TDD25
Distributed Systems

Models of Distributed Systems

Christoph Kessler

IDA
Linköping University
Sweden

2024

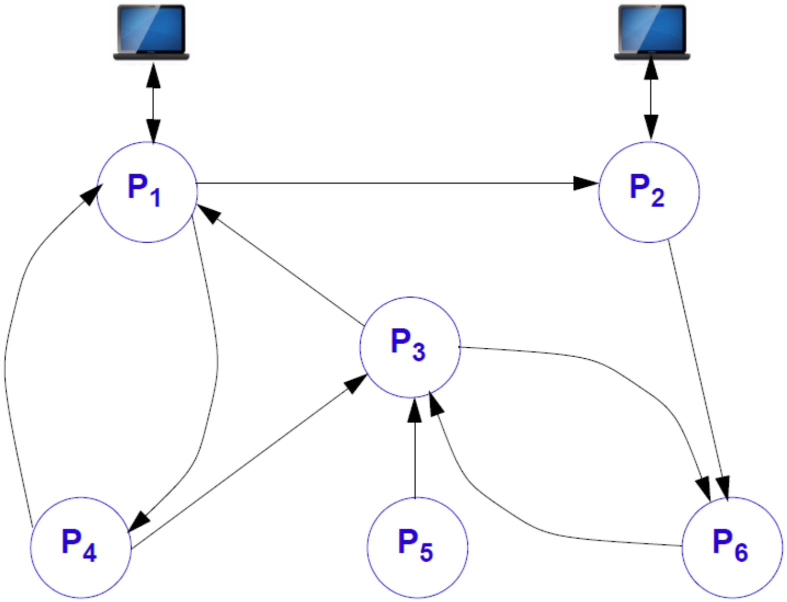
LINKÖPING UNIVERSITY

Agenda

1. **Architectural Models**
2. **Interaction Models**
3. **Fault Models**

Basic Notions

- **Resources** in a distributed system are *shared* between users.
  - They are normally *encapsulated* within *one* of the computers and can be accessed from other computers by *communication*.



- Each resource is managed by a program, the **resource manager**
  - It offers a *communication interface* enabling the resource to be accessed by its users.
  - Resource managers can, in general, be modelled as **processes**.

- If the system is designed according to an object-oriented methodology, resources are **encapsulated** in **objects**.

Architectural Models

What are architectural models about?

- ***Software*** architecture and hardware architecture
- How are **responsibilities** distributed between system components, and how are these components **placed**?
    - **Client-server model**
    - **Peer-to-peer**

And variations of the above two:

- **Proxy server**
- **Mobile code**
- **Mobile agents**
- **Network computers**
- **Thin clients**
- **Mobile devices**

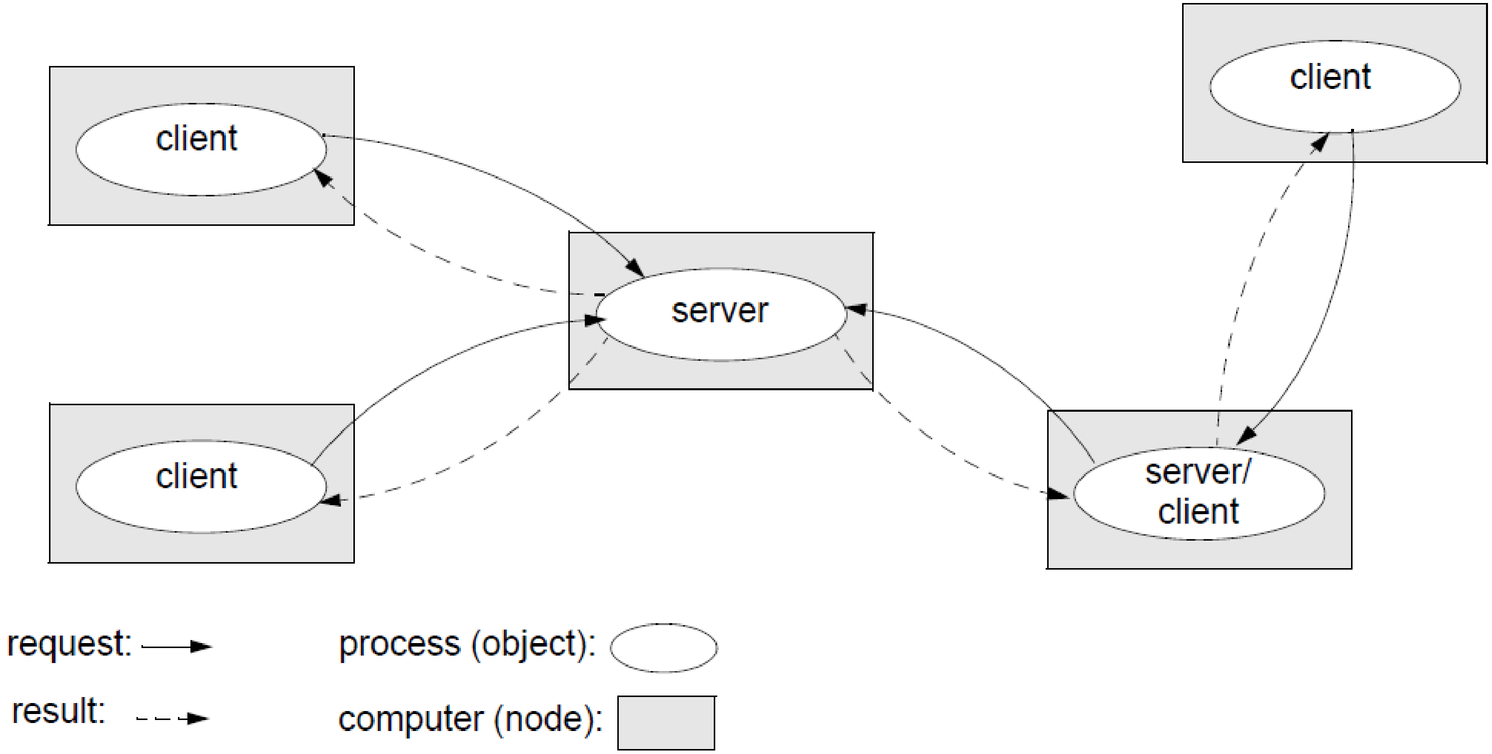
Client – Server Architecture Model

- The system is structured as a set of processes, called **servers**, that offer *services* to the service users, called **clients**.

- The client-server model is usually based on a simple request/reply protocol, implemented
  - with **send/receive** primitives or
  - using **remote procedure calls** (**RPC**) or **remote method invocation** (**RMI**):
    - The *client* sends a **request** (**invocation**) message to the server asking for some service.
    - The *server* does the work and returns a **result** (e.g. the data requested) or an **error code** if the work could not be performed.

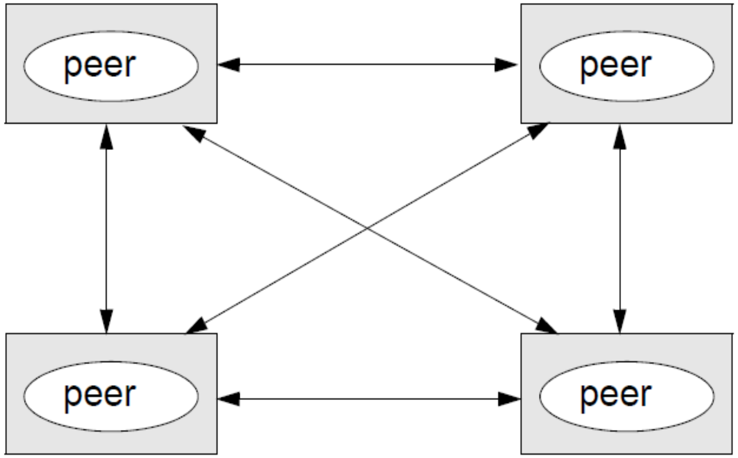
Client-Server Architecture Model

- *Client* and *Server* are **software roles** associated with **processes**, which may be mapped differently to hardware (computer nodes).
  - E.g., a server can itself request services from other servers; in this new relation, the server itself acts like a client.



Peer-to-Peer (P2P) Architecture Model

All processes (objects) play a similar role:



- Processes (objects) interact without particular distinction between clients and servers.
- The pattern of communication depends on the particular application.
- A large number of data objects are shared
  - Any individual computer holds only a small part of the application data(base).
- *Processing* and *communication loads* for access to objects are distributed across many computers and access links.

This is the most general and flexible model.

- Data / file sharing (→later)
- Most common representative / standard in HPC: **MPI** Message Passing Interface https://www.mpi-forum.org
  - Covered in great detail in TDDC78

Peer-to-Peer vs. Client-Server

Some problems with client-server:

- Centralisation of service → poor scaling

  Limitations:
  - capacity of server
  - bandwidth of network connecting the server

Peer-to-Peer tries to solve some of the above problems

- It distributes shared resources widely

  → computing and communication loads are shared

Problems with peer-to-peer:

- High complexity, due to need to
  - cleverly place individual objects
  - retrieve the objects
  - maintain a potentially large number of replicas.

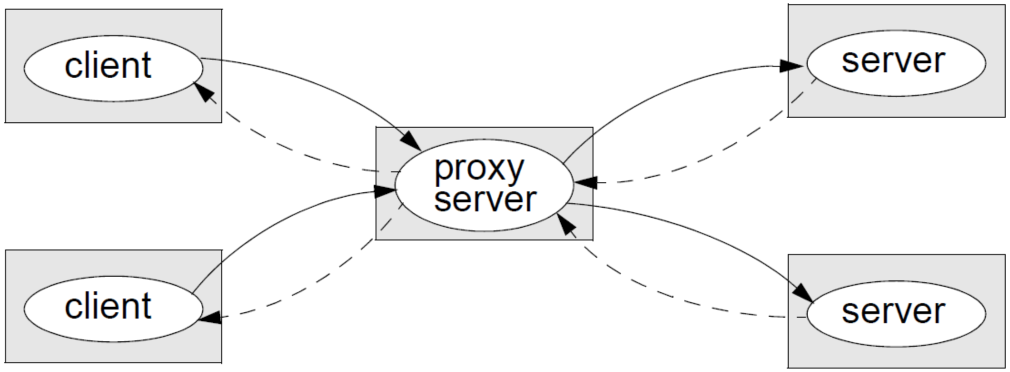
Variations of the Basic Models

- Client-server and peer-to-peer can be considered as basic models.

- Several variations have been proposed, → considering factors such as:
    - multiple servers and proxy servers / caches
    - mobile code and mobile agents
    - mobile devices

Proxy Server

A **proxy server** provides copies (replications) of resources which are managed by other servers.

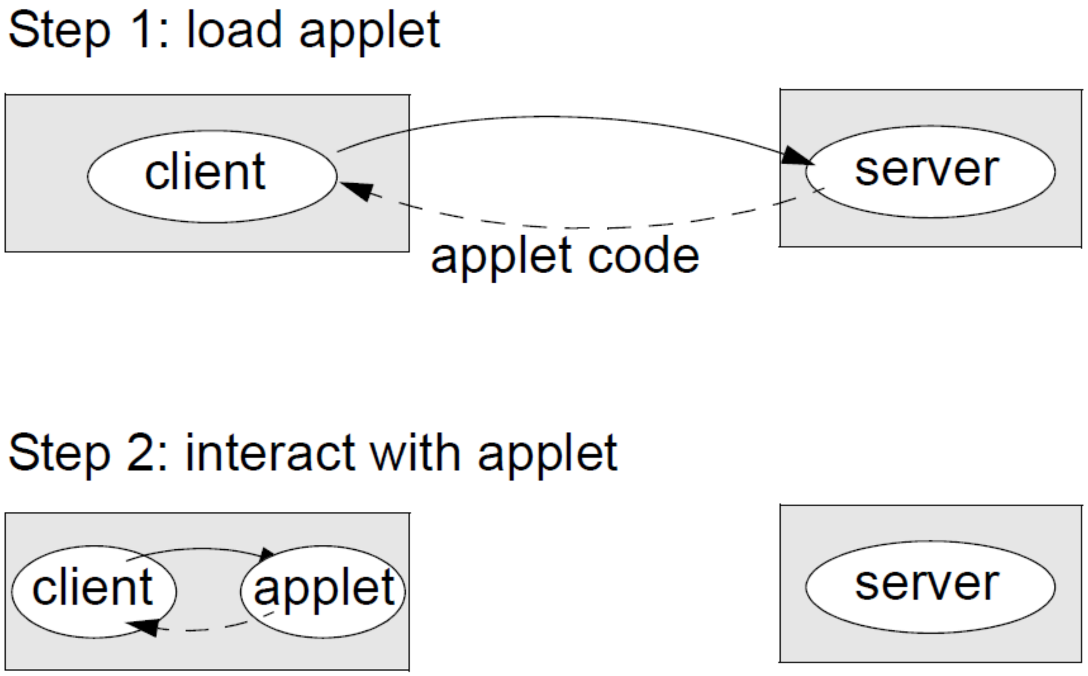


- Proxy servers are typically used as **caches** for remote resources.
  - They maintain a cache of recently visited web pages or other resources.
  - When a request is issued by a client, the proxy server is first checked if the requested object (information item) is available there.
- Proxy servers can be located at each client, or can be shared by several clients.
- The purpose is to increase performance and availability, by avoiding frequent accesses to remote servers.

- **Extension** of proxy principle: Heavily used servers can be **replicated** to multiple “back-end” servers (the service/data is “**mirrored**”)
  - server farm or spread geographically, plus front-end (proxy) server
  - the proxy server delegates service tasks (e.g., web page / file download, video streaming, search) e.g. **round-robin** across the back-end servers

Mobile Code

- **Mobile code**:
  code sent from one computer to another and run at the destination.
  - Advantage: remote invocations are replaced by local ones.
  - Typical example: Java applets.



Mobile Agents

Mobile agent:
a running program that travels from one computer to another, carrying out a task on someone’s behalf.

- A mobile agent is a complete program, code + data, that can work (relatively) independently.
- The mobile agent can invoke local resources/data.

Typical tasks:

- Collect information
- Install/maintain software on computers
- Compare prices from various vendors by visiting their sites.

Attention: potential security risk (like mobile code)!

Interaction Models

- How do we handle **time**?
- Are there **time limits** on process execution, message delivery, and clock drifts?

- **Synchronous distributed systems**
- **Asynchronous distributed systems**

Synchronous Distributed Systems

- **Main features:**
  - Lower and upper bounds on execution time of processes can be set.
  - Transmitted messages are received within a known bounded time.
  - Drift rates between local clocks have a known bound.

- **Important consequences:**
  1. In a synchronous distributed system, there is a notion of **global physical time** (with a known relative precision depending on the drift rate).
  2. Only synchronous distributed systems are **predictable** in terms of **timing**.
     - Only such systems can be used for **hard real-time** applications.
  3. In a synchronous distributed system, it is possible and safe to **use timeouts in order to detect failures** of a process or communication link.

But ...

- **It is difficult and costly to implement synchronous distributed systems.**

Asynchronous Distributed Systems

Many distributed systems (including those on the Internet) are **asynchronous**:

- No bound on process execution time (nothing can be assumed about speed, load, reliability of computers).
- No bound on message transmission delays (nothing can be assumed about speed, load, reliability of interconnections)
- No bounds on drift rates between local clocks.

Important consequences:

1. In an asynchronous distributed system, there is no global physical time. Reasoning can be only in terms of **logical time**.
2. Asynchronous distributed systems are unpredictable in terms of timing.
3. No timeouts can be used.

Asynchronous systems are widely and successfully used in practice.

- In practice, timeouts *are* used with asynchronous systems for failure detection.
  - However, additional measures have to be applied in order to avoid duplicated messages, duplicated execution of operations, etc. →

Fault Models

What kind of faults can occur and what are their effects?

- **Omission faults**
- **Arbitrary faults**
- **Timing faults**

Faults can occur both in processes and communication channels.

- The reason can be both software and hardware.

Fault models are needed in order to build systems with predictable behavior in case of faults (systems which are fault-tolerant).

A **fault-tolerant** system will function according to the predictions only as long as the real faults behave as defined by the *fault model*. Otherwise ... 

Omission Faults (Fail-Stop Model)

A processor or communication channel fails to perform actions it is supposed to do: the particular action is **not performed** by the faulty component!

- With **omission faults**:
  - If a component is faulty, it does *not* produce any output.
  - If a component produces an output, this output is *correct*.

- With omission faults, in *synchronous* systems, faults are detected by **timeouts**.
  - Since we are sure that messages arrive within a time interval, a timeout will indicate that the sending component is faulty.

  Such a system has a **fail-stop behavior**.

Arbitrary (Byzantine) Faults

This is the most general and worst possible fault semantics:

- Intended processing steps or communications are omitted or/and unintended ones are executed.
  Results may not come at all,
  or may come but carry wrong values.

→ Everything, including the worst, can happen!

Timing Faults

- Timing faults can occur in *synchronous* distributed systems, where *time limits* are set to process execution, communications, and clock drifts.
  - A **timing fault** results in any of these time limits being exceeded.

Acknowledgments

- Most of the slide contents is based on a previous version by Petru Eles, IDA, Linköping University.