Distributed Systems

Winter Term 2024/25

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Stand: October 17, 2024

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1 Introduction

1 Introduction ...

Contents

- What is a distributed system?
- Software architecture
- Architecture models
- Cluster

Literature

- Hammerschall: 1
- Tanenbaum, van Steen: 1
- Colouris, Dollimore, Kindberg: 1, 2
- Stallings: 13.4

1.1 What is a distributed system?

In a distributed system, components located on different computers work together to coordinate their actions by exchanging messages.

G. Coulouris

A distributed system is a set of independent computers that appear to the user as a single, coherent system.

A. Tanenbaum

A distributed system is a collection of processors that neither share main memory nor a clock.

A. Silberschatz

A distributed system is one on which I can’t do any work because some machine I’ve never heard of has crashed.

L. Lamport

1.1 What is a distributed system? ...

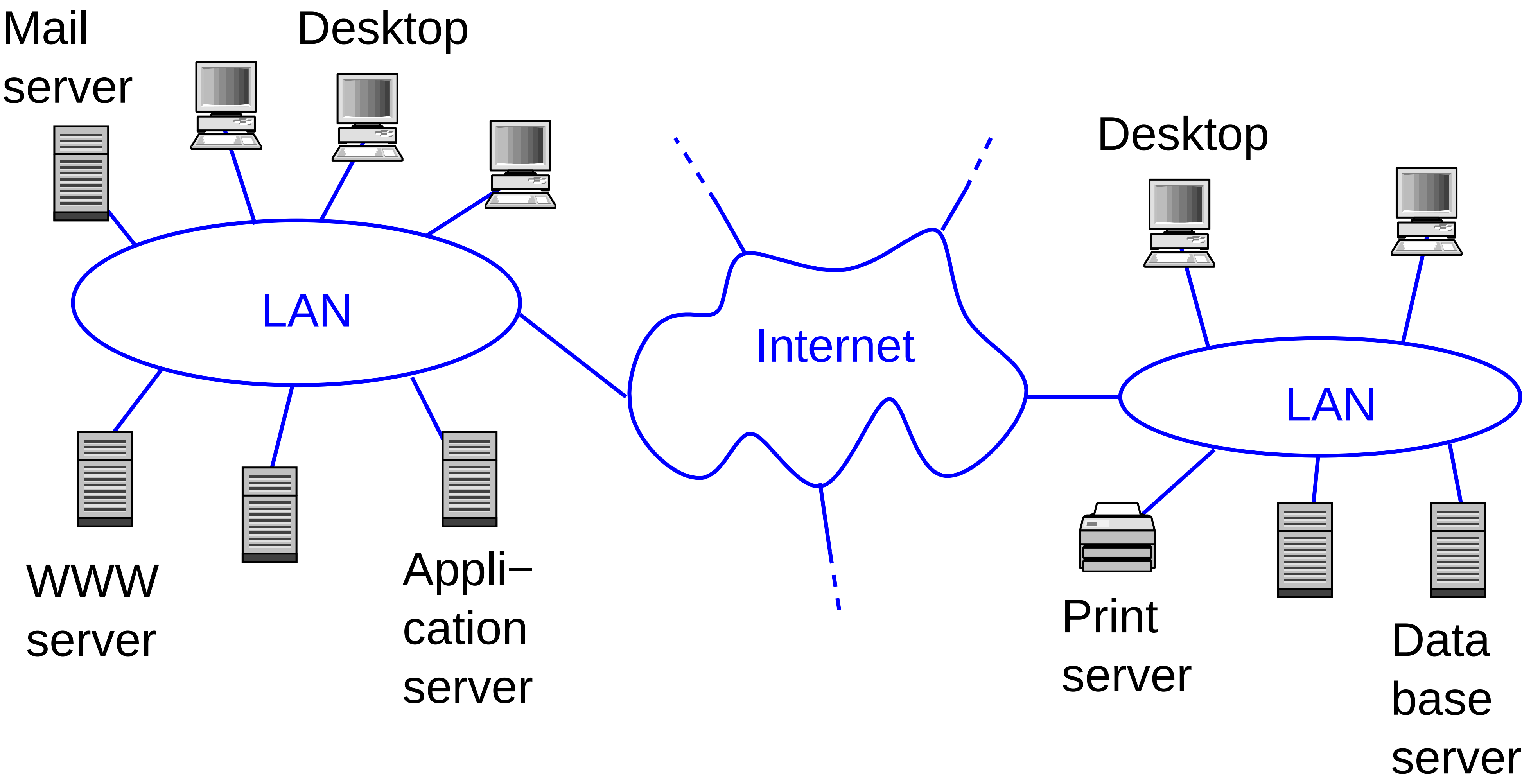
- A distributed system is **a system**
  - in which **hardware and software components** are based on **networked computers**, and
  - communicate and coordinate their actions only via the **exchange of messages**.
- The boundaries of the distributed system are defined by a common application
- Best known example: Internet
  - communication via the standardized Internet protocols
    - IP and TCP / UDP (☞ lecture Computer Networks)
  - users can use services / applications, regardless of the present location

What is a distributed application?

- Application that uses a distributed system to create a self-contained functionality
- Application logic distributed among several, largely independent components
- Components often executed on different machines
- Examples:
  - simple internet applications (e.g. WWW, FTP, email)
  - distributed information systems (e.g. flight booking)
    - SW intensive, data centered, interactive, highly concurrent
  - distributed embedded systems (e.g. in the car)
  - distributed mobile applications (e.g. for handhelds)

1.1 What is a distributed system? ...

A typical distributed system



1.1 What is a distributed system? ...

Why distribution?

- Central, non-distributed applications are
  - generally safer and more reliable
  - generally more performant
- Main reason for distribution: sharing of resources
  - hardware resources (printer, scanner, ...)
    - cost saving
  - data and information (file server, database, ...)
    - information exchange, data consistency
  - functionality (centralization)
    - error avoidance, reuse

1.2 Characteristics of distributed systems

- Resources (e.g. computers, data, users, ...) are distributed
  - sometimes worldwide
- Cooperation via message exchange
- Concurrency
  - but: parallel processing of **a single** request is not the primary goal
- No global clock (more precisely: no global time)
- Distributed status information
  - no uniquely determined global state
- Partial errors are possible (independent failures)

Parallel vs. distributed systems

- Parallel system:
  - motivation: higher performance through parallel execution
  - multiple tasks (processes/threads) working on one job
  - tasks are fine-grained: frequent communication
  - tasks work simultaneously (parallel)
  - homogeneous hardware / OSs, regular network structure
- Distributed system:
  - motivation: distributed resources (computers, data, users)
  - multiple tasks (processes/threads) working on one or many jobs
  - tasks are coarse grained: communication less frequent
  - tasks work synchronized (usually one after the other)
  - inhomogeneous (processors, networks, OSs, ...)

1.3 Challenges and Goals of Distributed Systems

- **Heterogeneity**: computer hardware, networks, OSs, programming languages, implementations by different developers, ...
  - solution: **middleware**
    - software layer that hides heterogeneity by providing a unified programming model
    - e.g. CORBA: distributed objects, remote method invocation
    - e.g. web services: remote procedure calls (services)
- **Openness**: easy extensibility (with new services)
  - requirements:
    - key interfaces are published / standardized
    - uniform communication mechanisms / protocols
    - components must conform to standards

[Coulouris, 1.4]

1.3 Challenges and Goals of Distributed Systems ...

- **Security**
  - information: confidentiality, integrity, availability
    - esp. with mobile code
  - users: authentication, authorization
- **Scalability**: number of resources or users can grow without negative impact on performance and cost
- **Error handling** (partial errors)
  - error detection (e.g. checksums)
  - error masking (e.g. retransmission of a message)
  - error tolerance (e.g. browser: “server not available”)
  - recovery (of data) after errors
  - redundancy (of hardware and software)

1.3 Challenges and Goals of Distributed Systems ...

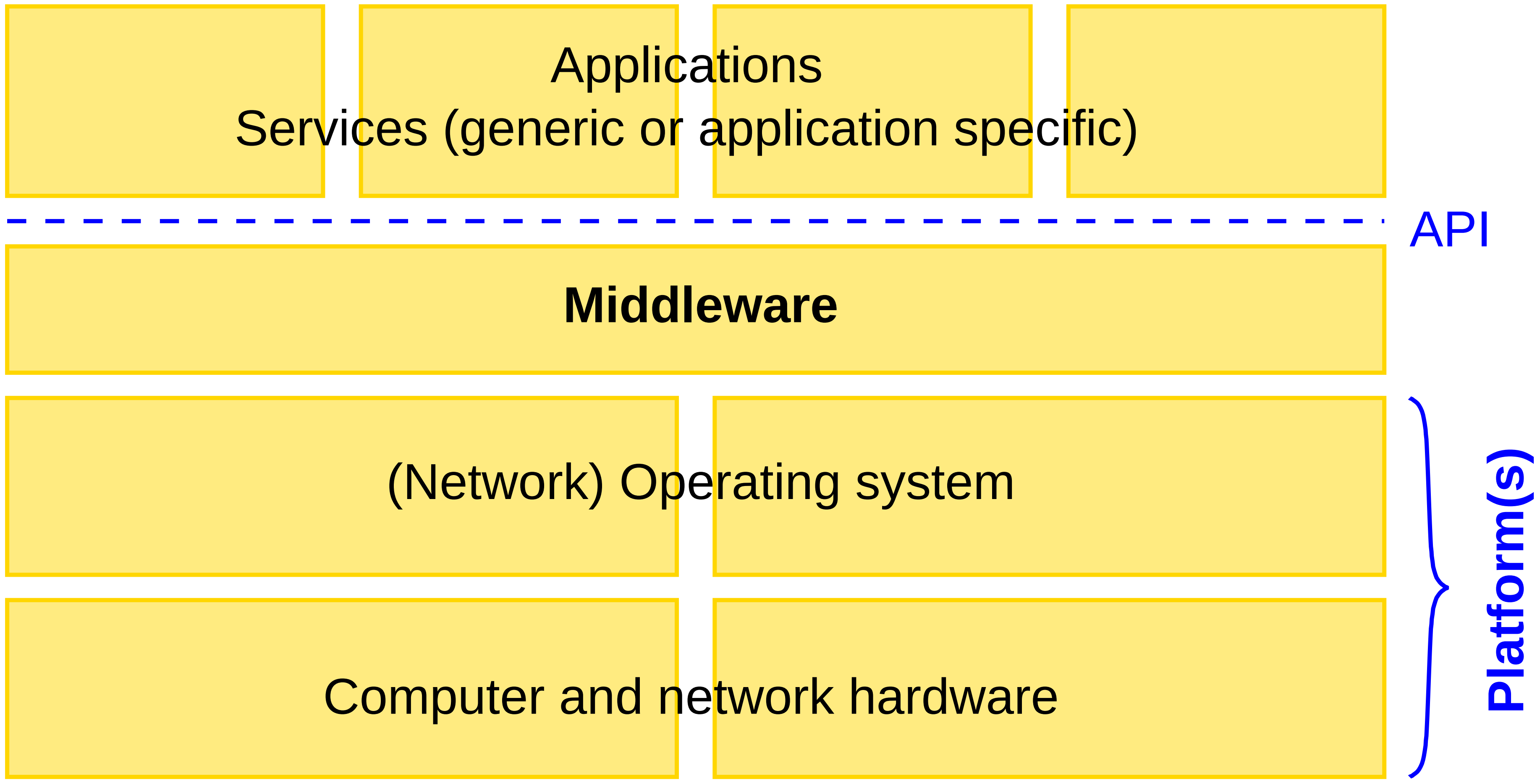
- **Concurrency**
  - synchronization, consistency of replicated data
  - lack of global time / global state
- **Transparency**
  - access∼: local and remote accesses identical
  - location∼: no need to know the location

  $\Big\}$ network∼
  - mobility∼: transparent relocation of resources
  - replication∼: transparent replication of resources
  - concurrency∼: shared use of resources without disruptions
  - error∼: hiding errors due to component failure
  - performance∼: performance is largely independent of the load
  - scaling∼: system scales without negative impact on users

Types of Operating Systems for Distributed Systems

- Network operating system:
  - traditional OS, extended by support for network applications (API for sockets, RPC, ...)
  - each computer has its own OS, but can use services of other computers (file system, email, `ssh`, ...)
  - the existence of the other computers is visible
- Distributed operating system:
  - uniform OS for a network of computers
  - transparent for the user
  - requires cooperation of the OS kernels
  - so far mainly research projects

Typical layers in a distributed system


Applications
Services (generic or application specific)
API
Middleware
(Network) Operating system
Computer and network hardware
Platform(s)

[Coulouris, 2.2.1]

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17.10.2024

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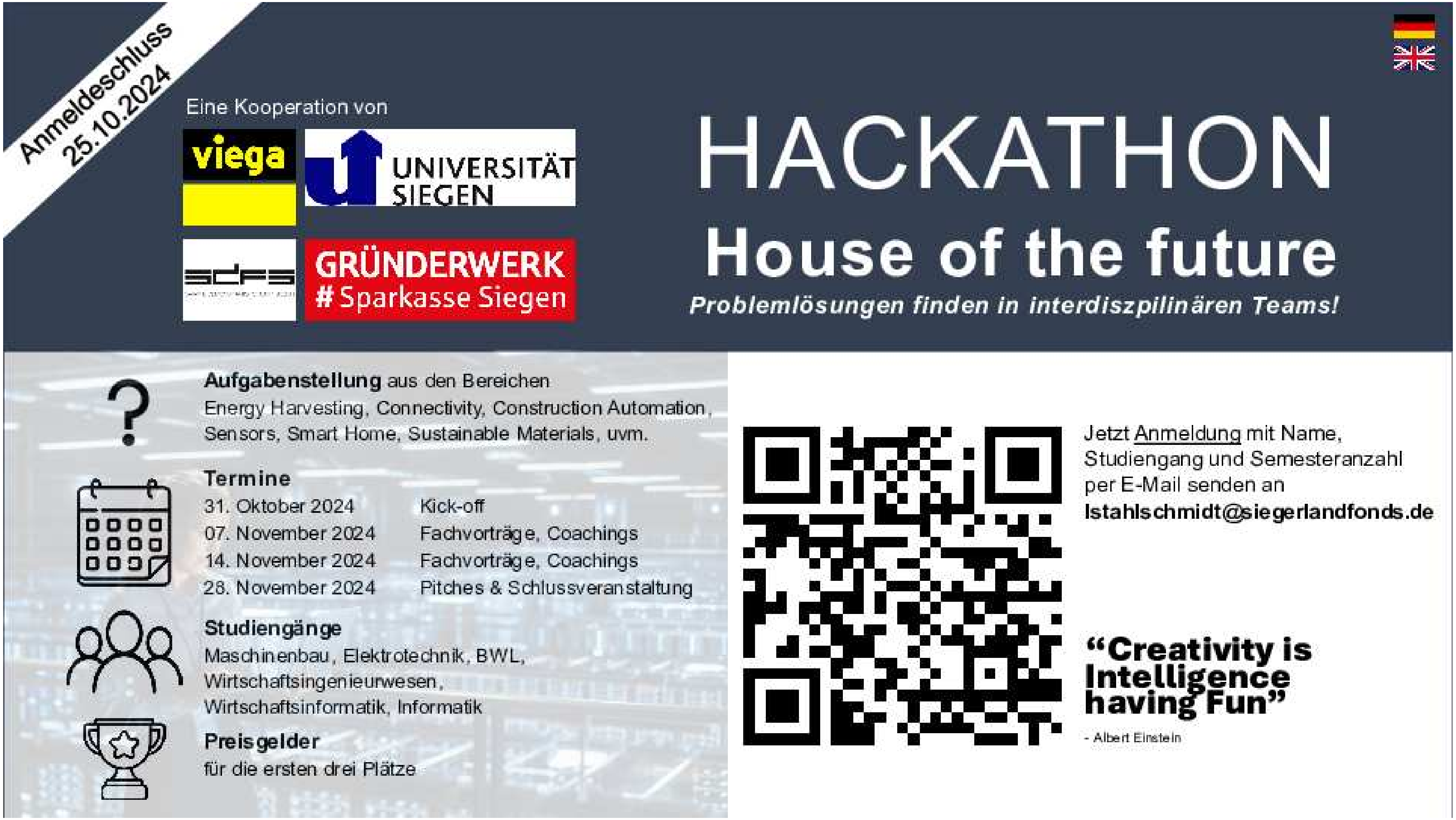

Anmeldeschluss 25.10.2024

Eine Kooperation von

viega

UNIVERSITÄT SIEGEN

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GRÜNDERWERK # Sparkasse Siegen

HACKATHON

House of the future

Problemlösungen finden in interdiszpilinären Teams!

Aufgabenstellung aus den Bereichen
Energy Harvesting, Connectivity, Construction Automation, Sensors, Smart Home, Sustainable Materials, uvm.

Termine

31. Oktober 2024	Kick-off
07. November 2024	Fachvorträge, Coachings
14. November 2024	Fachvorträge, Coachings
28. November 2024	Pitches & Schlussveranstaltung

Studiengänge
Maschinenbau, Elektrotechnik, BWL, Wirtschaftsingenieurwesen, Wirtschaftsinformatik, Informatik

Preisgelder
für die ersten drei Plätze

Jetzt Anmeldung mit Name, Studiengang und Semesteranzahl per E-Mail senden an
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"Creativity is Intelligence having Fun"

- Albert Einstein

Middleware

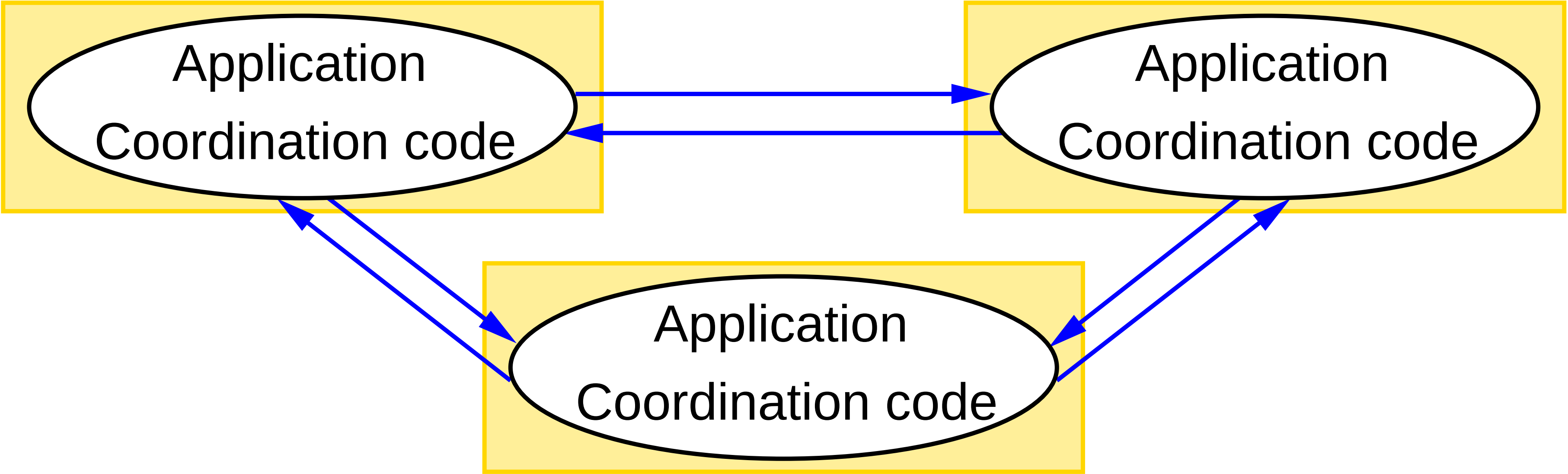
- Tasks:
  - hiding of distribution and heterogeneity
  - providing a common programming model / API
  - provision of general services
- Functions e.g:
  - communication services: remote method calls, group communication, event notifications
  - replication of shared data
  - security services
- Examples: CORBA, EJB, .NET, Web Services, ...

1.5 Architectural Models

- An architecture model characterizes:
  - roles of an application component within the distributed application
  - relationships between application components
- Role defined by the type of process the component is running in:
  - client process
    - short-lived (for the duration of use by the user)
    - acts as initiator of interprocess communication (IPC)
  - server process
    - lives ’unlimited’
    - acts as a service provider for an IPC
  - peer process
    - short-lived (for the duration of use by the user)
    - acts as initiator and service provider

Peer-to-Peer Model

- Collaboration of peer processes for a distributed activity
  - each process manages a local part of the resources
  - distributed coordination and synchronization of actions at application level

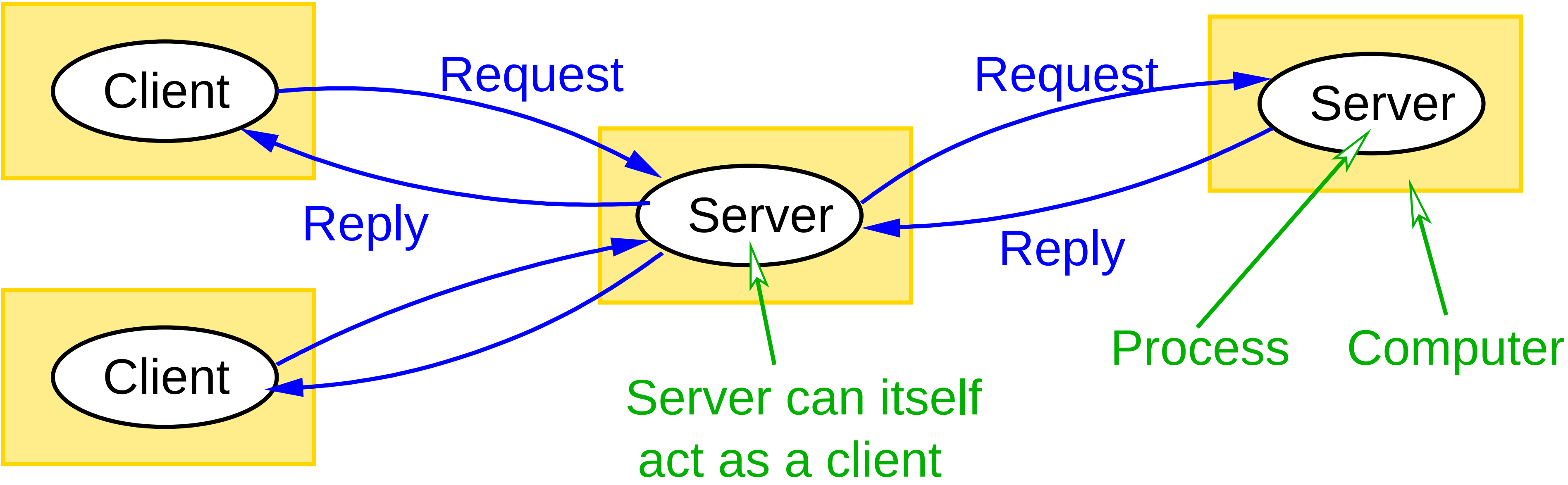


- E.g.: file sharing applications, routers, ...

Client/Server Model

[Coulouris, 2.2.2]

- Asymmetric model: Servers provide services that can be used by (multiple) clients.
  - servers usually manage resources (centralized)

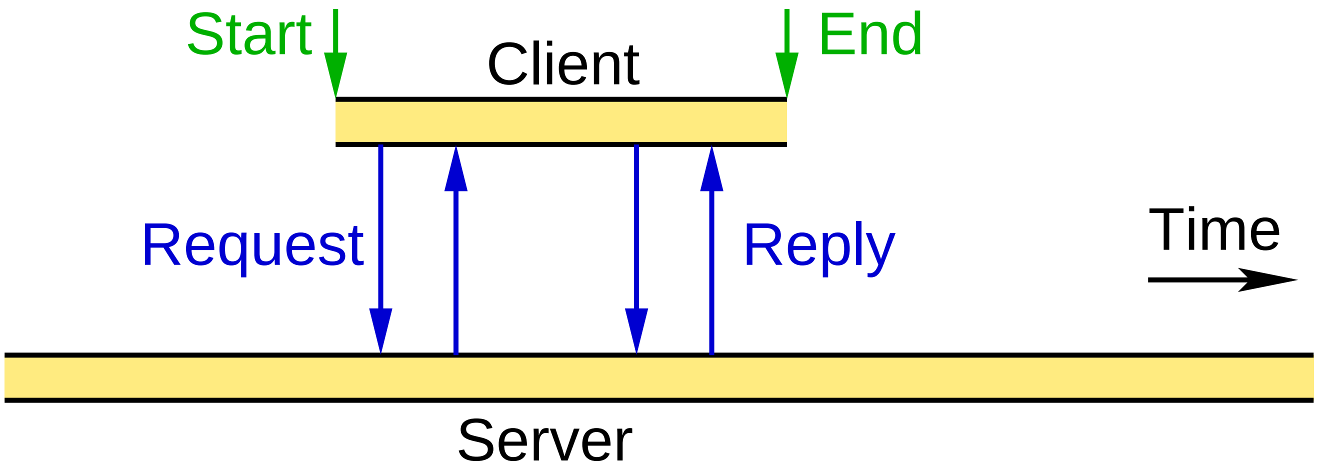


- Most common model for distributed applications (ca. 80 %)

1.5 Architectural Models ...

Client/Server Model ...

- Usually concurrent requests from several client processes to the server process



- Examples: file server, web server, database server, DNS server, ...

Client/Server Model ...

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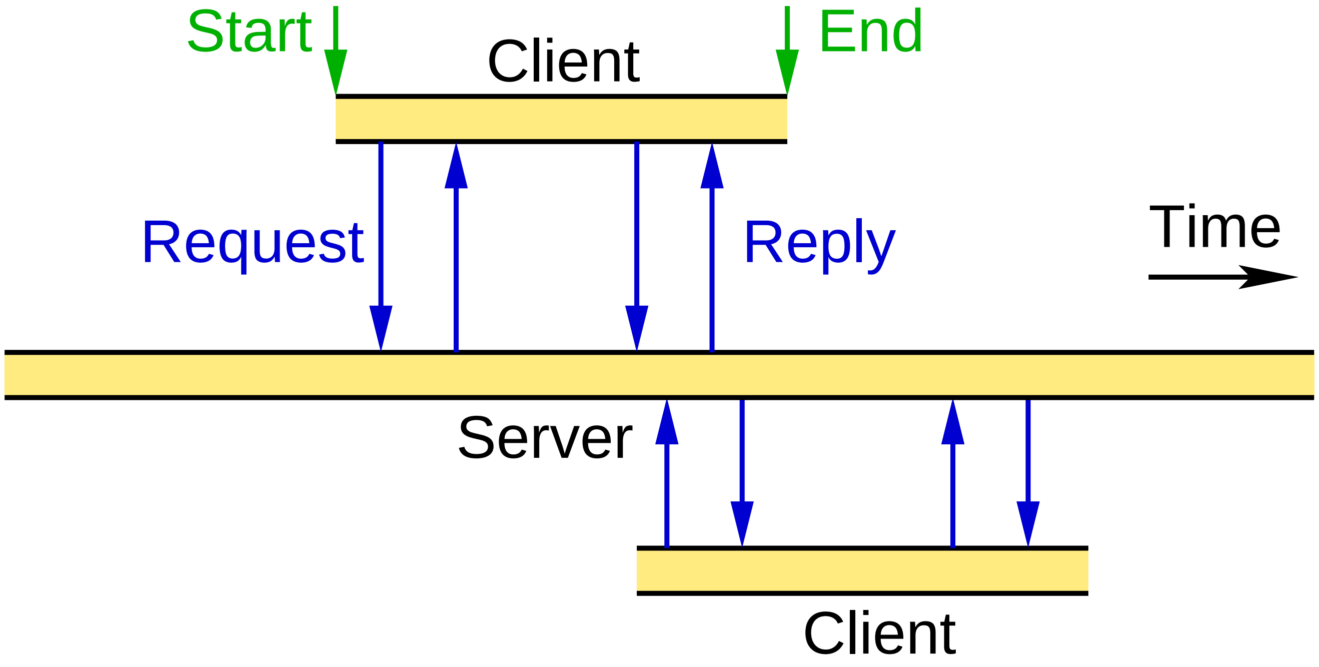
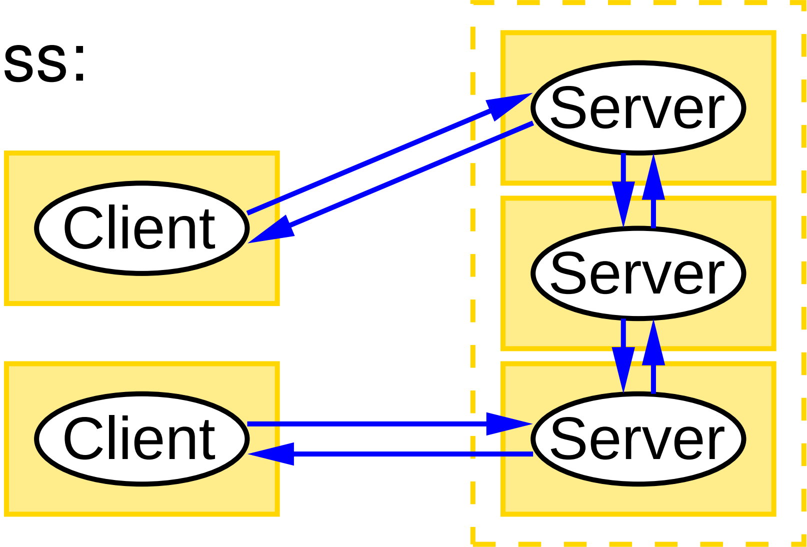


- Examples: file server, web server, database server, DNS server, ...

1.5 Architectural Models ...

Variants of the client/server model

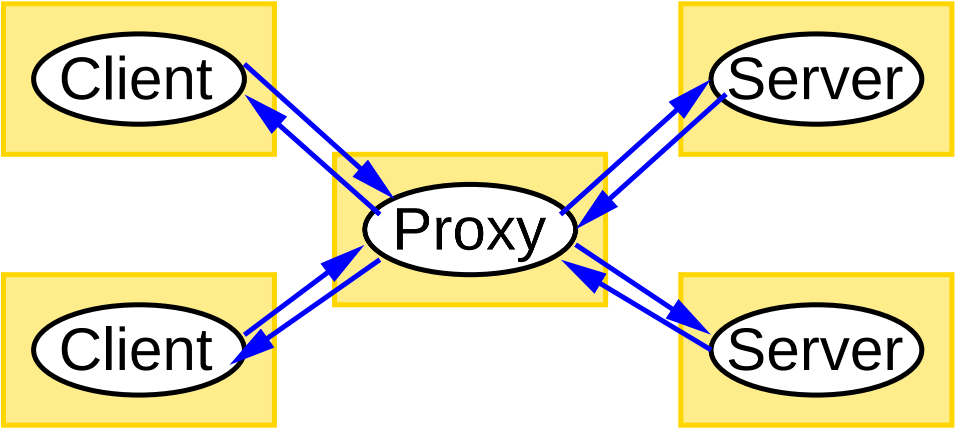
- Cooperating servers
  - Network of servers transparently processes a request
  - Example: Domain Name Server (DNS)
    - if server cannot determine address: request is transparently forwarded to another server



- Replicated servers
  - replicas of server processes are provided
    - transparent replicas (often in clusters)
      - requests are automatically distributed to the servers
    - public replicas (e.g. mirror servers)
  - goals: better performance, reliability

Variants of the client/server model ...

- Proxy-Server / Caches
  - proxy is a delegate for the server
  - task often is caching of data / results
  - e.g. web proxy



- Mobile code
  - executable server code migrates to client on request
  - code is executed by the client
  - best-known example: JavaScript / WebAssembly in the WWW
- Mobile agents
  - agent contains code and data, moves through the network and performs actions on local resources

1.5 Architectural Models ...

n-Tier Architectures

- Refinements of Client/Server Architecture
- Models for distributing an application to the nodes of a distributed system
- Mainly used in information systems

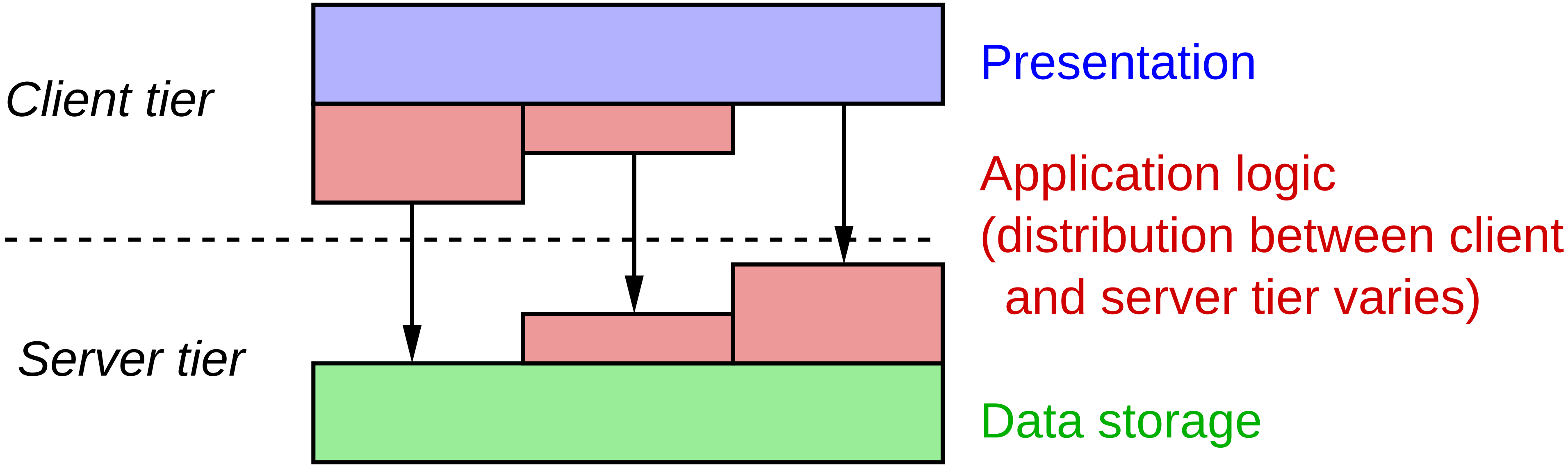
- **Tier** (german: Schicht / Stufe) denotes an independent process space within a distributed application
  - process space can, but does not have to, correspond to a physical host
  - several process spaces on one computer are possible

The Tier Model

- Typical tasks in an information system:
  - presentation – interface to the user
  - application logic – actual functionality
  - data storage – storage of data in a database
- The tier model determines:
  - assignment of tasks to application components
  - distribution of application components on tiers
- Architectures:
  - 2-tier architectures
  - 3-tier architectures
  - 4-or-more-tier architectures

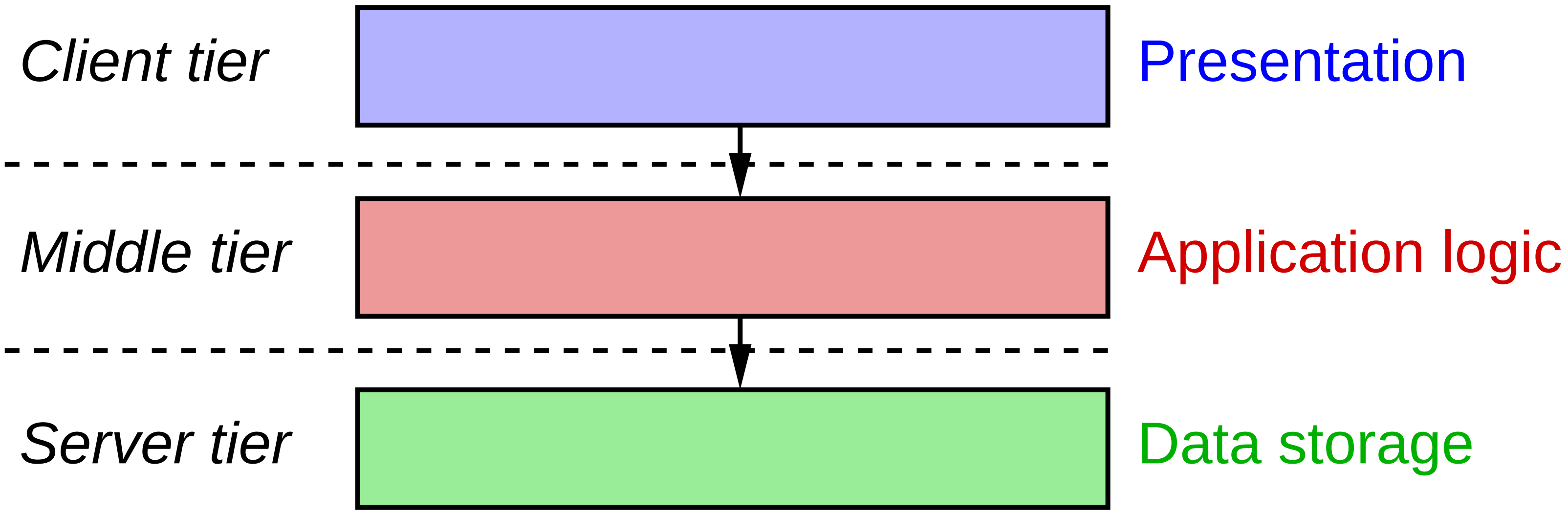
2-Tier Architecture

- Client and server tier
- No own tier for the application logic



- Advantage: simple, high performance
- Disadvantage: difficult to maintain, poorly scalable

3-Tier Architecture

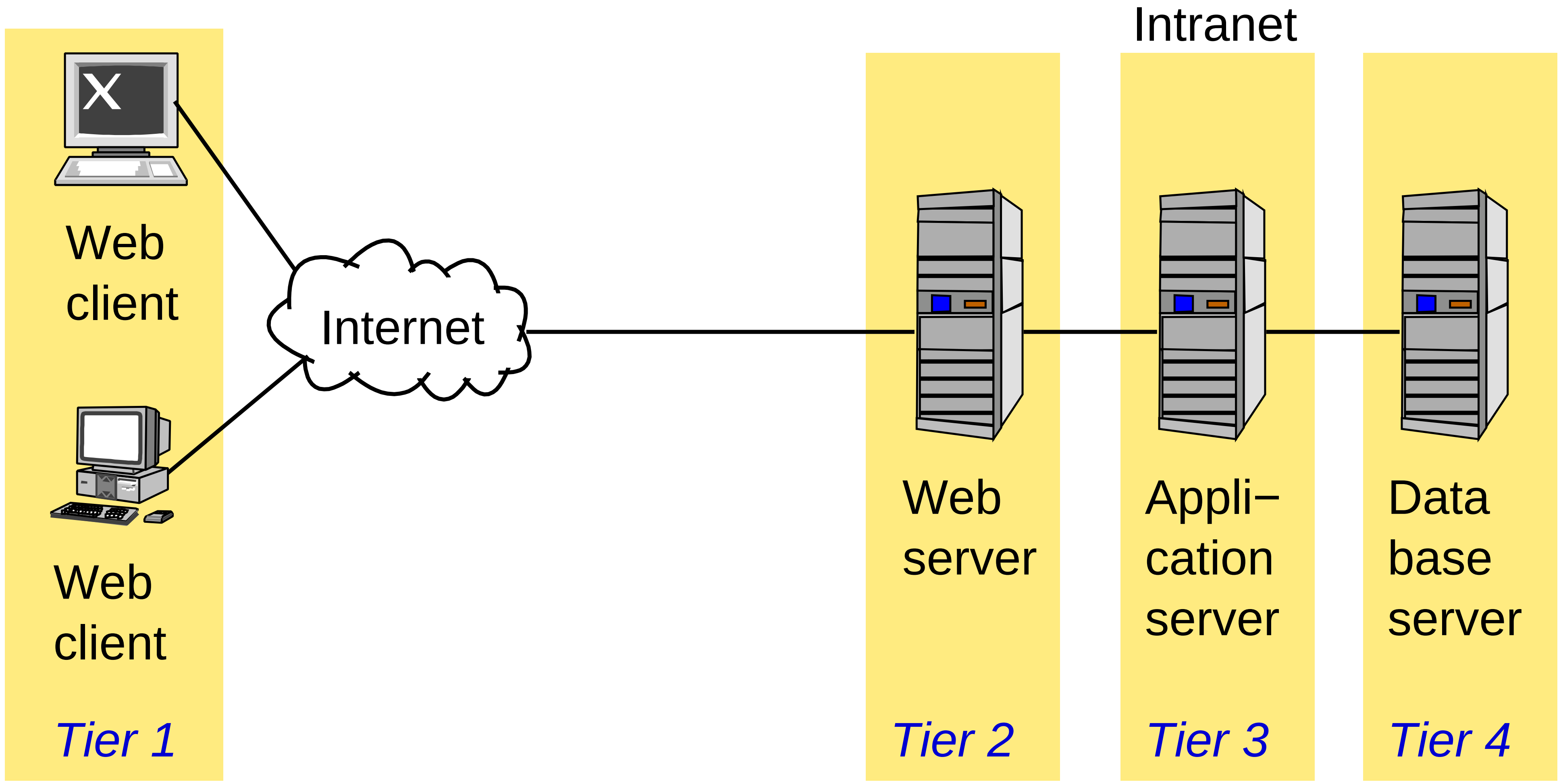


- Standard distribution model for simple web applications:
  - client tier: web browser for display
  - middle tier: web server with JSP / ASP / PHP ...
  - server tier: database server
- Advantages: central administration of application logic, scalable

4-or-more-Tier Architectures

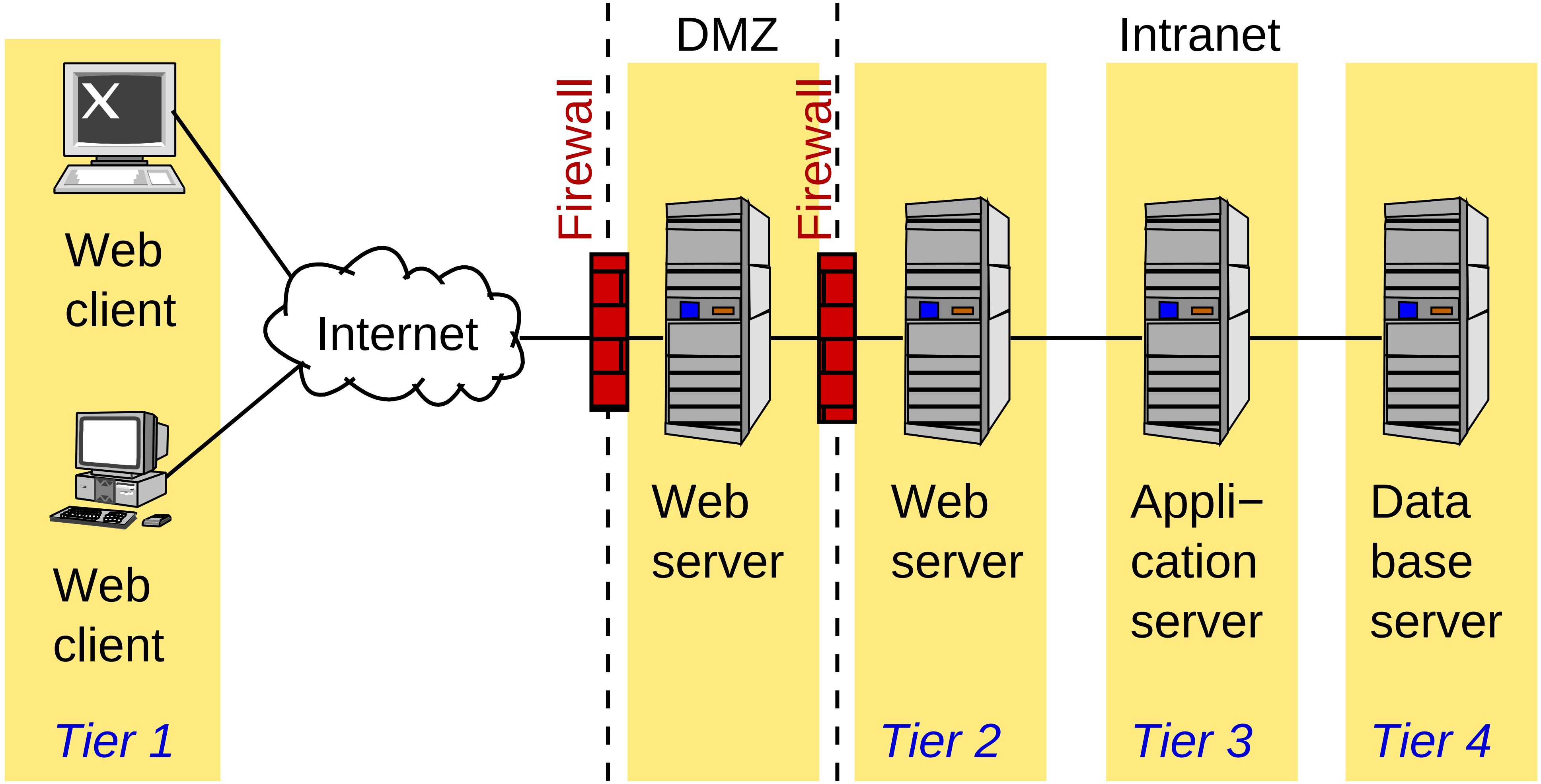
- Difference to 3-tier architecture:
  - application logic distributed across multiple tiers
- Motivation:
  - minimization of complexity (divide and conquer)
  - better protection of individual application parts
  - reusability of components
- Many distributed information systems have 4-or-more-tier architectures

Example: Typical Internet Application



1.5 Architectural Models ...

Example: Typical Internet Application



Thin and fat clients

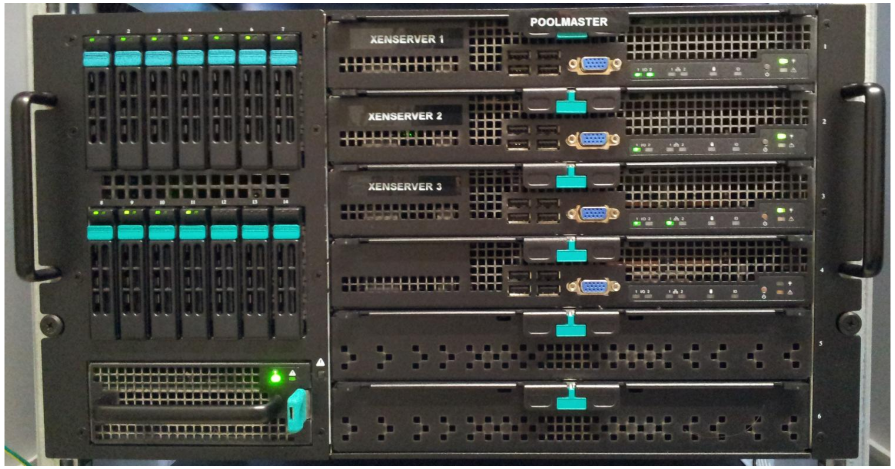
- Characterizes complexity of the application component on the client tier
- Ultra-thin client
  - client tier only for presentation: pure display of dialogs
  - presentation component: web browser
  - only possible with 3-or-more-tier architectures
- Thin client
  - client tier for presentation only: display of dialogs, preparation of data for display
- Fat client
  - parts of the application logic on the client tier
  - usually with 2-tier architectures

Distinction from Enterprise Application Integration (EAI)

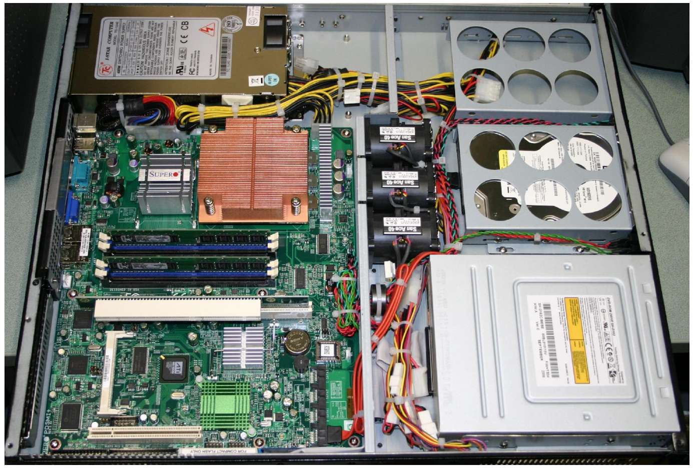
- EAI: integration of different applications
  - communication, exchange of data
- Goals similar to distributed applications / middleware
  - middleware is often used for EAI as well
- Differences:
  - distributed applications: application components, high degree of coupling, usually little heterogeneity
  - EAI: complete applications, low degree of coupling, mostly great heterogeneity (different technologies, systems, programming languages, ...)

1.6 Cluster

- Cluster: group of networked computers that acts as a unified computing resource
  - i.e. multicomputer system
  - nodes usually standard PCs or blade server



- Application mainly as high performance server
- Motivation:
  - (step-by-step) scalability
  - high availability
  - good price/performance ratio



[Stallings, 13.4]

1.6 Cluster ...

Uses for Clusters

- High availability (HA) clusters
  - improved reliability
  - when a node is faulty: services are migrated to other nodes (failover)
- Load balancing cluster
  - incoming requests are distributed to different nodes of the cluster
    - usually by a (redundant) central instance
  - frequently with WWW or email servers
- High performance computing cluster
  - cluster as parallel computer

Cluster configurations

- Passive standby (no actual cluster)
  - processing of all requests by primary server
  - secondary server takes over tasks (only) in case of failure
- Active standby
  - all servers process requests
  - enables load balancing and improved reliability
  - problem: access to data of other / failed server
  - alternatives:
    - replication of data (a lot of communication)
    - shared hard disk system (usually mirrored disks or RAID system for fail-safe operation)

Active Standby Configurations

- Separate servers with data replication
  - separate disks, data is continuously copied to secondary servers
- Server with shared hard disks
  - shared nothing cluster
    - separate partitions for each server
    - in case of server failure: reconfiguration of the partitions
  - shared disc cluster
    - simultaneous use by all servers
    - requires lock manager software to lock files or records

1.7 Summary

- Distributed system
  - HW and SW components on networked computers
  - no shared memory, no global time
  - motivation: use of distributed resources
- Challenges
  - heterogeneity, openness, security, scalability
  - error handling, concurrency, transparency
- Software architecture: middleware
- Architectural models:
  - peer-to-peer, client/server
  - n-tier models
- Cluster: high availability, load balancing