

Distributed Systems

Principles and Paradigms

Chapter 01

(version October 26, 2008)

Maarten van Steen

Vrije Universiteit Amsterdam, Faculty of Science

Dept. Mathematics and Computer Science

Room R4.20. Tel: (020) 598 7784

E-mail: steen@cs.vu.nl, URL: www.cs.vu.nl/~steen/

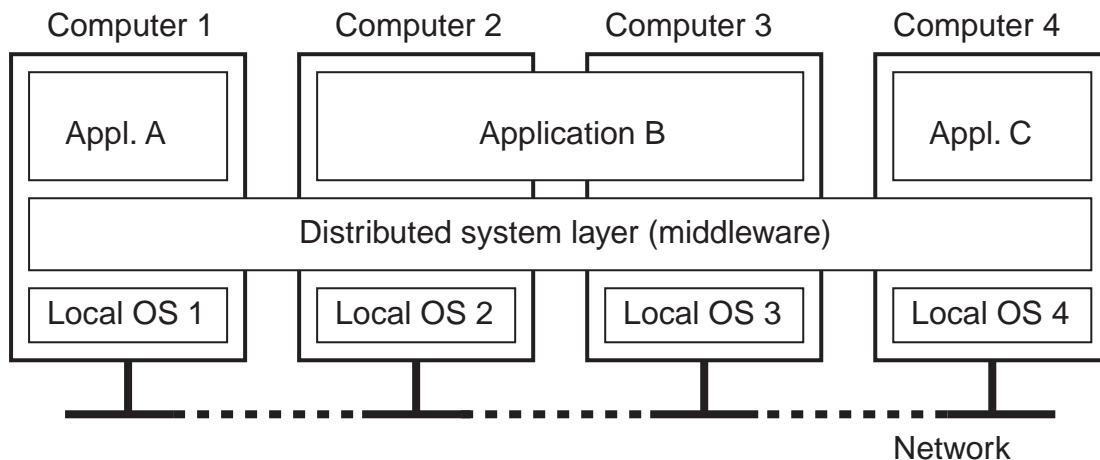
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Distributed System: Definition

A distributed system is a piece of software that ensures that:

*a collection of **independent computers** appears to its users as a **single coherent system***

Two aspects: (1) independent computers and (2) single system \Rightarrow **middleware**.



Goals of Distributed Systems

- Making resources available
- Distribution transparency
- Openness
- Scalability

Distribution Transparency

Transparency	Description
Access	Hides differences in data representation and invocation mechanisms
Location	Hides where an object resides
Migration	Hides from an object the ability of a system to change that object's location
Relocation	Hides from a client the ability of a system to change the location of an object to which the client is bound
Replication	Hides the fact that an object or its state may be replicated and that replicas reside at different locations
Concurrency	Hides the coordination of activities between objects to achieve consistency at a higher level
Failure	Hides failure and possible recovery of objects

Note: Distribution transparency may be set as a goal, but achieving it is a different story.

Degree of Transparency

Observation: Aiming at full distribution transparency may be too much:

- Users may be located in **different continents**; distribution is apparent and not something you want to hide
- **Completely hiding failures** of networks and nodes is (theoretically and practically) **impossible**
 - You cannot distinguish a slow computer from a failing one
 - You can never be sure that a server actually performed an operation before a crash
- Full transparency will **cost performance**, exposing distribution of the system
 - Keeping Web caches **exactly** up-to-date with the master copy
 - Immediately flushing write operations to disk for fault tolerance

Openness of Distributed Systems

Open distributed system: Be able to interact with services from other open systems, irrespective of the underlying environment:

- Systems should conform to well-defined **interfaces**
- Systems should support **portability** of applications
- Systems should easily **interoperate**

Achieving openness: At least make the distributed system independent from **heterogeneity** of the underlying environment:

- Hardware
- Platforms
- Languages

Policies versus Mechanisms

Implementing openness: Requires support for different **policies** specified by applications and users:

- What level of consistency do we require for client-cached data?
- Which operations do we allow downloaded code to perform?
- Which QoS requirements do we adjust in the face of varying bandwidth?
- What level of secrecy do we require for communication?

Implementing openness: Ideally, a distributed system provides only **mechanisms**:

- Allow (dynamic) setting of caching policies, preferably per cachable item
- Support different levels of trust for mobile code
- Provide adjustable QoS parameters per data stream
- Offer different encryption algorithms

Scale in Distributed Systems

Observation: Many developers of modern distributed system easily use the adjective “scalable” without making clear **why** their system actually scales.

Scalability: At least three components:

- Number of users and/or processes
(size scalability)
- Maximum distance between nodes
(geographical scalability)
- Number of administrative domains
(administrative scalability)

Most systems account only, to a certain extent, for size scalability. The (non)solution: powerful servers.

Today, the challenge lies in geographical and administrative scalability.

Techniques for Scaling

Hide communication latencies: Avoid waiting for responses; do something else:

- Make use of **asynchronous communication**
- Have separate handler for incoming response
- **Problem:** not every application fits this model

Distribution: Partition data and computations across multiple machines:

- Move computations to clients (Java applets)
- Decentralized naming services (DNS)
- Decentralized information systems (WWW)

Replication/caching: Make copies of data available at different machines:

- Replicated file servers and databases
- Mirrored Web sites
- Web caches (in browsers and proxies)
- File caching (at server and client)

Scaling – The Problem

Observation: Applying scaling techniques is easy, except for one thing:

*Having multiple copies (cached or replicated), leads to **inconsistencies**: modifying one copy makes that copy different from the rest.*

*Always keeping copies consistent and in a general way requires **global synchronization** on each modification.*

Global synchronization precludes large-scale solutions.

Observation: If we can tolerate inconsistencies, we may reduce the need for global synchronization.

Observation: Tolerating inconsistencies is application dependent.

Developing Distributed Systems: Pitfalls

Observation: Many distributed systems are needlessly complex caused by mistakes that required patching later on. There are many **false assumptions**:

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

Types of Distributed Systems

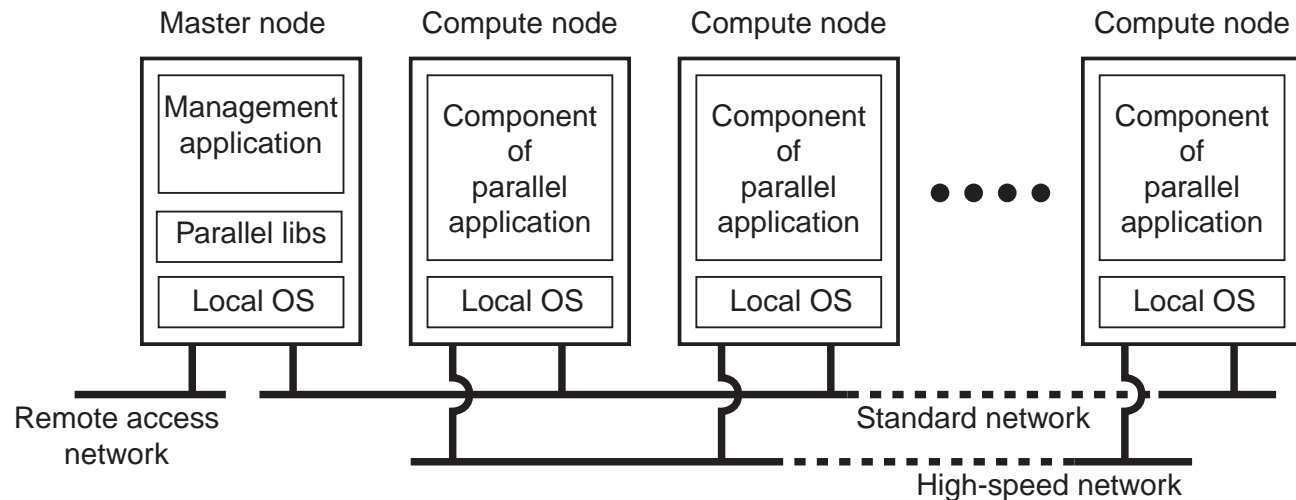
- Distributed Computing Systems
- Distributed Information Systems
- Distributed Pervasive Systems

Distributed Computing Systems (1/2)

Observation: Many distributed systems are configured for **High-Performance Computing**:

Cluster Computing: Essentially a group of high-end systems connected through a LAN:

- Homogeneous: same OS, near-identical hardware
- Single managing node



Distributed Computing Systems (2/2)

Grid Computing: The next step: lots of nodes from everywhere:

- Heterogeneous
- Dispersed across several organizations
- Can easily span a wide-area network

Note: To allow for collaborations, grids generally use **virtual organizations**. In essence, this is a grouping of users (or better: their IDs) that will allow for authorization on resource allocation.

Distributed Information Systems

Observation: The vast amount of distributed systems in use today are forms of traditional information systems, that now **integrate** legacy systems. **Example:** Transaction processing systems.

```
BEGIN_TRANSACTION(server, transaction);  
READ(transaction, file-1, data);  
WRITE(transaction, file-2, data);  
newData := MODIFIED(data);  
IF WRONG(newData) THEN  
    ABORT_TRANSACTION(transaction);  
ELSE  
    WRITE(transaction, file-2, newData);  
    END_TRANSACTION(transaction);  
END IF;
```

Essential: All READ and WRITE operations are executed, i.e. their effects are made permanent at the execution of END_TRANSACTION.

Observation: Transactions form an **atomic** operation.

Distributed Information Systems: Transactions

Model: A transaction is a collection of operations on the state of an object (database, object composition, etc.) that satisfies the following properties (**ACID**):

Atomicity: All operations either succeed, or all of them fail. When the transaction fails, the state of the object will remain unaffected by the transaction.

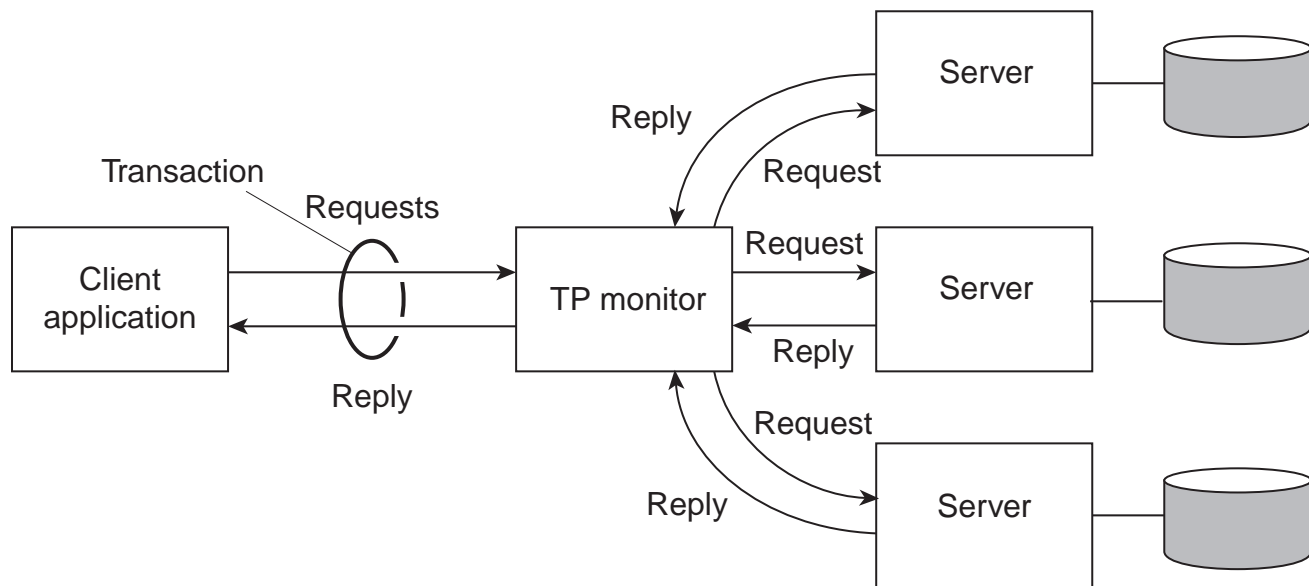
Consistency: A transaction establishes a valid state transition. This does not exclude the possibility of invalid, intermediate states during the transaction's execution.

Isolation: Concurrent transactions do not interfere with each other. It appears to each transaction T that other transactions occur either **before** T , or **after** T , but never both.

Durability: After the execution of a transaction, its effects are made permanent: changes to the state survive failures.

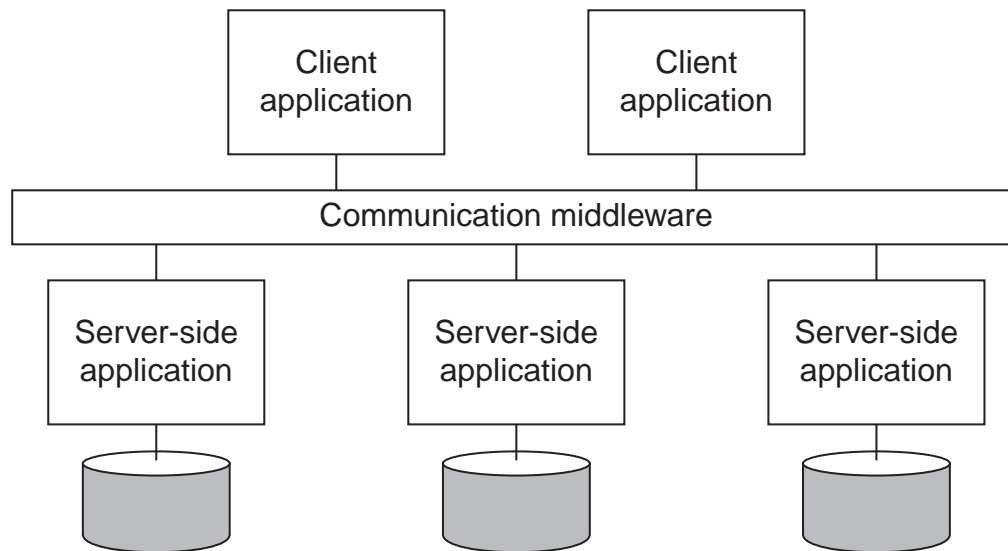
Transaction Processing Monitor

Observation: In many cases, the data involved in a transaction is distributed across several servers. A **TP Monitor** is responsible for coordinating the execution of a transaction:



Distributed Information Systems: Enterprise Application Integration

Problem: A TP monitor works fine for database applications, but in many cases, the apps needed to be separated from the databases they were acting on. Instead, what was needed were facilities for direct communication between applications:



- Remote Procedure Call (RPC)
- Message-Oriented Middleware (MOM)

Distributed Pervasive Systems

Observation: There is a next-generation of distributed systems emerging in which the nodes are small, mobile, and often embedded as part of a larger system. Some requirements:

- **Contextual change:** The system is part of an environment in which changes should be immediately accounted for.
- **Ad hoc composition:** Each node may be used in a very different ways by different users. Requires ease-of-configuration.
- **Sharing is the default:** Nodes come and go, providing sharable services and information. Calls again for simplicity.

Observation: Pervasiveness and distribution transparency may not always form a good match.

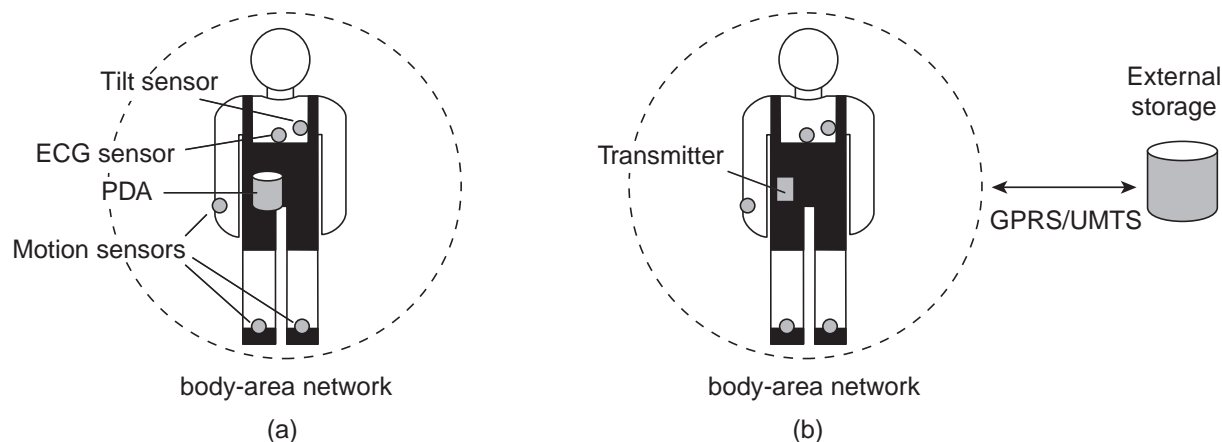
Pervasive Systems: Examples

Home Systems: Should be completely self-organizing:

- There should be no system administrator
- Provide a **personal space** for each of its users
- Simplest solution: a centralized **home box**?

Electronic health systems: Devices are physically close to a person:

- Where and how should monitored data be stored?
- How can we prevent loss of crucial data?
- What is needed to generate and propagate alerts?
- How can security be enforced?
- How can physicians provide online feedback?



Sensor networks

Characteristics: The **nodes** to which sensors are attached are:

- Many (10s-1000s)
- Simple (i.e., hardly any memory, CPU power, or communication facilities)
- Often battery-powered (or even battery-less)

Sensor networks as distributed systems: consider them from a **database perspective**:

