Distributed Systems
COMP 412

Fundamentals of Distributed Systems

2023

Outline

1. **What is a Distributed System?**
2. **Examples of Distributed Systems**
3. **Advantages and Disadvantages**
4. **Design Issues with Distributed Systems**
5. **Course Topics**

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What is a Distributed System?

- **A *distributed system* is a collection of autonomous computers linked by a computer network that appear to the users of the system as a single computer.**

Some comments:

- System architecture: The machines are ***autonomous***; this means they are computers which, in principle, could work independently.
- The user's perception: the distributed system is perceived as a ***single*** system solving a certain problem (even though, in reality, we have several computers placed in different locations).
- By running a ***distributed system software***, the computers are enabled to:
  - coordinate their activities
  - share resources: hardware, software, data.

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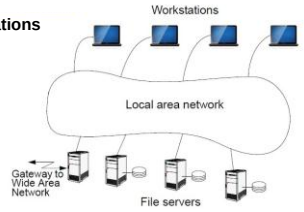
Examples of Distributed Systems (1)

Network of Workstations



Personal workstations + servers not assigned to specific users.

- **Single file system,** with all files accessible from all machines in the same way and using the same path name.
- For a certain command, the system can look for the best place (workstation) to execute it.

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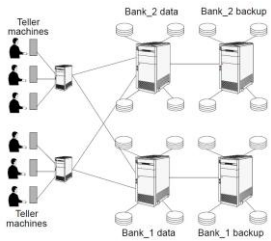
Examples of Distributed Systems (2)

Automated banking (teller machines) system



- **Primary requirements:**
  - security and reliability
- **Consistency of replicated data**
- **Concurrent transactions** (operations which involve accounts in different banks, simultaneous access from several users, etc.)
- **Fault tolerance**

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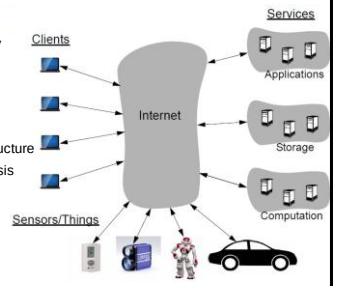
Examples of Distributed Systems (3)

The Cloud and IoT

- Computing as a utility (service)
  - Application
  - Storage
  - Computation
  - Platform / Infrastructure
- Pay on per-usage basis
- Main concerns:
  - Scaling
  - Performance
  - Security / Privacy
  - Reliability



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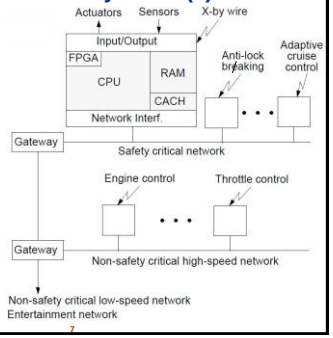
Examples of Distributed Systems (4)

Automotive system

- A distributed, embedded, real-time system



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Examples of Distributed Systems (5)

Distributed Real-Time Systems

- Synchronization of physical clocks
- Scheduling with hard time constraints
- Real-time communication
- Fault tolerance

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Why do we need them?

Advantages of Distributed Systems

- **Performance**
  - Very often, a collection of computers can provide higher performance (and better price/performance ratio) than a centralized computer.
- **Distribution**
  - Many applications involve, by their nature, spatially separated machines (banking, commercial, automotive system).
- **Reliability (fault tolerance)**
  - If some machine crashes, the system can survive.
- **Incremental growth**
  - As requirements on processing power grow, new machines can be added incrementally.
- **Sharing of data/resources**
  - Shared data is essential to many applications (banking, computer-supported cooperative work, reservation systems); other resources can be also shared (e.g., expensive printers).
- **Communication**
  - facilitates human-to-human communication

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Disadvantages of Distributed Systems

- **Difficulties of developing distributed software**
  - How should operating systems, programming languages and applications look like?
- **Networking problems**
  - several problems are created by the network infrastructure, which have to be dealt with:
    - Loss of messages
    - Overloading
    - ...
- **Security problems**
  - Sharing generates the problem of data security.

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Design Issues with Distributed Systems

Issues that arise specifically from the distributed nature of the application

- Transparency
- Communication
- Performance and scalability
- Heterogeneity
- Openness
- Reliability and fault tolerance
- Security

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Transparency

- How to achieve the **single system image**?
  - How to create the illusion for the user that the collection of machines is a "simple" computer?

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Transparency (1)

- **Access transparency**
  - Local and remote resources are accessed using *identical operations*.
- **Location transparency**
  - Users cannot tell *where* hardware and software resources (CPUs, files, databases) are located
    - The *name* of the resource should not encode the *location* of the resource.
- **Migration (mobility) transparency**
  - Resources should be free to *move* from one location to another without having their names changed.
- **Replication transparency**
  - The system is free to make additional *copies* of files and other resources (for purpose of performance and/or reliability), without the users noticing.

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Transparency (2)

- **Concurrency transparency**
  - The users will not notice the existence of *other users* in the system (even if they access the same resources).
- **Failure transparency**
  - Applications should be able to complete their task despite failures occurring in certain components of the system.
- **Performance transparency**
  - *Load variation* should not lead to performance degradation.
  - This could be achieved by *automatic reconfiguration* as response to changes of the load; it is difficult to achieve.

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Communication

Components of a distributed system must communicate in order to interact.

This implies support at two levels:

- **Networking infrastructure**
  - Interconnections and network software
- **Appropriate communication primitives and models**
  - **Communication primitives**
    - send
    - receive
    - remote procedure call (RPC)

    (send, receive: Message passing)
  - **Communication models**
    - client-server communication
      - implies a message exchange between two processes: the process that requests a service and the one that provides it;
    - group multicast
      - the target of a message is a set of processes, which are members of a given group.

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Performance and Scalability

Several factors influence the **performance** of a distributed system:

- The performance of involved individual computers (e.g., workstations, servers).
- The speed of the communication infrastructure.
- Extent to which reliability (fault tolerance) is provided
  - Replication and preservation of coherence imply large overheads.
- Flexibility in workload allocation
  - For example, idle processors (workstations) could be allocated automatically to a user's task.

Scalability

- The system should remain efficient even with a significant increase in the number of users and resources connected:
  - cost of adding resources should be reasonable;
  - performance loss with increased number of users and resources should be controlled;
  - *software* resources should not run out (e.g. number of bits allocated to addresses, number of entries in tables, etc.)

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Heterogeneity

Distributed applications are typically **heterogeneous**:

- **Different hardware**
  - mainframes, workstations, PCs, servers, mobile devices …
  - CPU types, accelerators, memory hierarchies …
- **Different system software**
  - UNIX, MS Windows, IBM OS/2, …, Android/iOS/…, Real-time OSs, …, file systems, executable formats, etc.;
- **Unconventional devices**
  - teller machines, telephone switches, robots, cars, manufacturing systems, etc.;
- **Diverse networks and protocols**
  - Ethernet, FDDI, ATM, TCP/IP, Novell Netware, Infiniband, etc.

The solution:

- **Middleware**, an additional software layer to mask heterogeneity

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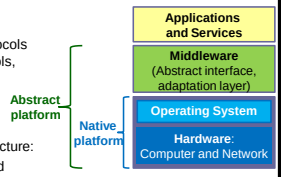
Openness

An important feature of distributed systems is **openness and flexibility**:

- Every service is equally accessible to every client (local or remote).
- It is easy to implement, install and debug new services.
- Users can write and install their own services.
- Portability of applications and services.

Key aspect of openness:

- ***Standard*** interfaces and protocols
  - e.g., XML, Internet protocols, HTTP, etc.
- Support of heterogeneity
  - by adequate ***middleware***, like CORBA, MPI, JVM, ...
- ***Layer-based*** software architecture:
  - Platforms could be stacked



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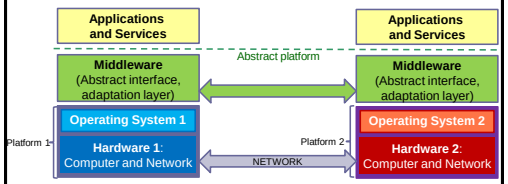
Openness

- **Middleware**
  (abstract platform interface and its implementation(s))
  - creates a ***portable*** platform for programming and execution atop a distributed system with its heterogeneous platforms



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Design Issues with Distributed Systems

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- **Reliability and fault tolerance**
- **Security**

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Reliability and Fault Tolerance

One of the main goals of building distributed systems is improved **reliability**.

Availability: If machines go down, the system should still work with the reduced amount of resources.

- There should be a very small number of critical resources (single points of failure);
  - ***critical resources***: resources which *have* to be up in order for the distributed system to work.
- Key pieces of hardware and software (critical resources) should be ***replicated***
  - if one of them fails, another one takes up - redundancy.
- Data on the system must not be lost, and copies stored *redundantly* on different servers must be kept ***consistent***.
  - The more copies are kept, the better the availability, but keeping consistency becomes more difficult.

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Reliability and Fault Tolerance

- Reliable systems need to have a high degree of availability; in order to achieve this, they *need to be fault tolerant*.
- **Fault tolerance**:
  the system has to detect faults and act in a reasonable way:
  - **mask** the fault: continue to work with possibly reduced performance but without loss of data/information.
  - **fail gracefully**: react to the fault in a predictable way and possibly stop functionality for a short period, but without loss of data/information.

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Security

Security of information resources implies:

1. **Confidentiality**
   - Protection against disclosure to unauthorised person
2. **Integrity**
   - Protection against alteration and corruption
3. **Availability**
   - Keep the resource accessible

Distributed systems allow communication between programs/users/resources on different computers.

Security risks associated with free access.

The appropriate use of resources by different users needs to be guaranteed!

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Course Topics

- **Basics**
  - Introduction √
  - Models of Distributed Systems
  - Communication in Distributed Systems(RPC/RMI)
  - Distributed Heterogeneous Applications and CORBA
  - Peer-to-Peer Systems
  - Name and naming Services
- **Theoretical Aspects and Distributed Algorithms**
  - Time and State in Distributed Systems
  - Distributed Mutual Exclusion
  - Election and Agreement
- **Distributed Data and Fault Tolerance**
  - Replication
  - Recovery and Fault Tolerance
  - Distributed transaction

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