TDTS04/TDDE35: Distributed Systems

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Notes derived from “Distributed Systems: Principles and Paradigms”, by Andrew S. Tanenbaum and Maarten Van Steen, Pearson Int. Ed.

The slides are adapted and modified based on slides used by other instructors, including slides used in previous years by Juha Takkinen, as well as slides used by various colleagues from the distributed systems and networks research community.

Goals with these four lectures

- Study concepts that build the foundations of large-scale systems
- Learn about tradeoffs when building large-scale systems
- Learn from case studies, example systems
- Get exposure to system building and (if time) distributed systems research

Distributed systems

?

Distributed systems

"A collection of independent computers that appears to its users as a single coherent system"

Distributed systems

"A collection of independent computers that appears to its users as a single coherent system"

- Examples include …
  -
  -
  -
  -
  -

Distributed systems

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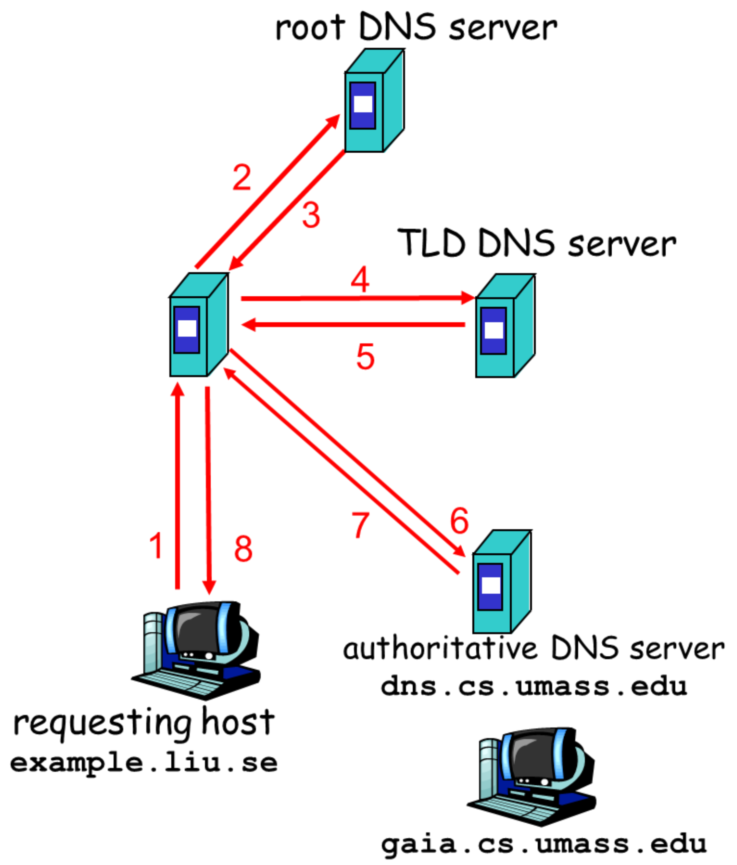

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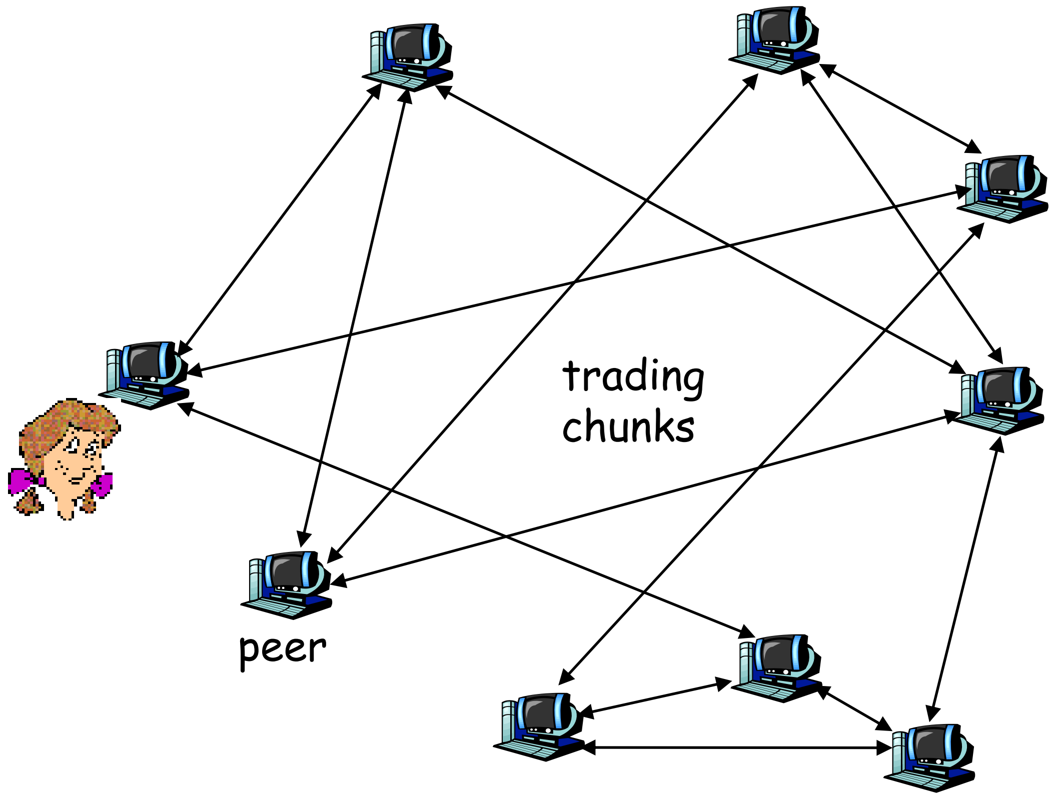

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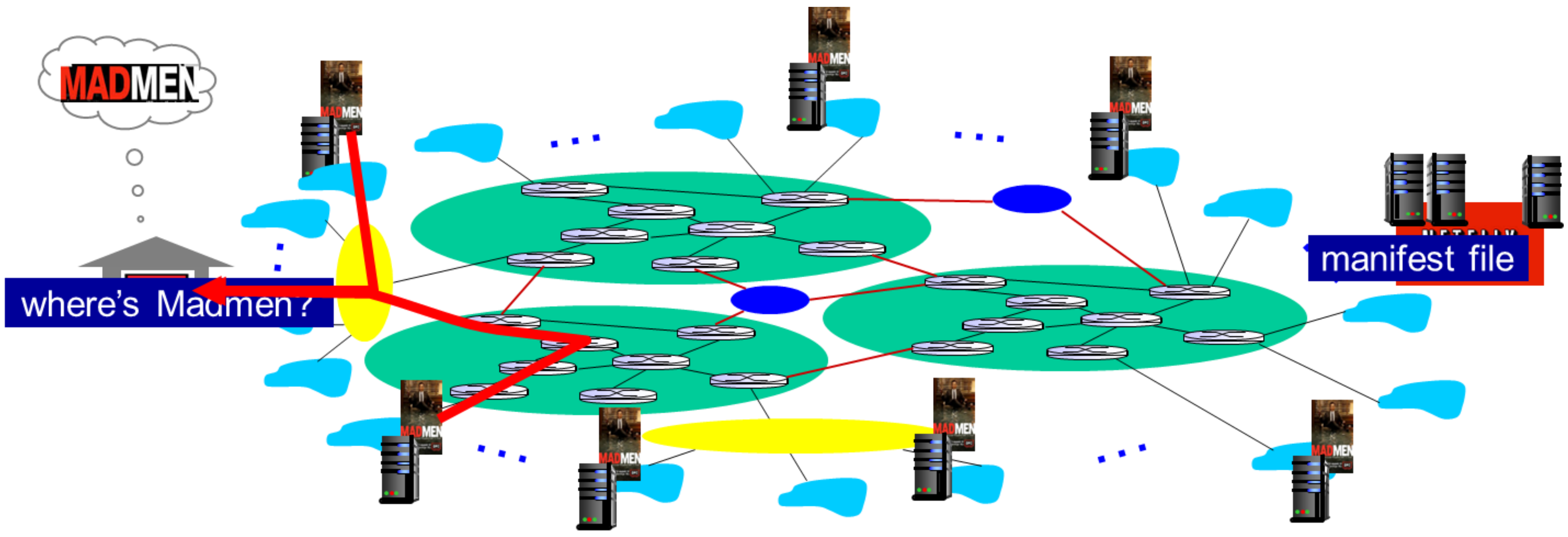

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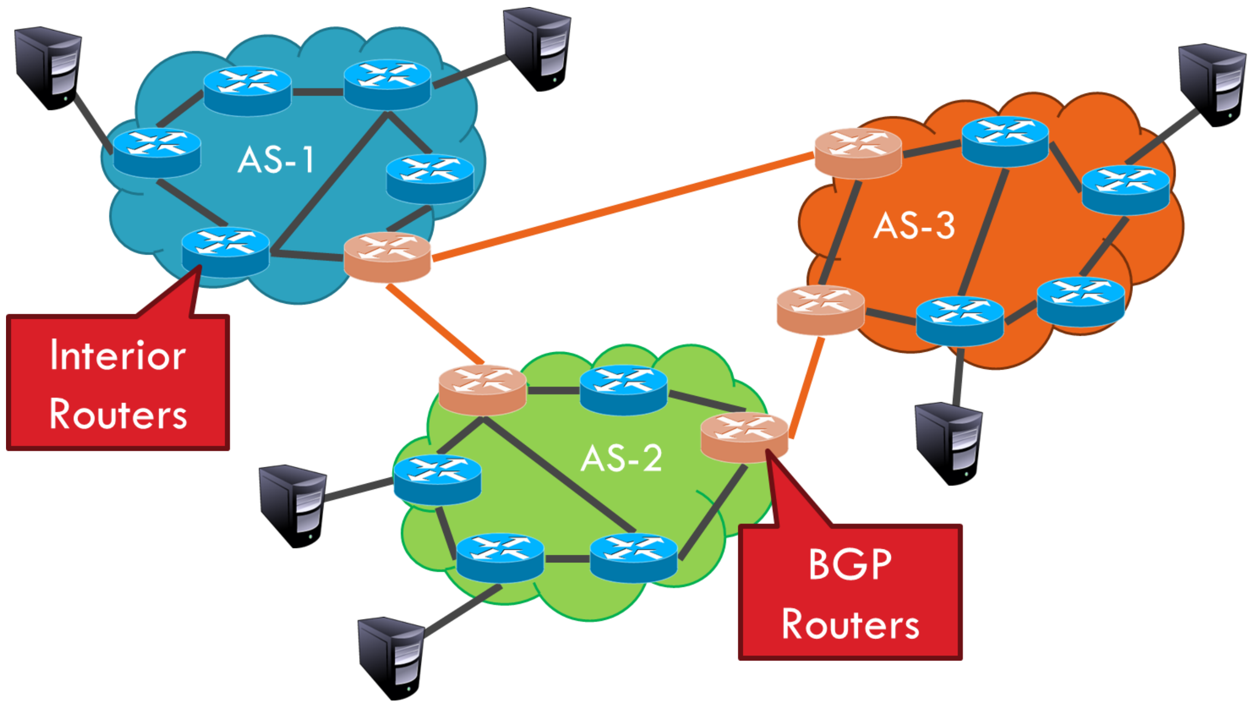

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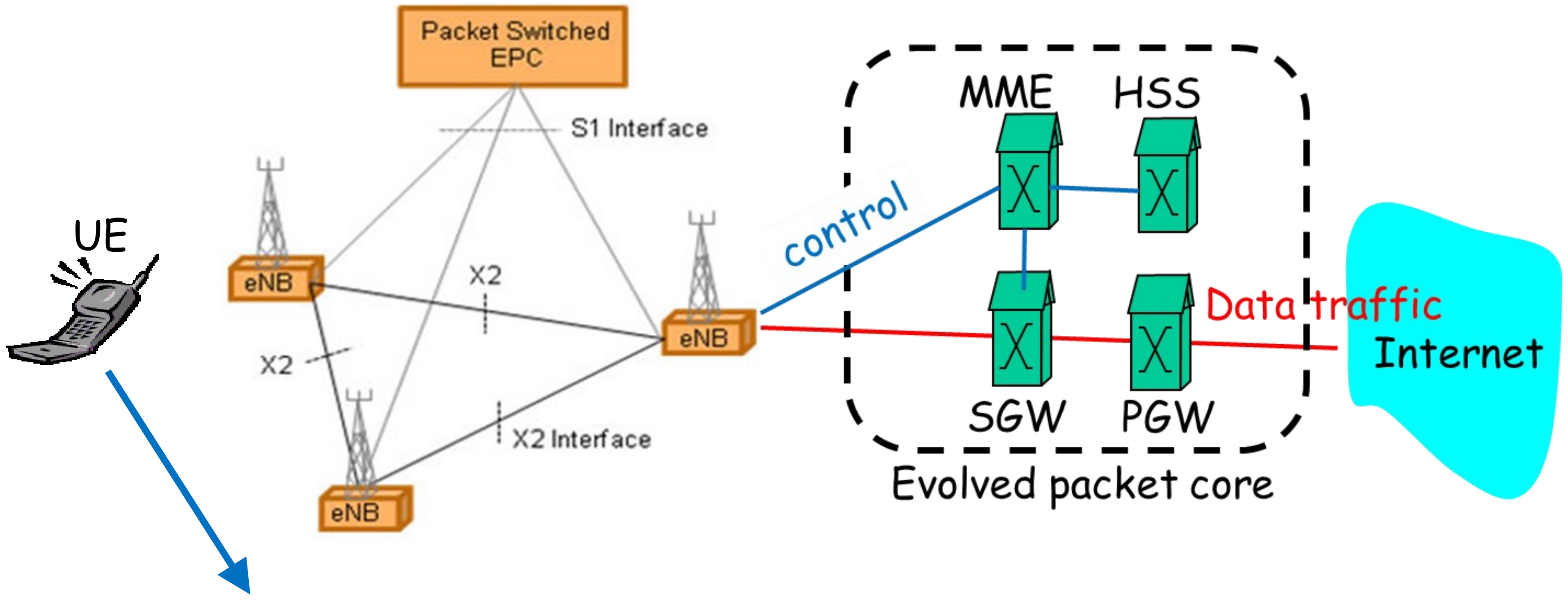

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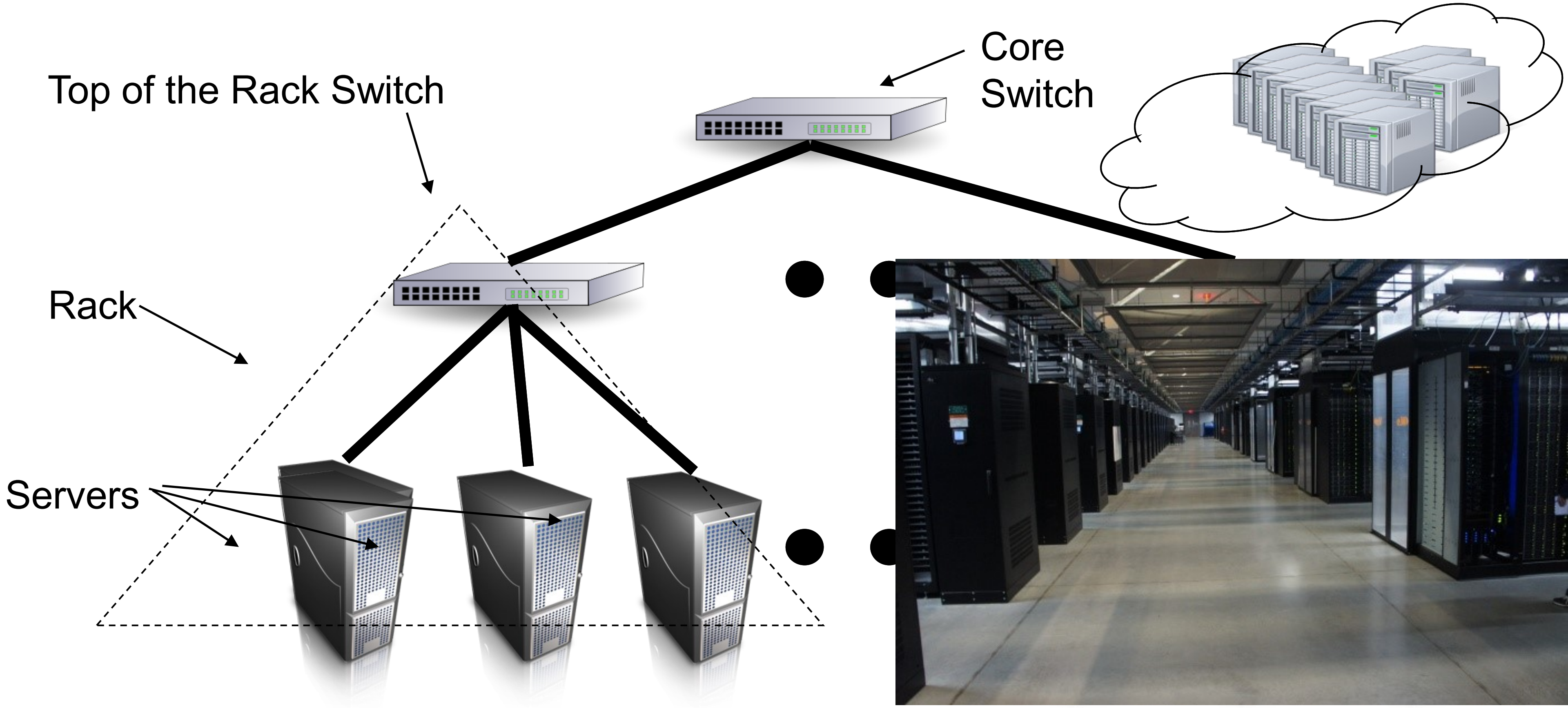


Distributed systems

"A collection of independent computers that appears to its users as a single coherent system"

- Examples include …
  - Web, web search, social networks, …
  - Peer-to-peer, file-sharing, …
  - Cloud services, scientific computing, …
  - Finance, healthcare, education, transportation/logistics, environmental engineering, entertainment/gaming, …
  - … (many many many more) ...

Distributed systems

"A collection of independent computers that appears to its users as a single coherent system"

- Networks of computers are everywhere!
  - Mobile phone networks
  - Corporate networks
  - Factory networks
  - Campus networks
  - Home networks
  - In-car networks
  - On-board networks in planes and trains
  - …

Distributed systems

"A collection of independent computers that appears to its users as a single coherent system"

- Hardware view
  - Multiple independent but cooperating resources
- Software view
  - Single unified system (e.g., application)
- Small vs large (full spectrum)
  - E.g., Multiprocessor vs. world-wide

Distributed systems

- Benefits?

- Problems?

Distributed systems

- Benefits?
  - Performance
  - Distribution
  - Reliability
  - Incremental growth
  - Sharing of data/resources
- Problems?

Distributed systems

- Benefits?
  - Performance
  - Distribution
  - Reliability
  - Incremental growth
  - Sharing of data/resources
- Problems?
  - Difficulties developing software
  - Network problems
  - Security problems

Common Distributed Systems Design Goals

- Heterogeneity – can the system handle a large variety of types of PCs and devices?
- Robustness – is the system resilient to host crashes and failures, and to the network dropping messages?
- Availability – are data+services always there for clients?
- Transparency – can the system hide its internal workings from the users?
- Concurrency – can the server handle multiple clients simultaneously?
- Efficiency – is the service fast enough? Does it utilize 100% of all resources?
- Scalability – can it handle 100 million nodes without degrading service? (nodes=clients and/or servers) How about 6 B? More?
- Security – can the system withstand hacker attacks?
- Openness – is the system extensible?
- Reliability – is the system available and fault tolerant?

Some examples …
Sharing (heterogeneity, openness, …)

- Multiple users can share + access remote resources
  - Hardware, files, data, etc.
- Open standardized interface
  - Often heterogeneous environment (hardware, software, devices, underlying network protocols, etc.)
  - Middleware layer to mask heterogeneity
- Separate policies from mechanisms

Transparency

- Hide the distributed nature of system from users
- Several types:
  - **Location:** Hide where a resource is located
  - **Migration:** Resources can be moved
  - **Relocation:** Resources can be moved while being used
  - **Replication:** Multiple copies of same resource can exist
  - **Failure:** Hide failures of remote resources
  - …

Transparency in a Distributed System

Transparency	**Description**
Access	Hide differences in data representation and how a resource is accessed
Location	Hide where a resource is located
Migration	Hide that a resource may move to another location
Relocation	Hide that a resource may be moved to another location while in use
Replication	Hide that multiple copies of a resource exist
Concurrency	Hide that a resource may be shared by several competitive users
Failure	Hide the failure and recovery of a resource
Persistence	Hide whether a (software) resource is in memory or on disk

Different forms of transparency in a distributed system.

(**Bold** mentioned on previous slide too.)

Scalability

- Allow the system to become bigger without negatively affecting performance

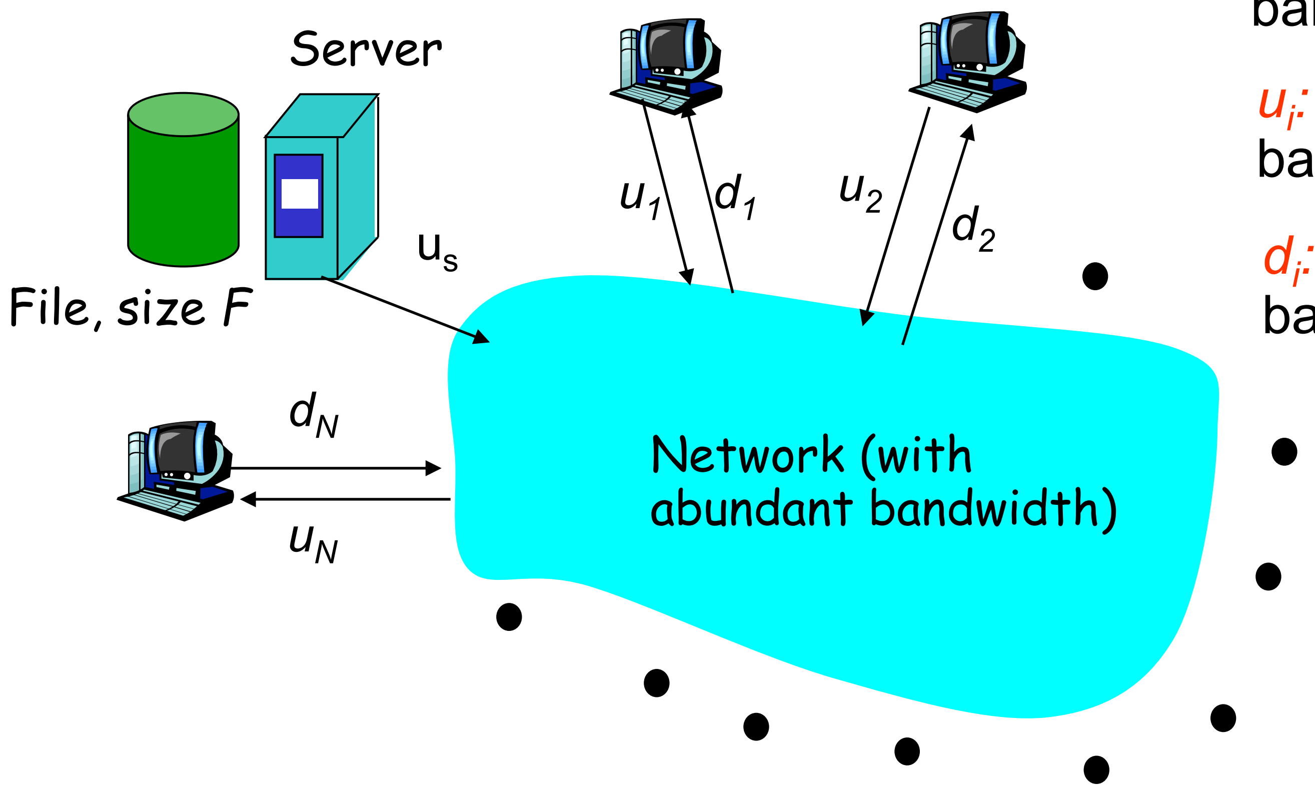
- Multiple dimensions:
  - **Size:** Adding more resources and users
  - **Geographic:** Dispersed across locations
  - **Administrative:** Spanning multiple administrative domains

Scalability

- Scalability problems appear as performance problems
  - System load, storage requirements, communication overhead, ...
- Some common techniques:
  - Divide and conquer
  - Replication
  - Distributed operation
  - Service aggregation
  - Asynchronous communication
  - Multicast

Scalability File Distribution Example: Client-server vs P2P

Question : How much time to distribute file from one server to *N peers*?



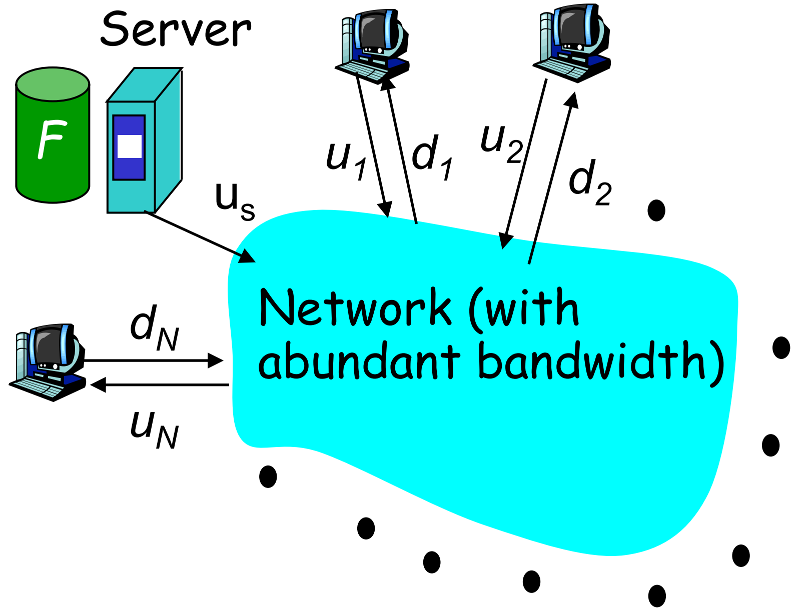
u_s: server upload bandwidth

u_i: peer i upload bandwidth

d_i: peer i download bandwidth

File distribution time: Client-server

- server must upload N copies:
  - NF/u_s time
- client i takes F/d_i time to download



Time to distribute F to N clients using client/server approach $= d_{cs} = \max_i \{ NF/u_s, F/\min(d_i) \}$

increases linearly in N (for large N)

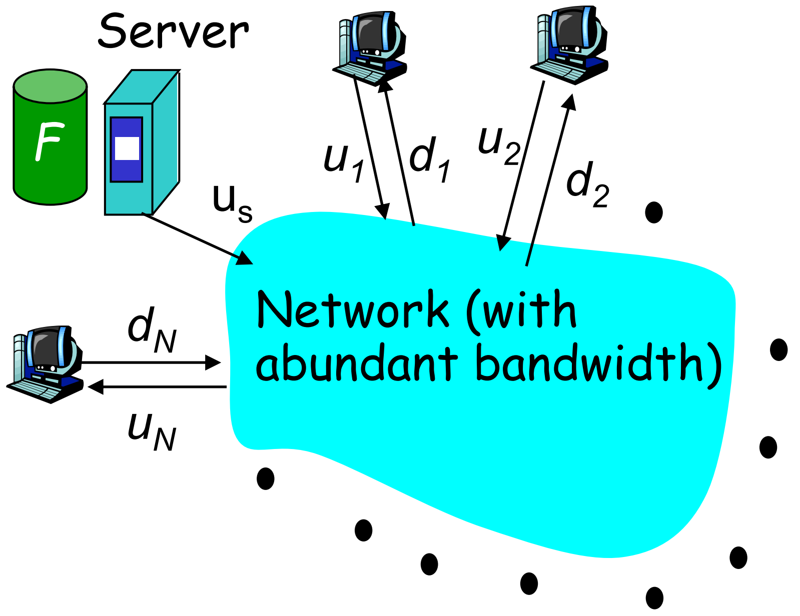
File distribution time: P2P

server must send one copy: F/u_s time

client i takes F/d_i time to download

NF bits must be downloaded (aggregate)

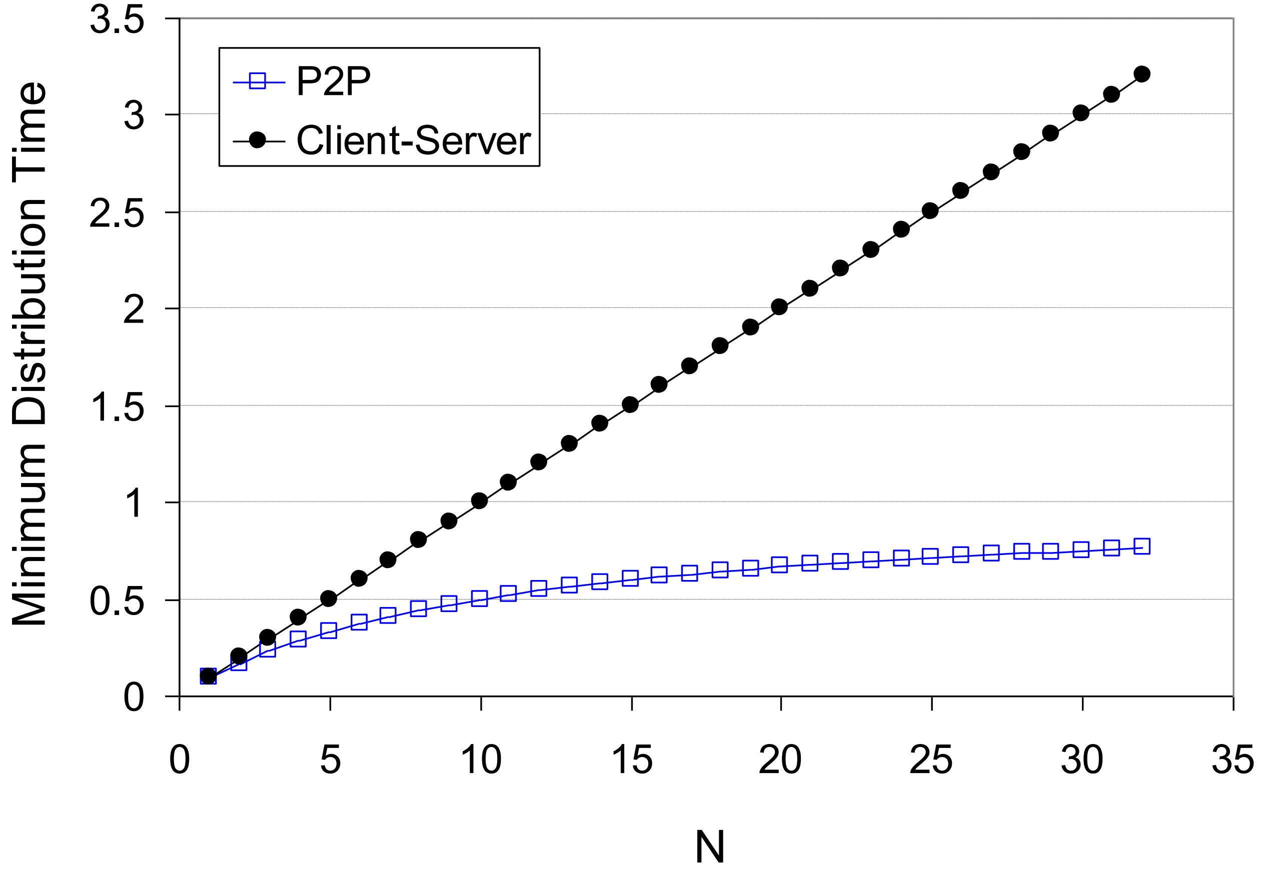
fastest possible upload rate: $u_s + \sum u_i$



$$d_{P2P} = \max_i \{ F/u_s, F/\min(d_i), NF/(u_s + \sum u_i) \}$$

Server-client vs. P2P: example

Client upload rate = u, F/u = 1 hour, u_s = 10u, $d_{min} \geq u_s$



Reliability

- Availability
  - If a machines goes down, the system should work with the reduced amount of resources
  - Replication used to ensure that data is not lost (should be consistent)
- Fault tolerance
  - The system must be able to detect faults, mask faults (if possible), or gracefully fail (if needed)

Distributed systems

- Remember the goals just discussed ...
  - Heterogeneity, Robustness, Availability, Transparency, Concurrency, Efficiency, Scalability, Security, Openness, Reliability, …

Question: What complicates these goals?

Common Pitfalls (bad/dangerous assumptions!)

- The network is reliable
- The network is secure
- The network is homogenous
- The topology does not change
- Latency is zero
- Bandwidth is infinite
- Transport cost is zero
- There is one administrator

Distributed system architecture

- A distributed application runs across multiple machines
  - How to organize the various pieces of the application?
  - Where is the user interface, computation, data?
  - How do different pieces interact with each other?

Architectures

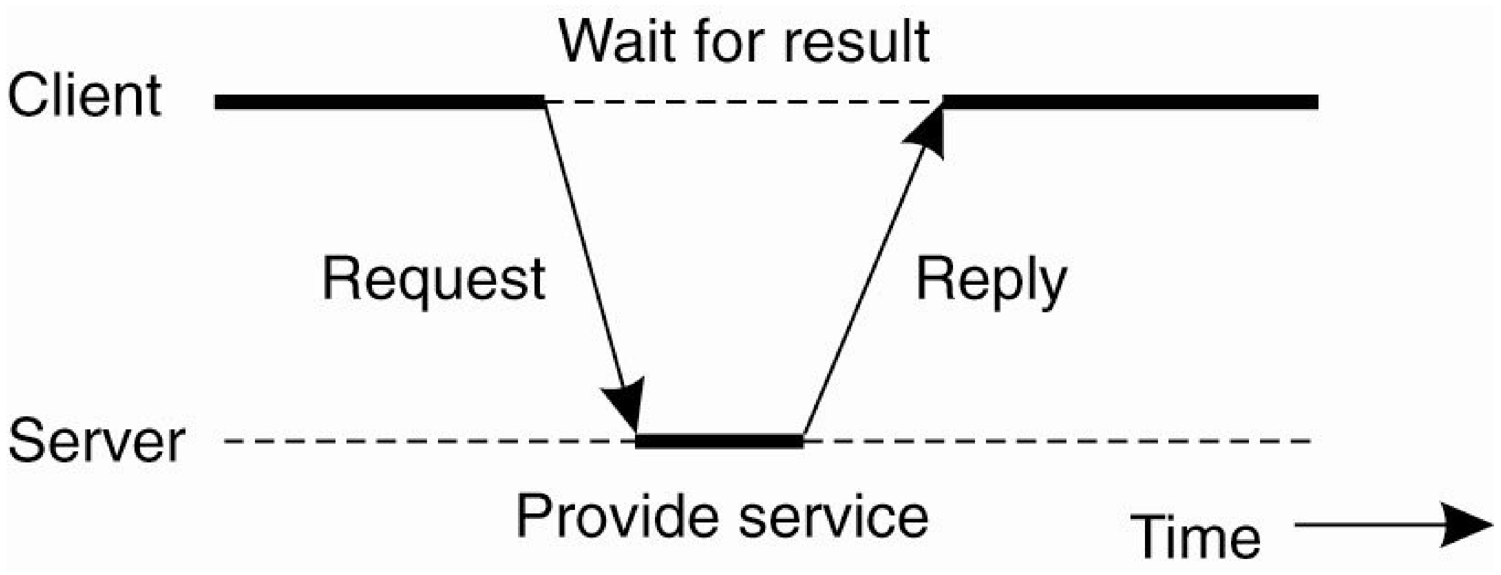
- **Centralized:** Most functionality is in a single machine
- **Distributed:** Functionality is spread across symmetrical machines
- **Hybrid:** Combination of the two

Centralized architecture

- Client-server
    - Client implements the user interface
    - Server has most of the functionality
        - Computation, data
    - E.g.: Web

Centralized architectures

Figure 2-3. General interaction between a client and a server.



Server design issues

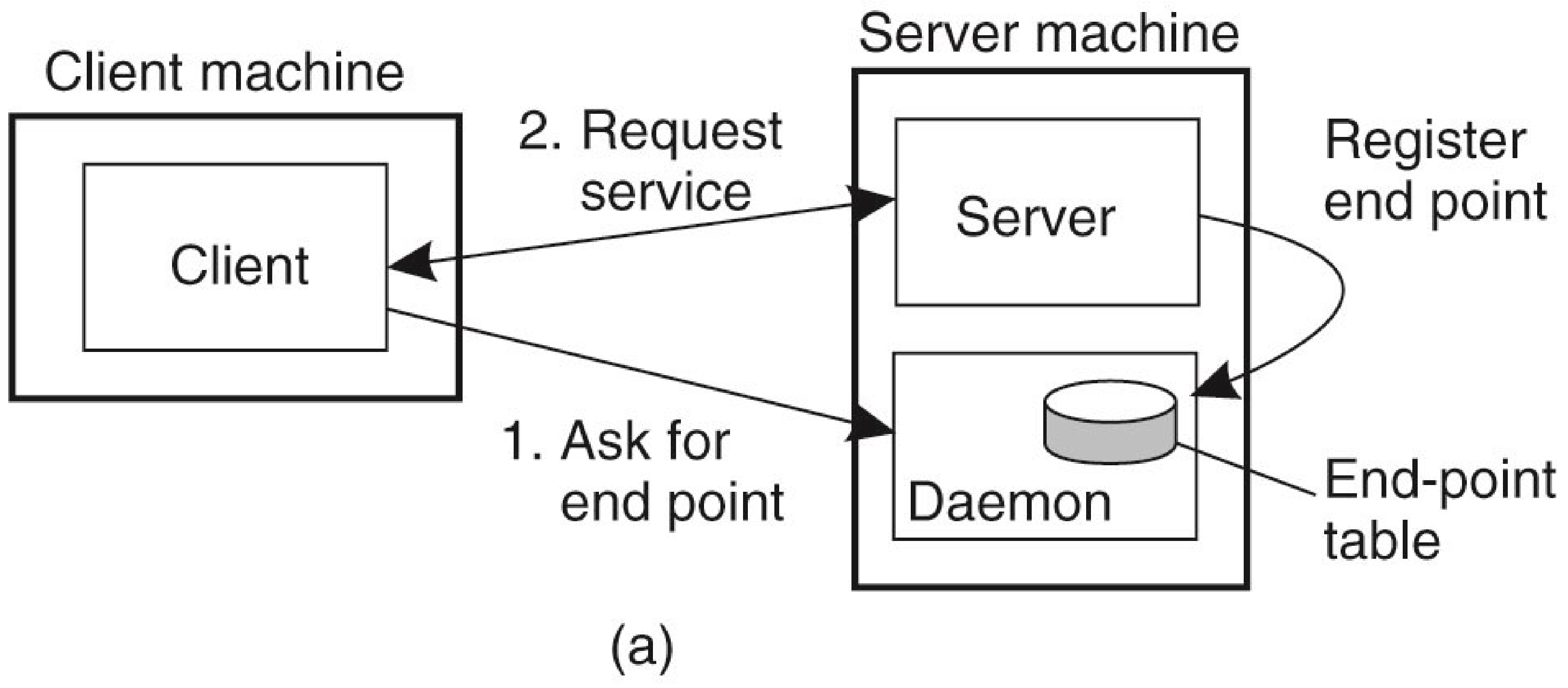
Server organization; e.g., How to process client requests?

- Iterative
- Concurrent
  - Multithreaded
  - Fork (unix)
- Stateless or stateful

Client contact; e.g., how to contact end point (port)

- Well-known (e.g., port 80 ...)
- Dynamic: daemon; superserver (unix)

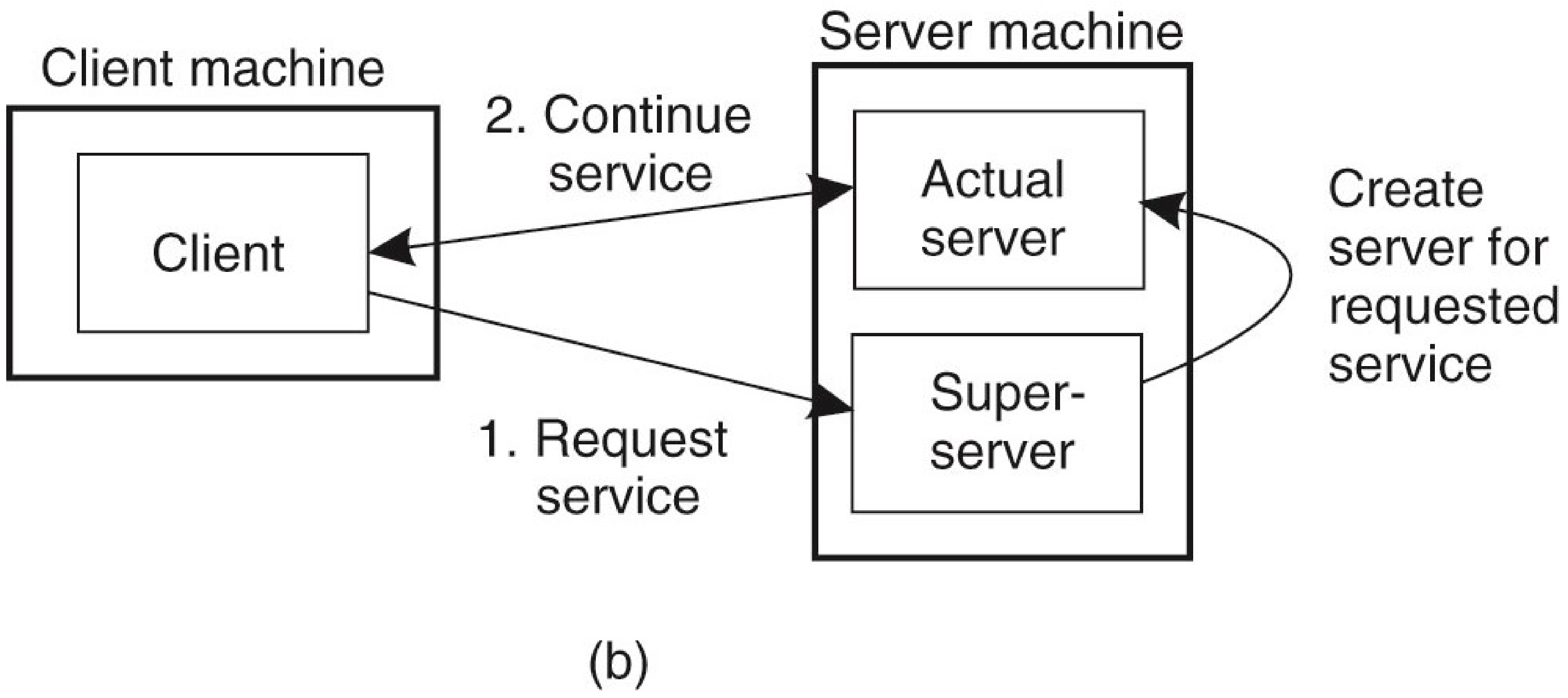
End point, general design issues



- Figure 3-11. (a) Client-to-server binding using a daemon.

End point, general design issues

Figure 3-11. (b) Client-to-server binding using a superserver.



Decentralized architectures

- Vertical distribution
  - Distribution along functionality
- Horizontal distribution
  - E.g., Peer-to-peer distribution

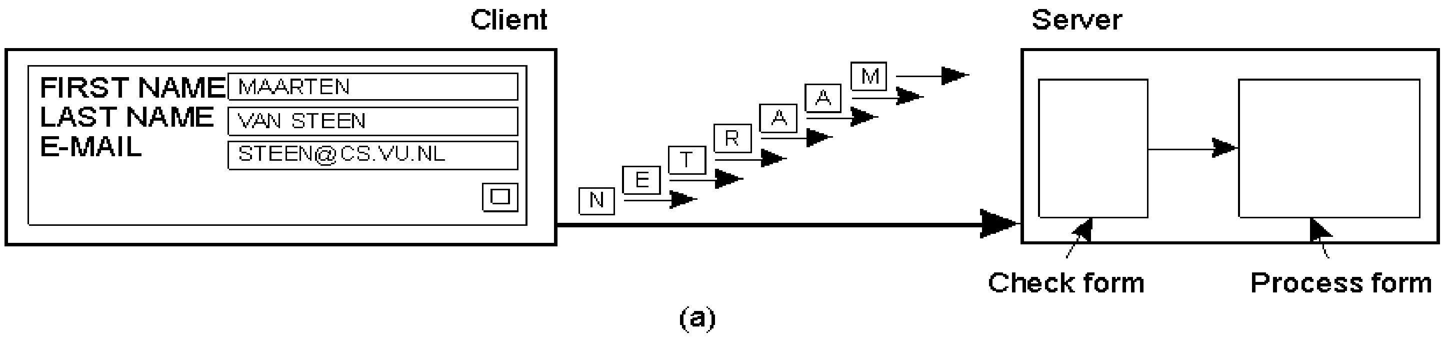
Client-server architecture

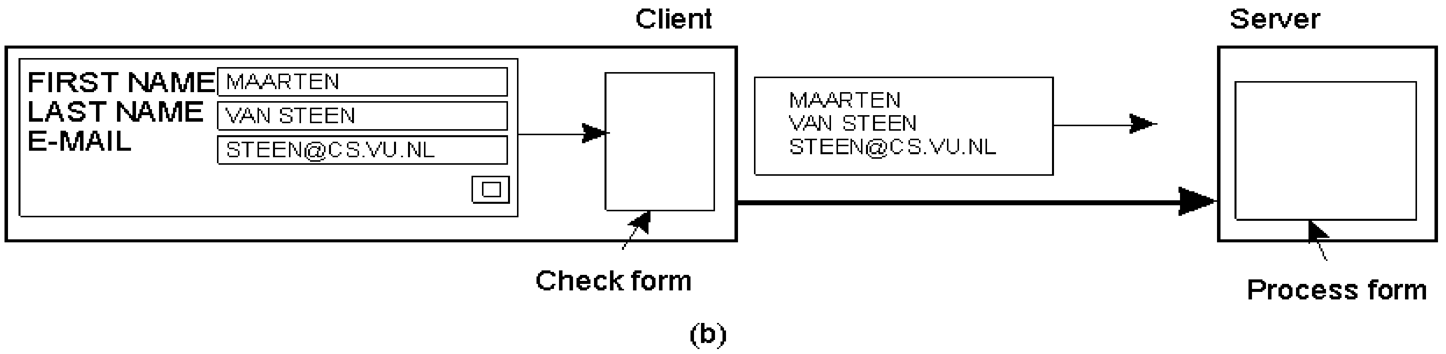
- Application is vertically distributed
  - Distribution along functionality
- Logically different component at different place

Component distribution

- Could have variations on component distribution
- Different amount of functionality between client-server
    - Only UI at client
    - UI+partial processing at client
    - UI+processing at client, data at server

Server offloading



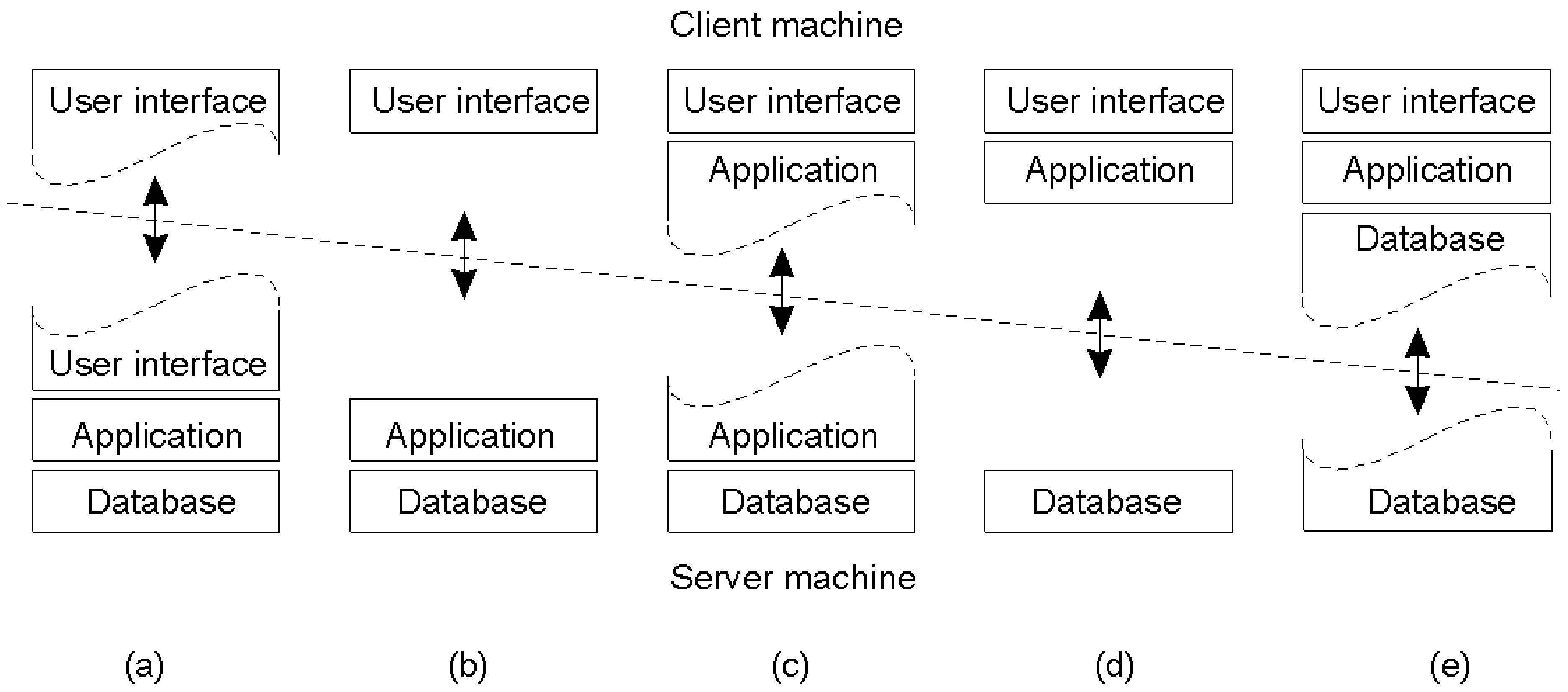


The difference between letting:

a) a server or

b) a client check forms as they are being filled

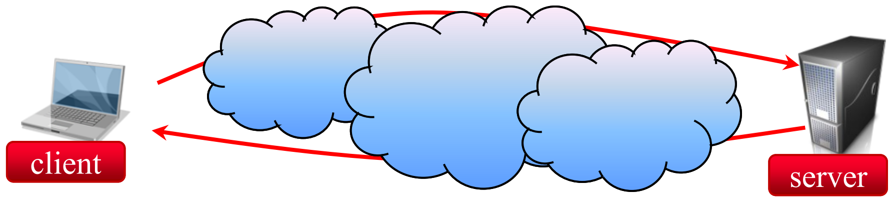
Physical two-tired architectures



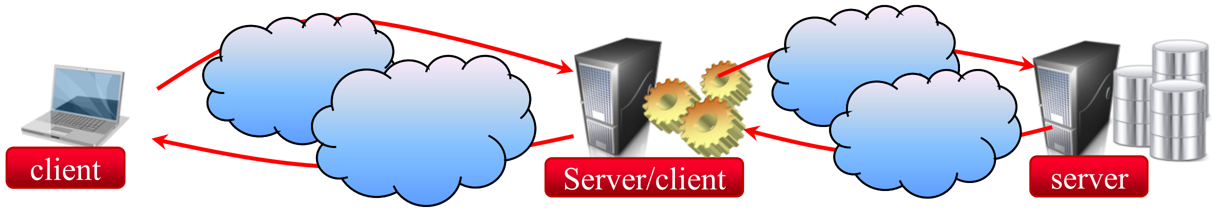
Alternative client-server organizations (a) – (e).

Client-Server Architecture (Tiered architecture)

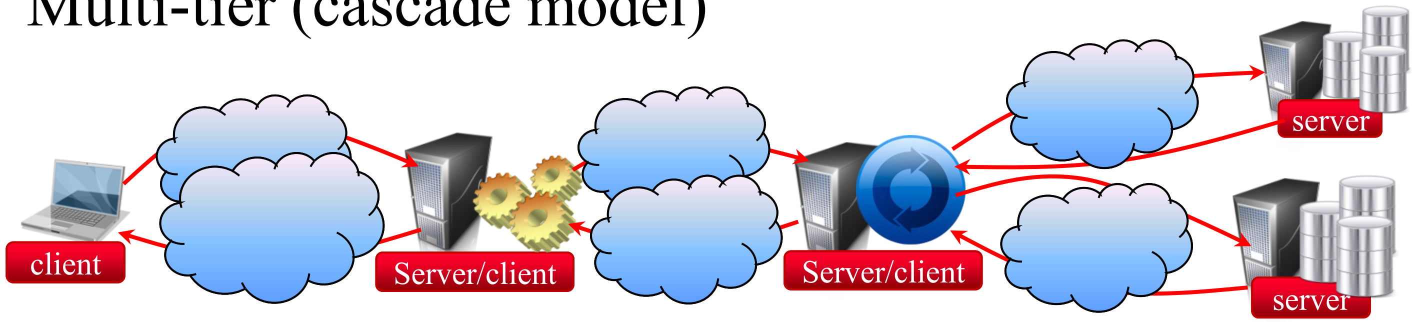
- Two-tier model (classic)



- Three-tier (when the server, becomes a client)



- Multi-tier (cascade model)



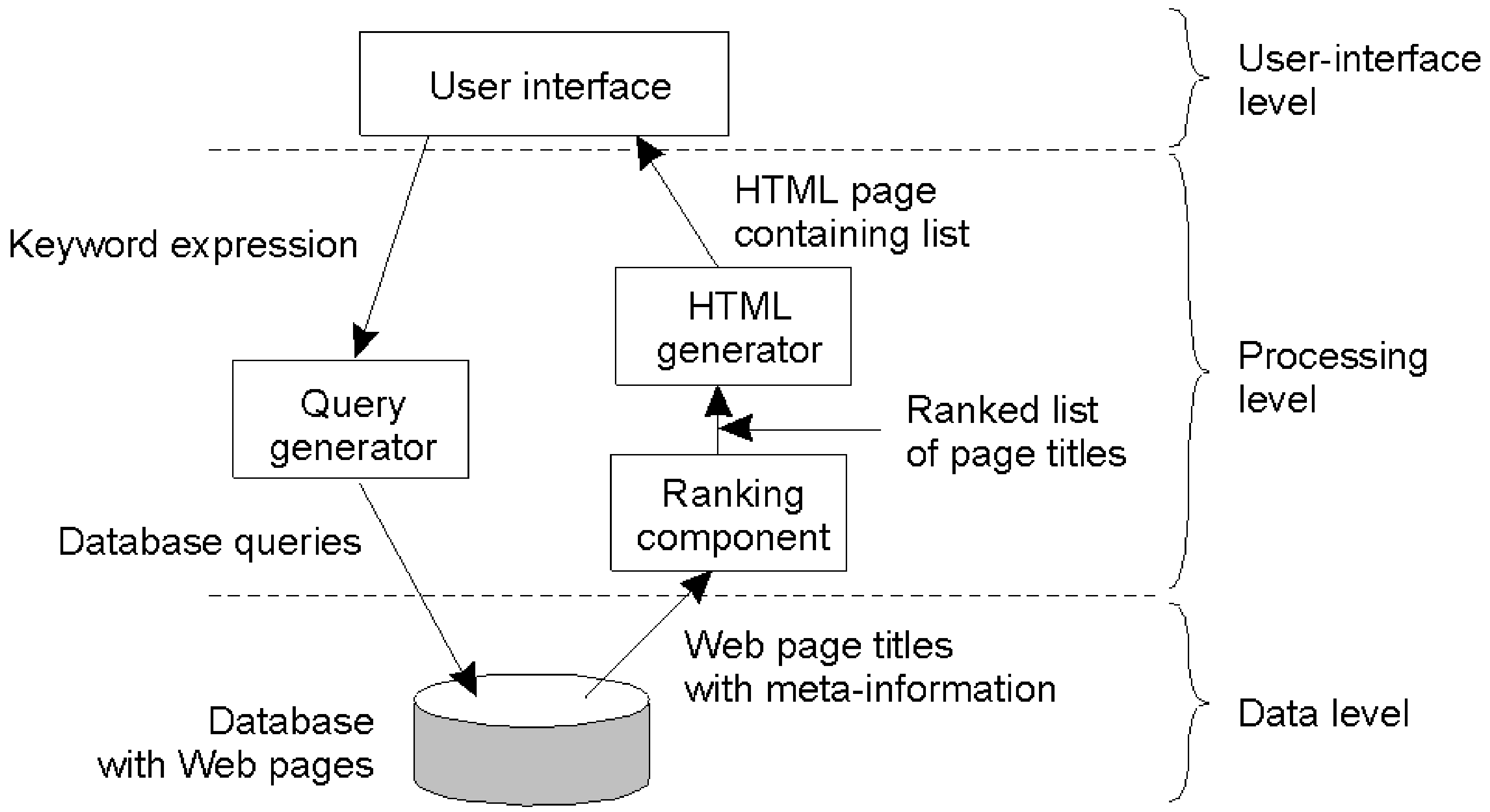
Multi-tiered servers

- Server may not be a single machine
- Multi-tiered architecture:
  - Front-end
  - Application server
  - Database

Application layering

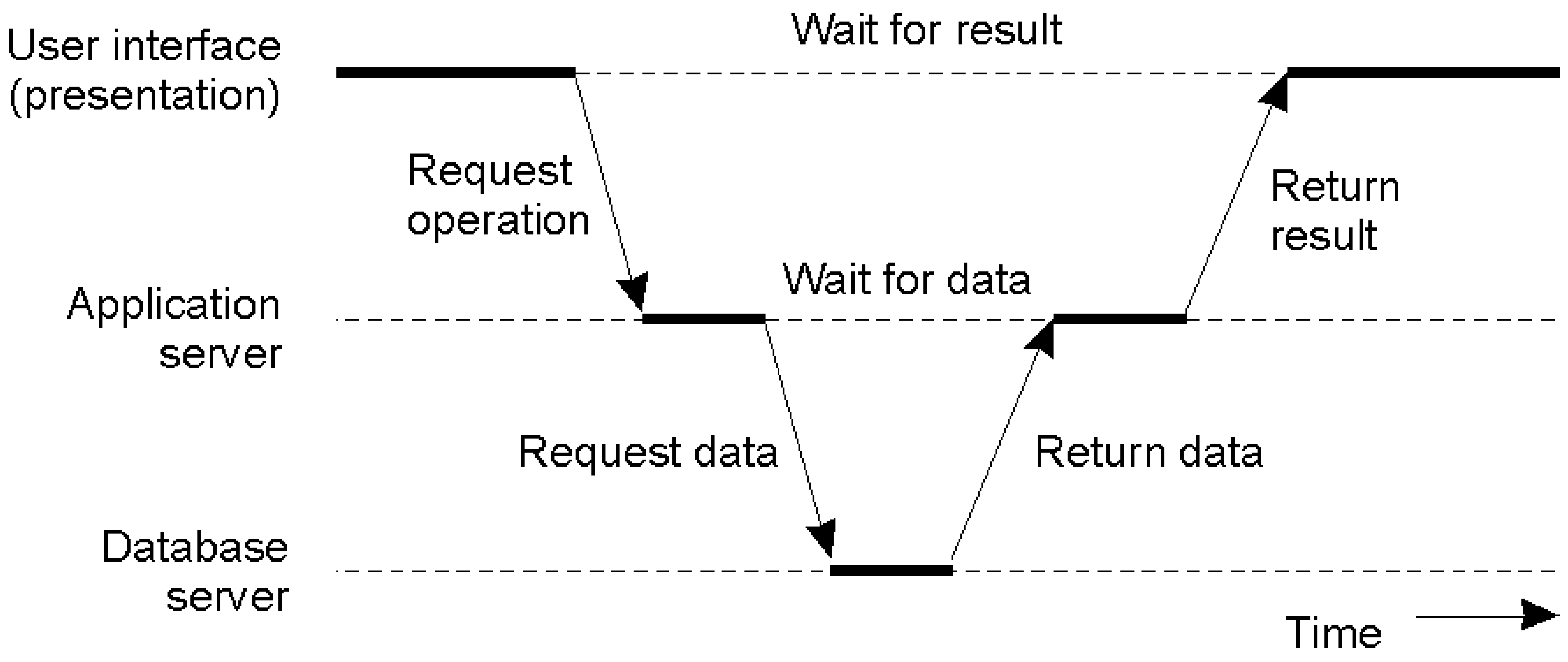
- The user-interface level
- The processing level
- The data level

Application layering



The general organization of an Internet search engine into three different layers

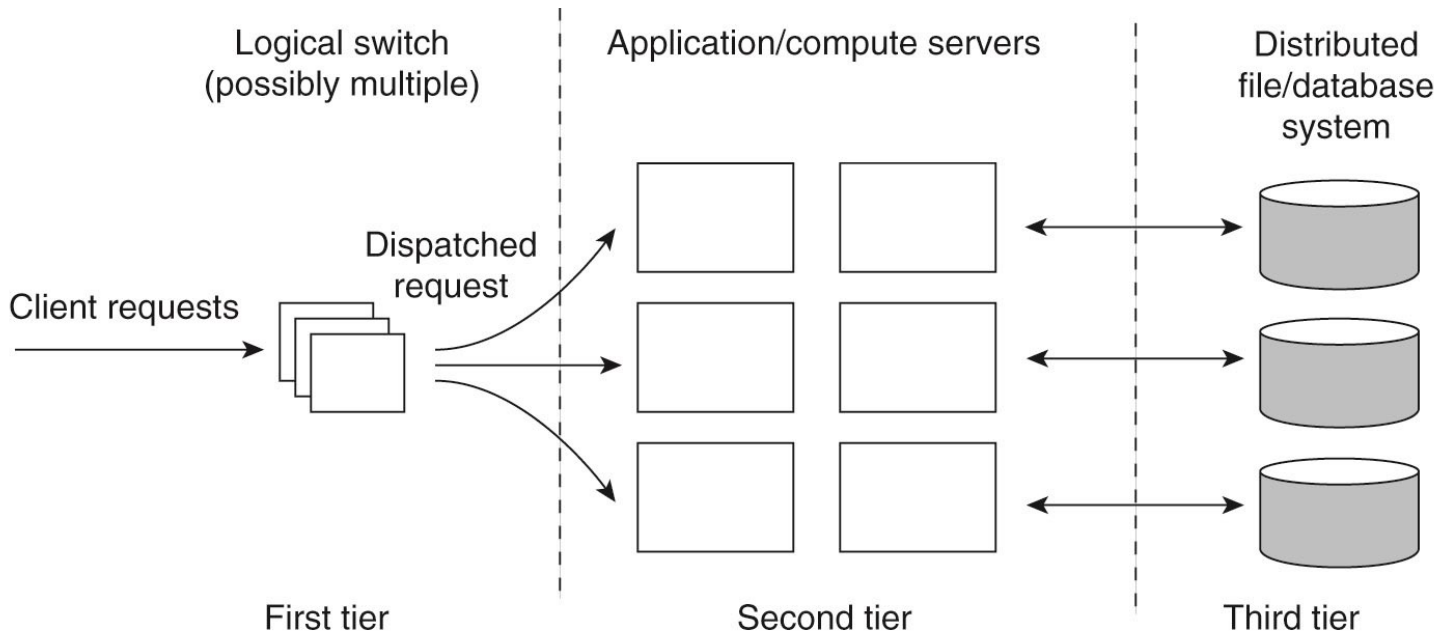
Multi-tiered architectures



An example of a server acting as a client.

Server clusters

- Replication of functionality across machines
  - Multiple front-ends, app servers, databases
- Client requests are distributed among the servers
  - Load balancing
  - Content-aware forwarding



Logical switch (possibly multiple)
Application/compute servers
Distributed file/database system
Dispatched request
Client requests
First tier
Second tier
Third tier

Server clusters

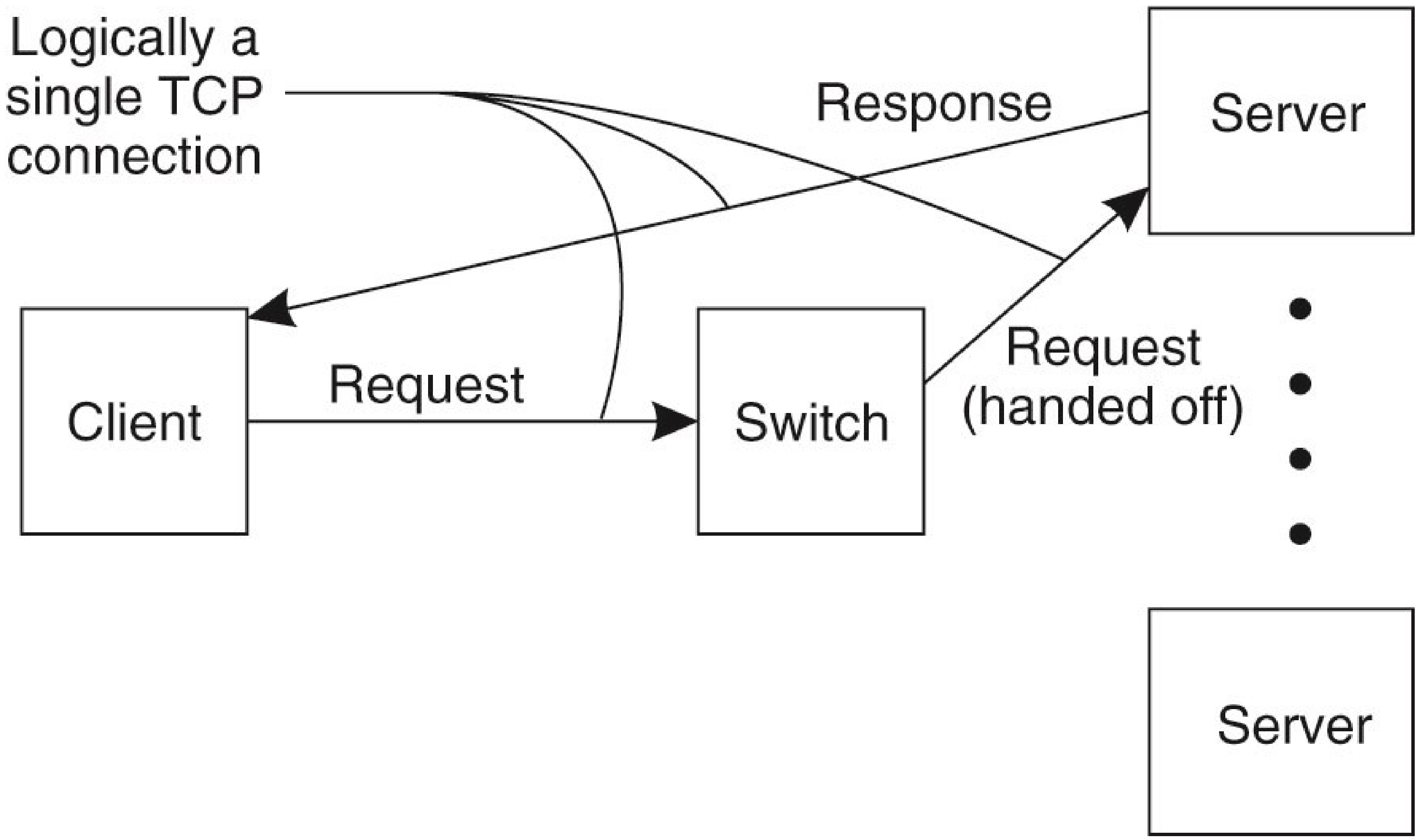
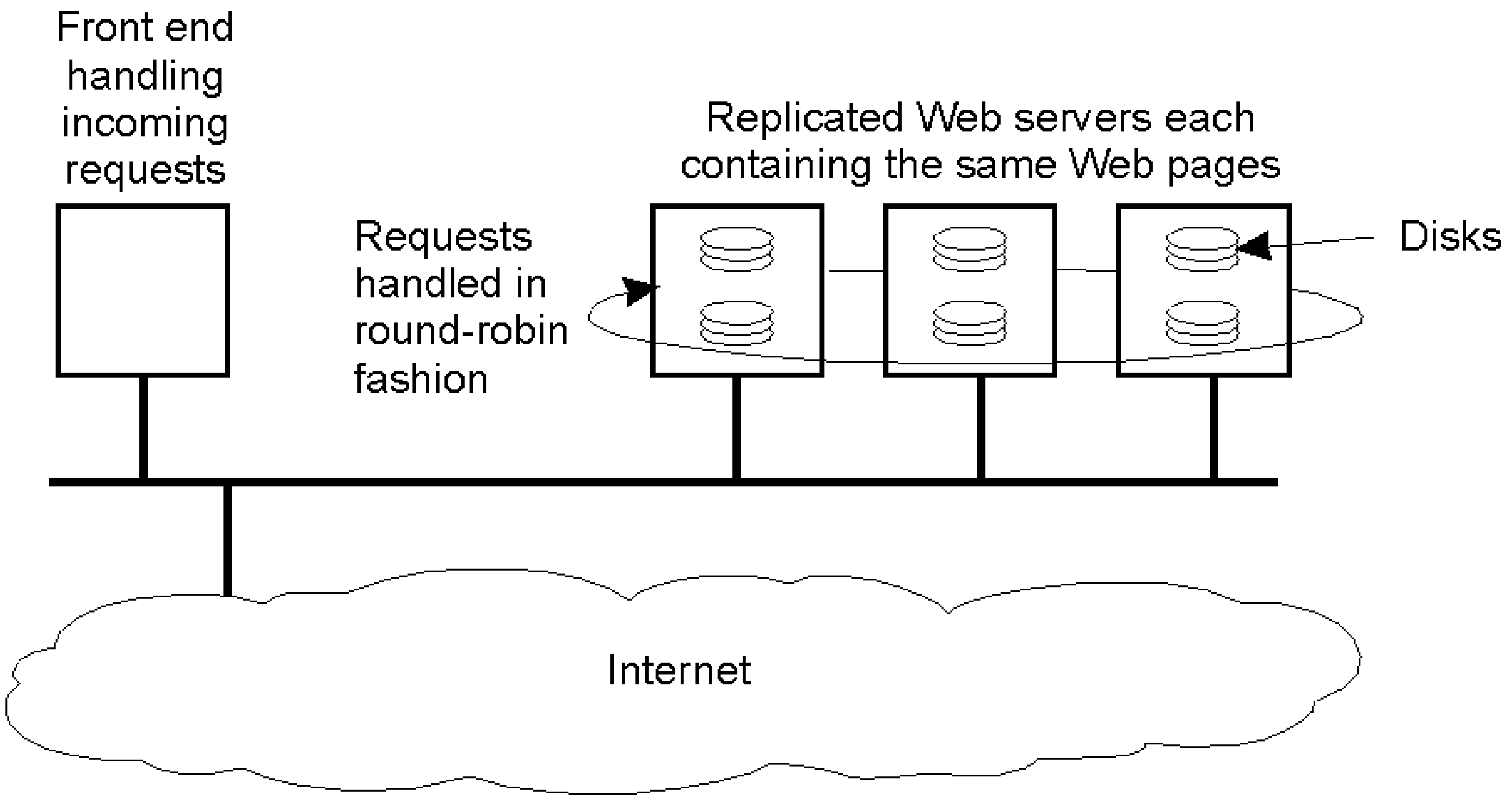


Figure 3-13. The principle of TCP handoff.

Modern Architectures


Front end handling incoming requests
Replicated Web servers each containing the same Web pages
Requests handled in round-robin fashion
Disks
Internet

An example of horizontal distribution of a Web service.

Replica selection Examples

- Round robin
- Load-based policies
- Payload-based methods (e.g., priorities)
- Energy/resource usage aware policies (e.g., costs)
- Nearby
- … and many other criteria ...