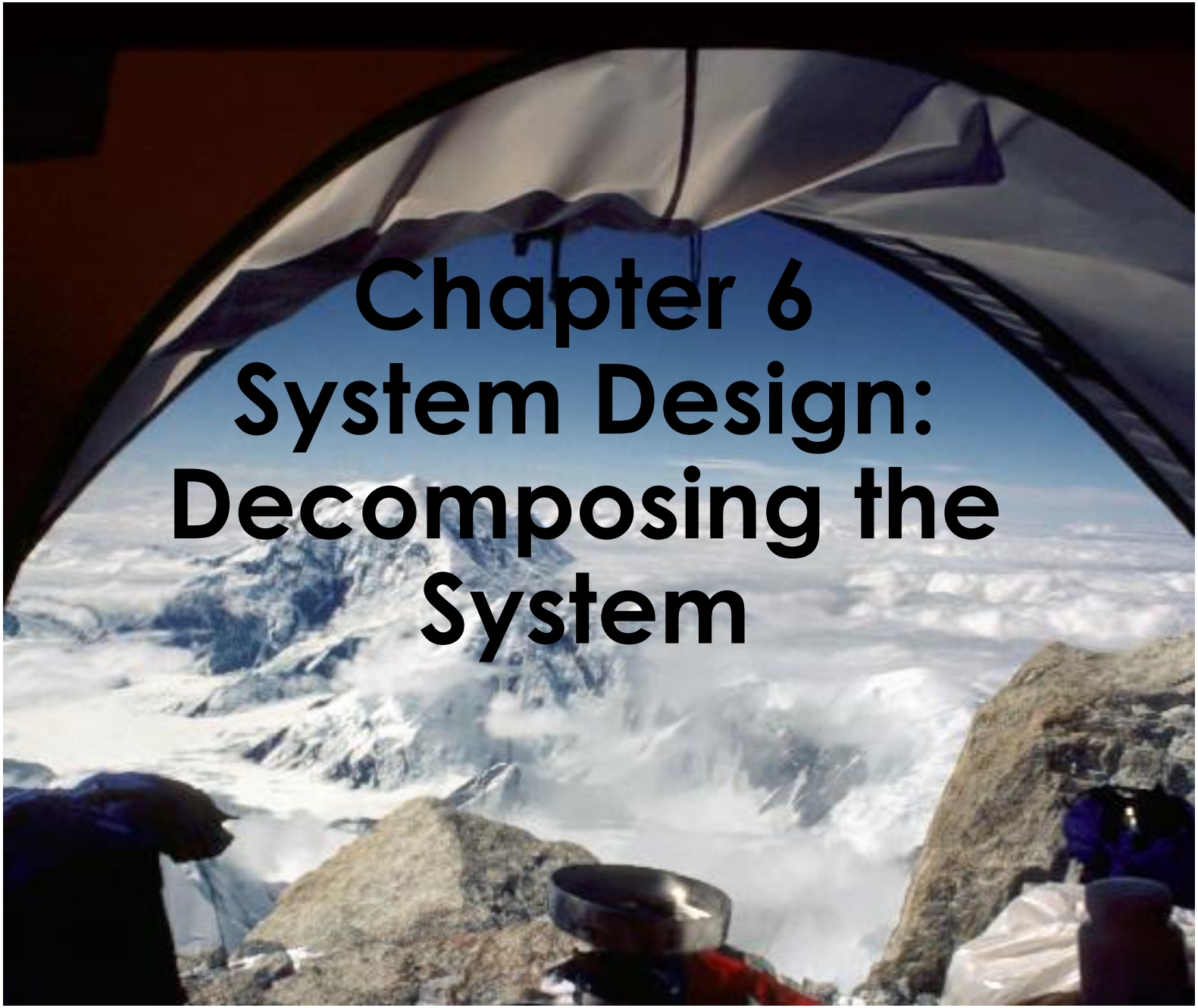
Object-Oriented Software Engineering
Using UML, Patterns, and Java



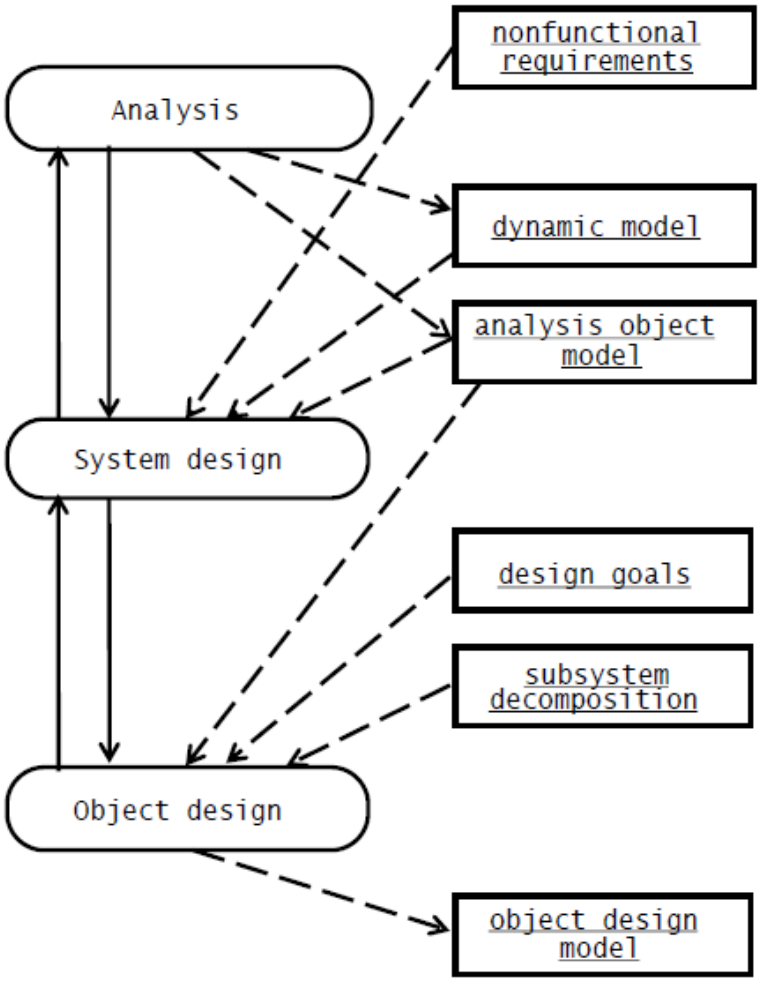
Chapter 6
System Design: Decomposing the System

Requirements Elicitation & Analysis results in;

- **Non-functional requirements and constraints**
- **Use-case model (functional model)**
- **Object Model**
- **Dynamic model**

The activities of System design;

- **Identify design goals**
- **Design the initial subsystem decomposition**
- **Refine the subsystem decomposition to address design goals**



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".

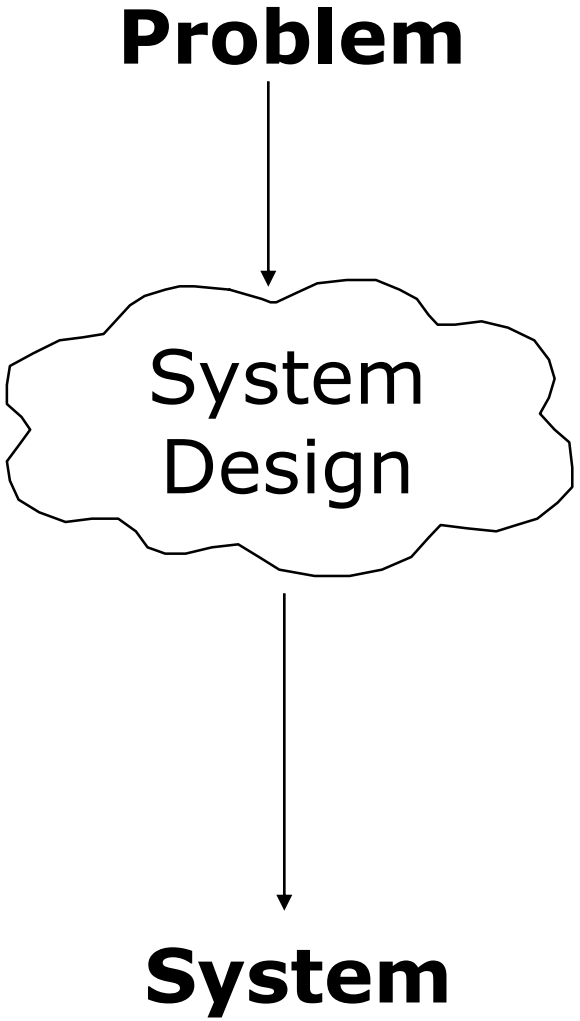
Why is Design so Difficult?

- 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
  - ➢ Design knowledge is a moving target

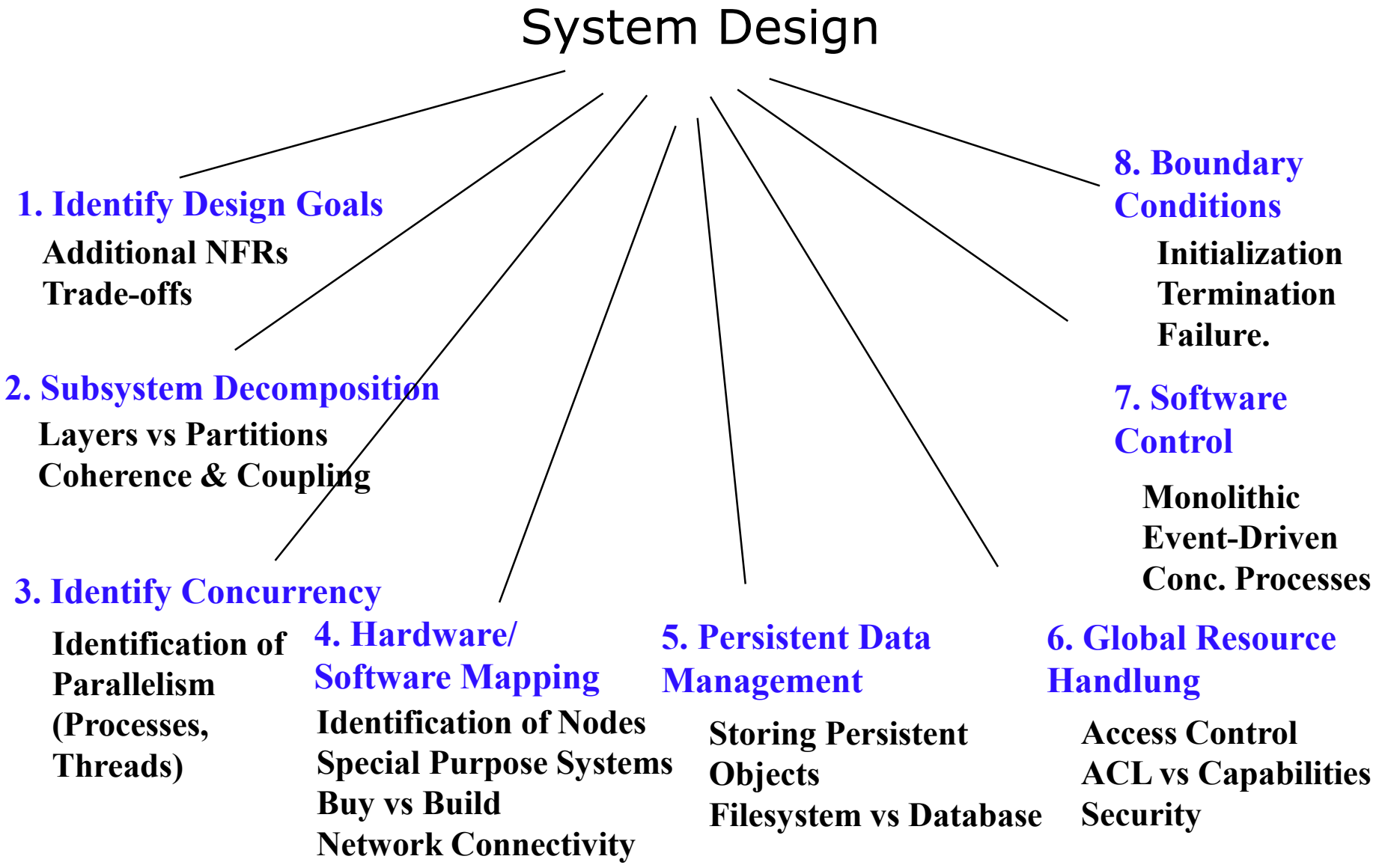
The Scope of System Design

- Bridge the gap
  - between a problem and an 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

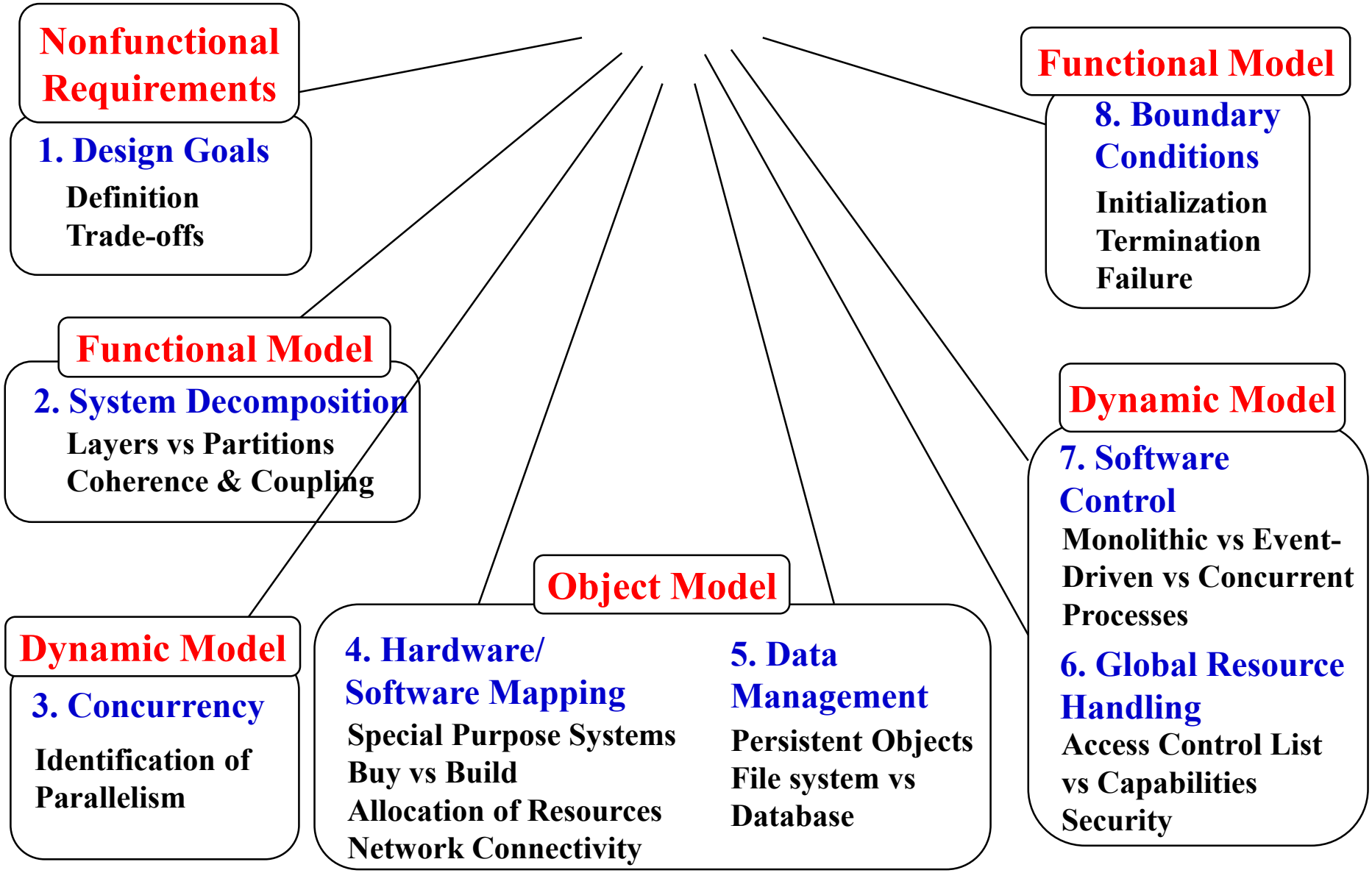
System Design I (This Lecture)

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

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.

From Analysis to System Design



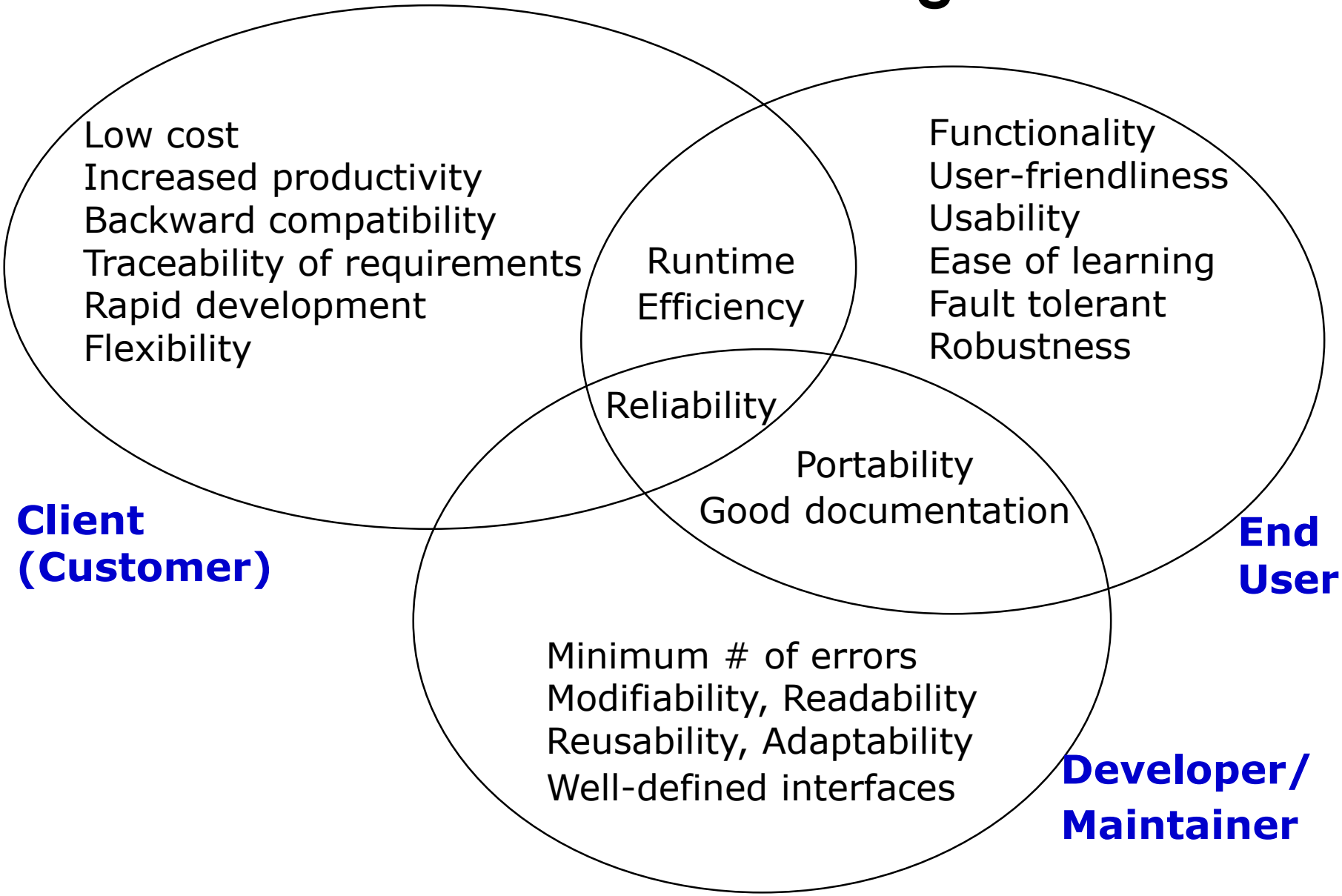
Example of Design Goals

Design goals guide the decisions to be made by developers

- 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

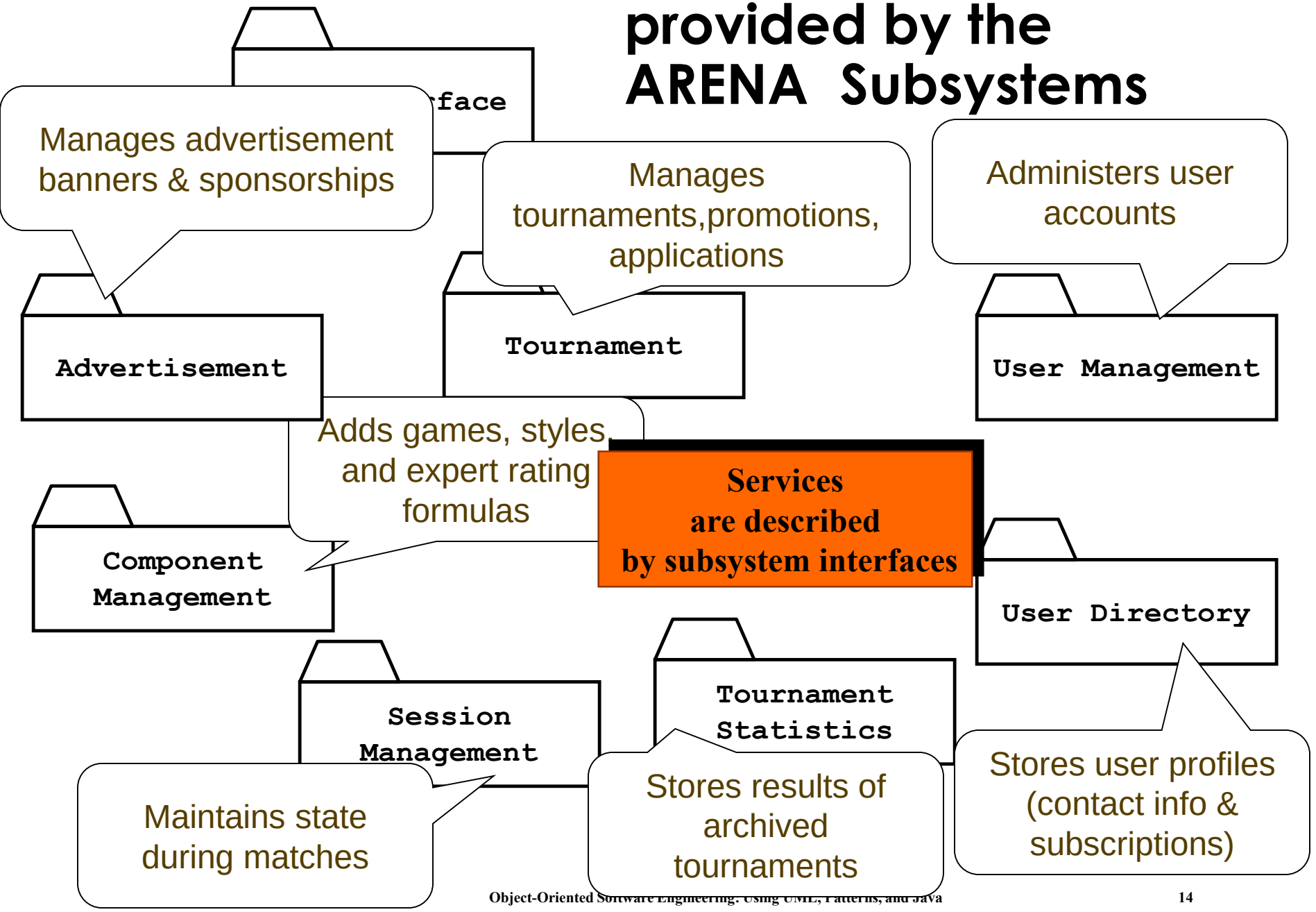
- Functionality v. Usability
- Cost v. Robustness
- Efficiency v. Portability
- Rapid development v. Functionality
- Cost v. Reusability
- Backward Compatibility v. Readability

- Security vs Usability

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
  - A subsystem is characterized by the services it provides to other subsystems
- 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.
- Advantage of System Decomposition?

Example: Services provided by the ARENA Subsystems



Conway's Law

CONWAY ' S LAW

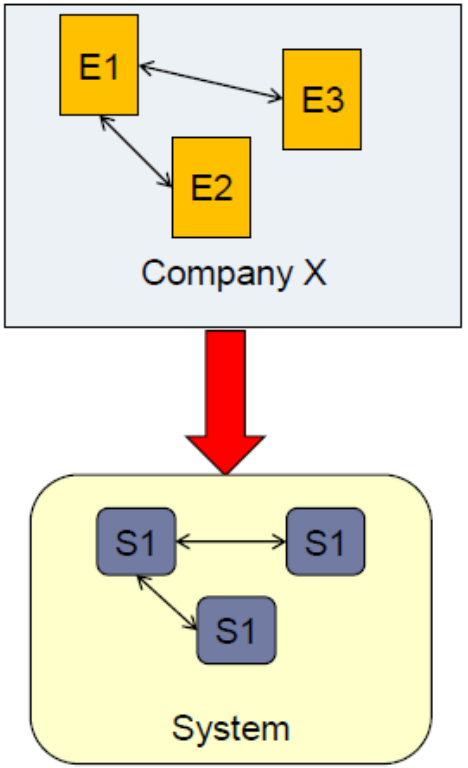
"Any organization that designs a system will inevitably produce a design whose structure is a copy of the organization's communication structure."
Melvin E. Conway, 1967

The structure of software reflects the organizational structure that produced it

* https://en.wikipedia.org/wiki/Conway%27s_law

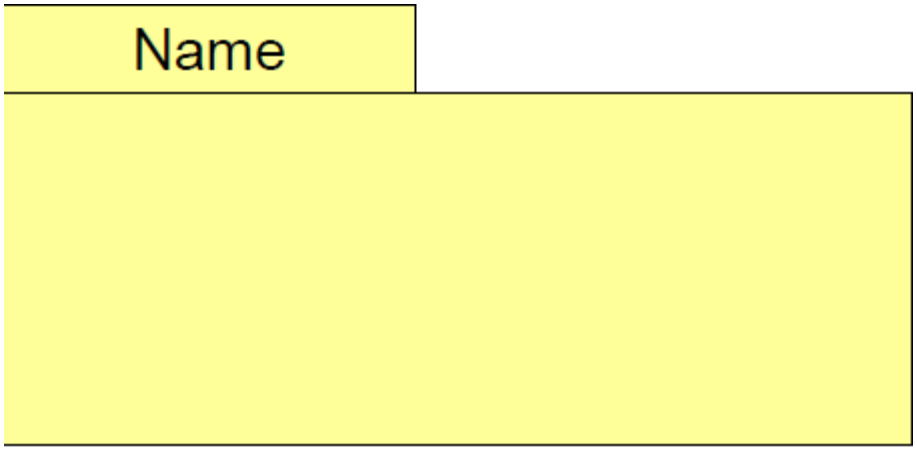
Conway's Law –Example

- Consider a large system S that the government wants to build. The government hires Company X to build system S. Say company X has three engineering groups, E1, E2 and E3 that participate in the project
- Conway's law suggest that it is likely that the resultant system will consist of 3 major subsystems (S1,S2, and S3), each built by one of the engineering groups.
- Further, the resultant interfaces among subsystems (S1-S2, S1-S3, S2-S3) will reflect the quality and nature of the real-world interpersonal communications among respective engineering groups (E1-E2, E1-E3, E2-E3)



Packages

- A **package** in the Unified Modeling Language is used to group elements (as **subsystem**).
- A package may contain other packages, thus providing for a hierarchical organization of packages.
- Pretty much all UML elements can be grouped into packages.

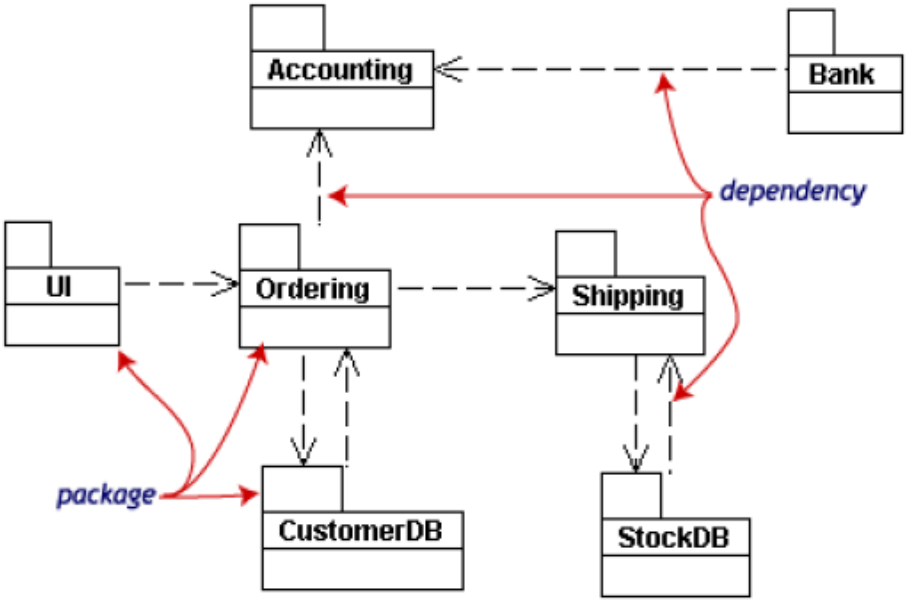


Package Diagram

To simplify complex class diagrams, you can group classes into **packages**. A package is a collection of logically related UML elements

A **package diagram** depicts the dependencies between the packages

The dotted arrows are **dependencies**. One package depends on another if changes in the other could possibly force changes in the first



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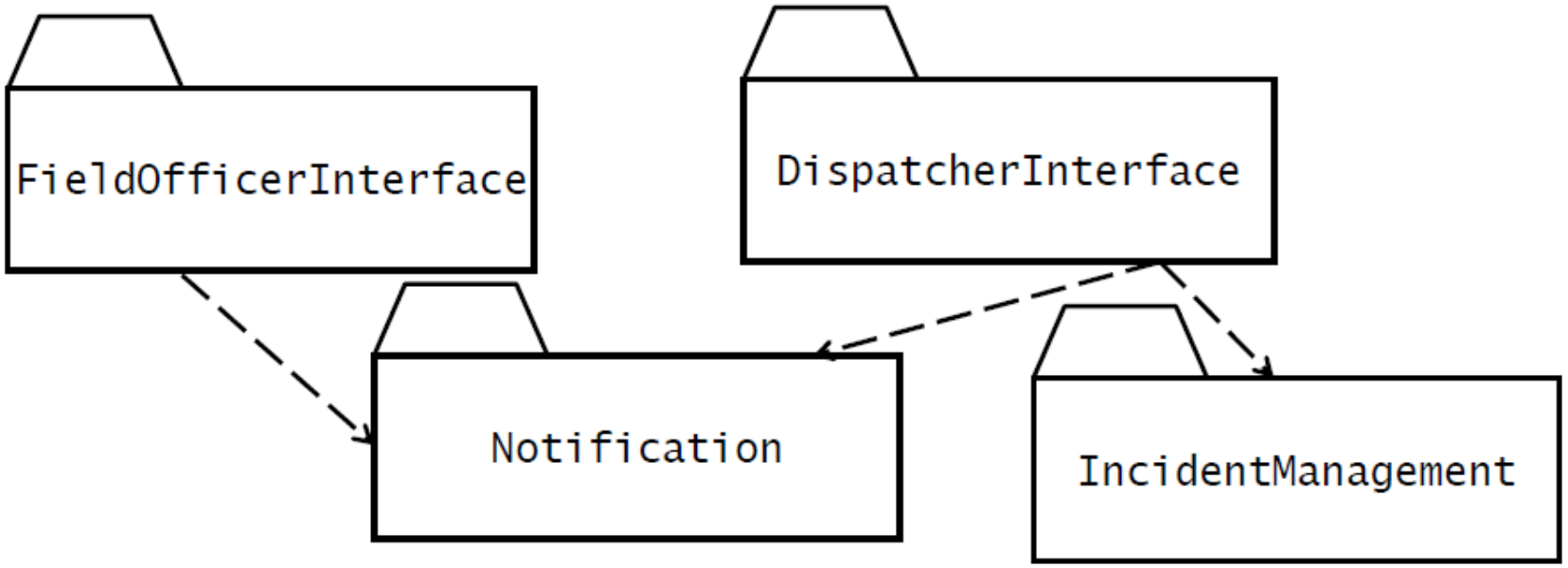
Subsystem Decomposition - Example

Accident Management System

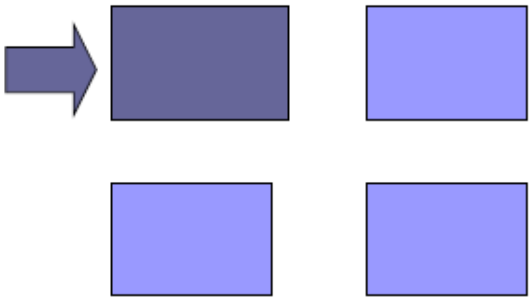


Coupling and Coherence of Subsystems

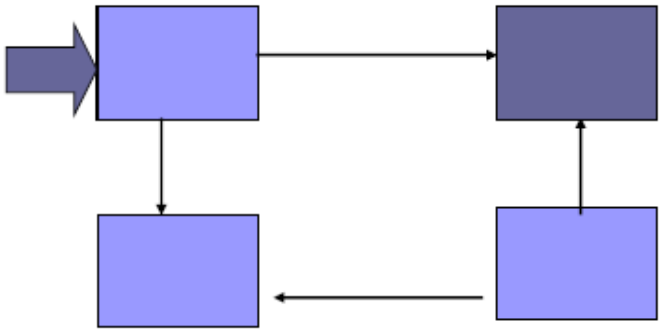
Good Design

- 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

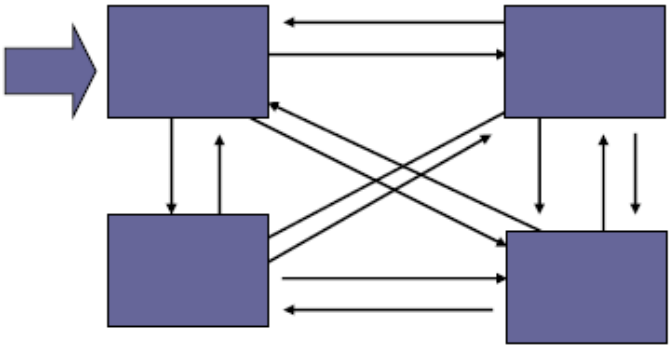
Coupling and Dependency



Uncoupled



Loosely Couple: Some Dependencies



'ripple' effect

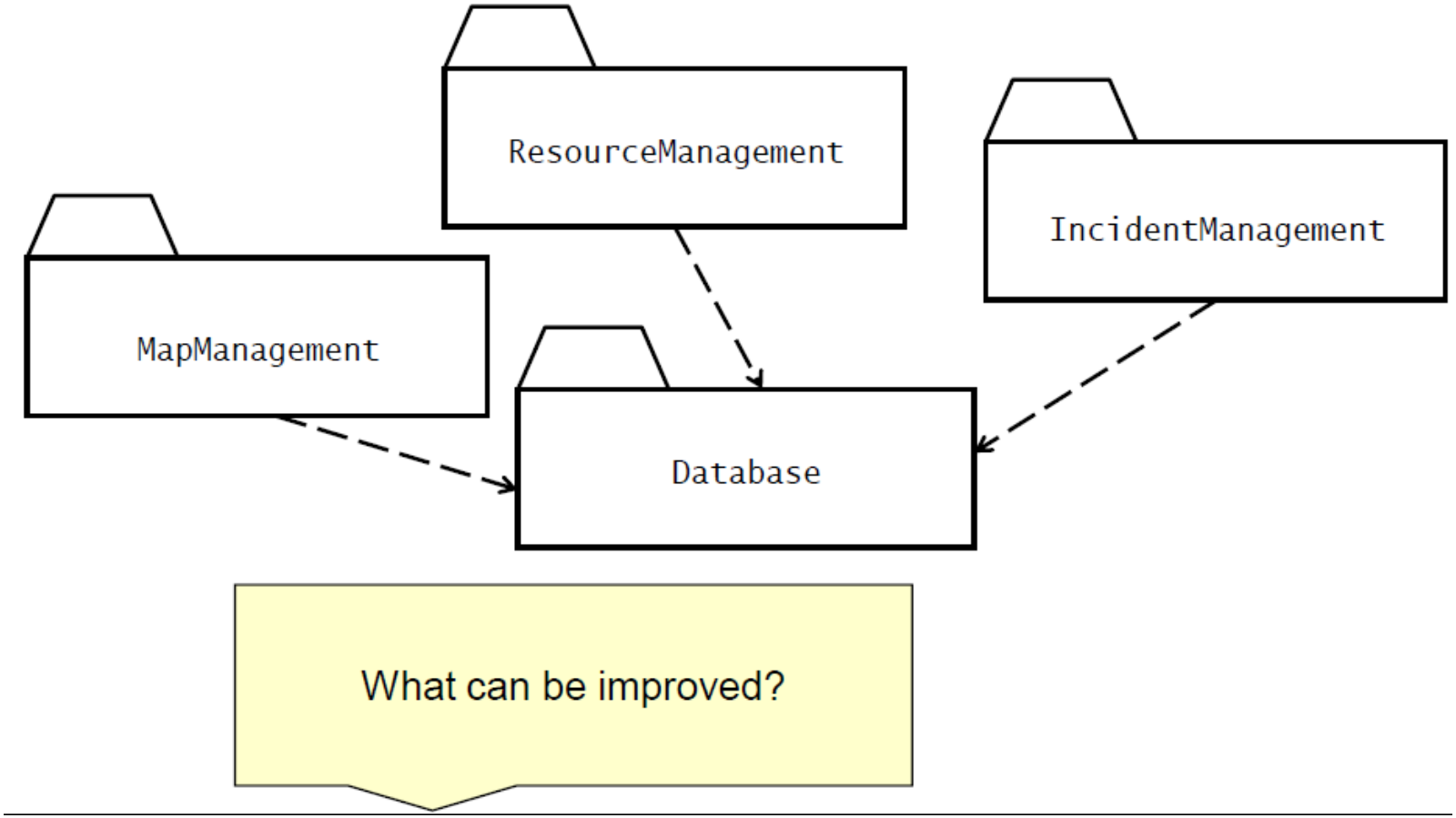
Highly Couple: Many Dependencies

How to achieve high Coherence

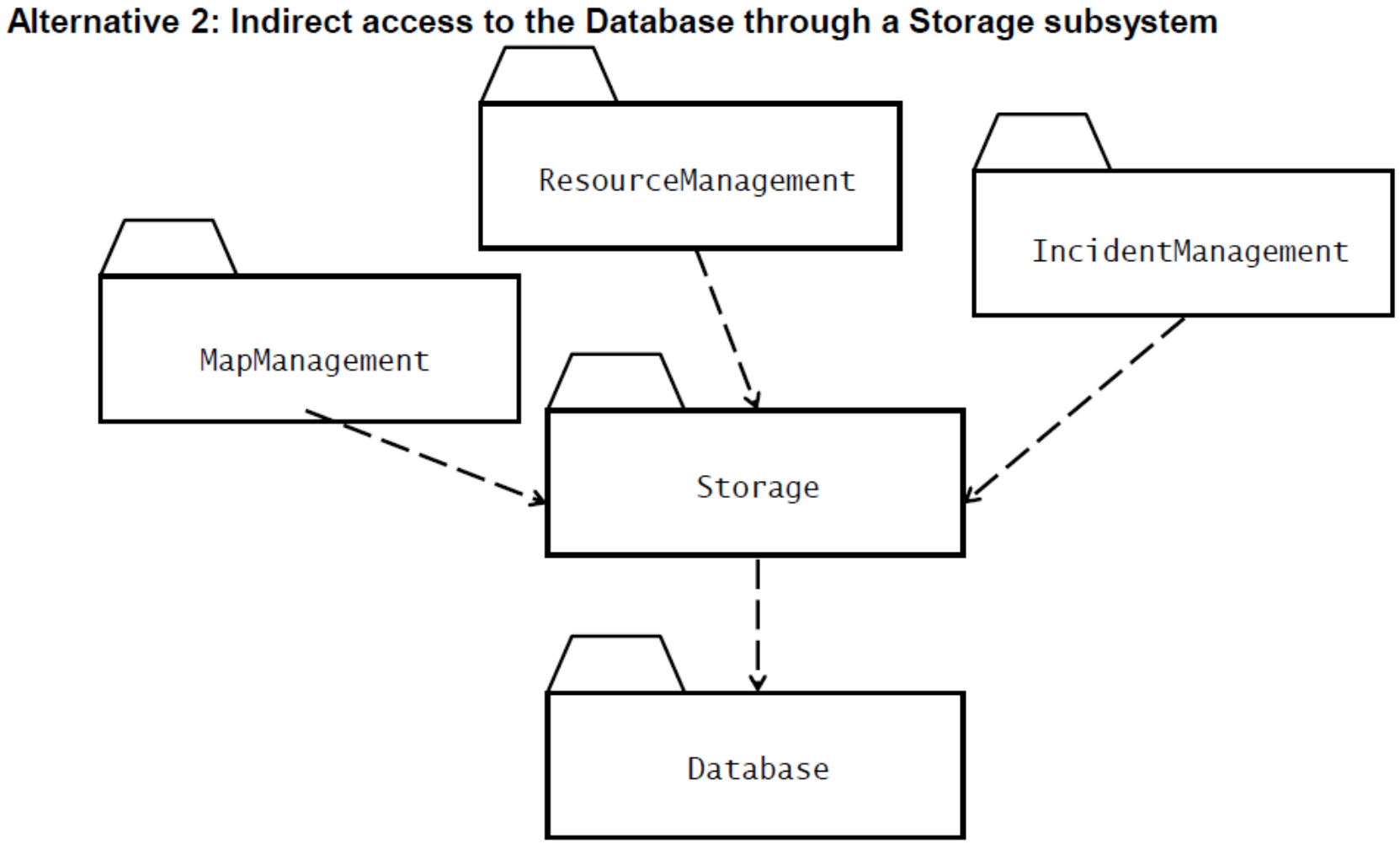
- High coherence can be achieved if most of the interaction is within subsystems, rather than across subsystem boundaries
- Questions to ask:
  - Does one subsystem always call another one for a specific service?
    - Yes: Consider moving them together into the same subystem.
  - Which of the subsystems 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)?

Examples of Reducing the coupling of subsystems

Alternative 1: Direct access to the Database subsystem

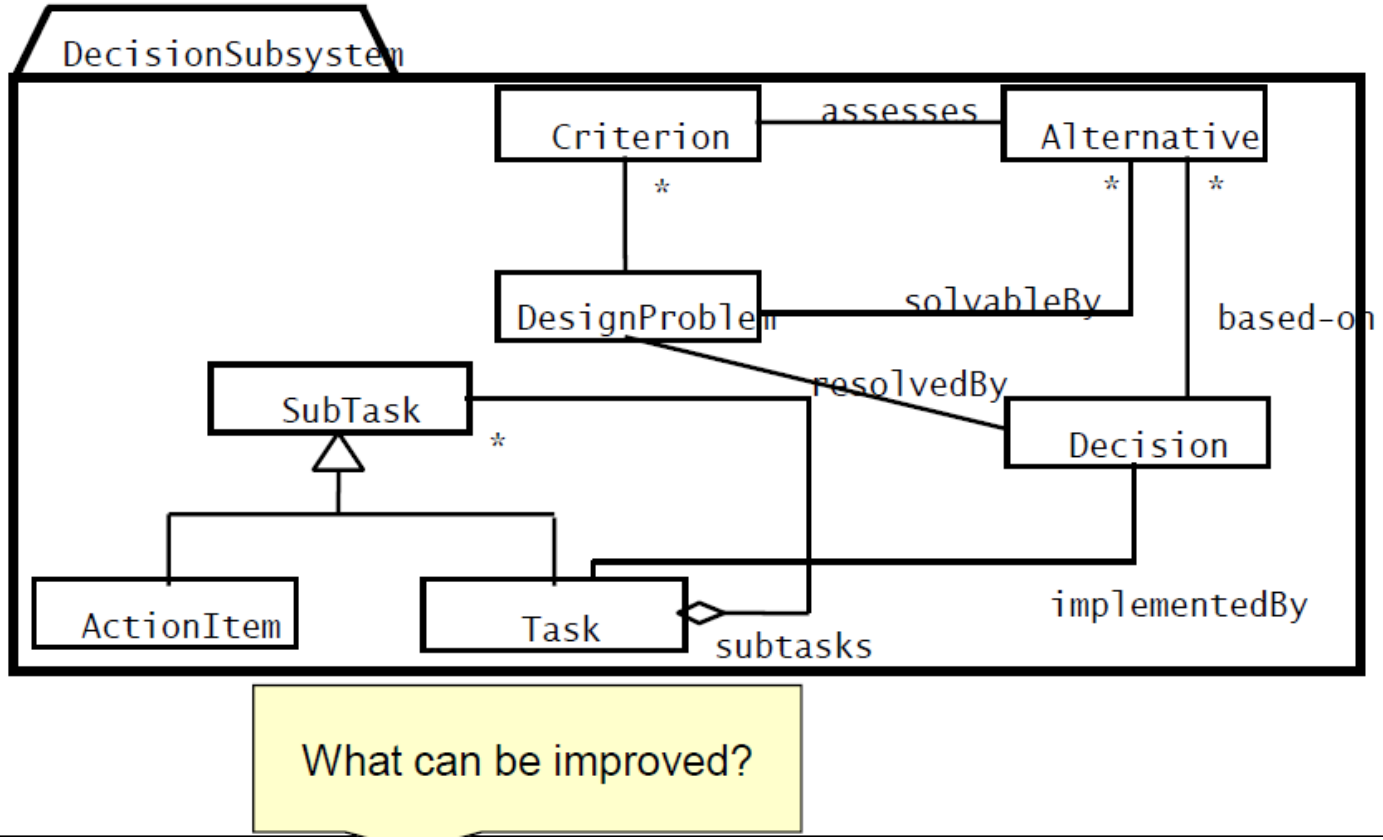


Example of Reducing the couple of subsystems

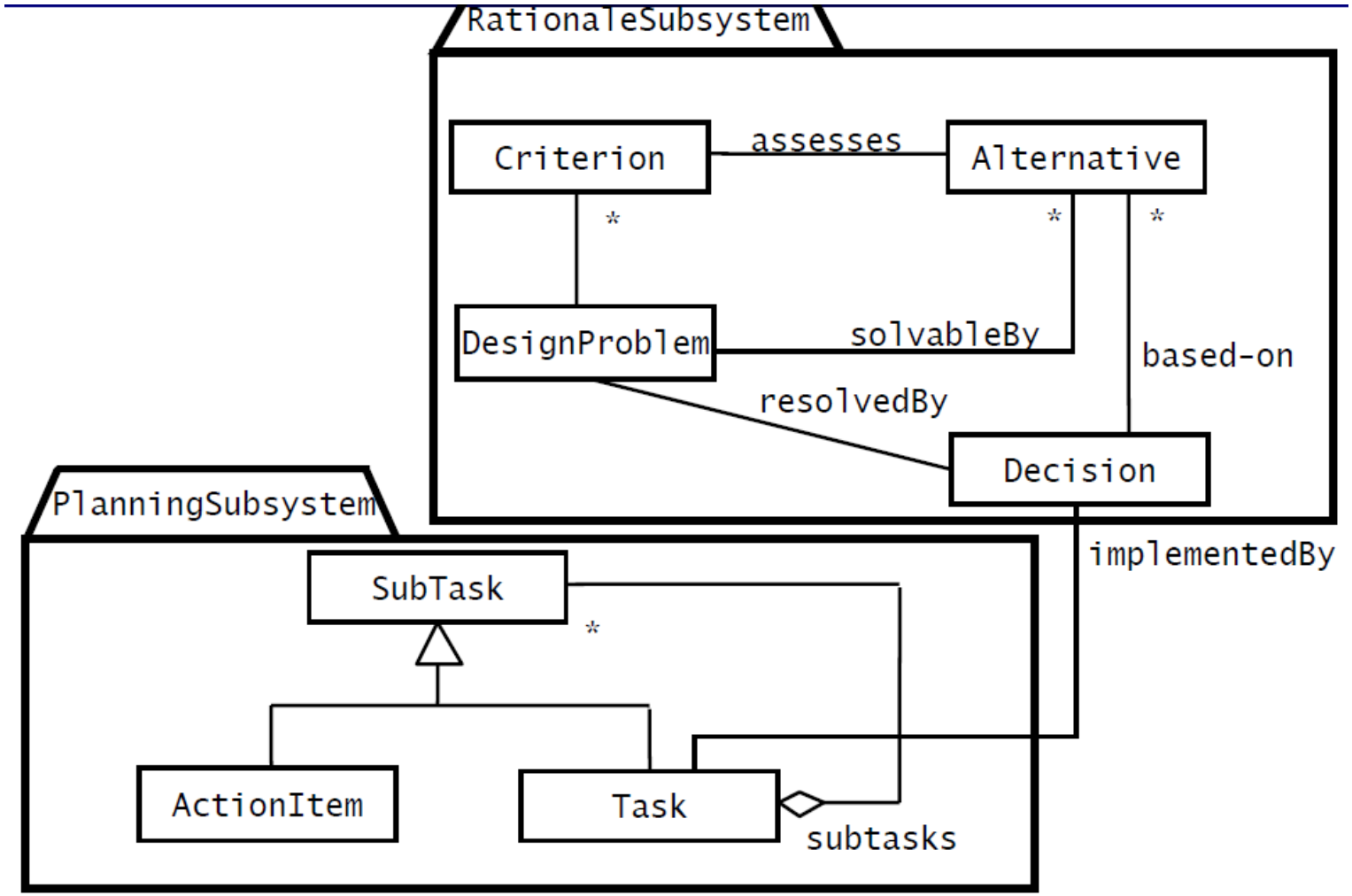


Decision Tracking System

- Decision Tracking system for recording design problems, discussions, decisions etc.



Alternative System Decomposition



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

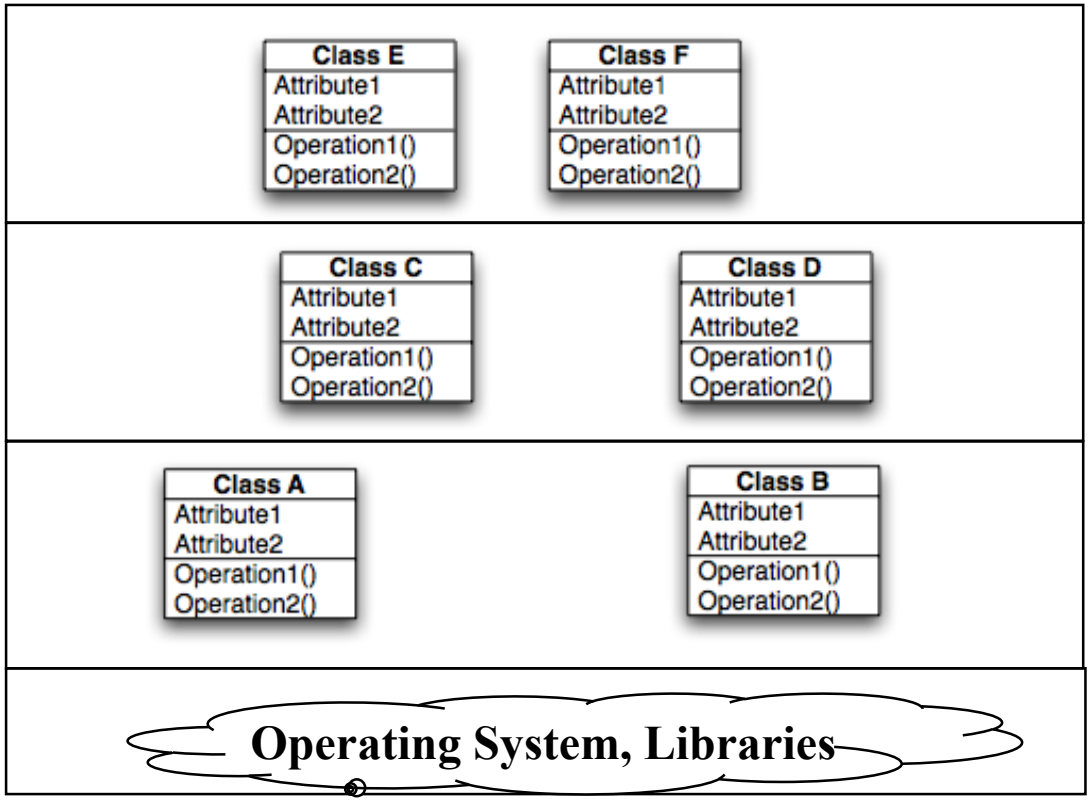
- Service provided by Notification Subsystem
  - LookupChannel()
  - SubscribeToChannel()
  - SendNotice()
  - UnscubscribeFromChannel()
- Subsystem Interface of Notification Subsystem
  - Set of fully typed UML operations
- API of Notification Subsystem
  - Implementation in Java

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.

3-Layer Architectural Style

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



Presentation Layer (Client Layer)

Application Layer (Middleware, Business Logic)

Data Layer

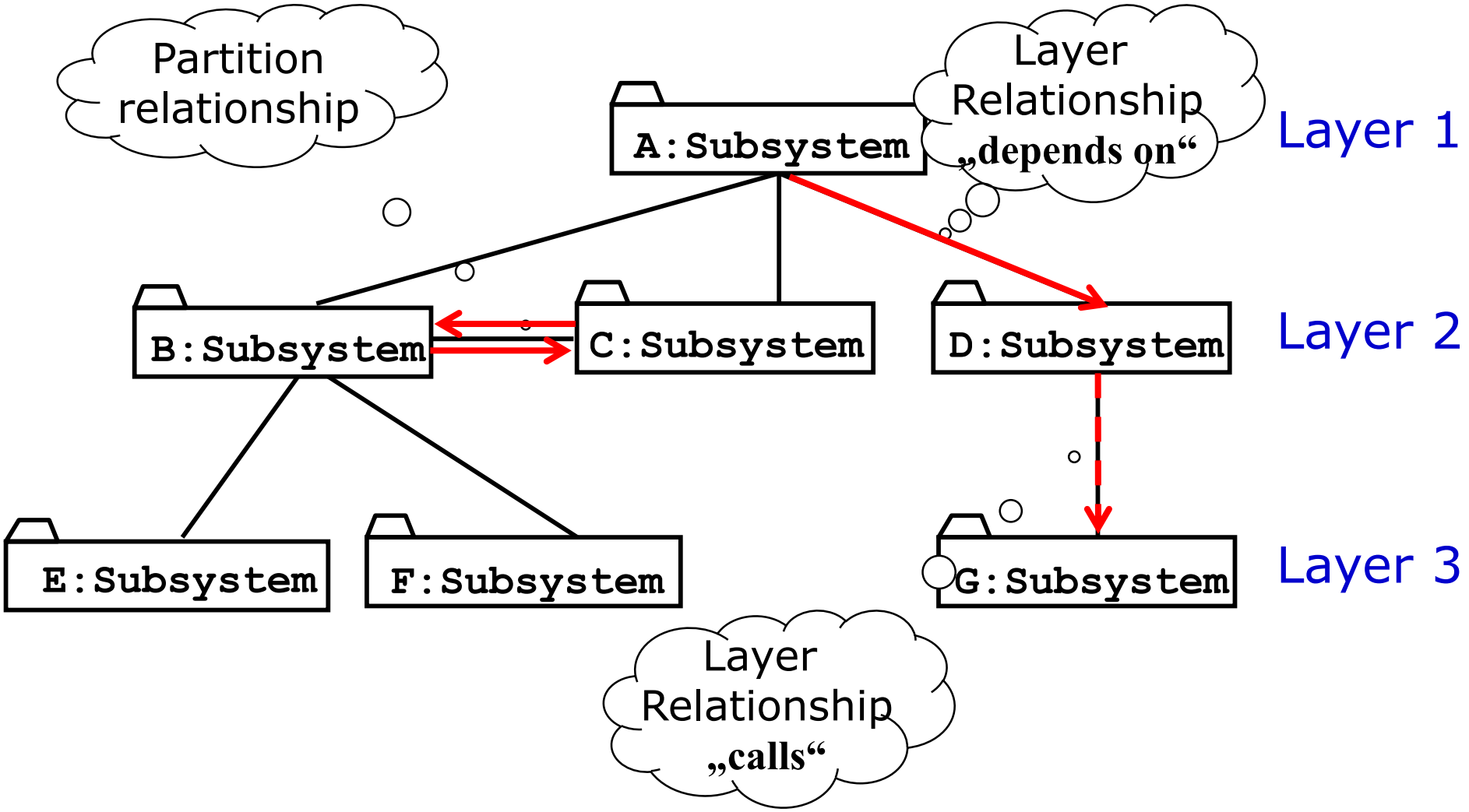
Existing System

Appeared first in 1965, proposed by Dijkstra, in the design of the T.H.E. system.

Relationships between Subsystems

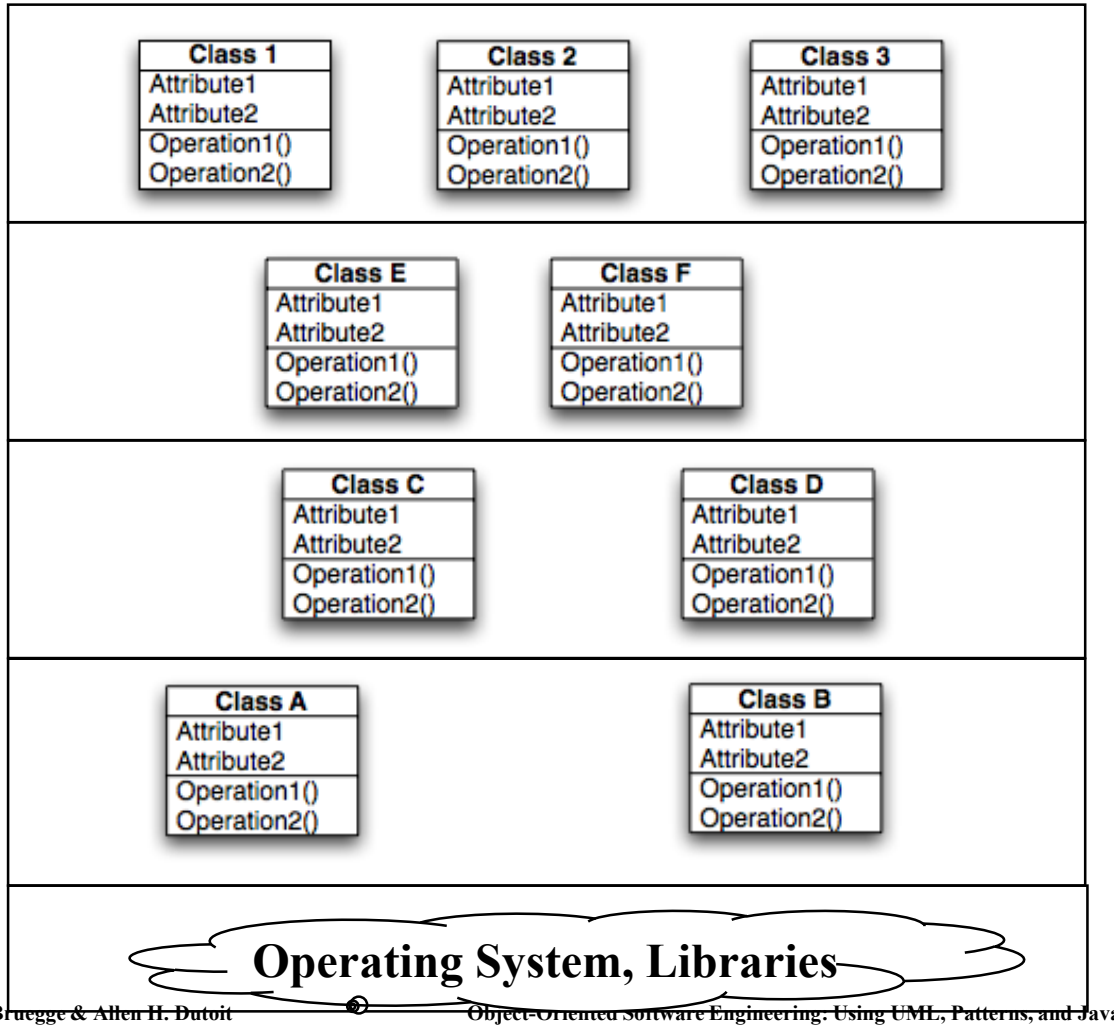
- Two major types of Layer relationships
  - Layer A "depends on" Layer B (compile time dependency)
    - Example: Build dependencies (make, ant, maven)
  - Layer A "calls" Layer B (runtime dependency)
    - Example: A web browser calls a web server
    - Can the client and server layers run on the same 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)
- UML convention:
  - Runtime dependencies are associations with dashed lines
  - Compile time dependencies are associations with solid lines.

Example of a Subsystem Decomposition



Building Systems as a Set of Layers

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



Layer 4

Layer 3

Layer 2

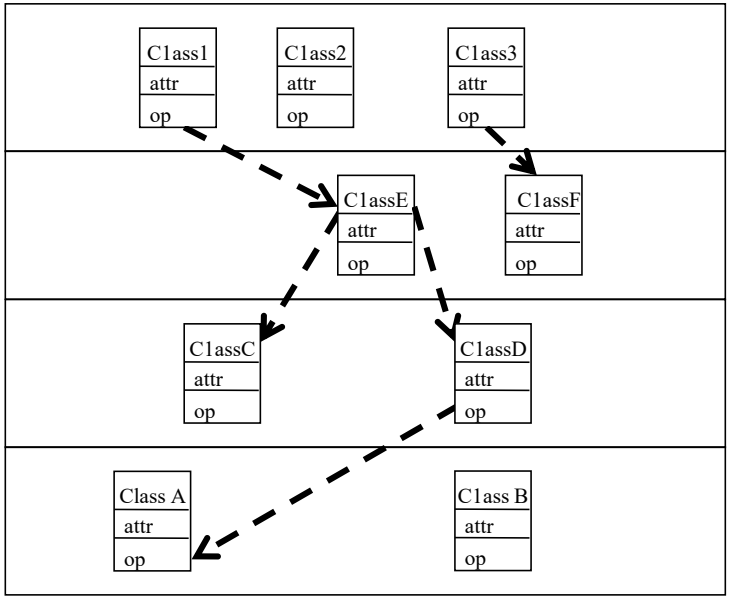
Layer 1

Existing System

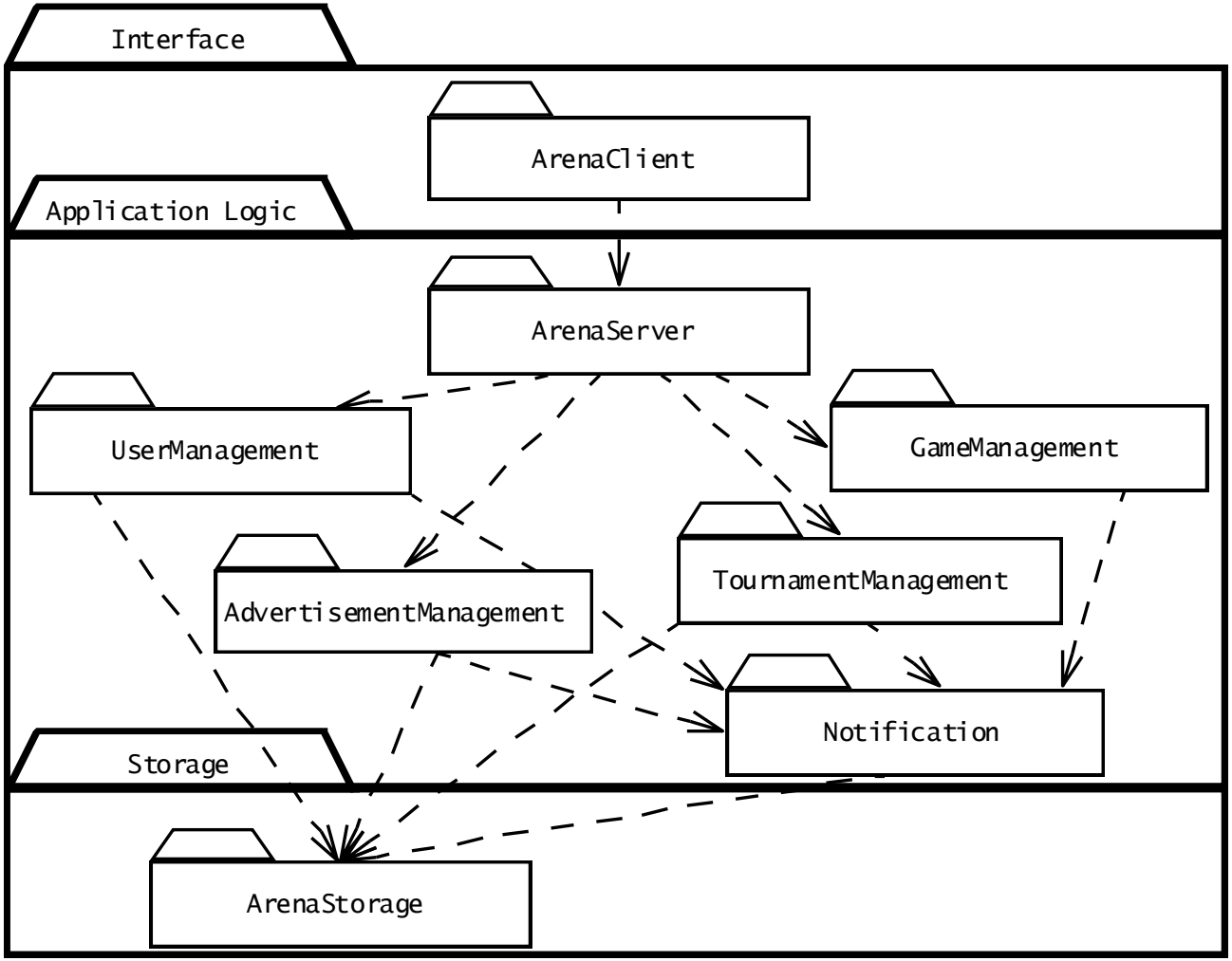
Closed Architecture (Opaque Layering)

- Each layer can only call operations from layer below

Design goals:
Maintainability, flexibility



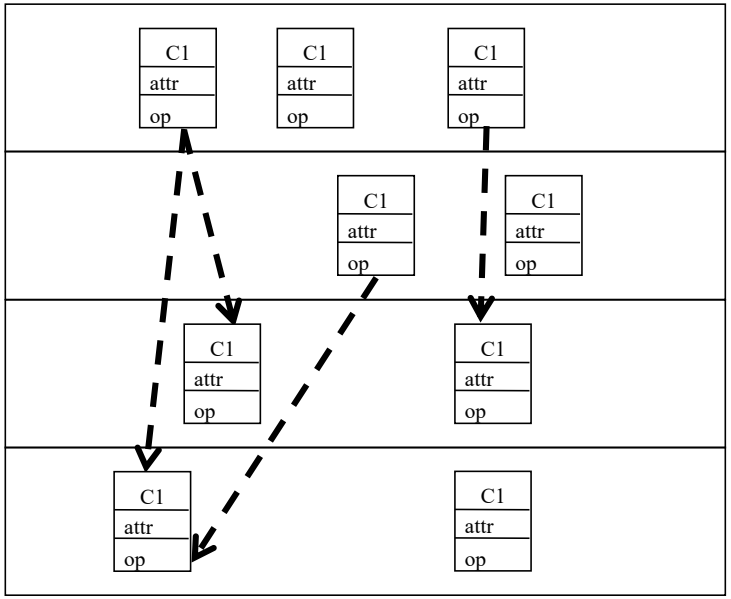
Opaque Layering in ARENA



Open Architecture (Transparent Layering)

- Each layer can call operations from any layer below

Design goal:
Runtime efficiency



Architectural Style vs Architecture

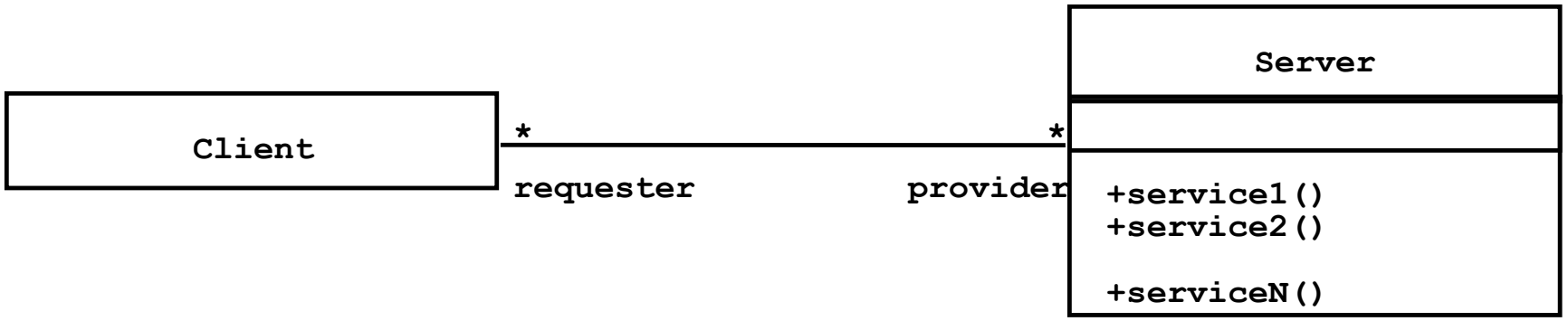
- Subsystem decomposition: Identification of subsystems, services, and their association to each other (hierarchical, peer-to-peer, etc)
- Architectural Style: A pattern for a subsystem decomposition
- Software Architecture: Instance of an architectural style.

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 other 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

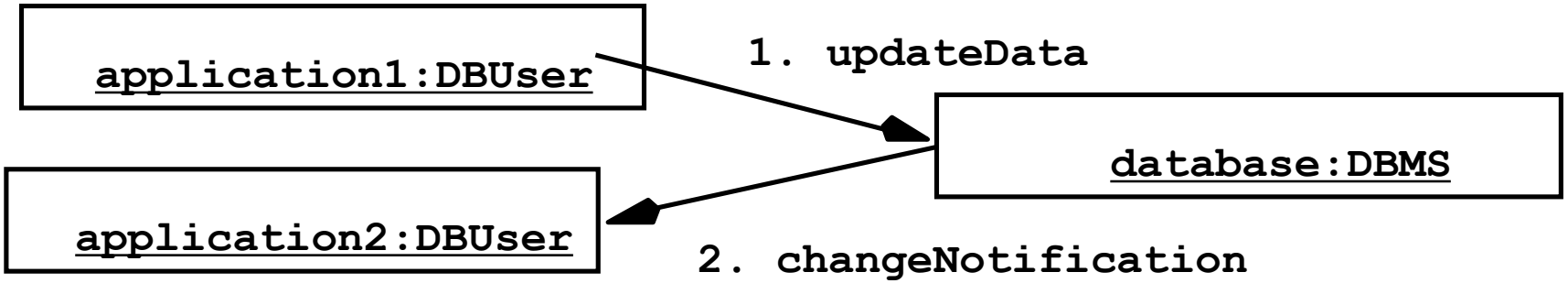
- Well suited for distributed systems that manage large amounts of data
- Often used in the design of database systems
  - Front-end: User application (client)
  - Back end: Database access and manipulation (server)
- Functions performed by client:
  - Input from the user (Customized user interface)
  - 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	**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

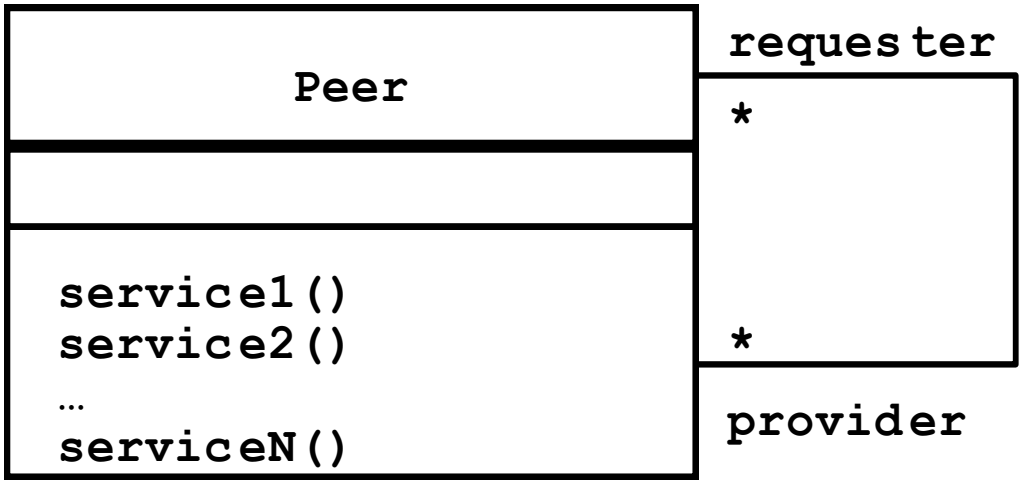
Generalization of Client/Server Architectural Style

"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?



Model-View-Controller Architectural Style

- Subsystems are classified into 3 different types

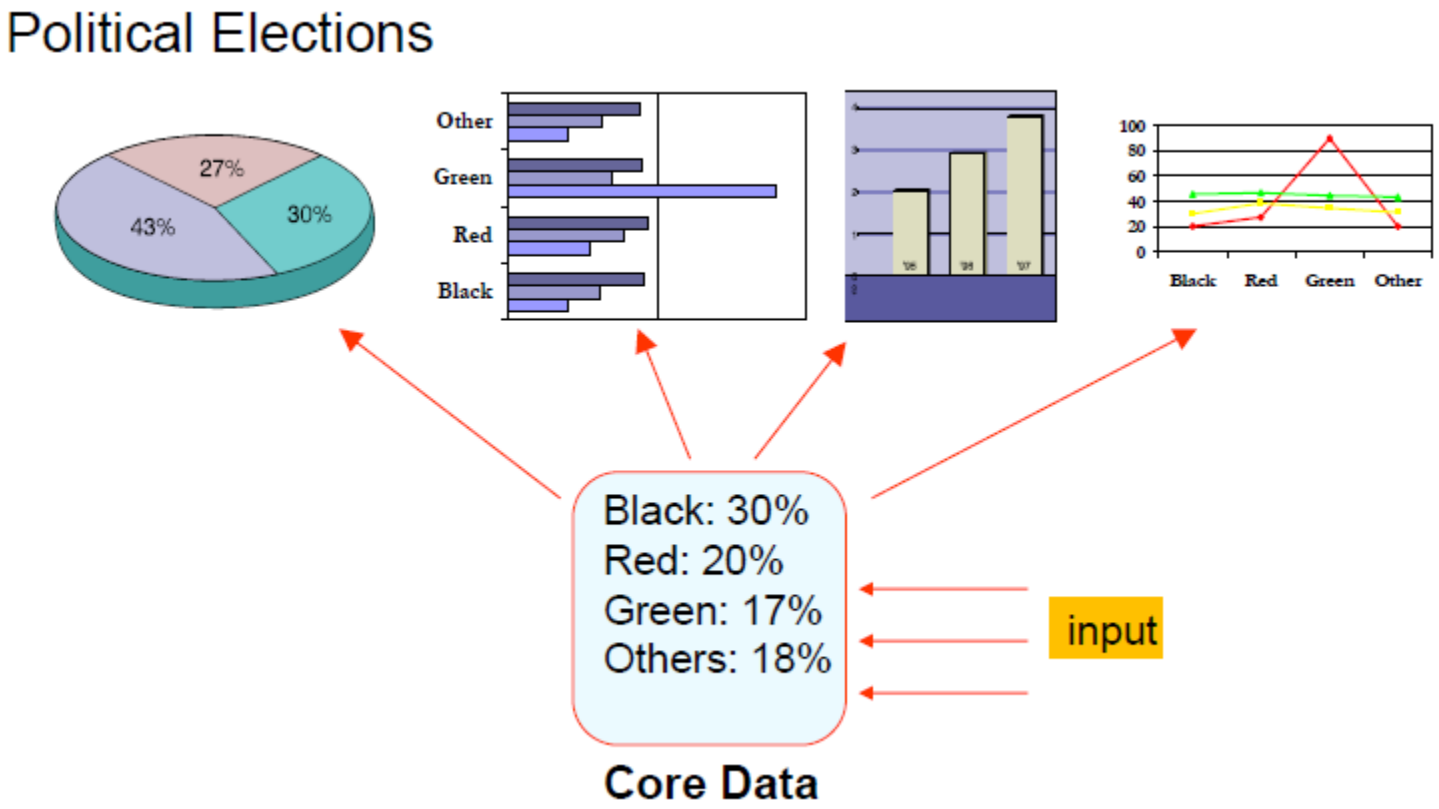
  Model subsystem: Responsible for application domain knowledge

  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

- **Model**: encapsulates core data and functionality; independent of specific output representations or input behavior
- **View**: Display information to the user; obtains data from the model; multiple views of the same model are possible.
- **Controller**: Receive input events which are translated to model and view services; user interacts solely through controller
- Well suited for interactive systems, especially when multiple views of the same model are needed.

Model-View-Controller Example



Model-View-Controller Architectural Style

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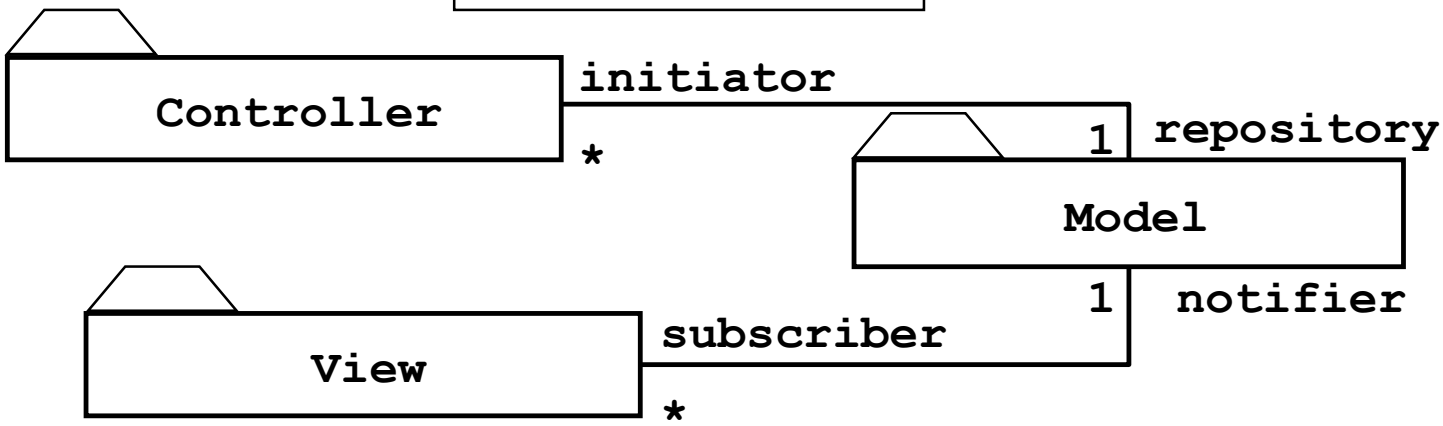
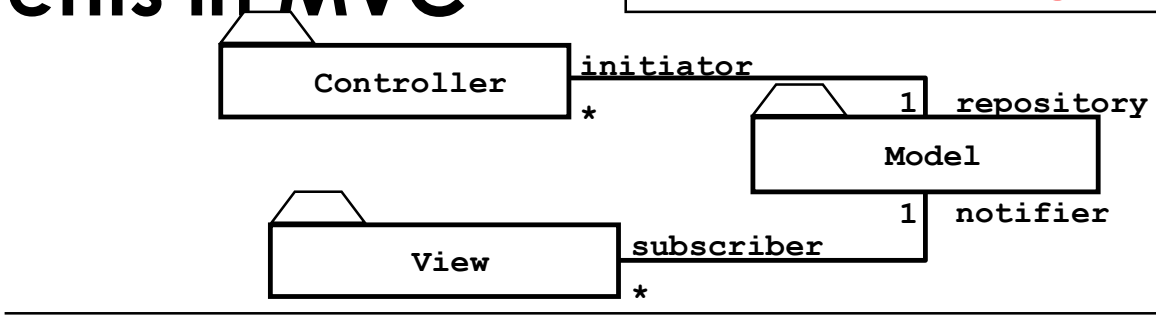
Class Diagram

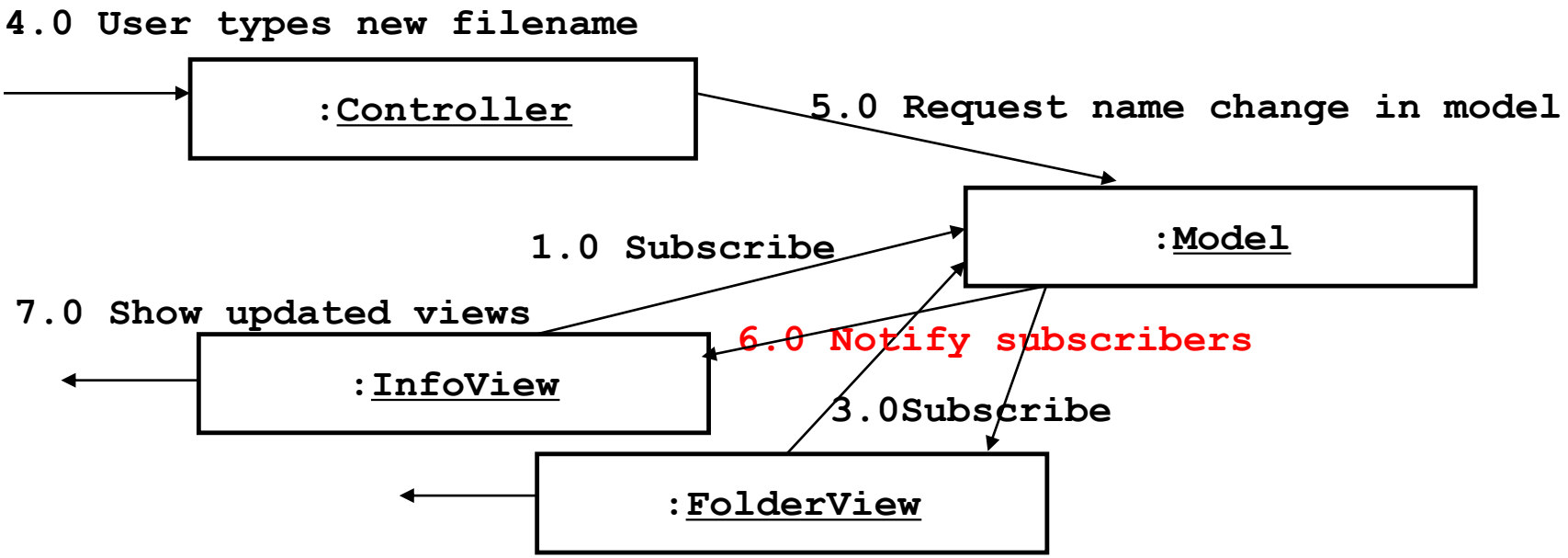


Better understanding with a Collaboration Diagram

Example: Modeling the Sequence of Events in MVC

UML Class Diagram

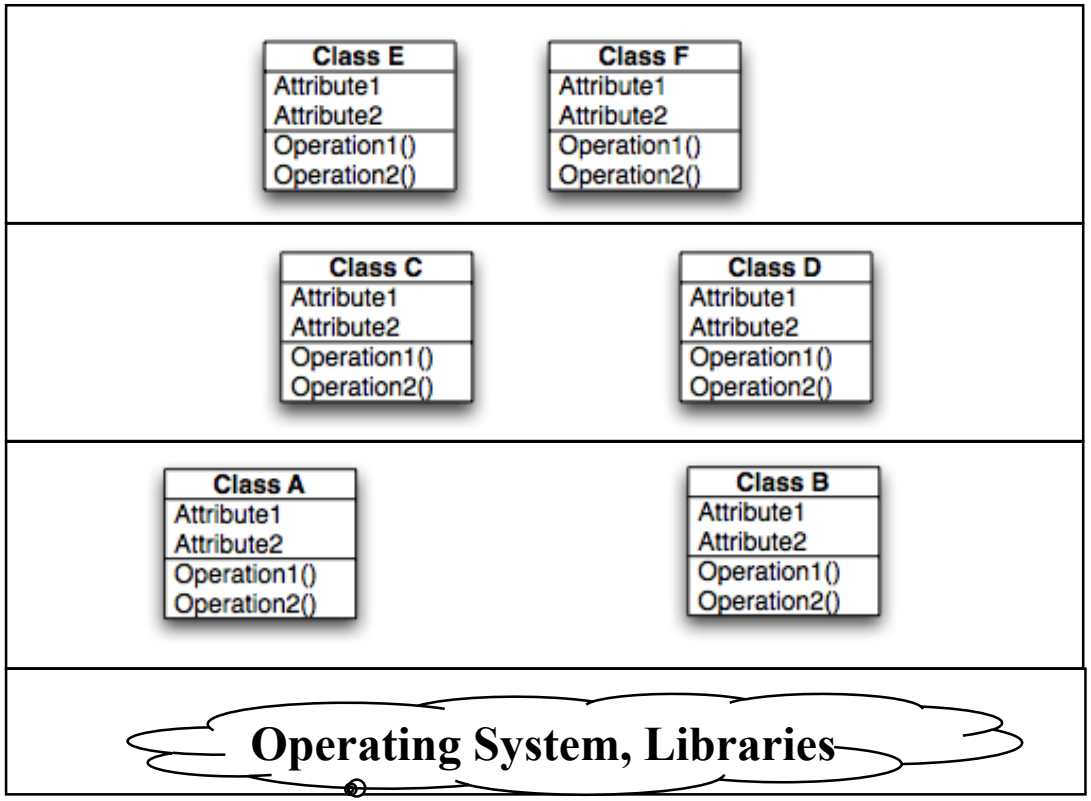




UML Collaboration Diagram

3-Layer Architectural Style

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



Presentation Layer (Client Layer)

Application Layer (Middleware, Business Logic)

Data Layer

Existing System

3-Layer-Architectural Style
3-Tier Architecture

Definition: 3-Layer 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.

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.

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

Summary

- System Design
  - An activity that reduces the gap between the problem and a solution
- 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.