# Distributed Systems
# Principles and Paradigms

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## Chapter 01: Introduction

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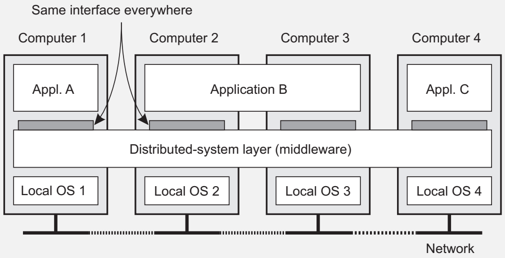
## Distributed System: Definition

A distributed system is

> *a collection of autonomous computing elements that appears to its users as a single coherent system*

Two aspects: (1) independent computing elements and (2) single system ⇒ middleware.



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## Goals of Distributed Systems

- Making resources available
- Distribution transparency
- Openness
- Scalability



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## Distribution transparency

| Transp. | Description |
|---|---|
| Access | Hide differences in data representation and how an object is accessed |
| Location | Hide where an object is located |
| Relocation | Hide that an object may be moved to another location while in use |
| Migration | Hide that an object may move to another location |
| Replication | Hide that an object is replicated |
| Concurrency | Hide that an object may be shared by several independent users |
| Failure | Hide the failure and recovery of an object |

**Note**

Distribution transparency is a nice a goal, but achieving it is a different story.



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## Degree of transparency

**Observation**

Aiming at full distribution transparency may be too much:

- Users may be located in different continents
- 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
  - Immediately flushing write operations to disk for fault tolerance



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## 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



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## Policies versus mechanisms

**Implementing openness**

Requires support for different policies:

- 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
- Support different levels of trust for mobile code
- Provide adjustable QoS parameters per data stream
- Offer different encryption algorithms



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## 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)

**Observation**

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.



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## 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



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## Techniques for scaling

**Distribution**

Partition data and computations across multiple machines:

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



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## Techniques for scaling

**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)



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## 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, but tolerating inconsistencies is application dependent.



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## 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



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## Types of distributed systems

- Distributed computing systems
- Distributed information systems
- Distributed pervasive systems



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## Distributed computing systems

**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



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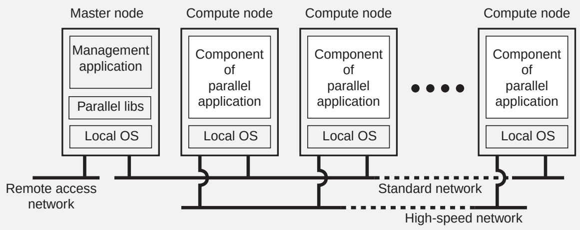
## Distributed computing systems



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## Distributed computing systems

**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.



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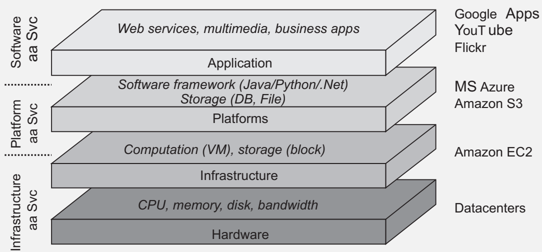
## Distributed computing systems: Clouds



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## Distributed computing systems: Clouds

### Cloud computing

Make a distinction between four layers:

- Hardware: Processors, routers, power and cooling systems. Customers normally never get to see these.
- Infrastructure: Deploys virtualization techniques. Evolves around allocating and managing virtual storage devices and virtual servers.
- Platform: Provides higher-level abstractions for storage and such. Example: Amazon S3 storage system offers an API for (locally created) files to be organized and stored in so-called buckets.
- Application: Actual applications, such as office suites (text processors, spreadsheet applications, presentation applications). Comparable to the suite of apps shipped with OSes.



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## 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
```

### Note

Transactions form an atomic operation.



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## 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.



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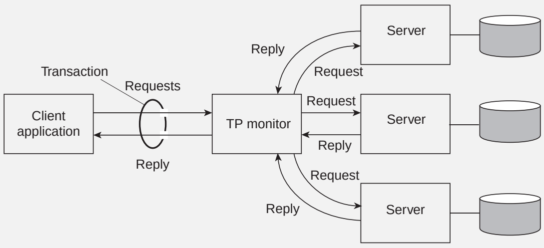
# Transaction processing monitor

**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



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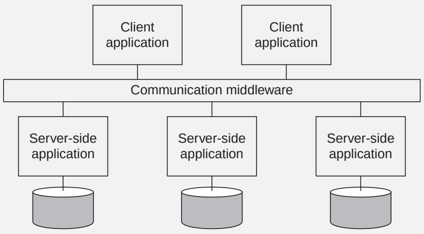
# Distr. info. systems: Enterprise application integration

**Problem**

A TP monitor doesn’t separate apps from their databases. Also needed are facilities for direct communication between apps.




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



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# Distributed pervasive systems

**Observation**

Emerging next-generation of distributed systems in which nodes are small, mobile, and often embedded in a larger system, characterized by the fact that the system naturally blends into the user’s environment.

**Three (overlapping) subtypes**

- Ubiquitous computing systems: pervasive and continuously present, i.e., there is a continous interaction between system and user.
- Mobile computing systems: pervasive, but emphasis is on the fact that devices are inherently mobile.
- Sensor (and actuator) networks: pervasive, with emphasis on the actual (collaborative) sensing and actuation of the environment.



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## Ubiquitous computing systems

### Basic characteristics

- (Distribution) Devices are networked, distributed, and accessible in a transparent manner
- (Interaction) Interaction between users and devices is highly unobtrusive
- (Context awareness) The system is aware of a user's context in order to optimize interaction
- (Autonomy) Devices operate autonomously without human intervention, and are thus highly self-managed
- (Intelligence) The system as a whole can handle a wide range of dynamic actions and interactions



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## Mobile computing systems

### Observation

Mobile computing systems are generally a subclass of ubiquitous computing systems and meet all of the five requirements.

### Typical characteristics

- Many different types of mobile divices: smart phones, remote controls, car equipment, and so on
- Wireless communication
- Devices may continuously change their location ⇒
  - setting up a route may be problematic, as routes can change frequently
  - devices may easily be temporarily disconnected ⇒ disruption-tolerant networks



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## Sensor networks

### Characteristics

The nodes to which sensors are attached are:

- Many (10s-1000s)
- Simple (small memory/compute/communication capacity)
- Often battery-powered (or even battery-less)



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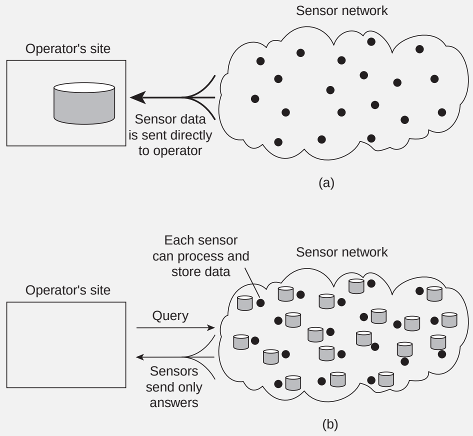
# Sensor networks as distributed systems



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