Chapter 6, System Design Lecture 1

Bernd Brügge
Allen H. Dutoit

Technische Universität München
Applied Software Engineering

29 November 2001

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."

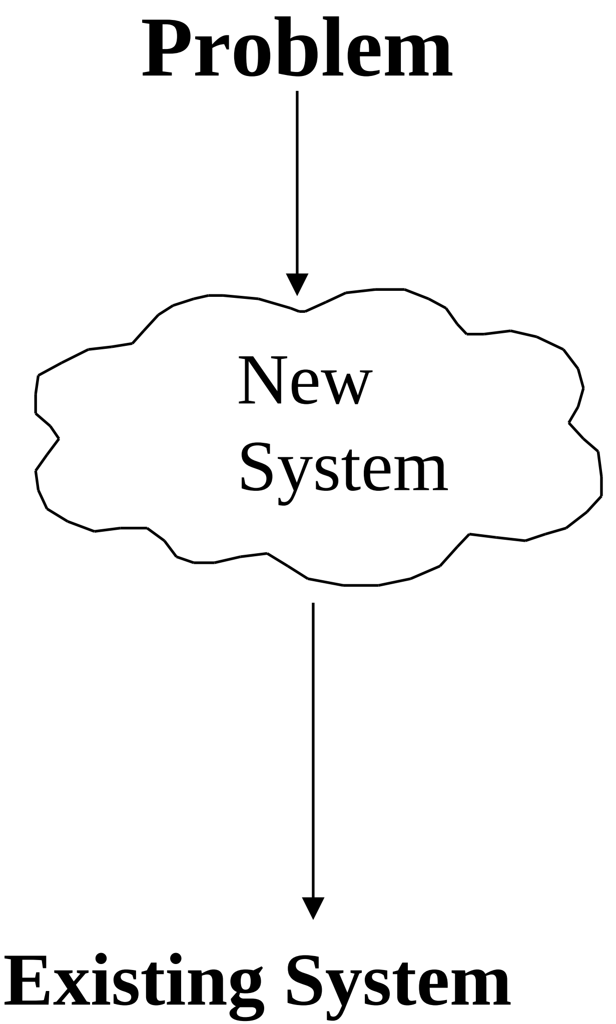
- C.A.R. Hoare

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**
    - **What I teach today will be out of date in 3 years**
    - **Cost of hardware rapidly sinking**
- "Design window":
  - **Time in which design decisions have to be made**
- Technique
  - **Time-boxed prototyping**

The Purpose of System Design

- Bridging the gap between desired and existing system in a manageable way
- Use Divide and Conquer
  - **We model the new system to be developed as a set of subsystems**



System Design

System Design

1. Design Goals
- Definition
- Trade-offs

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

3. Concurrency
- Identification of Threads

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

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

6. Global Resource Handling
- Access control
- Security

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

8. Boundary Conditions
- Initialization
- Termination
- Failure

Overview

System Design I (Today)

0. Overview of System Design

1. Design Goals

2. Subsystem Decomposition

System Design II (next lecture)

3. Concurrency

4. Hardware/Software Mapping

5. Persistent Data Management

6. Global Resource Handling and Access Control

7. Software Control

8. Boundary Conditions

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

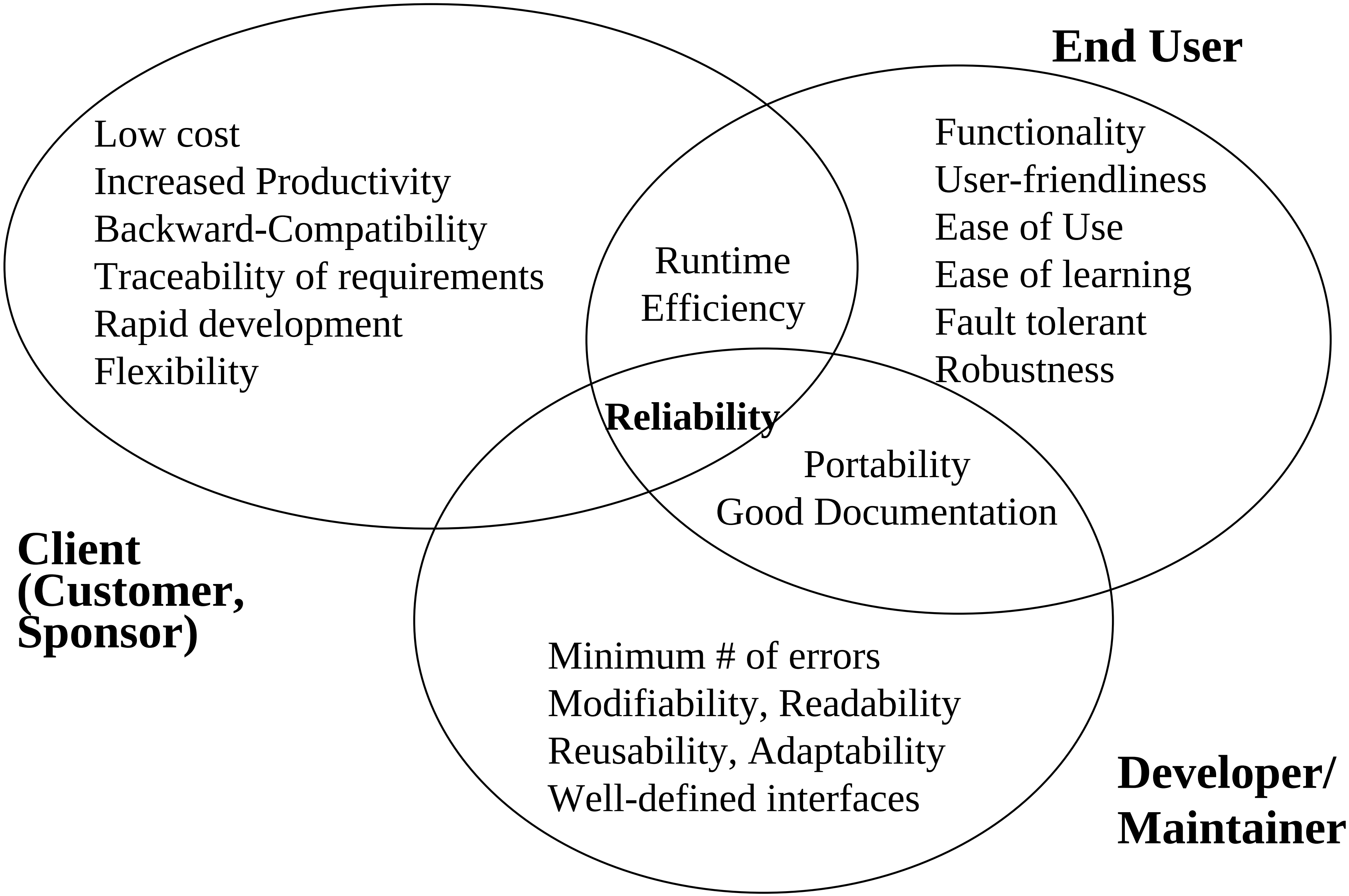
- Nonfunctional requirements =>
  - **Activity 1: Design Goals Definition**
- Functional model =>
  - **Activity 2: System decomposition (Selection of subsystems based on functional requirements, coherence, and coupling)**
- Object model =>
  - **Activity 4: Hardware/software mapping**
  - **Activity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

Section 1. Design Goals

- Reliability
- Modifiability
- Maintainability
- Understandability
- Adaptability
- Reusability
- Efficiency
- Portability
- Traceability of requirements
- Fault tolerance
- Backward-compatibility
- Cost-effectiveness
- Robustness
- High-performance

- Good documentation
- Well-defined interfaces
- User-friendliness
- Reuse of components
- Rapid development
- Minimum # of errors
- Readability
- Ease of learning
- Ease of remembering
- Ease of use
- Increased productivity
- Low-cost
- Flexibility

Relationship Between Design Goals



Typical Design Trade-offs

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

Nonfunctional Requirements give a clue for the use of Design Patterns

- Read the problem statement again
- Use textual clues (similar to Abbot's technique in Analysis) to identify design patterns

- *Text:* "manufacturer independent", "device independent", "must support a family of products"
  - **Abstract Factory Pattern**
- *Text:* "must interface with an existing object"
  - **Adapter Pattern**
- *Text:* "must deal with the interface to several systems, some of them to be developed in the future", " an early prototype must be demonstrated"
  - **Bridge Pattern**

Textual Clues in Nonfunctional Requirements

- *Text:* “complex structure”, “must have variable depth and width”
  - **Composite Pattern**
- *Text:* “must interface to an set of existing objects”
  - **Façade Pattern**
- *Text:* “must be location transparent”
  - **Proxy Pattern**
- *Text:* “must be extensible”, “must be scalable”
  - **Observer Pattern**
- *Text:* “must provide a policy independent from the mechanism”
  - **Strategy Pattern**

Section 2. System Decomposition

- Subsystem (UML: Package)
  - **Collection of classes, associations, operations, events and constraints that are interrelated**
  - **Seed for subsystems: UML Objects and Classes.**
- Service:
  - **Group of operations provided by the subsystem**
  - **Seed for services: Subsystem use cases**
- Service is specified by *Subsystem interface:*
  - **Specifies interaction and information flow from/to subsystem boundaries, but not inside the subsystem.**
  - **Should be well-defined and small.**
  - **Often called API: Application programmer's interface, but this term should used during implementation, not during System Design**

Services and Subsystem Interfaces

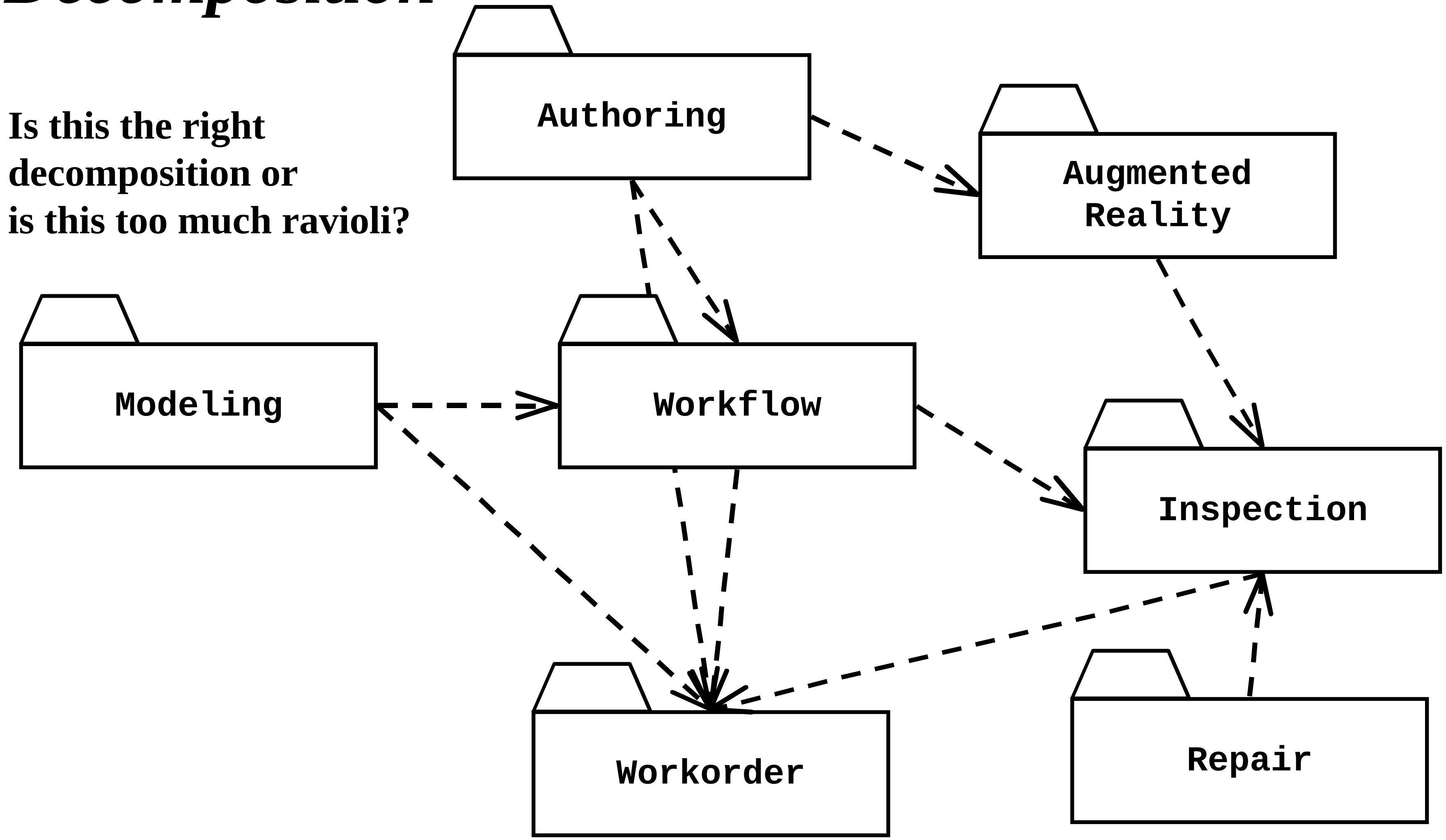
- Service: A set of related operations that share a common purpose
  - **Notification subsystem service:**
    - **LookupChannel()**
    - **SubscribeToChannel()**
    - **SendNotice()**
    - **UnscubscribeFromChannel()**
  - **Services are defined in System Design**
- Subsystem Interface: Set of fully typed related operations.
  - **Subsystem Interfaces are defined in Object Design**
  - **Also called application programmer interface (API)**

Choosing Subsystems

- Criteria for subsystem selection: Most of the interaction should be within subsystems, rather than across subsystem boundaries (High coherence).
  - **Does one subsystem always call the other for the service?**
  - **Which of the subsystems call each other for service?**
- Primary Question:
  - **What kind of service is provided by the subsystems (subsystem interface)?**
- Secondary Question:
  - **Can the subsystems be hierarchically ordered (layers)?**
- What kind of model is good for describing layers and partitions?

Example (from WS 2000): STARS Subsystem Decomposition

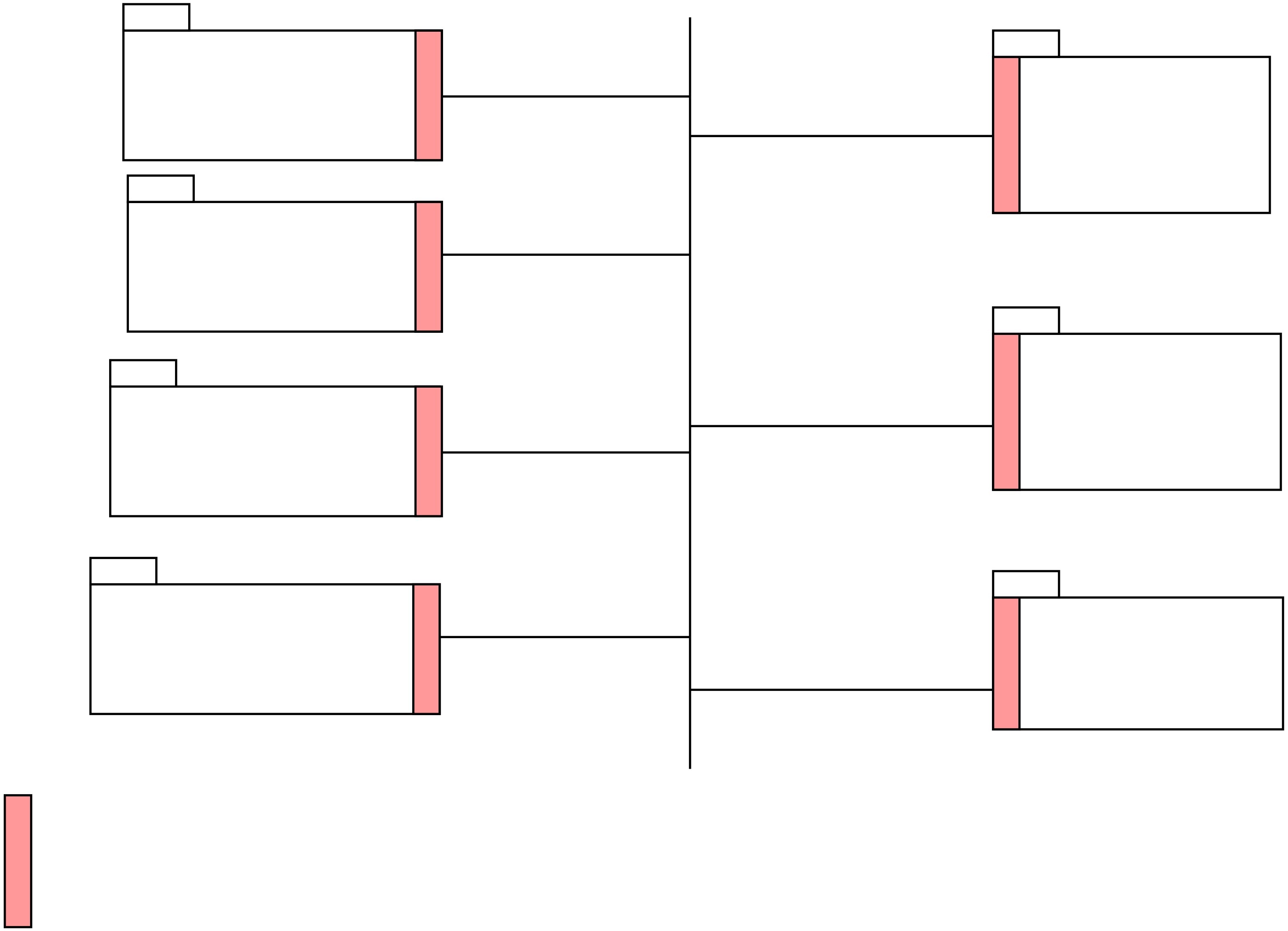
Is this the right decomposition or is this too much ravioli?



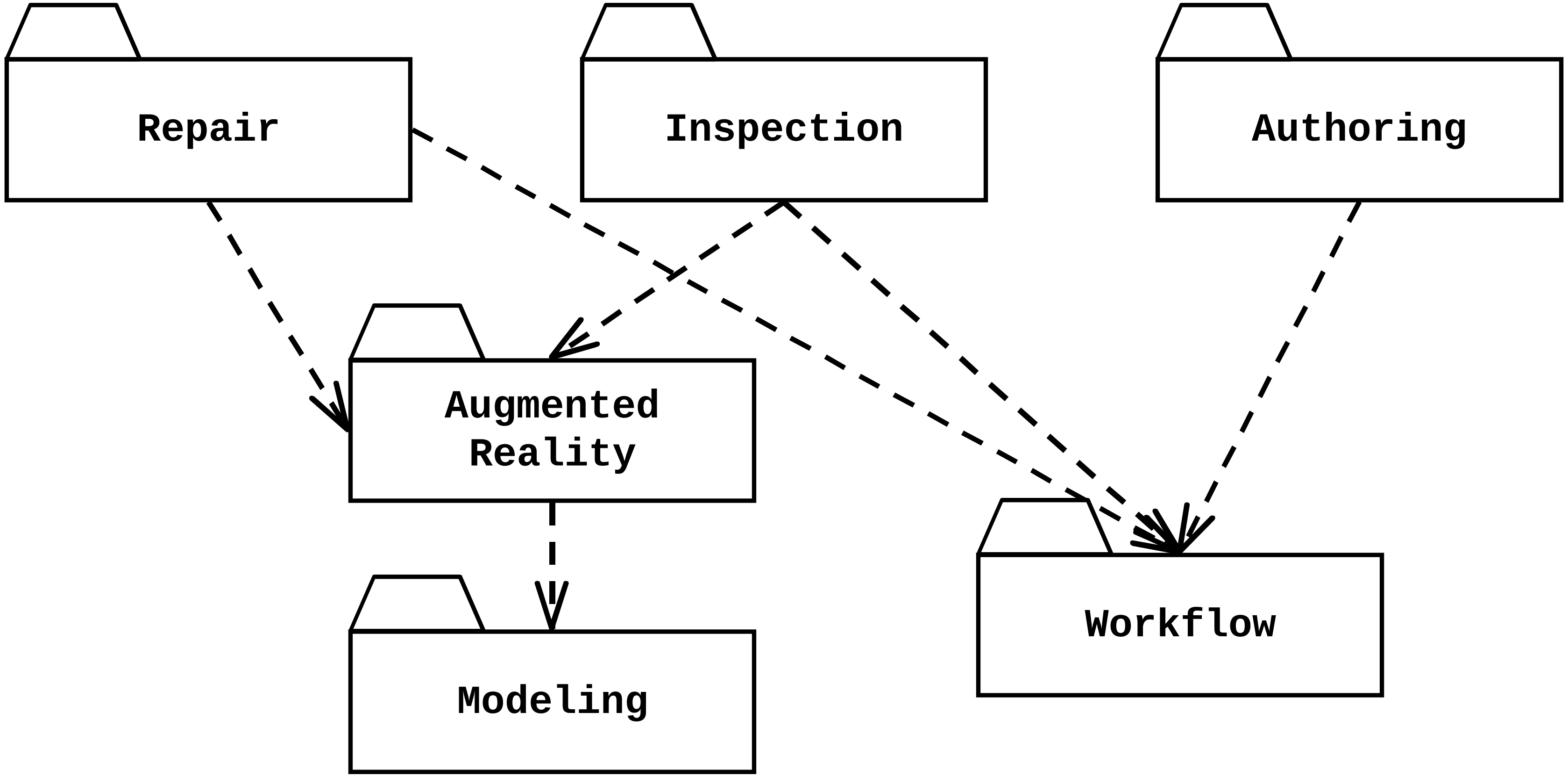
Definition: Subsystem Interface Object

- A *Subsystem Interface Object* provides a service
  - **This is the set of public methods provided by the subsystem**
  - **The Subsystem interface describes all the methods of the subsystem interface object**
- Use a Facade pattern for the subsystem interface object

STARS as a set of subsystems communicating via a software bus

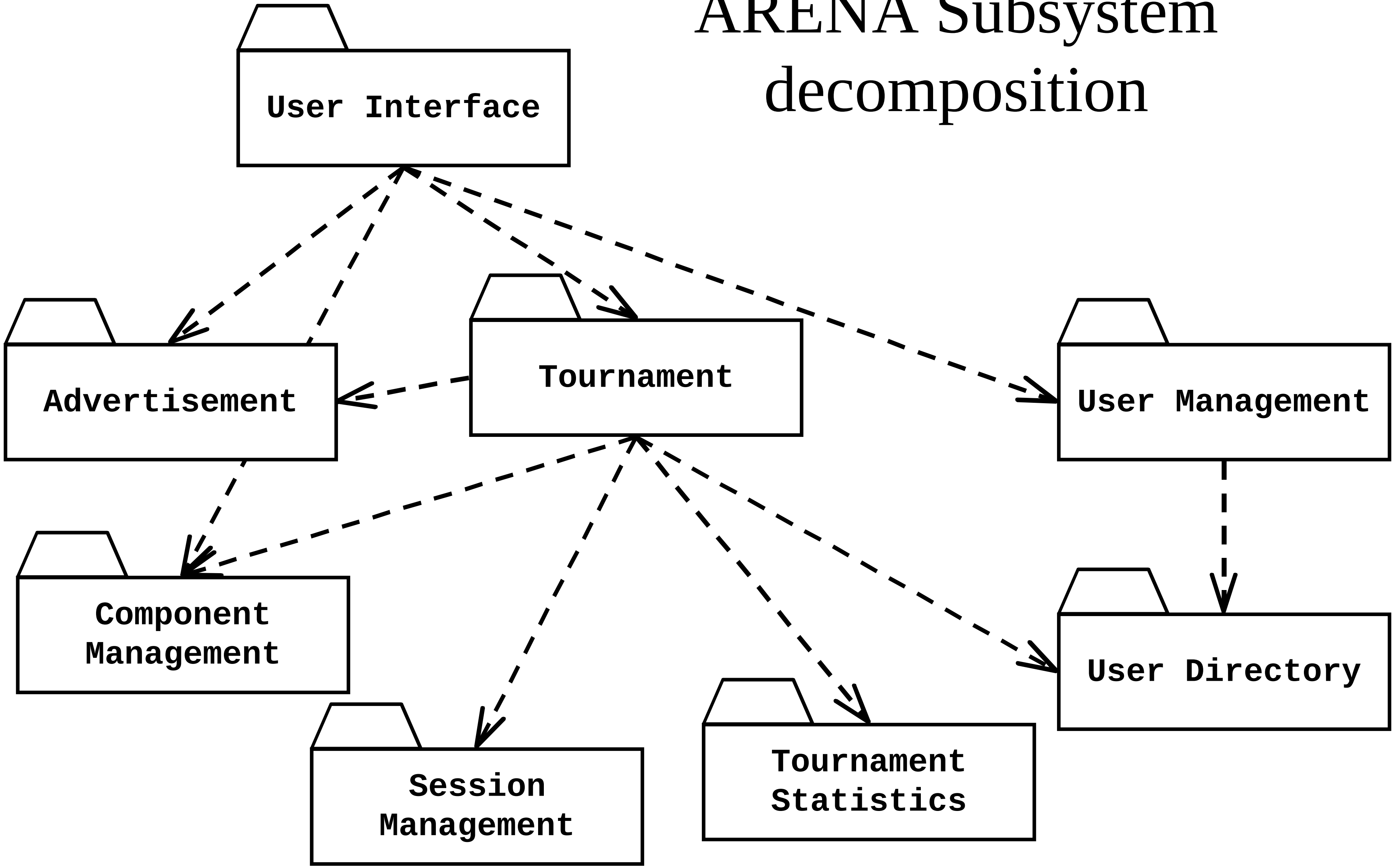


STARS as a 3-layered Architecture

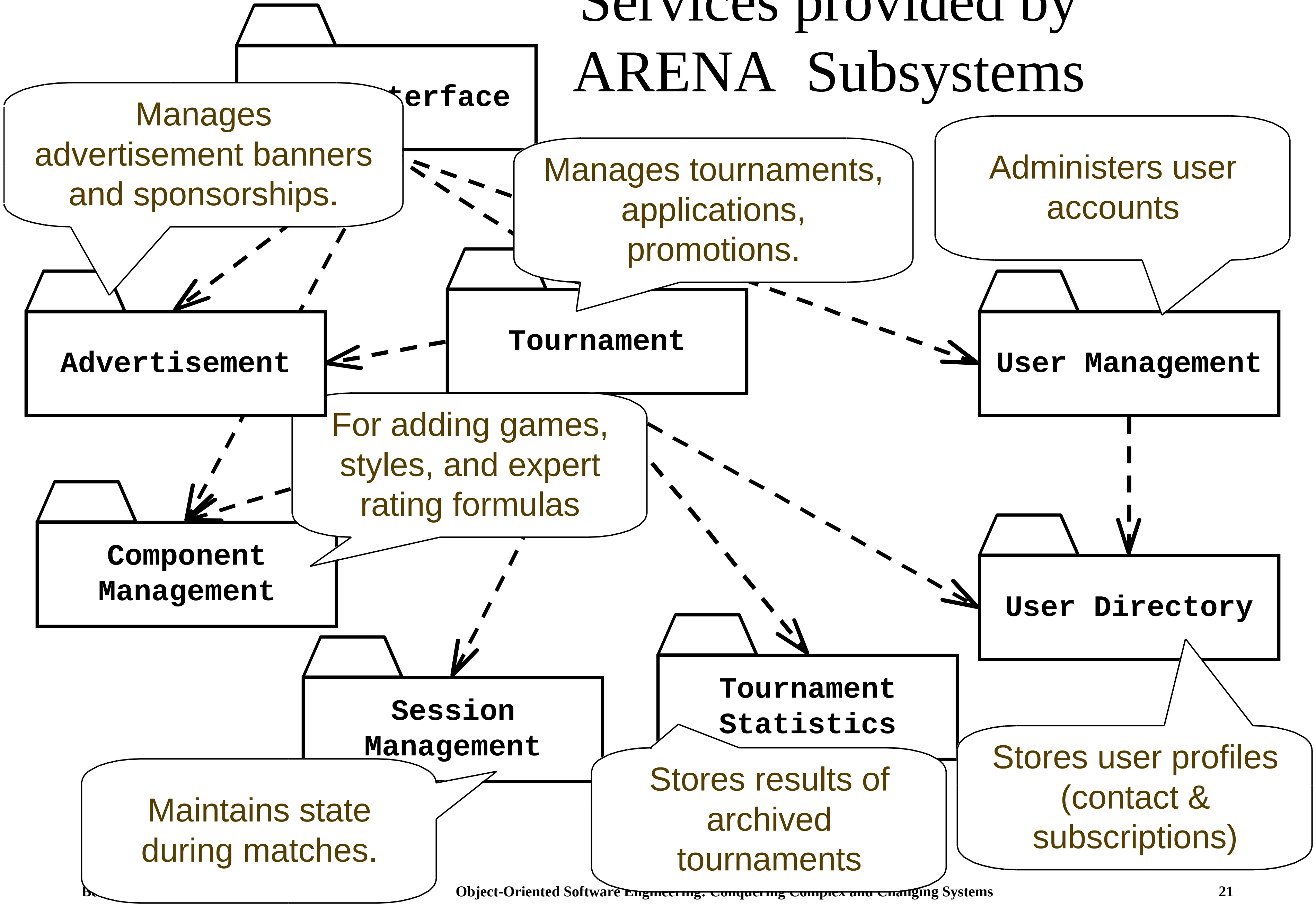


What is the relationship between Modeling and Authoring?
Are other subsystems needed?

ARENA Subsystem decomposition



Services provided by ARENA Subsystems



Coupling and Coherence

- Goal: Reduction of ***complexity while change occurs***
- Coherence measures the dependence 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 dependencies between subsystems
  - **High coupling: Changes to one subsystem will have high impact on the other subsystem (change of model, massive recompilation, etc.)**
  - **Low coupling: A change in one subsystem does not affect any other subsystem**
- Subsystems should have as maximum coherence and minimum coupling as possible:
  - **How can we achieve high coherence?**
  - **How can we achieve loose coupling?**

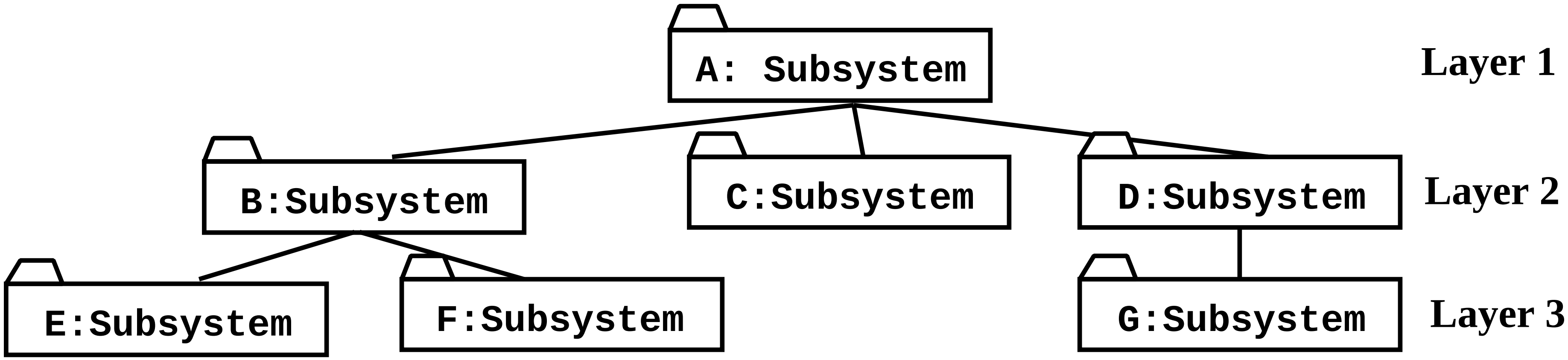
Partitions and Layers

Partitioning and layering are techniques to achieve low coupling.

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

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

Subsystem Decomposition into Layers



- Subsystem Decomposition Heuristics:
- No more than 7+/-2 subsystems
  - **More subsystems increase coherence but also complexity (more services)**
- No more than 5+/-2 layers

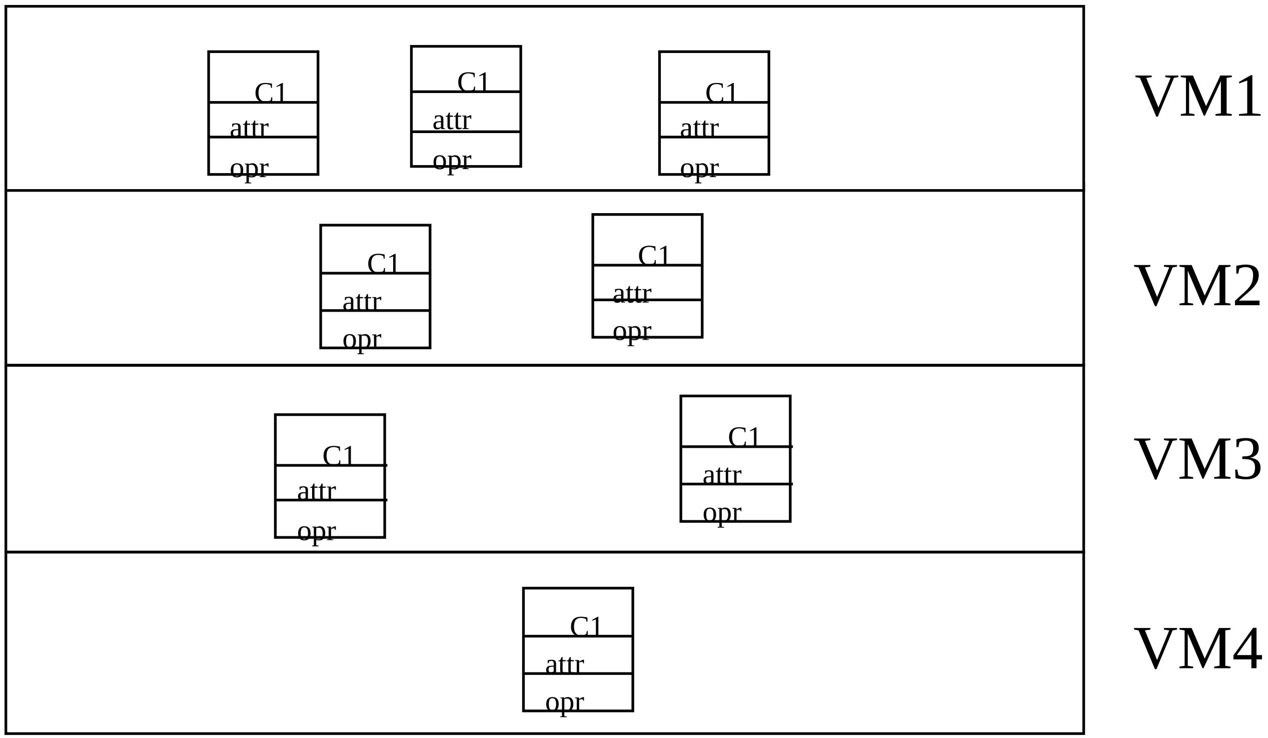
Layer and Partition Relationships between Subsystems

- Layer relationship
  - **Layer A "Calls" Layer B (runtime)**
  - **Layer A "Depends on" Layer B ("make" dependency, compile time)**
- Partition relationship
  - **The subsystem have mutual but not deep knowledge about each other**
  - **Partition A "Calls" partition B and partition B "Calls" partition A**

Virtual Machine (Dijkstra, 1965)

- A system should be developed by an ordered set of virtual machines, each built in terms of the ones below it.

Problem



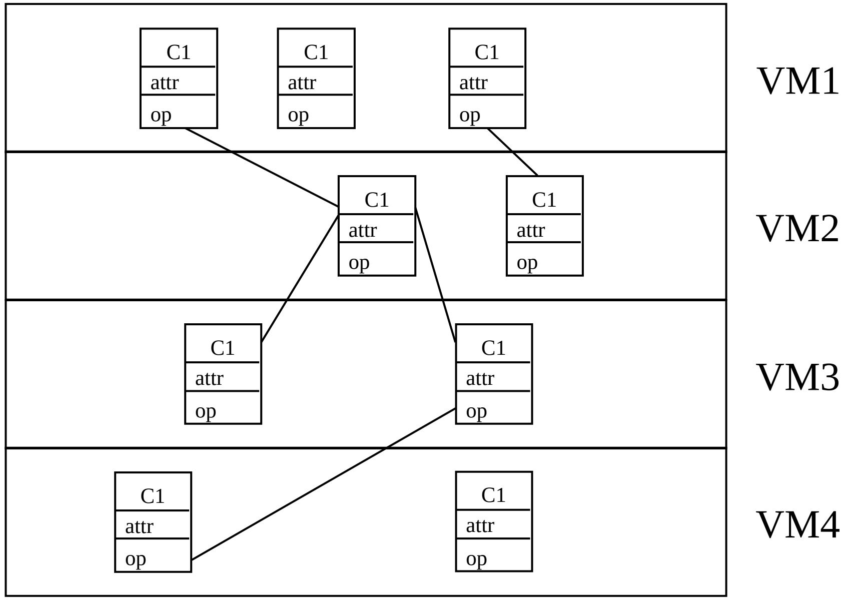
Existing System

Virtual Machine

- A virtual machine is an abstraction that provides a set of attributes and operations.
- A virtual machine is a subsystem connected to higher and lower level virtual machines by "provides services for" associations.
- Virtual machines can implement two types of software architecture: closed and open architectures.

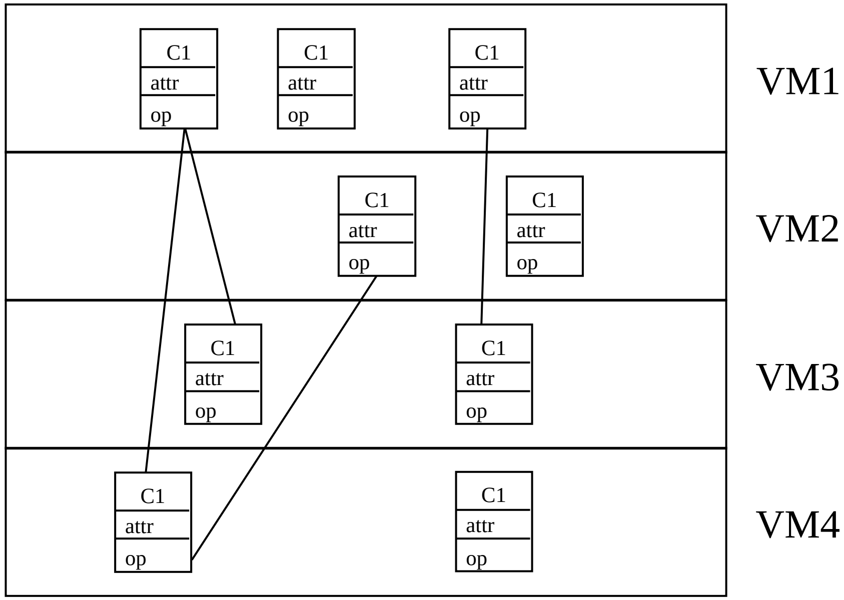
Closed Architecture (Opaque Layering)

- A virtual machine can only call operations from the layer below
- Design goal: High maintainability



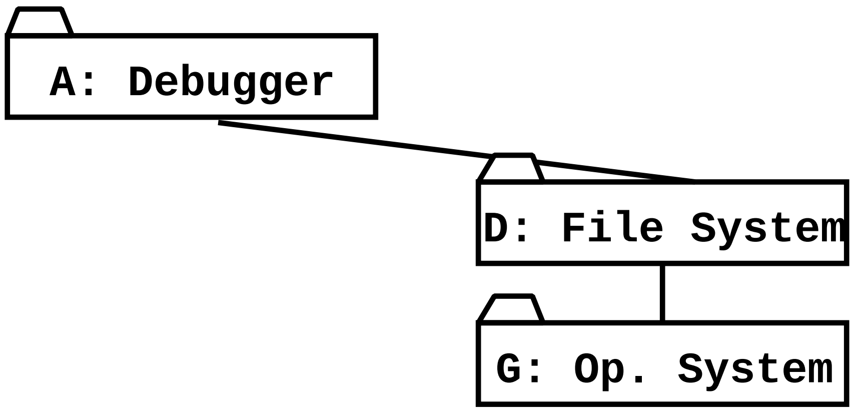
Open Architecture (Transparent Layering)

- A virtual machine can call operations from any layers below
- Design goal: Runtime efficiency



Properties of Layered Systems

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

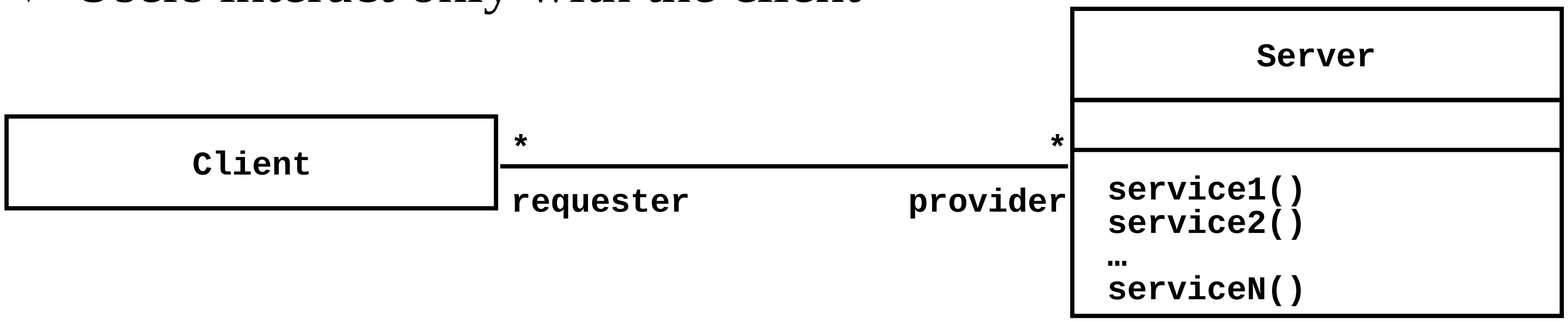


Software Architectures

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

Client/Server Architecture

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



Client/Server Architecture

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

Design Goals for Client/Server Systems

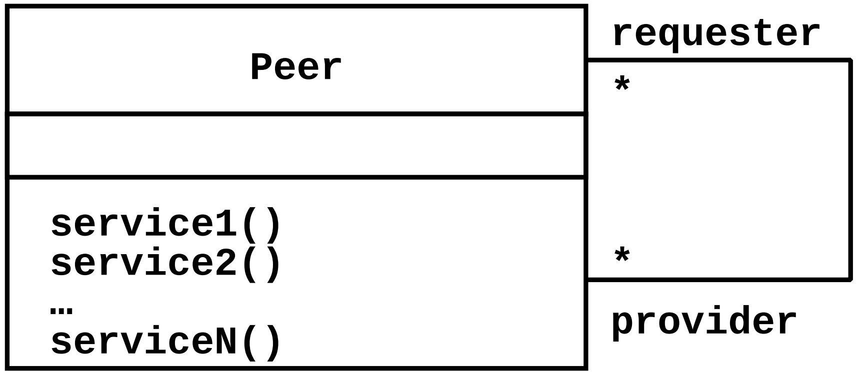
- *Portability*
  - **Server can be installed on a variety of machines and operating systems and functions in a variety of networking environments**
- *Transparency*
  - **The server might itself be distributed (why?), but should provide a single "logical" service to the user**
- *Performance*
  - **Client should be customized for interactive display-intensive tasks**
  - **Server should provide CPU-intensive operations**
- *Scalability*
  - **Server has spare capacity to handle larger number of clients**
- *Flexibility*
  - **Should be usable for a variety of user interfaces**
- *Reliability*
  - **System should survive individual node and/or communication link problems**

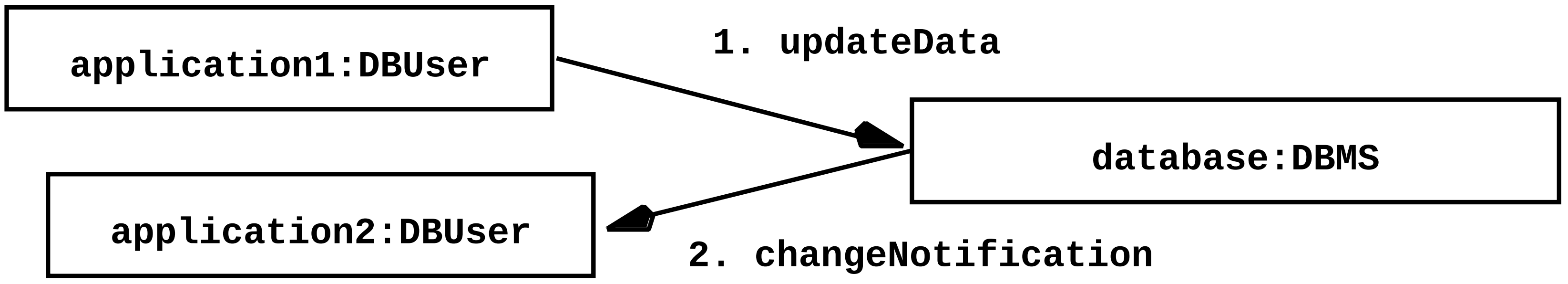
Problems with Client/Server Architectures

- Layered systems do not provide peer-to-peer communication
- Peer-to-peer communication is often needed
- Example: Database receives queries from application but also sends notifications to application when data have changed

Peer-to-Peer Architecture

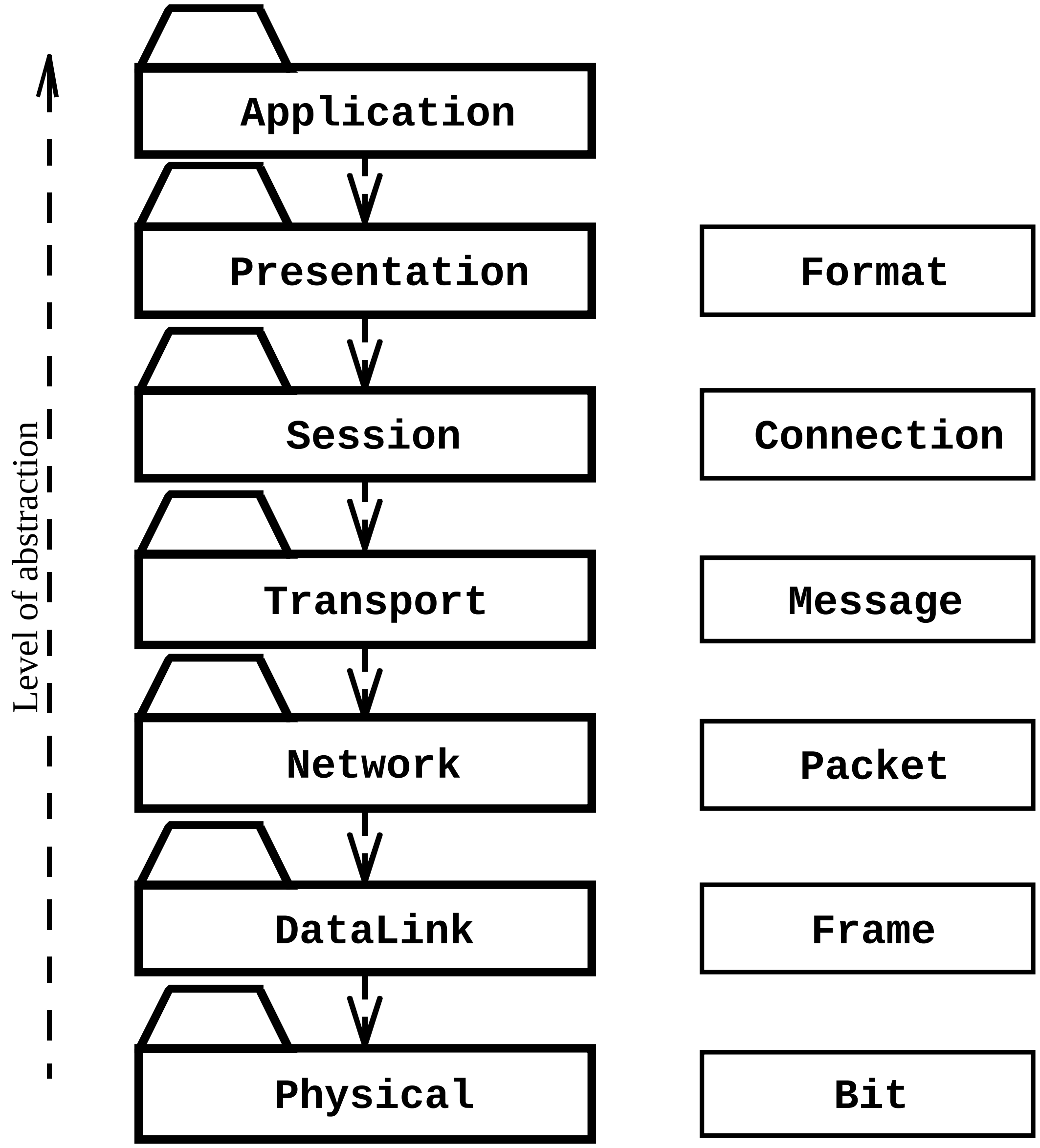
- Generalization of Client/Server Architecture
- Clients can be servers and servers can be clients
- More difficult because of possibility of deadlocks



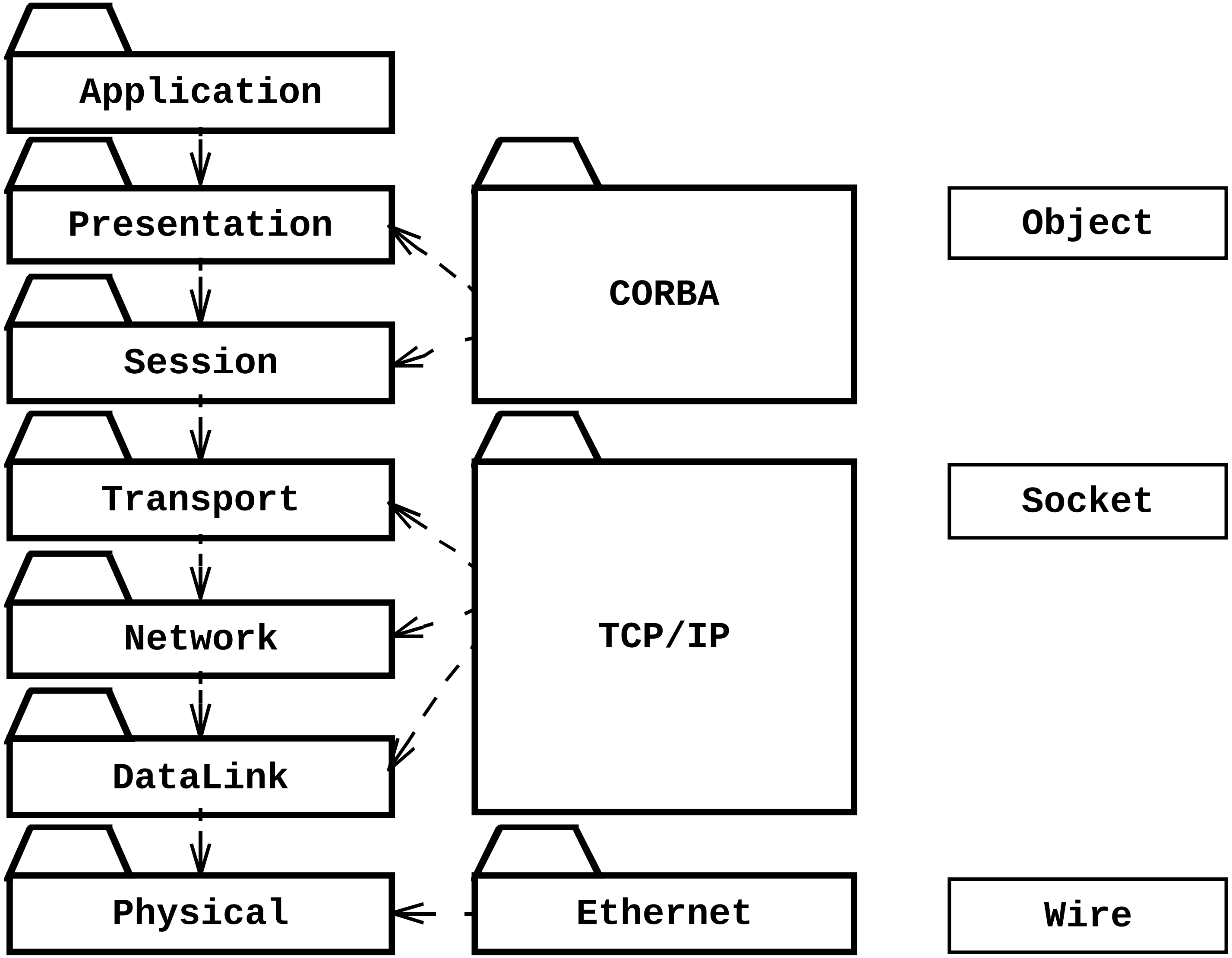


Example of a Peer-to-Peer Architecture

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

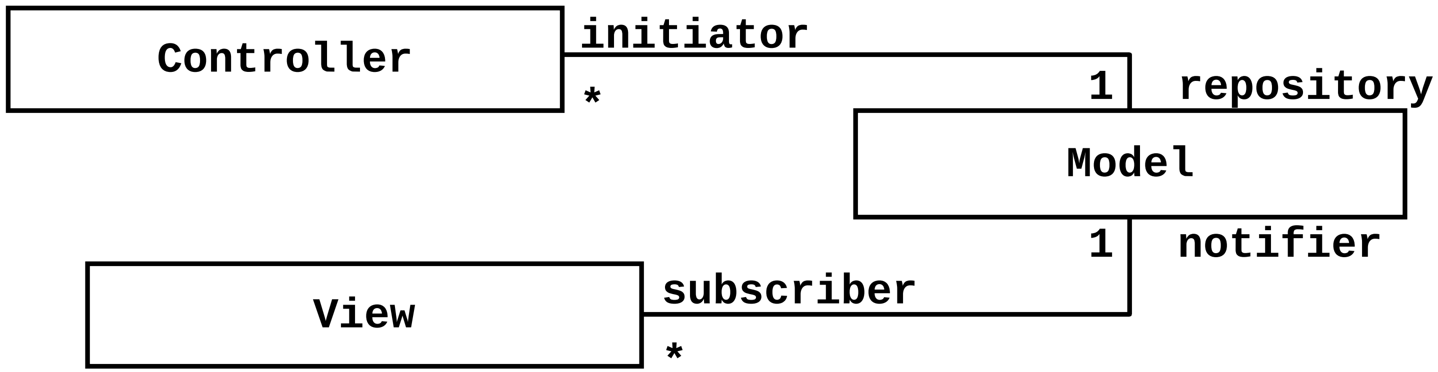


Middleware Allows You To Focus On The Application Layer

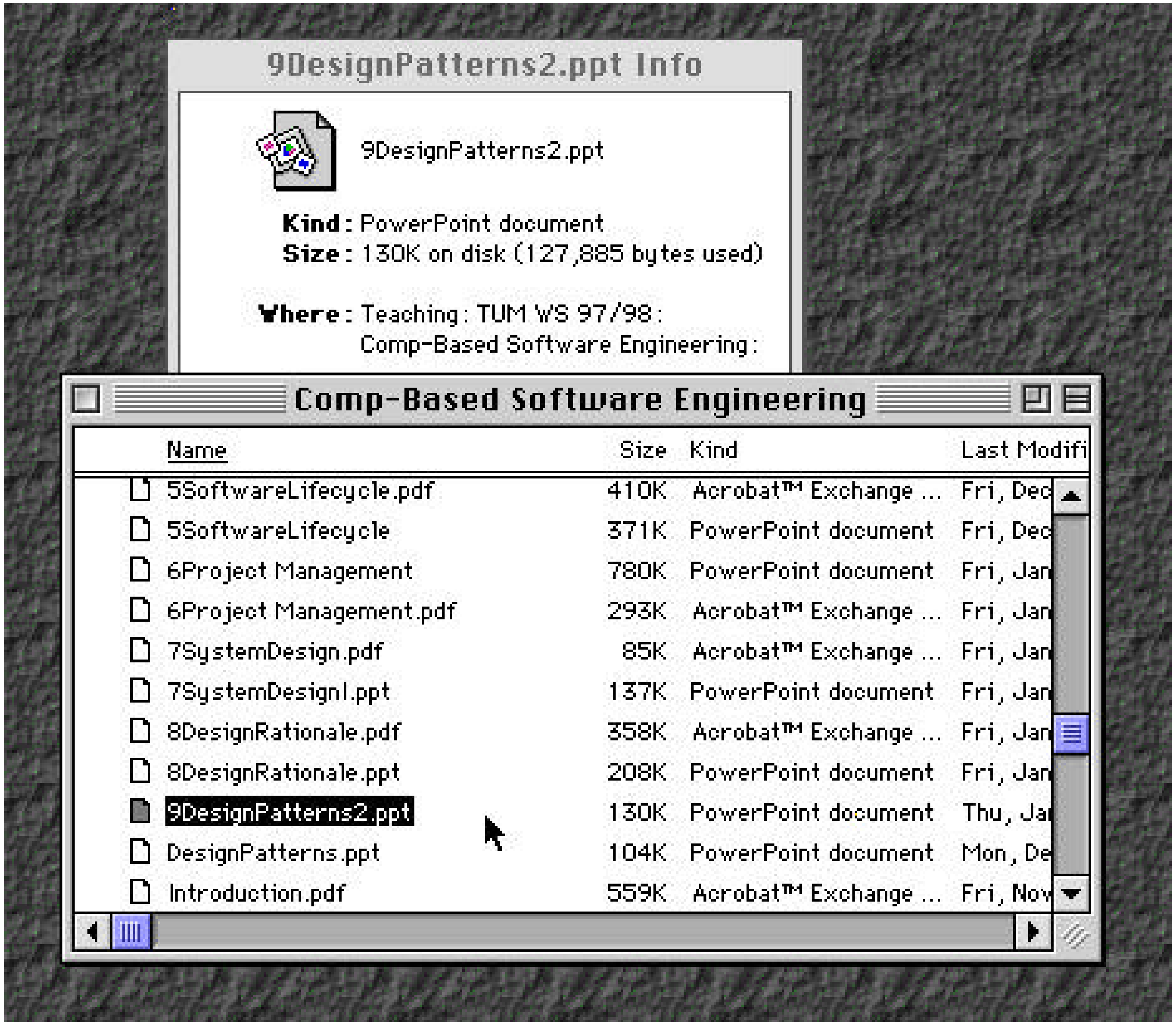


Model/View/Controller

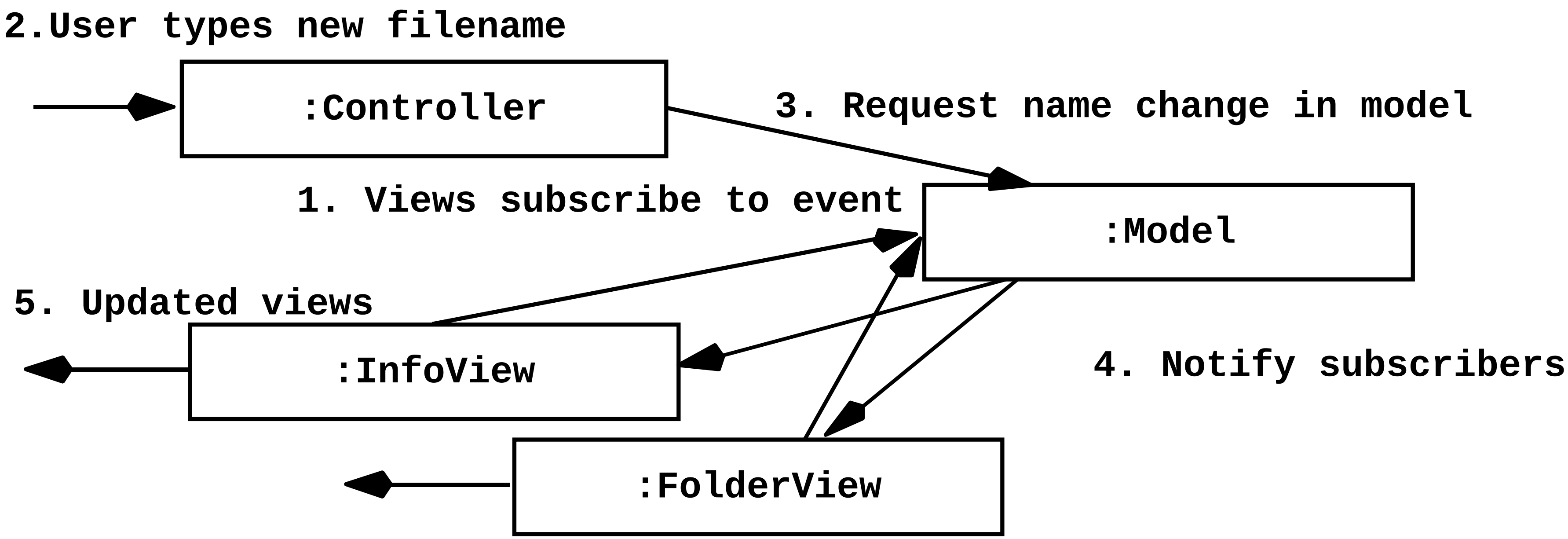
- Subsystems are classified into 3 different types
  - **Model subsystem:** Responsible for application domain knowledge
  - **View subsystem:** Responsible for displaying application domain objects to the user
  - **Controller subsystem:** Responsible for sequence of interactions with the user and notifying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



Example of a File System based on MVC Architecture

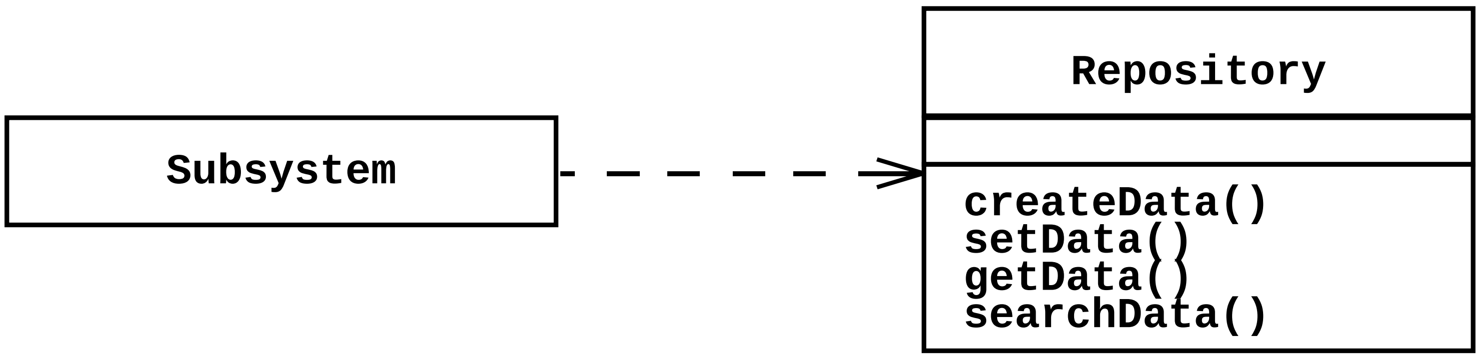


Sequence of Events

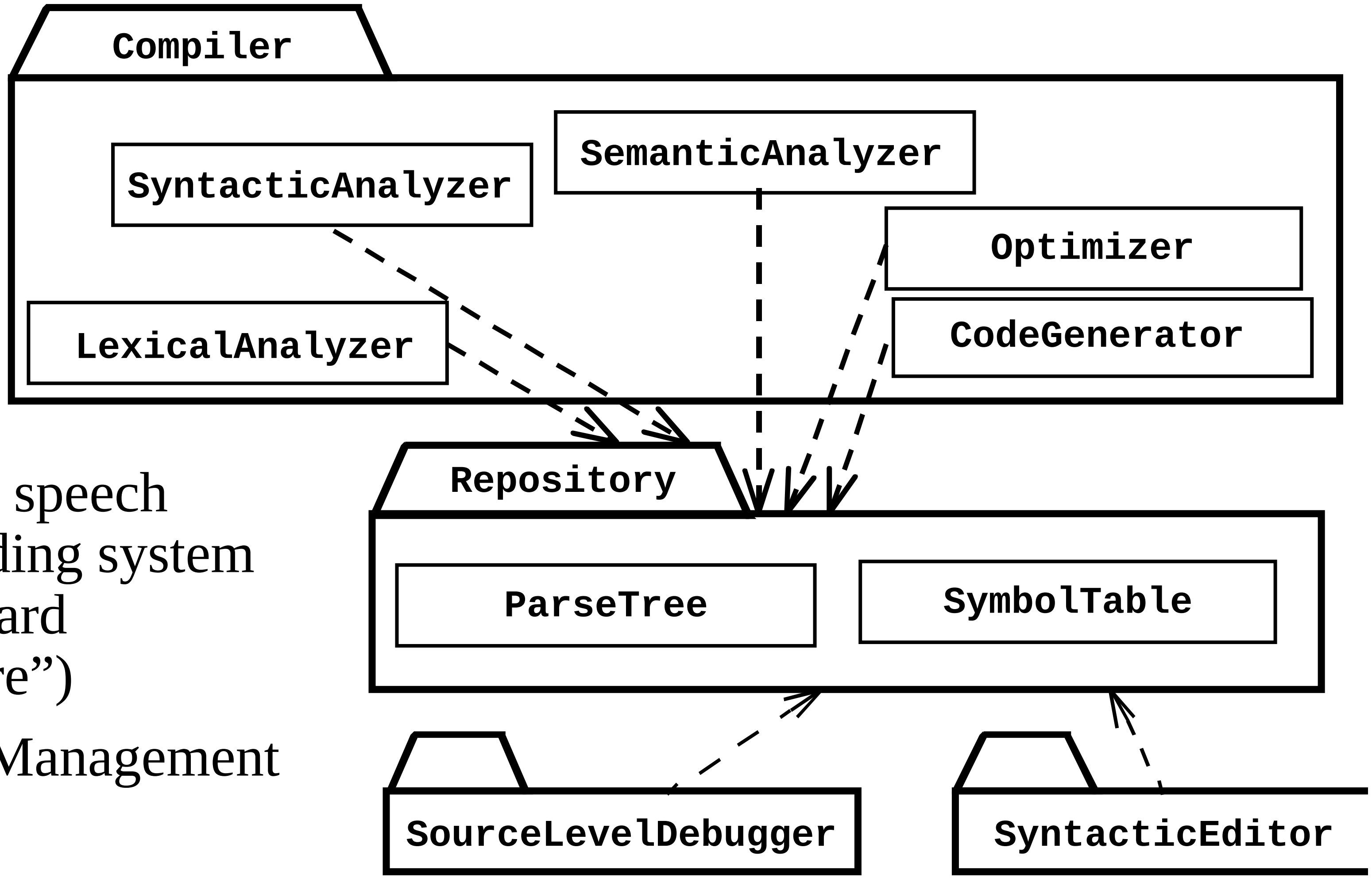


Repository Architecture

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



Examples of Repository Architecture



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

Summary

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