Chapter 6, System Design – Software Architectures

Object-**O**riented
Software**C**onstruction

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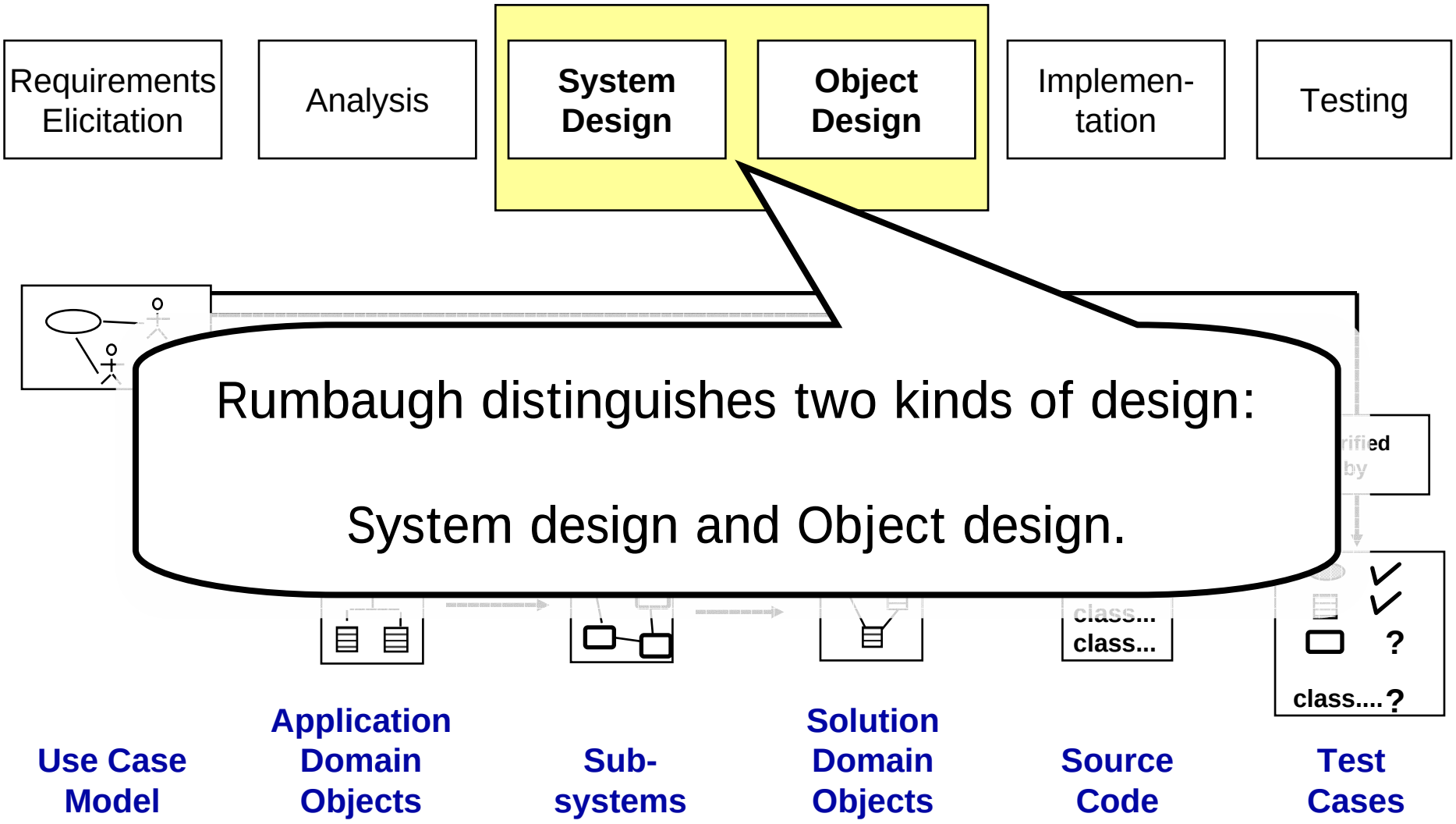
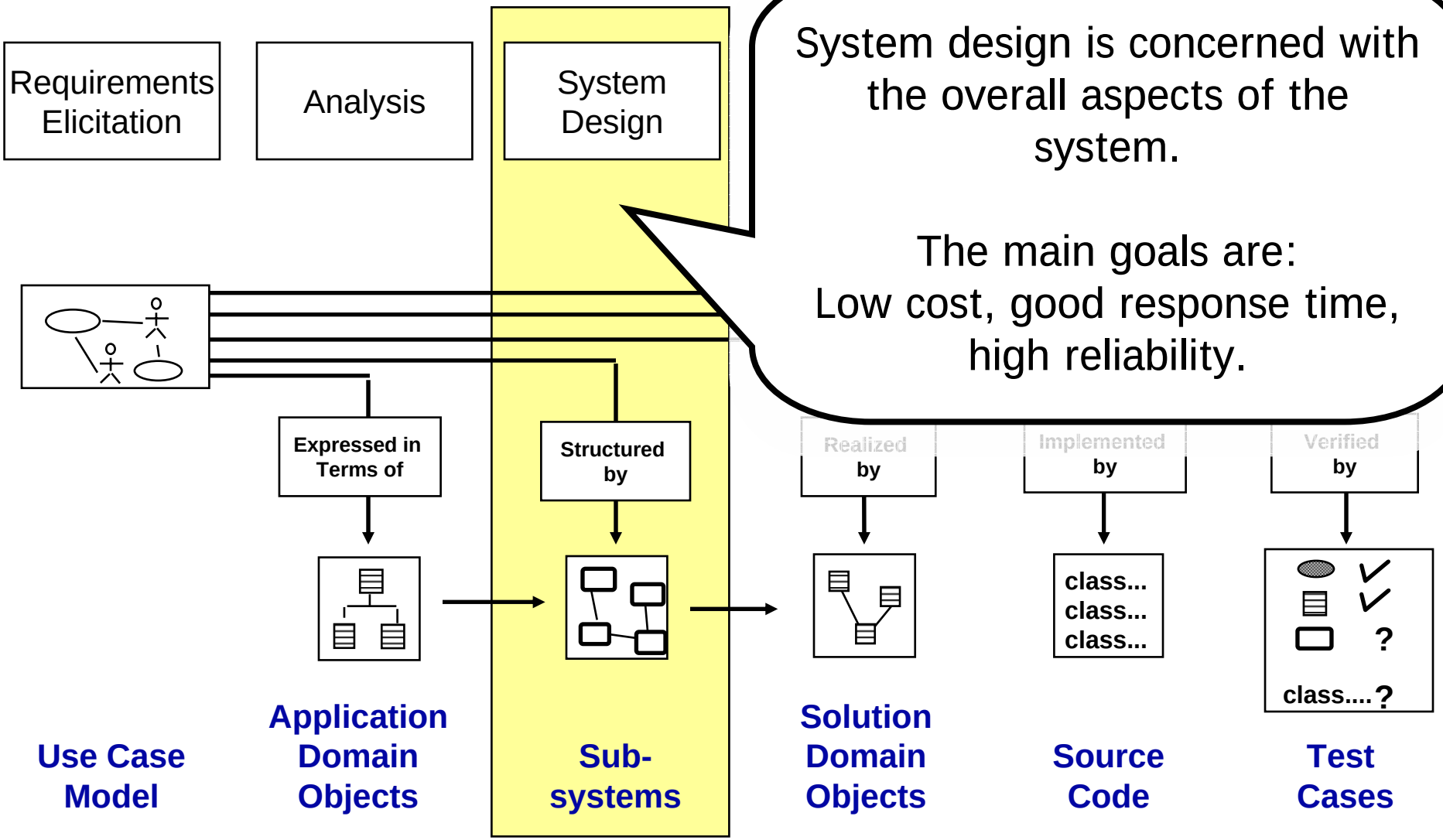
(based on Bruegge & Dutoit)

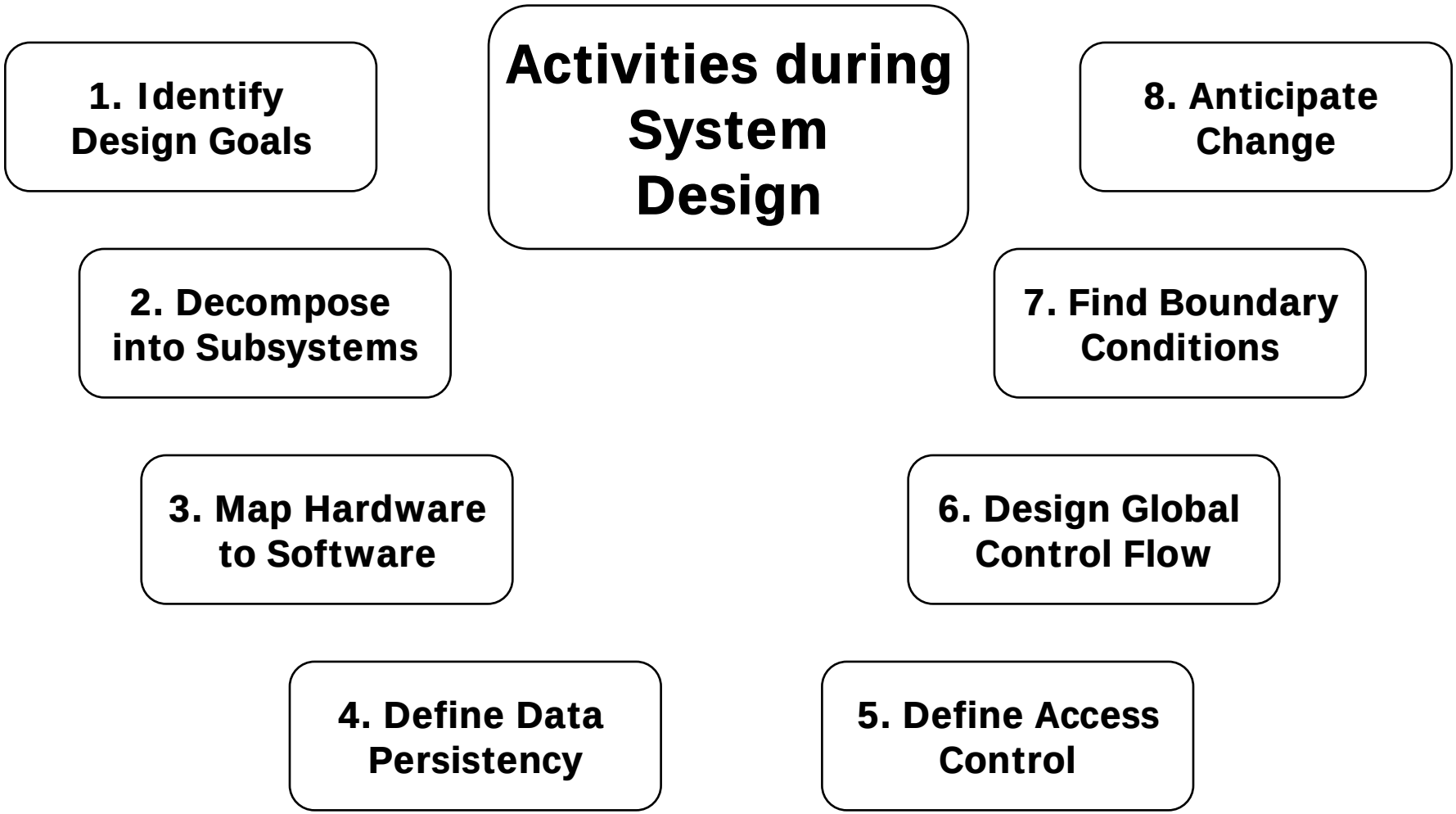
Software Lifecycle Activities … design



Software Lifecycle Activities ...system design



Activities during System Design



The Output: Software Architecture

- The software architecture of a system is its structure, comprising
  - components (here: subsystems)
  - the externally visible properties of those components (here: service interface)
  - and the relationships among them (Bass et al., 1998)
- The architecture describes the structure of a *single* system.
- Guidelines for building software architectures:
  - Software architectural styles (later on)

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

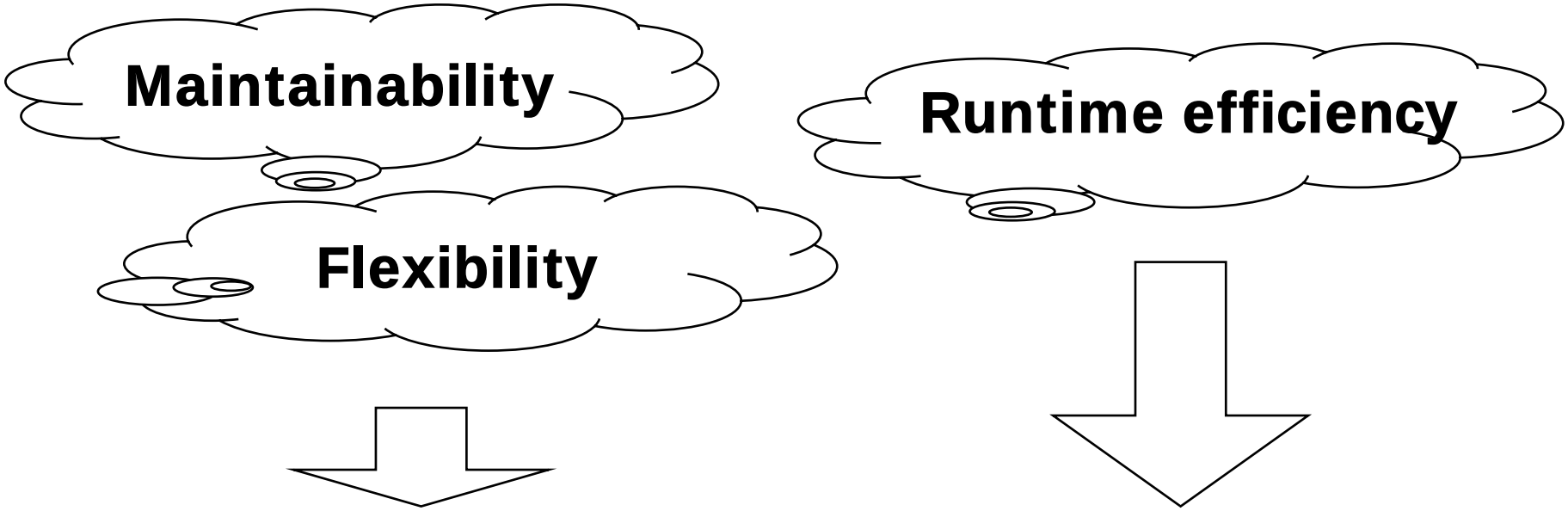
- Nonfunctional requirements →
  - Activity 1: Design Goals Definition
- Functional model →
  - Activity 2: System decomposition (Selection of subsystems based on functional requirements)
- Object model →
  - Activity 3: Hardware/software mapping
  - Activity 4: Persistent data management
- Dynamic model →
  - Activity 6: Global resource control flow

1. Identify Design Goals

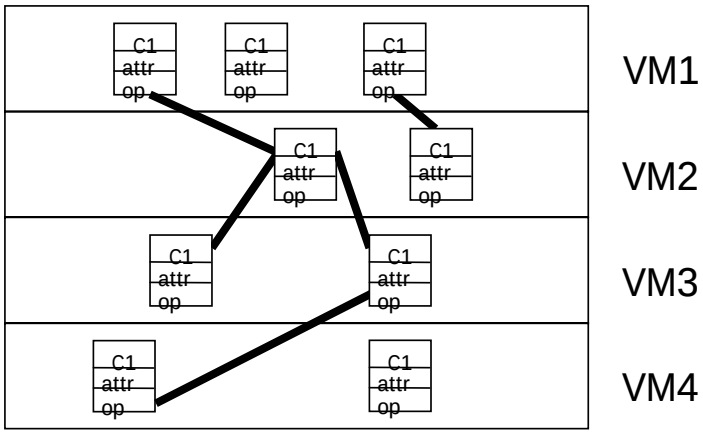
Why is it important to identify design goals early?

Because they can determine the overall architecture.

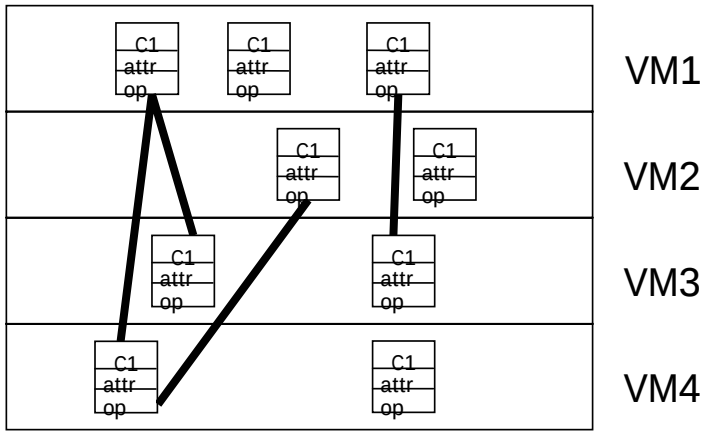
Identify Design Goals - Example



Opaque Layering



Transparent Layering



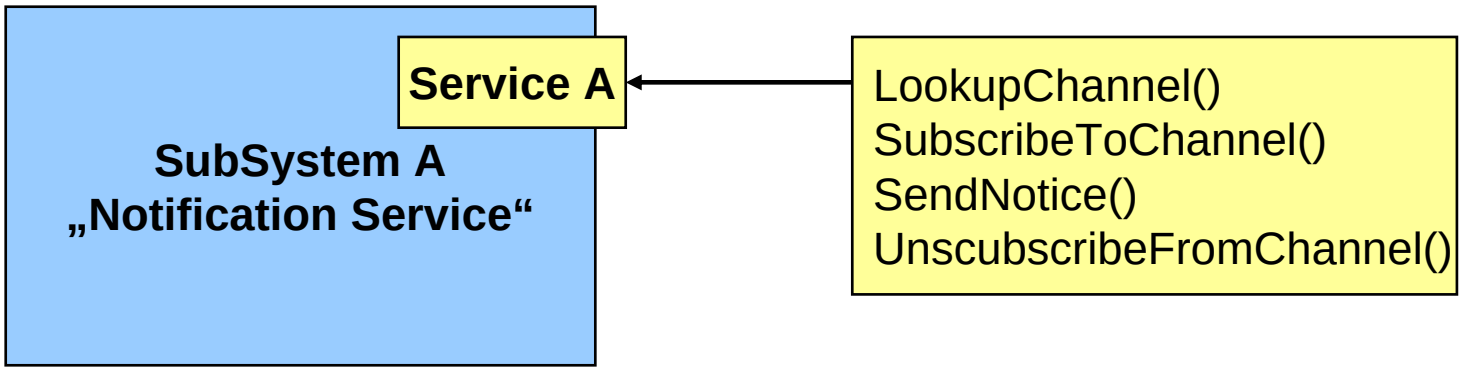
Design Goals are legion ...

... hence, we organize them into five groups:

- performance
  - response time, throughput, memory, ...
- dependability
  - robustness, reliability, availability, security, safety, ...
- cost
  - development cost, deployment cost, maintenance cost, ...
- maintenance
  - extensibility, adaptability, portability, readability, ...
- end user
  - utility, usability

2. Decompose into Subsystems

- Subsystem (UML: Package)
  - Collection of classes, associations, operations, events and constraints that are interrelated
- (Subsystem) Service:
  - A set of related operations that share a common purpose
  - Services are defined in System Design



What is a Service?

A Service is

- a set of operations
- that are related
- with a common purpose

Example:

Bank Account Management Service

- withdraw money
- deposit money
- accumulate interest
- ...

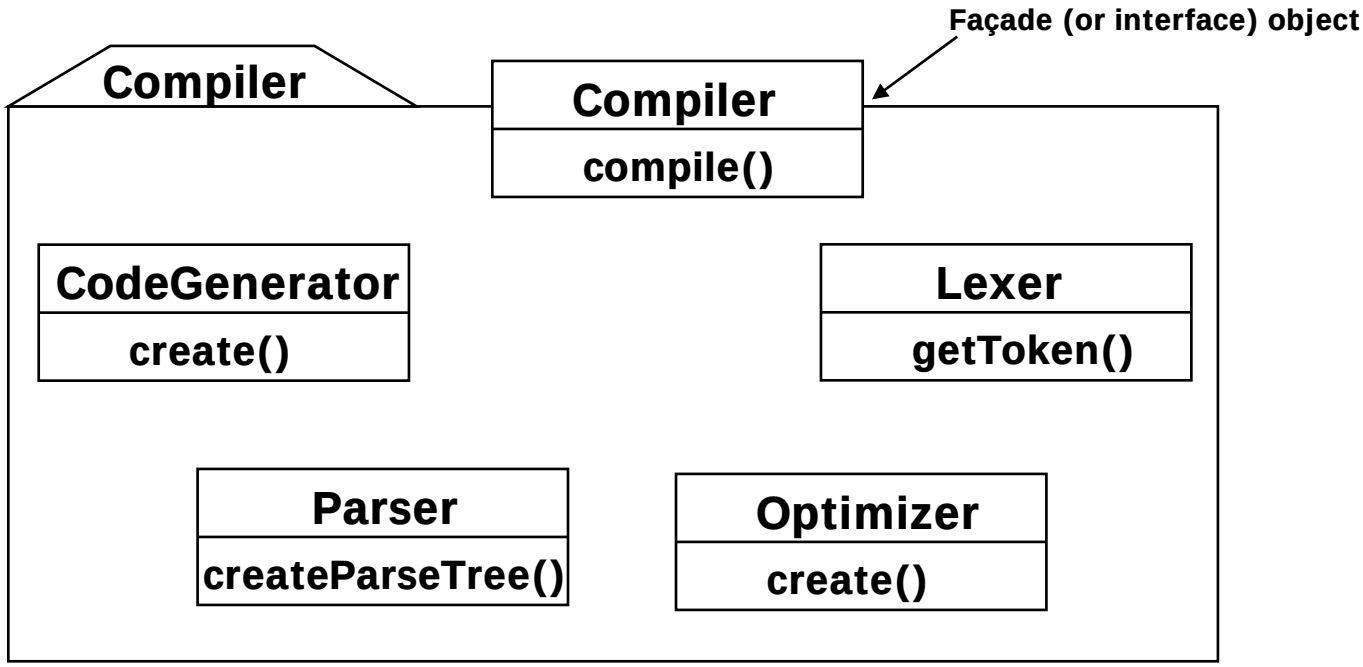
Services and Subsystem Interfaces

- Service is specified by Subsystem interface
  - Specifies interaction and information flow from/to subsystem boundaries
  - No information about information flow within the subsystem
  - Should be well-defined and small
  - Subsystem Interfaces are refined in Object Design
  - Services lead to APIs during implementation, for now this view would be too concrete and technical

- In Programming Languages subsystems are often bundled
  - Java: Packages
  - C++: Namespaces
  - Modula: Modules
  - ...

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



From Use Cases to Subsystems
Some heuristics

- No straightforward method available
- Start with UML use case and class diagram
  - representation of functional behavior (requirements)
- Assign objects identified in one use case into the same subsystem
- For those objects that exist in several use case: create a dedicated subsystem (e.g. data sharing)
- All objects in the same subsystem should be functionally related

- Each subsystem could be realized by an individual team

Choosing Subsystems

- Primary Question
  - What kind of service is provided by the subsystems (subsystem interface)?
  - How do we implement the subsystem (→ Object Design)
- Secondary Question
  - Who or what interacts with that service and in what order?

Choosing Subsystems

- Criteria for subsystem selection
  - Self-contained
    - Most of the interaction should be within subsystems, rather than across subsystem boundaries
  - Reusable
    - Usage of the same subsystem in a different context
  - Maintainable
    - Understanding the purpose of a subsystem even in the future
    - Make modifications easily
  - Correct
    - No side effects

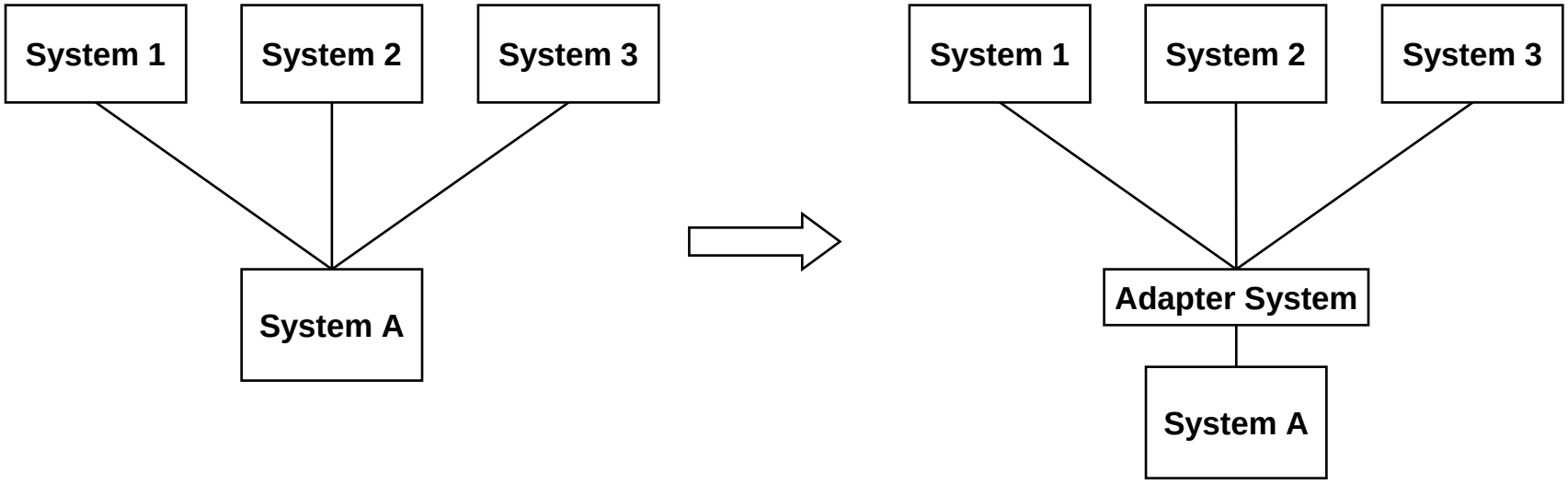
➔ Goal: Reduction of Complexity

➔ Approach: Adopt metrics to measure the style of subsystem(s)

Decomposition Aspects
Coupling and Cohesion

- Cohesion measures the dependency among classes (within a subsystem)
  - High cohesion: The classes in the subsystem perform similar tasks and are related to each other (via associations, use relations)
  - Low cohesion: Lots of miscellaneous and helping classes, no relationships identifiable
- 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 low coupling?

Decomposition Aspects A:
Reducing Coupling



- Systems n are all dependent on System A
- If System A‘s interface will change other subsystems have to be rearranged too

- Adapter system reduces coupling

Decomposition Aspects:
Low Cohesion (Coincidental Cohesion)

- A subsystem has coincidental cohesion if it performs multiple, completely unrelated actions
- Example: Subsystem for “dealing with clients”
  - print_next_line();
  - addClient();
  - rollbackTransaction();
  - openOnlineHelp();

It’s BAD BECAUSE:

- No clear purpose
- It degrades maintainability
- A module with coincidental cohesion is not reusable
- The problem is easy to fix
  - Break the module into separate modules, each performing one task

Decomposition Aspects:
High Cohesion (Informational Cohesion)

- A subsystem has informational cohesion if it performs a number of actions, each with its own entry point, with independent code for each action, all performed on the same data structure
- Example: Subsystem for creating a client record
  - createClient()
  - deleteClient()
  - addDateOfBirth()
  - addAddress()

It's GOOD BECAUSE:

- Exact purpose
- It increases maintainability
- High reusability

Decomposition Aspects
Trade-Off

- Cohesion and Coupling Measures are dependent
- Increase cohesion by decomposing the system into smaller subsystems
  - → Consequence: increase of coupling

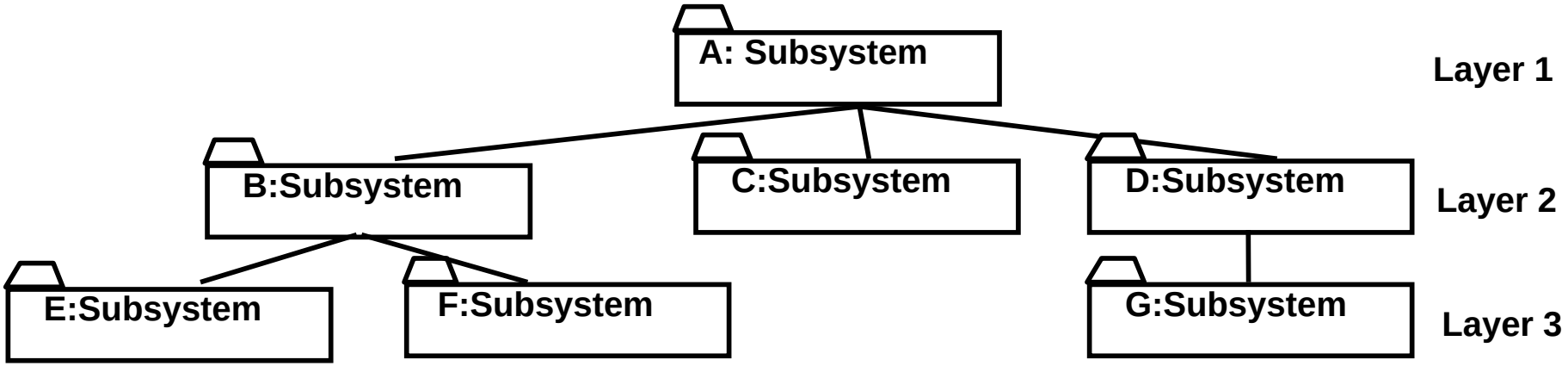
- Recommendations
  - Re-Think the system architecture
  - Right amount of interacting subsystems has to be found
    - context-dependent
    - creative process

Decomposition Aspects
Partitions and Layers

- Partitioning and layering are techniques to achieve low coupling
- *Partitions* vertically divide a system into several independent (or weakly-coupled) subsystems that provide services on the same level of abstraction
  - Subsystems depend loosely on each other, mostly operate in isolation
- 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

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

Decomposition Aspects
Subsystem Decomposition into Layers



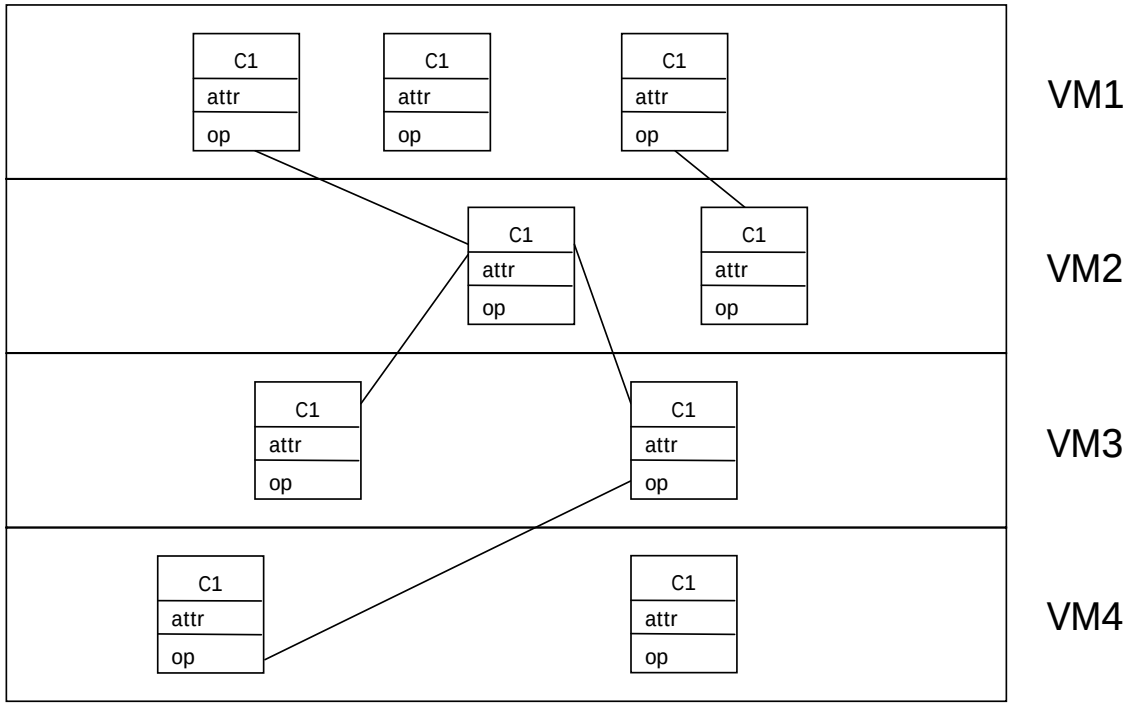
- Subsystem Decomposition Heuristics:
- No more than 7+/-2 subsystems
  - More subsystems increase cohesion but also complexity (more services)
- No more than 4+/-2 layers, use 3 layers (good)

Decomposition Aspects
Virtual Machine

- Virtual Machines: 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
- A virtual machine is an abstraction
  - It provides a set of attributes and operations.
- A virtual machine is a (sub)system
  - uses services provided by lower level virtual machines and provides a service to higher level machines
- Virtual machines can implement two types of software architecture
  - Open and closed architectures

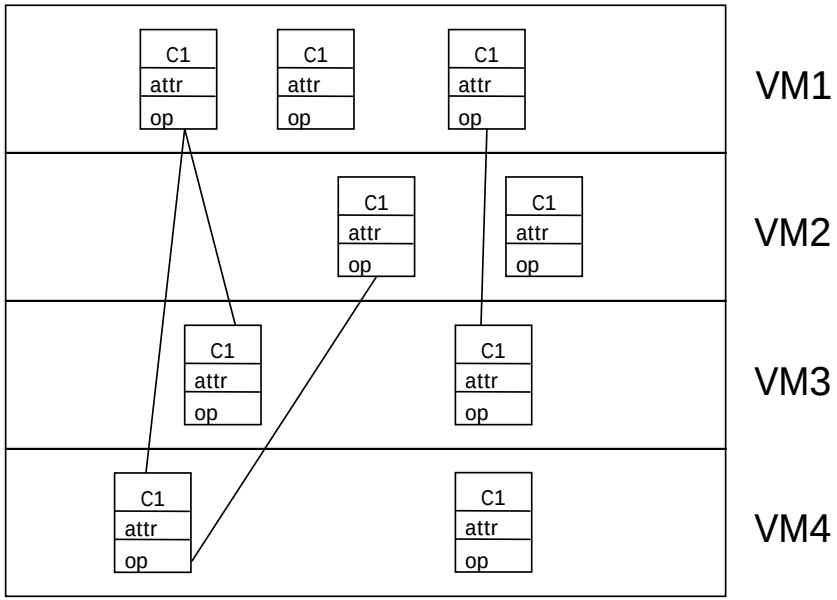
Decomposition Aspects
Closed Architecture (Opaque Layering)

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

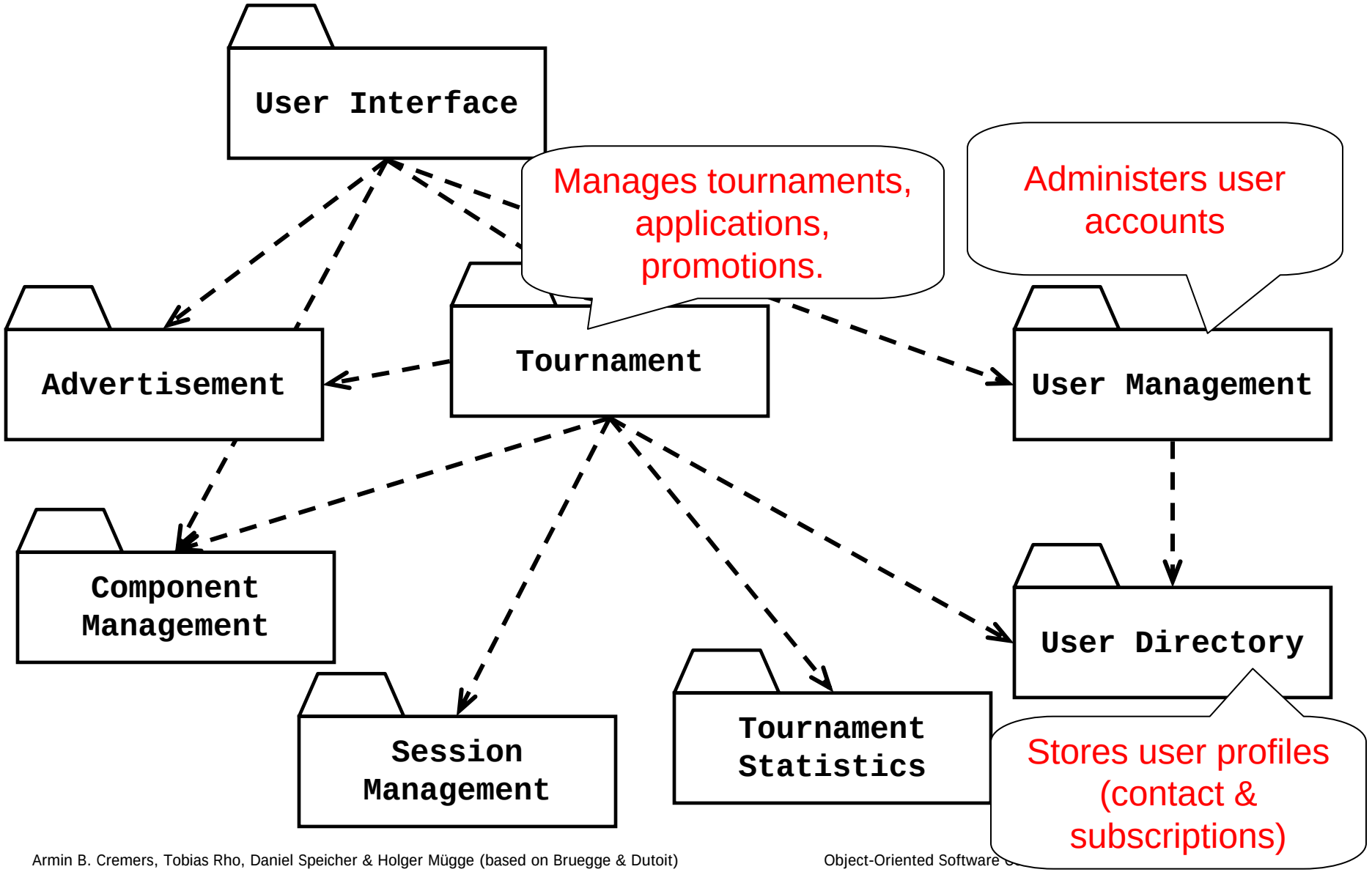


Decomposition Aspects
Open Architecture (Transparent Layering)

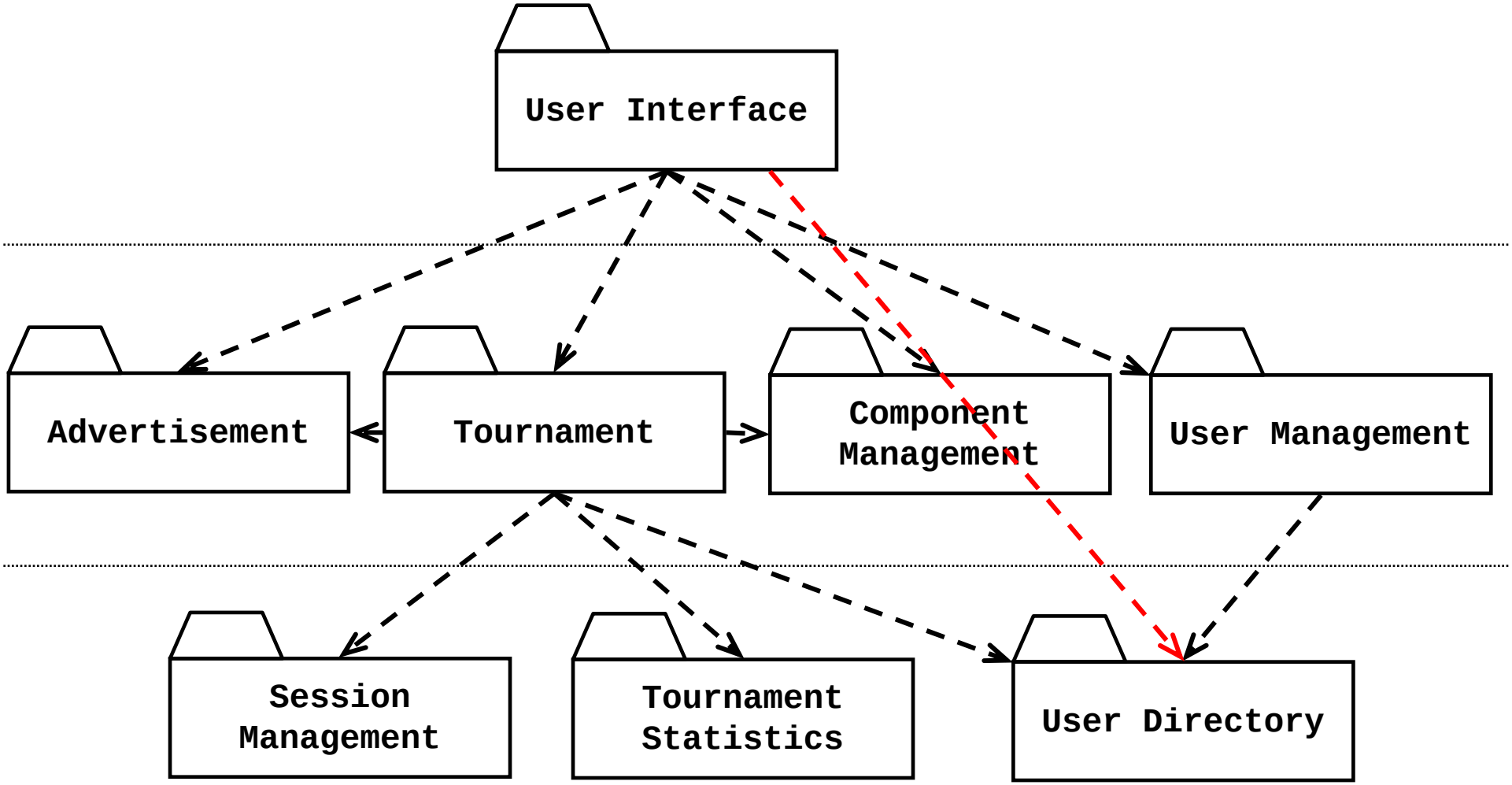
- Any layer can invoke operations from any layers below
- Design goal: Runtime efficiency



ARENA Example

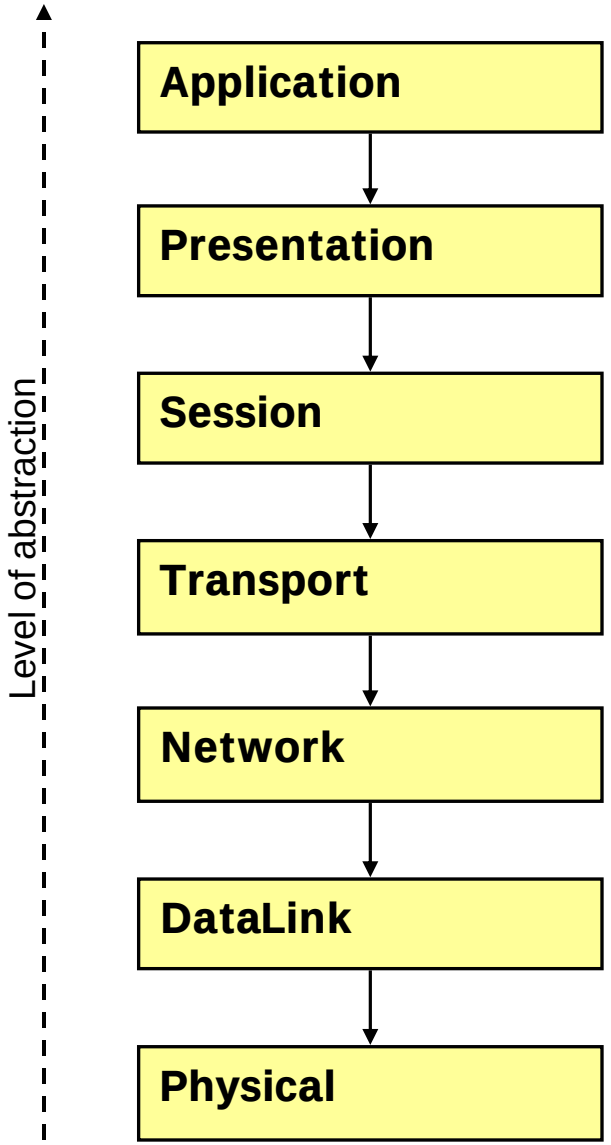


ARENA Example
A 3-layered architecture

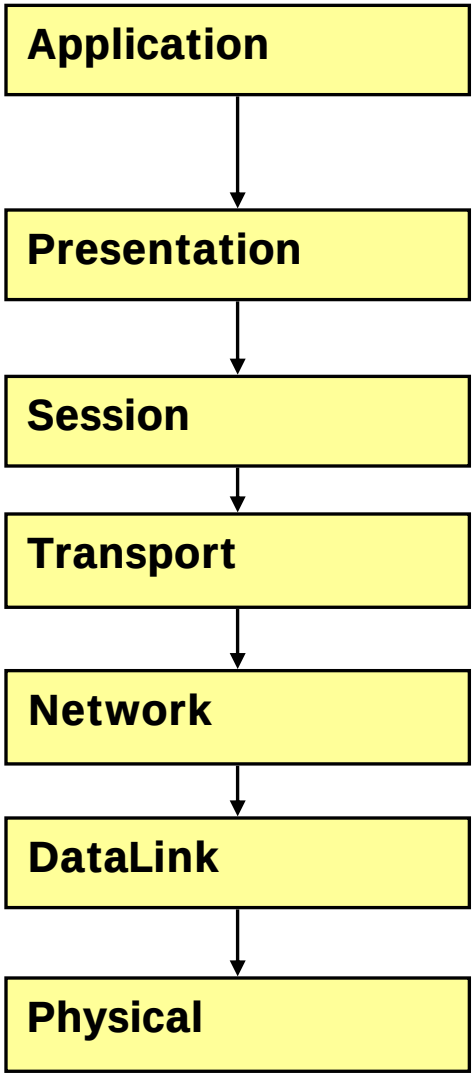


Example of a Closed Layering: ISO OSI 7-Layer Model

- 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

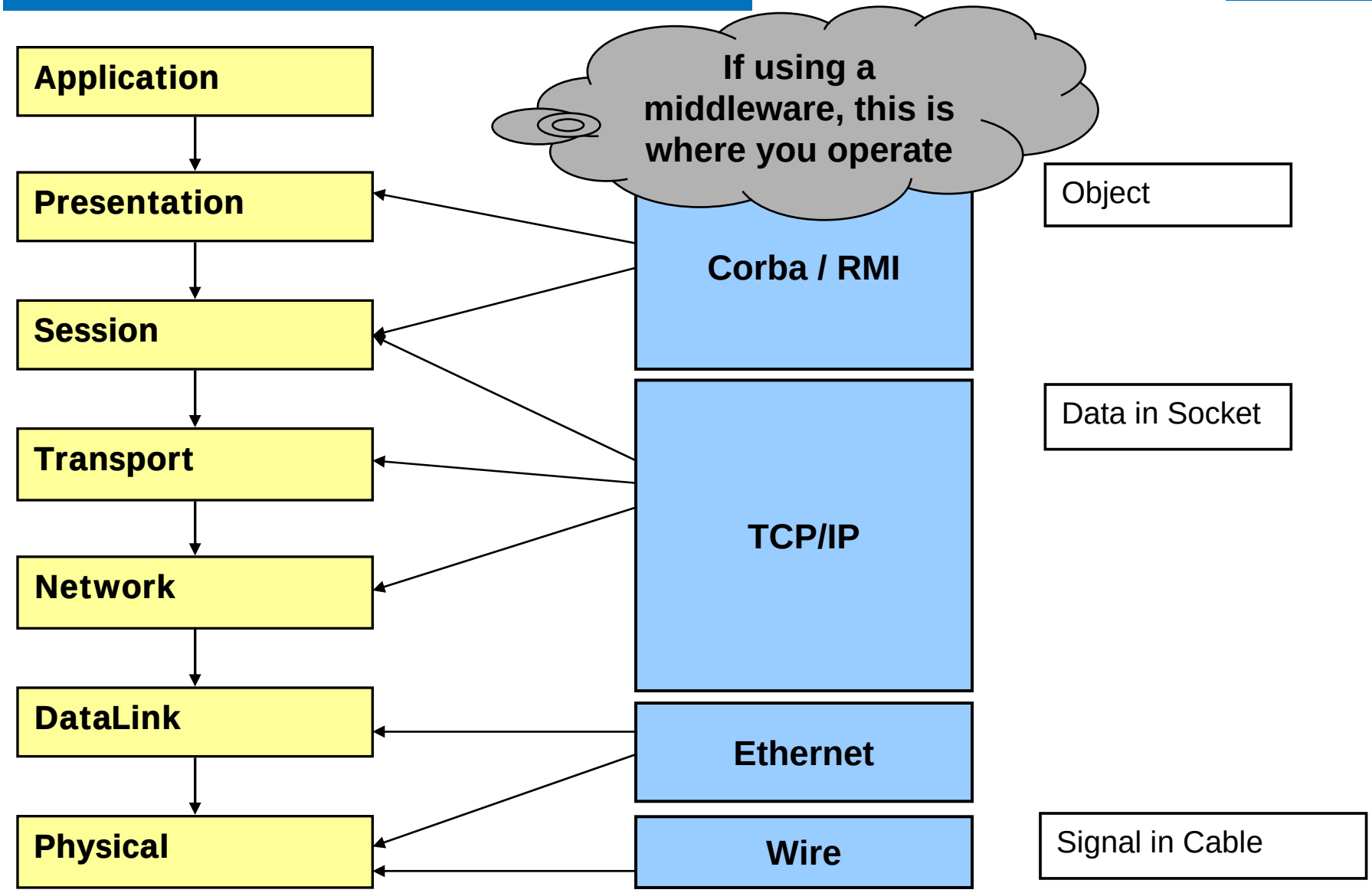


Example of a Open Layering: OSI model Packages and their Responsibility



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

Example of a Open Layering: Middleware allows Focus On The Application Layer



Software Architectural Styles

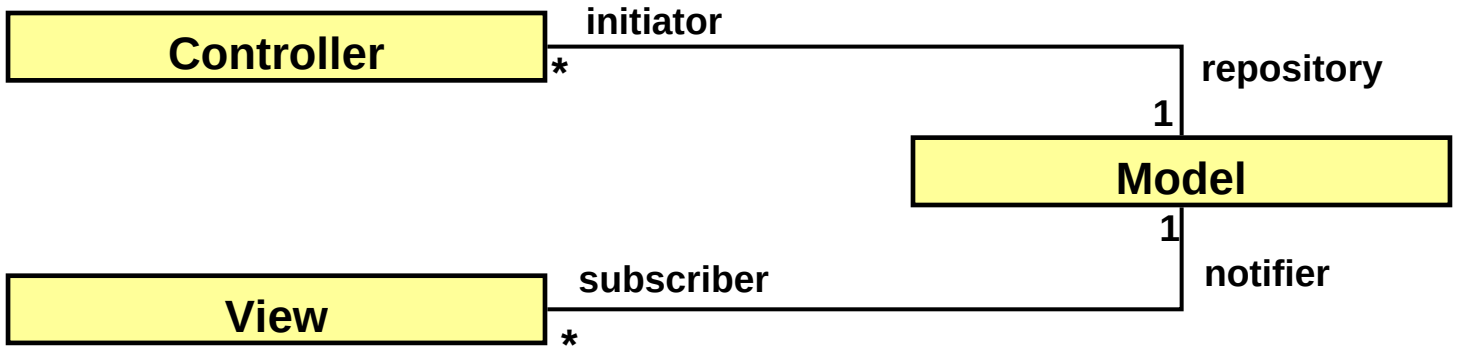
- More sophisticated decomposition rules are required
- Need for recurring patterns → architectural styles
- Architectural Style:
  - A description of element and relation types together with a set of constraints on how they are used (Shaw and Garlan, 1996).
  - Describes a family (or set) of software architectures
  - Concrete Architecture = instance of a style
- An architectural style also includes
  - Control issues
  - Data Issues
  - Constraints
- Prominent software architectural styles:
  - Client/Server, Peer-To-Peer, Repository, Model/View/Controller
  - Three Tier, Four-Tier, Service-oriented (SOA)

Software Architectural Style:
Repository (Blackboard Architecture)

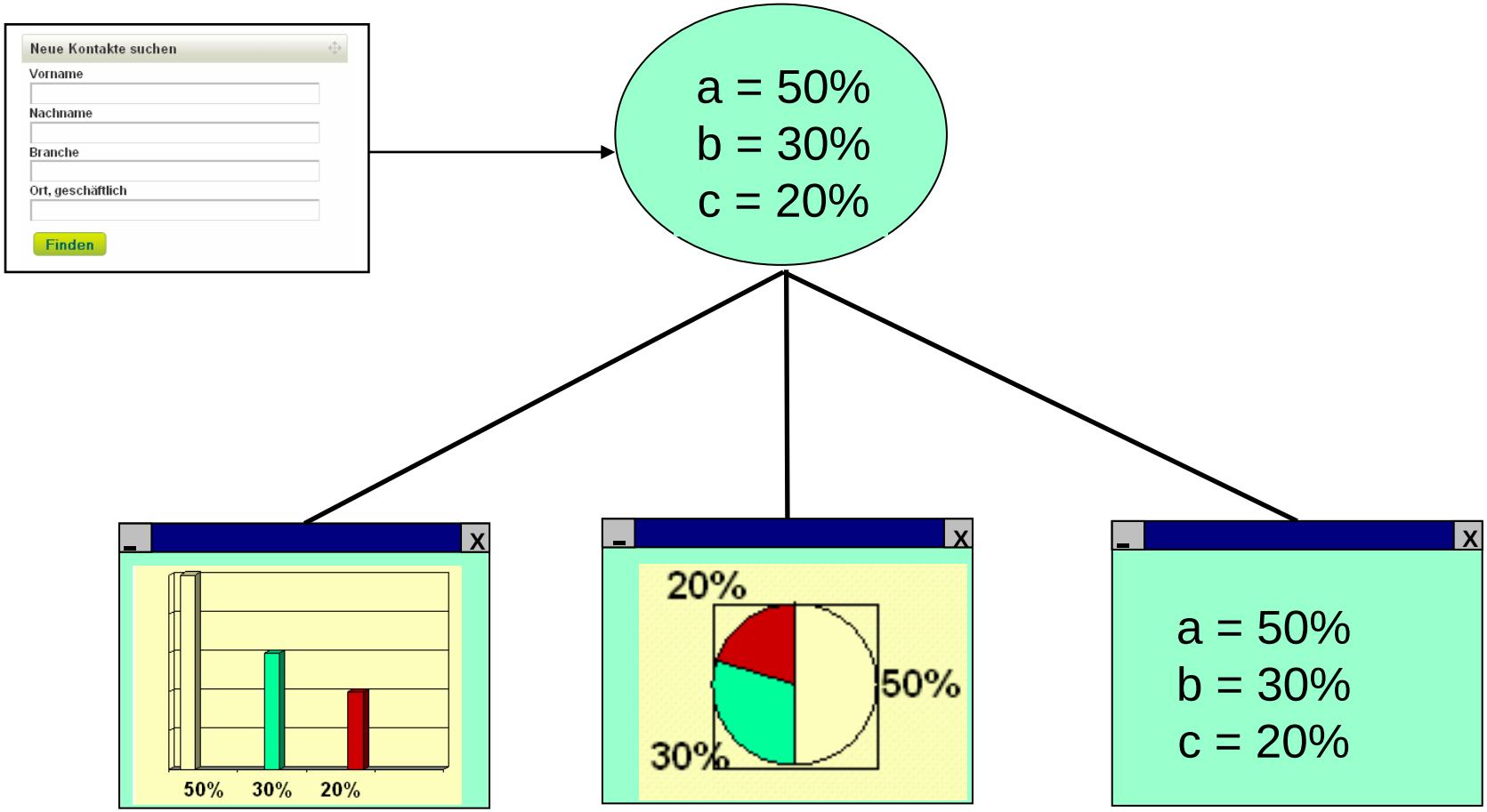
- Subsystems access and modify data from a single data structure
- Subsystems are loosely coupled (interact only through the repository)
- Control flow is dictated by central repository (triggers) or by the subsystems (locks, synchronization primitives)
- Difference to client-server system?

Software Architectural Styles:
Model/View/Controller

- Used to model interactive systems
- Subsystems are classified into 3 different types
  - Model subsystem
    - Responsible for maintaining a central data structure (knowledge)
  - View subsystem
    - Responsible for displaying data of the model to the user
  - Controller subsystem
    - Responsible for sequence of interactions with the user
- Model subsystem notifies views whenever changes have occurred

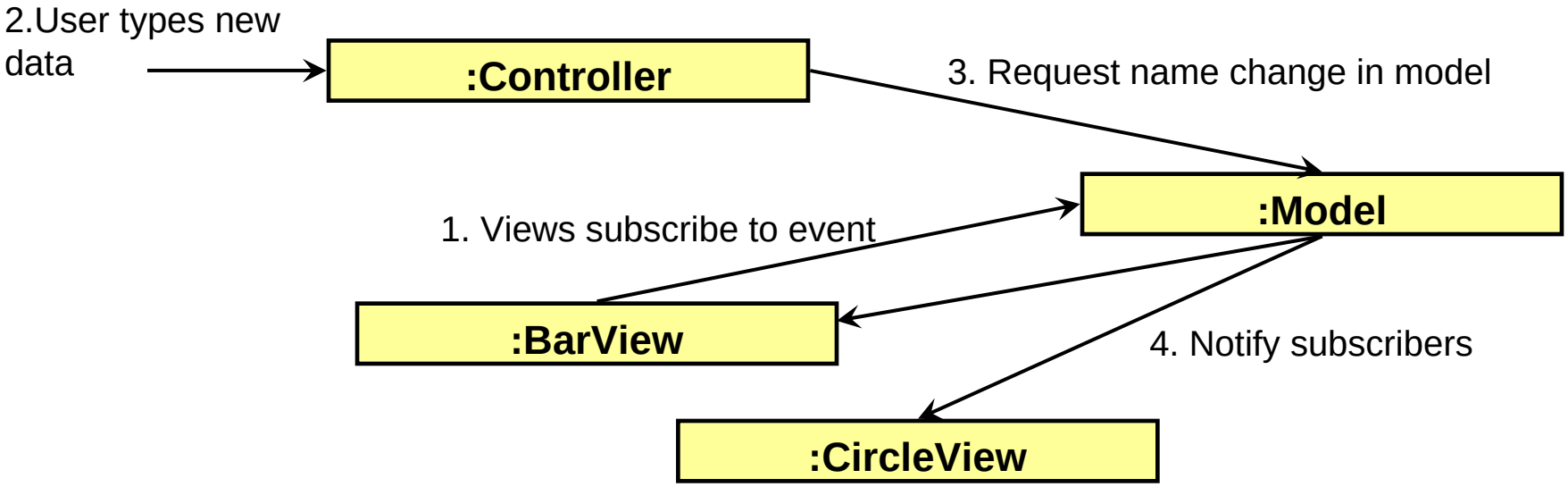


Model View Controller



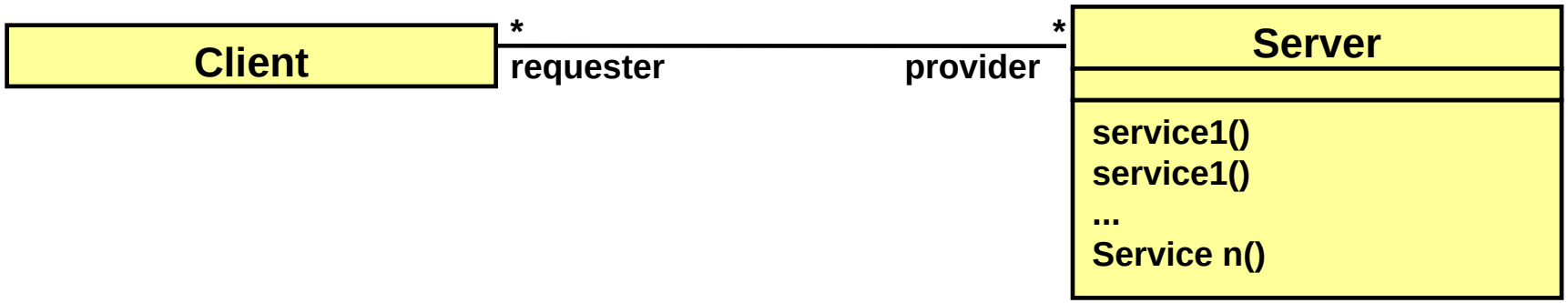
- Multiple views can exist at the same time
- New views can be added without any changes to the model

Software Architectural Styles:
Sequence of Events (Communication)



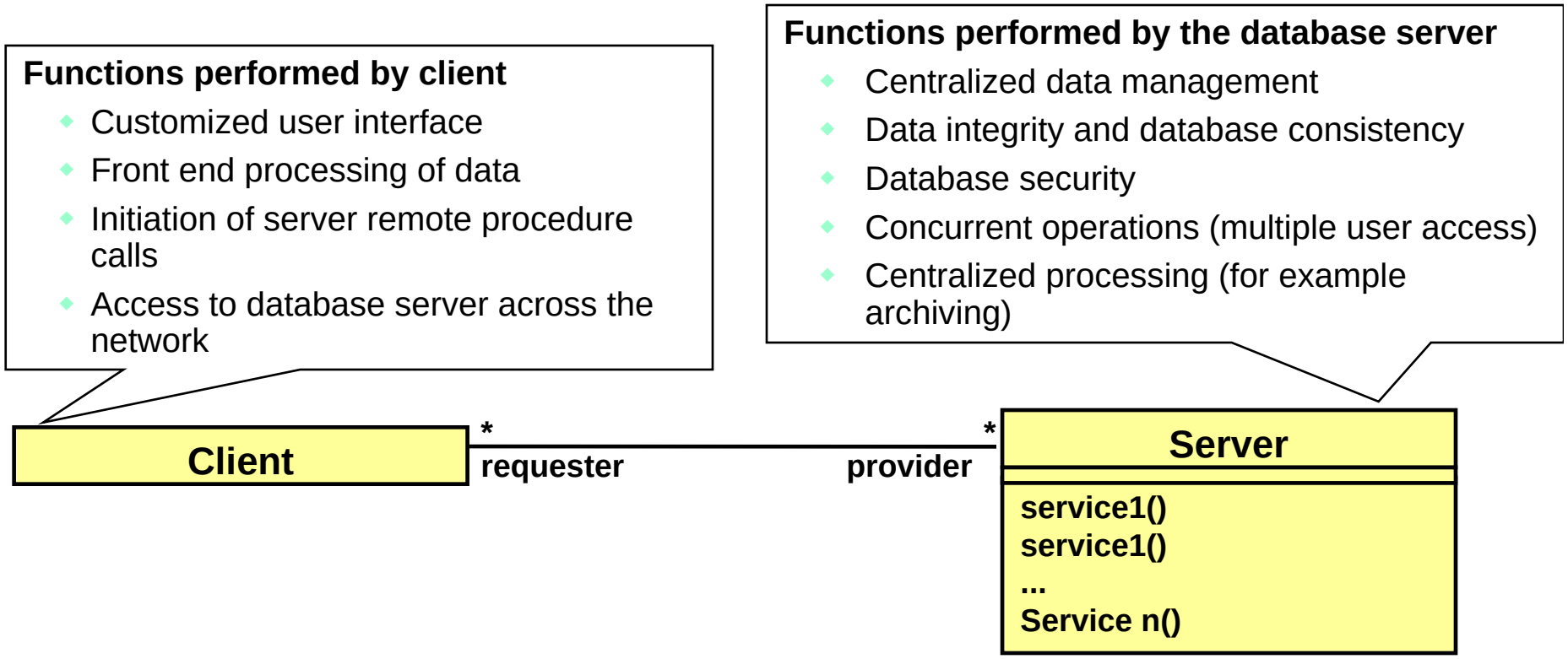
Software Architectural Styles:
Client/Server Pattern (1/2)

- 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



Software Architectural Styles:
Client/Server Pattern (2/2)

- Often used in database systems
  - Front end: User application (client)
  - Back end: Database access and manipulation (server)

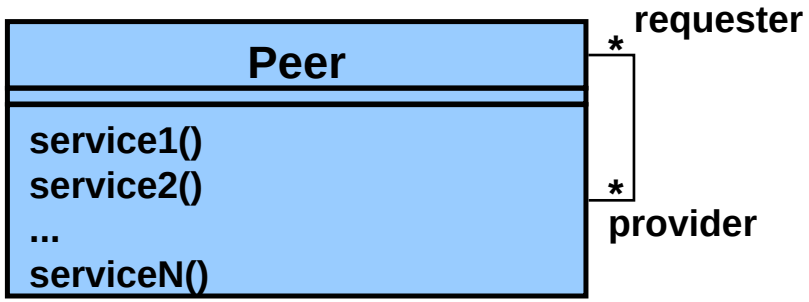


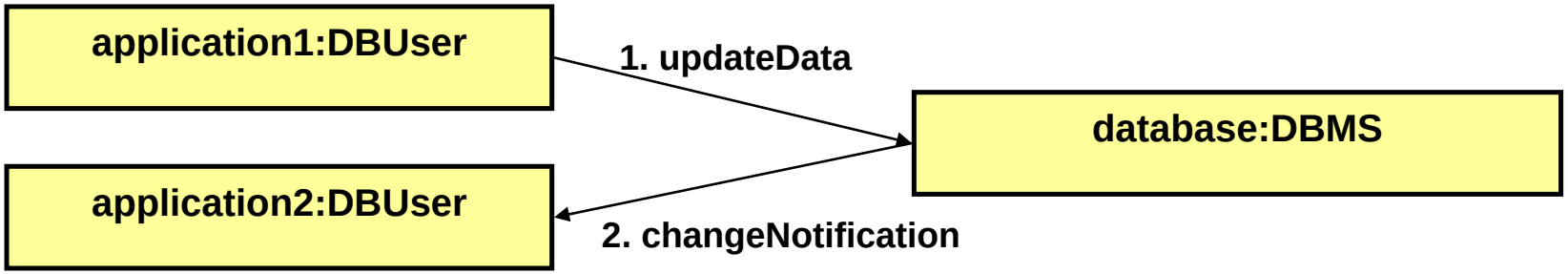
Software Architectural Styles:
Design Goals for Client/Server Systems

- 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, 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

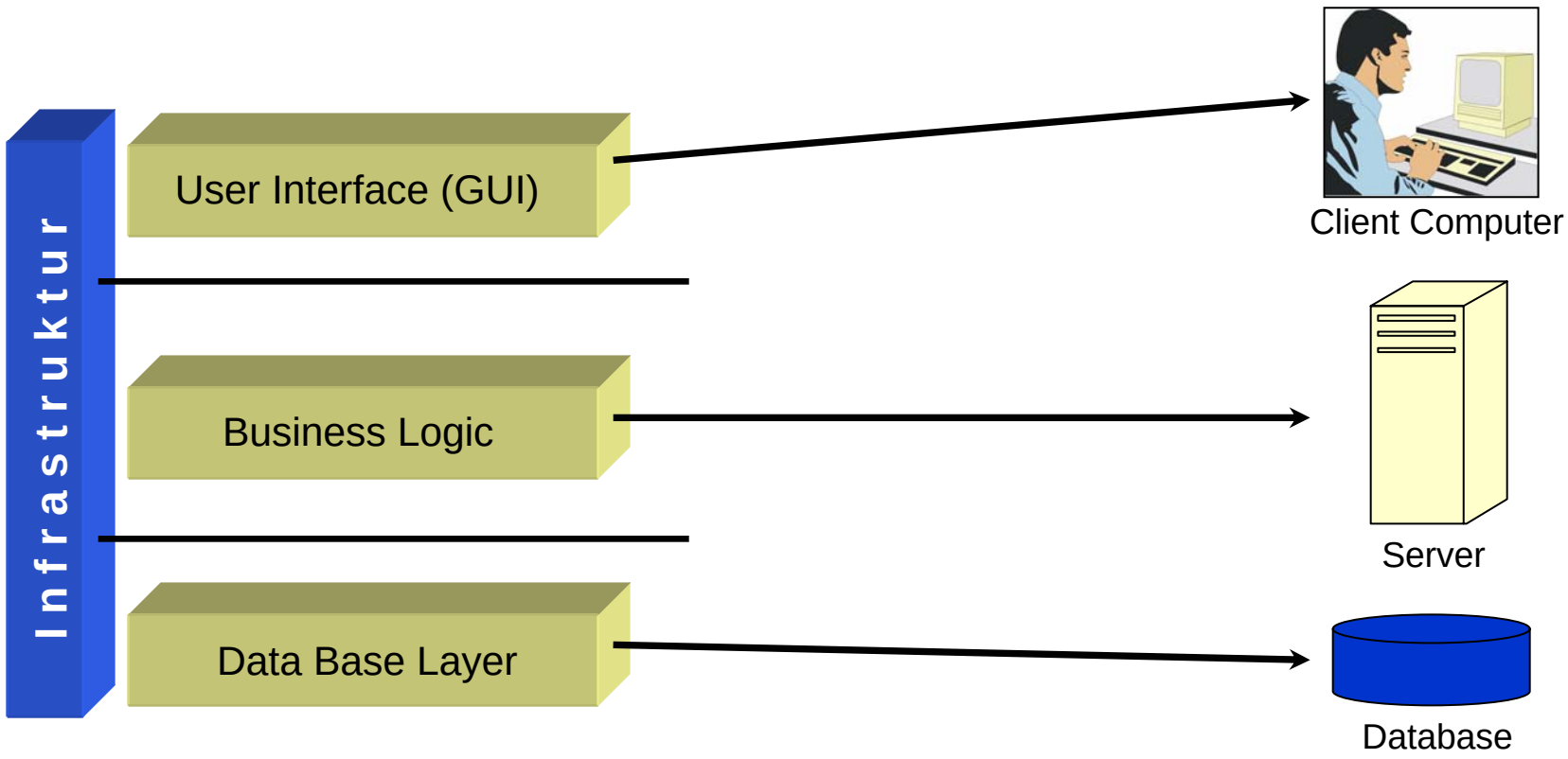
Software Architectural Styles:
Peer-to-Peer Architectural Style

- Generalization of Client/Server Architecture
- Peer acts as a client and a server at the same time
- More difficult to implement due to possible constraints:
  - Temporary availability
  - End-user interaction
- Further problems:
  - Maintainability





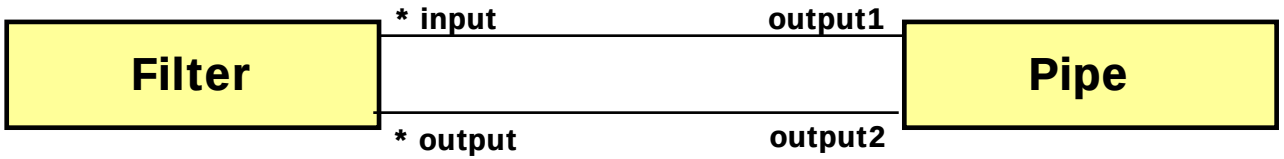
Software Architectural Style:
Three Tier



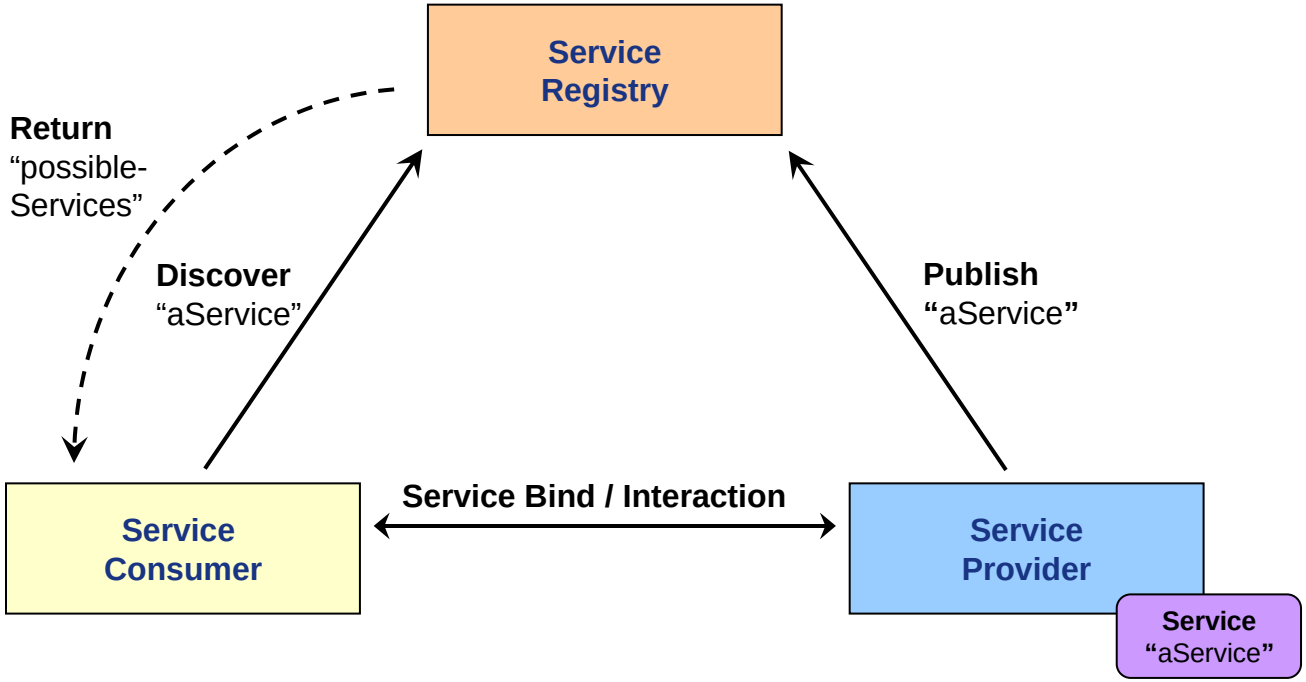
- Typically used for Enterprise Applications (booking systems, portals)
- Essentially a three layered architecture (layer = tier)
- Very substantial
- J2EE 1.4 specification: approx. 1400 pages (!)

Software Architectural Style:
Pipe and Filter

- Subsystems process data received from a set of inputs and send results to other, subsequent subsystems via a set of outputs
- Subsystems: filters
- Associations between filters: pipe
- Application: Transformations of data streams
- Example: Unix shell



Software Architectural Style: SOA



- Default Standard: Web Services (SOAP, UDDI, WSDL)
- Service Composition (BPEL, WSCI)

Summary

- System Design
  - Reduces the gap between requirements and the (virtual) machine
  - Decomposes the overall system into manageable parts
- Subsystem Decomposition
  - Results into a set of loosely dependent parts which make up the system
- Next:
  - Architecture Organization (activities 3. to 8.)