System Design

(chapter 7, Bruegge et al)
(chapter 6, Sommerville, 9th ed.)

Prof. Adel Taweel
ataweel@birzeit.edu

Objectives

To provide an overview of System Design

To appreciate issues addressed during the system design phase

To understand consequences of design goals and how to achieve them

To appreciate the value of architectural styles in formulating system designs.

Design is multi-perspective

Analysis: Focuses on the business (or problem) domain.

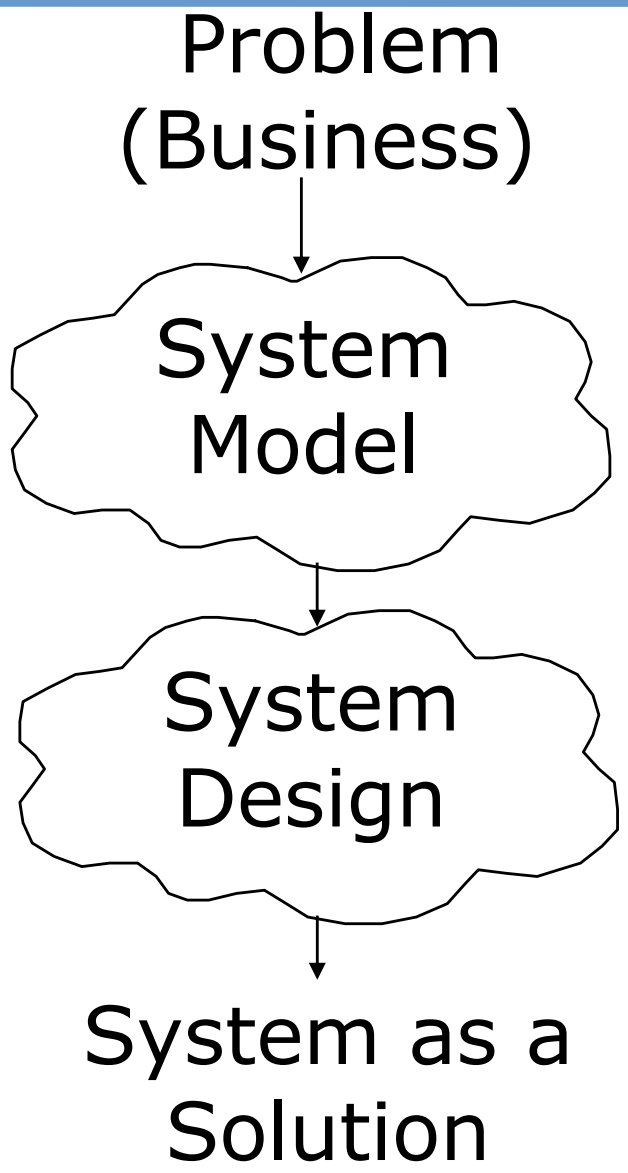
Design: Focuses on the solution domain.

The (system) solution perspective considers three aspects:

- Software artifacts
- Associated technologies
- Hardware limitations or solutions

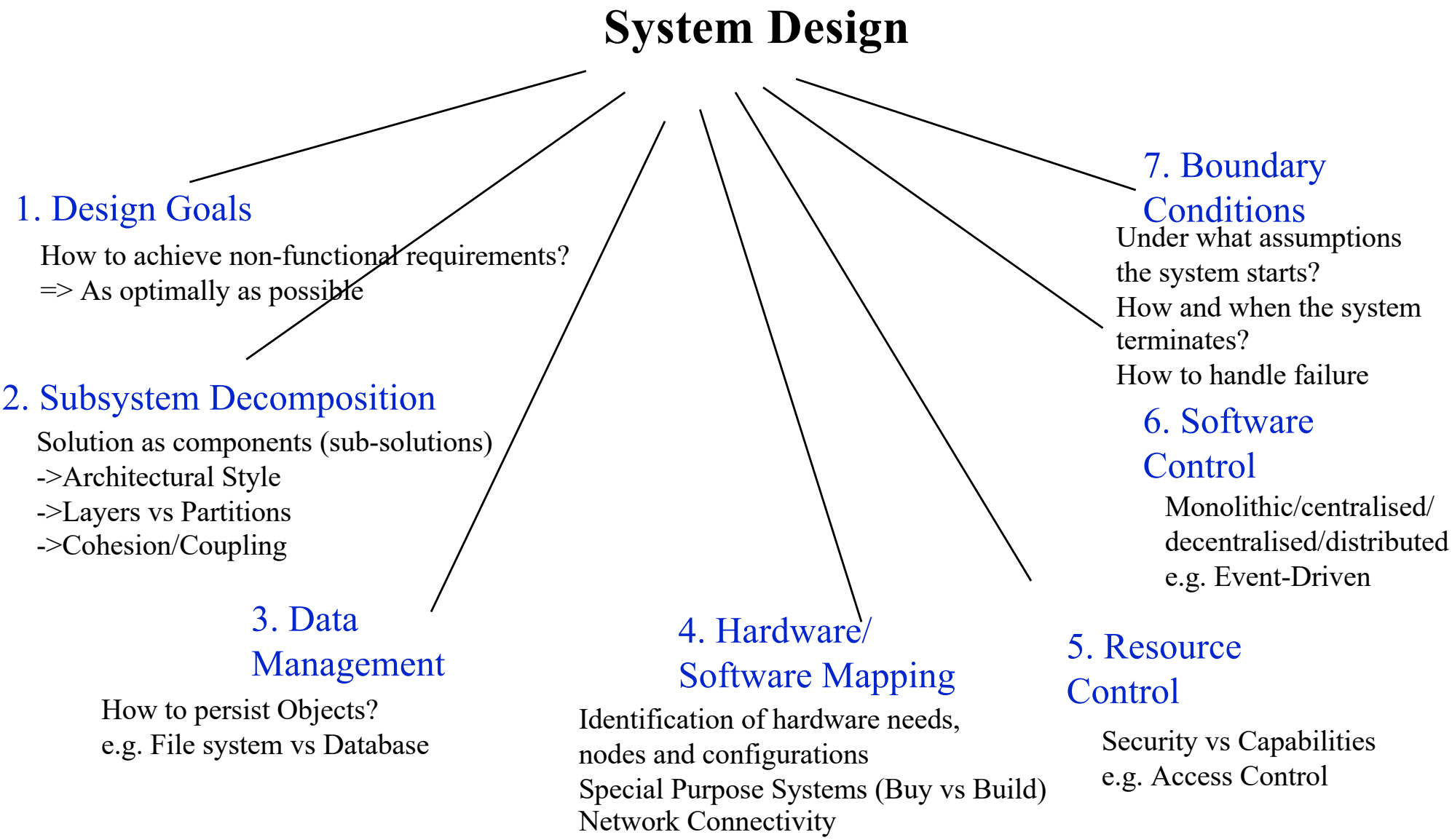
The Scope of System Design

It bridges the gap between a (business) problem and an system solution in a structured way

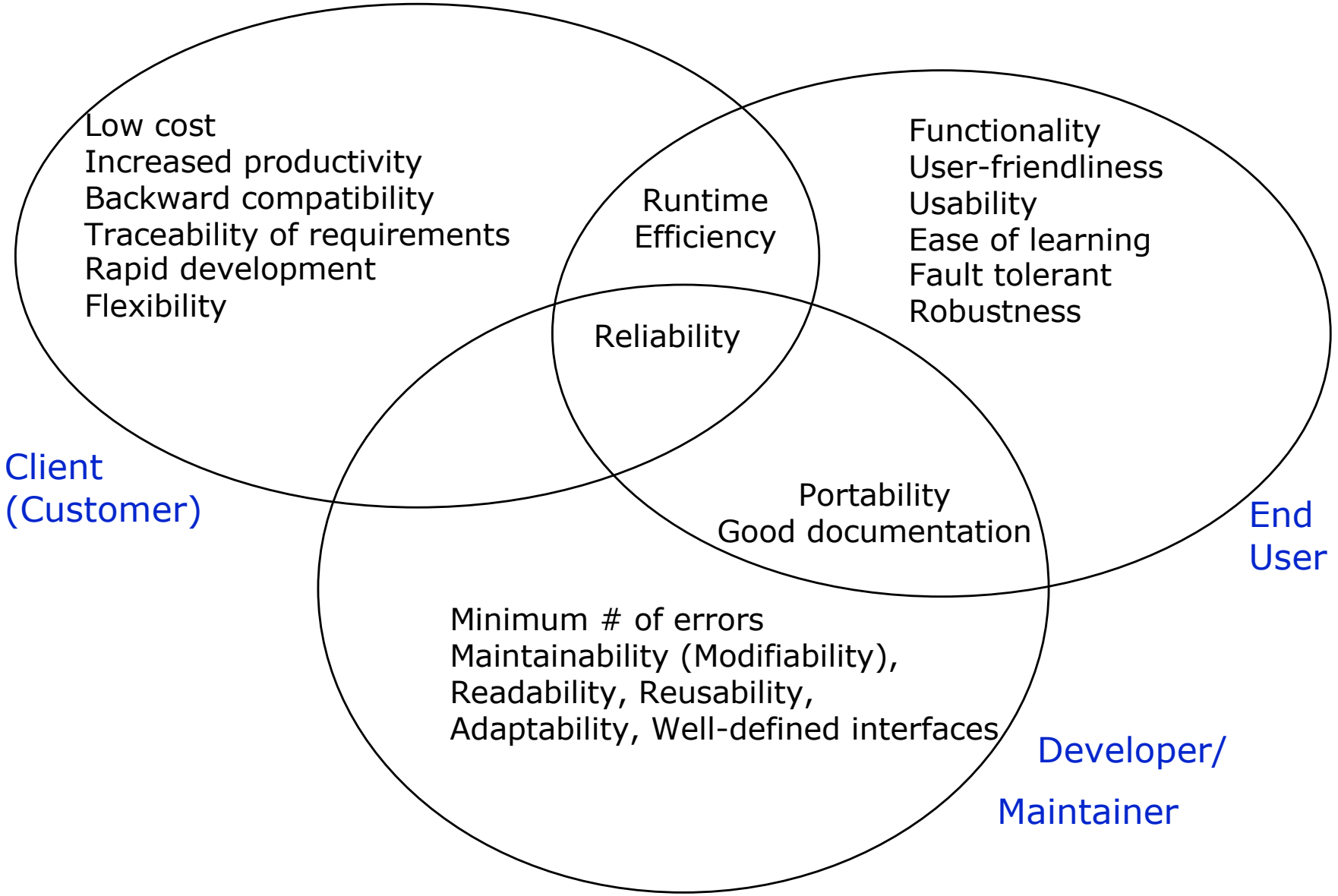


- How?
- Use Divide & Conquer (see next slide):
  1) Identify design goals
  2) Model the new system design as a set of components (subsystems) or sub-solutions
  3-8) Address main design goals.

System Design: Seven Key Issues to address



Stakeholders have different Design Goals (OR Issues of Concerns)



Some Design Trade-offs for a developer

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

Design Goals: Coupling and Cohesion

Cohesion measures degree of the strength of functional relatedness within classes (or among classes) in a component

High cohesion: The classes in a component (a subsystem) perform similar or related tasks/functions and are related to each other via many associations

Low cohesion: classes are grouped with no clear relatedness between them, but lots of miscellaneous and auxiliary classes, almost no associations

Coupling measures degree of interdependence between components (or subsystems)

High coupling: Changes to one component will cause significant changes to another component

Low coupling: A change in one component will cause minimal or no effect to other components

Why high Cohesion?

- increases the clarity and ease of comprehension of the design
- simplifies maintenance and future upgrades and enhancements
- often supports low coupling
- supports increased reuse
  - a highly cohesive (i.e. a highly related functionality) component can be re-used for the same specific purpose!

How to achieve high Cohesion?

High Cohesion can be achieved if most of the interaction is kept within a component (opposed to “between components”)

Indicators:

Does a component (or a subsystem) often or always call another component (or subsystem) for a specific service?

⇒ If yes: Consider moving them together into the same subsystem, preferably on the same h/w physical node.

Which of the components call each other for services?

⇒ Can this be avoided by restructuring the components (i.e. classes within) or changing their interfaces?

Can the components be hierarchically ordered (in layers)?

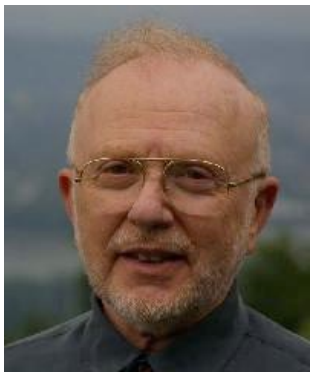
How to achieve Low Coupling?

Low coupling can be achieved by making (self-contained components) as independent as possible by not needing any knowledge of or relying on other components to complete its function.

Indicator: if a calling class does not need to know about the internal (knowledge, e.g. attributes) of the called class (Principle of information hiding, Parnas)

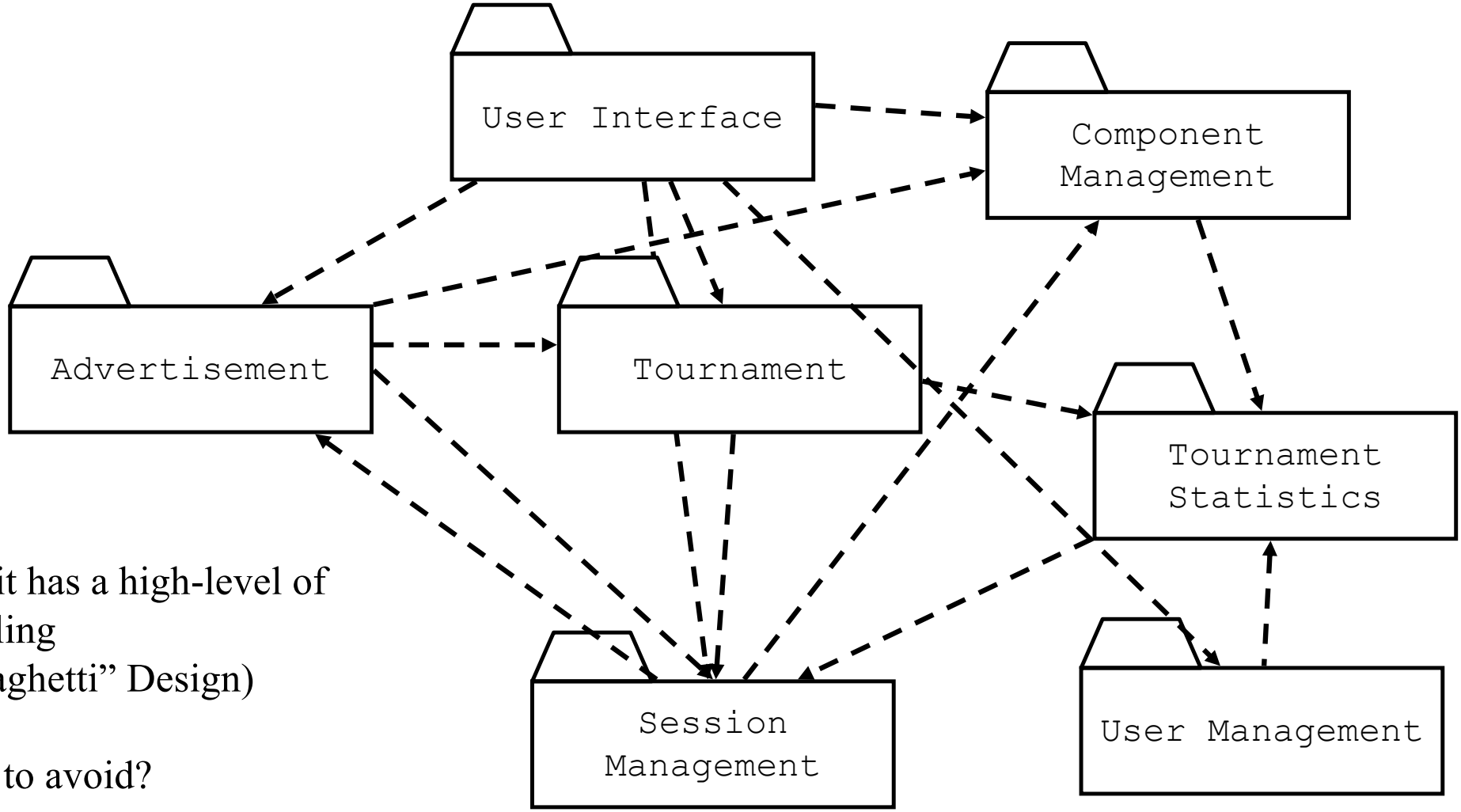
Does the calling class need to know about attributes of other called classes?
=> Define as interfaces (or public operations)

David Parnas,
Developed the concept of
Information Hiding in modular programming.



Is this a Good Design?

Package Diagram Each package contains a component or a collection of components (similar to component diagram)



No, it has a high-level of coupling
("Spaghetti" Design)

How to avoid?

Example of Design Goals

Performance

How to achieve: Localise critical operations and minimise communications (between components). Use large rather than fine-grain components.

Security

How to achieve : Use a layered architecture with critical assets in the inner layers.

Safety

How to achieve : Localise safety-critical features in a small number of sub-systems.

Availability (similarly Robustness)

How to achieve : Include redundant components and mechanisms for fault tolerance.

Maintainability

How to achieve : Use fine-grain, replaceable components.

Example of Design Goals

To whom (the customer, end-user or developer) each of the following design goals is most important to?

- 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

Architectural Design

(architectural patterns or styles)

How to order or organise software components of a system?

What is the optimal architecture model or style for different design goals?

Architectural design

- Architectural design is concerned with understanding how a software system should be organised and designing the overall structure of that system.
- Architectural design is the critical link between design and requirements engineering, as it identifies the main structural components in a system and the relationships between them.
- The output of the architectural design process is an architectural model that describes how the system is organized as a set of communicating components.

Advantages of Employing Architectures

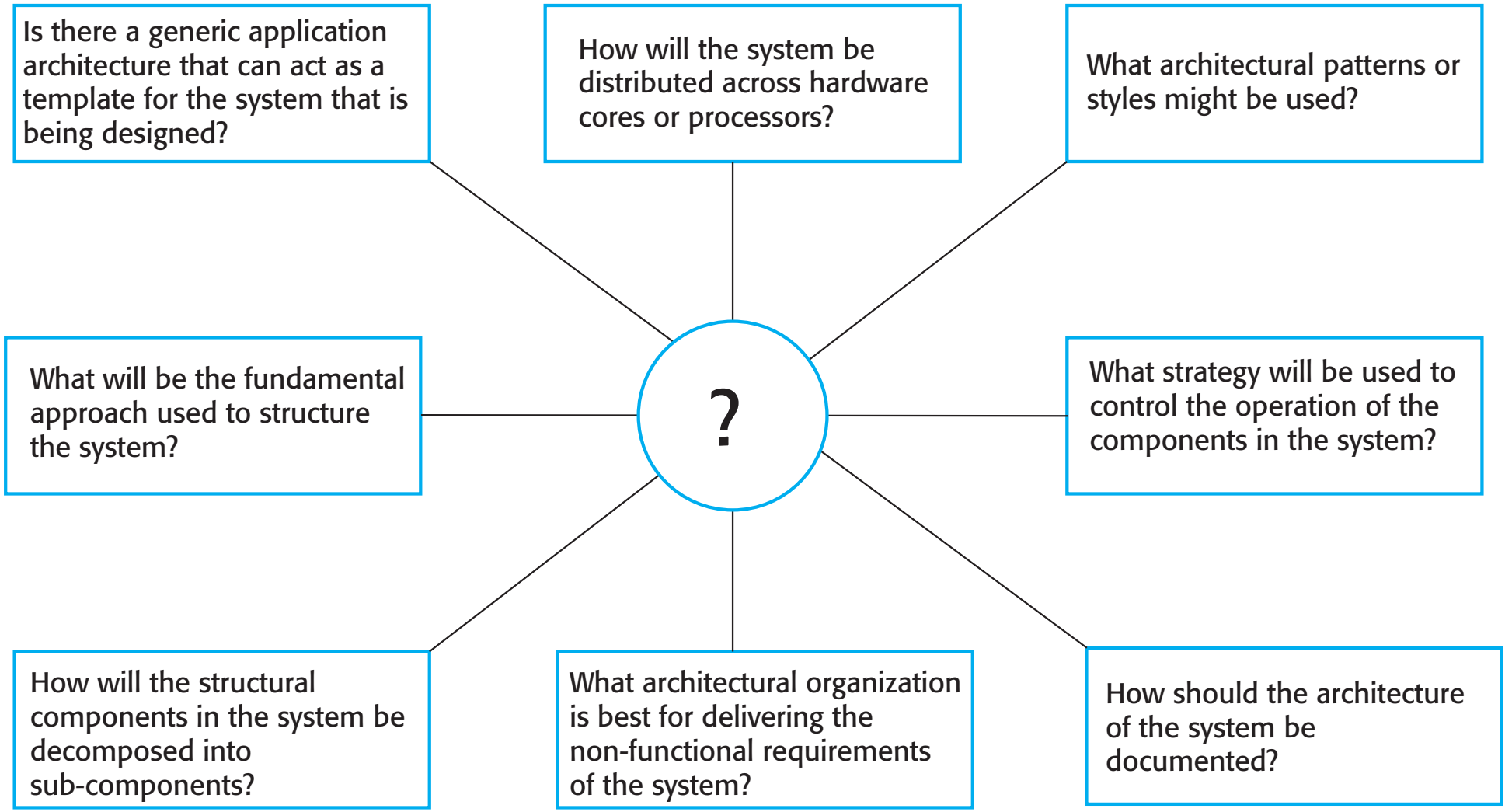
- Stakeholder communication
  - Architecture may be used as a focus of discussion by system stakeholders.
- System analysis
  - Means that analysis of whether the system can meet its *non-functional* requirements is possible.
- Large-scale reuse
  - The architecture may be reusable across a range of systems
  - Product-line architectures may be developed.

Architectural design decisions

Architectural design is a creative process so the process differs depending on the type of system being developed.

However, a number of common decisions span all design processes and these decisions affect the non-functional characteristics of the system.

Architectural design decisions



Source: Sommerville, 9th Ed.

Architectural Style vs Architecture

Subsystem decomposition:

Identification of subsystems, services, and their relationship to each other

Architectural Style:

A pattern for a subsystem decomposition

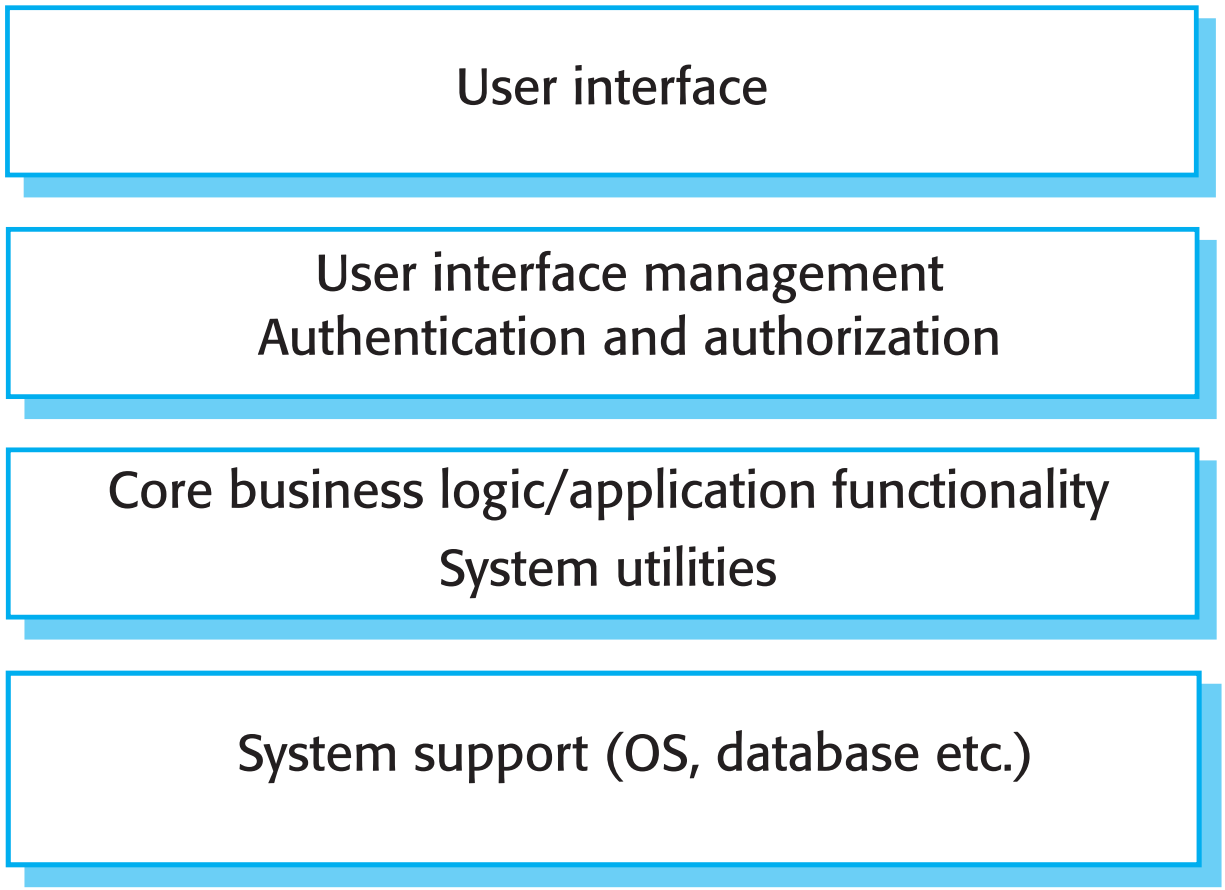
Software Architecture:

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

A generic layered architecture



Source: Sommerville, 9th Ed.

Layers and Partitions

A **layer** is a subsystem that provides a service to another subsystem with the following restrictions:

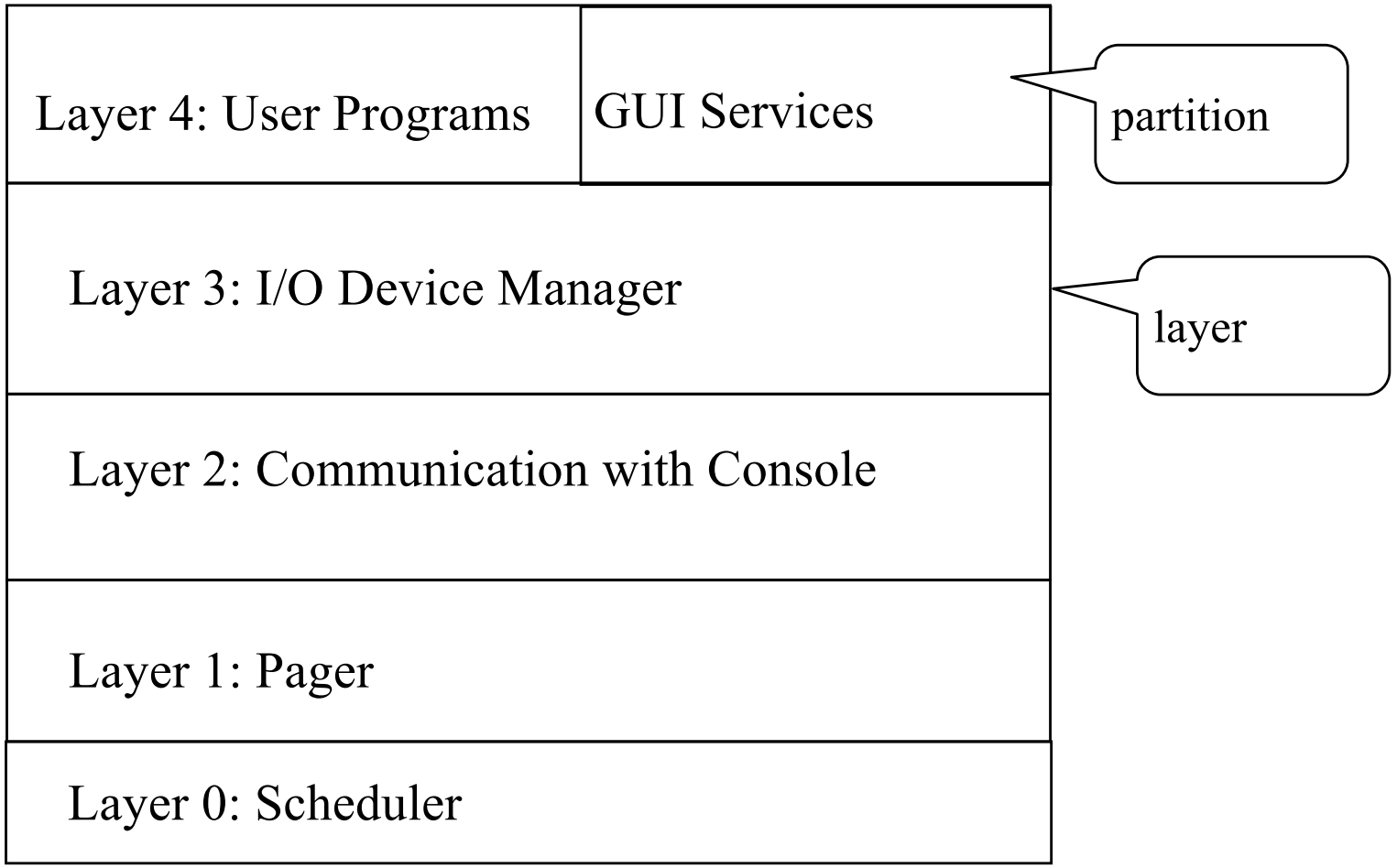
- A layer only depends on services from lower layers
- A layer has no knowledge of higher layers

A layer can be divided horizontally into several independent subsystems called **partitions**

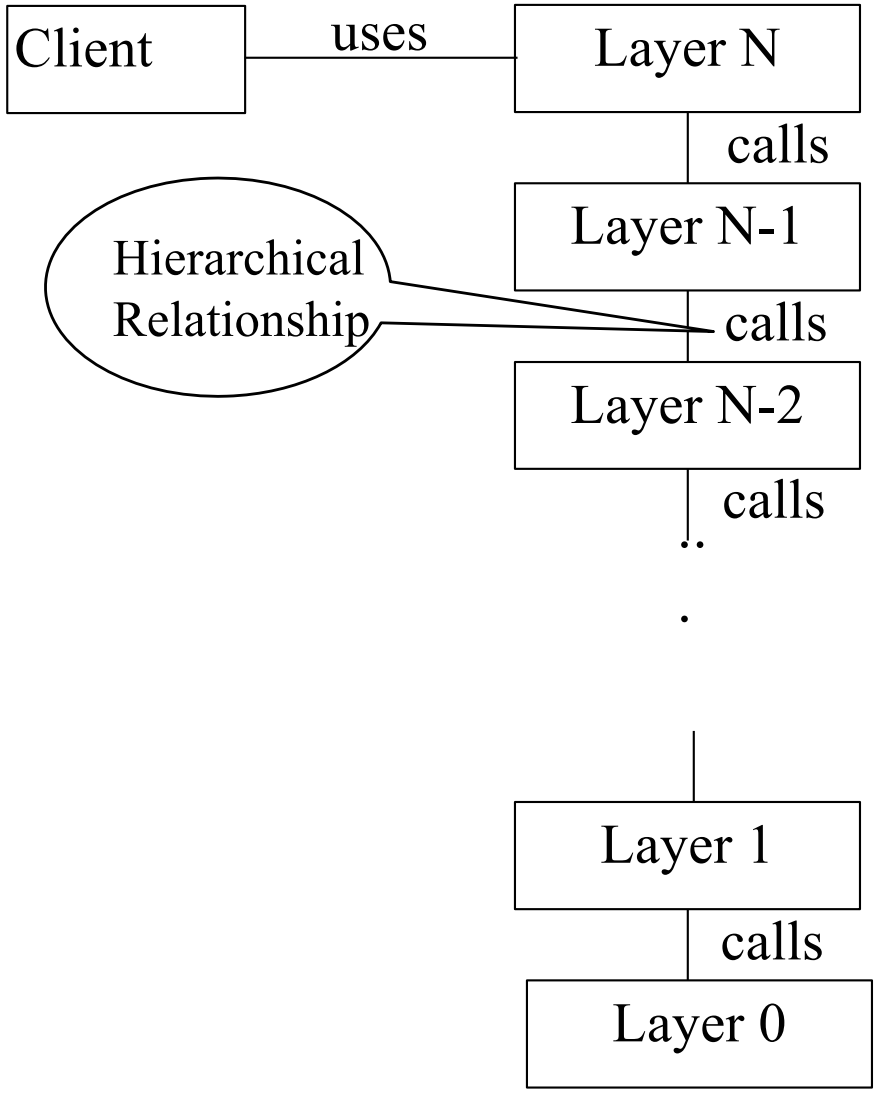
- Partitions provide services to other partitions on the same layer
- Partitions are also called “weakly coupled” subsystems.

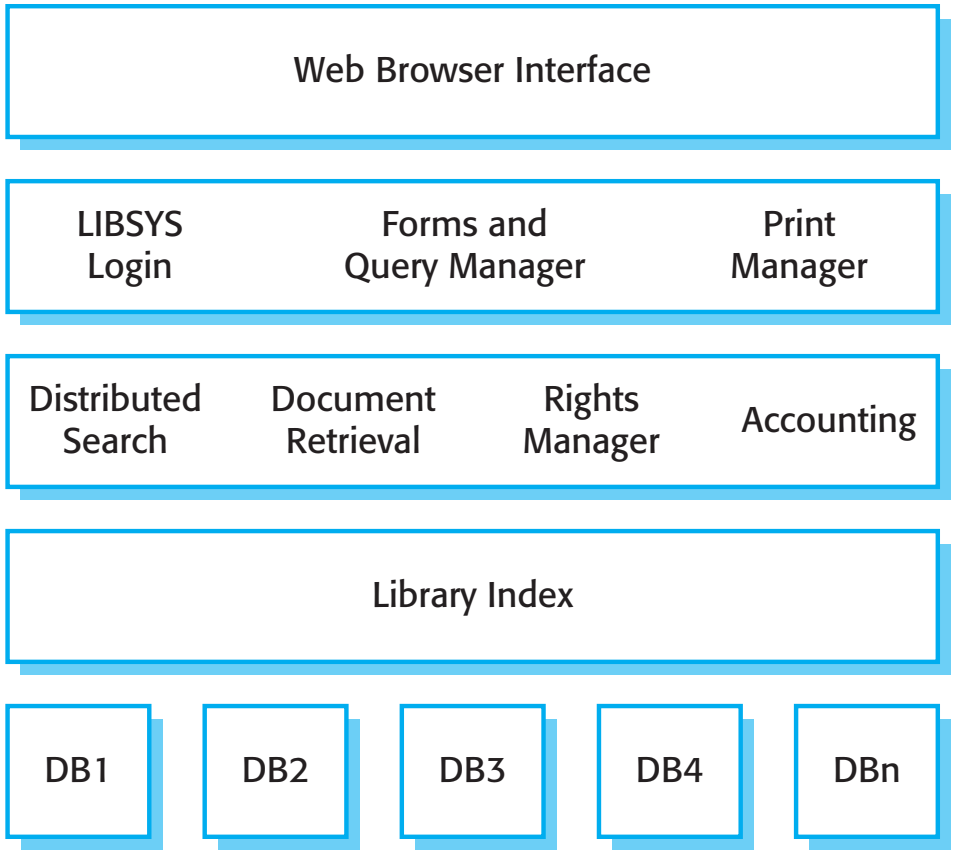
The Layers of an O.S. System

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



The Layered Architectural Style





Example: The architecture of the LIBSYS

Source: Sommerville, 9th Ed.

The Layered architecture pattern

Name	Layered architecture
Description	Organizes the system into layers with related functionality associated with each layer. A layer provides services to the layer above it so the lowest-level layers represent core services that are likely to be used throughout the system. See Figure 6.6.
When used	Used when building new facilities on top of existing systems; when the development is spread across several teams with each team responsibility for a layer of functionality; when there is a requirement for multi-level security.
Advantages	Allows replacement of entire layers so long as the interface is maintained. Redundant facilities (e.g., authentication) can be provided in each layer to increase the dependability of the system.
Disadvantages	In practice, providing a clean separation between layers is often difficult and a high-level layer may have to interact directly with lower-level layers rather than through the layer immediately below it. Performance can be a problem because of multiple levels of interpretation of a service request as it is processed at each layer.

Source: Sommerville, 9th Ed.

Hierarchical Relationships between Subsystems

There are two major types of hierarchical relationships

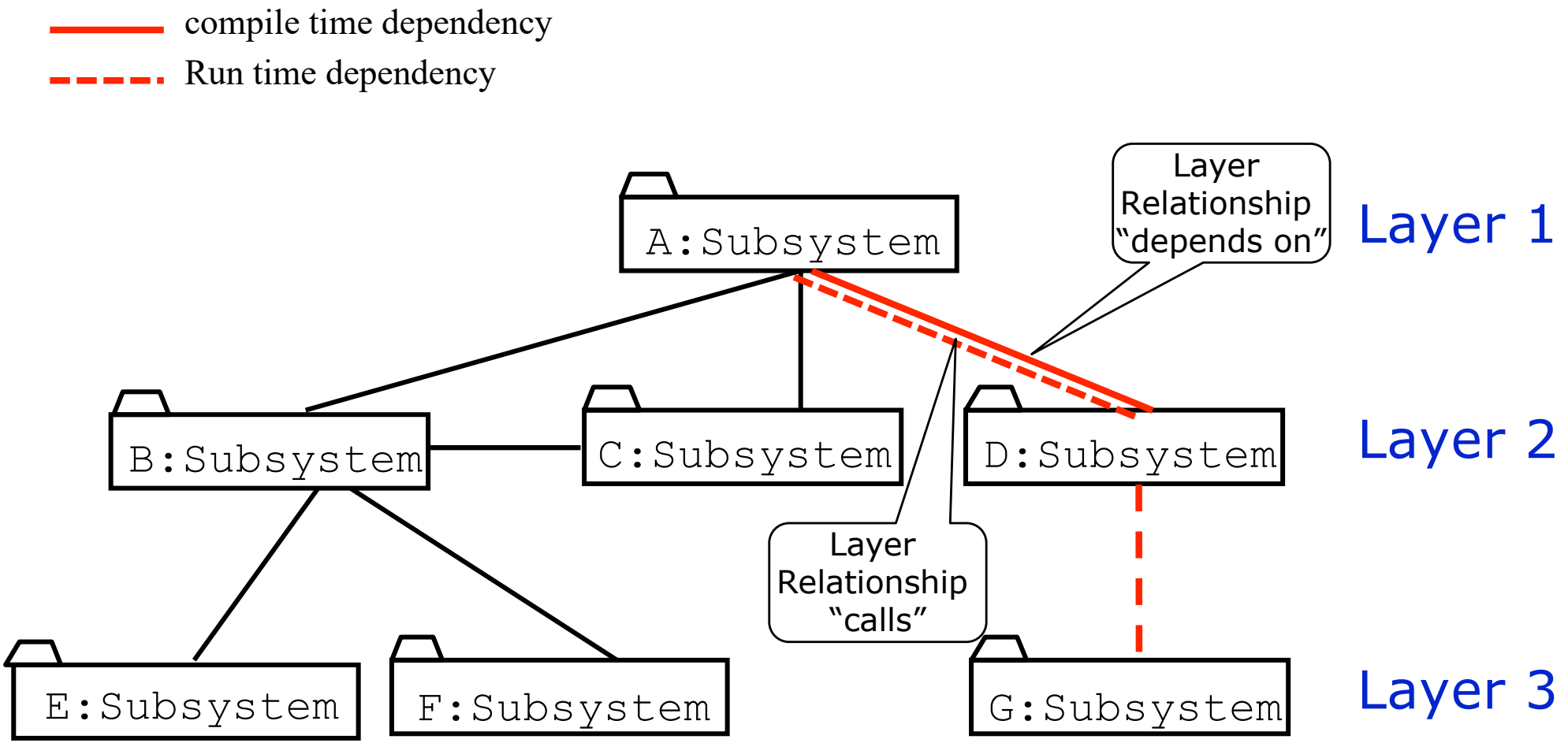
- Layer A "depends on" layer B (compile time dependency)
  - Example: Build dependencies (e.g. make, ant, maven)

- Layer A "calls" layer B (runtime dependency)
  - Example: A web browser calls a web server

UML convention:

- ⇒ Runtime relationships are represented with dashed lines
- ⇒ Compile time relationships are represented with solid lines

Example of a System with more than one Hierarchical Relationship



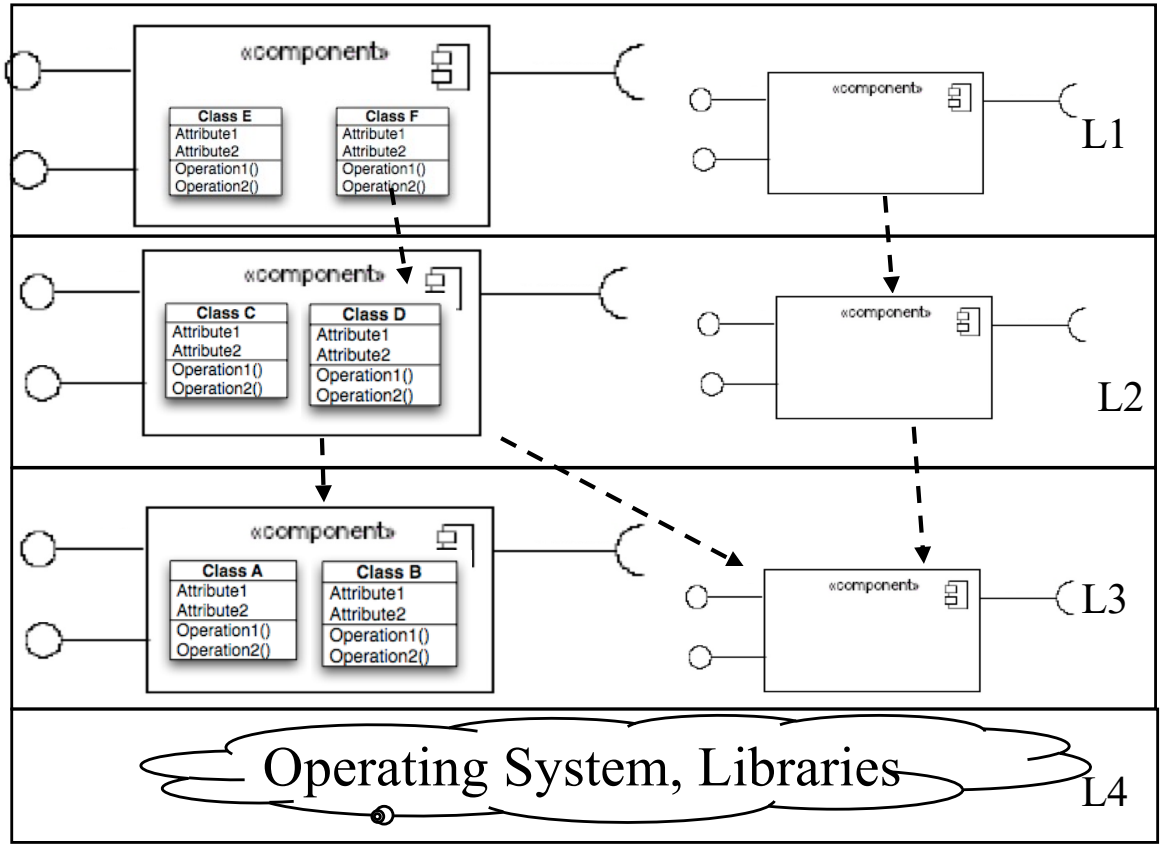
Closed Architecture (Opaque Layering)

Each layer can only call operations from the layer below (called "direct addressing")

Closed architectures are considered more portable

and provide low coupling

Design goals:
Maintainability, flexibility.



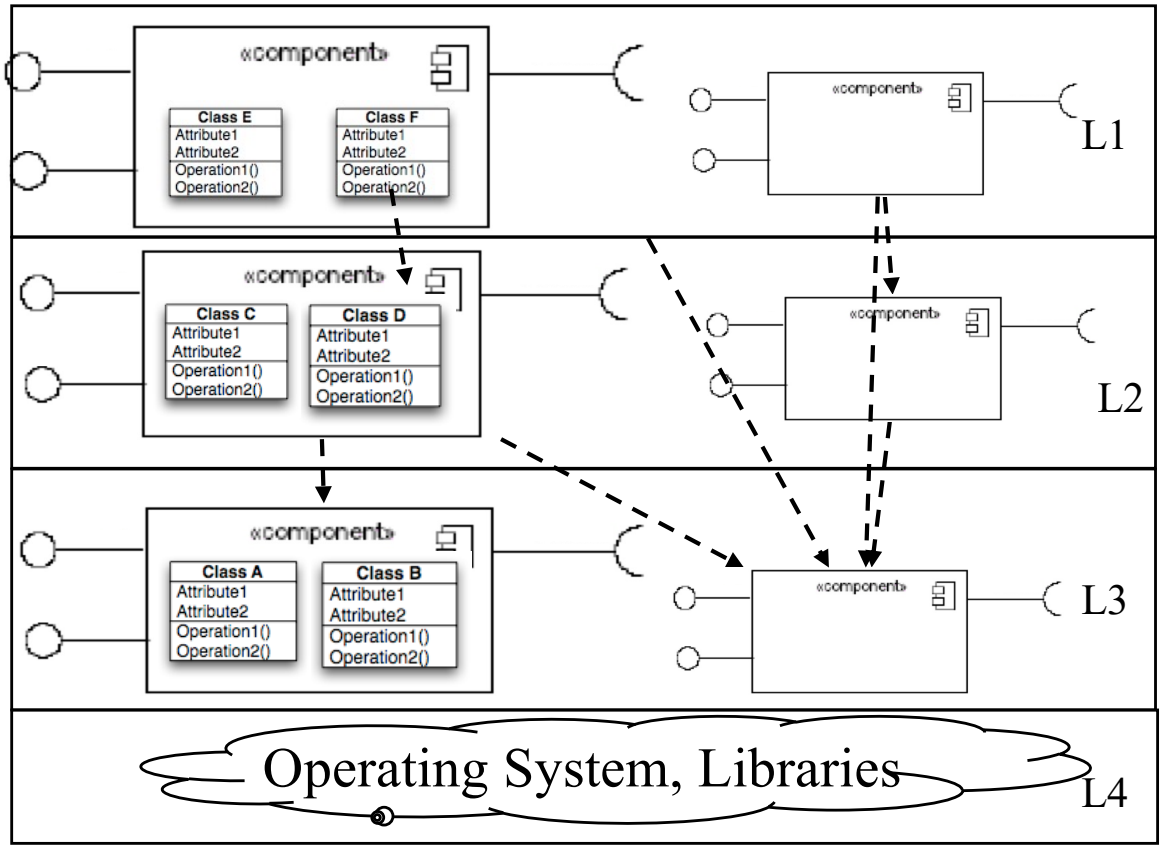
Open Architecture (Transparent Layering)

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

Open architectures are considered more efficient

however, they increase coupling!

Design goal:
Runtime efficiency.



Client/Server Architectures

Often used in the design of many applications

e.g. 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:

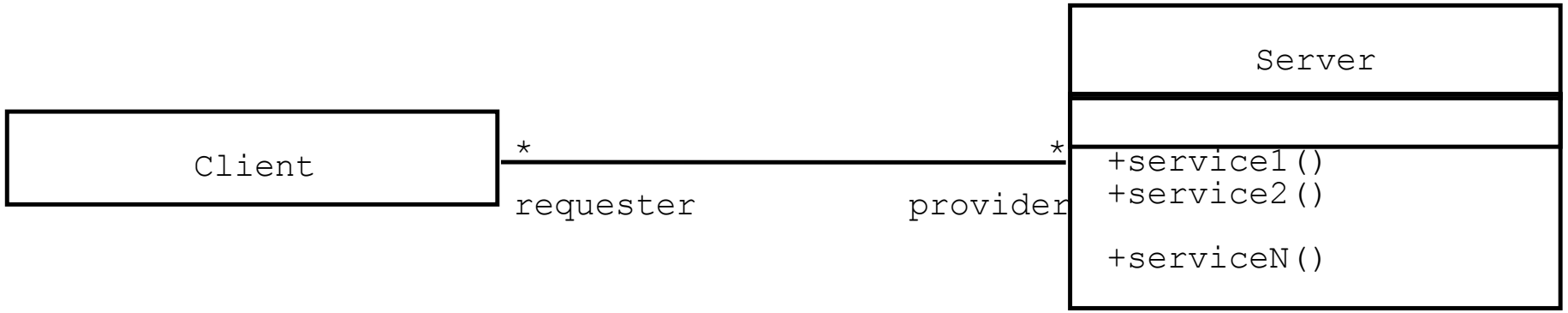
- Centralized data management
- Data integrity and database consistency
- Database security

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 is, in general, reasonably fast
- End users interact only with the client



The Client–server pattern

Name	Client-server
Description	In a client–server architecture, the functionality of the system is organized into services, with each service delivered from a separate server. Clients are users of these services and access servers to make use of them.
When used	Used when data in a shared database has to be accessed from a range of locations. Because servers can be replicated, may also be used when the load on a system is variable.
Advantages	The principal advantage of this model is that servers can be distributed across a network. General functionality (e.g., a printing service) can be available to all clients and does not need to be implemented by all services.
Disadvantages	Each service is a single point of failure so susceptible to denial of service attacks or server failure. Performance may be unpredictable because it depends on the network as well as the system. May be management problems if servers are owned by different organizations.

Source: Sommerville, 9th Ed.

Client/Server Architectures: Design Features/goals

Service Portability	**High**=>Server runs on many operating systems and many networking environments
Location-Transparency	**Reasonable**=> Server might itself be distributed, but provides a single "logical" service to the user
High Performance	**Reasonable**=>Client optimized for interactive display-intensive tasks; Server optimized for CPU-intensive operations
Scalability	**High**=>Server can handle large # of clients
Client Portability	**Reasonable**=>User interface of client can support a variety of end devices (PDA, Handy, laptop, wearable computer)
Reliability	**Reasonable**=>Server would survive some client and communication problems. e.g. crash of a client does not cause all the system to fail

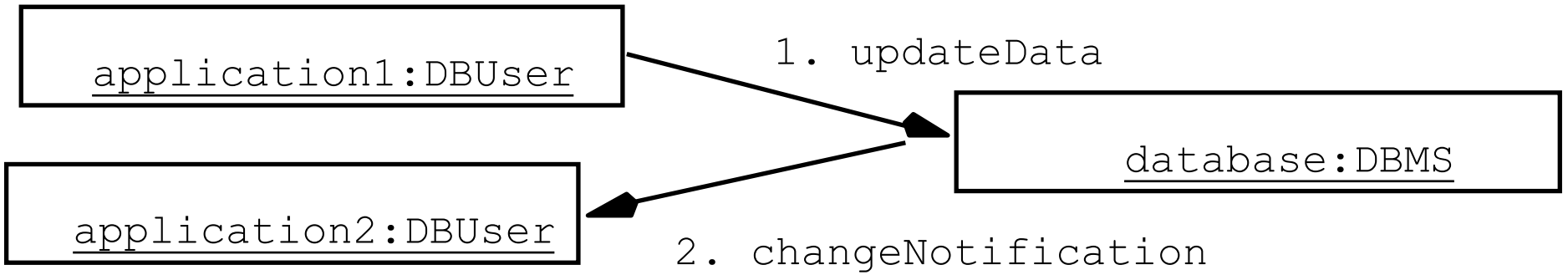
Client/Server Architectures: Limitations

Client/Server systems do not provide peer-to-peer communication, e.g. calls can only be triggered from a client NOT vice versa

Peer-to-peer communication is often needed for improved robustness.

Example:

In some situations, it would useful if a Database could process queries from an application/client and be able to send notifications to the application when data have changed – this is not possible in client-server!



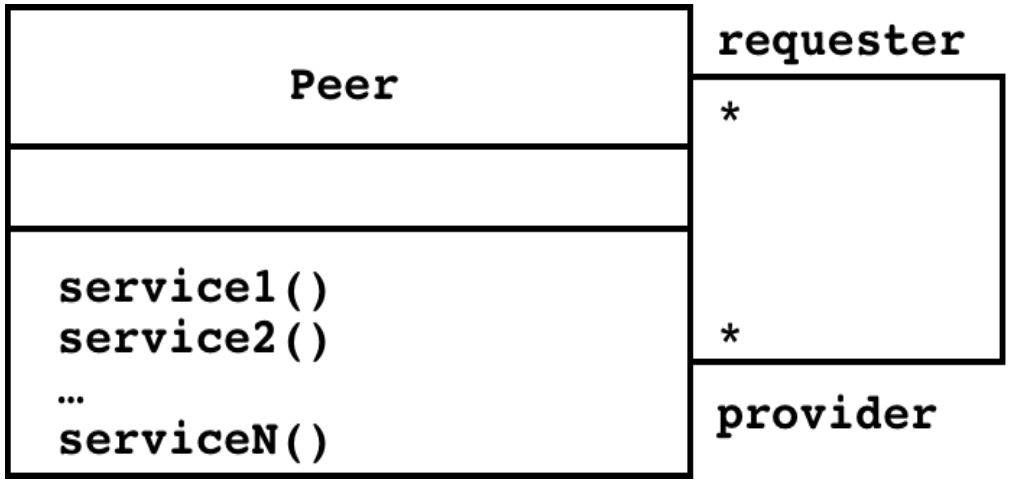
Peer-to-Peer Architectural Style

Generalization of Client/Server Architectural Style
"Clients can be servers and servers can be clients"

Introduces a new abstraction: Peer
"Clients and servers can both be 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".

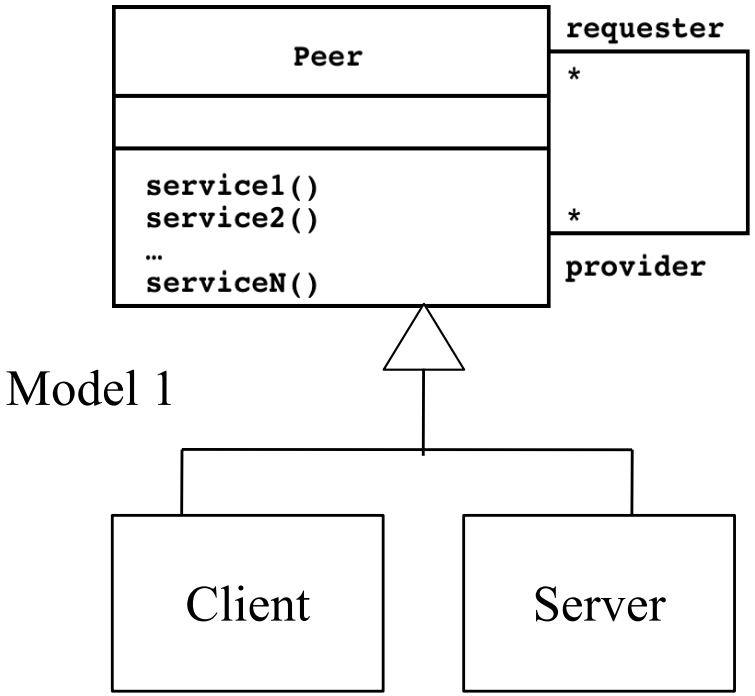


Client/Server Vs Peer-to-Peer

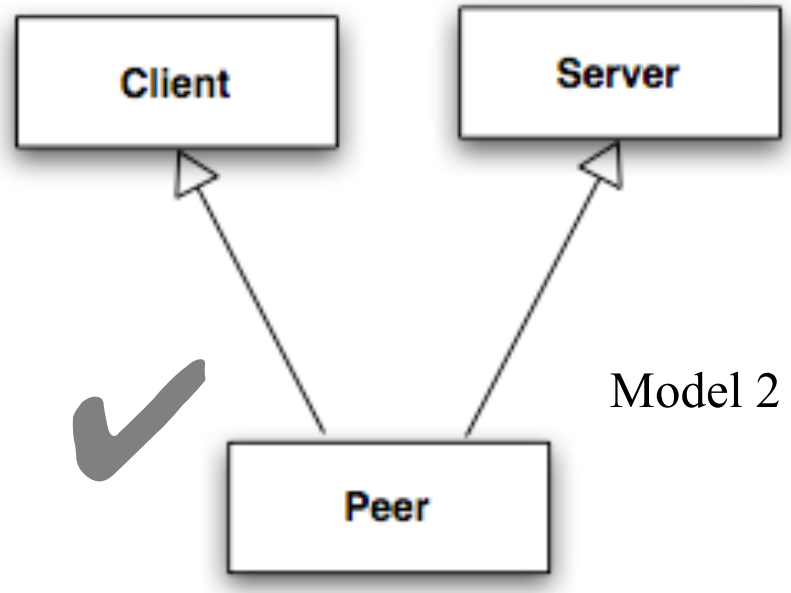
"Clients can be servers and servers can be clients"
How to Model?
Which model is correct?

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

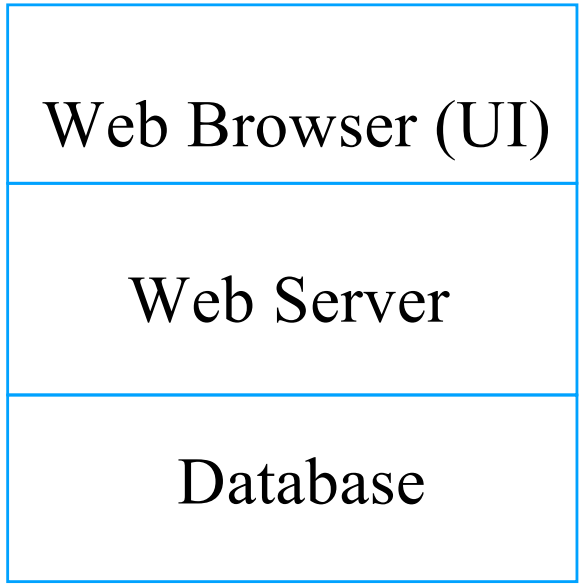
Note: Layer is a type (e.g. class, subsystem) and Tier is an instance (e.g. object, hardware node)

Layer and Tier are often used interchangeably.

Example of a 3-Layered Architectural Style

Three-Layered Architectural style are often used for the development of Websites:

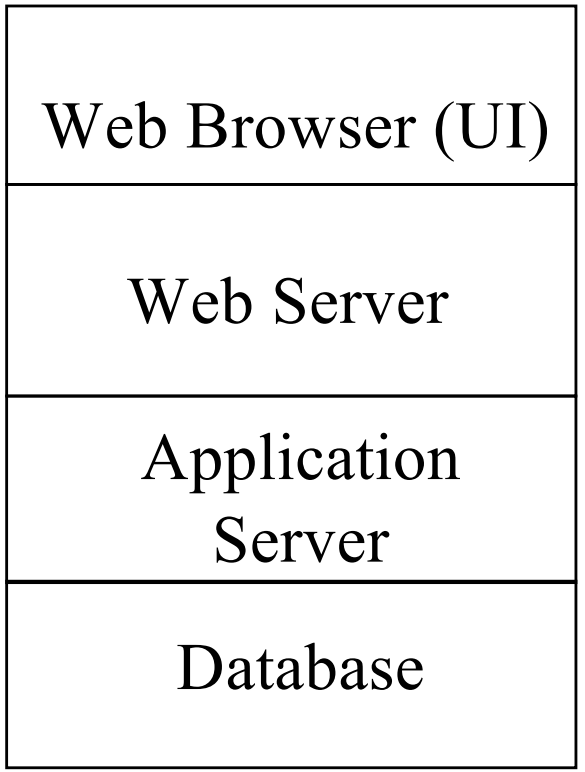
1. The Web Browser implements the user interface
2. The Web Server serves requests from the web browser
3. The Database manages and provides access to the persistent data.



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).



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 re-implemented 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 (MVC) Architectural Style

MVC separates presentation and interaction from the system data. The system is structured into three logical components that interact with each other, classified into 3 different types:

Model: Provides application domain knowledge, manages the system data and associated operations on that data

View: Responsible for displaying information to the user- defines and manages how the data is presented to the user

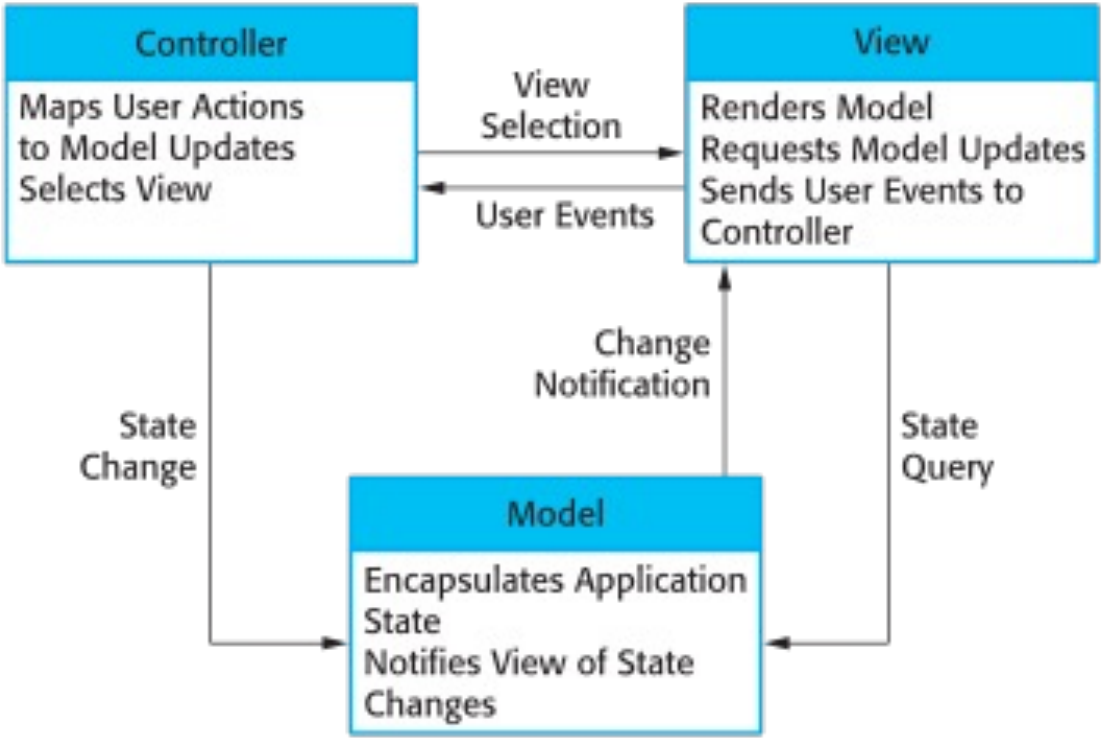
Controller: controls interacting with the user, passes these interactions (e.g., key presses, mouse clicks, etc.) to the View and the Model and notifying views of changes in the model

Advantages: allows the data to change independently of its representation and vice versa. Supports presentation of the same data in different ways with changes made in one representation shown in all of them.

Disadvantages: It may require additional code and code complexity even in cases where the data model and interactions are simple.

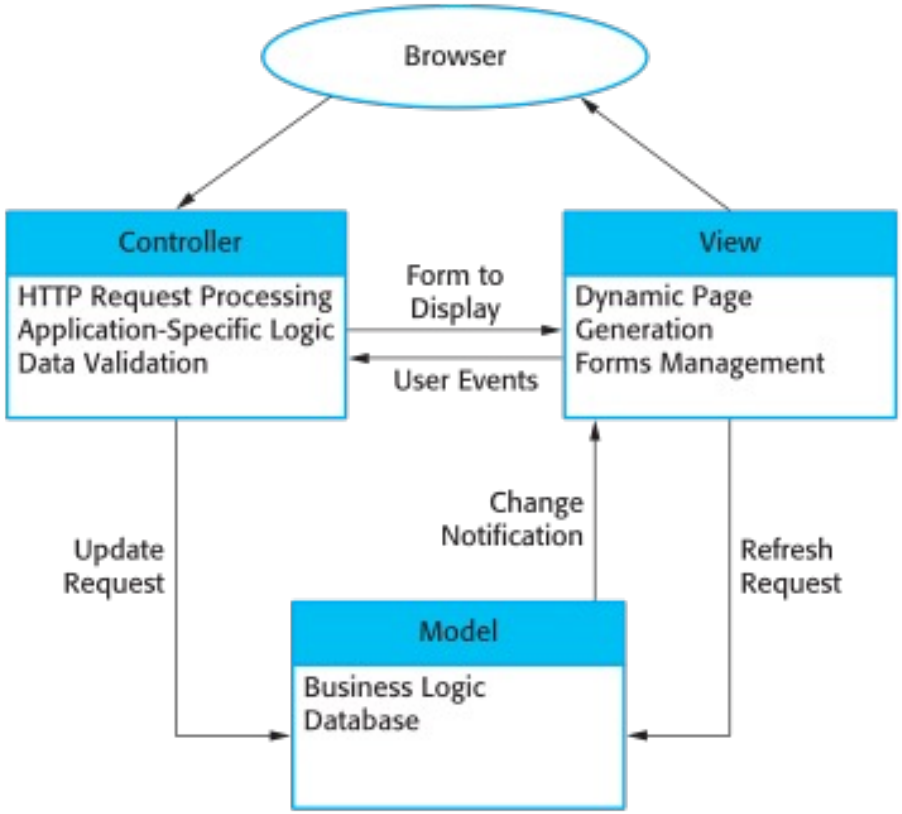
Source: Sommerville, 9th Ed.

Model-View-Controller (MVC) Architectural Style



Organisation of MVC

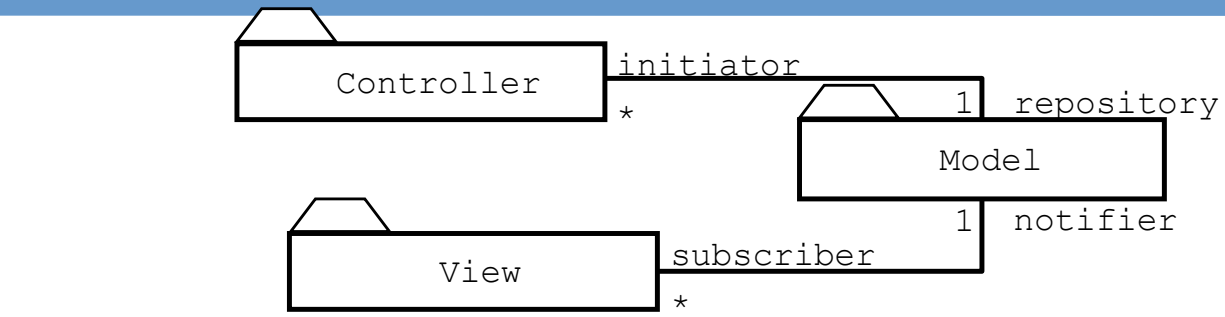
Example: Web Application in MVC

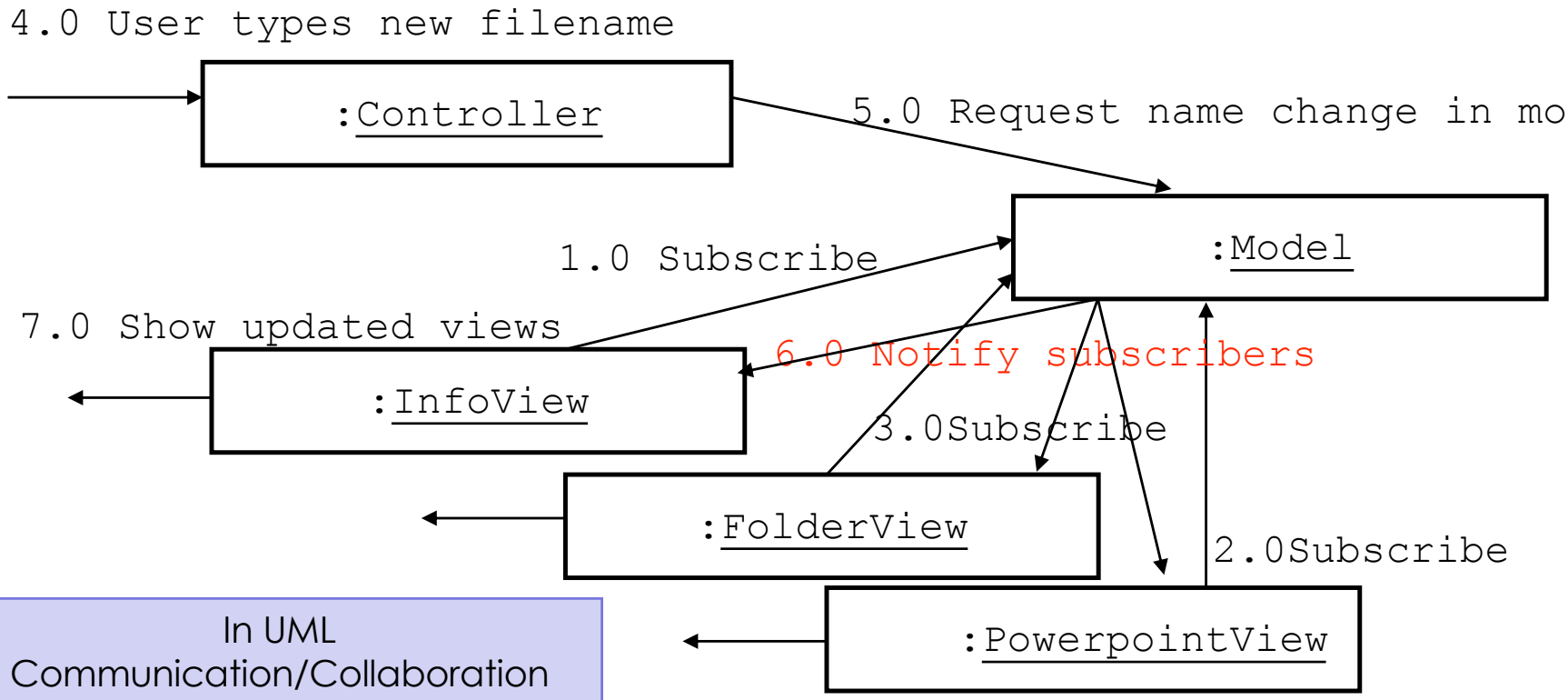


Source: Sommerville, 9th Ed.

Example: Modeling the Sequence of Events in MVC

package Diagram





In UML Communication/Collaboration Diagram

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

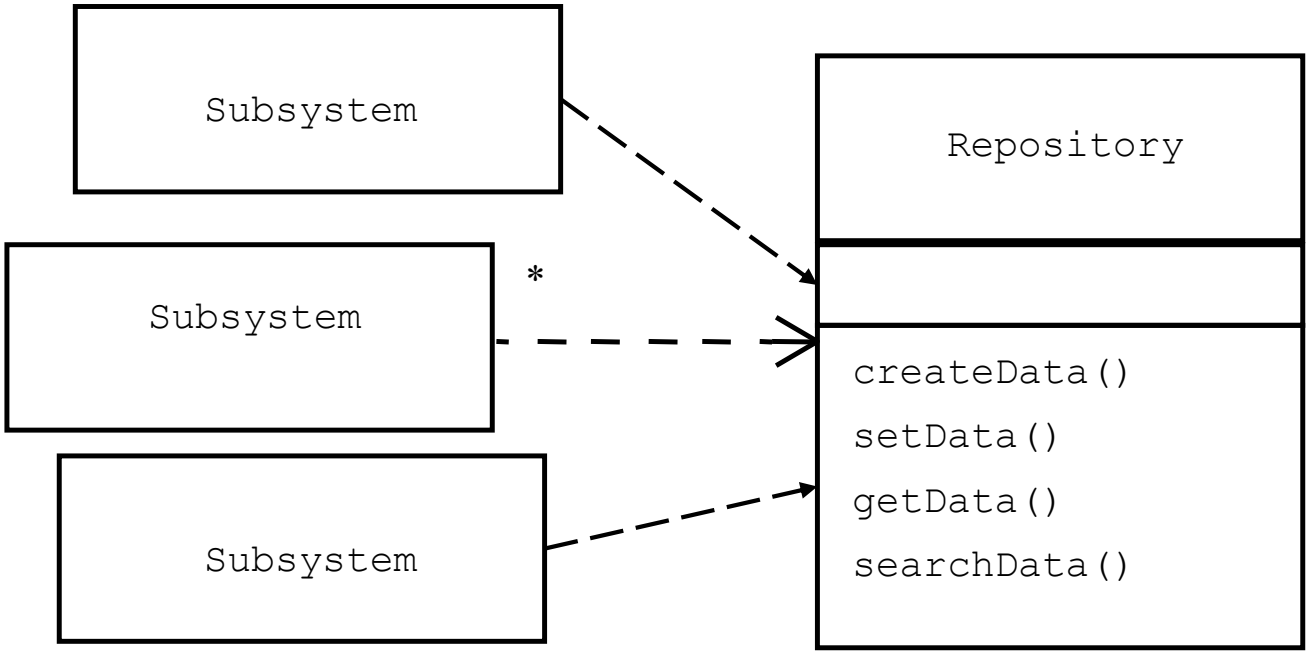
History:

- 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.

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).

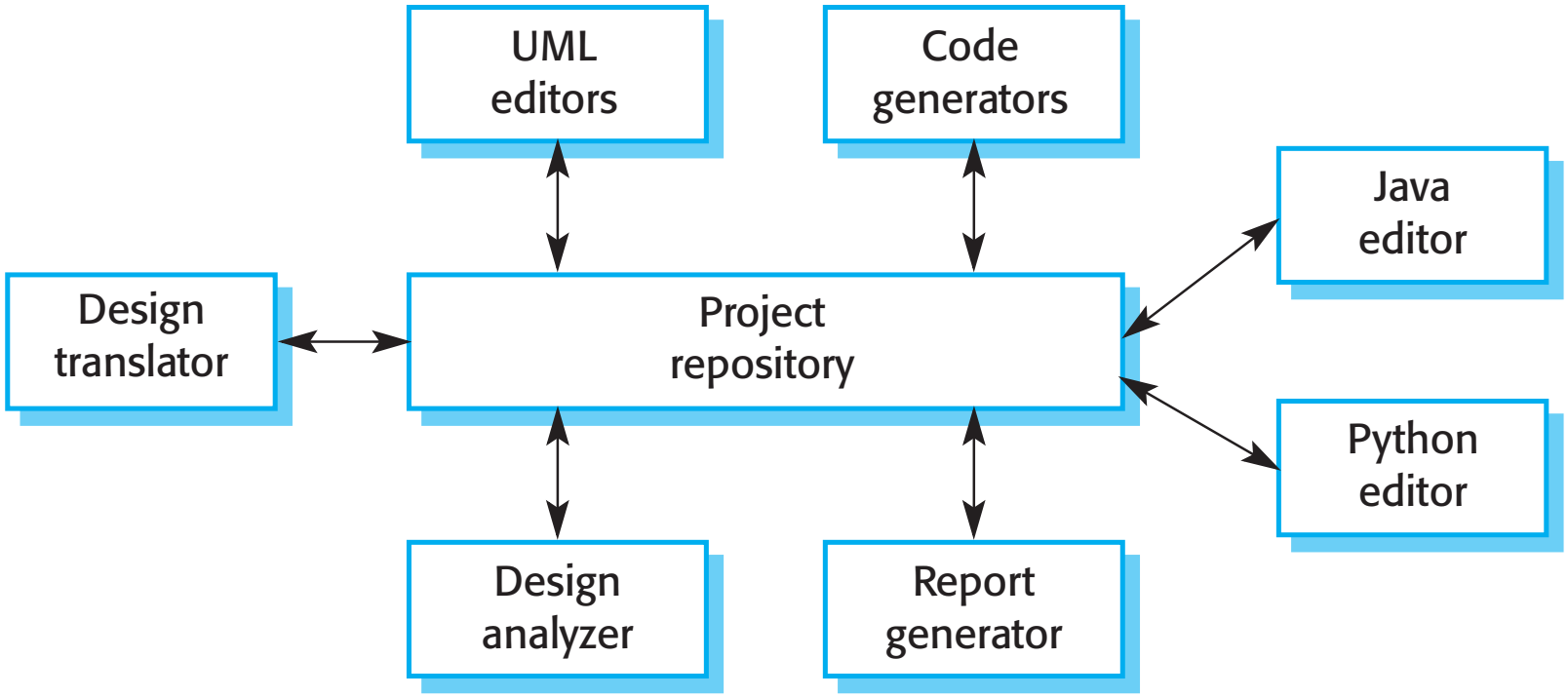


The Repository pattern

Name	Repository
Description	All data in a system is managed in a central repository that is accessible to all system components. Components do not interact directly, only through the repository.
When used	You should use this pattern when you have a system in which large volumes of information are generated that has to be stored for a long time. You may also use it in data-driven systems where the inclusion of data in the repository triggers an action or tool.
Advantages	Components can be independent—they do not need to know of the existence of other components. Changes made by one component can be propagated to all components. All data can be managed consistently (e.g., backups done at the same time) as it is all in one place.
Disadvantages	The repository is a single point of failure so problems in the repository affect the whole system. May be inefficiencies in organizing all communication through the repository. Distributing the repository across several computers may be difficult.

Source: Sommerville, 9th Ed.

A repository architecture for an IDE



Repository Architecture example of an IDE where the components use a repository of system design information. Each software tool generates information which is then available for use by other tools.

Source: Sommerville, 9th Ed.

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

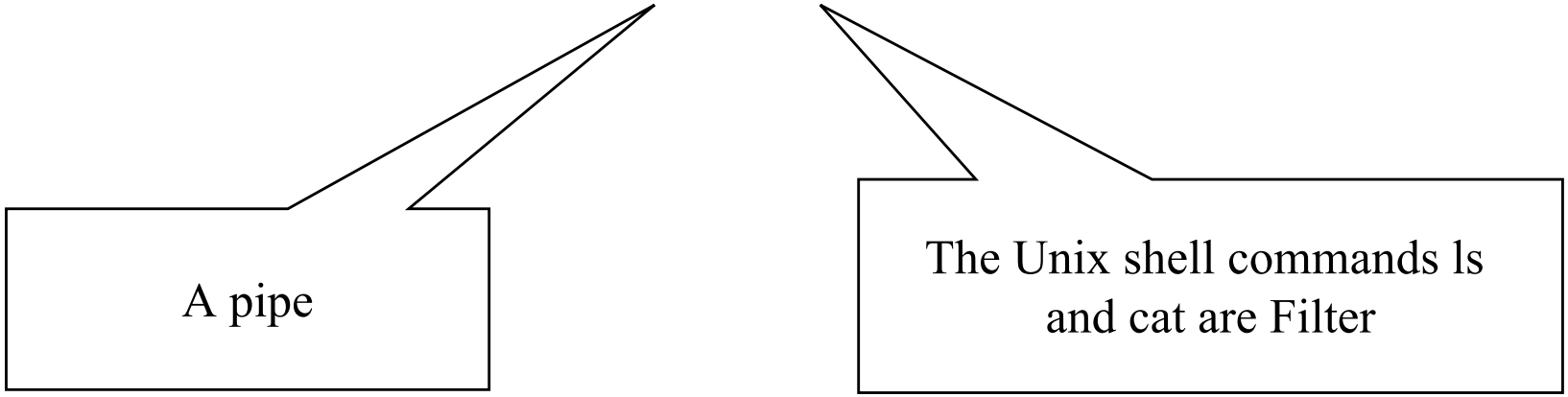
Pipe: A Pipe is a connection between two processing steps

Each filter has an input pipe and an output pipe.

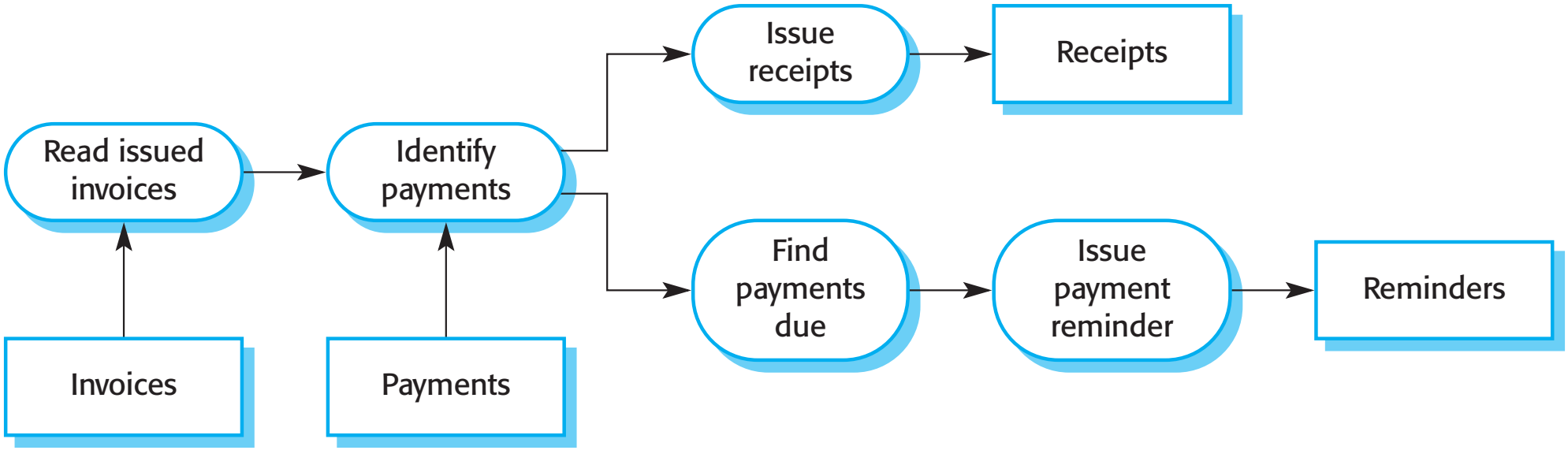
The data from the input pipe are processed by the filter and then moved to the output pipe

Example of a Pipes-and-Filters architecture: Unix

Unix shell command: **ls -a | cat**



An example of the pipe and filter architecture used in a payments system



A payments System, as an example of a pipe and filter system used for processing invoices.

Source: Sommerville, 9th Ed.

The pipe and filter pattern

Name	Pipe and filter
Description	The processing of the data in a system is organized so that each processing component (filter) is discrete and carries out one type of data transformation. The data flows (as in a pipe) from one component to another for processing.
When used	Commonly used in data processing applications (both batch- and transaction-based) where inputs are processed in separate stages to generate related outputs.
Advantages	Easy to understand and supports transformation reuse. Workflow style matches the structure of many business processes. Evolution by adding transformations is straightforward. Can be implemented as either a sequential or concurrent system.
Disadvantages	The format for data transfer has to be agreed upon between communicating transformations. Each transformation must parse its input and unparse its output to the agreed form. This increases system overhead and may mean that it is impossible to reuse functional transformations that use incompatible data structures.

Summary

System Design

Focuses on finding an optimal solution combining software and hardware approaches

Design Goals

Evaluates important system features against alternative designs (design-tradeoffs)

Considers General Design Goals and principles (cohesion and coupling) and system specific ones (from non-functional requirements) in design

System Composition

Modularising the system from parts or modules in creating an optimal design based on the general and specific design goals/principles.

Architectural Style

Choosing a suitable pattern of system layout (architectural style) that meets the needs of identified design goals; from layer styles (C/S, SOA, n-Tier), MVC, Repository, Pipes & Filters

Software architecture

An instance of an architectural style: e.g. client/server, SOA etc.