DISTRIBUTED SYSTEMS

(TDDB37)

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Course Information

Web page: http://www.ida.liu.se/~TDDB37

Examination: written

Lecture notes: available from the web page, latest 24 hours before the lecture.

Text book:

George Coulouris, Jean Dollimore, Tim Kindberg: "Distributed Systems - Concepts and Design", Addison Wesley Publ. Comp., 4th edition, 2005.

Other titles can be used in addition:

Andrew S. Tanenbaum, Maarten van Steen: "Distributed Systems", Prentice-Hall International, 2002.

Mukesh Singhal, Niranjan G. Shivaratri: "Advanced Concepts in Operating Systems. Distributed, Database, and Multiprocessor Operating Systems", McGraw-Hill, 1994.

Course Information (cont'd)

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DISTRIBUTED SYSTEMS

Basic Issues

1. What is a Distributed System?

2. Examples of Distributed Systems

3. Advantages and Disadvantages

4. Design Issues with Distributed Systems

5. Preliminary Course Topics

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).

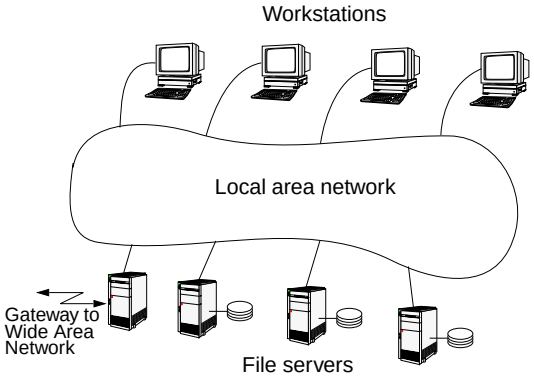
By running a *distributed system software* the computers are enabled to:

- coordinate their activities
- share resources: hardware, software, data.

☞ According to this definition, the *Internet* as such, is not a distributed system, but an infrastructure on which to implement distributed applications/services (such as the World Wide Web).

Examples of Distributed Systems

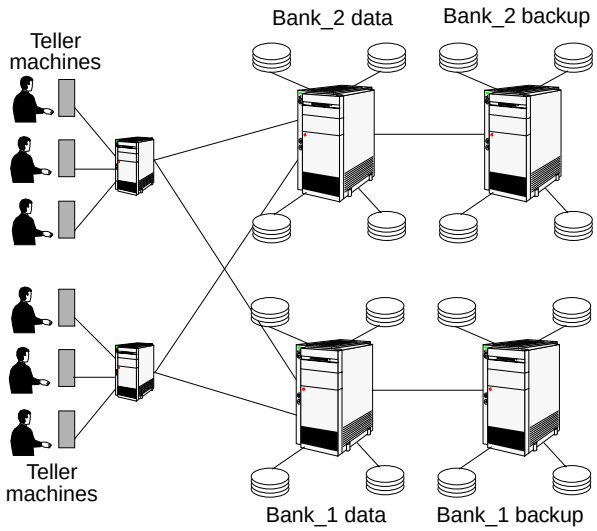
Network of workstations



- Personal workstations + processors 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.

Examples of Distributed Systems (cont'd)

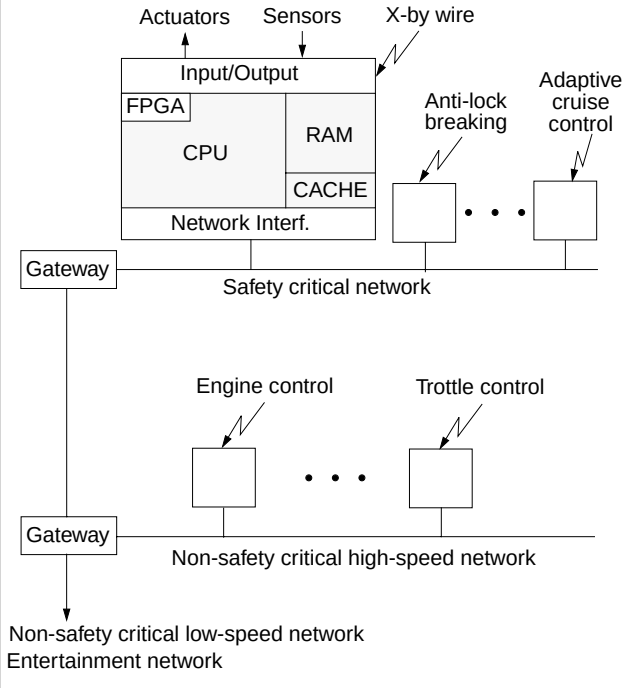
Automatic banking (teller machine) system



- 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

Examples of Distributed Systems (cont'd)

Automotive system (a distributed real-time system)



Examples of Distributed Systems (cont'd)

Distributed Real-Time Systems

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

Why do we Need Them?
Advantages of Distributed Systems

Performance: very often a collection of processors 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 of the machines crash, 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.

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.

Design Issues with Distributed Systems

Design issues that arise *specifically* from the distributed nature of the application:

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

Transparency

☞ How to achieve the single system image?

☞ How to "fool" everyone into thinking that the collection of machines is a "simple" computer?

- Access transparency
  - local and remote resources are accessed using identical operations.
- Location transparency
  - users cannot tell where hardware and software resources (CPUs, files, data bases) are located; the name of the resource shouldn't 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.

Transparency (cont'd)

- 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.
    Example: several copies of a file; at a certain request that copy is accessed which is the closest to the client.
- 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.

Communication

☞ Components of a distributed system have to communicate in order to interact. This implies support at two levels:

1. Networking infrastructure (interconnections & network software).
2. Appropriate communication primitives and models and their implementation:
   - communication primitives:
     - *send*, *receive* } message passing
     - *remote procedure call* (RPC)
   - communication models
     - *client-server communication*: implies a message exchange between two processes: the process which requests a service and the one which provides it;
     - *group muticast*: the target of a message is a set of processes, which are members of a given group.

Performance and Scalability

Several factors are influencing the performance of a distributed system:

- The performance of individual workstations.
- 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 (number of bits allocated to addresses, number of entries in tables, etc.)

Heterogeneity

- Distributed applications are typically heterogeneous:
  - different hardware: mainframes, workstations, PCs, servers, etc.;
  - different software: UNIX, MS Windows, IBM OS/2, Real-time OSs, etc.;
  - unconventional devices: teller machines, telephone switches, robots, manufacturing systems, etc.;
  - diverse networks and protocols: Ethernet, FDDI, ATM, TCP/IP, Novell Netware, etc.

The solution

Middleware, an additional software layer to mask heterogeneity

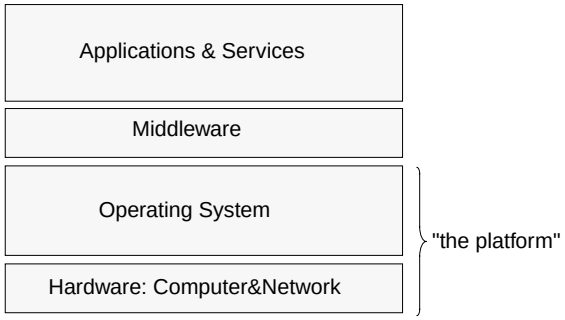
Openness

- One of the important features 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.

- Key aspect of openness:
  - Standard interfaces and protocols (like Internet communication protocols)
  - Support of heterogeneity (by adequate *middleware*, like CORBA)

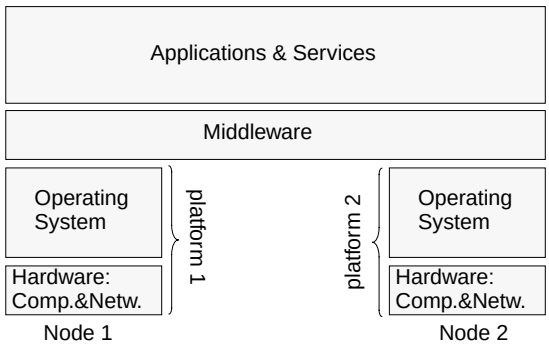
Openness (cont'd)

Software Architecture:



Openness (cont'd)

The same, looking at two distributed nodes:



Reliability and Fault Tolerance

☞ One of the main goals of building distributed systems is improvement of reliability.

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

- There should be a very small number of critical resources;
  critical resources: resources which have to be up in order 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 kept, the better the availability, but keeping consistency becomes more difficult.

Fault-tolerance is a main issue related to reliability: 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.

Security

Security of information resources:

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

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

Security risks associated with free access.

The appropriate use of resources by different users has to be guaranteed.

Course Topics at a Glance

Basics
- Introduction
- Models of Distributed Systems
- Communication in Distributed Systems

Middleware
- Distributed Heterogeneous Applications and CORBA
- Peer-to-Peer Systems

Theoretical Aspects/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 Real-Time Systems

Course Topics

- Introduction
  - just finished!
- Communication in Distributed Systems
  - Message passing and the client/server model
  - Remote Procedure Call
  - Group Communication
- Distributed Heterogeneous Applications and CORBA
  - Heterogeneity in distributed systems
  - Middleware
  - Objects in distributed systems
  - The CORBA approach
- Peer-to-Peer Systems
  - Basic design issues
  - The Napster file sharing system
  - Peer-to-peer middleware
- Time and State in Distributed Systems
  - Time in distributed systems
  - Logical clocks
  - Vector clocks
  - Causal ordering of messages
  - Global states and state recording

Course Topics (cont'd)

- Distributed Mutual Exclusion
  - Mutual exclusion in distributes systems
  - Non-token based algorithms
  - Token based algorithms
  - Distributed elections
- Replication
  - Motivation for replication
  - Consistency and ordering
  - Total and causal ordering
  - Update protocols and voting
- Recovery and Fault Tolerance
  - Transaction recovery
  - Checkpointing and recovery
  - Fault tolerance in distributed systems
  - Hardware and software redundancy
  - Byzantine agreement
- Distributed Real-Time Systems
  - Physical Clocks
  - Clock Synchronization
  - Real-Time Scheduling
  - Real-Time Communication