System Models for Distributed Systems

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Outline

1. Introduction
2. Physical Models
3. Architectural Models
4. Fundamental Models

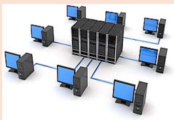
System Models

- Purpose:

  To illustrate/describe **common properties** and **design choices** for distributed systems in a **single descriptive model**

- Three types of models
  - **Physical models:** capture the hardware composition of a system in terms of computers and other devices and their interconnecting network
  - **Architectural models:**
    - *software architecture:* the main components of the system + their roles + how they interact
    - *system architecture:* how they are deployed in an underlying network of computers
  - **Fundamental models:** formal description of the properties that are common to architecture models. Three fundamental models:
    - interaction models, failure models and security models

Physical Models

Distributed Systems	Early	Internet-scale	Contemporary
	 LAN (1970s)	 Internet (1980s–1990s)	 Cloud computing (2000s)
Scale	Small (10-100)	Large	Ultra-large
Heterogeneity	Limited (typically relatively homogeneous configurations)	Significant in terms of platforms, languages and middleware	Added dimensions introduced including radically different styles of architecture
Openness	Not a priority	Significant priority with rage of standards introduced	Major challenge with existing standards: not yet able to embrace complex systems
Quality of Service	Not a priority	Significant priority with range of services introduced	Major challenge with existing services: not yet able to embrace complex systems

System Models for DS

Architectural Models

- To master the complexity of distributed systems, it is crucial that they are properly organized
- Concern the logical organization of distributed systems into:

1. Communicating entities
   - **Objects** — Object-based DS
   - **Components** — Distributed Components
   - **Web services** — Web-Based Systems
2. Communication paradigms
   - **Interprocess communication**
   - **Remote invocation**
   - **Indirect communication** — Communication Paradigms
3. Roles and responsibilities
4. Placement Strategies

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System Models for DS 3. Architectural Models

Indirect Communication Example

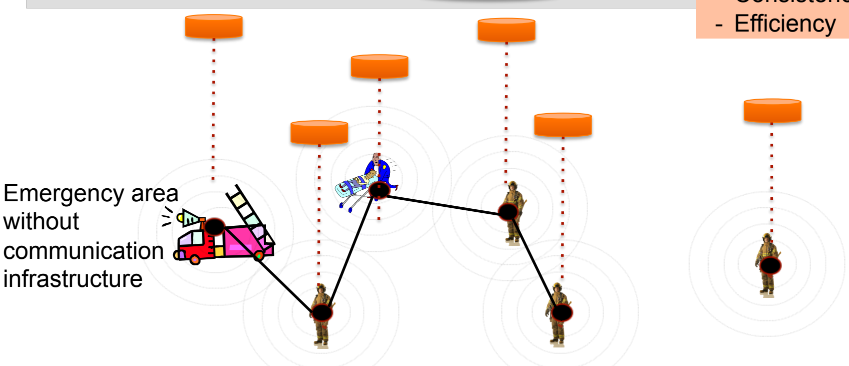
- Distributed shared data space

Information sharing through a database-like distributed system called **MIDAS Data Space**

Application

Select, Insert, …

Implementation challenges:
- Availability
- Fault-tolerance
- Scalability
- Consistency
- Efficiency



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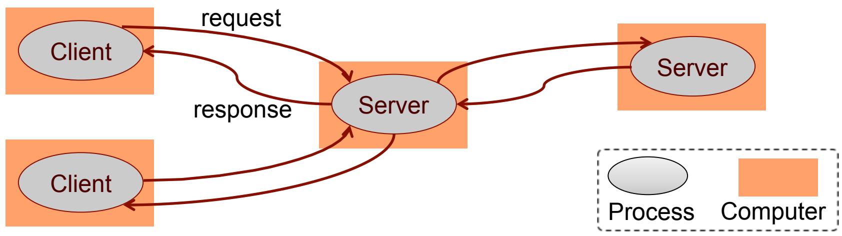
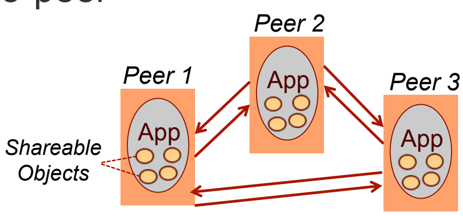
System Models for DS 3. Architectural Models

Roles and Responsibilities

- Component view of client-server model



- Peer-to-peer



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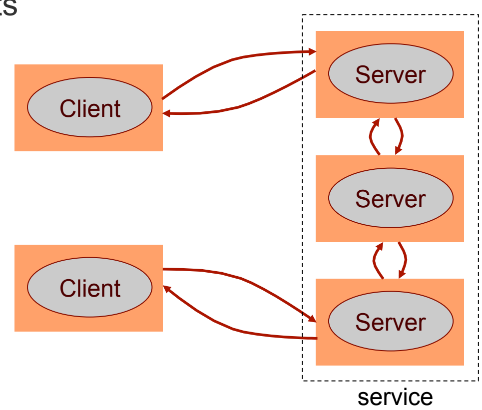
System Models for DS 3. Architectural Models

Placement Strategies - 1

- Multiple server processes:
  - service realized as a number of server-processes
  - several access points



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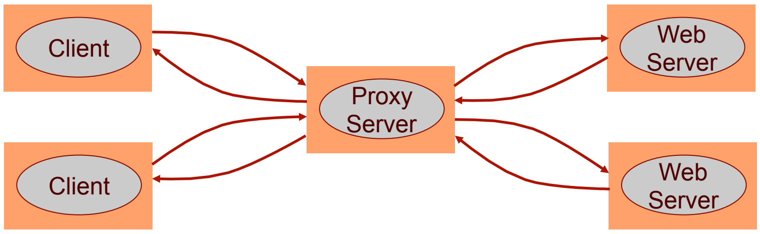
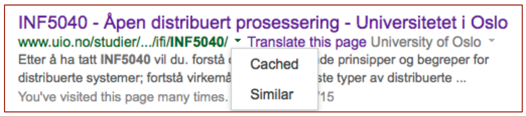
Placement Strategies - 2

- Client/server model with proxy-server:
  - Cache: stores recently-used data objects that are closer to the client than the original objects themselves.
  - Proxy server: cache that is shared between several clients





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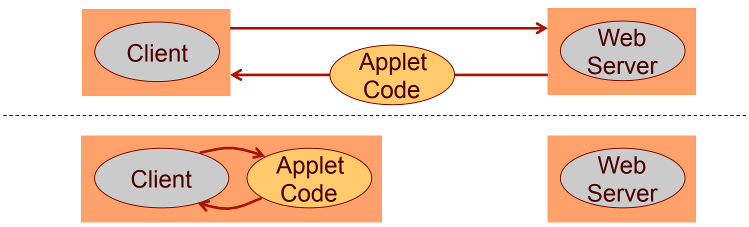
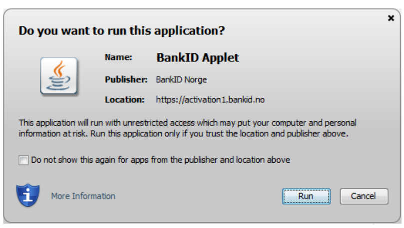
Placement Strategies - 3

- Mobile code (applets)
  - Enables e.g., “push-model”: the server invokes the client, or more advanced user interfaces





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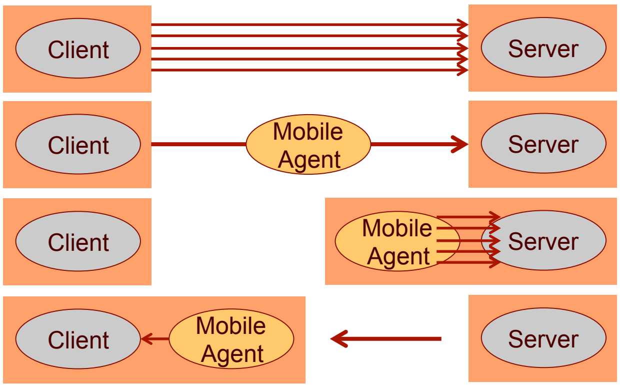
Placement Strategies - 4

- Mobile agents:
  - Program (code + data) that migrates between computers and executes a task on behalf of someone.

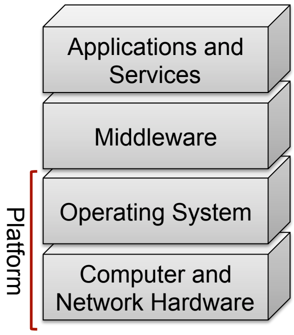


Architectural Patterns – 1

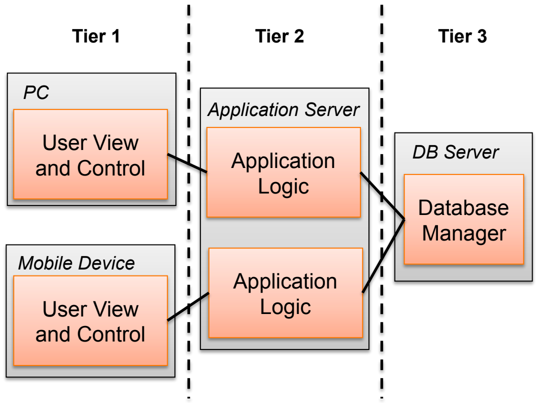
- Build on more primitive architectural elements
  - Recurring structures that have been shown to work well
  - Layering Architecture
  - Tiered Architecture
  - Thin Clients (Cloud Clients)
  - Among other patterns: Proxy, Brokerage and Reflection

Architectural Patterns – 2

- Layered



- Tiered



Middleware Solutions

- Support to architectural models
- Categories:
  - Distributed Objects, Distributed Components, Publish-subscribe, Message queues, Web services, Peer-to-peer
- Limitations:
  - Dependability aspects
  - End-to-end argument
  - Context-aware and adaptive solutions

System Models for DS | 3. Architectural Models

Architectural Patterns – 3

- Thin Clients
  - Move complexity away from end-user devices

  - For example:
    - Virtual Network Computing (VNC): graphical desktop sharing system to remotely control another computer

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System Models for DS

Fundamental Models

- Properties shared by all architecture models
  - **communicates** by sending messages across a network
  - requirements of **performance**, reliability, and security
- Fundamental models
  - abstracts over unnecessary details
  - used to address questions like
    - what are the most **important entities** in the system?
    - how do they **interact**?
    - what are the characteristics that affect their **individual and collective behaviour**?
- The purpose of fundamental models
  - to make explicit all **relevant assumptions** about the modeled system
  - to find out what is generally **feasible and not feasible** under the **given** assumptions

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Fundamental Models

- Aspects of distributed systems we want to express
  - Interaction model
    - processes, messages, coordination (synchronization and ordering)
    - must reflect that messages are subject to delays, and that delay limits exact **coordination** and maintenance of global time
  - Failure model
    - **defines and classifies** failures that can occur in a DS
    - basis for analysis of **effects** of failures and for design of fault-tolerant systems
  - Security model
    - defines and classifies security attacks that can occur in a DS
    - basis for analysis of threats to a system and for design of systems that are able to resist them

Significant Factors

- Performance of communication:
  - **Latency** – delay between the start of the transmission and the beginning of reception
  - **Bandwidth** – Total amount of information that can be transmitted
  - **Jitter** – Variation in the time taken to deliver a series of messages: relevant for multimedia data
- Computer Clocks:
  - Each computer: its own clock
  - Two processes running on different computers: timestamps?
  - Even reading at the same time: different timestamps!
  - **Clock drift:** rate for deviation from reference clock
  - How to correct time: from GPS or reference computer in the network

Two Variants

- **Synchronous** distributed systems
  - the time to execute each step of a process: known lower and upper bounds
  - each message transmitted over a channel is received within a known bounded time
  - local clock's drift rate from real time has a known bound
- **Asynchronous** distributed systems
  - the time to execute each step of a process can take arbitrarily long
  - each message transmitted over a channel can be received after an arbitrarily long time
  - local clock's drift rate from real time can be arbitrarily large

Significance of Syn. vs Asyn. DS

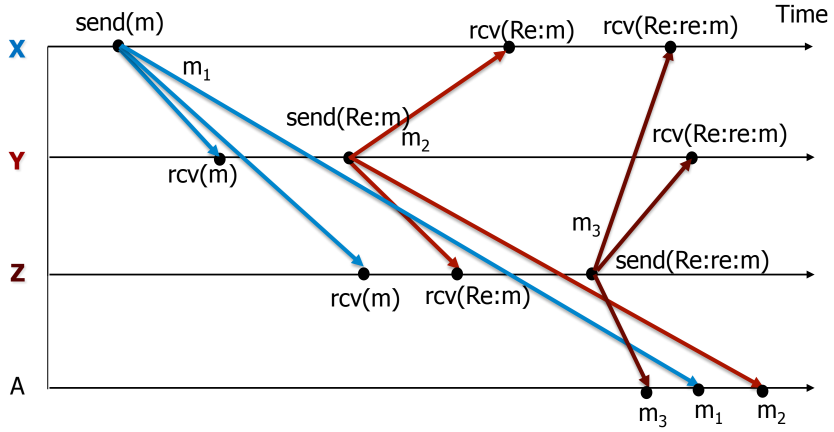
- Many coordination problems have a solution in synchronous distributed systems, but not in asynchronous
  - e.g., "The two army problem" or "Agreement in Pepperland" (see [Coulouris])
- Often we assume synchrony even when the underlying distributed system in essence is asynchronous
  - **Internet** is in essence asynchronous but we use timeouts in protocols over Internet to detect failures
  - based on **estimates of time limits**
  - but: design based on **time limits** that can not be guaranteed, will generally be **unreliable**

Ordering of Events

- distributed coordination protocols have a need for ordering of events in time (**“happened before”-relationship**)
  - events: sending and receiving messages
  - example: update of replicated data must generally be done in the same order in all replica
- difficult to use physical clocks in computers for coordination (e.g., clock values in messages)
  - have limited time resolution and ticks with different rates (clock drift)
  - basic properties of message exchange limit the accuracy of the synchronization of clocks in a DS [Lamport 78]

Example: E-mail Exchange

- Example: e-mail exchange



System Models for DS 4. Fundamental: Timing

Logical Clocks

- Possible to describe logical ordering of events even without accurate clocks by using logical clocks
- Principle
  - If two A and B happen in the same process, then they occur in the same order: $A \rightarrow B$
  - if A is sending of a message by one process and B is the receipt of the same message by another process, then $A \rightarrow B$
- Happened-before relationship
  - is derived by generalizing the two relationships above such that if A, B and C are events and $A \rightarrow B$ and $B \rightarrow C$, then $A \rightarrow C$
- Logical clocks extends the idea above
  - more later in the course ------ Time and Coordination in DS

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System Models for DS 4. Fundamental: Failure

A Failure Model

- Is a definition of in which **way failures may occur** in distributed systems
- Provides a basis for understanding the **effects** of failures
- Definition of the failure model of a service enables construction of a *new* service that **hides the faulty behavior** of the service it builds upon
  - example: TCP on top of IP
    - TCP: reliable byte-stream service
    - IP: unreliable datagram service

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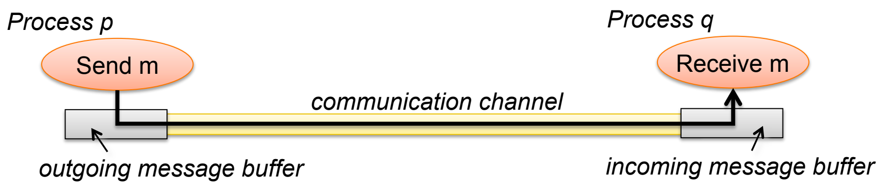
System Models for DS 4. Fundamental: Failure

Specification of a Failure Model

- Specification of failure models requires a way to describe failures
- One approach is to classify failure types (Cristian, 1991) (Hadzilacos & Toueg, 1994)
  - **Omission** failures
  - **Arbitrary** failures
  - **Timing** failures
- System model:



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System Models for DS 4. Fundamental: Failure

Omission Failures

- A **process** or **channel fails** to perform actions that it is supposed to do

Failure class	Affects	Description
Fail-stop	Process	Process halts and remains halted. Other processes may detect this state.
Crash	Process	Process halts and remains halted. Other processes may not be able to detect this state.
Omission	Channel	A message inserted in an outgoing message buffer never arrives in the other end's incoming buffer.
Send omission	Process	A process completes a *send*-operation, but the message is not put into the outgoing message buffer.
Receive- -omission	Process	A message is put into a process's incoming message buffer, but the process does not receive it.

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Arbitrary failures (Byzantine failures)

- **Process** or **channel** may exhibit **arbitrary behavior** when failing,
  - send/receive arbitrary messages at arbitrary intervals
  - a process may halt or perform "faulty" steps
  - a process may omit to respond now and then
- By adopting a byzantine failure model, we can attempt to make systems that are "**ultra-reliable**" (handles HW failures, and provide guaranteed response times)
  - control systems in air planes
  - patient monitoring systems
  - robot control systems
  - control systems for nuclear power plants

Timing Failures

- Applicable in synchronous distributed systems
  - responses that are not available to clients in a specified time interval
  - timing guarantees requires guaranteed access to resources when they are needed
- Examples:
  - control and monitoring systems, multimedia systems

Failure class	Effects	Description
Clock	Process	Process's local clock exceeds the bounds on its rate of drift from real time
Performance	Process	Process exceeds the bounds on the interval between two processing steps
Performance	Channel	A message's transmission takes longer than the stated bounds

System Models for DS 4. Fundamental: Failure

Masking Failures

- Masking a failure by
  - hiding it all together or
    - e.g., message retransmission: hiding omission failures
  - converting it into a more acceptable type of failure
    - e.g., checksums for masking corrupted messages: in fact an arbitrary failure => an omission failure
- Reliable 1-to-1 communication
  - To mask some communication omission failures
  - Defined in terms of:
    - **Validity** – Any message in the outgoing message buffer is eventually delivered to the incoming message buffer
    - **Integrity** – The message received is identical to the one sent, and no messages are delivered twice
  - Threats:
    - Retransmission with no duplicate detection
    - Malicious injection of messages

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System Models for DS

Summary

- Three types of system models
  - **Physical models:** capture the hardware composition of a system in terms of computers and other devices and their interconnecting network
  - **Architecture models**: defines the components of the system, the way they interact, and the way the are deployed in a network of computers
    - Architectural elements (entities, communication paradigms)
    - Architectural patterns (layering, tiered)
    - Middleware solutions
  - **Fundamental models**: formal description of the properties that are common to all architecture models
    - interaction models
    - failure models
    - Security models (not covered in this course)

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