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Distributed Systems
Application Architectures

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Agenda

1. Motivation
2. Middleware based Architectures
   - Message orientation
   - Service Orientation
   - Object Orientation
   - Component Orientation
   - Service Oriented Architecture
3. Basic Architecture Models
   - Client/Server Model
   - P2P-Modell
   - Multi-Tier Model
   - SOA-Modell

Agenda

Main Driver of Commercial IT Products

- High **flexibility** ($\rightarrow$ Ability to adapt)
  - Flexible modelling of today's and prospective **business processes**
  - Reduction of development time (**time-to-market**)
  - **Integration** of existing (partial) solutions
  - **Interoperability** with third-party components
  - Considering current technological trends:
    - Internet of Things
    - Cloud Computing
    - Big Data
- **Low costs**
  - Reduction of **development costs**
  - Reduction of operation, maintenance, and management costs

    $\rightarrow$ **Total cost of ownership**

Approaches

- Open systems (vendor independence)
- Standard solutions (instead of proprietary development)
- Client/Server models and distributed computing
- Middleware
- Web services
- Application server
- Software reuse and componentware
- Reuse of services/Service Oriented Architectures (SOA)

Which standards/protocol may help here?

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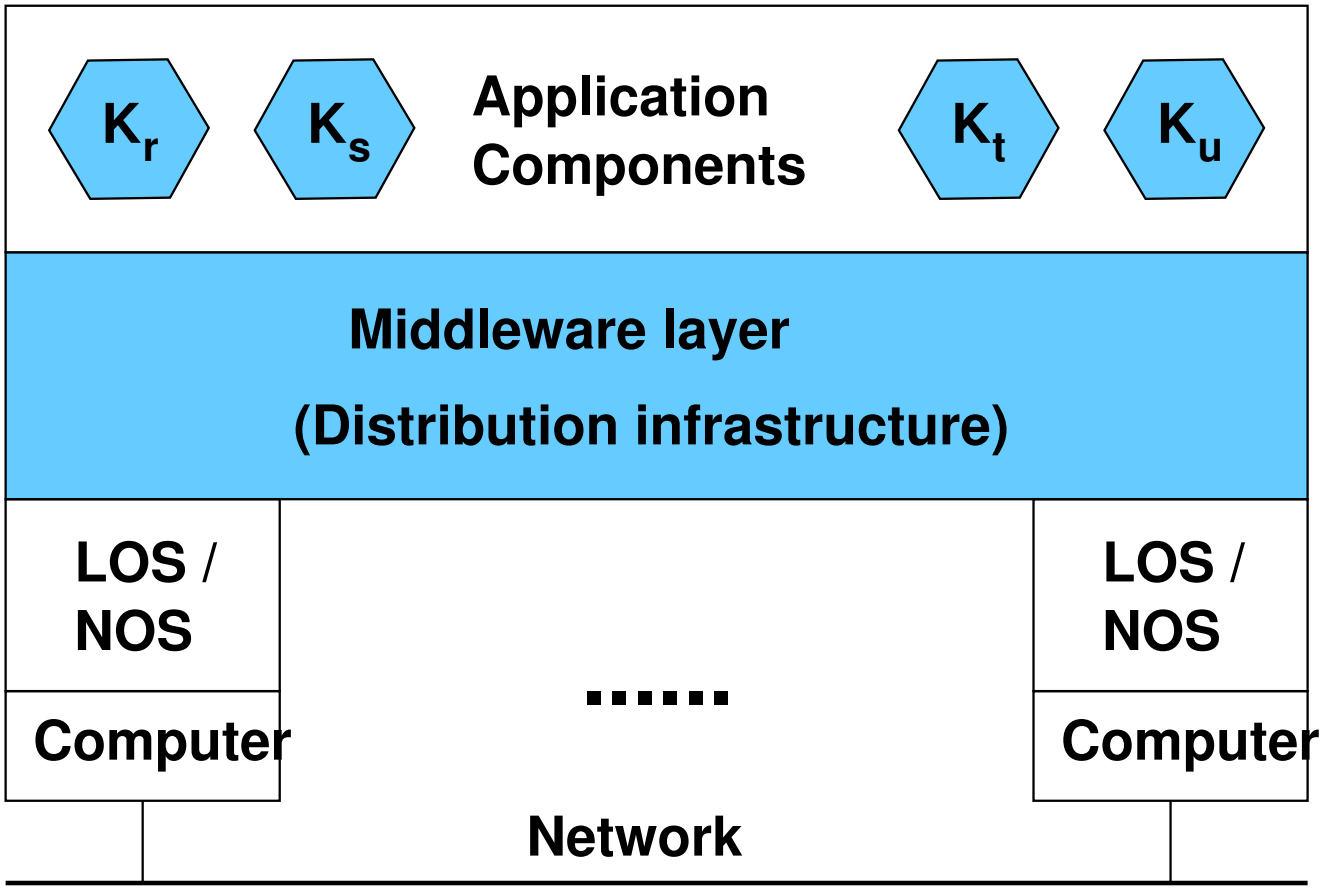
What is the role of Middleware?

Tasks of the Middleware

- Software layer as distribution platform for the integration of program components



Middleware Architectures

Each middleware can be characterized by a certain architecture paradigm along with its structural and activity model

- **Structural model** defines ...
  - the distributable units (program components)
  - their naming and addressing
  - potential auxiliary components
- **Activity model** defines the dynamics and as such the ...
  - the stakeholders
  - interaction pattern
  - communicated units
  - synchronization
- Implementing a middleware requires access to the components of the underlying layers (esp. the OS)

Middleware Properties

- Degree of specialization can be differ a lot, e.g., ...
  - support of a generic cooperation approach
    ($\rightarrow$ main focus of our course)
  - database centric
    (SQL middleware, transaction processing monitor)
  - document or workflow oriented
- Dependence on programming languages
  - Sometimes very high (e.g., only usable with Java)
- Dependence on the underlying OS
  - Often less strong
- Dependence on the underlying hardware
  - Typically very low

Evolution

- **Message** orientation
- **Service** orientation
- **Object** orientation
- **Component** orientation
- **Service Oriented Architecture** (document orientation)

→ Surveyed in the following

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Paradigm: Message orientation

- Basic model of communicating processes ($\rightarrow$ IPC) of traditional OS adapted to a distributed system environment
  - **Processes** as distributable units
  - **Messages** as communicated units
- **Message-oriented Middleware (MOM)**
  - Typically support for persistence and transactions
  - Examples:
    - IBM Websphere MQ
    - Java Messaging Service (JMS) (Teil von J2EE)
    - RabbitMQ

What could you use to realize a MOM?

Example: Socket Programming

- Berkeley Sockets (UNIX)
- Winsock (MS Windows sockets API)
  - Library that basically adopts the UNIX/BSD functions
- Sockets are today the de-facto standard, sometimes via decorated by libraries or classes
- Java Sockets (java.net)
  correspond mostly the model of Berkeley sockets

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Paradigm: Service Orientation

Foundation: Remote Procedure Call (RPC)

- Services as distributable units
- Service: set of provided operations/functions
- Use of remote services via procedure calls
- Typically **synchronous** processing
- Communicated units are **requests and responses** (containing typed parameters etc. using a common network representation)
- Foundation for client-server applications
- Binding of client and server rather static

Common RPC Platforms

SunRPC

- public domain, available for many systems
- Importance is decreasing
- But the still widely used network file system (NFS) is based on SunRPC

OSF DCE RPC, Microsoft RPC

- DCE (Distributed Computing Environment): first feature rich service environment
- Too complex for use
- Microsoft RPC mostly compatible with DCE RPC
- Today hardly used any more

Apache Thrift

- Very flexible RPC system
- Support for all relevant programming languages
- Widely used

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Paradigm: Object Orientation

- Objects (in the meaning of OOP) as distributable units
- Application := distributed object network
- Interaction by **method invocation** (with location and access transparency), based on a RPC mechanism
- Reuse of classes on the source code level
- Most relevant platforms
  - OMG CORBA
  - Microsoft DCOM
  - Java RMI

Example: RMI

- **Java Remote Method Invocation (RMI)** (Sun/Oracle)
  - Rather young platform
  - Simple use
  - Supports only the homogeneous world of distributed Java objects

Example: Microsoft DCOM

- Microsoft DCOM
  - Extension of COM/OLE via Microsoft RPC
  - Mostly proprietary platform
  - Handed over to Open Group in 1999
  - Subsequently Microsoft services were based on .NET
  - Decreasing importance, but still used in automation

Example: OMG CORBA

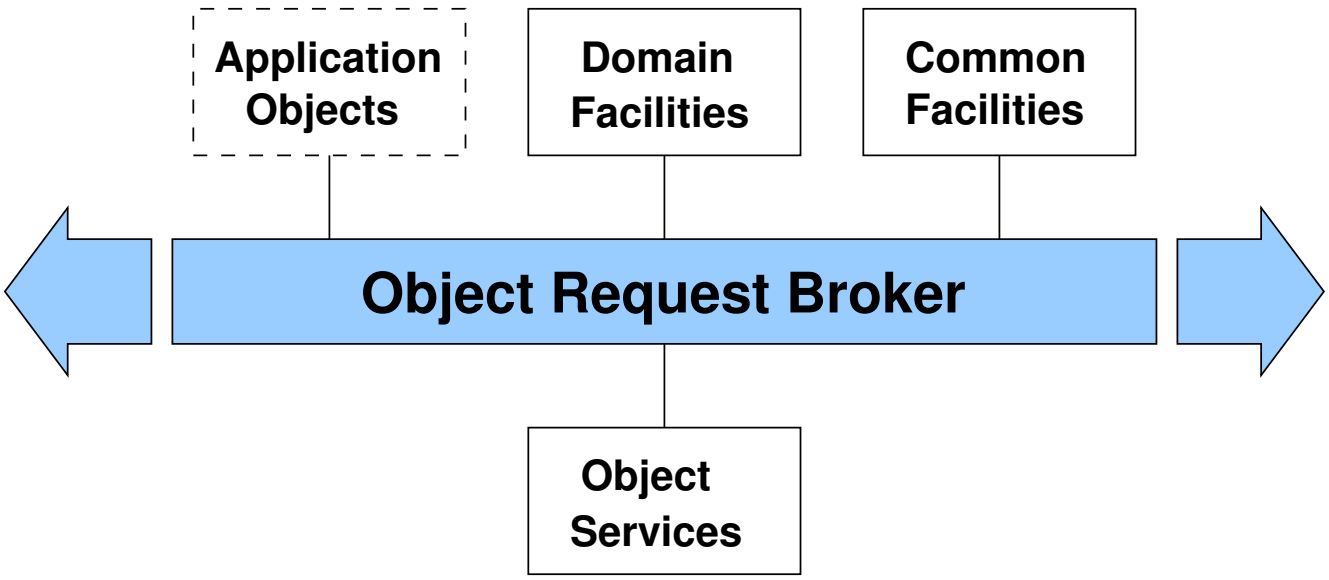
- **Object Management Group (OMG)**
  - international non-profit organisation of manufacturers, software components, and users
  - Founded in 1989
    - 3Com, American Airlines, Canon, Data General, HP, Philips, Sun, Unisys, ...
  - 1.000+ members (companies, organizations, universities . . .)
  - Rather fast moving standard body
  - Open, formal standardization process based on Request for Proposals (RFPs)
  - Goal: definition of interfaces, not product development
  - `http://www.omg.org` : freely available documents
  - Still relevant wrt. . . .
    - UML standardization
    - Model Driven Architecture (MDA)

CORBA (Common Object Request Broker Architecture)

- **Independent** from architecture, OS, or programming language
- CORBA IDL is the **interface description language** (resembling C++ syntax)
- Interoperable Object Reference (IOR) as system wide **object reference**
- General/Internet Inter-ORB Protocol (GIOP/IIOP) as **message protocol**
- Many object oriented services and implementations available
- Hardly used for new business applications, but still maintained

Object Management Architecture (OMA)

- Reference model for distributed, object oriented applications in heterogeneous environments



ORB = Object Request Broker

- **Object bus** as the core for the OMA
- Communicating calls between objects (independent of site, platform, and programming language)
- **Interoperability** between different ORBs

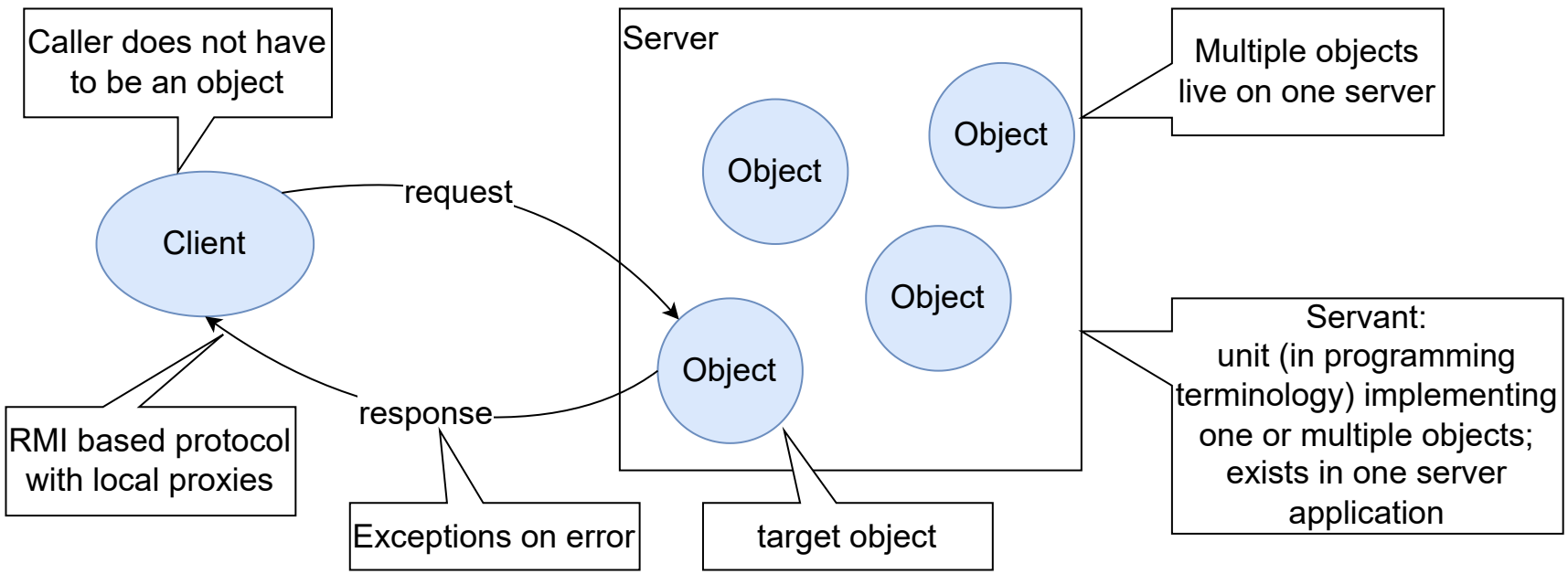
OMA Objects

- Conceived encapsulated unit on a single system
  - → Realized by an implementation in any given programming language
  - ⇒ Does not necessarily correspond to an object on the programming language level
- Has immutable **identity**
- Has a **state**
- Can be localized via ORB
- Possesses **attributes** (which can be accessed from the outside)
- Provides **operations** (methods) which can be accessed via client requests

OMA Object References

- **Handle** to identify, address, and locate an object
- **Internal structure** is **opaque** to the client
- Refers to a certain object

Relationship



Type of Requests

- **Synchronous**
  - Client blocks until response is received
- **Deferred synchronous**
  - Client continues processing after sending a request, asks later for the response (requires special API → Dynamic Invocation Interface (DII))
- **Oneway request**
  - Best-effort delivery without a response
    May never arrive at the destination
- **Asynchronous requests**
  - Defined as part of CORBA messaging (as part of CORBA 2.5 (2001))

Application Development

CORBA Interface Definition Language (IDL)

- Descriptive language for the definition of object interfaces ($\rightarrow$ no control constructs)
- **Strongly typed**
- `any` type allows for flexibility
- ISO 14750
- Description is **independent from the programming language** of the implementation
- Syntactical close to C++

Simple CORBA IDL Example

```
1 interface balance {
2     exception out_of_tolerance {};
3     readonly attribute long mode;
4     long getweight_in_grams() raises (out_of_tolerance);
5     void set_ref_weight_mode(in long ref_weight);
6     unsigned short get_weight_in_percent();
7     void reset_ref_weight_mode();
8 };
```

```
1 interface ext_balance : balance {
2     exception out_of_tolerance {long difference};
3     readonly attribute long mode;
4     long getweight_in_carat() raises (out_of_tolerance);
5     void set_tare_weight_mode(in long tare_weight);
6     void reset_tare_weight_mode();
7     void set_tolerance_weight_mode(in long min, in long max);
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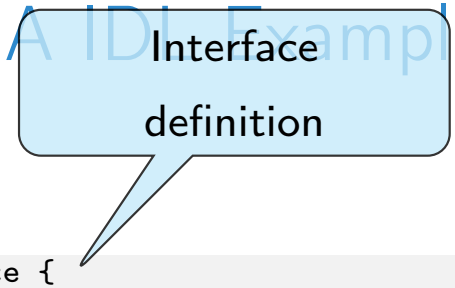


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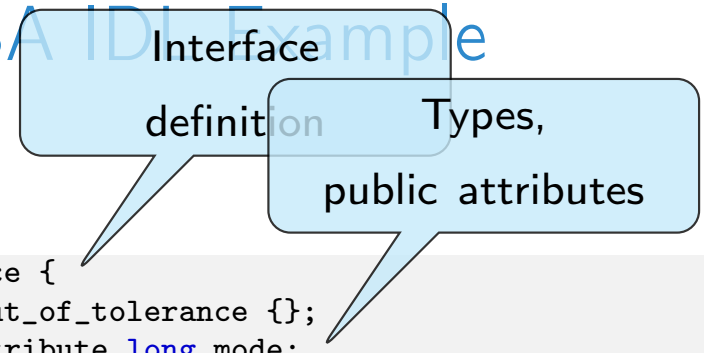


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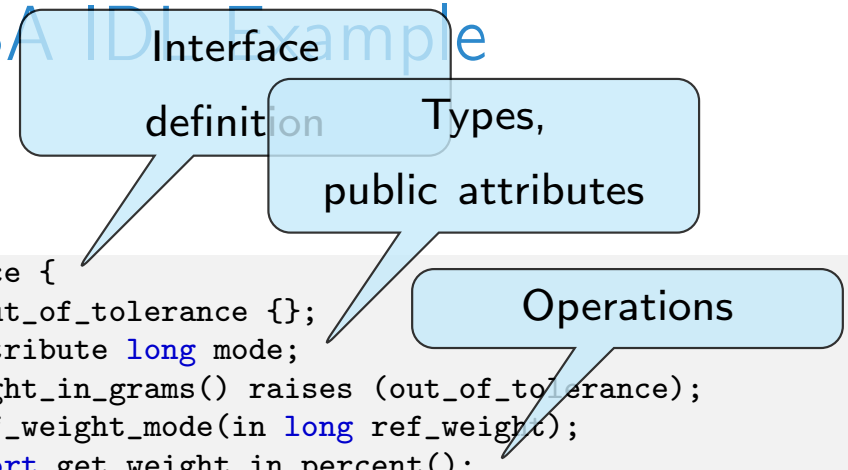


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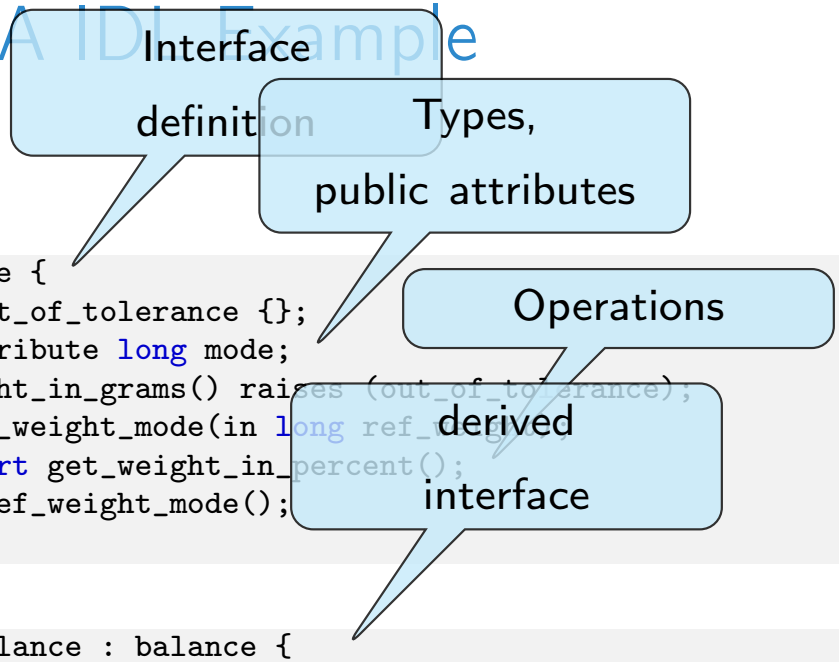


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Language Mappings

- Specification how IDL is mapped to different programming languages
  - e.g., IDL **module** for C++ namespace or Java package
  - IDL **interface** as C++/Java class
  - IDL **operation** as their member methods
- Standardized language mappings for
  - C, C++, Java, Smalltalk, COBOL, Ada, Lisp, PL/1, Python, IDLscript
- Other defined language mappings for:
  - Tcl, Perl, Eiffel, ...
- Consequence:
  - Various parts of a distributed application can be developed in various languages
  - e.g., server application in C++, clients in Java

Products

Important commercial ORBs:

- BEA M3 (as part of BEA Tuxedo) (BEA bought by Oracle, 2008)
- IONA Orbix (IONA bought by Progress, 2008)
- ORBexpress RT, Orbriver RT, PrismTech OpenFusion (for real-time applications)

Important free ORBs:

- OOC ORBacus (partly freely available, 2001 bought by IONA)
- MICO (Open Source Projekt, origins at the Universität Frankfurt)
- JacORB (FU Berlin, today PrismTech OpenFusion)
- TAO (WUSTL) (Real-time processing)
- ORBit (Middleware for GNOME)

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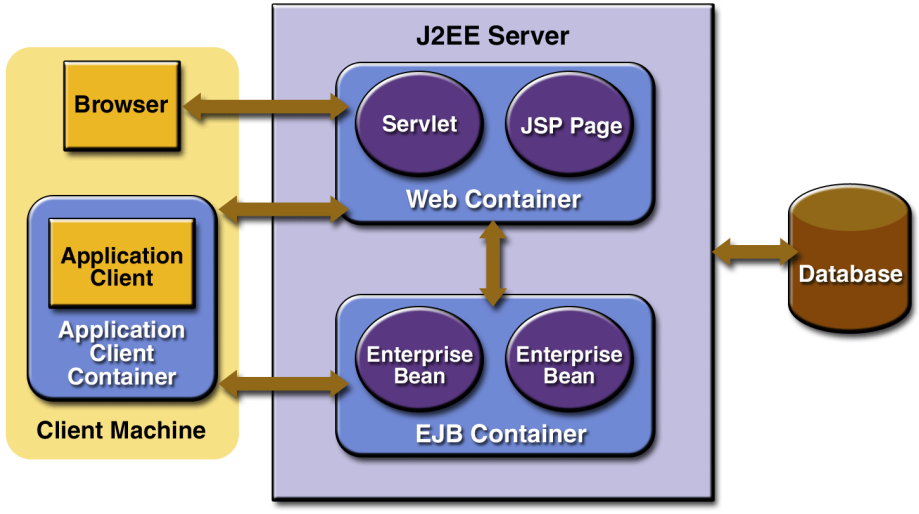
Paradigm: Component Orientation

- Components as distributable units
- **Strong independence** and **interchangeability** of the components
- Interaction via method calls (based on RPC)
- **Enterprise Java Beans (EJB)** (today Jakarte Enterprise Beans) is the most commonly used component model along with Microsoft .NET
  - Part of the specification of Java interfaces for server-side components (J2EE/JEE)
  - Tightly coupled with CORBA
  - Goal: Simplified application development
  - Application server as integrated infrastructure for **transaction oriented business applications**
  - Interfaces to standardized services (persistence, transaction management, directory serivces, messaging), bound at deployment time
  - High **scalability** for server side web applications
  - Rather **heavyweight**

Enterprise Java Beans



http://www.rizzimichele.it/enterprise-java-beans-and-all-j2ee/

- **Components**
  - Stateless and stateful **session beans** (Execution of a task for a client without resp. with memory for this client)
  - **Entity Beans** (Representation of business objects in persistent memory, support for transactions)
  - **Message-driven Beans** (asynch. processing of messages, JMS-API)

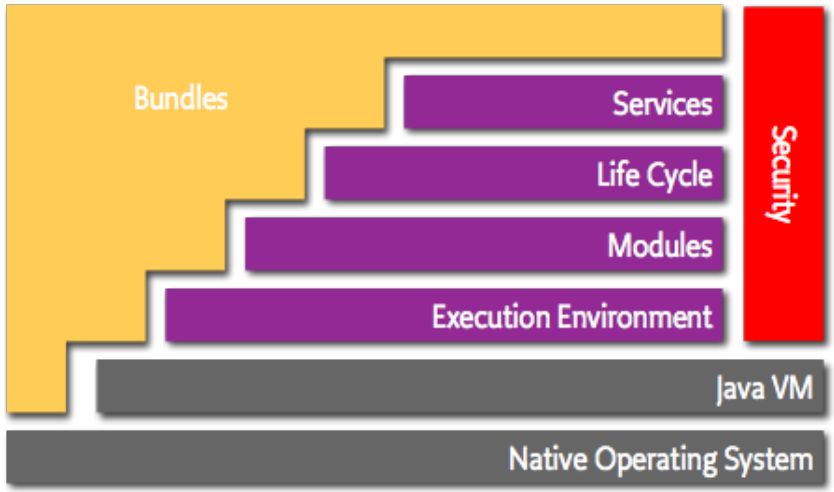
Common Products

- Free:
  - JBoss Application Server (today Red Hat)
  - Geronimo (Apache)
  - JOnAS (Object Web, Bull)
- IBM Websphere
- Oracle/BEA Weblogic
- SAP NetWeaver
- Sun GlassFish

OSGi - Component Model

- Formerly Open Services Gateway initiative is an **open standards** organization founded in 1999
- Commonly used Java-related component model for big distributed systems and even embedded systems
- Components created by the developers are called **bundles**
- **Dynamic component management** (lifecycle, incl. updates, remote management)
- Supports **versioning**
- **Application:**
  - Equinox platform in Eclipse for dynamic plugin management
  - For internal modularization of many application servers
  - origins at home automation and still very active in this context (Smart Home, Residential Gateways, e.g., Telekom Qivicon)
  - Automotive/Telematics ...

OSGi - Architecture



https://www.osgi.org/developer/architecture/

- Services connect bundles dynamically
- Life-Cycle - API for `install`, `start`, `stop`, `update`, uninstall
- Modules layer, defines import/export code
- Execution environment - defines classes and methods of the platform

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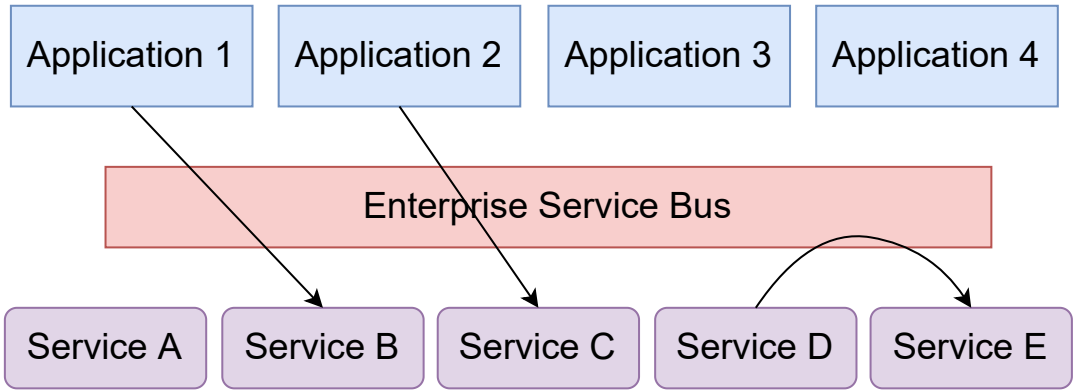
Paradigm: Service Oriented Architecture (SOA)

- Architectural approach for **business applications**
- For structuring and the use of distributed services under potentially differing governance
- **Goal:** achieve technical structuring of application sets
- **Expected benefits:**
  - Definition of services by the means of the business process
  - At the same time multiple use of services in different applications

  $\Rightarrow$ Maintenance reduction
  - Central integration of various applications instead of pairwise interfaces

SOA: Services - Applications

- **Ideal image:**



- **Challenges:**
  - Complete decomposition of existing applications is difficult, costly, and not visible for the user
  - Changes to central services affect many applications
  - Formalizing business processes via services is difficult for departments

SOA: Technical View

- Autonomous services described with formal interfaces (service contracts) in XML schema documents
- Services do not hold any state whenever possible
- XML documents as communicated units (messages)
- Service descriptions (meta data) in a directory (service registry)
- Services can be identified and accessed via their descriptions dynamically ($\rightarrow$ no linking required)
- Programming language or technology is irrelevant
- SOA services are currently often implemented as web services
- Enterprise Service Bus (ESB) for loose coupling of services

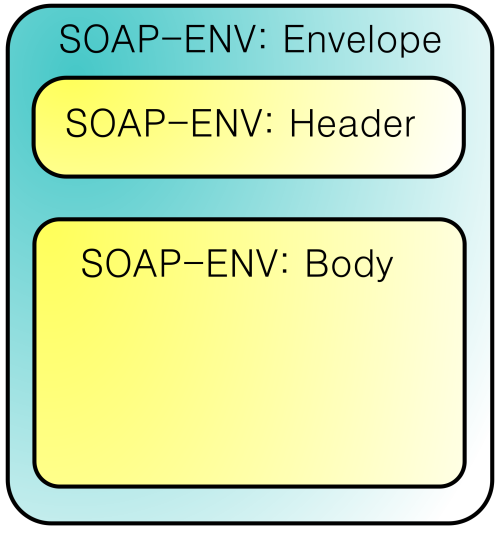
WSDL (Web Service Description Language)

- Interface/contract description language:
  - Types
  - Messages
  - Interfaces
  - Services
- W3C standard
- XML based

SOAP

- SOAP (formerly Simple Object Access Protocol)
  - W3C standard
  - There are no objects in the meaning of OOP
  - **XML document** based interaction framework for **web services**
    - **SOAP Messages** (Envelopes with opt. header and body)
    - Asynchronous processing possible
    - SOAP request/response messages for RPC style
  - Protocol binding framework allows for various underlying transport services, besides HTTP(s), e.g., also SMTP or JMS
  - Java API for XML Web Services (JAX-WS) is part of Java SE

SOAP: Example



https://commons.wikimedia.org/wiki/File:SOAP.svg

```xml
<?xml version="1.0"?>
<s:Envelope xmlns:s="http://www.w3.org/2003/05/soap-envelope">
    <s:Body>
        <m:TitleInDatabase xmlns:m="http://www.lecture-db.de/soap">
            DOM, SAX und SOAP
        </m:TitleInDatabase>
    </s:Body>
</s:Envelope>
```

Business Processes

- Modelling of business processes
  - A business process can be described as a **complex interaction between services**
  - Also called **web service orchestration**
  - Programming in large
    - Web services as elementary units
  - WS-BPEL (Business Process Execution Language)
    - OASIS standard
    - Program itself is a XML document
    - Decreasing importance
  - BPMN (Business Process Model and Notation)
    - Formerly known as: Business Process Modelling Notation
    - OMG standard, related to UML activity diagrams
    - Standardized as ISO/IEC 19510
    - Designed to improve understanding between technicians and managers

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Basic Architecture Models

Basic architecture models for complex distributed applications

1. Client/Server model
2. Peer-to-peer (P2P) model
3. Multi-Tier model
4. SOA model

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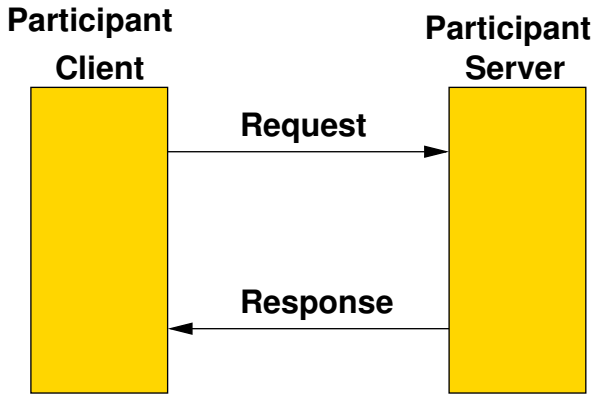
Agenda

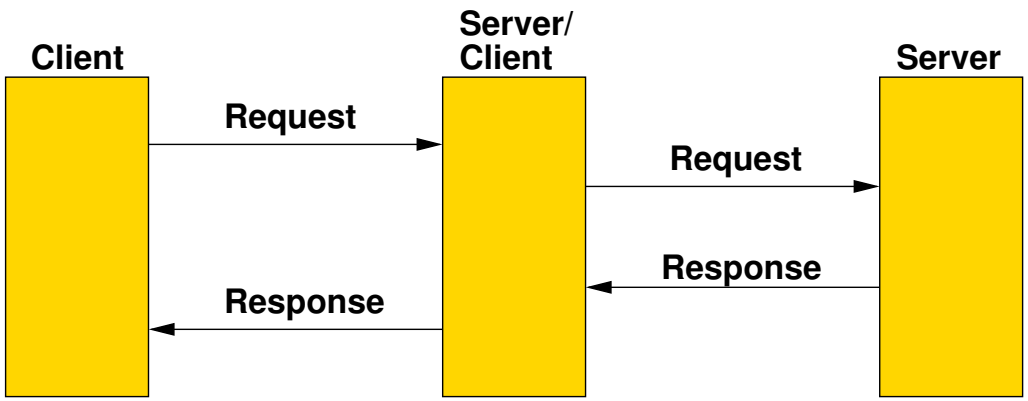
Client/Server Model (1)

- Two different **roles**
  - Server: **Service provider**, e.g., web server delivers web pages
  - Client: **Service user**, customer, consumer, e.g., web browser requesting web pages
- Client and server run typically on different computers



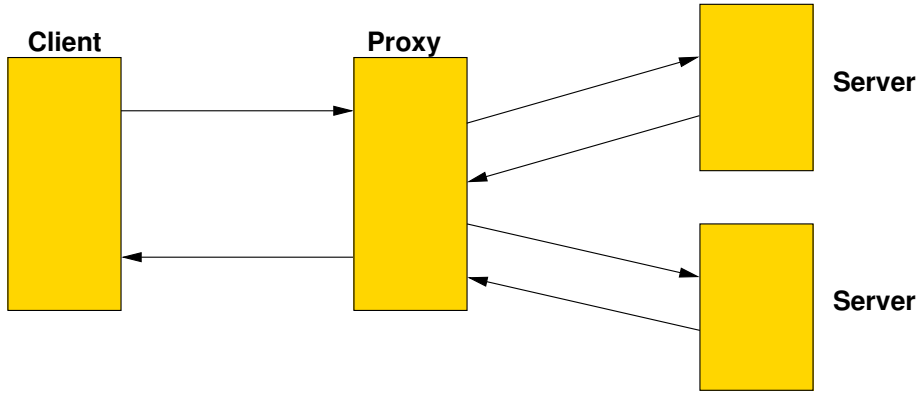
Client/Server Model (2)

- Communication processes are based on **request/response** interaction pattern
- Initiated by the client
- A client can interact with multiple servers over time
- A server may process requests for multiple clients
- A server may act as a client towards other servers (change of role):



Proxy

- Intermediary instance
- Acts as a server towards the client
- Acts as a client towards the actual servers
- Tasks are, e.g., caching, modification of requests ...
- Example: proxy server for web pages



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Peer-to-Peer Model (P2P)

- Decentralized communication between peers
- No additional infrastructure (e.g., servers) required
- Basis for ad-hoc communication
- Can be implemented at the network or application level
- Arbitrary message oriented interaction
- Examples
  - File-Sharing, e.g., BitTorrent, Gnutella, eMule
  - P2P development platforms JXTA, MSP2P

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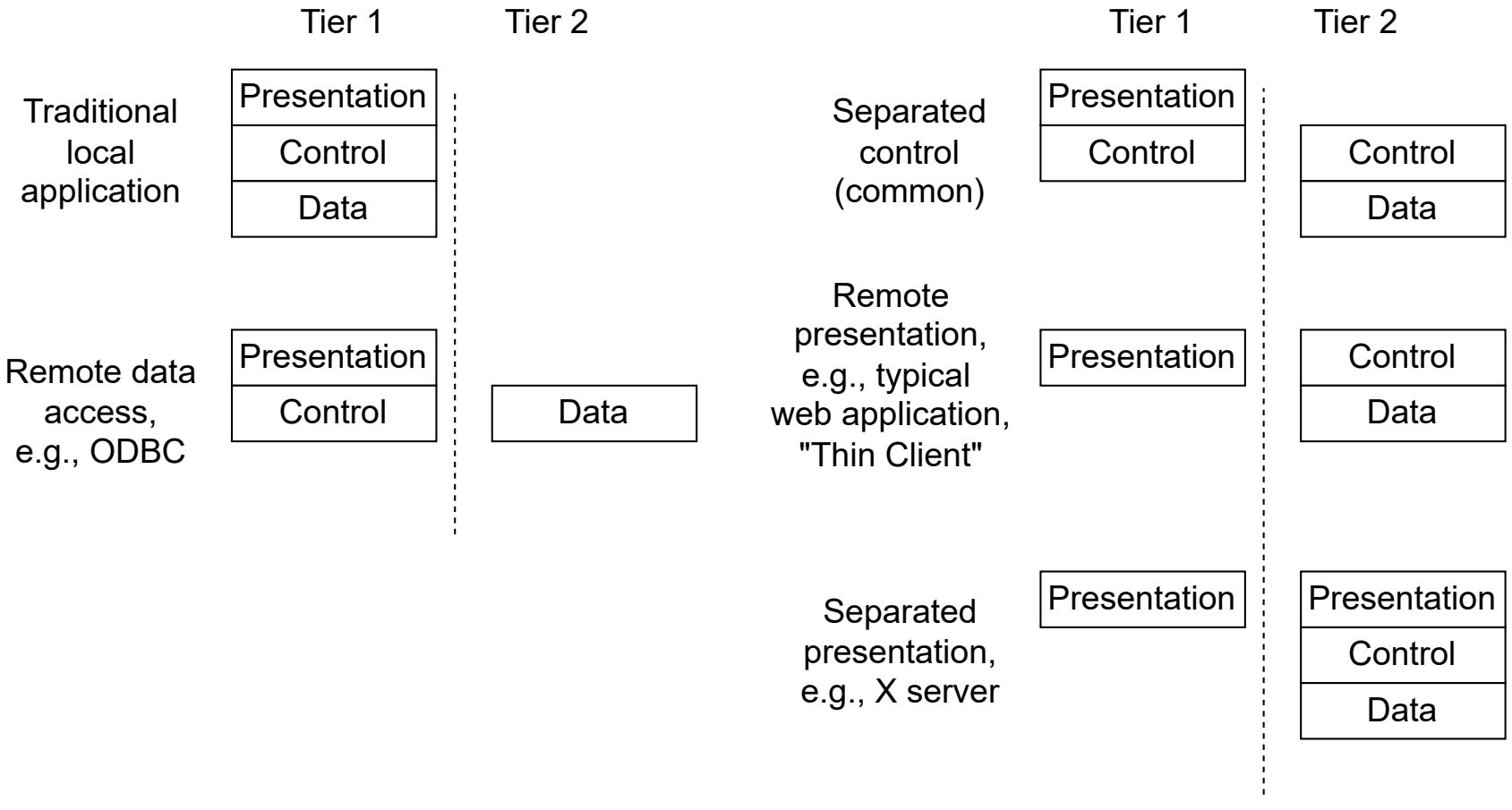
Multi-Tier Model

- Tiers are rather orthogonal wrt (abstraction) layers, typically oriented to
  - User interface/**presentation**
  - Application **control**/logic/function
  - **Data** storage
- No predetermination to used middleware
- Very common today
  - Two-Tier architecture
  - 3-Tier architecture
  - N-Tier architecture

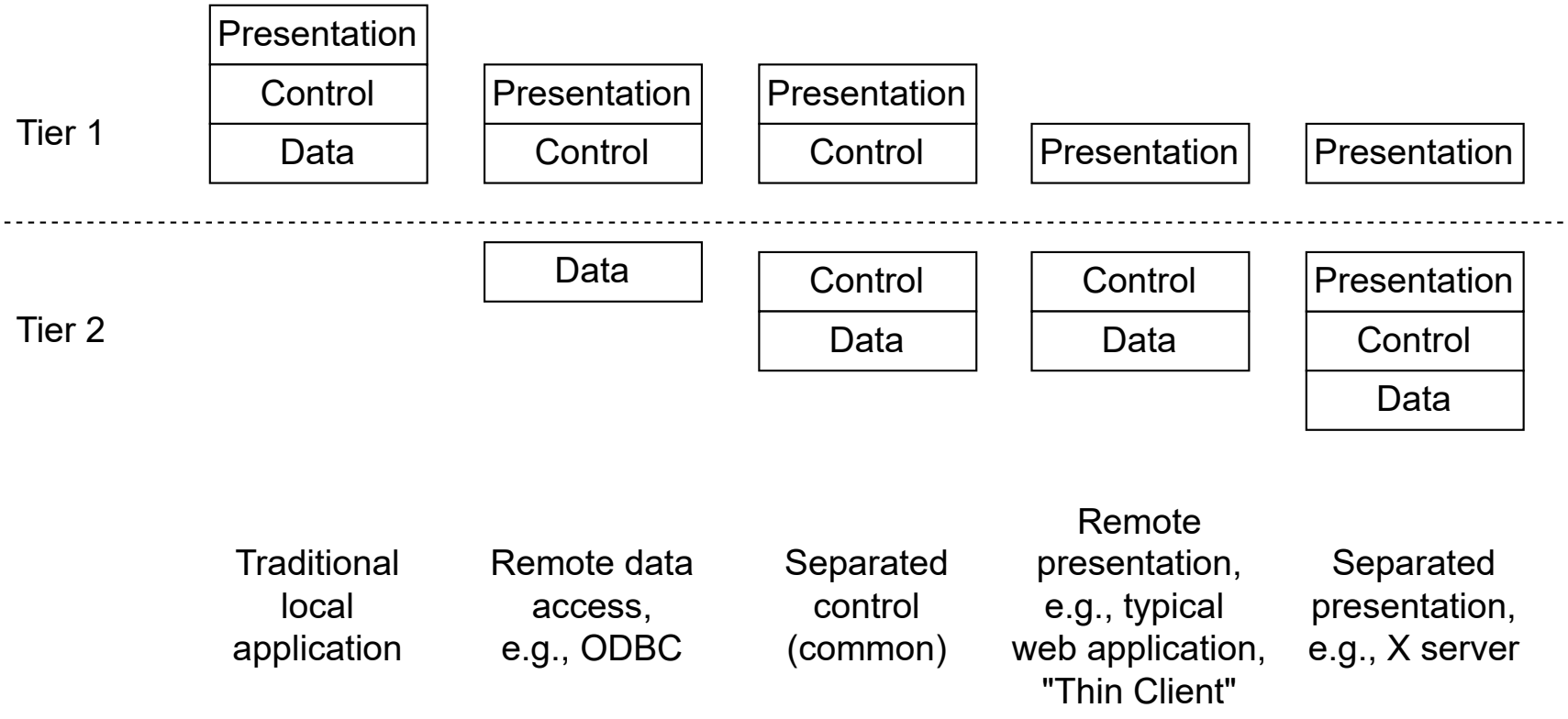
Two-Tier Architecture (1)

- Contains client tier (tier 1) and server tier (tier 2)
- Possible assignments



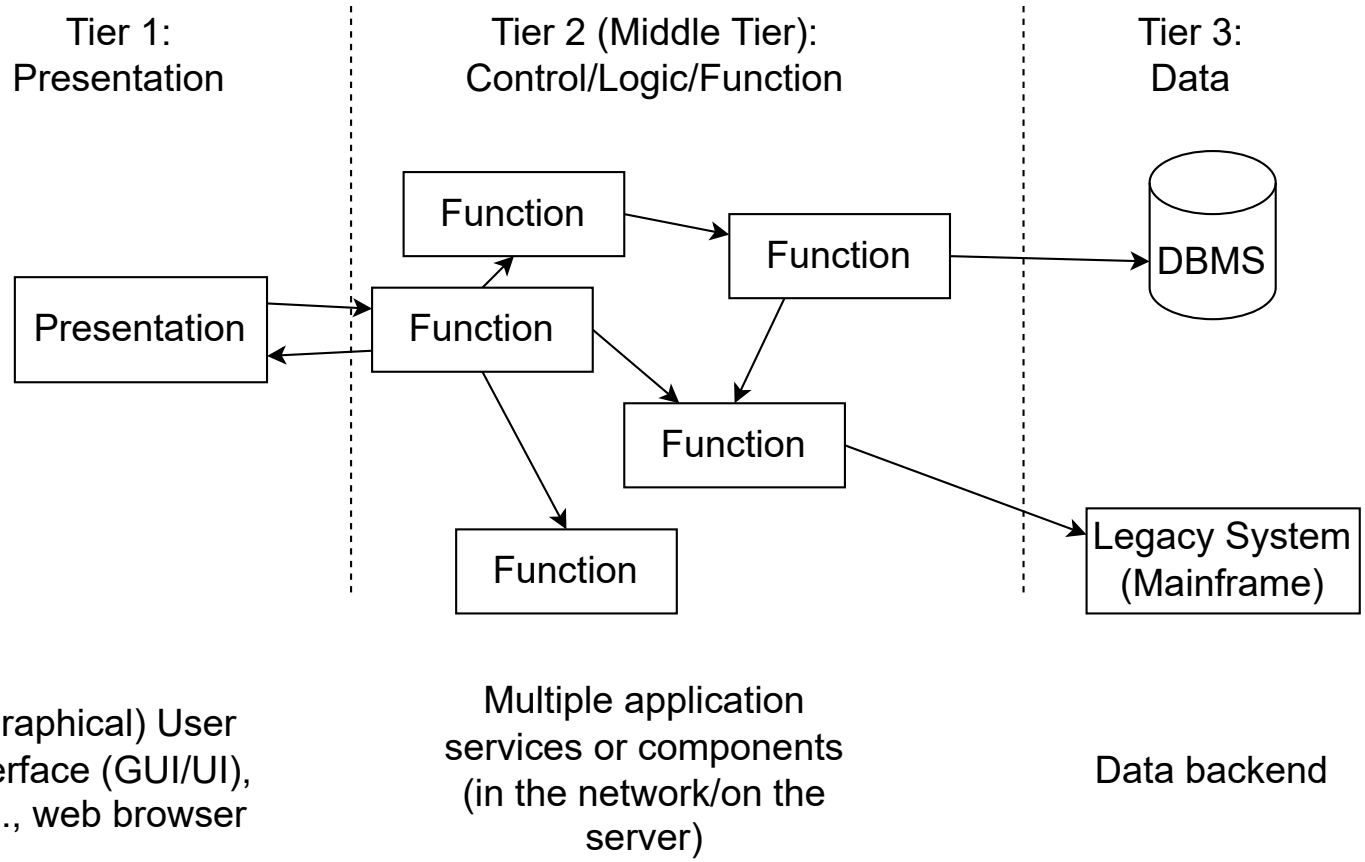
Two-Tier-Architektur (2)

- Different perspective



3-Tier Architecture

- Current structure model for complex applications



- Extension to N-Tier architecture

  Dividing primarily the middle tier

Example: J2EE Application

Client tier

- Internet browser or Java client

Web tier

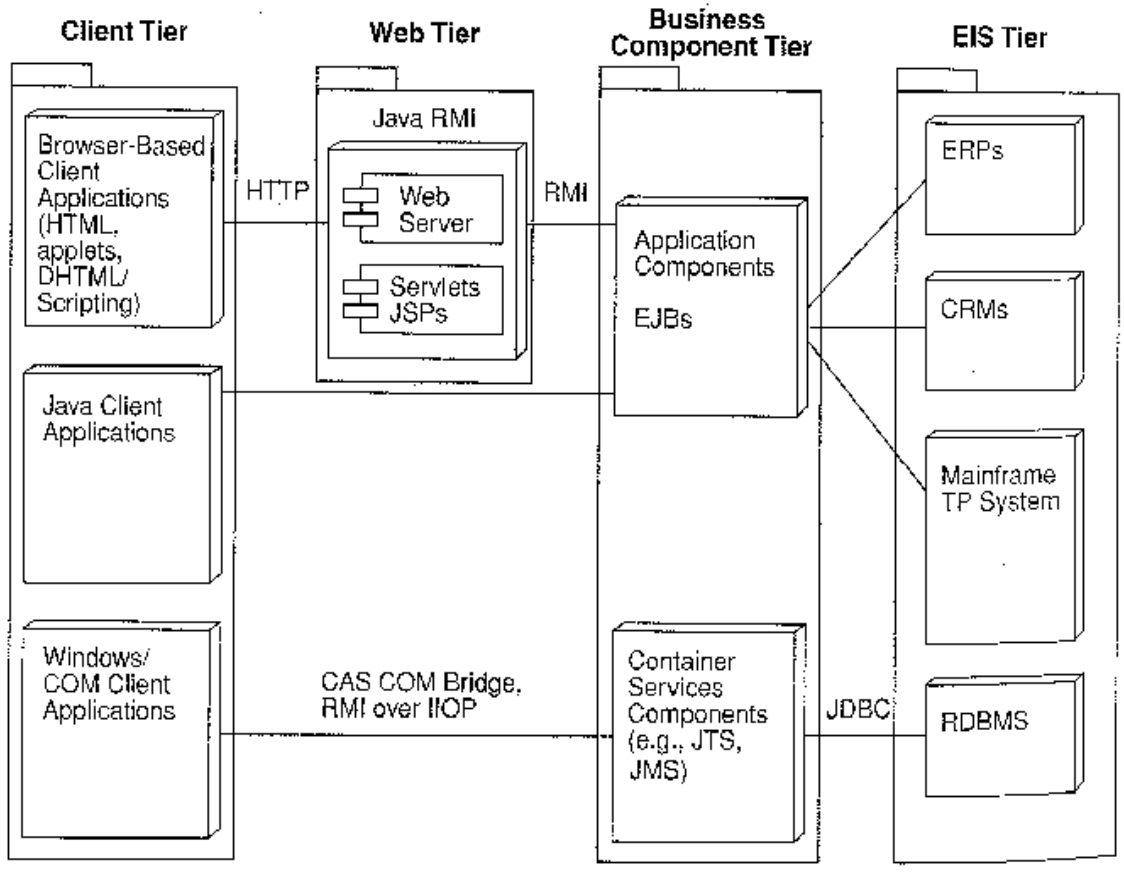
- Web server handling requests through JSPs and servlets

Business component tier (EJBs)

- Functional units that implement business rules and manipulate data

Enterprise information systems tier

- Databases, CRMs, mainframes, etc.



Source: R. Greespan

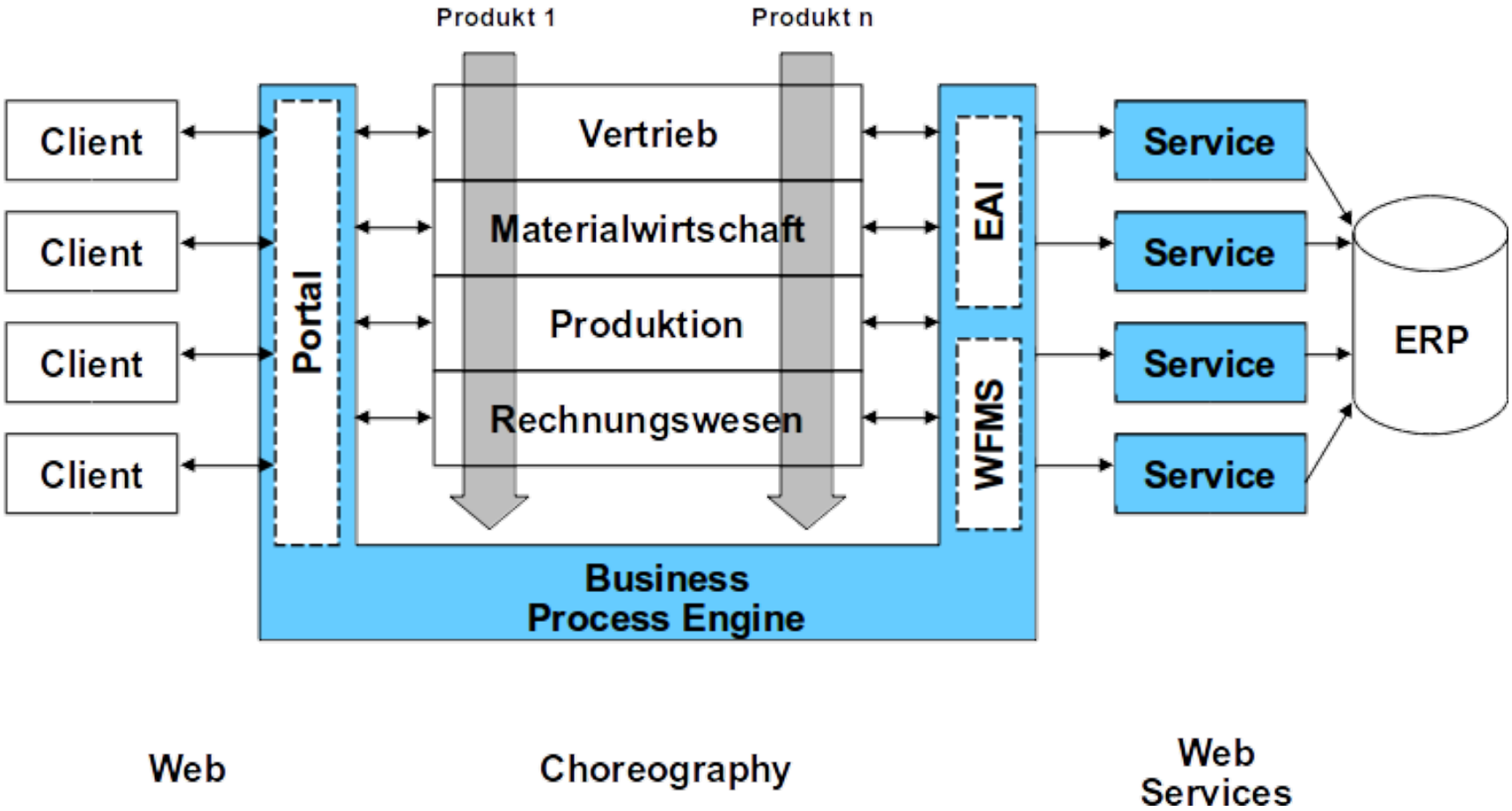
Agenda

1 Motivation

2 Middleware based Architectures
- Message orientation
- Service Orientation
- Object Orientation
- Component Orientation
- Service Oriented Architecture

3 Basic Architecture Models
- Client/Server Model
- P2P-Modell
- Multi-Tier Model
- SOA-Modell

SOA Model



After Scheer

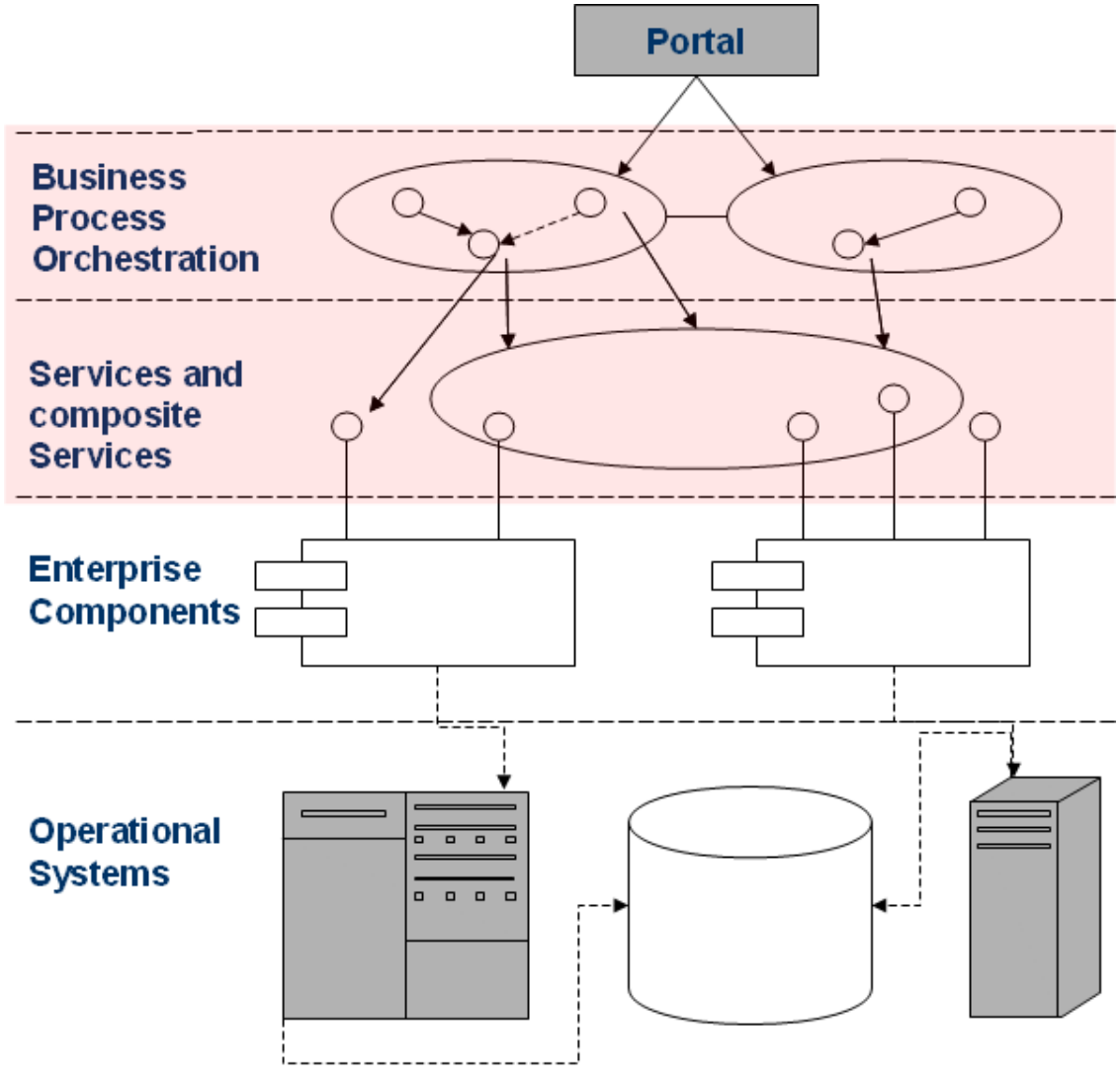
SOA from a Technical Perspective

Layered System

- IT business components are using resources
- Components provide sub-functionality as service
- Complex services can be combined through individual basic services
- Business processes link services to applications (Choreography/Orchestration)

Optional

- Enterprise Service Bus for communication beyond protocol boundaries



Important takeaway messages of this chapter

- Middleware acts as a layer between the OS and the application in order to abstract distributed applications from the underlying layers
- Middleware architectures describe the distributable units and interaction models
- For the design of a distributed system various architecture models can be used