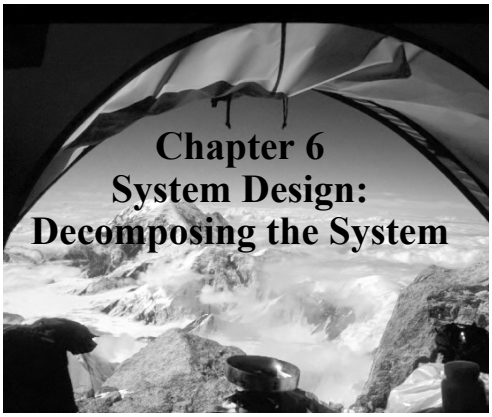
Object-Oriented Software Engineering
Using UML, Patterns, and Java



Chapter 6
System Design: Decomposing the System

Design

"There are two ways of constructing a software design: One way is to make it so simple that there are obviously no deficiencies, and the other way is to make it so complicated that there are no obvious deficiencies."

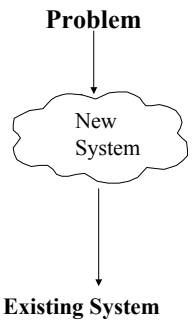
- C.A.R. Hoare

Why is Design so Difficult?

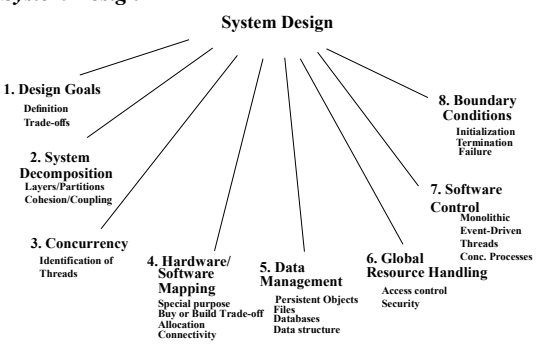
- *Analysis:* Focuses on the application domain
- *Design:* Focuses on the solution domain
  - **Design knowledge is a moving target**
  - **The reasons for design decisions are changing very rapidly**
    - **Halftime knowledge in software engineering: About 3-5 years**
    - **What I teach today will be out of date in 3 years**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



Overview

System Design I (This week – Chapter 6)
- **0. Overview of System Design**
- **1. Design Goals**
- **2. Subsystem Decomposition**

System Design II: Addressing Design Goals (Next week – Chapter 7)
- **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, cohesion, 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**
- Subsystem Decomposition
  - **Activity 8: Boundary conditions**

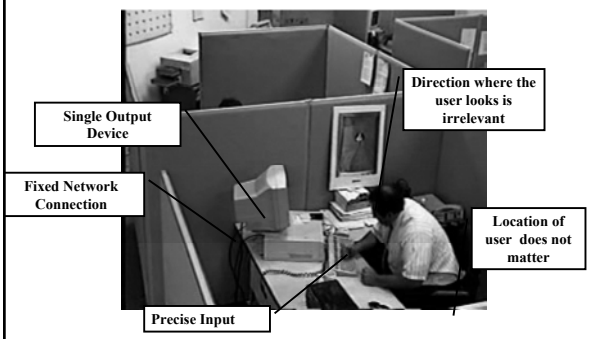
How do we get the Design Goals?

Let's look at a small example

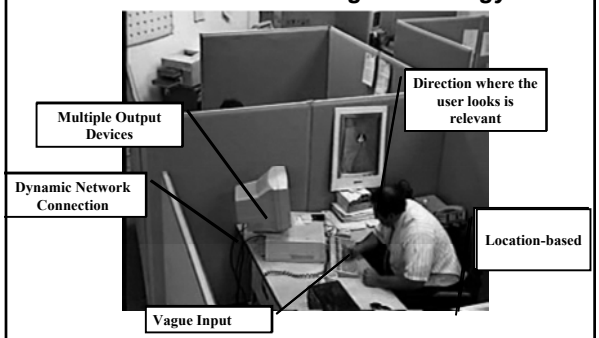
- **Current Situation:**
  - Computers must be used in the office
- **What we want:**
  - A computer that can be used in mobile situations.

Example: Current Desktop Development

Identify Current Technology Constraints



Generalize Constraints using Technology Enable



Establish New Design Goals

- **Mobile Network Connection**
- **Multiple Output Devices**
- **Location-Based**
- **Multimodal Input (Users Gaze, Users Location, …)**
- **Vague input**

Sharpen the Design Goals

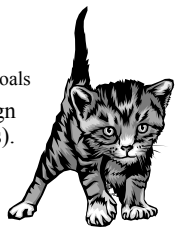
- **Location-based input**
  - Input depends on user location
  - Input depends on the direction where the user looks ("egocentric systems")
- **Multi-modal input**
  - The input comes from more than one input device
- **Dynamic connection**
  - Contracts are only valid for a limited time
- **Is there a possibility of further generalizations?**
- **Example: location can be seen as a special case of context**
  - User preference is part of the context
  - Interpretation of commands depends on context

List of Design Goals

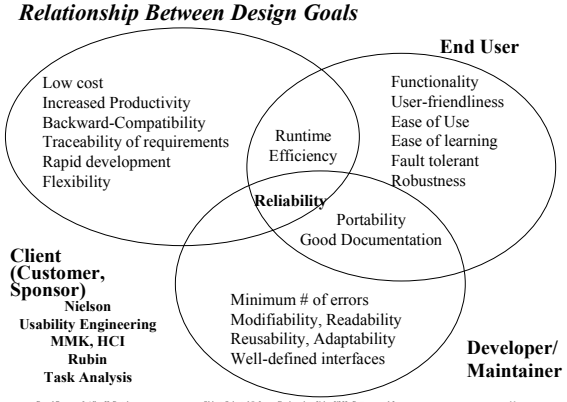
- Reliability
- Modifiability
- Maintainability
- Understandability
- Adaptability
- Reusability
- Efficiency
- Portability
- Traceability of requirements
- Fault tolerance
- Backward-compatibility
- Cost-effectiveness
- Robustness
- High-performance
- Good documentation
- Well-defined interfaces
- User-friendliness
- Reuse of components
- Rapid development
- Minimum # of errors
- Readability
- Ease of learning
- Ease of remembering
- Ease of use
- Increased productivity
- Low-cost
- Flexibility

Classroom Activity – Design Goals

- Description: Identify and prioritize the design goals for your project.
- Process:
  - Meet as teams
    - Choose a scribe to record design goals
  - Identify top 5 – 10 ordered design goals (there may be more or less).
  - You have about 5 minutes.



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 may 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.**
- (Subsystem) 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

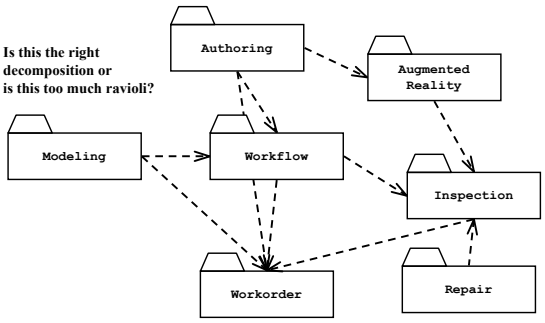
- Service: A set of related operations that share a common purpose
  - **Notification subsystem service:**
    - **LookupChannel()**
    - **SubscribeToChannel()**
    - **SendNotice()**
    - **UnscubscribeFromChannel()**
  - **Services are defined in System Design**
- Subsystem Interface: Set of fully 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 cohesion).
  - **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?

Subsystem Decomposition Example

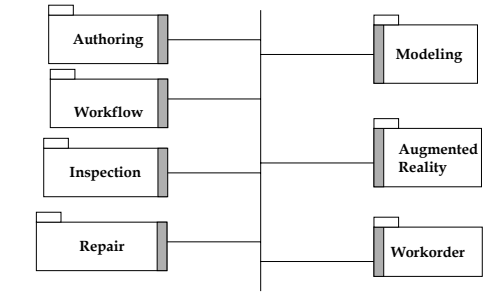
Is this the right decomposition or is this too much ravioli?



Definition: Subsystem Interface Object

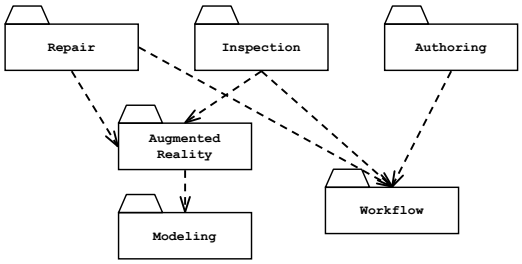
- A *Subsystem Interface Object* provides a service
  - **This is the set of public methods provided by the subsystem**
  - **The Subsystem interface describes all the methods of the subsystem interface object**
- Use a Facade pattern for the subsystem interface object

System as a set of subsystems communicating via a software bus



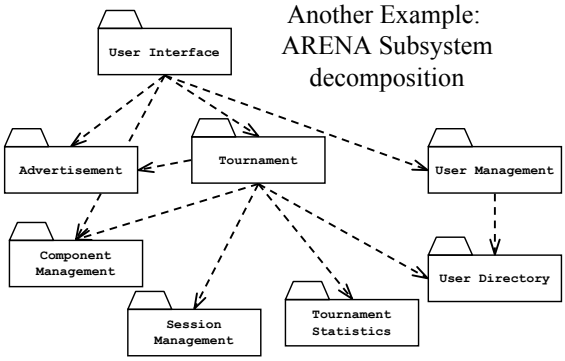
A Subsystem Interface Object publishes the service (= Set of public methods) provided by the subsystem

A 3-layered Architecture

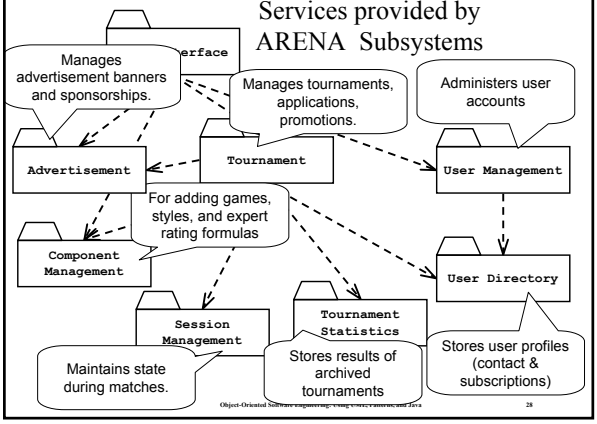


What is the relationship between Modeling and Authoring? Are other subsystems needed?

Another Example: ARENA Subsystem decomposition



Services provided by ARENA Subsystems



Coupling and Cohesion

- Goal: Reduction of ***complexity while change occurs***
- Cohesion measures the dependence among classes
  - **High cohesion: The classes in the subsystem perform similar tasks and are related to each other (via associations)**
  - **Low cohesion: 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 cohesion and minimum coupling as possible:
  - **How can we achieve high cohesion?**
  - **How can we achieve loose coupling?**

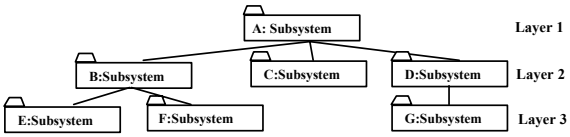
Partitions and Layers

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 subsystem services to a higher layers (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 cohesion but also complexity (more services)**
- No more than 4+/-2 layers, use 3 layers (good)

Classroom Activity – Partitioning

- Description: Partition you system into subsystems using the ideas of coupling and cohesion.
- Process:
  - Meet as teams
    - Choose a scribe to record design goals
  - Use heuristics
    - 7 +/-2 subsystems
    - 4+/-2 layers.
  - You have about 10 minutes.

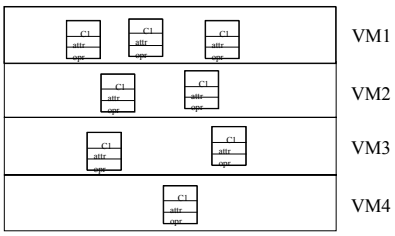
Relationships between Subsystems

- 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: T.H.E. operating system (1965)
  - **A system should be developed by an ordered set of virtual machines, each built in terms of the ones below it.**

Problem



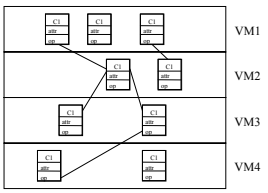
Existing System

Virtual Machine

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

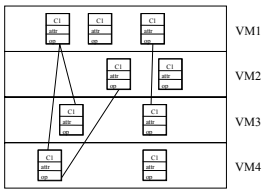
Closed Architecture (Opaque Layering)

- Any layer can only invoke operations from the immediate layer below
- Design goal: **High maintainability, flexibility**



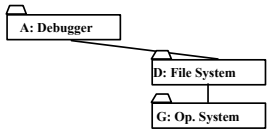
Open Architecture (Transparent Layering)

- Any layer can invoke 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**

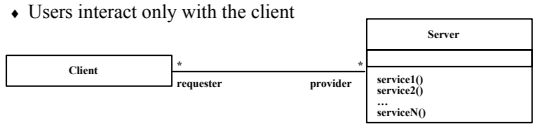


Software Architectural Styles

- 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**
  - **Peer-To-Peer**
  - **Repository**
  - **Model/View/Controller**
  - **Pipes and Filters**

Client/Server Architectural Style

- 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 Architectural Style

- 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

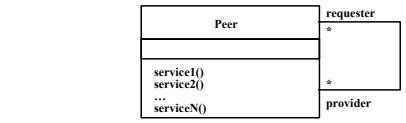
- *Service Portability*
  - **Server can be installed on a variety of machines and operating systems and functions in a variety of networking environments**
- *Transparency, Location-Transparency*
  - **The server might itself be distributed (why?), but should provide a single "logical" service to the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

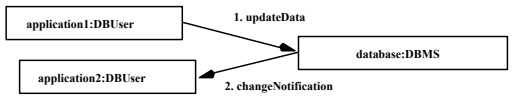
Problems with Client/Server Architectural Styles

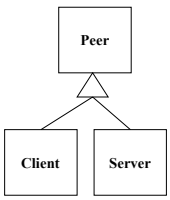
- Layered systems do not provide peer-to-peer communication
- Peer-to-peer communication is often needed
- Example: Database receives queries from application but also sends notifications to application when data have changed

Peer-to-Peer Architectural Style

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

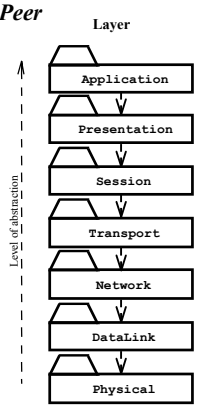






Example of a Peer-to-Peer Architectural Style

- 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.
- Closed software architecture

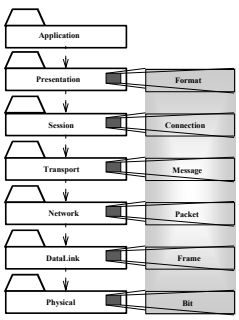


OSI model Packages and their Responsibility

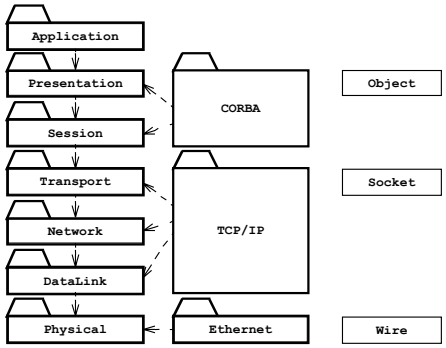
- The **Physical** layer represents the hardware interface to the net-work. It allows to **send()** and **receive bits** over a **channel**.
- The **Datalink** layer allows to send and receive **frames** without error using the services from the Physical layer.
- The **Network** layer is responsible for that the data are reliably **transmitted** and **routed** within a network.
- The **Transport** layer is responsible for reliably transmitting from end to end. (This is the interface seen by Unix programmers when transmitting over TCP/IP sockets)
- The **Session** layer is responsible for initializing a connection, including authentication.
- The **Presentation** layer performs data transformation services, such as byte swapping and encryption
- The **Application** layer is the system you are designing (unless you build a protocol stack). The application layer is often layered itself.

Another View at the ISO Model

- A closed software architecture
- Each layer is a UML package containing a set of objects

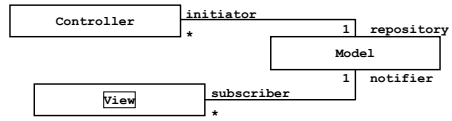


Middleware Allows Focus On The Application Layer

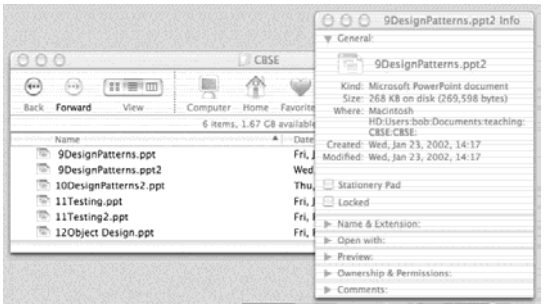


Model/View/Controller

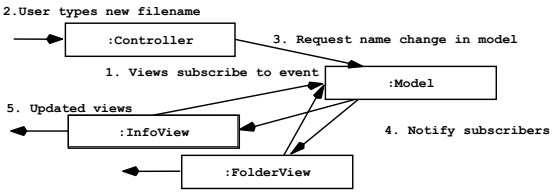
- Subsystems are classified into 3 different types
  - **Model subsystem:** Responsible for application domain knowledge
  - **View subsystem:** Responsible for displaying application domain objects to the user
  - **Controller subsystem:** Responsible for sequence of interactions with the user and notifying 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 the MVC Architectural Style

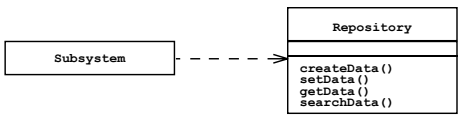


Sequence of Events (Collaborations)

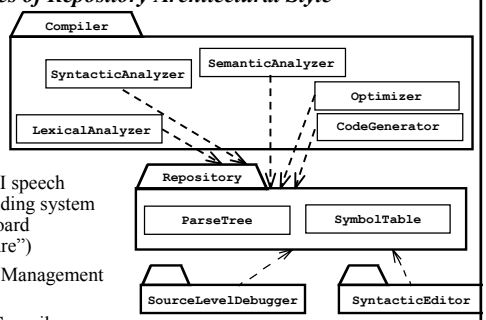


Repository Architectural Style (Blackboard Architecture, Hearsay II Speech Recognition System)

- 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 Architectural Style



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

Classroom Activity – Architectural Style

- Description: Select one of the architectural styles just discussed that best fits your system and redo the subsystem breakdown.
- Process:
  - Meet as teams
    - Choose a scribe to record design goals
  - Use architectural styles/patterns
    - Client/Server
    - Peer-To-Peer
    - Repository
    - Model/View/Controller
    - Pipes and Filters
  - Use heuristics
    - 7 +/-2 subystems
    - 4+/-2 layers.
  - You have about 10 minutes.

Summary

- System Design
  - **Reduces the gap between requirements and the (virtual) 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**