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

System Design I: System Decomposition

Design is Difficult

- There are two ways of constructing a software design (Tony Hoare):
  - One way is to make it so simple that there are obviously no deficiencies
  - The other way is to make it so complicated that there are no obvious deficiencies."
- Corollary (Jostein Gaarder):
  - If our brain would be so simple that we can understand it, we would be too stupid to understand it.

Sir **Antony Hoare,** *1934
- Quicksort
- Hoare logic for verification
- CSP (Communicating Sequential Processes): modeling language for concurrent processes (basis for Occam).

Jostein Gardner, *1952, writer
Uses metafiction in his stories:
Fiction which uses the device of fiction
- Best known for: „Sophie's World".

Why is Design so Difficult?

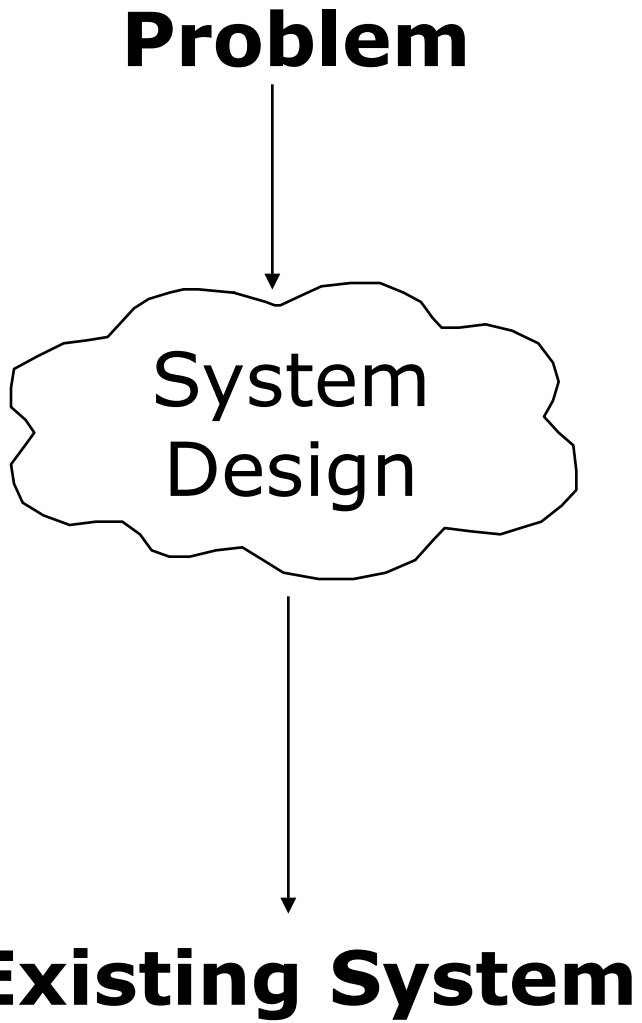
- Analysis: Focuses on the application domain
- Design: Focuses on the solution domain
  - The solution domain is changing very rapidly
    - Halftime knowledge in software engineering: About 3-5 years
    - Cost of hardware rapidly sinking
  - ➢ Design knowledge is a moving target

- Design window: Time in which design decisions have to be made.

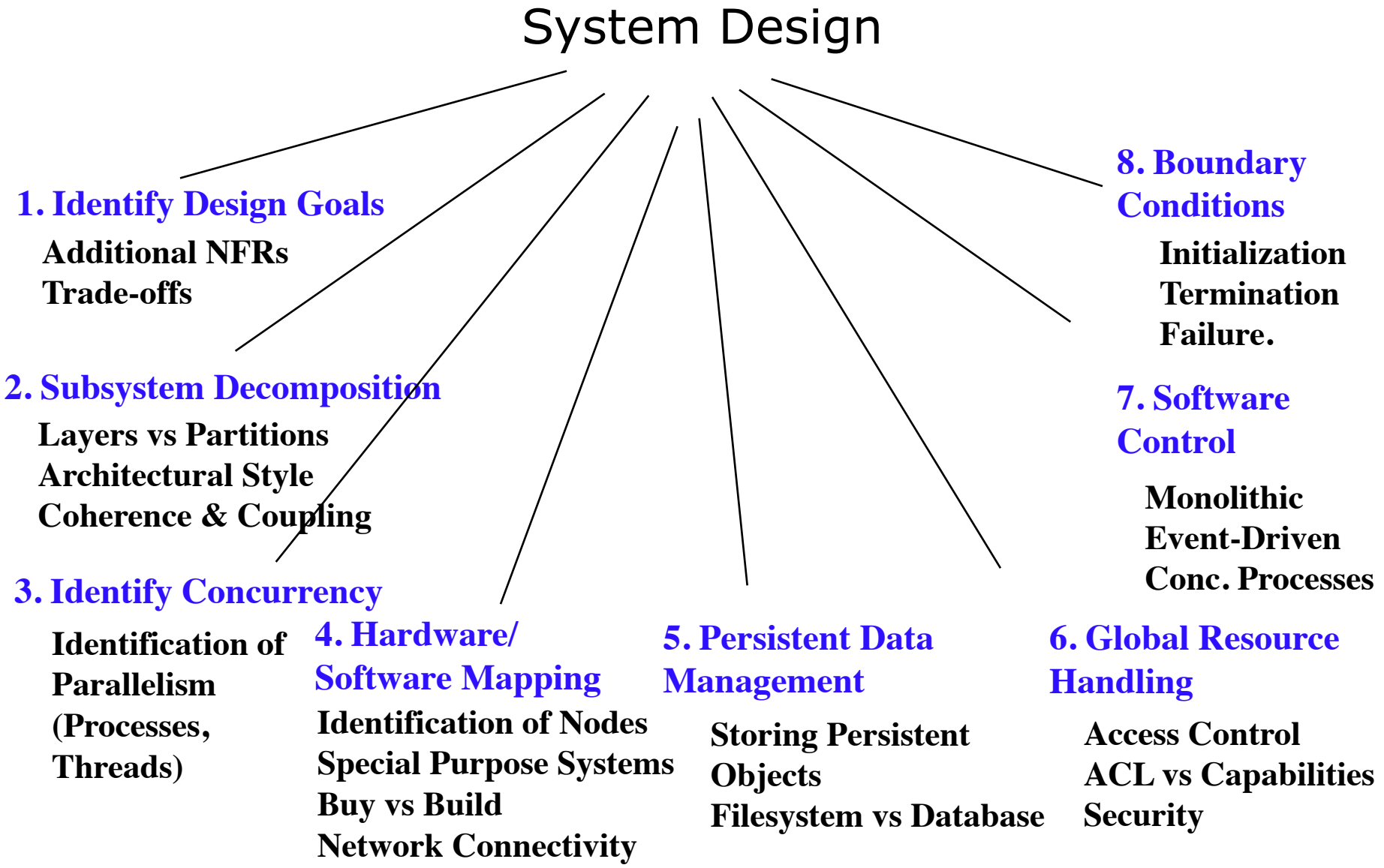
The Scope of System Design

- 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



Overview

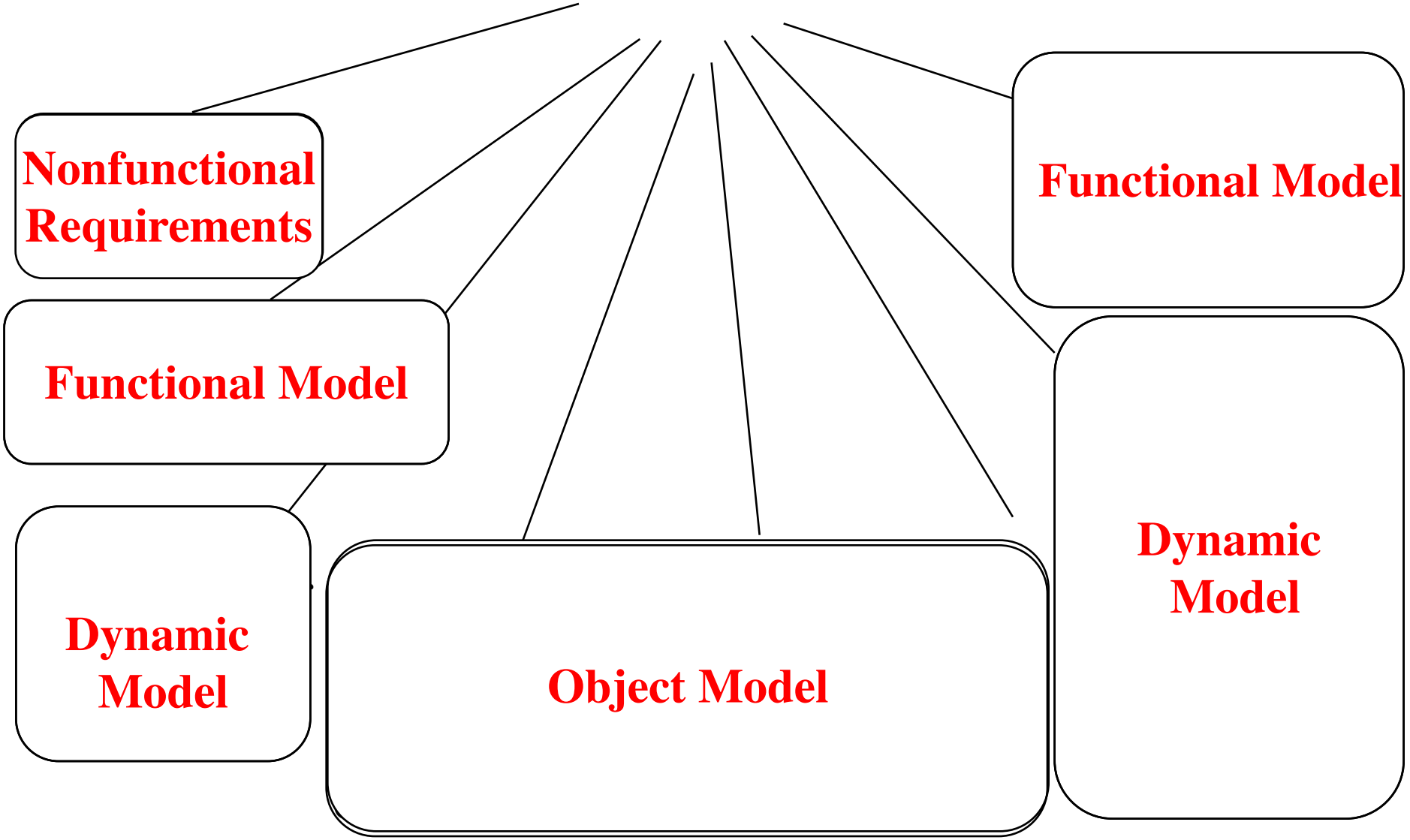
System Design I (This Lecture)

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

System Design II (Next Lecture)

3. Concurrency: Identification of parallelism
4. Hardware/Software Mapping:
   Mapping subsystems to processors
5. Persistent Data Management: Storage for entity objects
6. Global Resource Handling & Access Control:
   Who can access what?)
7. Software Control: Who is in control?
8. Boundary Conditions: Administrative use cases.

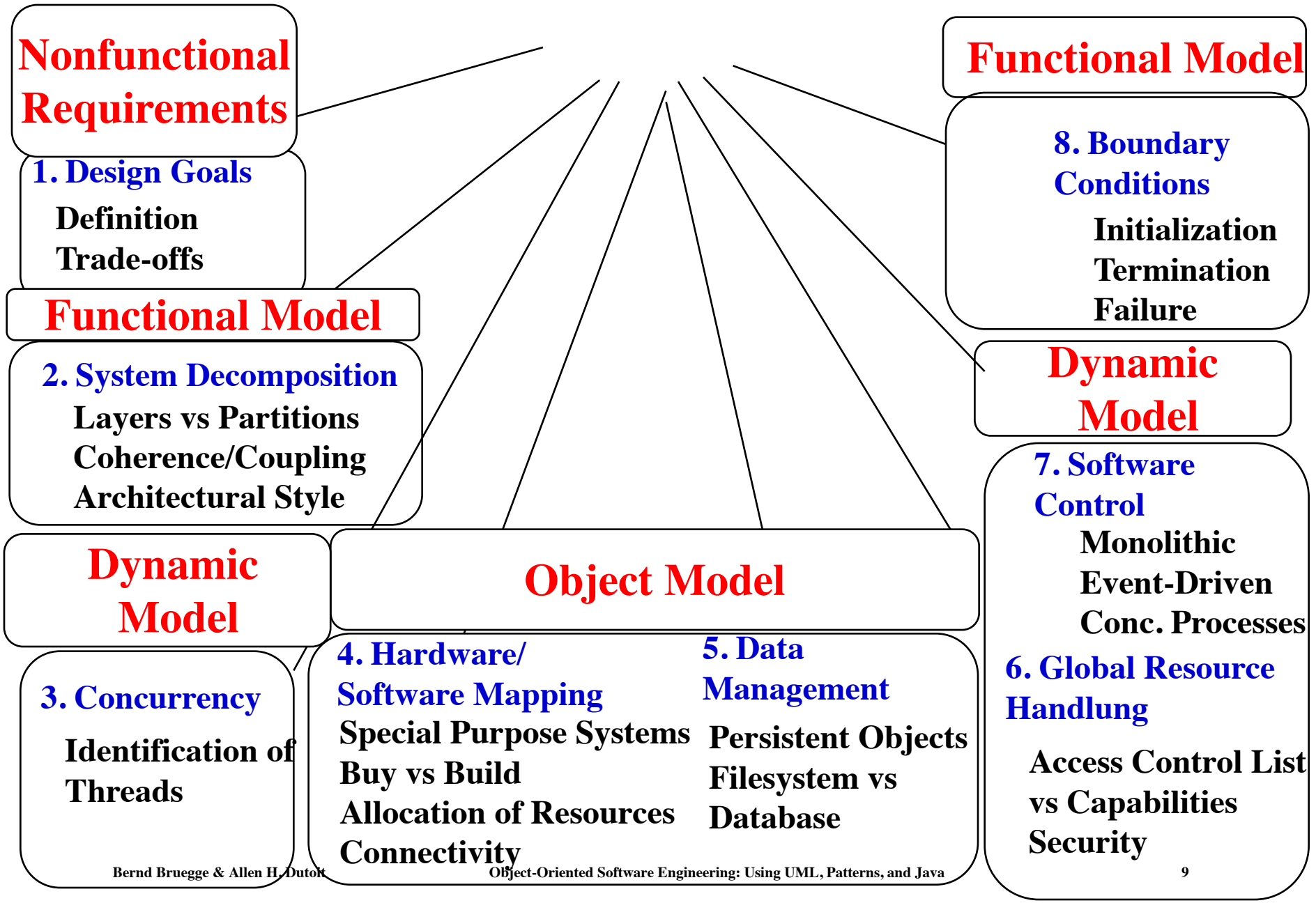
Analysis Sources: Requirements and System Model



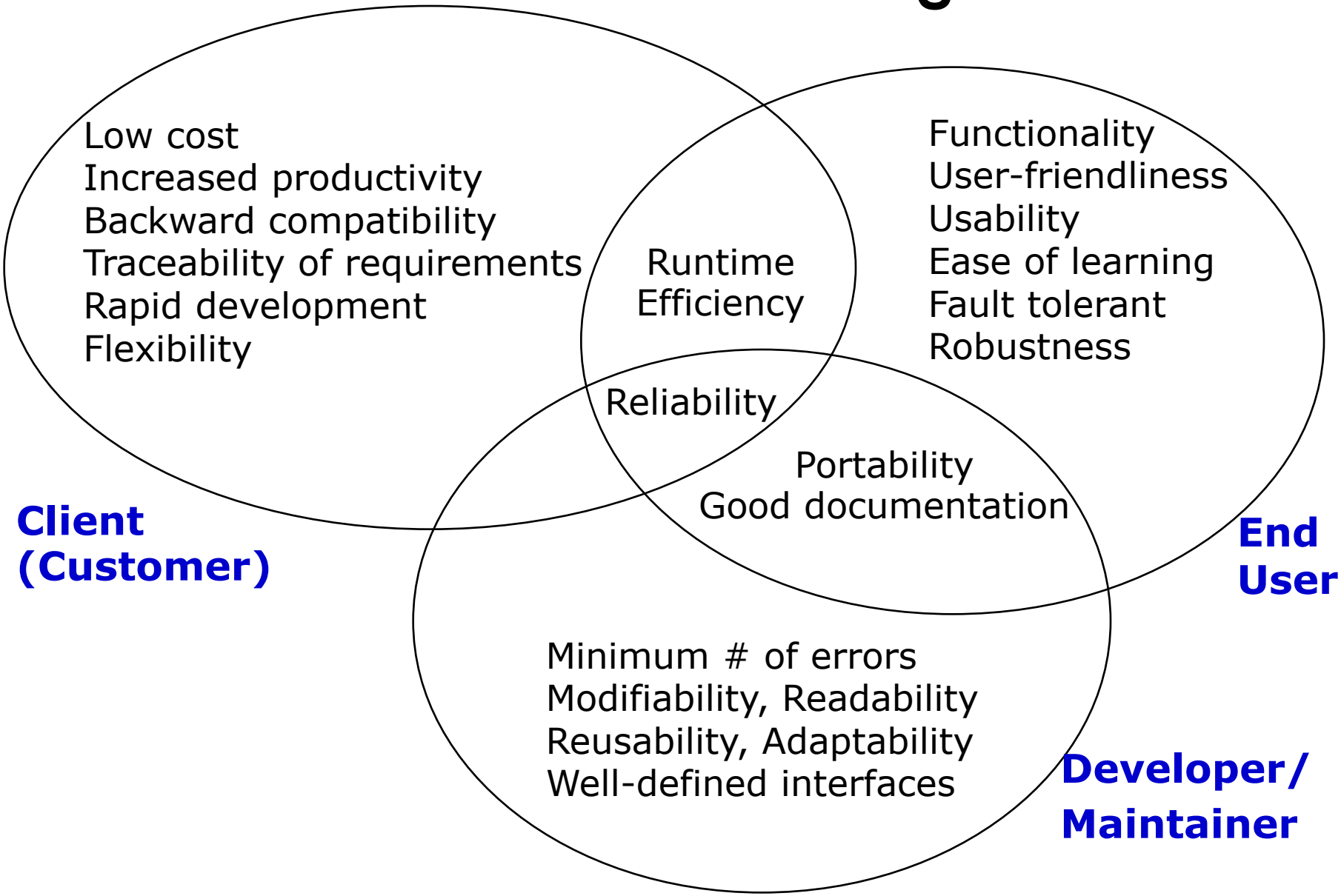
How the Analysis Models influence System Design

- 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: Hardware/Software Mapping
  => Boundary conditions

From Analysis to System Design



Stakeholders have different Design Goals



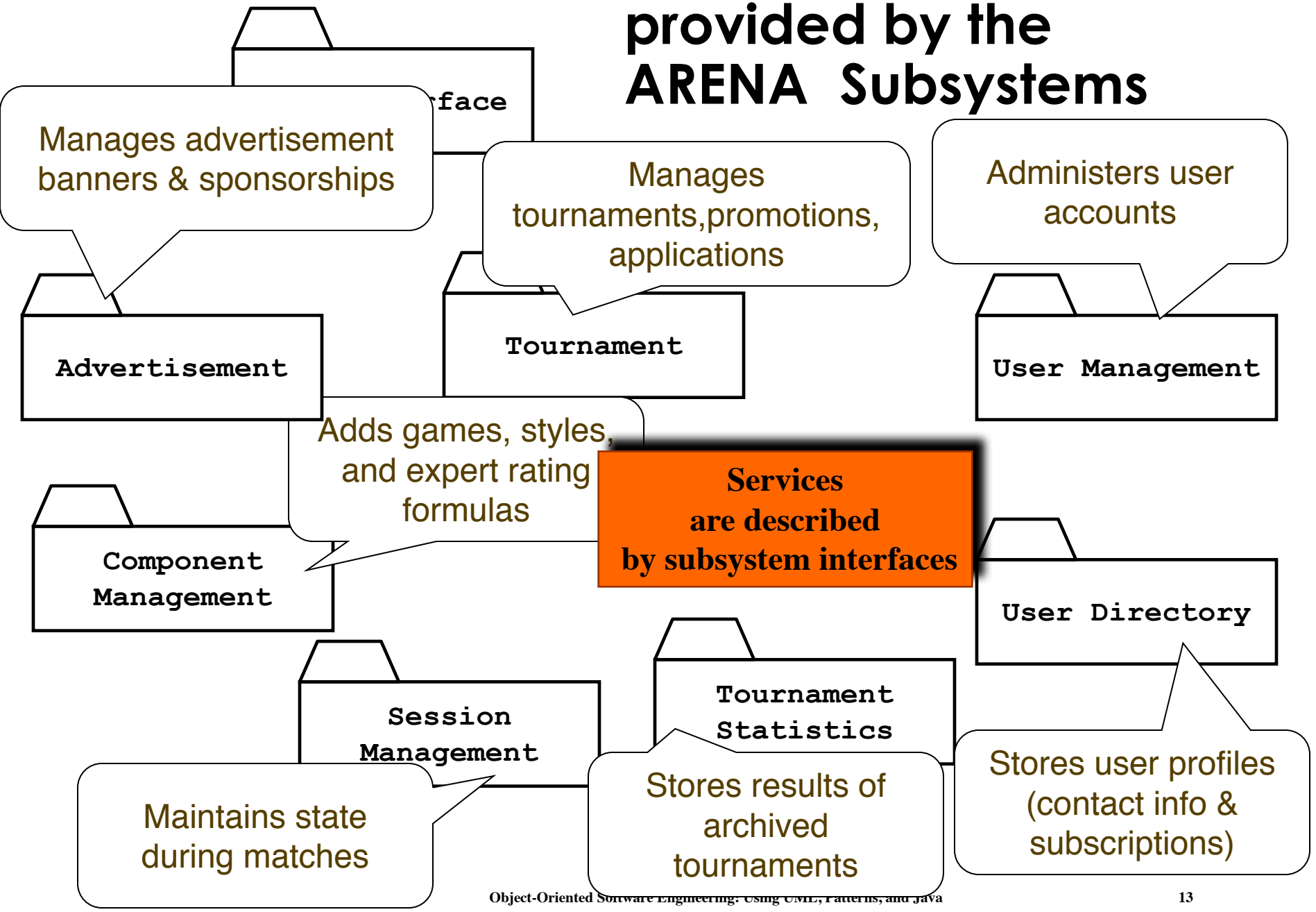
Typical Design Trade-offs

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

Subsystems and Services

- Subsystem
  - Collection of classes, associations, operations, events that are closely interrelated with each other
  - The classes in the object model are the "seeds" for subsystems
- Service
  - A group of externally visible operations provided by a subsystem (also called subsystem interface)
  - The use cases in the functional model provide the "seeds" for services

Example: Services provided by the ARENA Subsystems



Subsystem Interface

- 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
    - Left as an Exercise
- API of Notification Subsystem
  - Implementation in Java
    - Left as an Exercise.

Subsystem Interface Object

Subsystem Interface Object

- The set of public operations provided by a subsystem

Good system design

- The subsystem interface object describes *all* the services of the subsystem interface
- Subsystem interface objects can be realized with the Façade pattern (=> chapter on design patterns).

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 System Design

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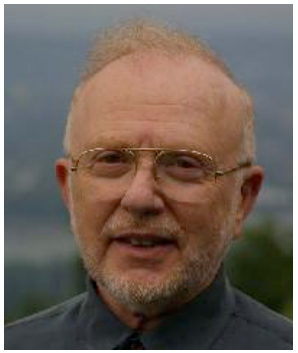
How to achieve high Coherence

- High coherence can be achieved if most of the interaction is within subsystems, rather than across subsystem boundaries
- Questions to ask:
  - Does one subsystem always call another one for a specific service?
    - Yes: Consider moving them together into the same subystem.
  - Which of the subsystems call each other for services?
    - Can this be avoided by restructuring the subsystems or changing the subsystem interface?
  - Can the subsystems even be hierarchically ordered (in layers)?

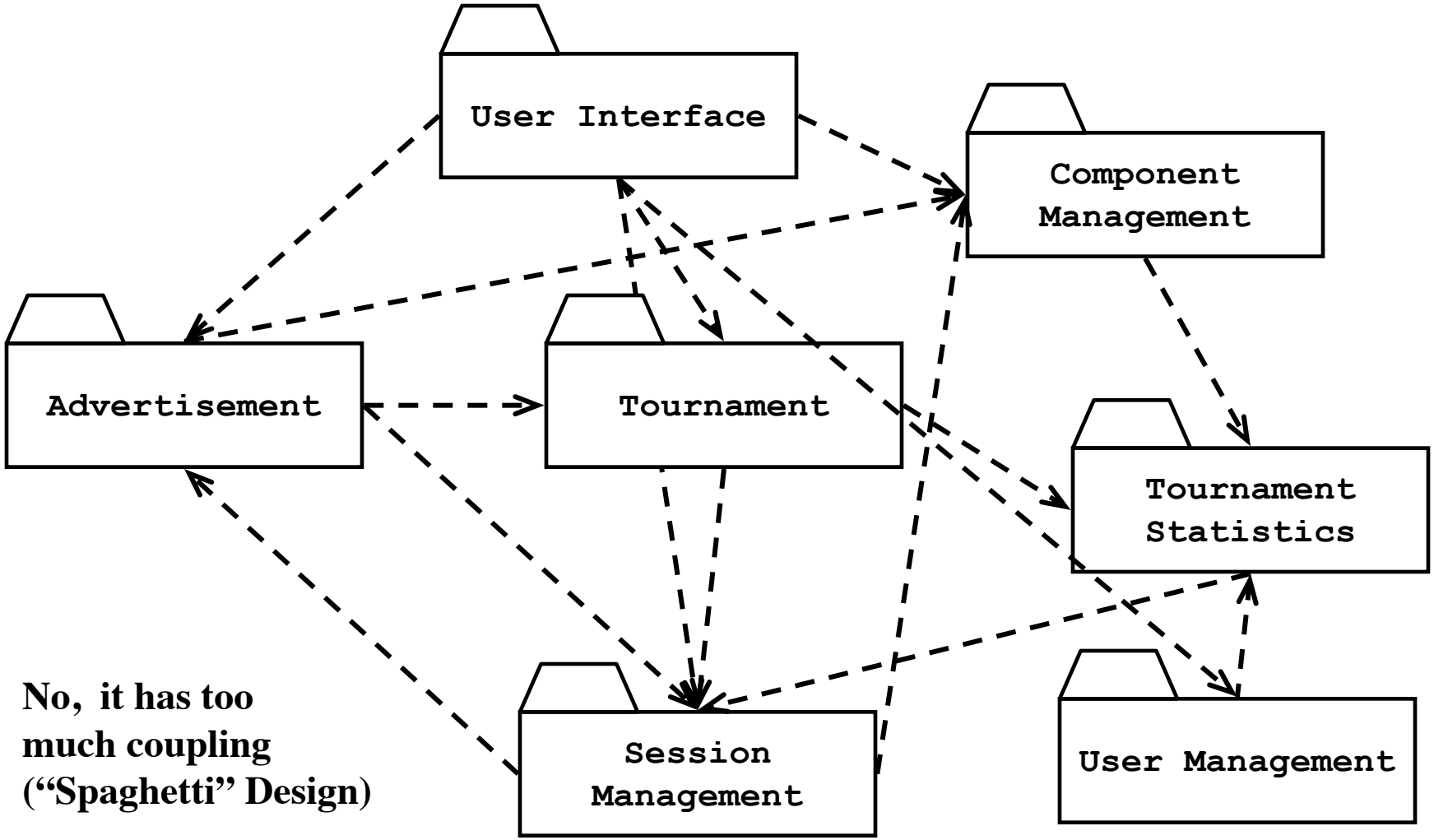
How to achieve Low Coupling

- Low coupling can be achieved if a calling class does not need to know anything about the internals of the called class (Principle of information hiding, Parnas)
- Questions to ask:
  - Does the calling class really have to know any attributes of classes in the lower layers?
  - Is it possible that the calling class calls only operations of the lower level classes?

David Parnas, *1941,
Developed the concept of
modularity in design.



Is this a Good Design?



No, it has too much coupling ("Spaghetti" Design)

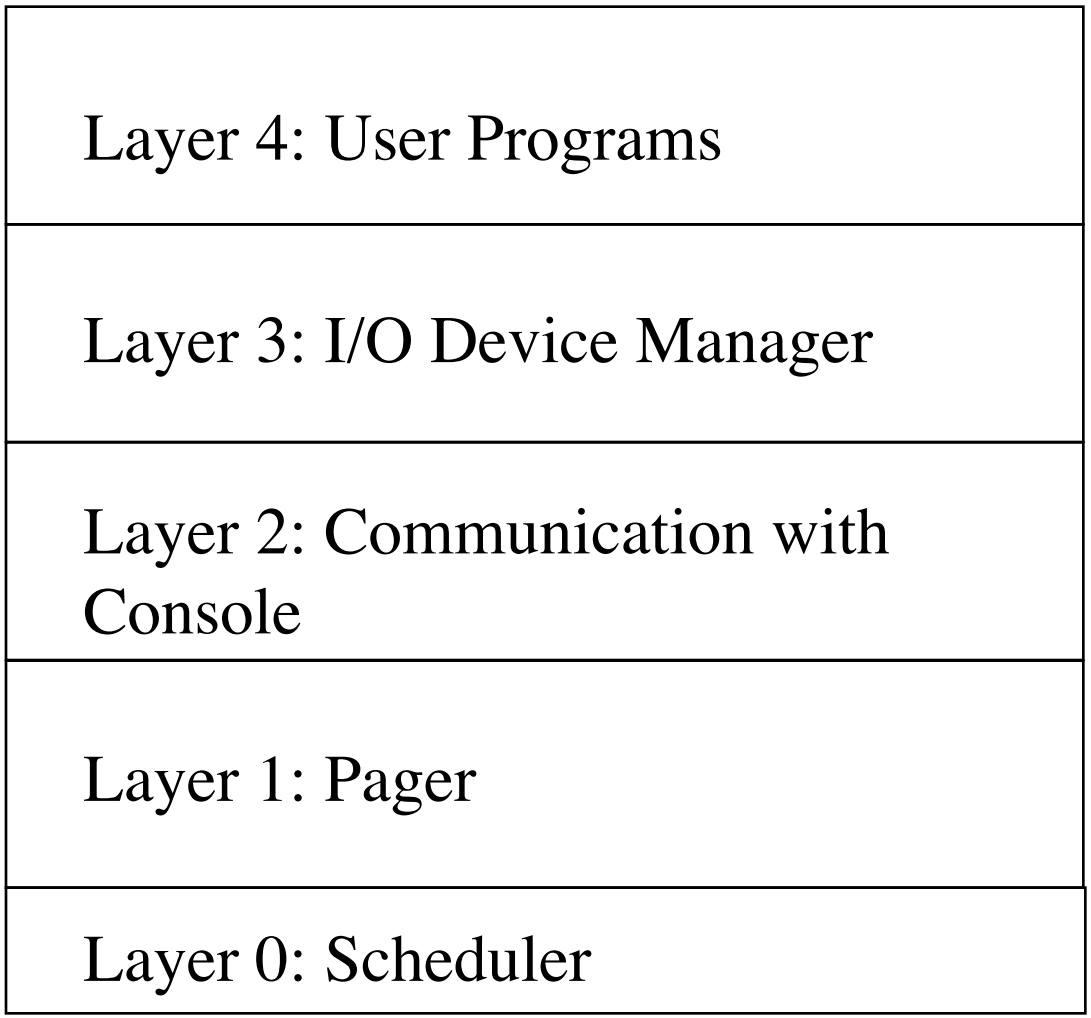
Dijkstra's answer to "Spaghetti Design"

- Dijkstra revolutionary idea in 1968
  - An system should be designed and built as a hierarchy of layers: Each layer uses only the services offered by the lower layers
- The T.H.E. system
  - T.H.E. = Technische Hochschule Eindhoven
- An operating system for single user operation
  - Supporting batch-mode
  - Multitasking with a fixed set of processes sharing the CPU

Edser W. Dijkstra, 1930-2002
Formal verification: Proofs for programs
Dijkstra Algorithm, Banker's Algorithm,
Gotos considered harmful, T.H.E.,
1972 Turing Award

The Layers of the T.H.E. System

"An operating system is a hierarchy of layers, each layers using services offered by the lower layers"



Retrospectively, T.H.E was the first system that used an architectural style!

Architectural Style vs Architecture

- Subsystem decomposition: Identification of subsystems, services, and their relationship to each other
- Architectural Style: A pattern for a subsystem decomposition
- Software Architecture: Instance of an architectural style.

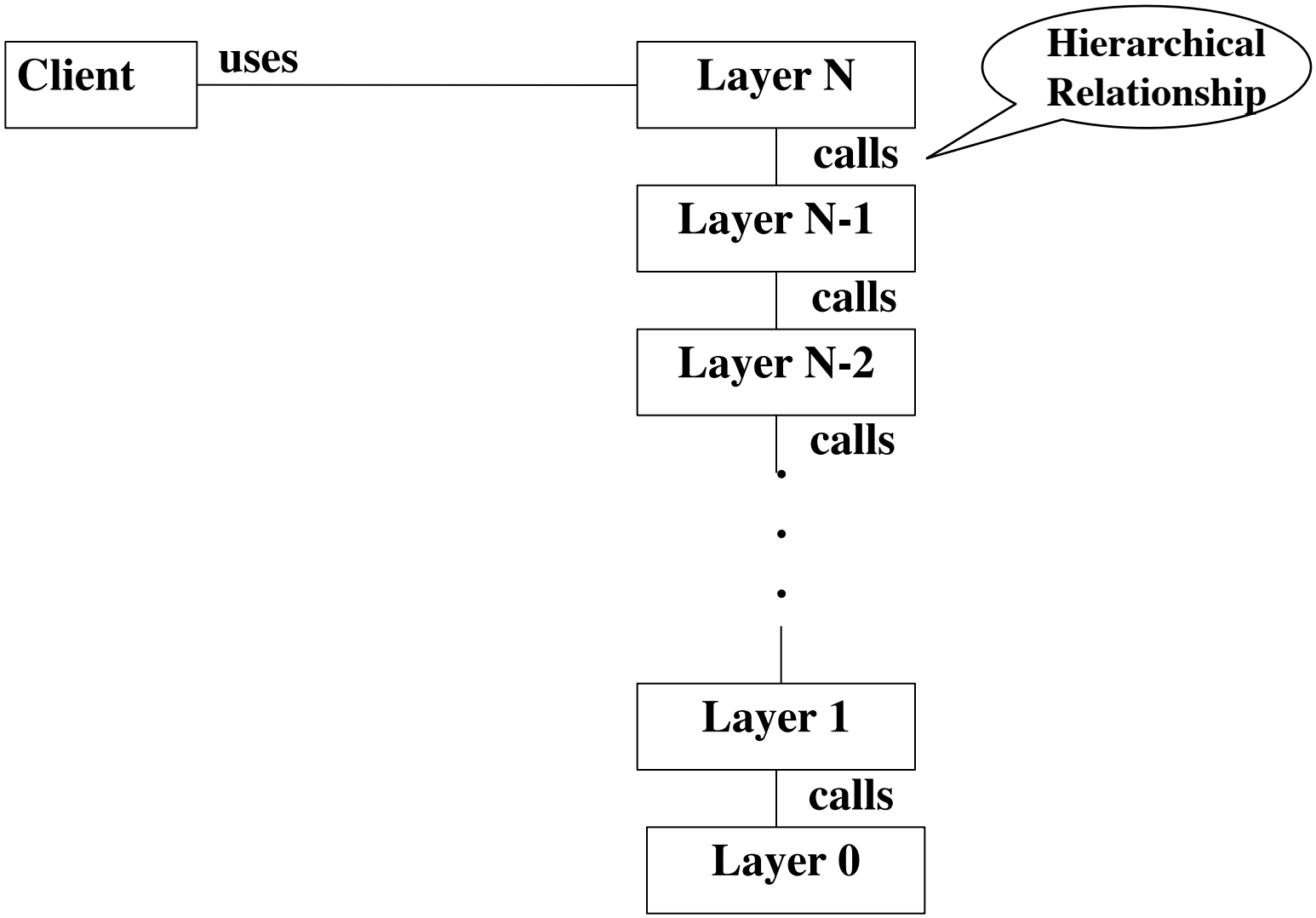
Examples of Architectural Styles

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

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.

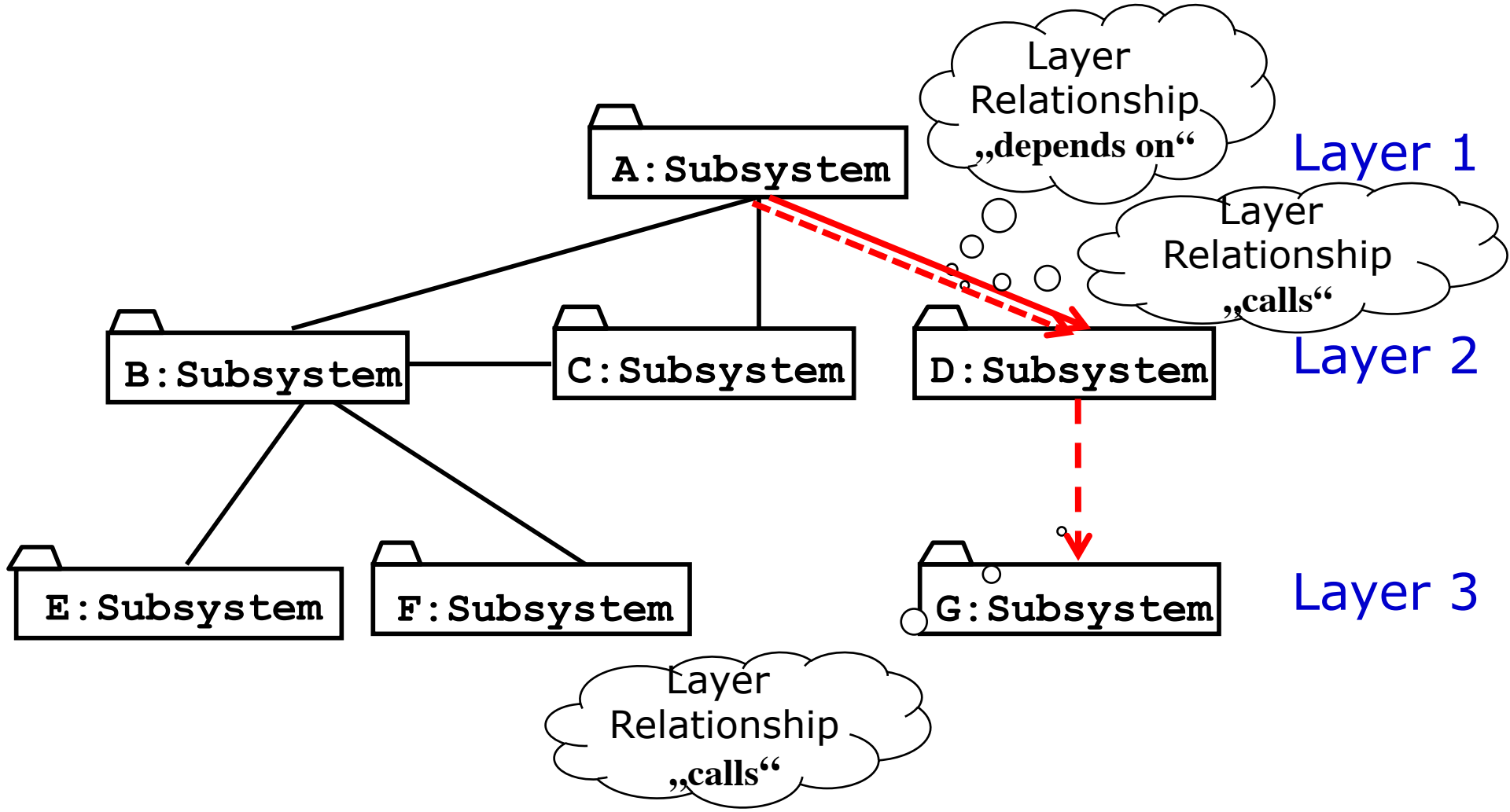
The Layered Architectural Style



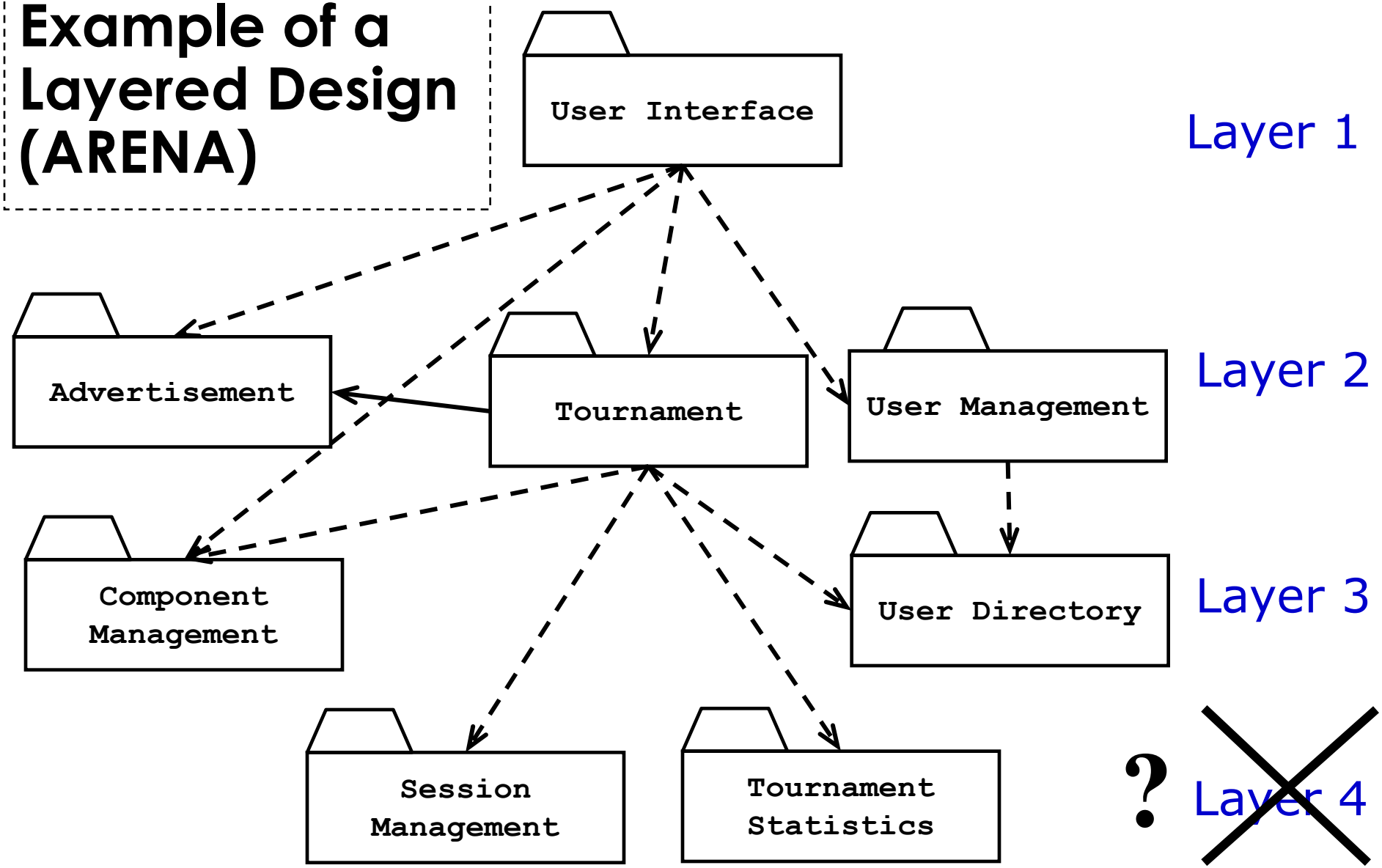
Hierarchical Relationships between Subsystems

- There are two major types of hierarchical relationships
  - Layer A "depends on" layer B (compile time dependency)
    - Example: Build dependencies (make, ant, maven)
  - Layer A "calls" layer B (runtime dependency)
    - Example: A web browser calls a web server
    - Can the client and server layers run on the same machine?
      - Yes, they are layers, not processor nodes
      - Mapping of layers to processors is decided during the Software/hardware mapping!
- UML convention:
  - Runtime relationships are associations with dashed lines
  - Compile time relationships are associations with solid lines.

Example of a System with more than one Hierarchical Relationship



Example of a Layered Design (ARENA)

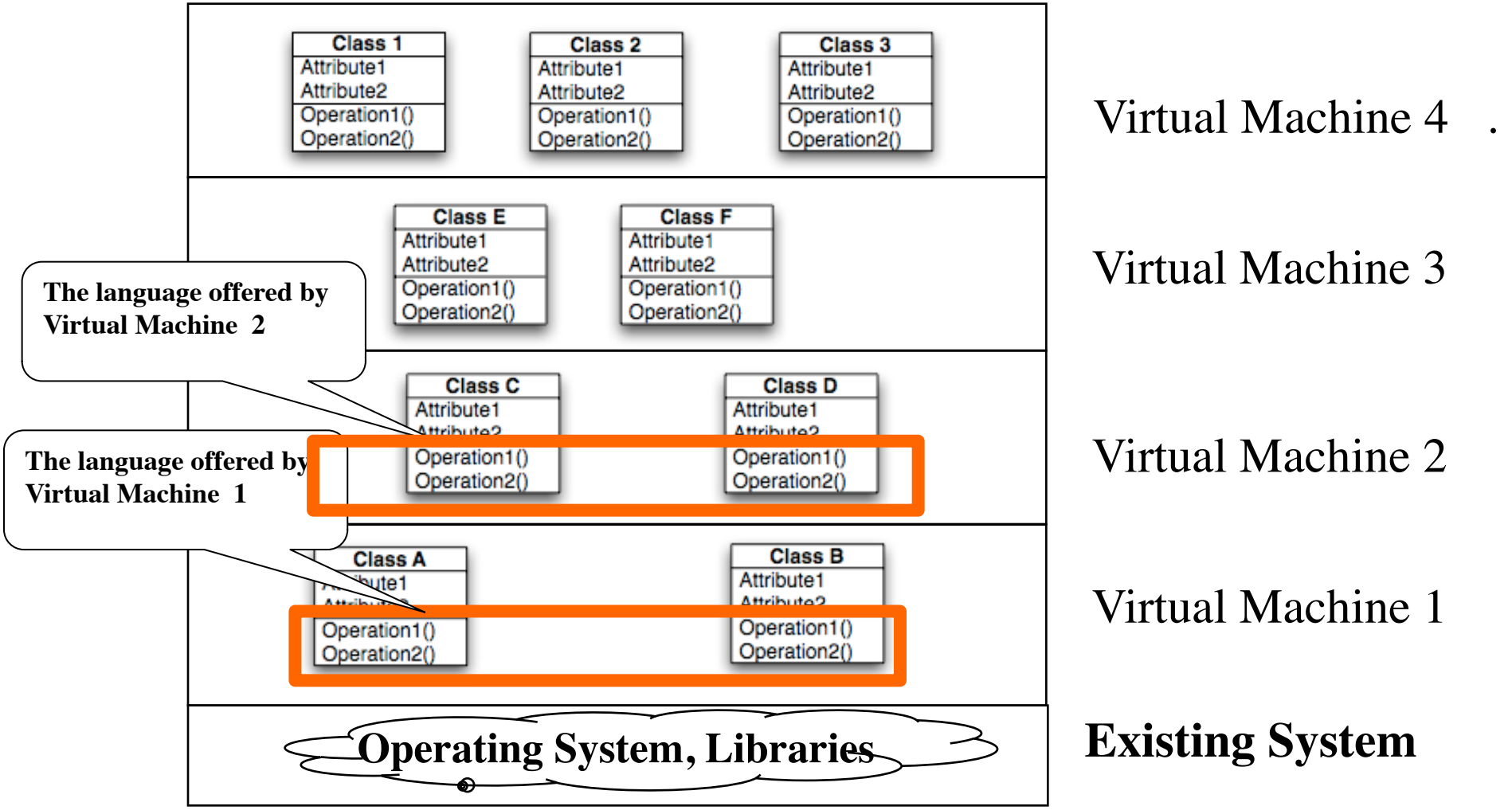


Virtual Machine

- 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

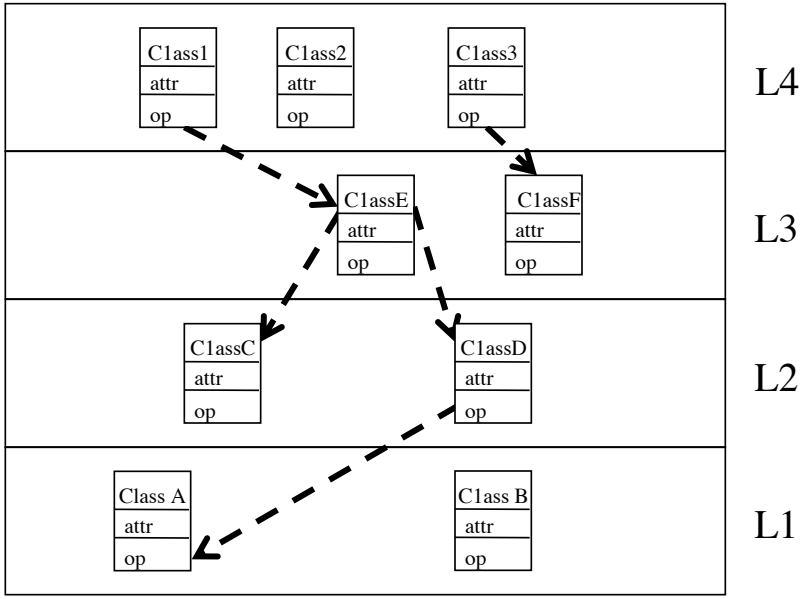
A system is a hierarchy of virtual machines, each using language primitives offered by the lower machines.



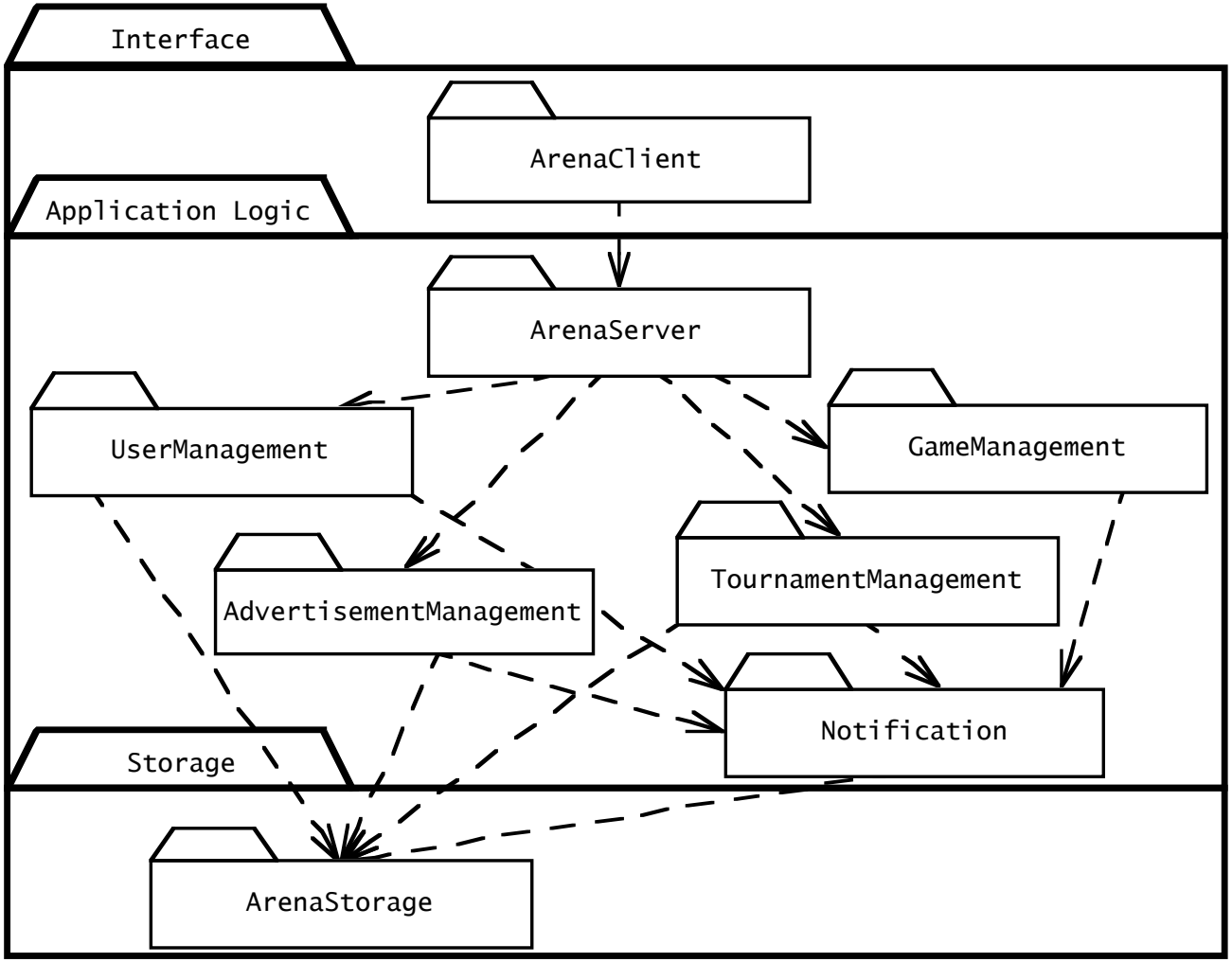
Closed Architecture (Opaque Layering)

- Each layer can only call operations from the layer below (called "direct addressing" by Buschmann et al)

Design goals:
Maintainability, flexibility.



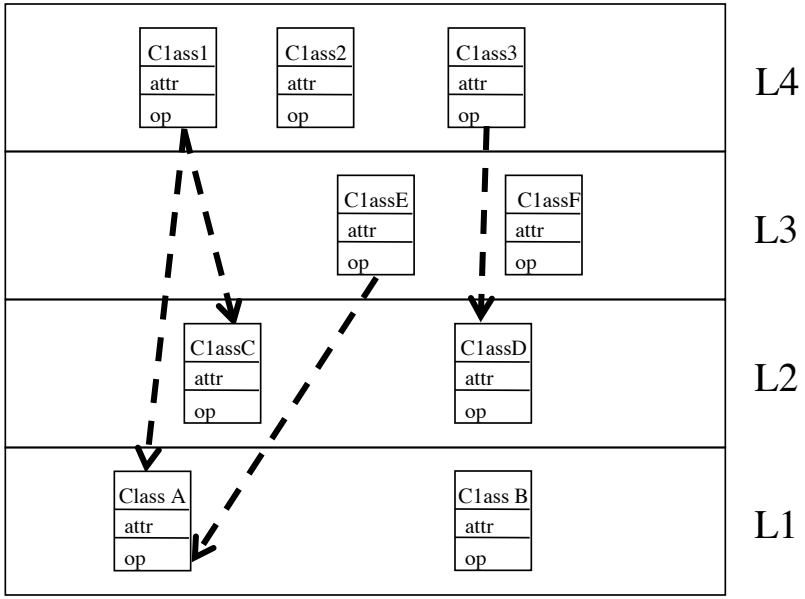
Opaque Layering in ARENA



Open Architecture (Transparent Layering)

- Each layer can call operations from any layer below ("indirect addressing")

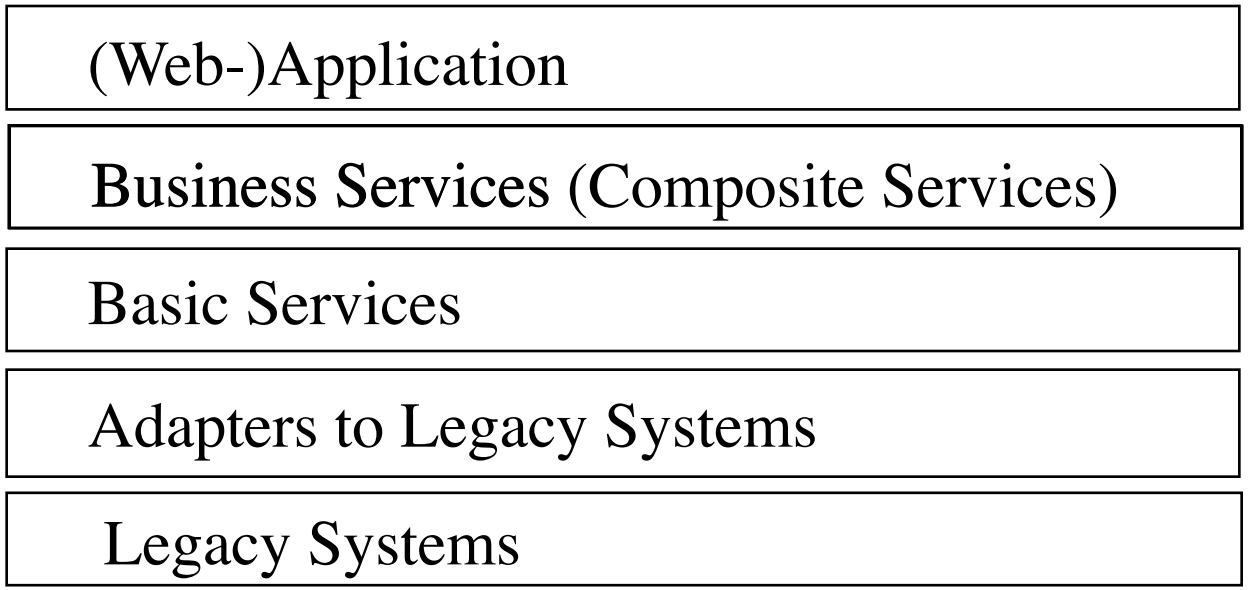
Design goal:
Runtime efficiency.



SOA is a Layered Architectural Style

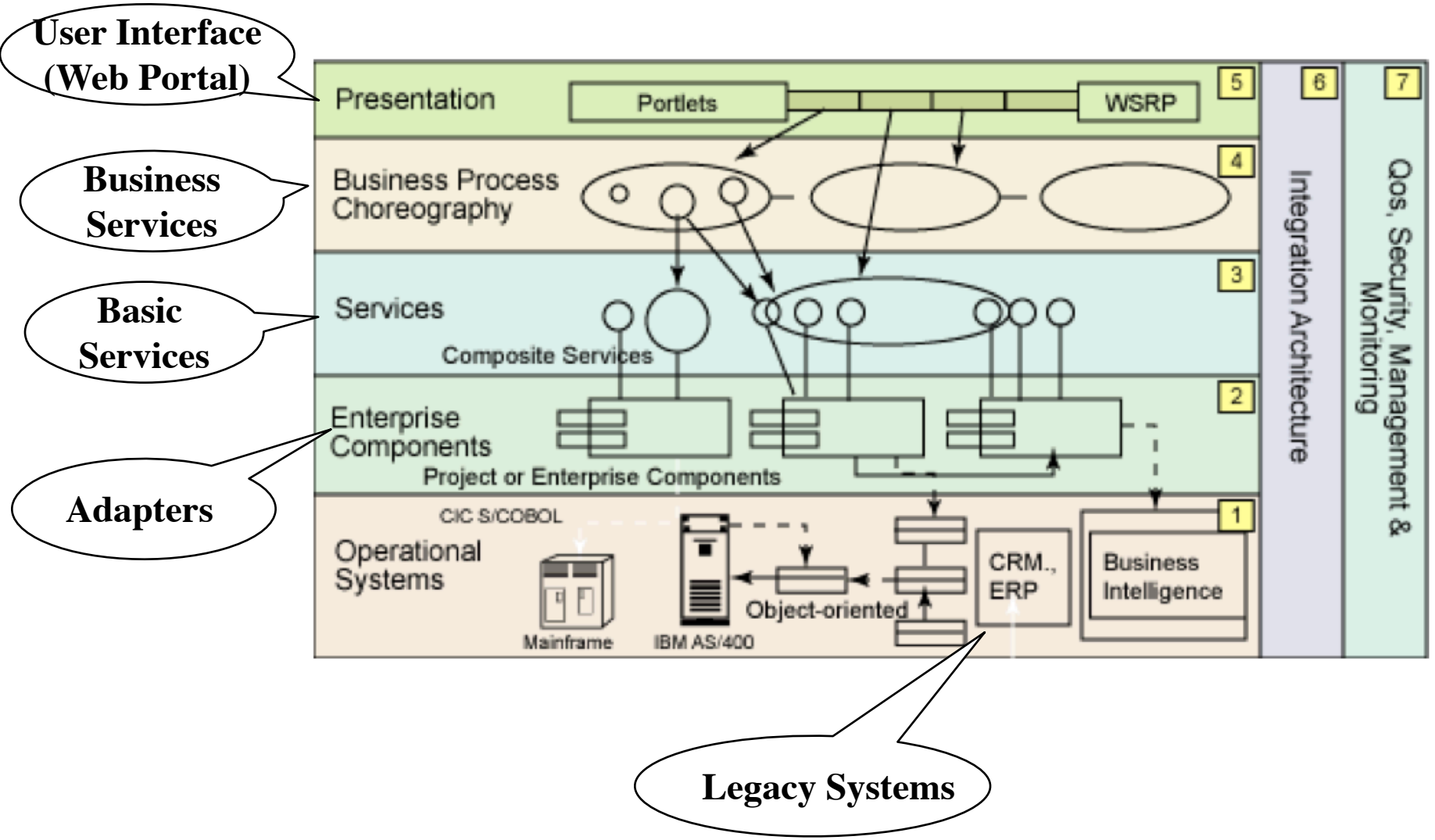
Service Oriented Architecture (SOA)

- Basic idea: A **service provider** (" business") offers business services ("business processes") to a **service consumer** (application, "customer")
  - The business services are dynamically discoverable, usually offered in web-based applications
- The business services are created by composing (choreographing) them from lower-level services (basic services)
- The basic services are usually based on legacy systems
- Adapters are used to provide the "glue" between basic services and the legacy systems.



IBM's View of a Service Oriented Architecture

Source http://www.ibm.com/developerworks/webservices/library/ws-soa-design1/

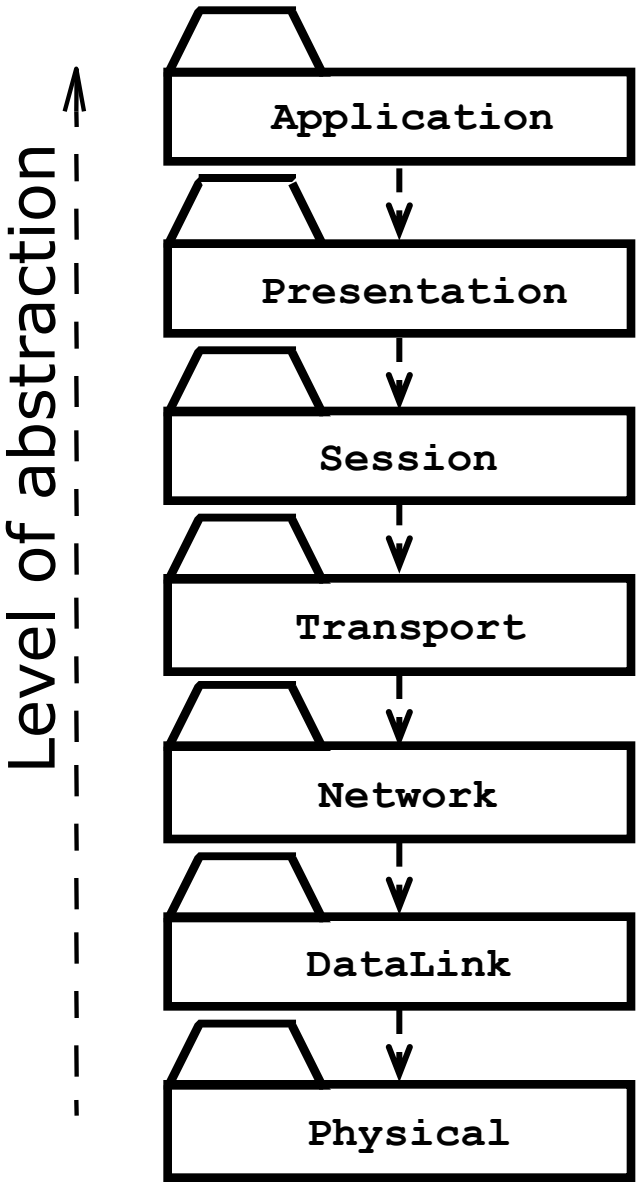


Properties of Layered Systems

- Layered systems are hierarchical. This is a desirable design
  - Hierarchy reduces complexity
- Closed architectures are more portable
  - Provide very low coupling
- Open architectures are more efficient

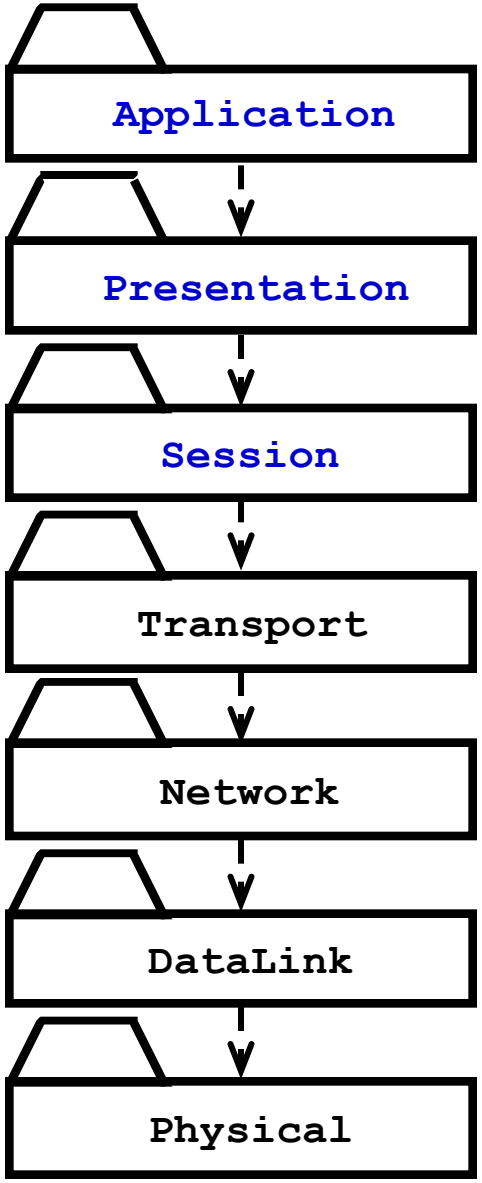
Another Example of a Layered Architectural Style

- 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



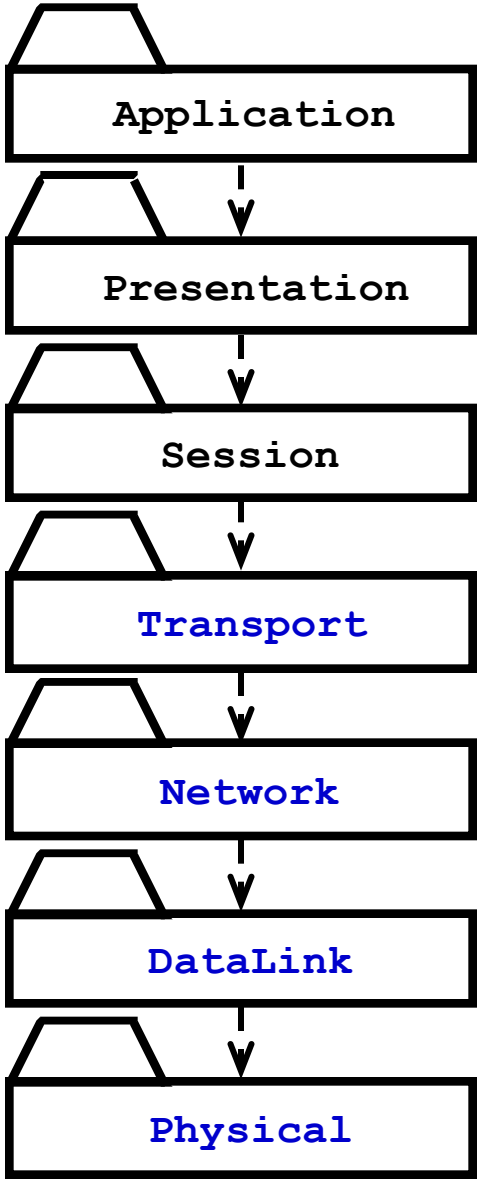
OSI Model Layers and their Services

- 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



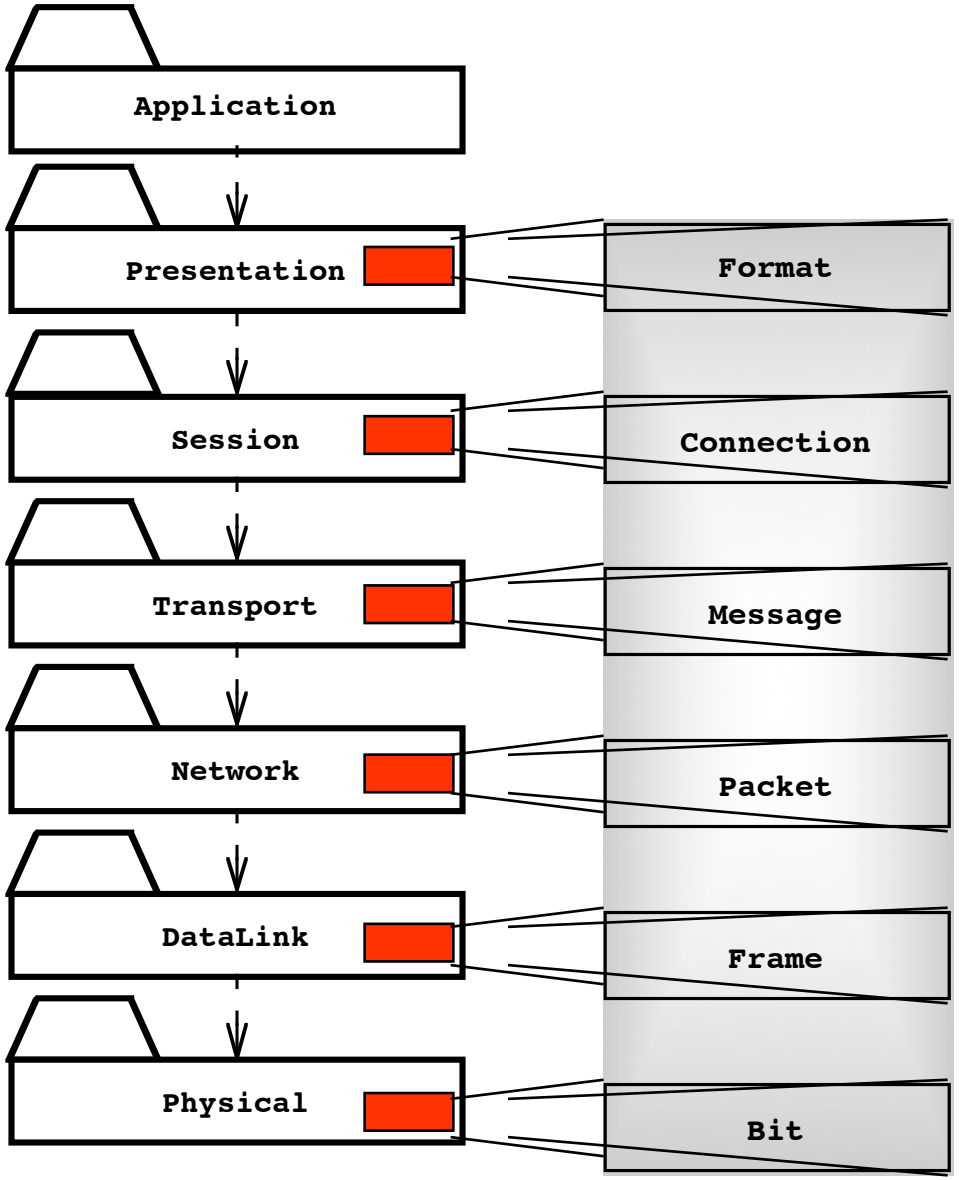
OSI Model Layers and their Services

- 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
  - Service: Transmit and route data within the network
- The Datalink layer models frames
  - Service: Transmit frames without error
- The Physical layer represents the hardware interface to the network
  - Service: sendBit() and receiveBit()

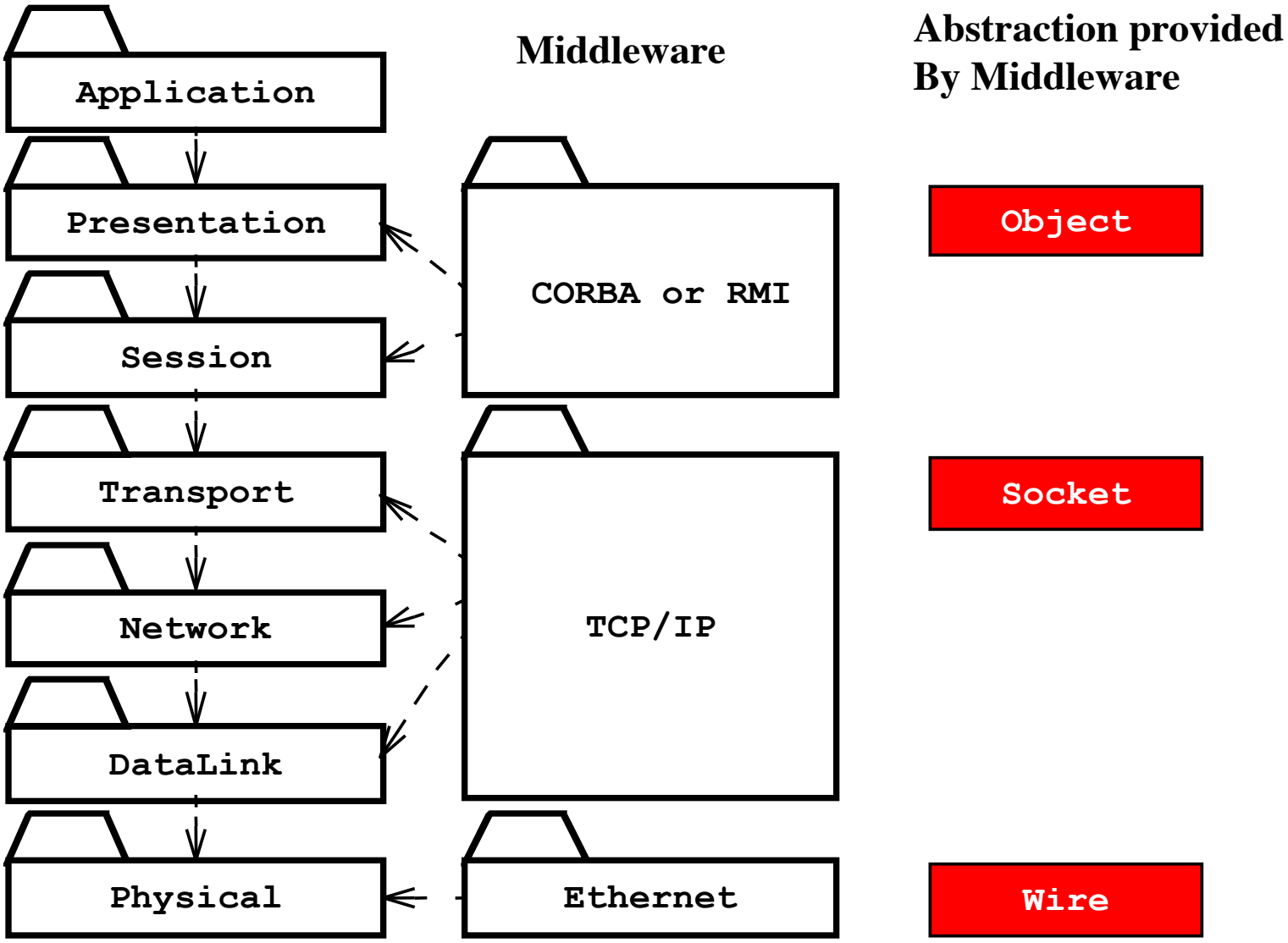


An Object-Oriented View of the OSI Model

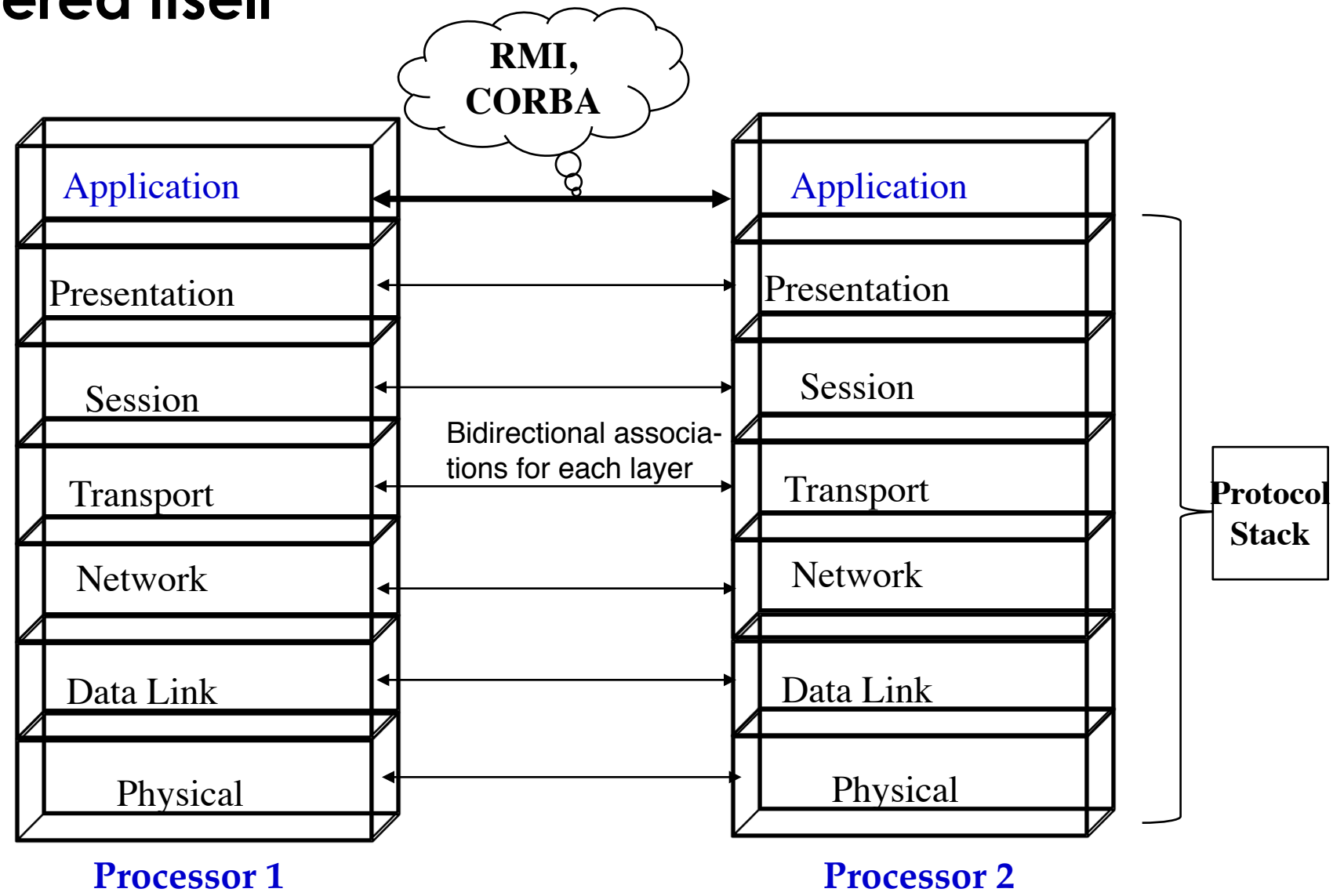
- The OSI Model is a closed software architecture (i.e., it uses opaque layering)
- Each layer can be modeled as a UML package containing a set of classes available for the layer above

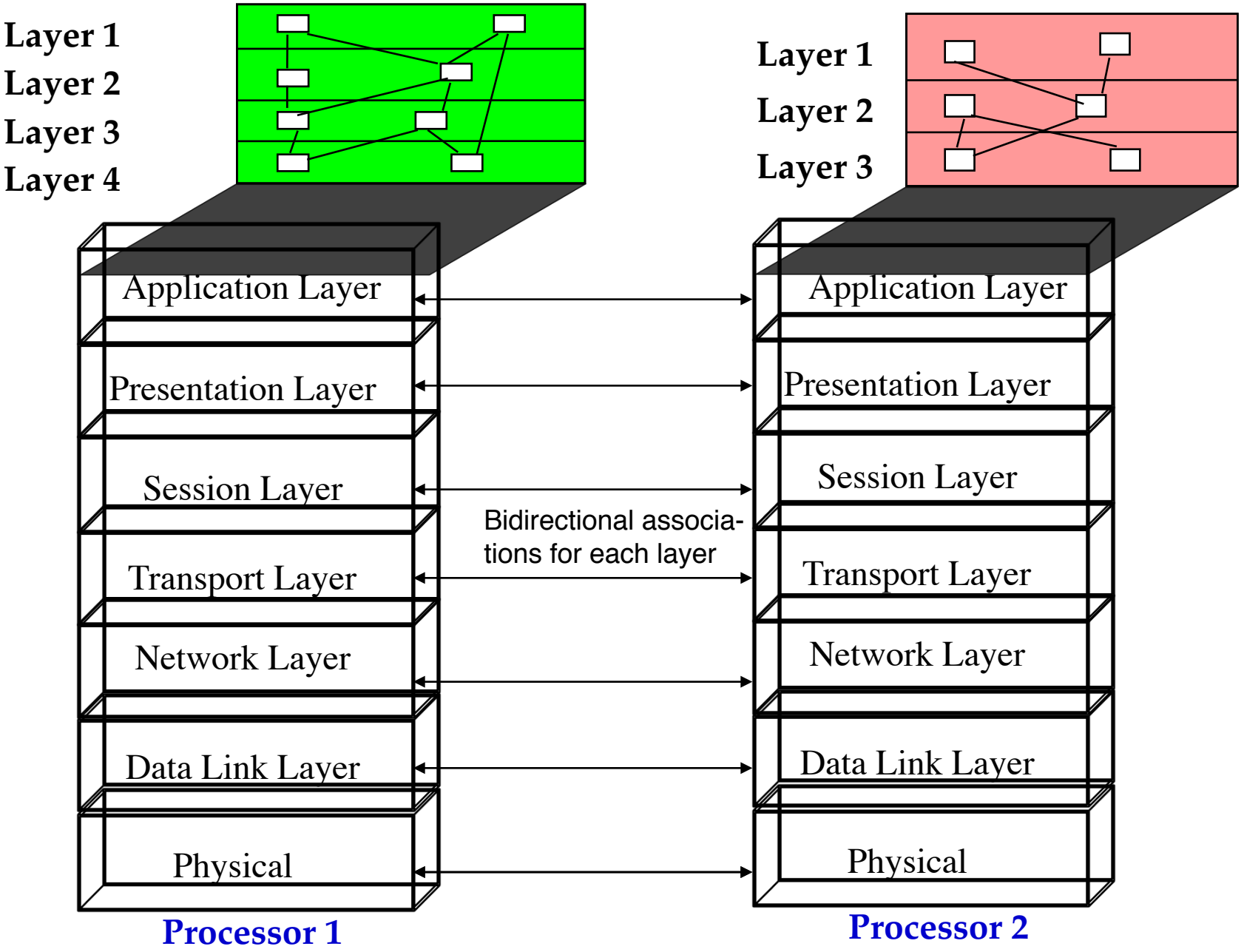


Middleware Allows Focus On Higher Layers



The Application Layer provides the Abstractions of the "New System". It is usually layered itself




Layer 1
Layer 2
Layer 3
Layer 4
Layer 1
Layer 2
Layer 3
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical
Bidirectional associa-
tions for each layer
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical
Processor 1
Processor 2

Examples of Architectural Styles

- ✓Layered Architectural Style
  - ✓Service-Oriented Architecture (SOA)
- Client/Server
- Peer-to-Peer
- Three-tier, Four-tier Architecture
- Repository
  - Blackboard
- Model-View-Controller
- Pipes and Filters

Client/Server Architectures

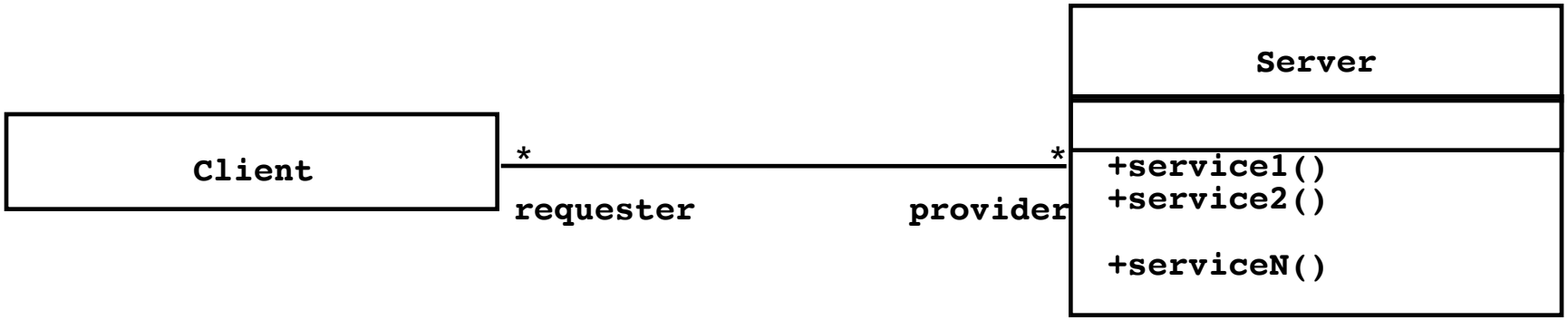
- Often used in the design of database systems
  - Front-end: User application (client)
  - Back end: Database access and manipulation (server)
- Functions performed by client:
  - Input from the user (Customized user interface)
  - Front-end processing of input data
- Functions performed by the database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

Client/Server Architectural Style

- Special case of the Layered 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.

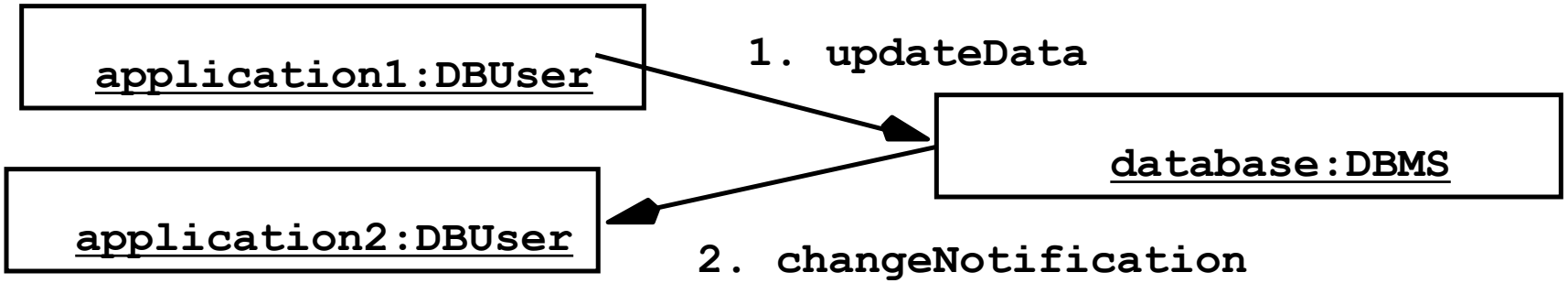


Design Goals for Client/Server Architectures

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	**A measure of success with which the observed behavior of a system confirms to the specification of its behavior (Chapter 11: Testing)**

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"

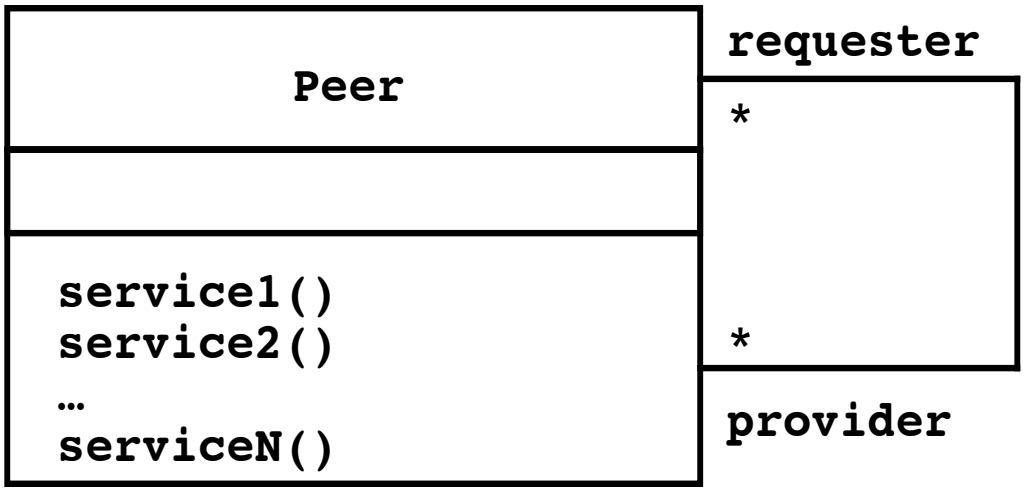
Introduction a new abstraction: Peer

"Clients and servers can be both peers"

How do we model this statement? With Inheritance?

Proposal 1: "A peer can be either a client or a server"

Proposal 2: "A peer can be a client as well as a server".



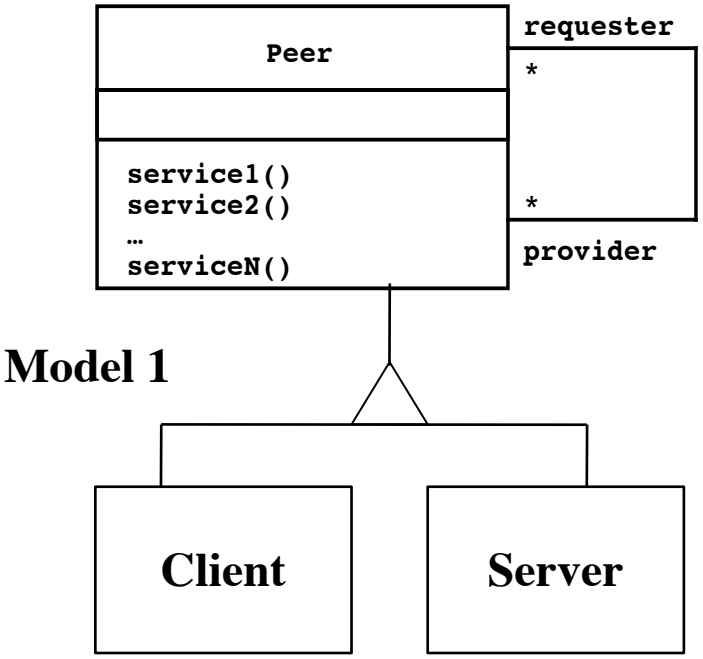
Relationship Client/Server & Peer-to-Peer

Problem statement "Clients can be servers and servers can be clients"

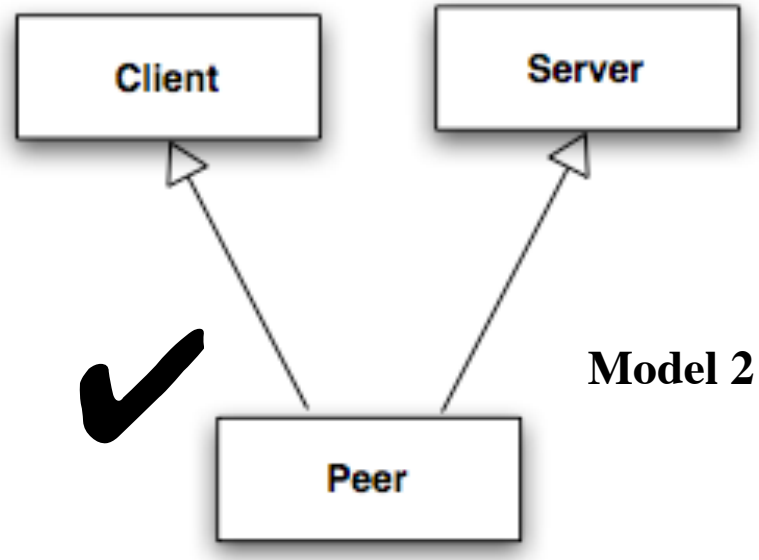
Which model is correct?

Model 1: "A peer can be either a client or a server"

Model 2: "A peer can be a client as well as a server"



?



3-Layer-Architectural Style
3-Tier Architecture

Definition: 3-Layered Architectural Style

- An architectural style, where an application consists of 3 hierarchically ordered subsystems
  - A user interface, middleware and a database system
  - The middleware subsystem services data requests between the user interface and the database subsystem

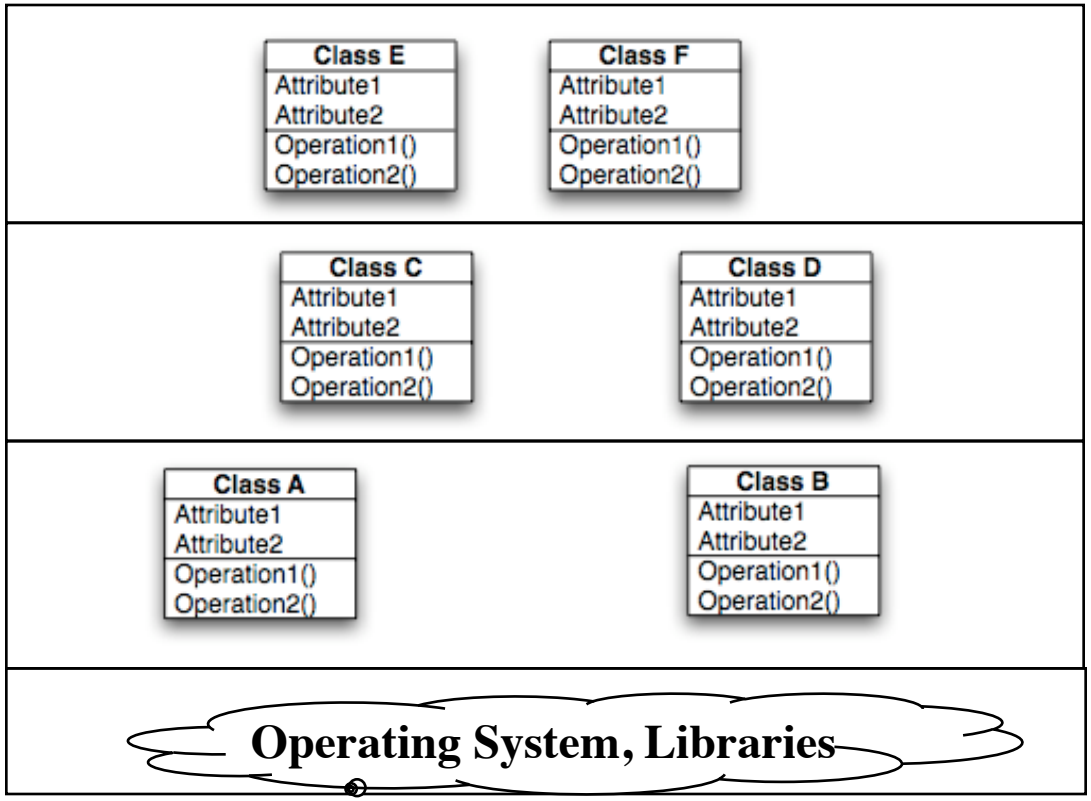
Definition: 3-Tier Architecture

- A software architecture where the 3 layers are allocated on 3 separate hardware nodes

- Note: Layer is a type (e.g. class, subsystem) and Tier is an instance (e.g. object, hardware node)
- Layer and Tier are often used interchangeably.

Virtual Machines in 3-Layered Architectural Style

A 3-Layered Architectural Style is a hierarchy of 3 virtual machines usually called presentation, application and data layer



Presentation Layer (Client Layer)

Application Layer (Middleware, Business Logic)

Data Layer

Existing System

Example of a 3-Layered Architectural Style

- Three-Layered Architectural style are often used for the development of Websites:
  1. The Web Browser implements the user interface
  2. The Web Server serves requests from the web browser
  3. The Database manages and provides access to the persistent data.

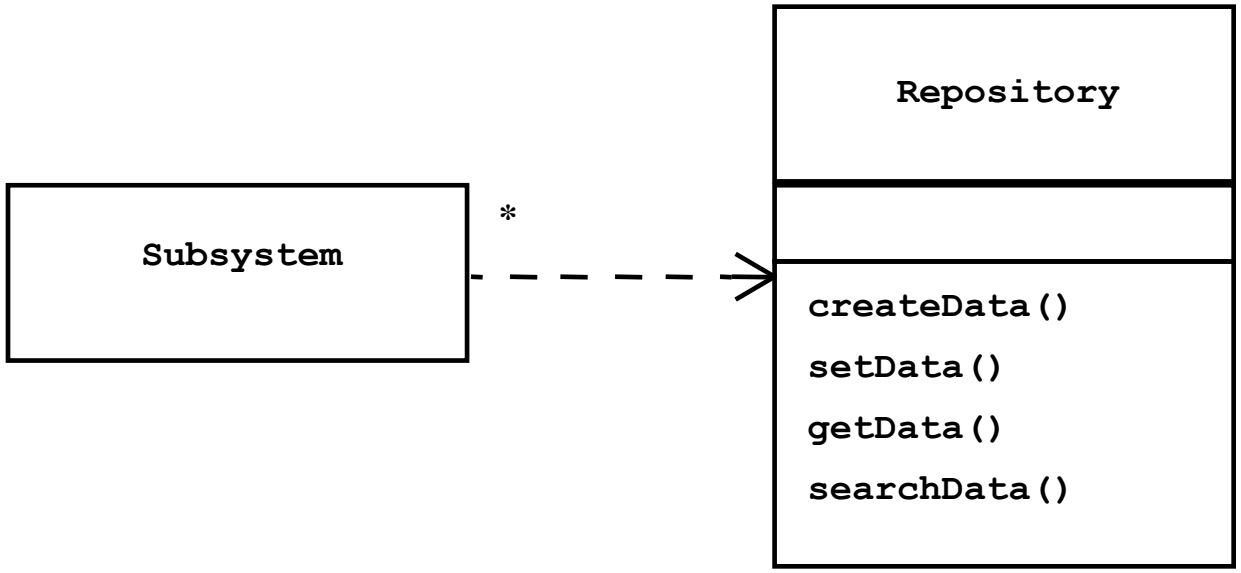
Example of a 4-Layered Architectural Style

4-Layer-architectural styles are usually used for the development of electronic commerce sites. The layers are

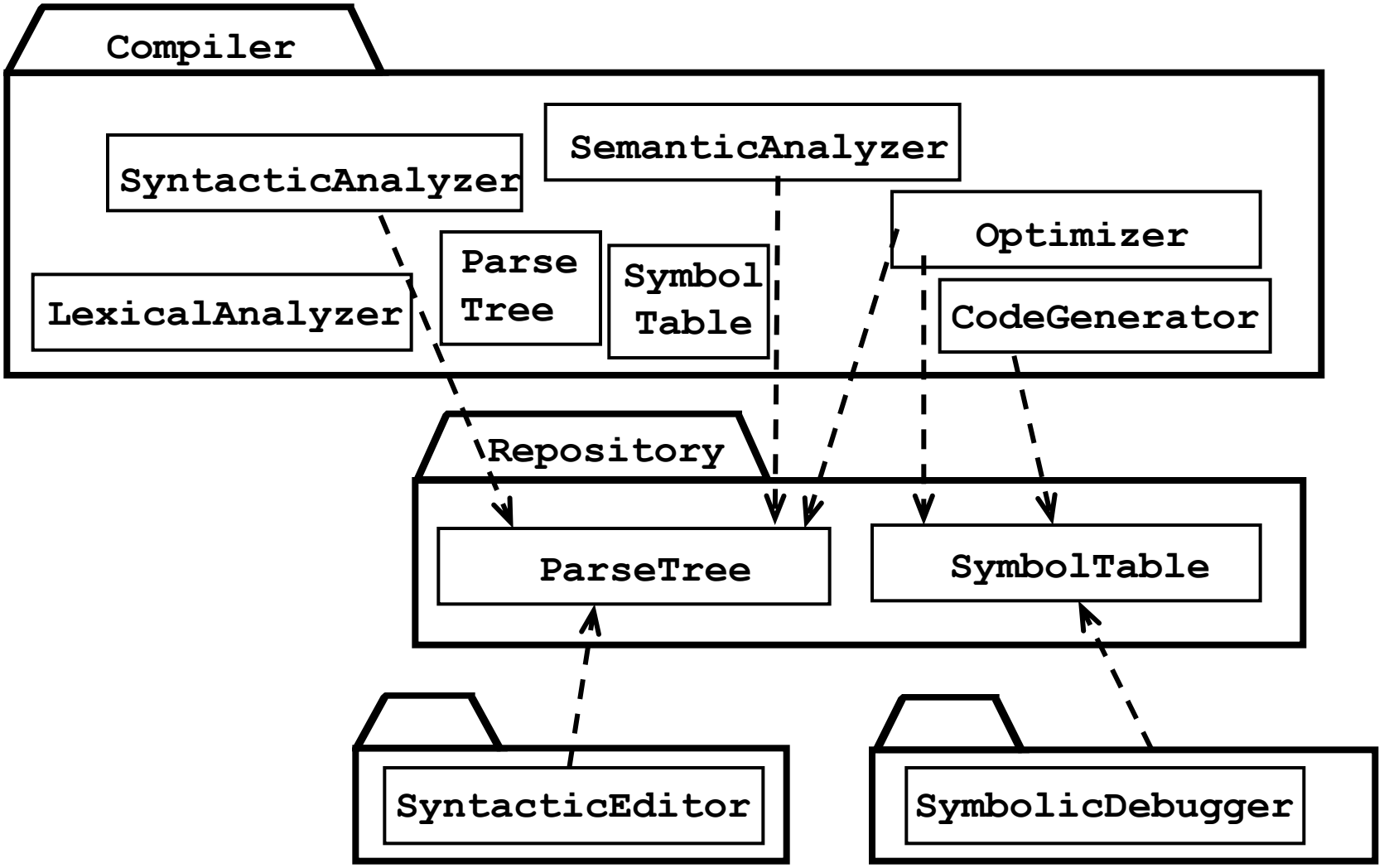
1. The Web Browser, providing the user interface
2. A Web Server, serving static HTML requests
3. An Application Server, providing session management (for example the contents of an electronic shopping cart) and processing of dynamic HTML requests
4. A back end Database, that manages and provides access to the persistent data
   - In commercially available 4-tier architectures, this is usually a relational database management system (RDBMS).

Repository Architectural Style

- The basic idea behind this architectural style is to support a collection of independent programs that work cooperatively on a common data structure called the repository
- Subsystems access and modify data from the repository. The subsystems are loosely coupled (they interact only through the repository).



Repository Architecture Example: Incremental Development Environment (IDE)



From Repository to Blackboard

- The repository architectural style does not specify any control
  - The control flow is dictated by the repository through triggers or by the subsystems through locks and synchronization primitives
- In the blackboard architectural style, we can model the controller more explicitly
  - This style is used for solving problems for which an algorithmic solution does not (yet) exist
  - => Buschmann et al 1995
  - => WS 2009-10: Patterns in Software Engineering

Model-View-Controller Architectural Style

- Problem: In systems with high coupling changes to the user interface (boundary objects) often force changes to the entity objects (data)
  - The user interface cannot be reimplemented without changing the representation of the entity objects
  - The entity objects cannot be reorganized without changing the user interface
- Solution: Decoupling! The model-view-controller (MVC) style decouples data access (entity objects) and data presentation (boundary objects)
    - Views: Subsystems containing boundary objects
    - Model: Subsystem with entity objects
    - Controller: Subsystem mediating between Views (data presentation) and Models (data access).

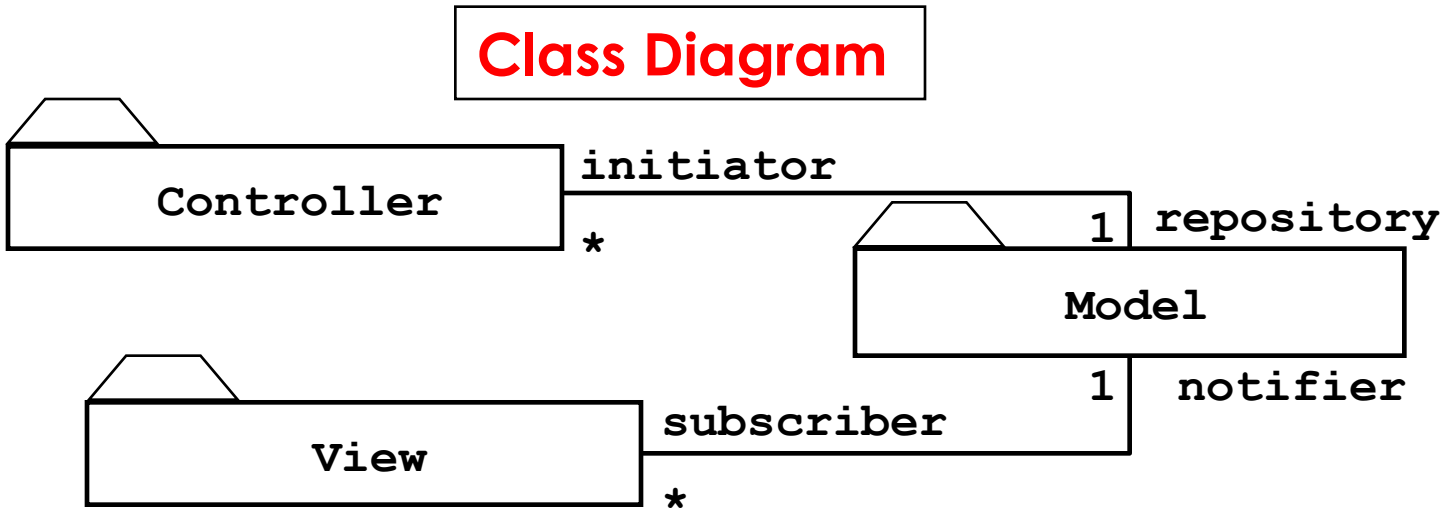
Model-View-Controller Architectural Style

- Subsystems are classified into 3 different types

  Model subsystem: Responsible for application domain knowledge

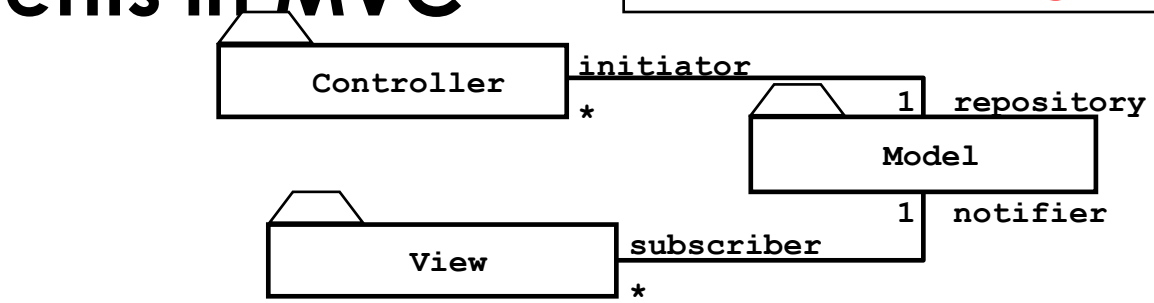
  View subsystem: Responsible for displaying information to the user

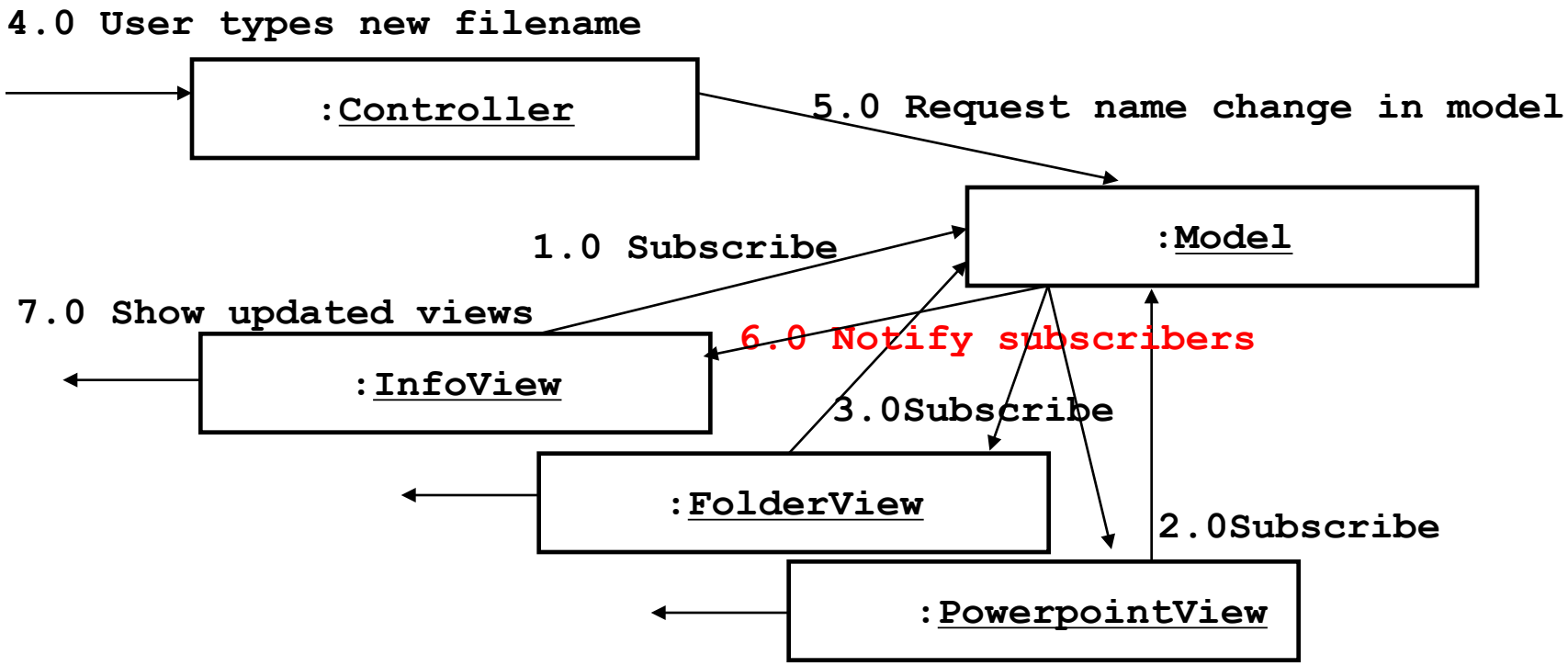
  Controller subsystem: Responsible for interacting with the user and notifying views of changes in the model



Example: Modeling the Sequence of Events in MVC

UML Class Diagram





UML Communication Diagram

Review: UML Communication Diagram

- A Communication Diagram visualizes the interactions between objects as a flow of messages. Messages can be events or calls to operations
- Communication diagrams describe the static structure as well as the dynamic behavior of a system:
  - The static structure is obtained from the UML class diagram
    - Communication diagrams reuse the layout of classes and associations in the class diagram
  - The dynamic behavior is obtained from the dynamic model (UML sequence diagrams and UML statechart diagrams)
    - Messages between objects are labeled with a number and placed near the link the message is sent over
- Reading a communication diagram involves starting at message 1.0, and following the messages from object to object.

MVC vs. 3-Tier Architectural Style

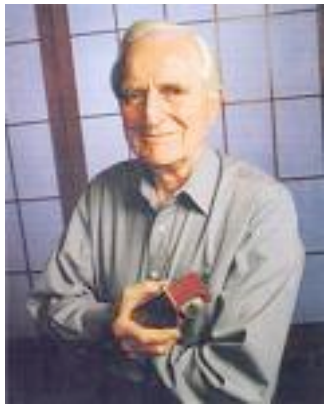
- The MVC architectural style is nonhierarchical (triangular):
  - View subsystem sends updates to the Controller subsystem
  - Controller subsystem updates the Model subsystem
  - View subsystem is updated directly from the Model
- The 3-tier architectural style is hierarchical (linear):
  - The presentation layer never communicates directly with the data layer (opaque architecture)
  - All communication must pass through the middleware layer
- History:
  - MVC (1970-1980): Originated during the development of modular graphical applications for a single graphical workstation at Xerox Parc
  - 3-Tier (1990s): Originated with the appearance of Web applications, where the client, middleware and data layers ran on physically separate platforms.

Xerox Parc

Xerox PARC (Palo Alto Research Center)

Founded in 1970 by Xerox, since 2002 a separate company PARC (wholly owned by Xerox). Best known for the invention of

- Laser printer (1973, Gary Starkweather)
- Ethernet (1973, Bob Metcalfe)
- Modern personal computer (1973, Alto, Bravo)
- Graphical user interface (GUI) based on WIMP
  - Windows, icons, menus and pointing device
    - Based on Doug Engelbart´s invention of the mouse in 1965



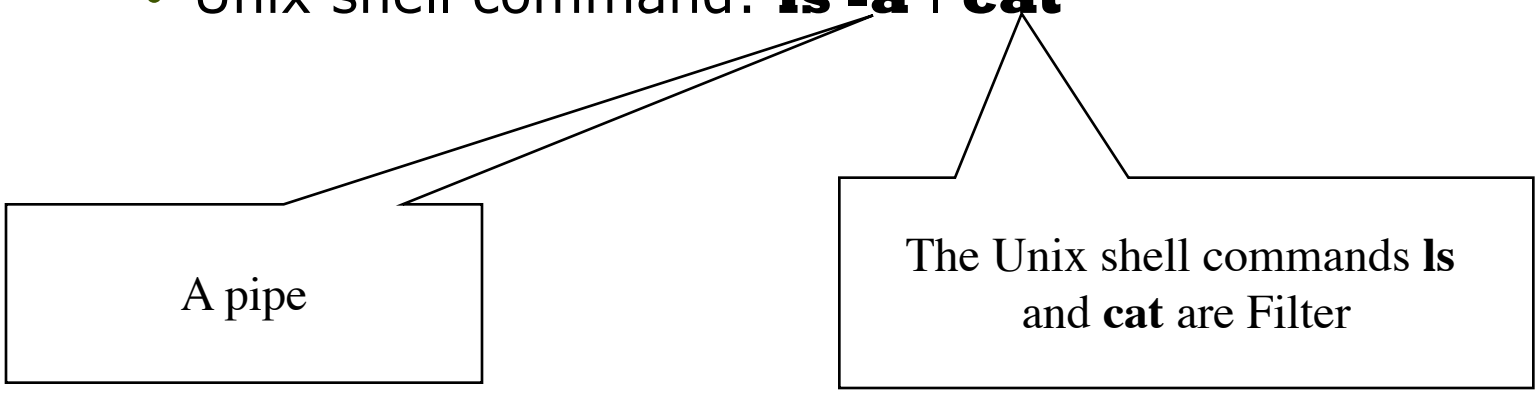
- Object-oriented programming (Smalltalk, 1970s, Adele Goldberg)
- Ubiquitous computing (1990, Mark Weiser).

Pipes and Filters

- A pipeline consists of a chain of processing elements (processes, threads, etc.), arranged so that the output of one element is the input to the next element
  - Usually some amount of buffering is provided between consecutive elements
  - The information that flows in these pipelines is often a stream of records, bytes or bits.

Pipes and Filters Architectural Style

- An architectural style that consists of two subsystems called pipes and filters
  - **Filter:** A subsystem that does a processing step
  - **Pipe:** A Pipe is a connection between two processing steps
- Each filter has an input pipe and an output pipe.
  - The data from the input pipe are processed by the filter and then moved to the output pipe
- Example of a Pipes-and-Filters architecture: Unix
  - Unix shell command: **ls -a** | **cat**



Summary

- System Design
  - Reduces the gap between problem and existing machine
- Design Goals
  - Describe important system qualities and values against which alternative designs are evaluated (design-tradeoffs)
  - Additional nonfunctional requirements found at design time
- Subsystem Decomposition
  - Decomposes the overall system into manageable part by using the principles of cohesion and coherence
- Architectural Style
  - A pattern for a subsystem decomposition: All kind of layer styles (C/S, SOA, n-Tier), Repository, MVC, Pipes&Filters
- Software architecture
  - An instance of an architectural style.

Additional Readings

- E.W. Dijkstra (1968)
  - The structure of the T.H.E Multiprogramming system, Communications of the ACM, 18(8), pp. 453-457
- D. Parnas (1972)
  - On the criteria to be used in decomposing systems into modules, CACM, 15(12), pp. 1053-1058
- J.D. Day and H. Zimmermann (1983)
  - The OSI Reference Model,Proc. IEEE, Vol.71, 1334-1340
- Jostein Gaarder (1991)
  - Sophie‘s World: A Novel about the History of Philosophy
- Frank Buschmann et al:
  - Pattern-Oriented Software Architecture, Vol 1: A System of Patterns, Wiley, 1996.