Introduction to Distributed Systems (DS)

INF5040 autumn 2006

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What is a distributed system?

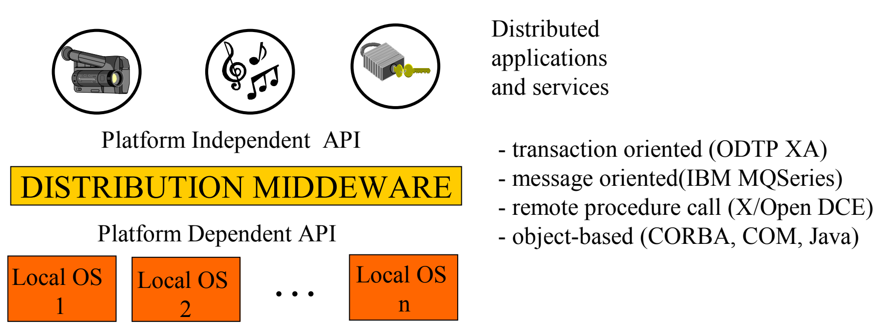
- Definition [Coulouris & Emmerich]
  - A distributed system consists of hardware and software components located in a network of computers that communicate and coordinate their actions only by passing messages.
- Definition [Lamport]
  - A distributed system is a system that prevents you from doing any work when a computer you have never heard about, fails.

Types of distributed system

- Distributed Computing Systems
  - Used for high performance computing tasks
  - Cluster computing systems
  - Grid computing systems
- Distributed Information Systems
  - Systems mainly for management and integration of business functions
  - Transaction processing systems
  - Enterprise Application Integration
- Distributed Pervasive Systems
  - Mobile and embedded systems
  - Home systems
  - Sensor networks

A distributed system organized as middleware

- Layer of software offering a single-system view
- Offers portability and interoperability
- Simplifies development of distributed applications and services



Implications of distributed systems

- Indpendent failure of components
  - "partial failure" & incomplete information
- Unreliable communication
  - Loss of connection and messages. Message bit errors
- Unsecure communication
  - Possibility of unauthorised recording and modification of messages
- Expensive communication
  - Communication between computers usually has less bandwidth, longer latency, and costs more, than between independent processes on the same computer
- Concurrency
  - components execute in concurrent processes that read and update shared resources. Requires coordination
- No global clock
  - makes coordination difficult

Requirements leading to distributed systems

- resource sharing
  - the possibility of using available resources any where
- openness
  - an open system can be extended and improved incrementally
- scalability
  - serve more users, provide shorter response times
- fault tolerance
  - maintain availability even when individual components fail
- heterogeneity
  - network and hardware, operating system, programming languages, implementations by different developers

Resource sharing

- The opportunity to use available hardware, software or data any where in the system
- Resource managers control access, offer a scheme for naming, and controls concurrency
- A resource manager is a software module that manages a resource of a particular type
- A resource sharing model describes how
  - resources are made available
  - resources can be used
  - service provider and user interact with each other

Models for resource sharing

- Client-server resource model
  - Server processes act as resource managers, and offer services (collection of procedures)
  - Client processes send requests to servers
- Object-based resource model
  - Any entity in a process is modeled as an object with a message based interface that provides access to its operations
  - Any shared resource is modeled as an object

Openness

- An open DS can be extended and improved incrementally
- Requires a uniform IPC mechanism and publication of component interfaces (e.g., subject to standardisation)
  - IETF RFC: Protocol specifications (www.ietf.org)
  - OMG: interface specifications etc. (www.omg.org)
- New components can be integrated with existing components

Concurrency

- Components in DS execute in concurrent processes
- Components access and update shared resources (e.g., variables, data bases, device drivers)
- Integrity of the system may be violated if concurrent updates are not coordinated
- Preservation of integrity requires concurrency control where concurrent access to the same resource is synchronized

Scalability

- A system is scalable if it remains effective when there is a significant increase in the amount of resources and number of users
  - Internet: no of users and services has grown enormously
- Scalability denotes the ability of a system to handle an increasing future load
- Requirements of scalability often leads to a distributed system architecture (several computers)

Scalability : challenges

- Controlling the costs of physical resources
  - A system with n users is resource-scalable if the amount of resources required to support them is at most O(*n*)
- Controlling the performance loss (when the amount of data increases)
  - A system is performance scalable if the time it takes to access hierarchically ordered data is at most O(log *n*) where *n* is the amount of data
- Preventing software resources running out:
  - Dimension data structures o.a. such that the system can meet future requirements (difficult – cf. IP addresses)
- Avoiding performance bottlenecks
  - require decentralized algorithms (partitioning, caching and replication)

Failure handling

- Hardware, software and network fail!!
- DS must maintain availability even in cases where hardware/software/network have low reliability
- Failures in distributed systems are partial
  - makes error handling particularly difficult
- Many techniques for handling failures
  - Detecting failures (checksum o.a)
  - Masking failures (retransmission in protocols, replication …)
  - Tolerating failures (as in web-browsers)
  - Recovery from failures
  - Redundancy (replicate servers in failure-independent ways)

Heterogeneity

- Variations and differences that must be handled
  - network
    - The Internett-protocol is implemented over many different networks
  - Hardware
    - difference in representation of data types on different processors
  - operating system
    - API to the same protocol and services varies
  - programmng languages
    - different representation of character set and data structurs
  - implementation by different developers
    - ensure that different programs can communicate
      - requires agreement on a number of things (cf. standards)

Transparency

- Transparency hides the consequences of distribution
- Transparency has different dimensions
- These represents different properties a distributed system might have (metric to assess the design of a system)

Access transparency

- Enables local and remote resources/components to be accessed using identical operations
- Example: File system operations in NFS
- Example : Navigation in www
- Example : SQL-queries in distributed data bases

- Components that do not have transparent access can not easily be moved to another computer

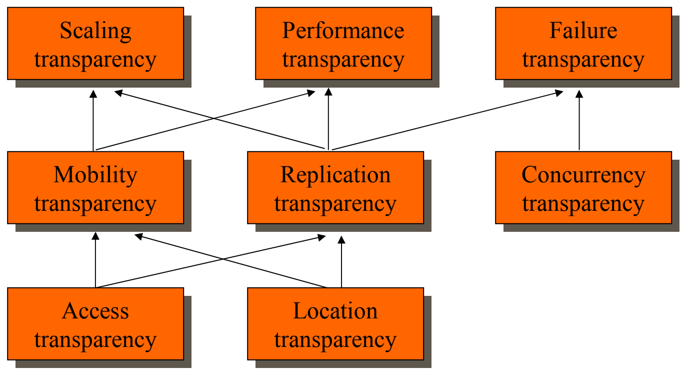
Location transparency

- Enables local and remote resources/components to be accessed without knowledge of their location
- Example: File system operations in NFS
- Example : Web pages (URLs) in www
- Example : Tables in distributed databases

Other transparency dimensions (Coulouris)

- Concurrency transparency
- Replication transparency
- Failure transparency
- Mobility transparency
- Performance transparency
- Scaling transparency

Distribution transparencies



Summary

- Distributed systems:
  - harware and software-components located in a network of computers that communicates and coordinates their actions exclusively by sending messages
- Consequences of distributed systems
  - Independent failure of components
  - Unsecure communication
  - No global clock
- Requirements like resource sharing, openness, scalability, fault tolerance and heterogeneity can be satisfied by distributed systems
- Distributed systems organized as middleware
  - Harvest potential advantages of distributed systems without having to pay for all their challenges and problems (transparency)

Design of distributed objects

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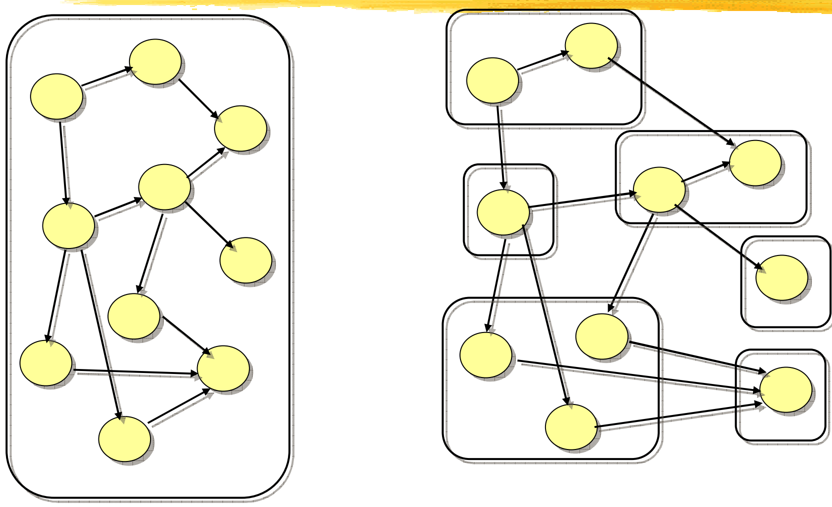
Design of distributed objects

- Many has experience with design of local objects that are all located in the execution environment of a OO programming language
- Design of distributed objects is different!

Design of distributed objects



Local vs distributed objects

- References
- Activation/deactivation
- Migration/mobility
- Persistence
- Latency for method calls
- Concurrency
- Communication
- Security
- Many pit falls!!

Object references

- References to objects in OOPS are usually pointers to memory cells
- References to distributed objects are more complex
  - location information
  - security information
  - references to object type
- References to distributed objects are larger (e.g., 350 byte i Orbix)

Activation/deactivation

- Objects in OOPS reside in main memory during their whole life time
- This does not always suit distributed objects
  - no of objects
  - objects can be used over a long period of time
  - some servers must be shut down from time to time without stopping the applications
- Distributed object implementations are
  - read into main memory (activation)
  - removed from main memory (deactivation)

Activation/deactivation

- Issues:
  - repository for implementations
  - association between objects and processes
  - explicit vs implicit activation
  - when to deactivate objects?
  - how to handle concurrent calls
- Who decides?
  - Designer?
  - Programmer?
  - Administrator?

Persistence

- Stateless vs stateful objects
- Stateful objects must store its state in a persisent repository between
  - object-deactivation and
  - object-activation
- Can be achieved by
  - making an external representation for file system
  - map to relational database
  - object database
- Decided at object design time

Object life cycle

- Objects in OOPS exist in a single virtual machine
- Distributed objects can be created on different computers
- Distributed objects can be copied or moved from one computer to an other
- Removal of objects by "garbage collection" is difficult in a distributed environment
  - Java RMI: "reference counting"
  - Jini: "leases"
- Life cycle must be considered at design time of distributed objects

Latency of method calls

- To execute a local method call requires a few hundred nanoseconds
- A remote method call requires between 0.1 og 10 milliseconds, or more
- ⇒ interfaces of distributed objects must be constructed such that
  - methods perform larger processing tasks
  - highly frequent method calls are not required

Parallelism

- Execution of objects in OOPS
  - sequential
  - concurrent with multiple threads
- Distributed objects execute in parallel
- Can be used to accelerate computations

Communication

- Method calls in OOPS are synchronous
- Alternatives for distributed objects:
  - synchronous requests
  - oneway requests
  - deferred synchronous requests
  - asynchronous requests
- Who decides for each call?
  - designer of service?
  - designer of client?
- How to document?

Security

- Security in OO applications can be handled at session level
- Objects in OOPS do not have to be written in a particular way
- For distributed objects
  - Who issues the method call?
  - How do we know that the client is the one he claims to be?
  - How can we decide whether to grant the client the right to use the service?
  - How can we prove that we have delivered the service to enable later billing for the use of the service?

Summary

- Design of distributed objects is different from design of programs where all object are located in the same process
- Many pit falls!!