persistent Objects
- Filesystem vs Database

Functional Model

8. Boundary Conditions
- Initialization
- Termination
- Failure

Dynamic Model

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

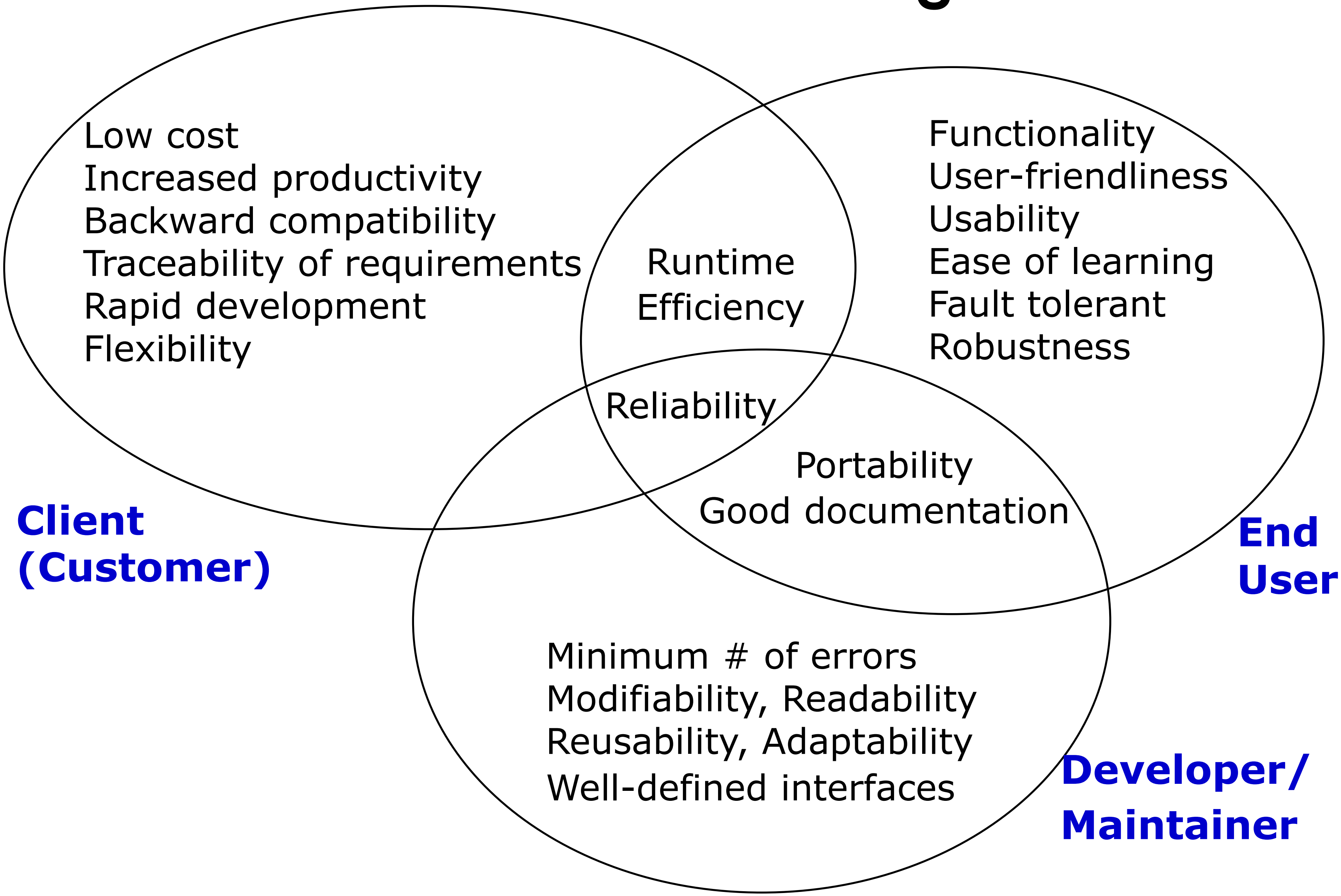
6. Global Resource Handlung
- Access Control List vs Capabilities
- Security

Example of 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 number of errors
Readability
Ease of learning
Ease of remembering
Ease of use
Increased productivity
Low-cost
Flexibility

Stakeholders have different Design Goals



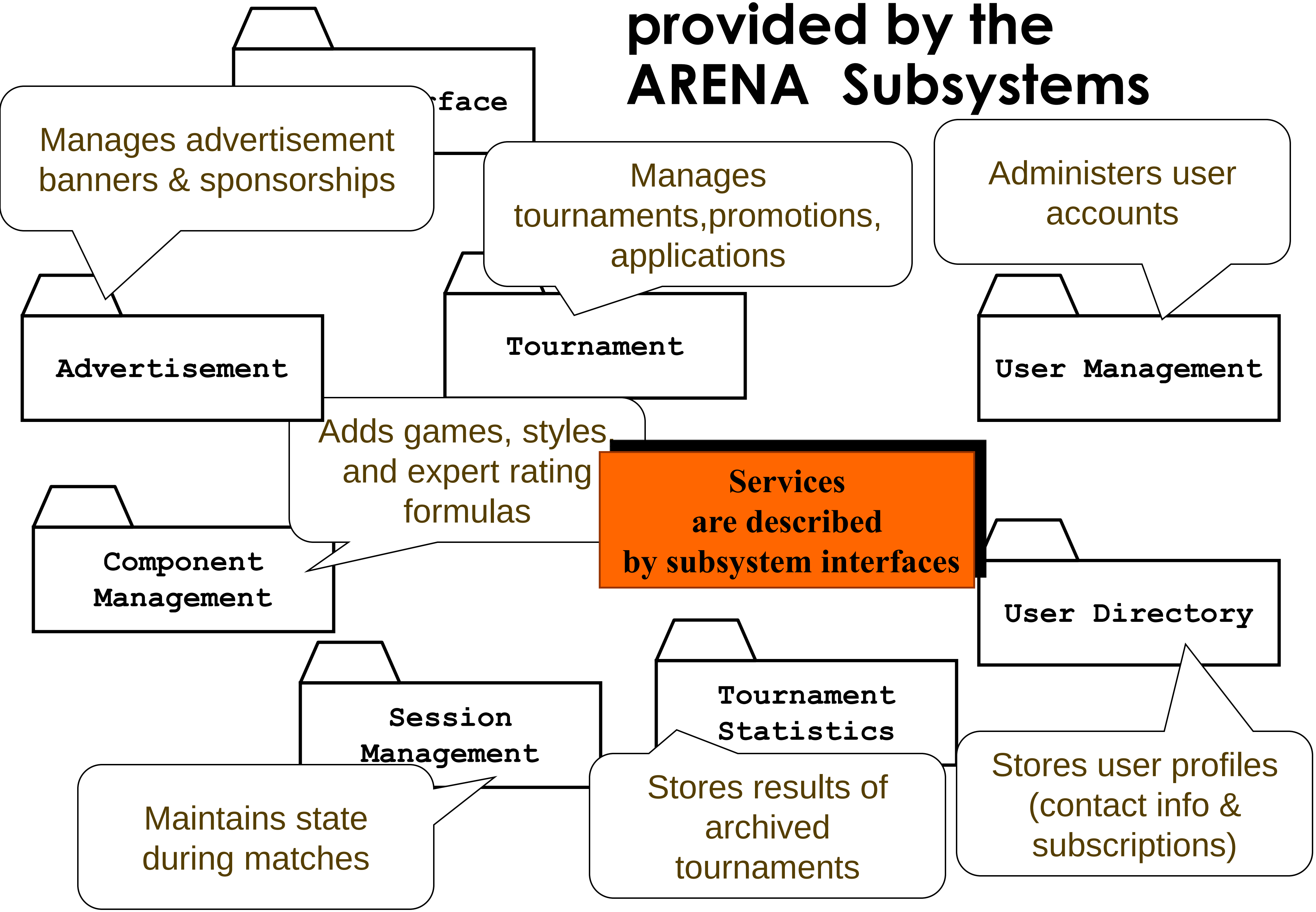
Typical Design Trade-offs

- Functionality v. Usability
- Cost v. Robustness
- Efficiency v. Portability
- Rapid development v. Functionality
- Cost v. Reusability
- Backward Compatibility v. Readability

Subsystem Decomposition

- Subsystem
  - Collection of classes, associations, operations, events and constraints that are closely interrelated with each other
  - The objects and classes from the object model are the "seeds" for the subsystems
  - In UML subsystems are modeled as packages
- Service
  - A set of named operations that share a common purpose
  - The origin ("seed") for services are the use cases from the functional model
- Services are defined during system design

Example: Services provided by the ARENA Subsystems



Subsystem Interfaces vs API

- Subsystem interface: Set of fully typed UML operations
  - Specifies the interaction and information flow from and to subsystem boundaries, but not inside the subsystem
  - Refinement of service, should be well-defined and small
  - *Subsystem interfaces are defined during object design*
- Application programmer's interface (API)
  - The API is the specification of the subsystem interface in a specific programming language
  - *APIs are defined during implementation*
- The terms subsystem interface and API are often confused with each other
  - *The term API should not be used during system design and object design, but only during implementation*

Example: Notification subsystem

- Service provided by Notification Subsystem
  - LookupChannel()
  - SubscribeToChannel()
  - SendNotice()
  - UnscubscribeFromChannel()
- Subsystem Interface of Notification Subsystem
  - Set of fully typed UML operations
- API of Notification Subsystem
  - Implementation in Java

Subsystem Interface Object

- Good design: The subsystem interface object describes *all* the services of the subsystem interface
- Subsystem Interface Object
  - The set of public operations provided by a subsystem

    Subsystem Interface Objects can be realized with the Façade pattern

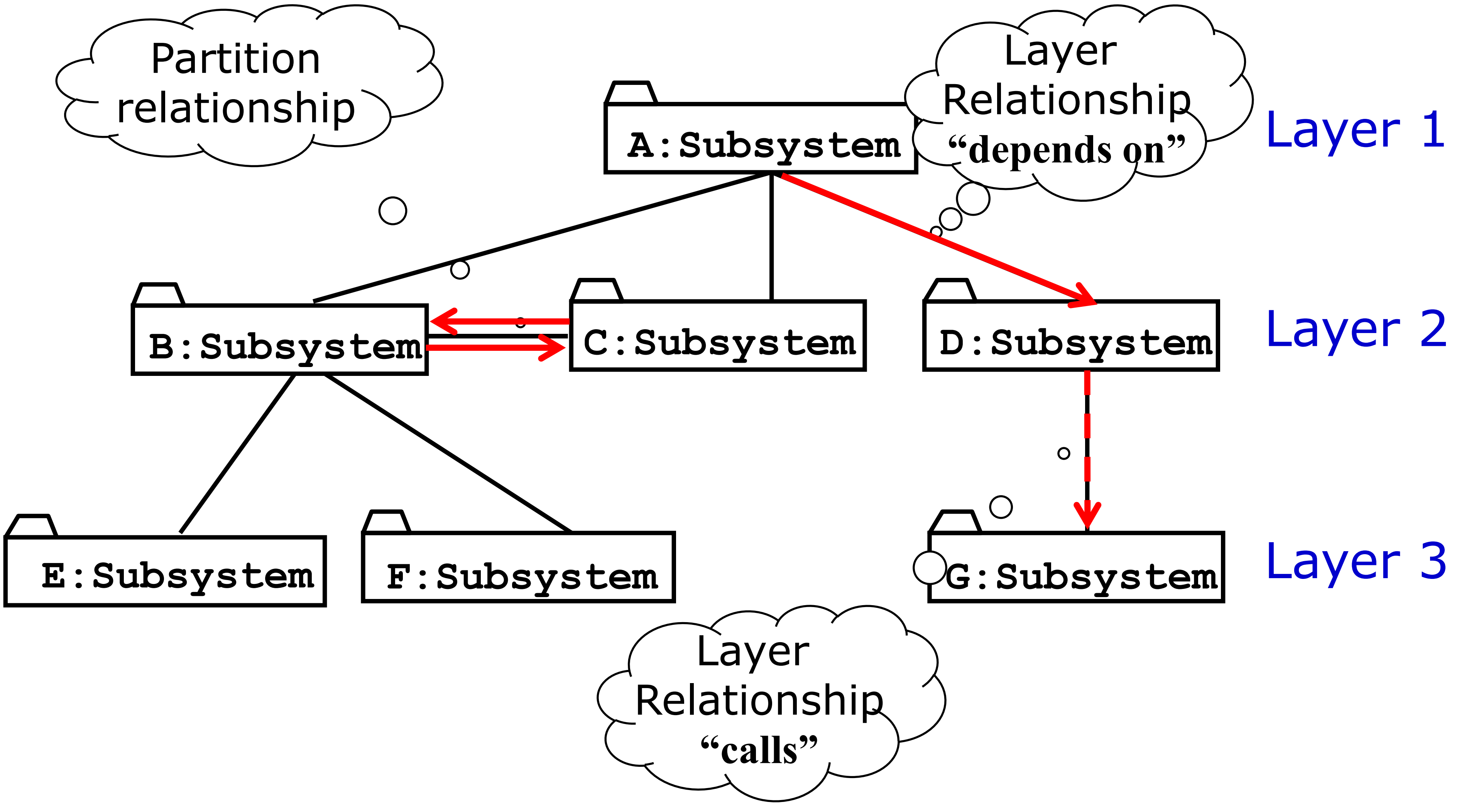
Properties of Subsystems: Layers and Partitions

- A layer is a subsystem that provides a service to another subsystem with the following restrictions:
  - A layer only depends on services from lower layers
  - A layer has no knowledge of higher layers
- A layer can be divided horizontally into several independent subsystems called partitions
  - Partitions provide services to other partitions on the same layer
  - Partitions are also called “weakly coupled” subsystems

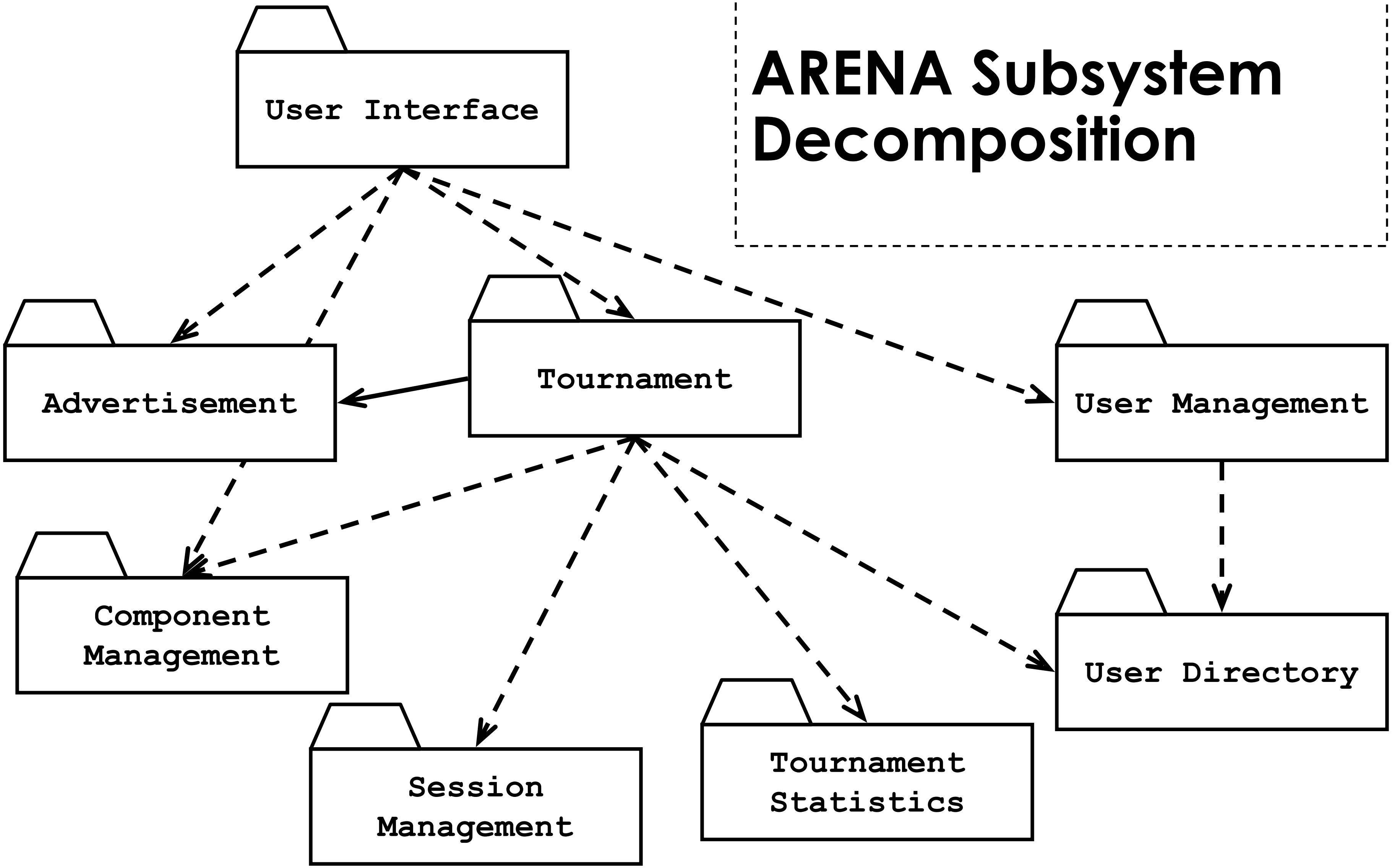
Relationships between Subsystems

- Two major types of Layer relationships
  - Layer A “depends on” Layer B (compile time dependency)
    - Example: Build dependencies
  - Layer A “calls” Layer B (runtime dependency)
    - Example: A web browser calls a web server
- Partition relationship
  - The subsystems have mutual knowledge about each other
    - A calls services in B; B calls services in A (Peer-to-Peer)
- UML convention
  - Runtime dependencies are associations with dashed lines
  - Compile time dependencies are associations with solid lines.

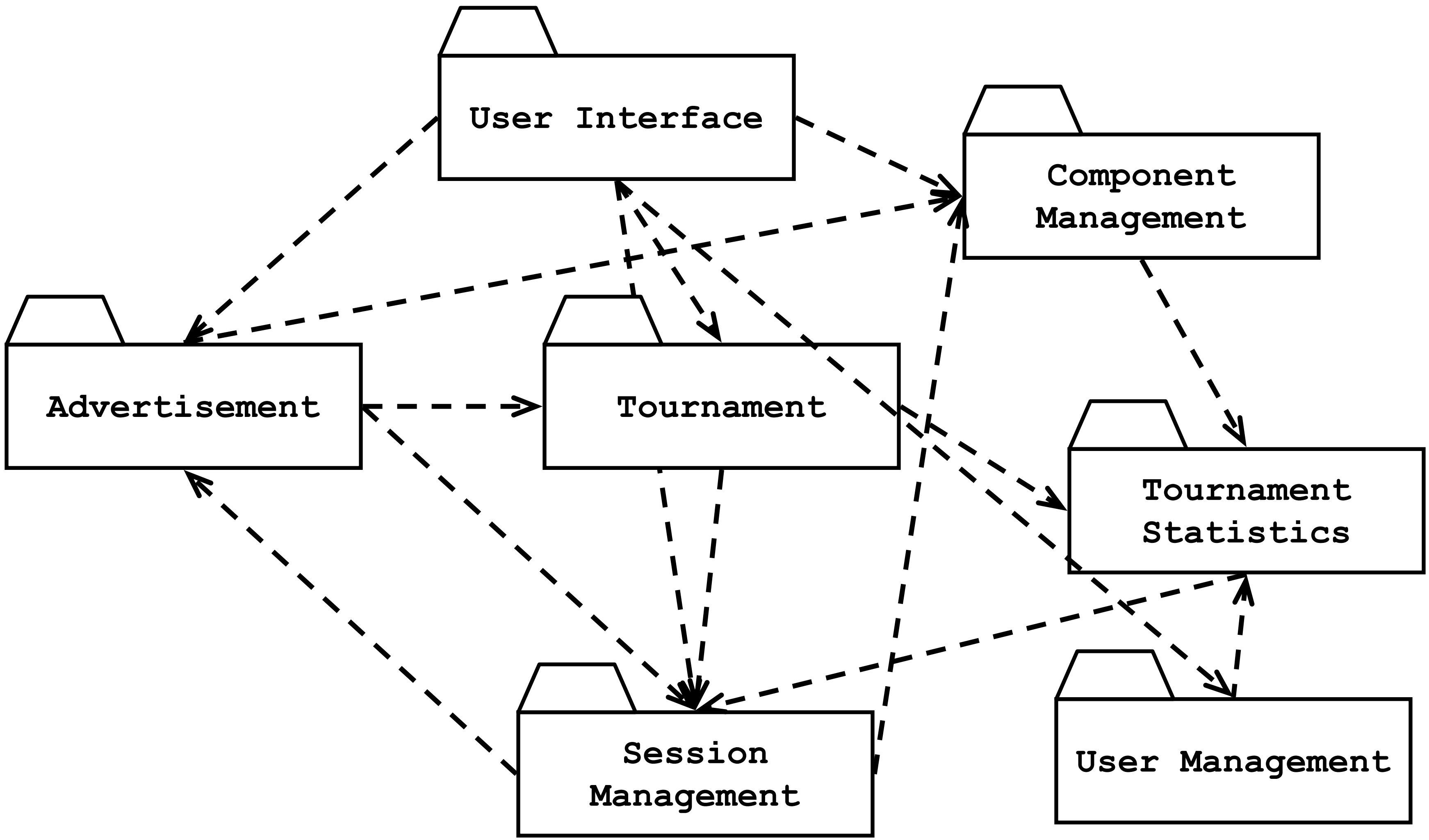
Example of a Subsystem Decomposition



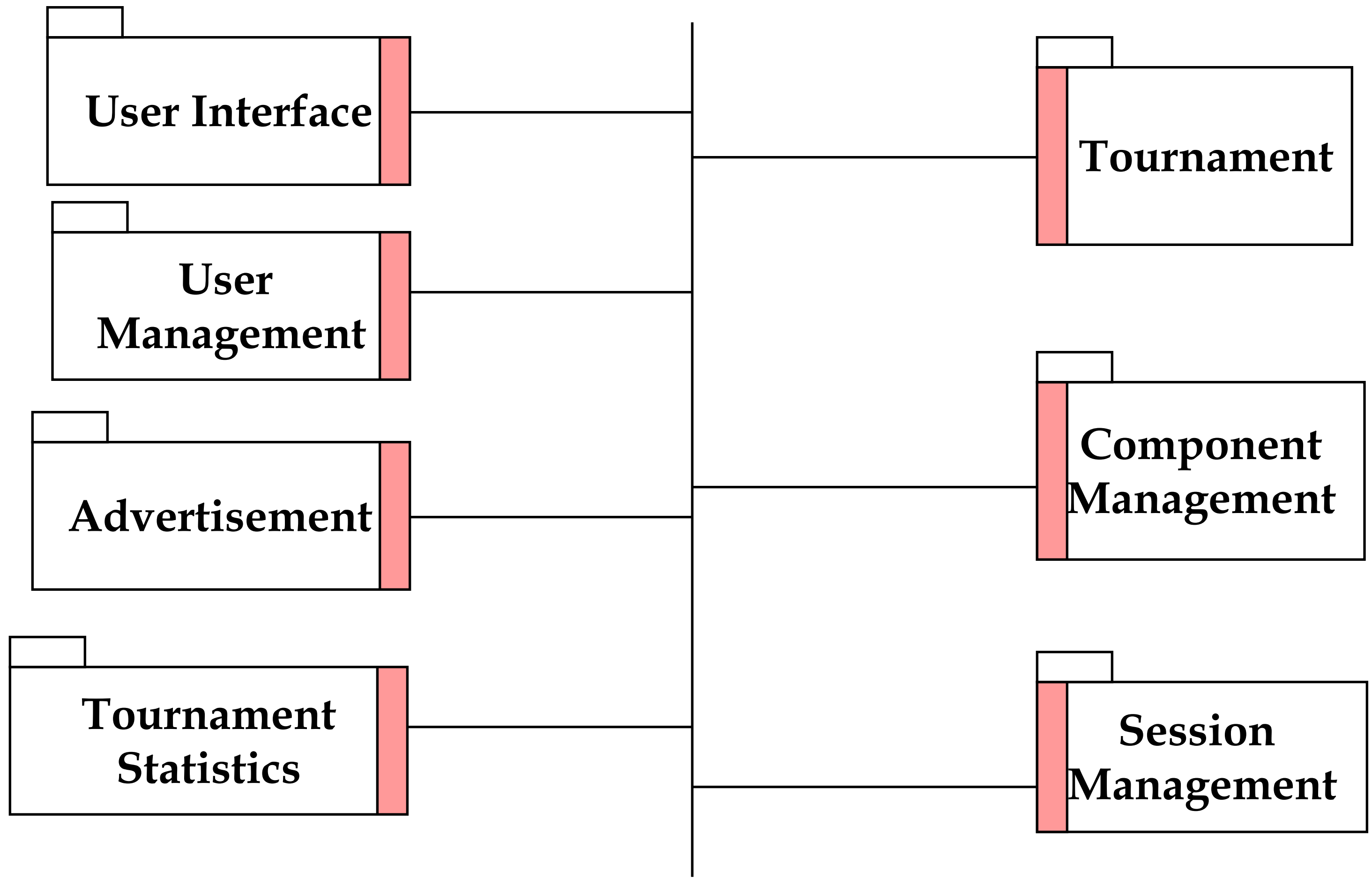
ARENA Subsystem Decomposition



Example of a Bad Subsystem Decomposition



Good Design: The System as set of Interface Objects



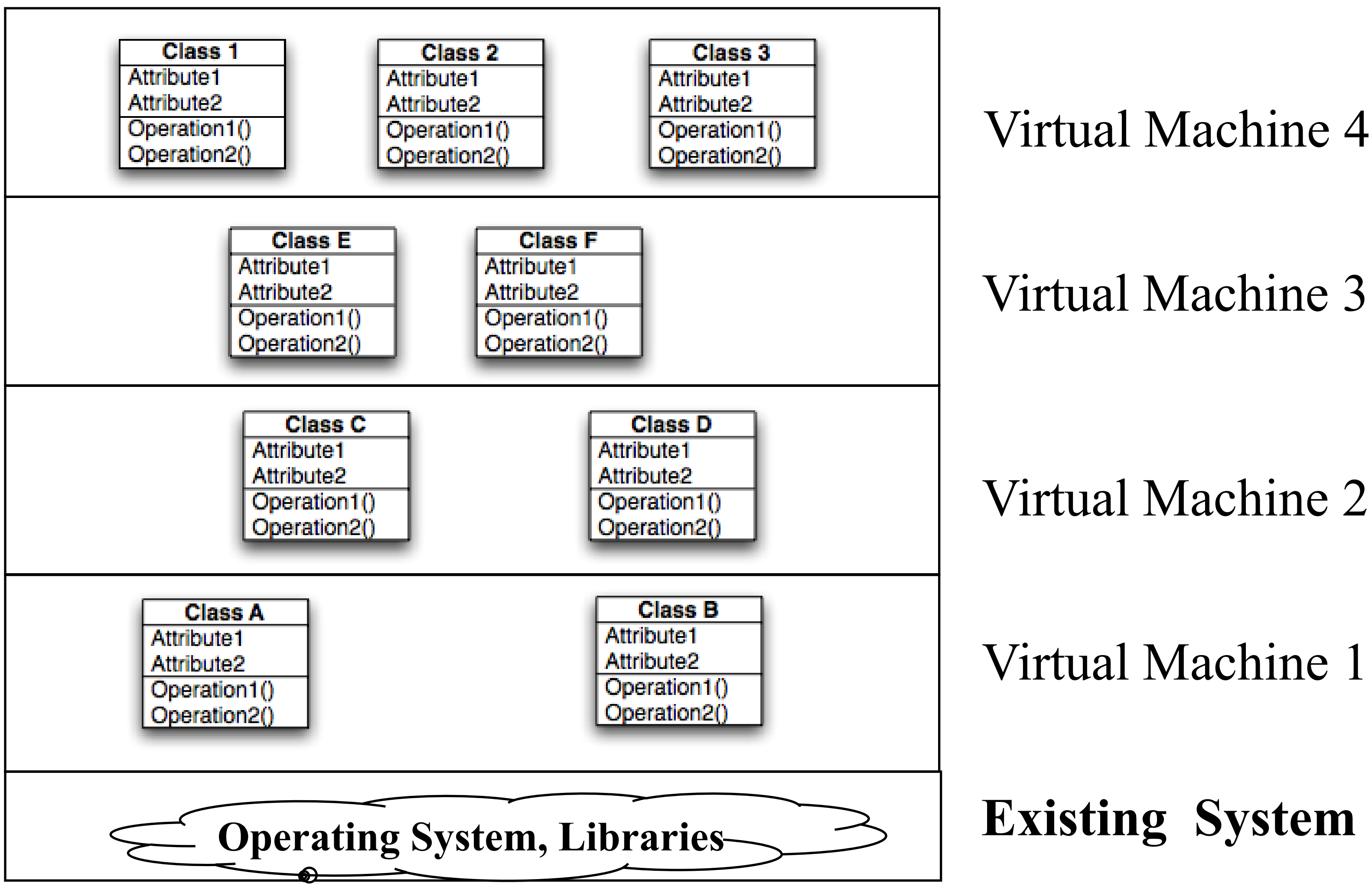
Subsystem Interface Objects

Virtual Machine

- A virtual machine is a subsystem connected to higher and lower level virtual machines by "provides services for" associations
- A virtual machine is an abstraction that provides a set of attributes and operations
- The terms layer and virtual machine can be used interchangeably
  - Also sometimes called “level of abstraction”.

Building Systems as a Set of Virtual Machines

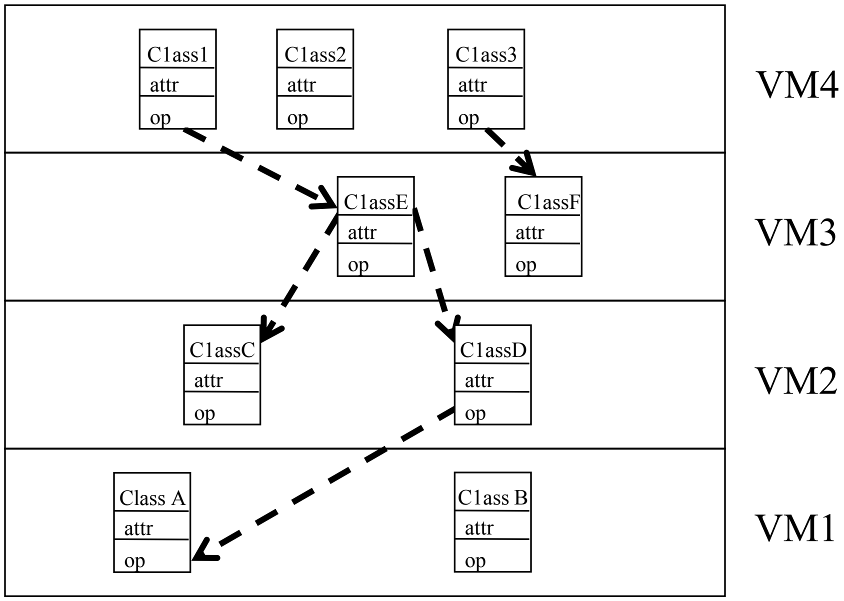
A system is a hierarchy of virtual machines, each using language primitives offered by the lower machines



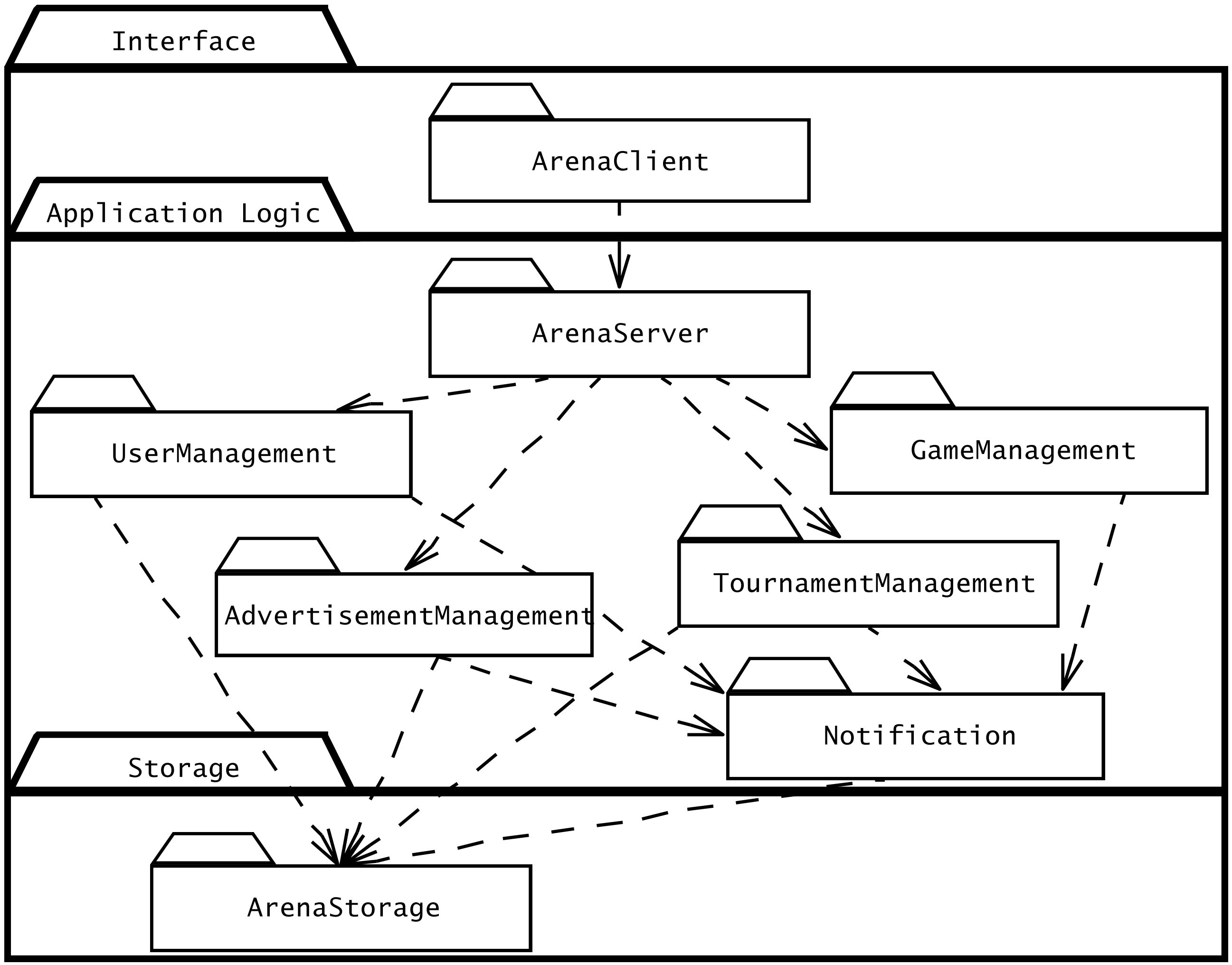
Closed Architecture (Opaque Layering)

- Each virtual machine can only call operations from the layer below

Design goals: Maintainability, flexibility.



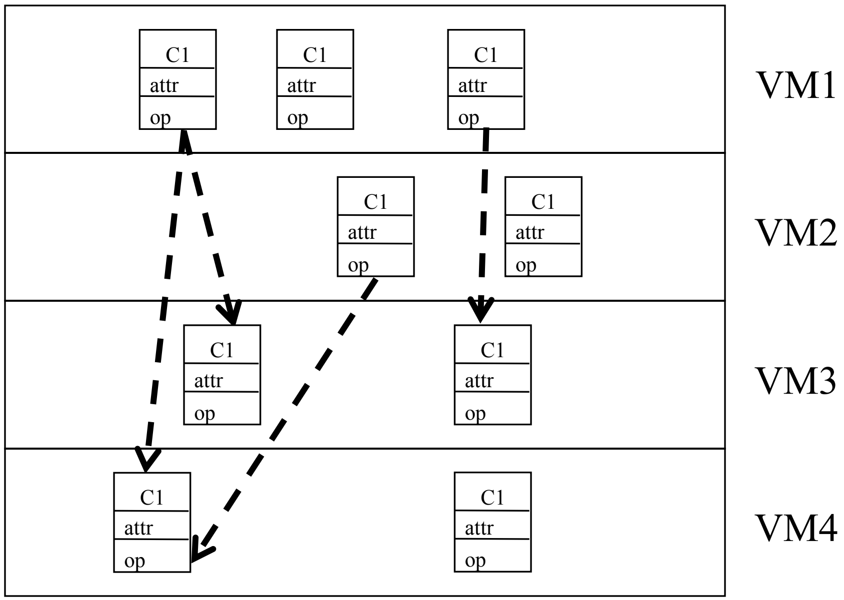
Opaque Layering in ARENA



Open Architecture (Transparent Layering)

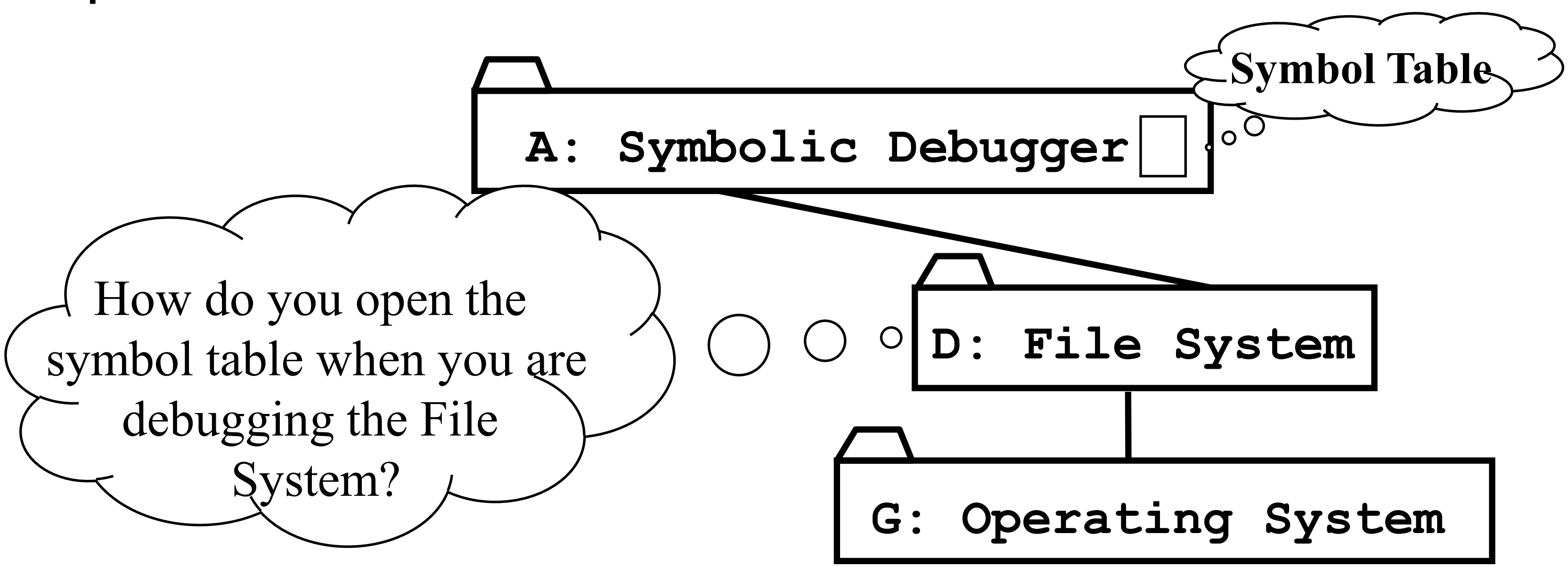
- Each virtual machine can call operations from any layer below

Design goal:
Runtime efficiency



Properties of Layered Systems

- Layered systems are hierarchical. This is a desirable design, because hierarchy reduces complexity
- Closed architectures are more portable
- Open architectures are more efficient
- Layered systems often have a chicken and egg problem



Coupling and Coherence of Subsystems

- Goal: Reduce system complexity while allowing change
- Coherence measures dependency among classes
  - High coherence: The classes in the subsystem perform similar tasks and are related to each other via many associations
  - Low coherence: Lots of miscellaneous and auxiliary classes, almost no associations
- Coupling measures dependency among subsystems
  - High coupling: Changes to one subsystem will have high impact on the other subsystem
  - Low coupling: A change in one subsystem does not affect any other subsystem.

Coupling and Coherence of Subsystems

Good Design

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Architectural Style vs Architecture

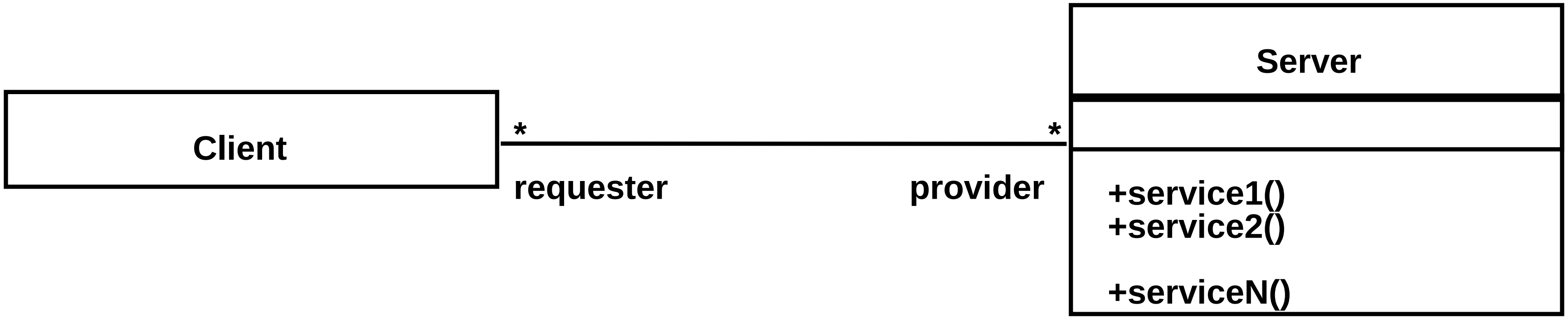
- Subsystem decomposition: Identification of subsystems, services, and their association to each other (hierarchical, peer-to-peer, etc)
- Architectural Style: A pattern for a subsystem decomposition
- Software Architecture: Instance of an architectural style

Examples of Architectural Styles

- Client/Server
- Peer-To-Peer
- Repository
- Model/View/Controller
- Three-tier, Four-tier Architecture
- Service-Oriented Architecture (SOA)
- Pipes and Filters

Client/Server Architectural Style

- One or many servers provide services to instances of subsystems, called clients
- Each client calls on the server, which performs some service and returns the result
  - The clients know the *interface* of the server
  - The server does not need to know the interface of the client
- The response in general is immediate
- End users interact only with the client



Client/Server Architectures

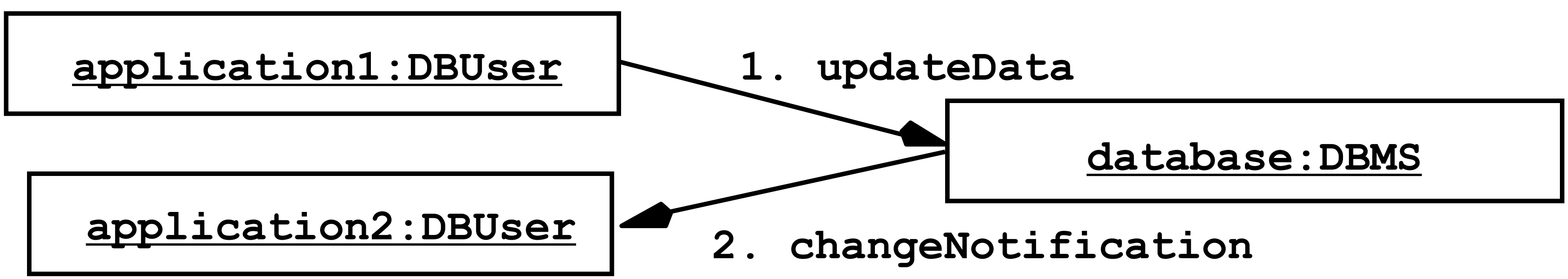
- Often used in the design of database systems
  - Front-end: User application (client)
  - Back end: Database access and manipulation (server)
- Functions performed by client:
  - Input from the user (Customized user interface)
  - Front-end processing of input data
- Functions performed by the database server:
  - Centralized data management
  - Data integrity and database consistency
  - Database security

Design Goals for Client/Server Architectures

Service Portability	Server runs on many operating systems and many networking environments
Location-Transparency	Server might itself be distributed, but provides a single "logical" service to the user
High Performance	Client optimized for interactive display-intensive tasks; Server optimized for CPU-intensive operations
Scalability	Server can handle large # of clients
Flexibility	User interface of client supports a variety of end devices (PDA, Handy, laptop, wearable computer)
Reliability	Server should be able to survive client and communication problems

Problems with Client/Server Architectures

- Client/Server systems do not provide peer-to-peer communication
- Peer-to-peer communication is often needed
- Example:
  - Database must process queries from application and should be able to send notifications to the application when data have changed

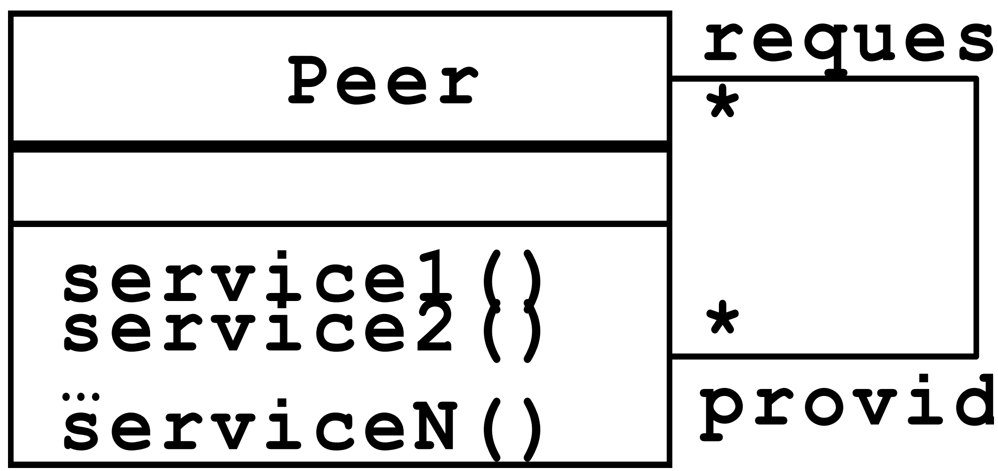


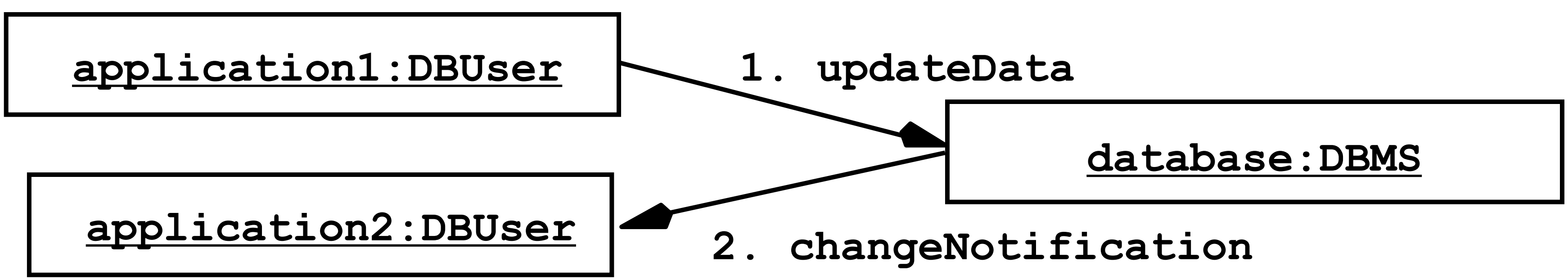
Peer-to-Peer Architectural Style

Generalization of Client/Server Architectural Style

"Clients can be servers and servers can be clients"

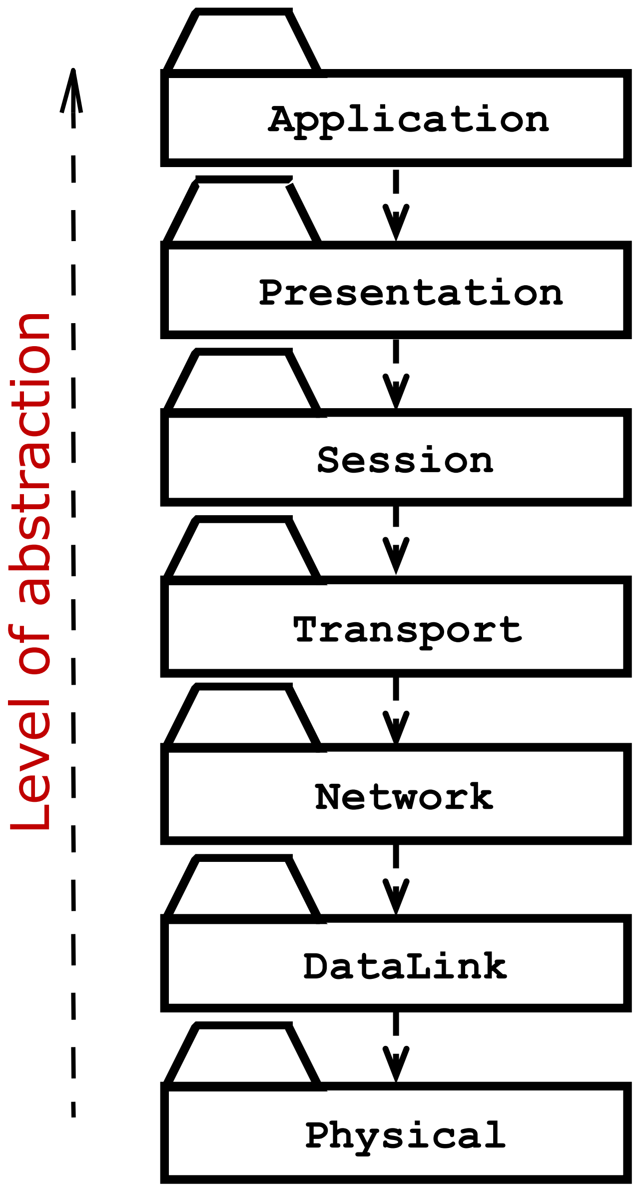
Introduction a new abstraction: Peer





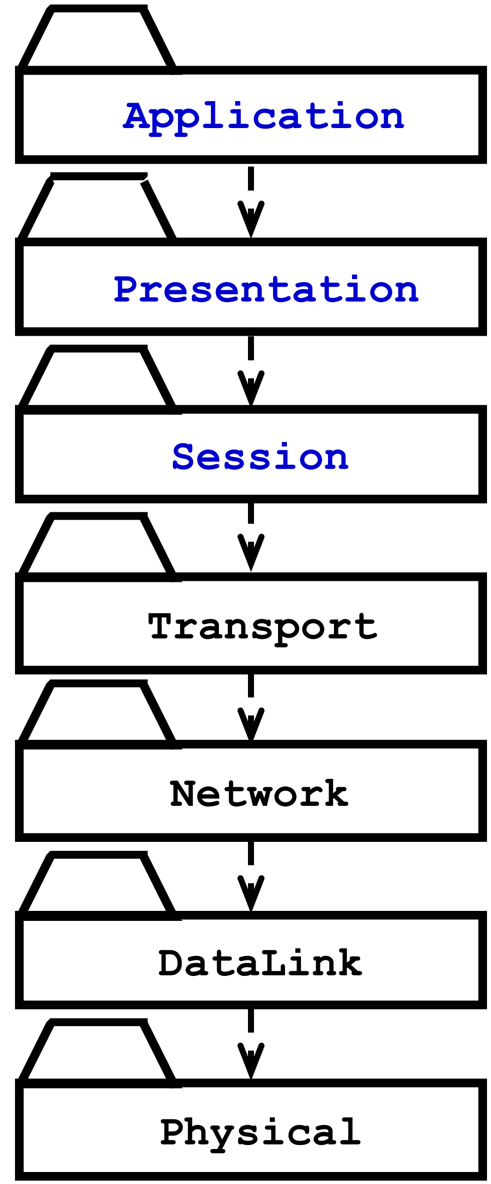
Example: Peer-to-Peer Architectural Style

- ISO's OSI Reference Model
  - **ISO = International Standard Organization**
  - **OSI = Open System Interconnection**
- Reference model which defines 7 layers and communication protocols between the layers



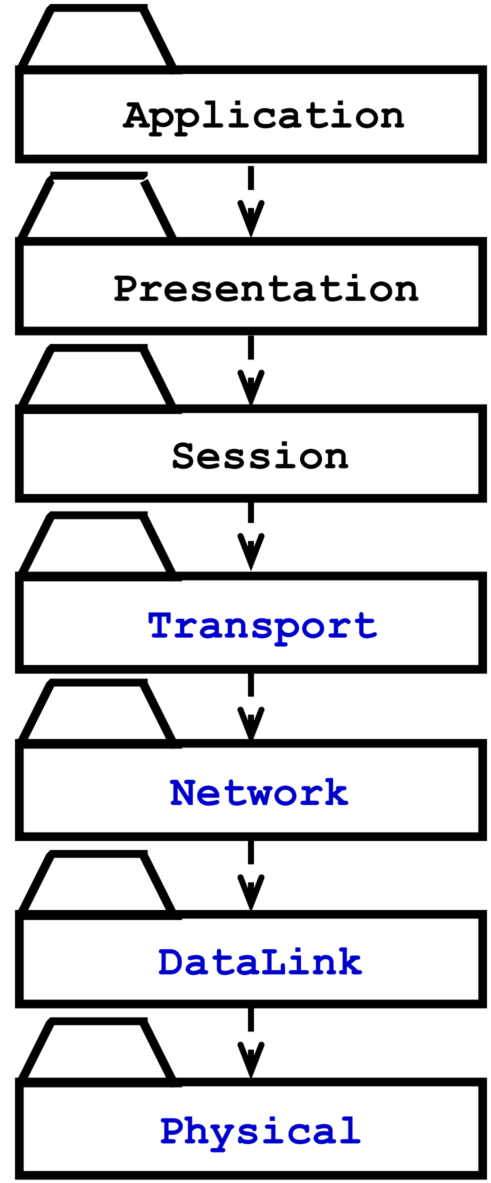
OSI Model Layers and Services

- The Application layer is the system you are building (unless you build a protocol stack)
  - The application layer is usually layered itself
- The Presentation layer performs data transformation services, such as byte swapping and encryption
- The Session layer is responsible for initializing a connection, including authentication



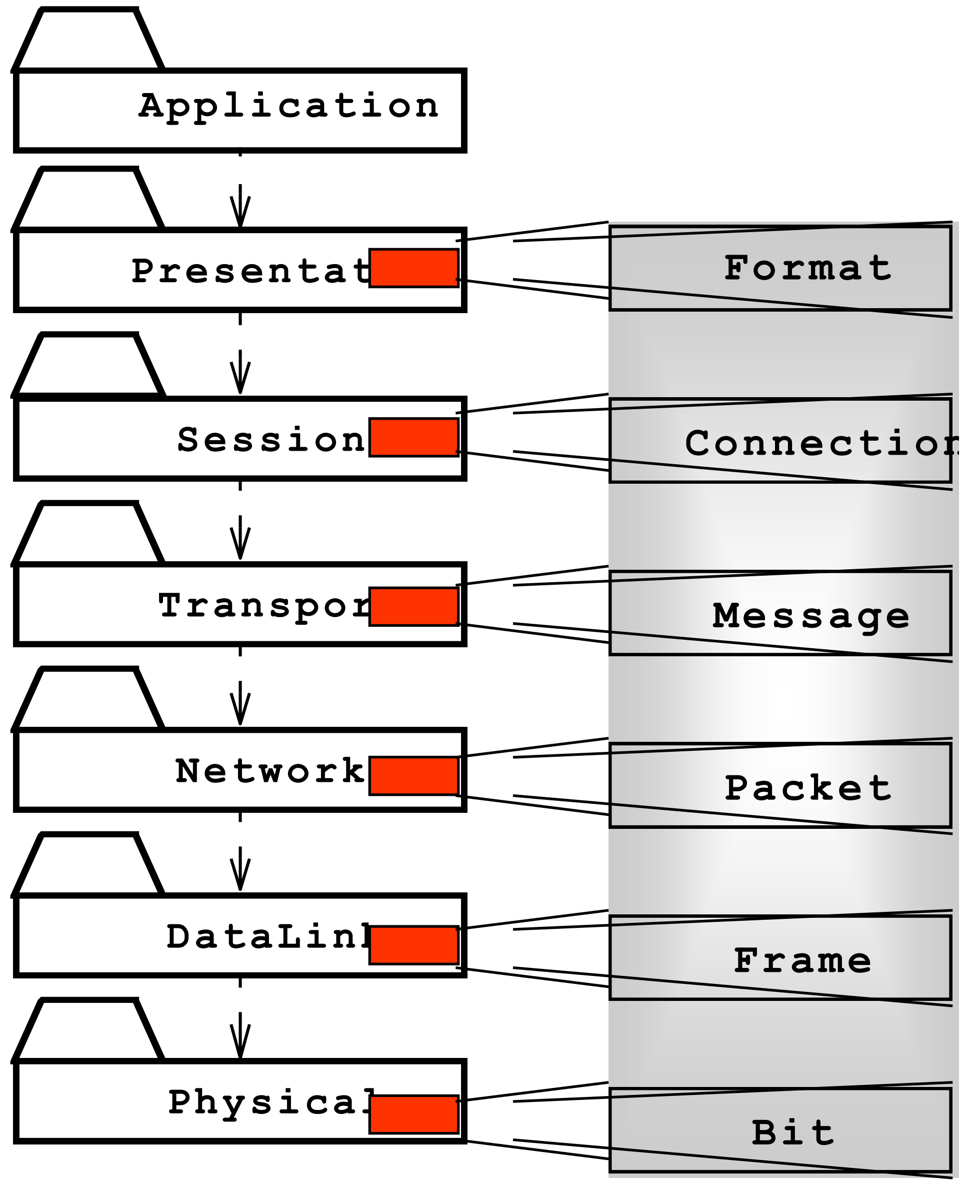
OSI Model Layers and their Services

- The Transport layer is responsible for reliably transmitting messages
  - Used by Unix programmers who transmit messages over TCP/IP sockets
- The Network layer ensures transmission and routing
  - Services: Transmit and route data within the network
- The Datalink layer models frames
  - Services: Transmit frames without error
- The Physical layer represents the hardware interface to the network
  - Services: sendBit() and receiveBit()

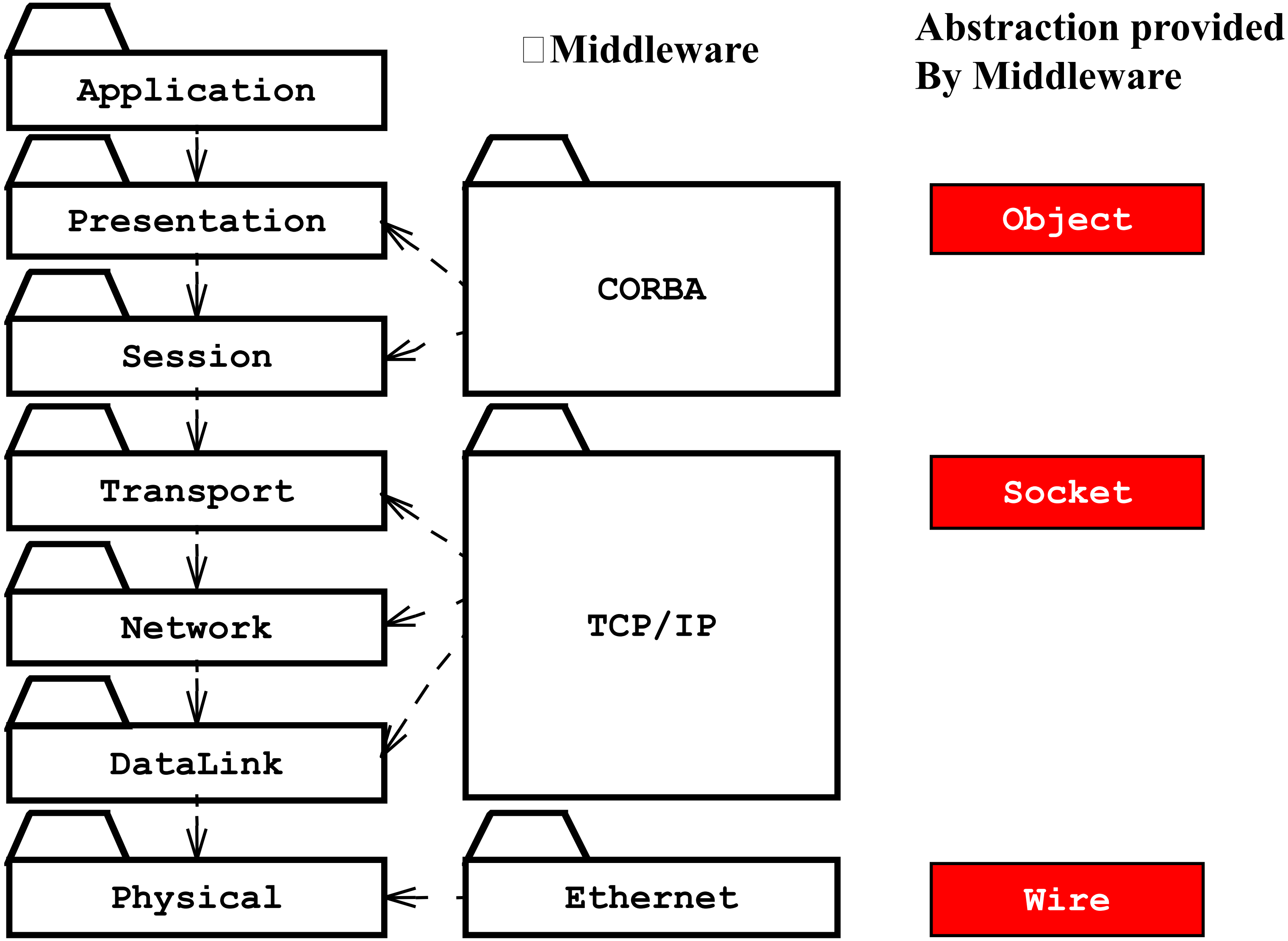


An Object-Oriented View of the OSI Model

- The OSI Model is a closed software architecture (i.e., it uses opaque layering)
- Each layer can be modeled as a UML package containing a set of classes available for the layer above

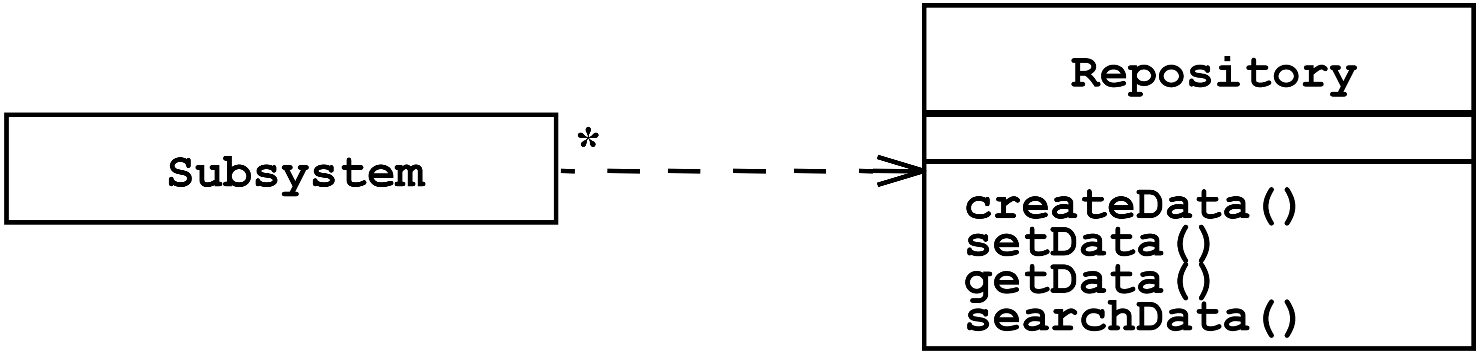


Middleware Allows Focus On Higher Layers

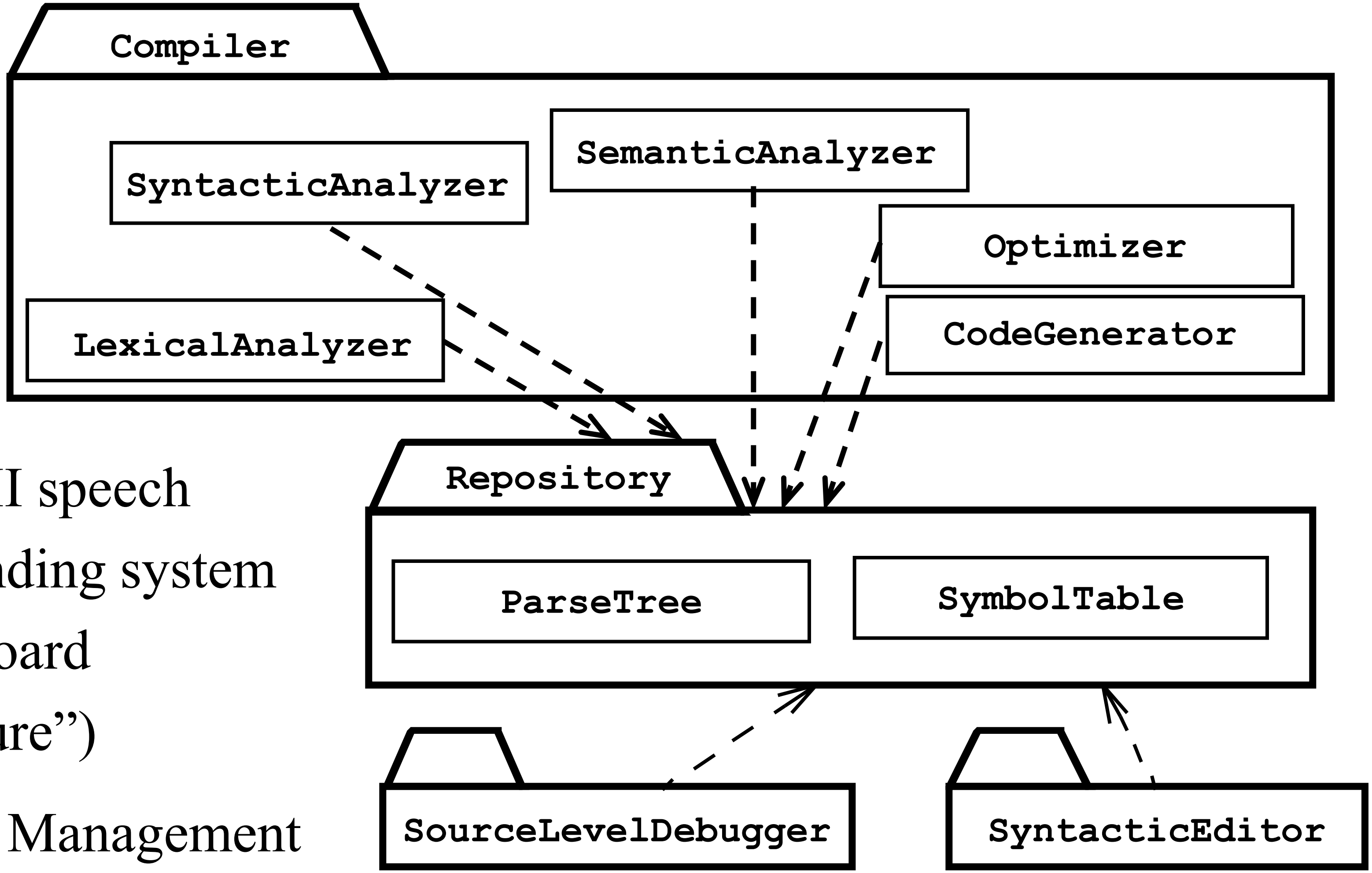


Repository Architectural Style

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



Examples of Repository Architectural Style



- Hearsay II speech understanding system ("Blackboard architecture")
- Database Management Systems
- Modern Compilers

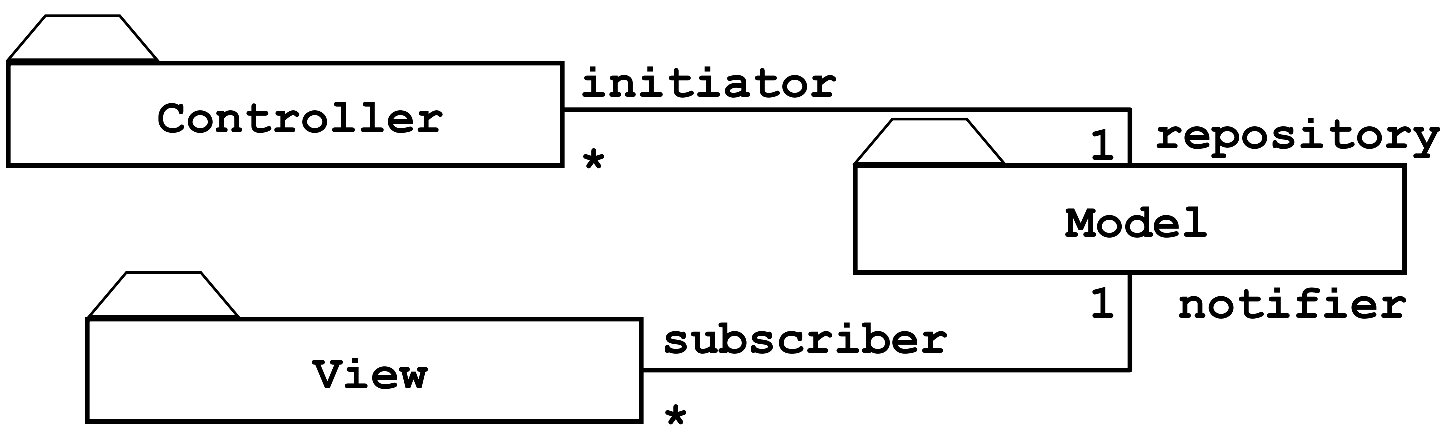
Model-View-Controller (MVC) Architectural Style

- Subsystems are classified into 3 different types

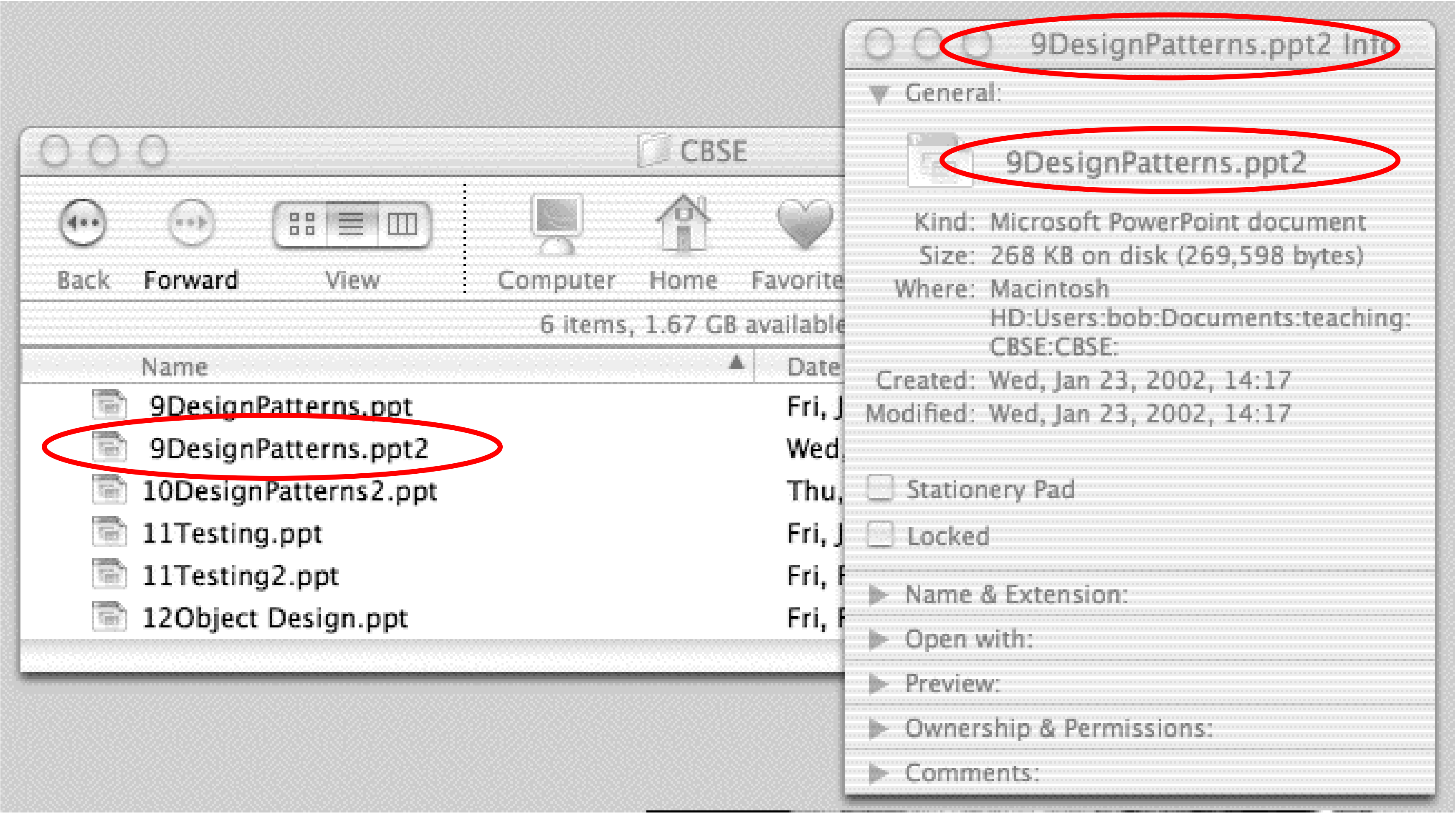
  Model subsystem: Responsible for application domain knowledge

  View subsystem: Responsible for displaying application domain objects to the user

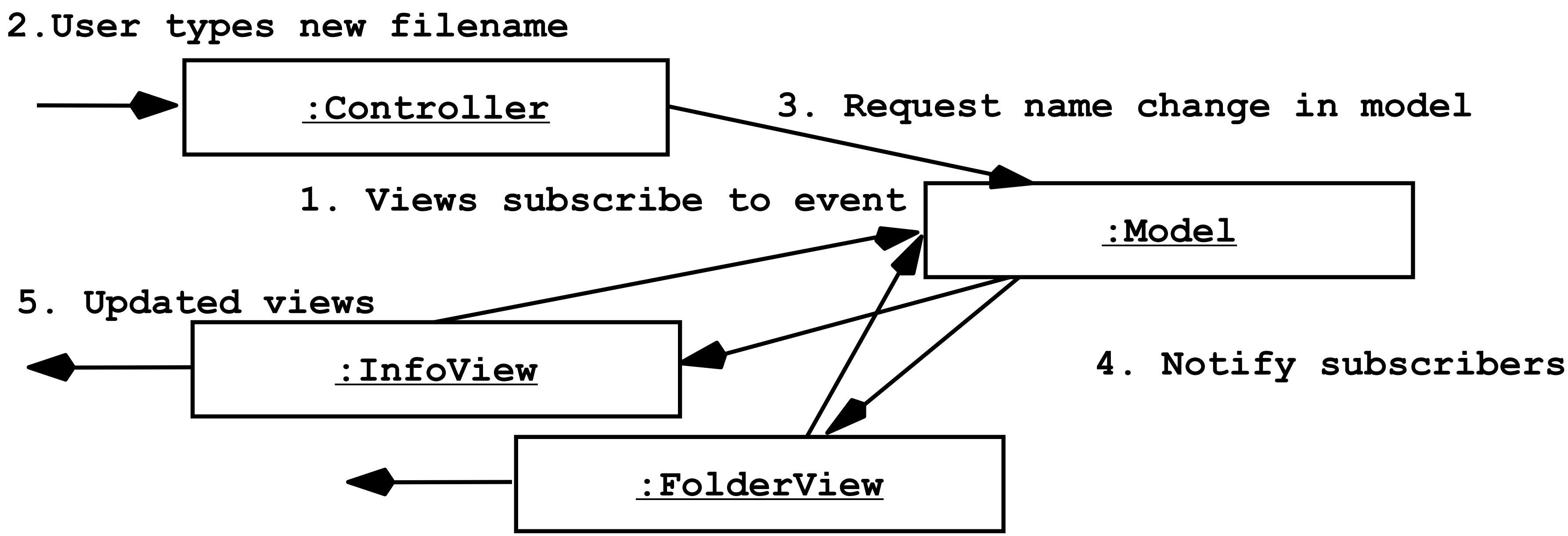
  Controller subsystem: Responsible for sequence of interactions with the user and notifying views of changes in the model



Example of a File System Based on the MVC Architectural Style



Sequence of Events (Collaborations)



Summary

- System Design
  - **An activity that reduces the gap between the problem and an existing (virtual) machine**
- Design Goals Definition
  - **Describes the important system qualities**
  - **Defines the values against which options are evaluated**
- Subsystem Decomposition
  - **Decomposes the overall system into manageable parts by using the principles of cohesion and coherence**
- Architectural Style
  - **A pattern of a typical subsystem decomposition**
- Software architecture
  - **An instance of an architectural style**
  - **Client Server, Peer-to-Peer, Repository, Model-View-Controller, …**