Software Engineering I: Software Technology

WS 2008/09

System Design and Software Architecture

Bernd Bruegge
Applied Software Engineering
Technische Universitaet Muenchen

Where are we?

- We have covered Ch 1 - 4
- We are moving to Chapter 5 and 6.

Munich Airport

- Sign up for the tour of the Munich Airport
- 3 possible slots, each of them between 10:30 and 12:30 o‘clock.

  1. December 08

  11 December 08

  12 December 08

Why is Design so Difficult?

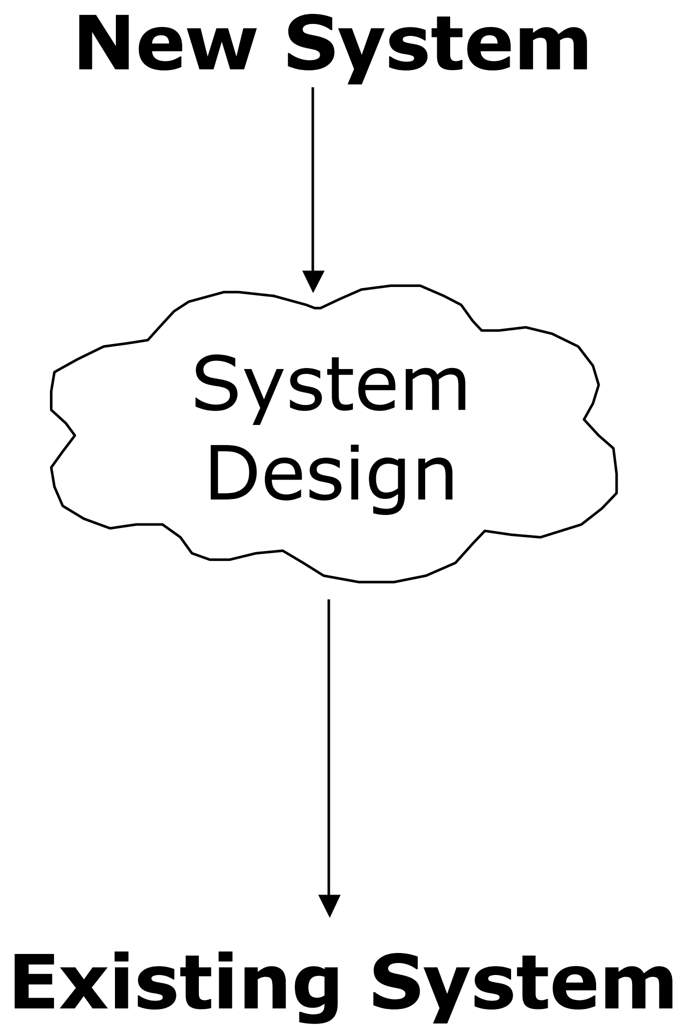
- Analysis: Focuses on the application domain
  - Relatively stable
- Design: Focuses on the solution domain
  1. The solution domain is changing very rapidly
     - Halftime knowledge in software engineering: About 3-5 years
  2. Cost of hardware rapidly sinking
  3. Design knowledge is a moving target
  4. Design must be done in a specific time

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

The Scope of System Design

Bridge the gap

- between a new system and an existing system in a manageable way



How?

- Use Divide & Conquer:
  1) Identify design goals
  2) Model the new system as a set of subsystems
  3-8) Address the major design goals.

System Design: Eight Issues

System Design

1. Identify Design Goals
- Identify Additional Nonfunc-
  tional Requirements
- Discuss 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 Decisions
- Network Connectivity

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

**6. Global Resource
Handlung**
- Access Control
- ACL vs Capabilities
- Security

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

**8. Boundary
Conditions**
- Initialization
- Termination
- Failure.

Overview

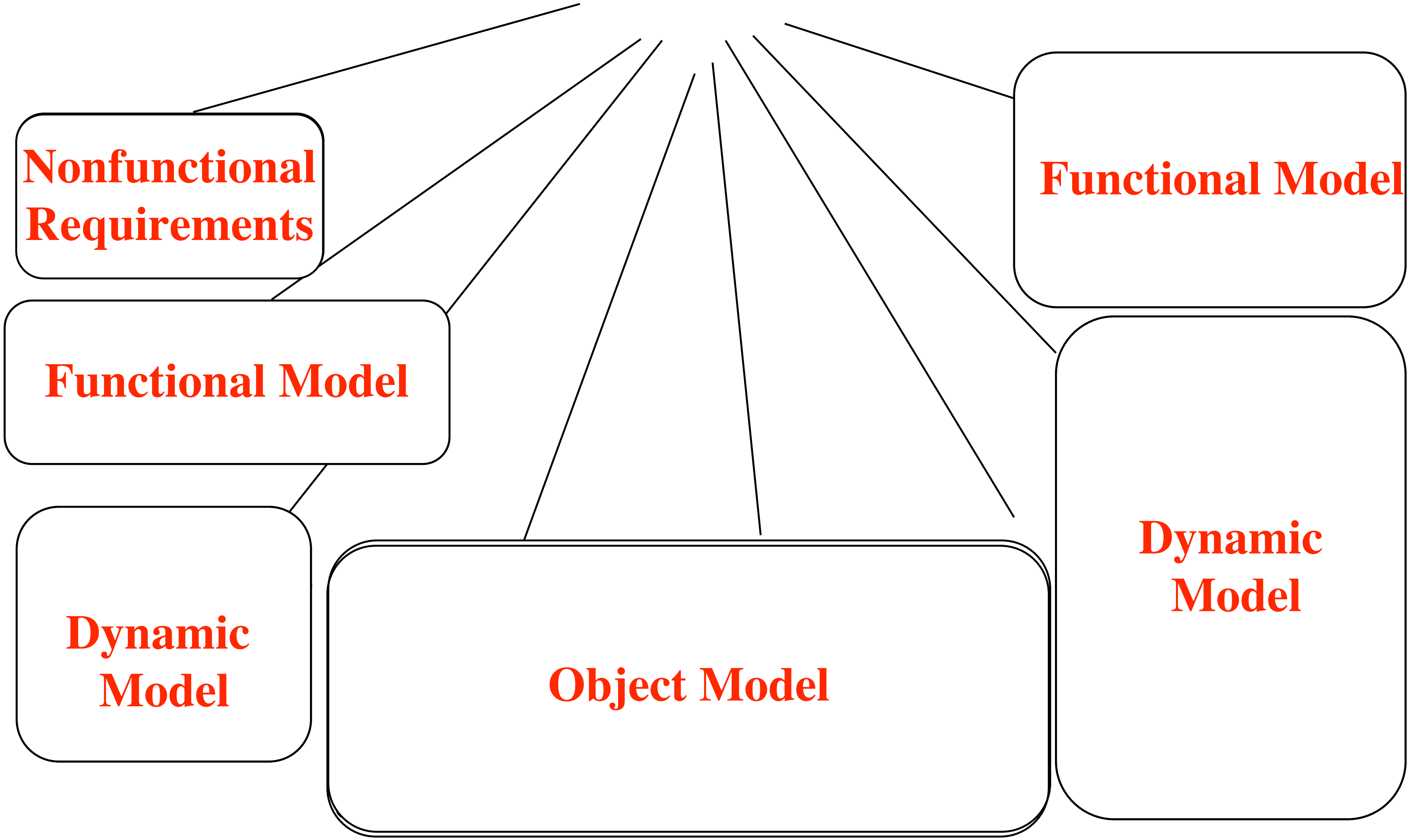
System Design I (This Lecture)

0. Overview of System Design
1. Design Goals
2. Subsystem Decomposition, Software Architecture

System Design II

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

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

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

Dynamic Model

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

Functional Model

8. Boundary Conditions
- Initialization
- Termination
- Failure

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
  - Subsystems are modeled in UML as components
- 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.

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.*

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 should be realized with the Façade pattern (=> lecture on design patterns).

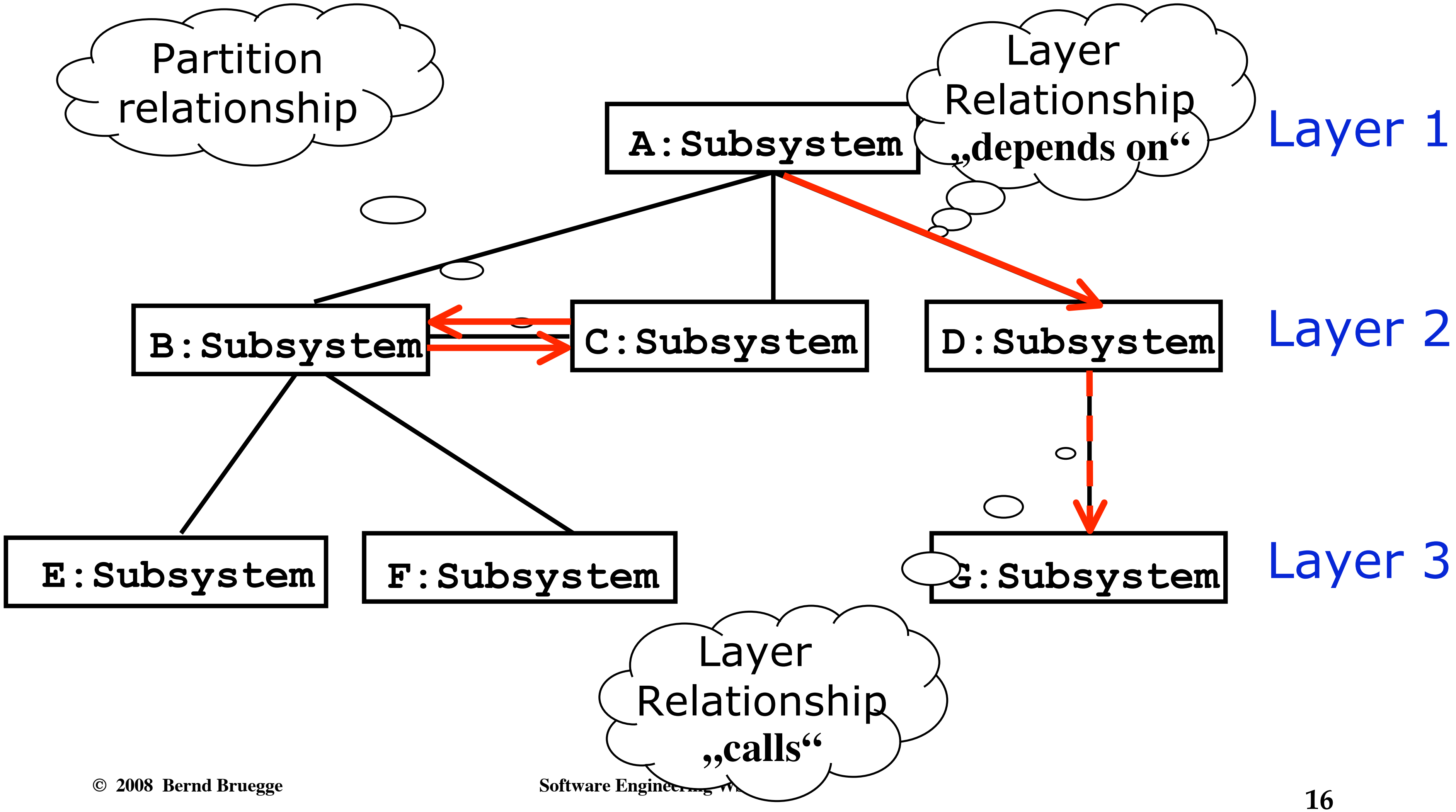
Properties of Subsystems: Layers and Partitions

- 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 (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!
- Partition relationship
  - The subsystems have mutual knowledge about each other
    - A calls services in B; B calls services in A (Peer-to-Peer) .

Example of a Subsystem Decomposition

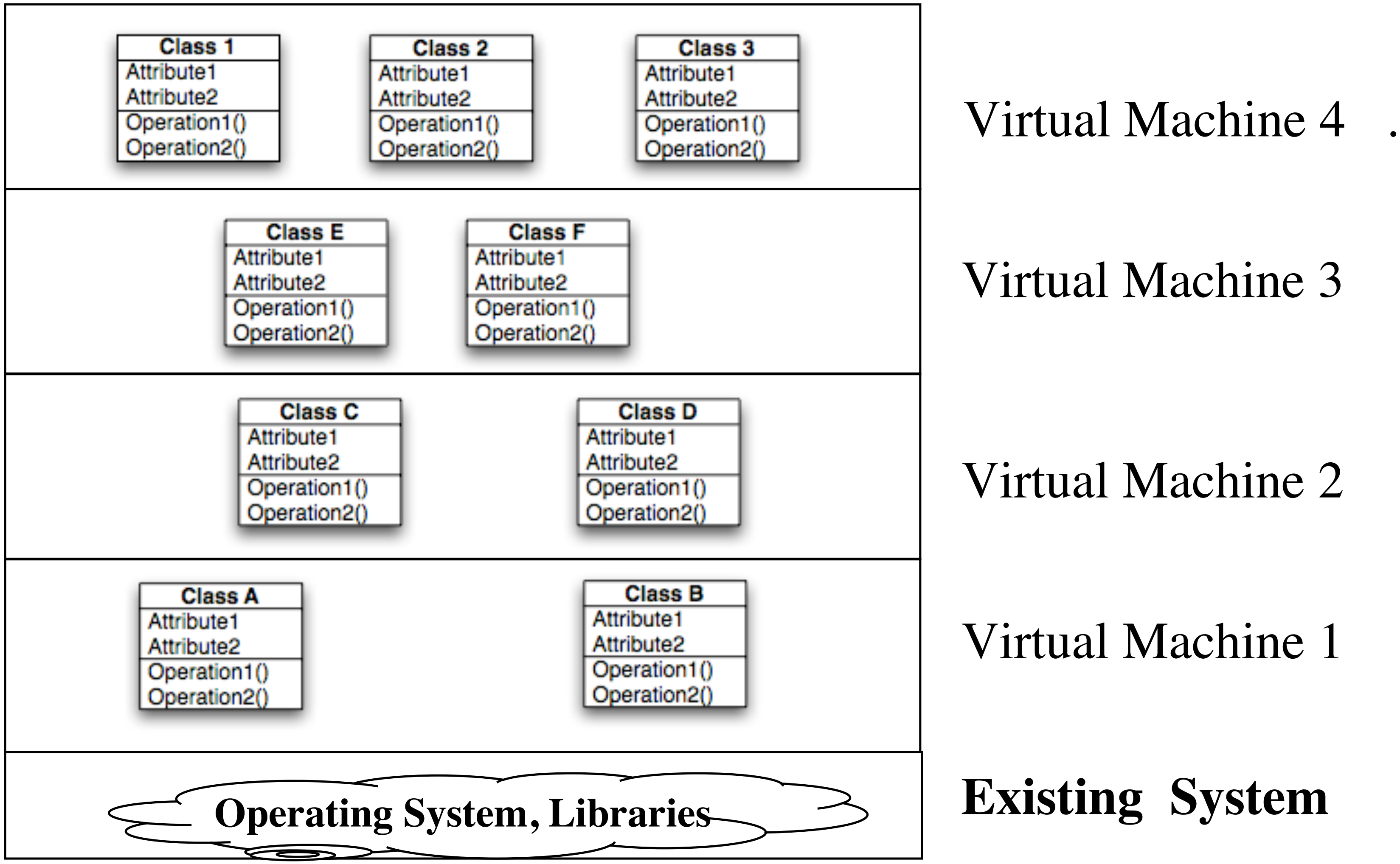


Virtual Machine

- 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”.

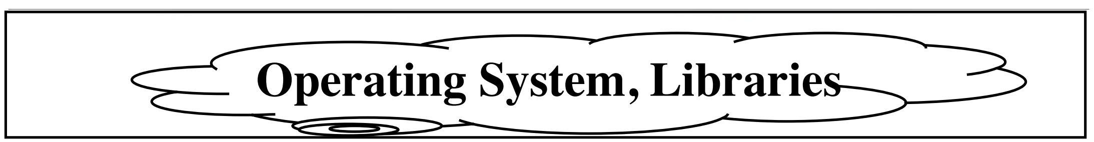
Building Systems as a Set of Virtual Machines

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



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.

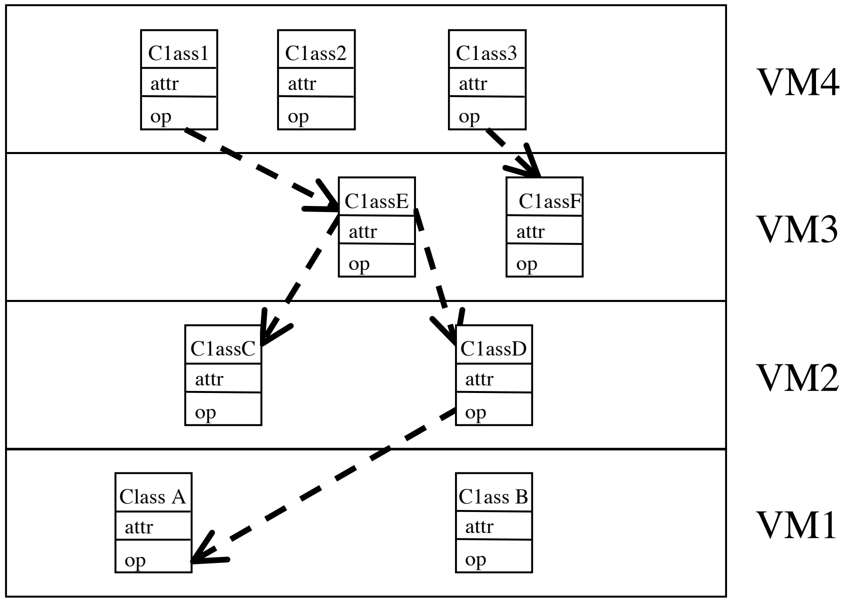


Existing System

Closed Architecture (Opaque Layering)

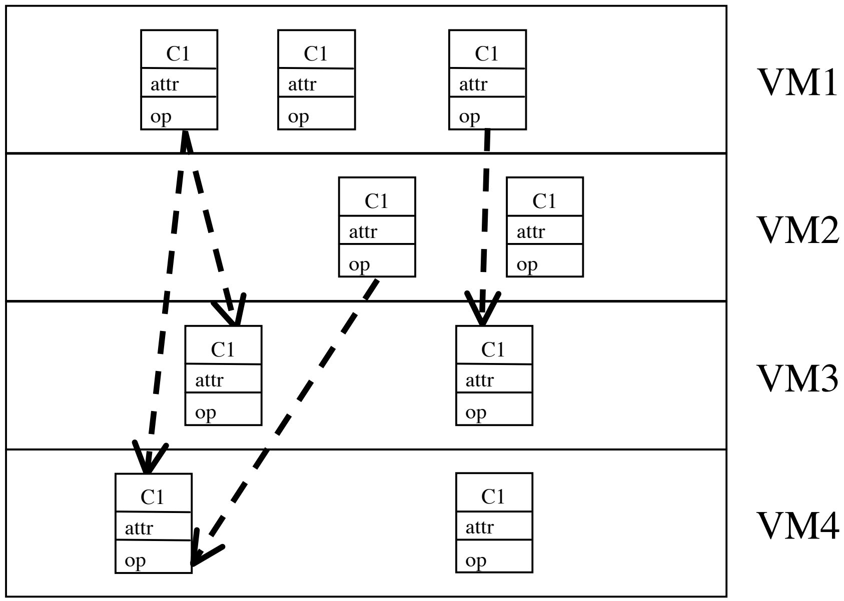
- Each virtual machine can only call operations from the layer below

Design goals: Maintainability, flexibility.



Open Architecture (Transparent Layering)

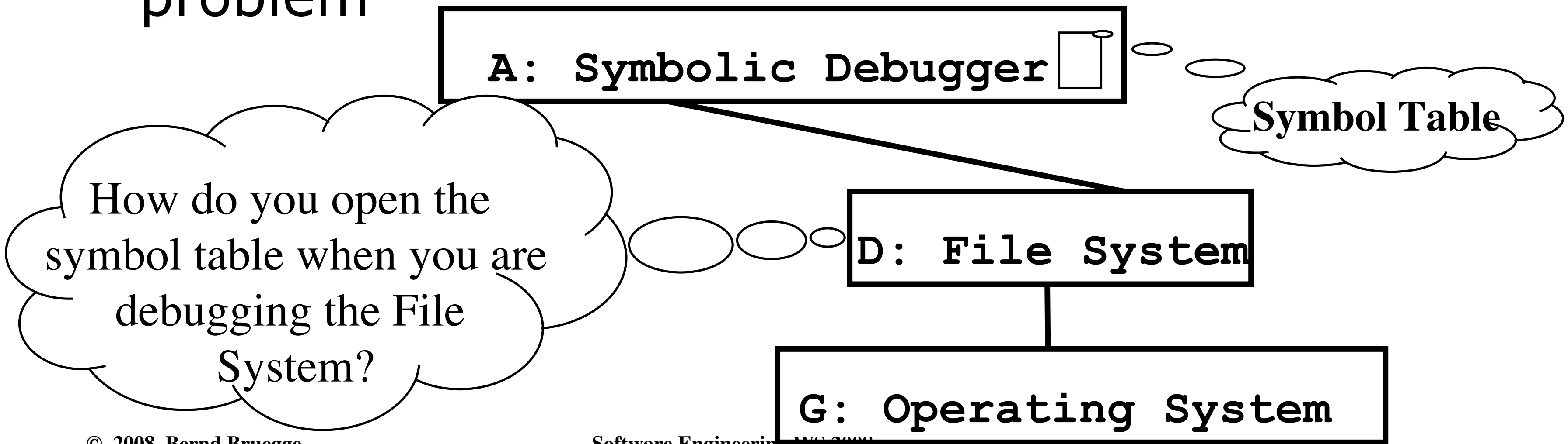
- Each virtual machine can call operations from any layer below



Design goal:
Runtime efficiency

Properties of Layered Systems

- Layered systems are hierarchical. This is a desirable design, because it reduces complexity
  - low coupling
- They have also reduced testing times
- 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

- 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 associations
  - Low coherence: Lots of miscellaneous and auxiliary classes, 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 11 07 2008

Good Design

- 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 associations
  - Low coherence: Lots of miscellaneous and auxiliary classes, 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

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.

Architectural Style & Software Architecture

- Subsystem decomposition: Identification of subsystems, services, and their relationship to each other.

- Architectural Style: A pattern for subsystem decomposition

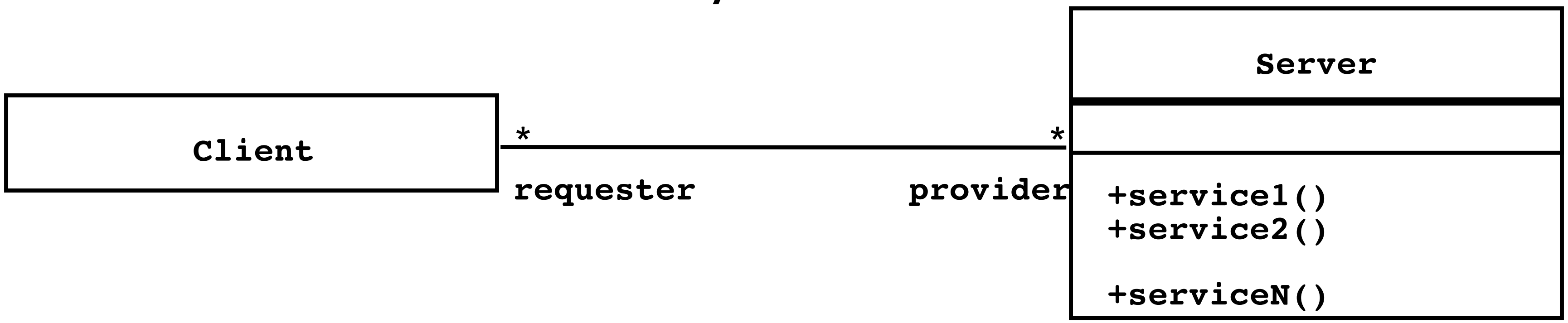
- Software Architecture: Instance of an architectural style

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.

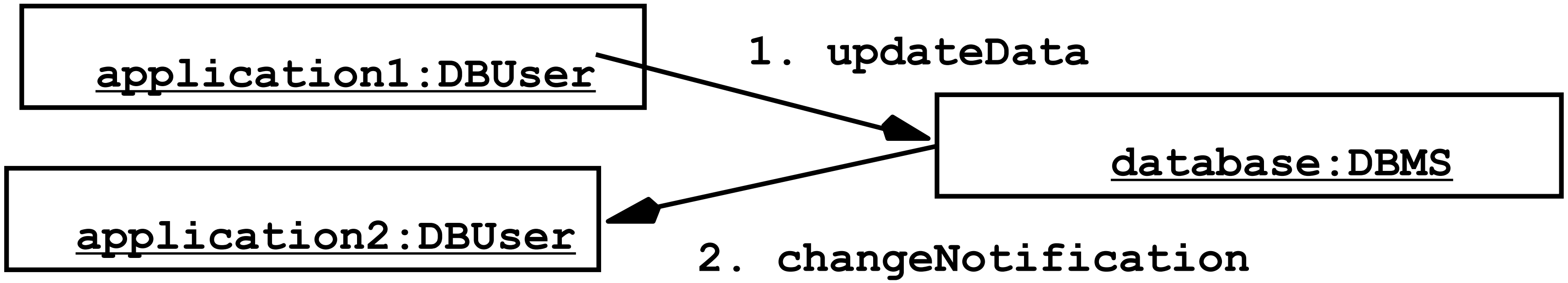


Client/Server Architectures

- 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

Problems with Client/Server Architectures

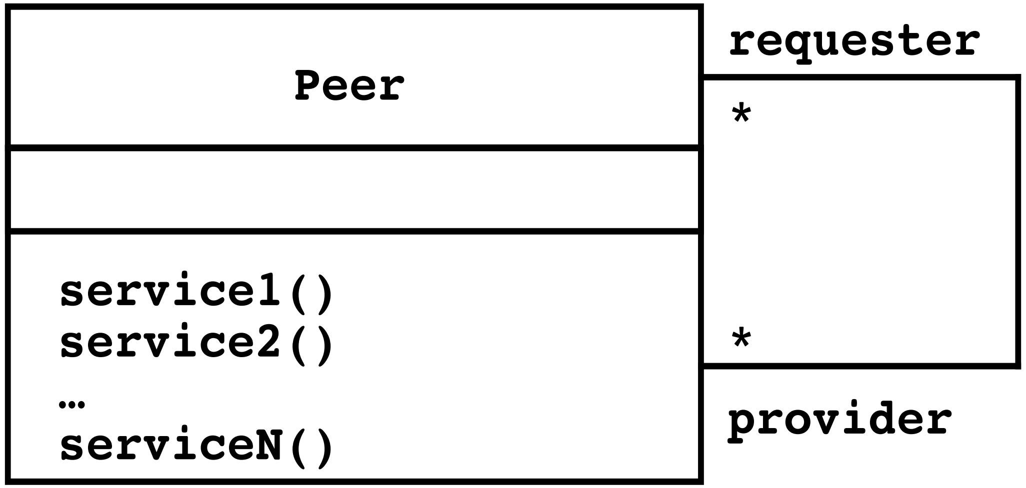
- Client/Server systems do not provide peer-to-peer communication
- Peer-to-peer communication is often needed
- Example:
  - Database must process queries from application and should be able to send notifications to the application when data have changed

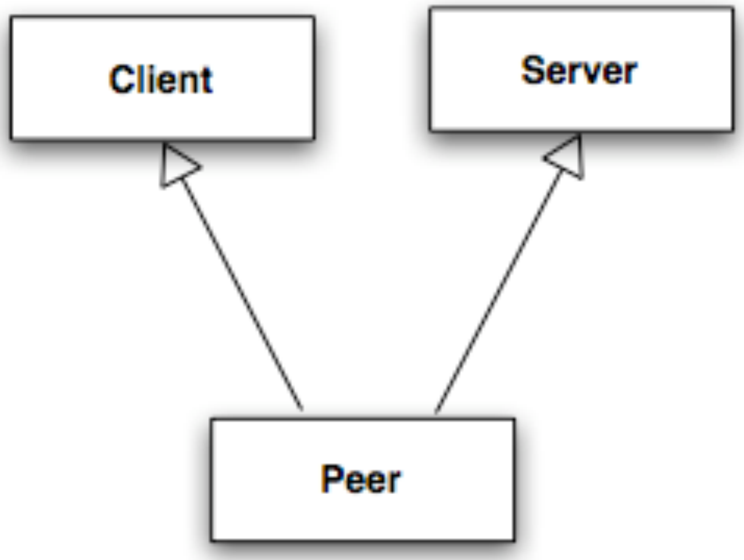


Peer-to-Peer Architectural Style

Generalization of Client/Server Architecture

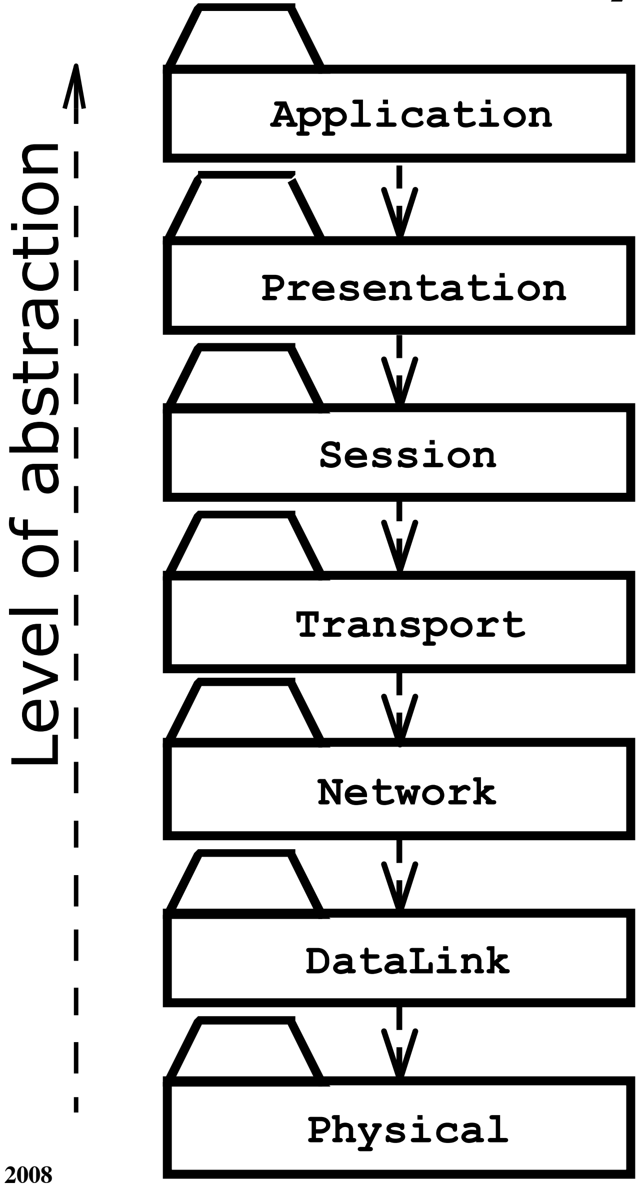
Clients can be servers and servers can be clients
=> "A peer can be a client as well as a server".





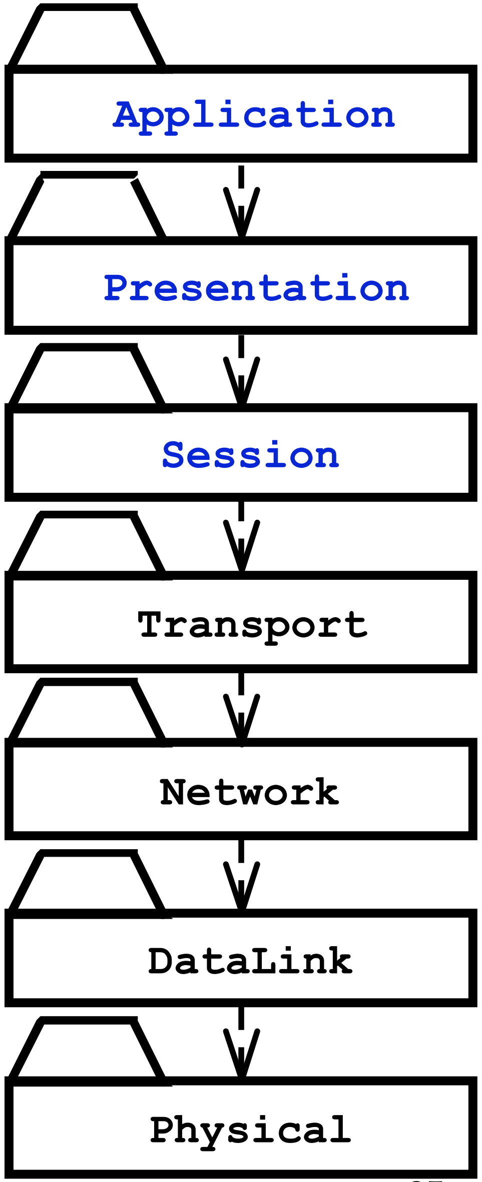
Example: Peer-to-Peer Architectural Style

- 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



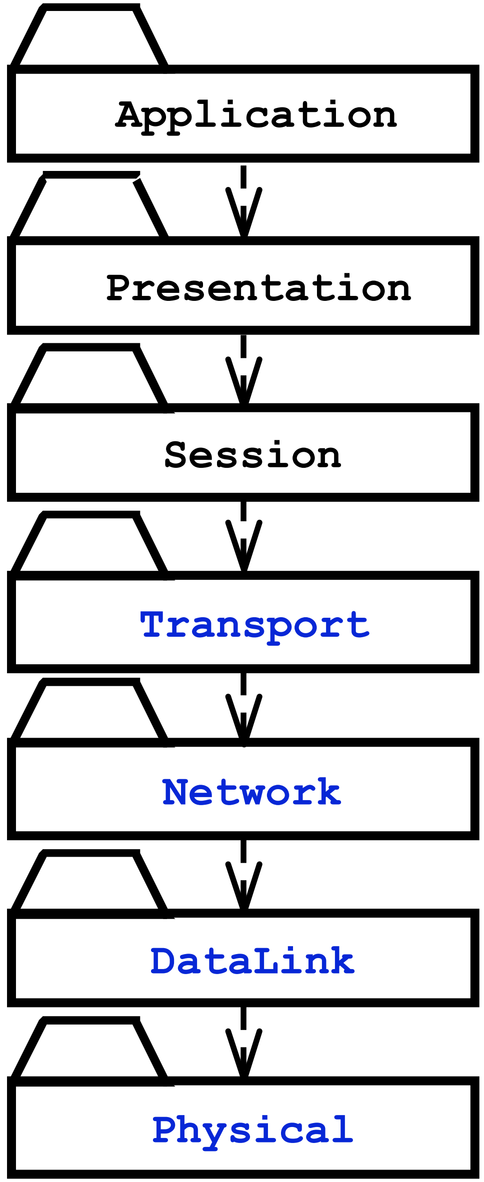
OSI Model Layers and Services

- 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

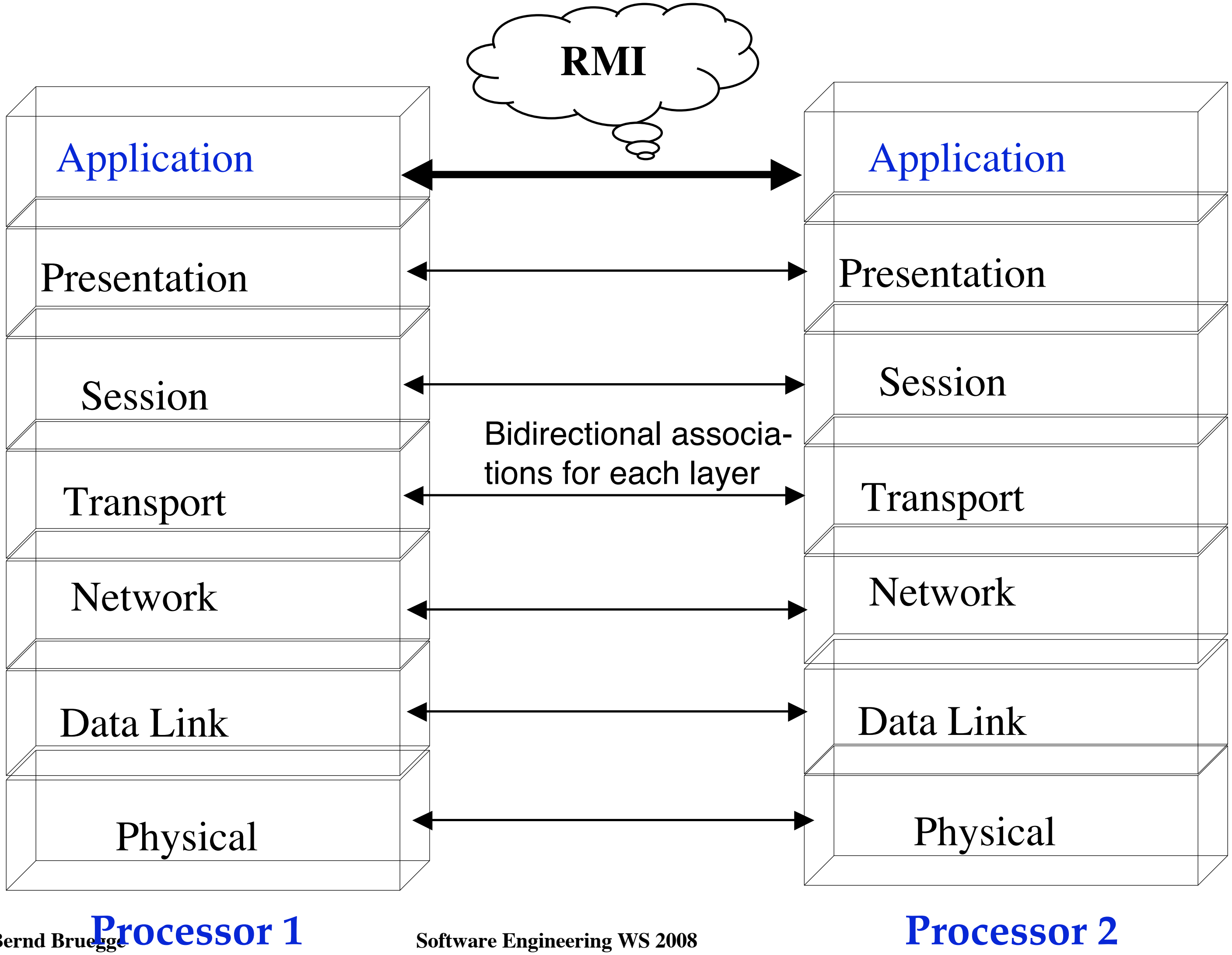


OSI Model Layers and their Services

- 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()

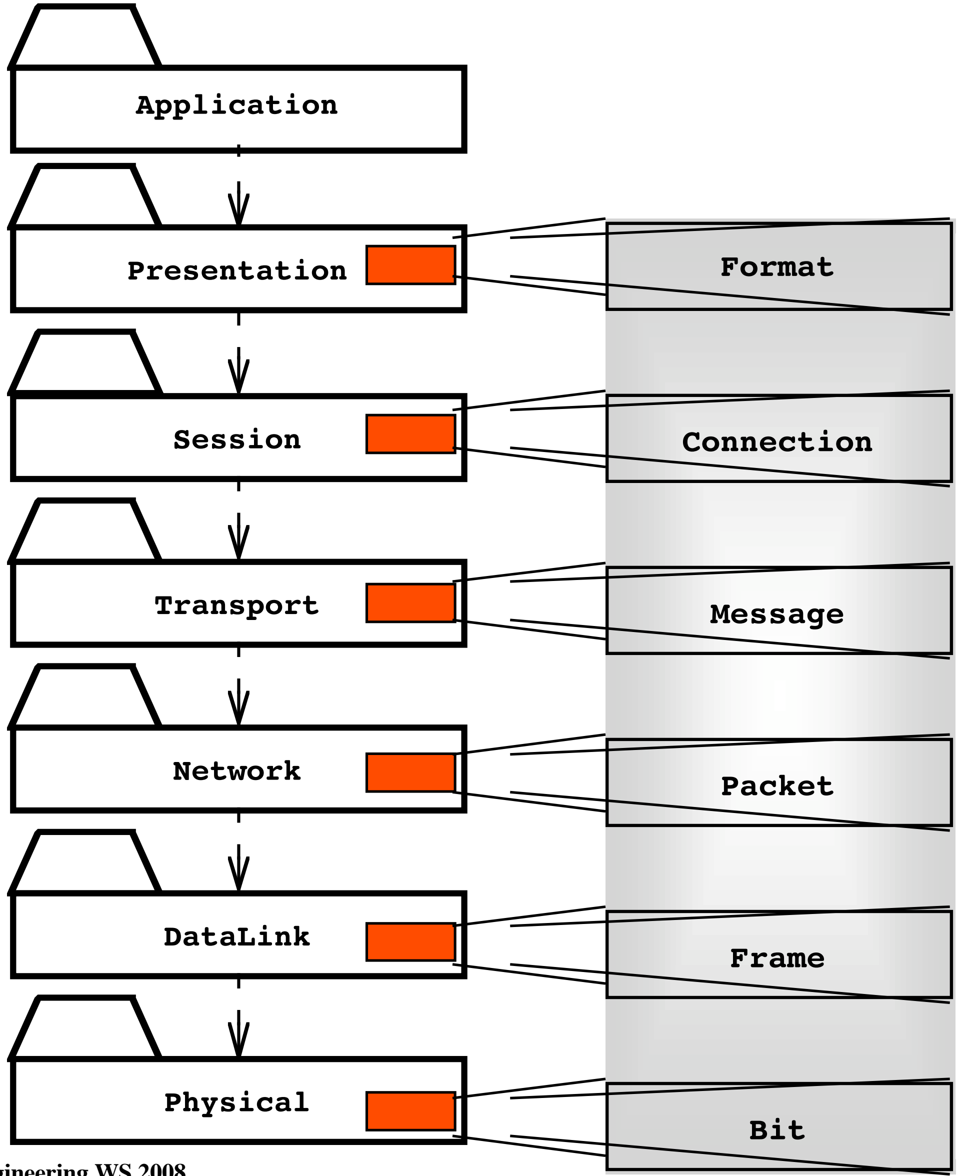


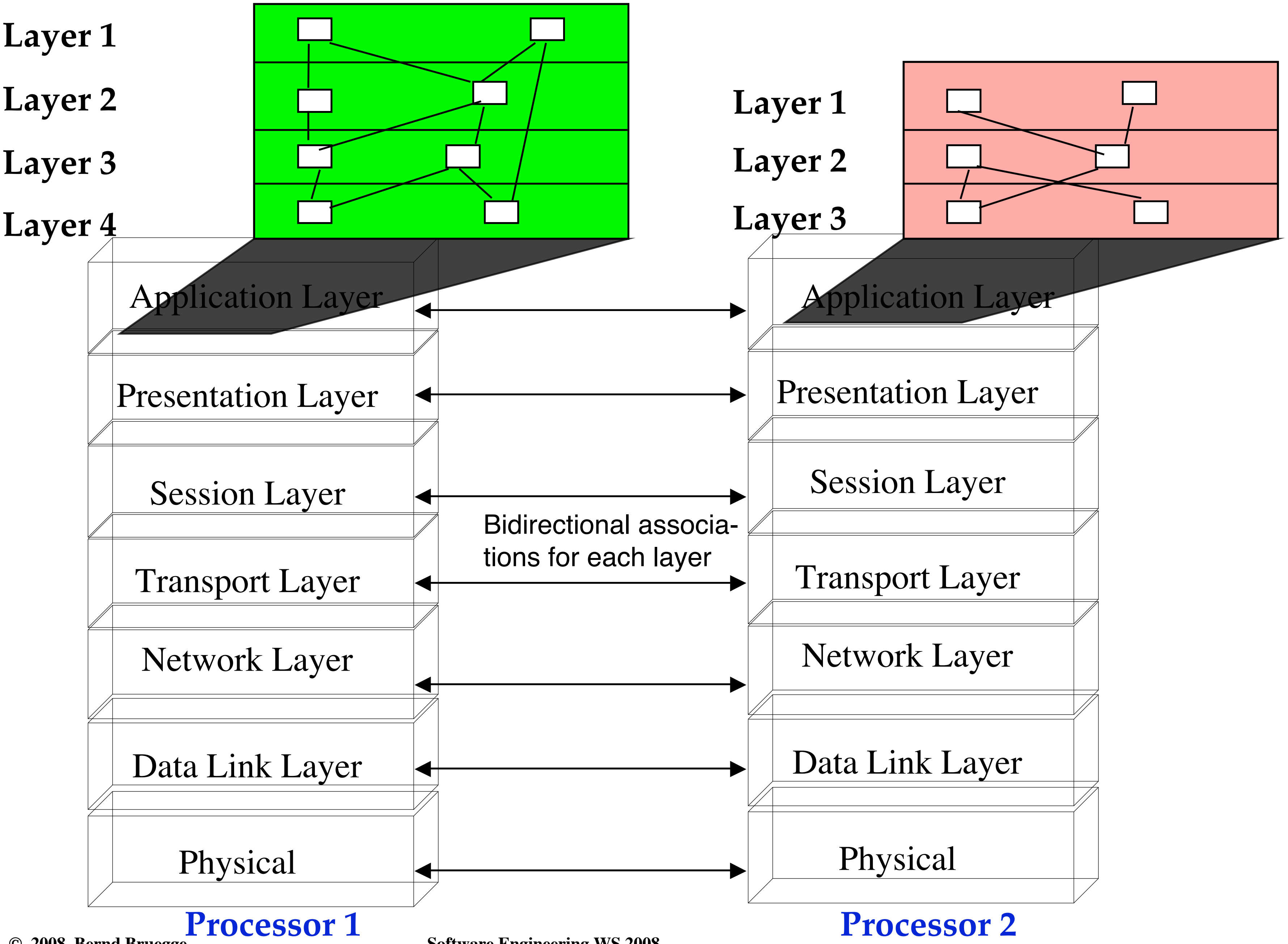
The Application Layer Provides the Abstractions of the "New System"



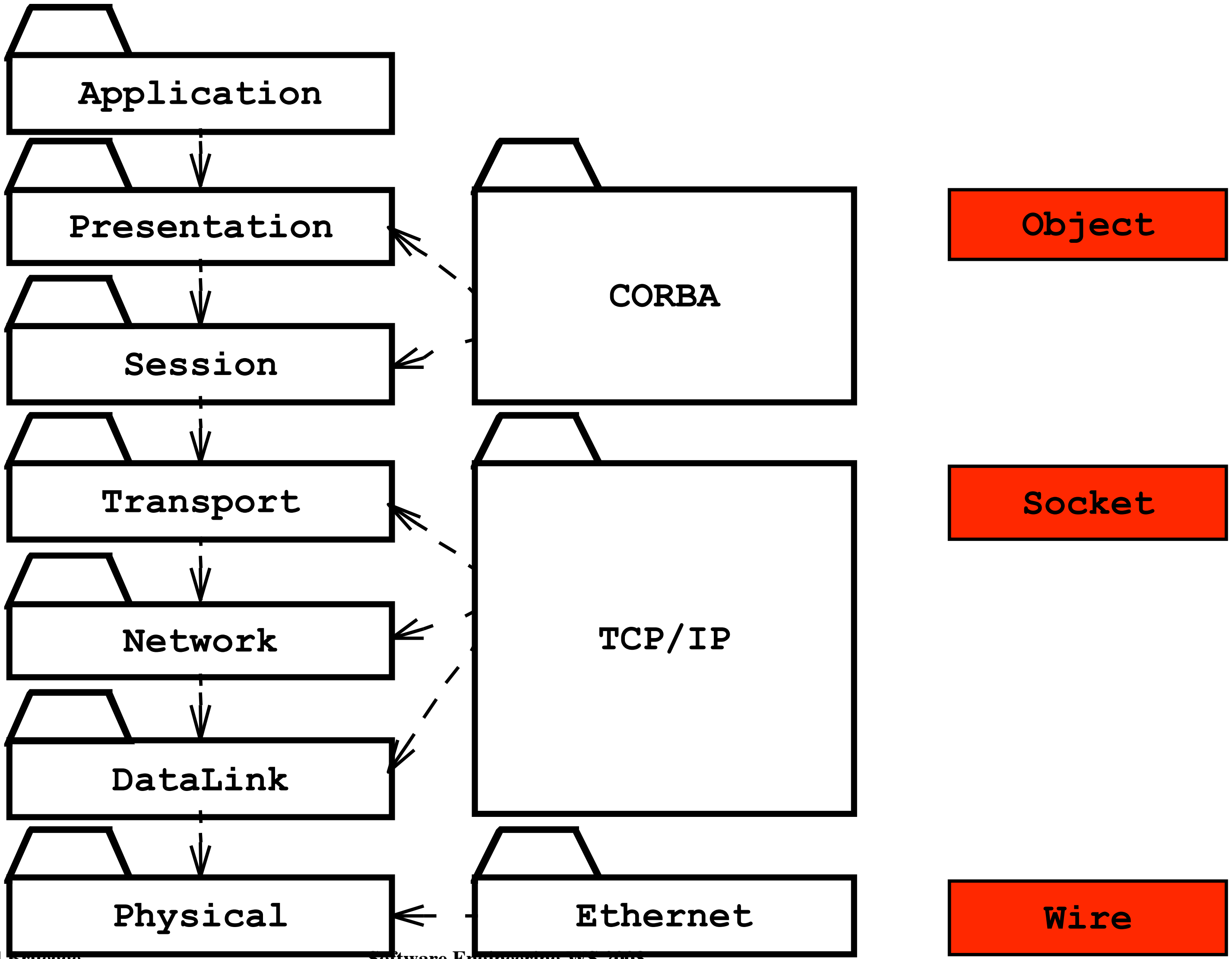
An Object-Oriented View of the OSI Model

- 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



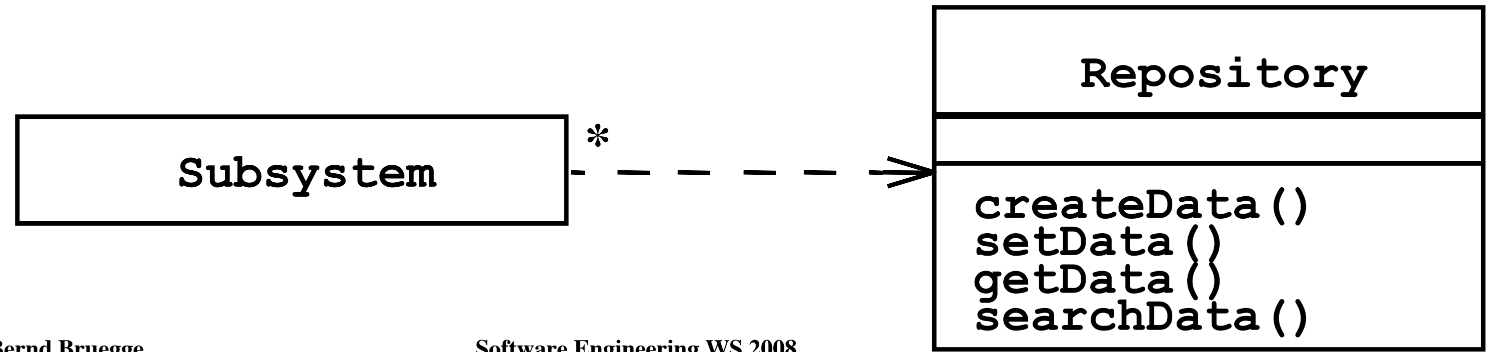

Layer 1
Layer 2
Layer 3
Layer 4
Layer 1
Layer 2
Layer 3
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical
Bidirectional associa-
tions for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

Middleware Allows Focus On Higher Layers

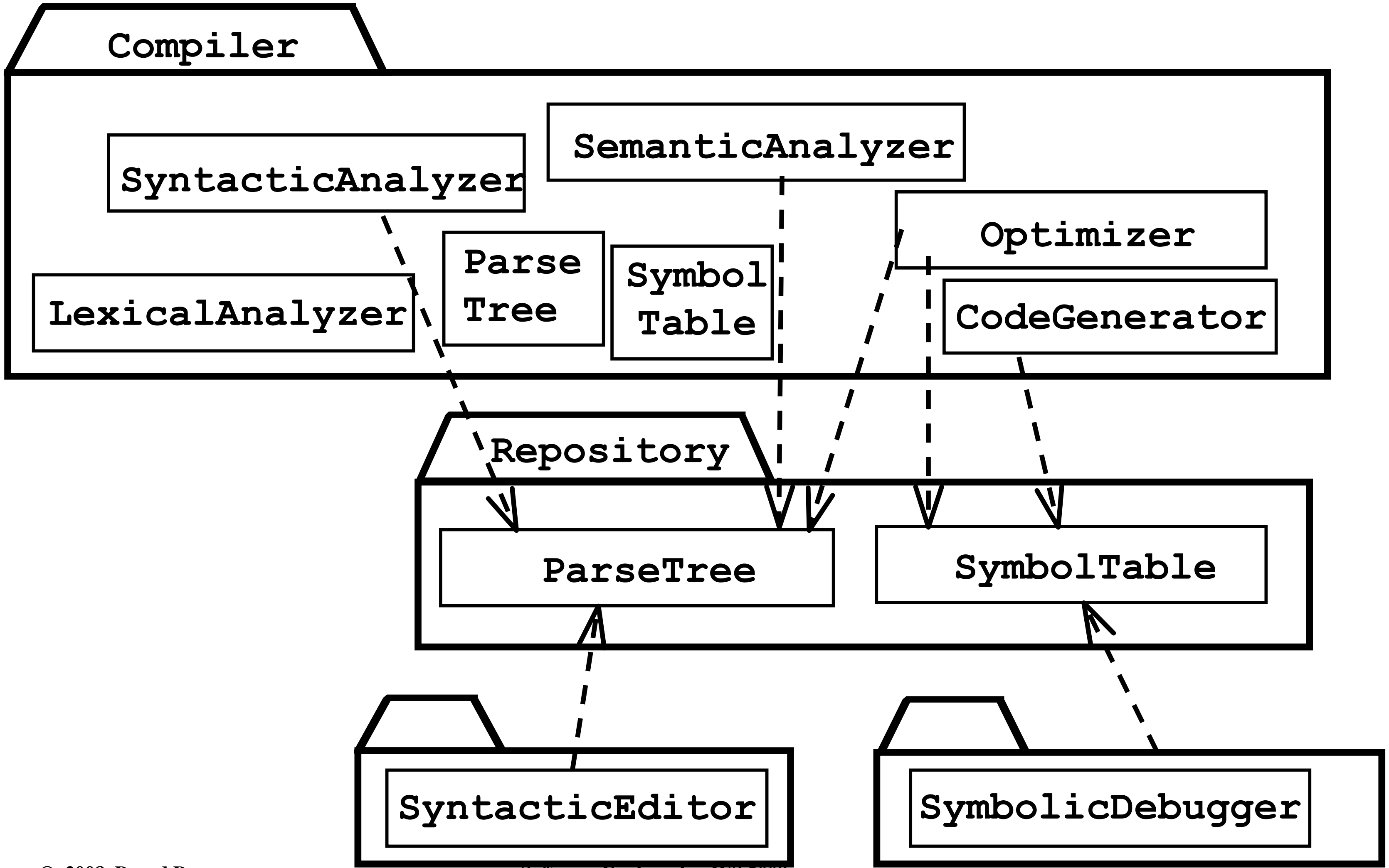


Repository Architectural Style

- Subsystems access and modify data from a single data structure called the repository
- Also called blackboard architecture
- 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



Repository Architecture Example: Incremental Development Environment (IDE)



Model-View-Controller

- Problem: Assume a system with high coupling. Then changes to the boundary objects (user interface) 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: The model-view-controller architectural style, which decouples data access (entity objects) and data presentation (boundary objects)
  - The Data Presentation subsystem is called the View
  - The Data Access subsystem is called the Model
    - So far this is the observer pattern!
  - The Controller is a new subsystem that mediates between View (data presentation) and Model (data access)
- Often called MVC.

Model-View-Controller Architectural Style

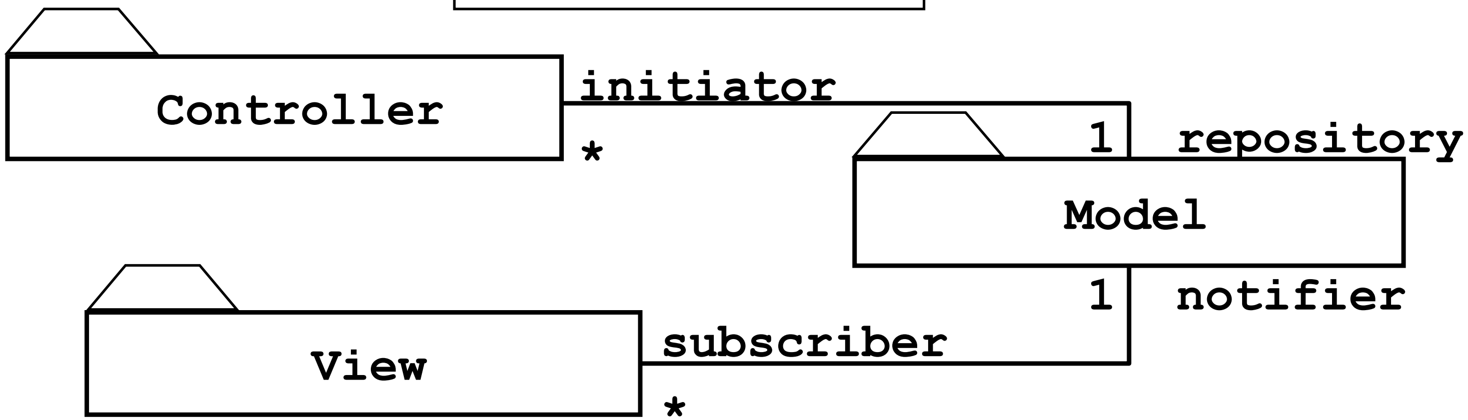
- Subsystems are classified into 3 different types

  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

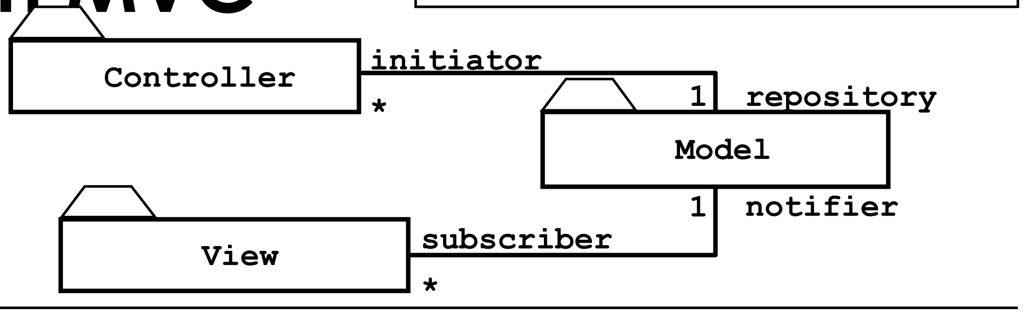
Class Diagram

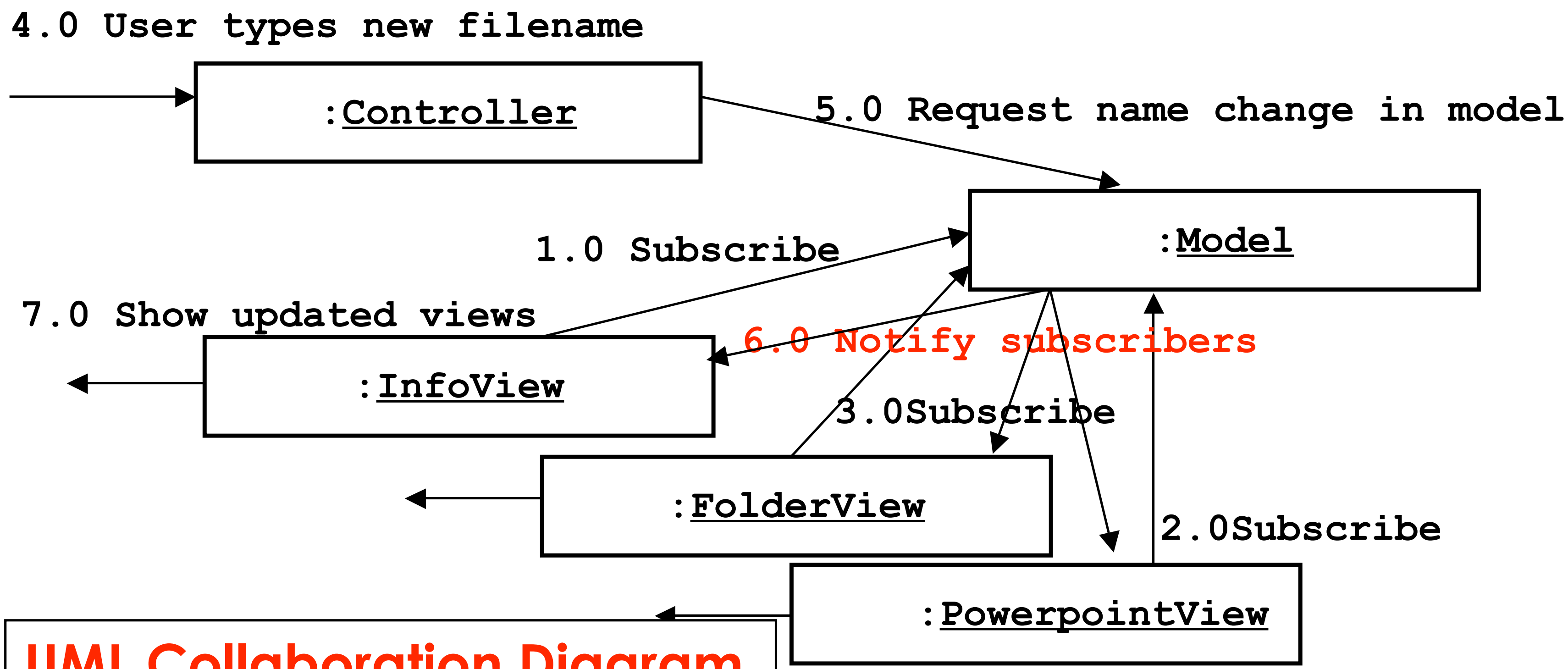


Better understanding with a Collaboration Diagram

Example: Modeling the Sequence of Events in MVC

UML Class Diagram





UML Collaboration Diagram

3-Layer-Architectural Style
3-Tier Architecture

Definition: 3-Layer Architectura 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

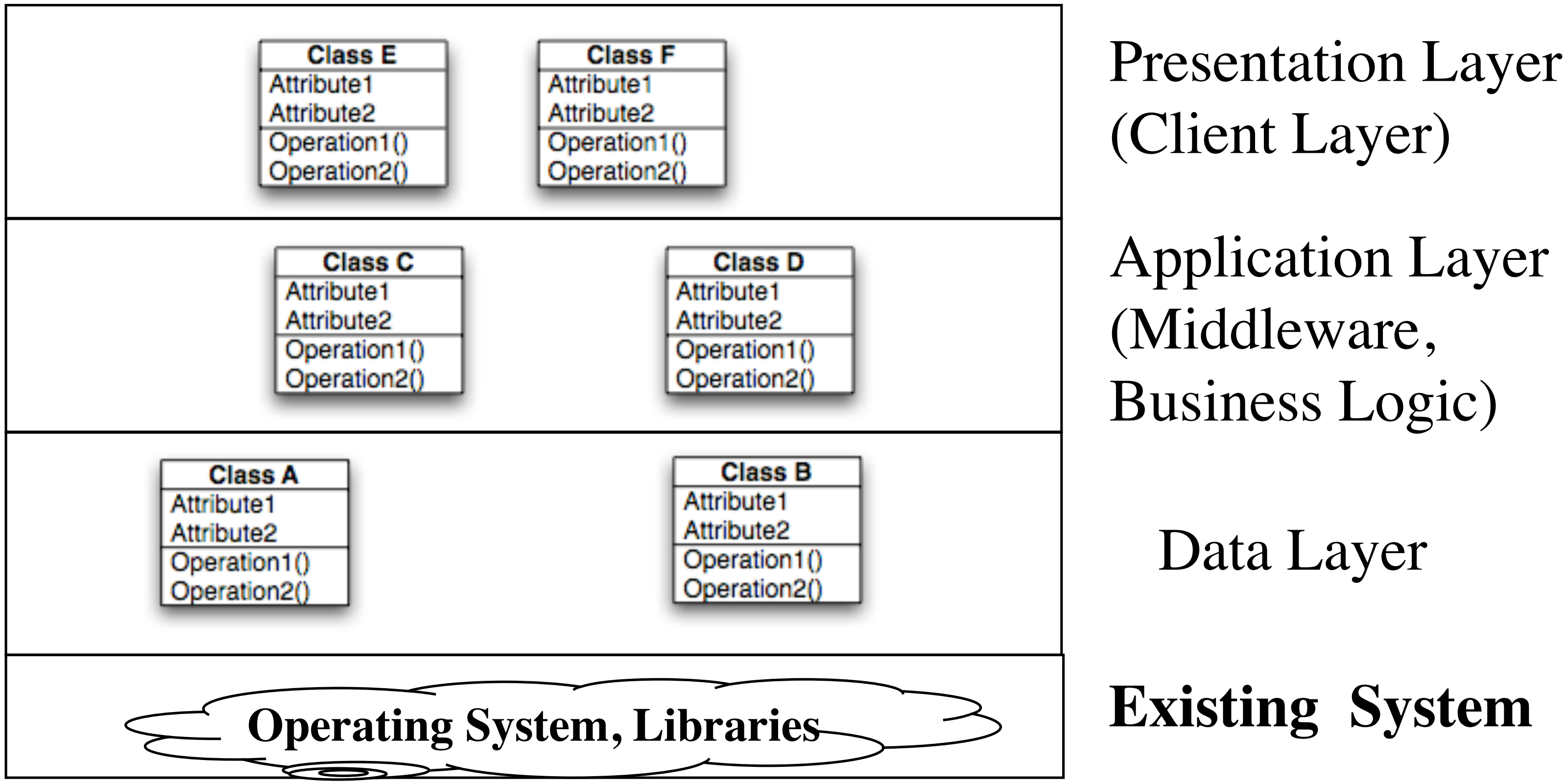
Definition: 3-Tier Architecture

- 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-Layer Architectural Style

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



Example of a 3-Layer Architectural Style

- Three-Layer 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-Layer Architectural Style

4-Layer-architectural styles (4-Tier Architectures) 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 current 4-tier architectures, this is usually a relational Database management system (RDBMS).

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 subsystem
- 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

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
- L.D. Erman, F. Hayes-Roth (1980)
  - The Hearsay-II-Speech-Understanding System, ACM Computing Surveys, Vol 12. No. 2, pp 213-253
- 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.

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, Model-View-Controller.