Lecture 1
CMPU4021 Distributed Systems

Characterization of Distributed Systems

Based on Chapter 1: Coulouris, Dollimore and Kindberg, Distributed Systems: Concepts and Design

Introduction

What is a Distributed System (DS)?

- Multiple computers working together on one task
- Computers are connected by a network, and exchange information
- A distributed system is one in which
  - Component systems are networked for communication; and
  - Coordination through *message passing* only
    - allowing transparency of independent failure; and
    - lack of global clocks
- Key motivation for DS is
  - Sharing resources, e.g.
    - data storage, printers, files, databases, programs/applications, multimedia services: camera video/image, frames, audio/phone data

Characteristics

- Concurrency
  - Collaborative and cooperative problem-solving (interdependencies)
- Independent failures of components
  - Autonomous but interdependent - requires coordination, graceful degradation
- Lack of global clocks
  - Local (component) clocks and relativity of time when distributed
- Heterogeneity
  - Hardware/software (programs, data) variations in component systems

Characteristics I

- Openness
  - Modularity, architecture and standards allow extensibility
- Security
  - Protection (internal and external) against malicious use or attack – integrity
- Scalability
  - Accommodation of increased users and resource demands over time
- Transparency
  - Hide separation of components (hidden by middleware)

Examples of DS

- The Internet, WWW (Web), intranet, Web search, Massively multiplayer online games (MMOGs)

  – The internet is a very large DS, which provides worldwide services, e.g., the www services, emails, search engine services, file transfer (ftp), …

  – An intranet is a part of the Internet, separately owned and protected with firewalls local security and internal data sharing using file services

- Example systems using DS principles

  – Mobile computing (laptops, PDAs, wearable computing devices), uses wireless technologies

  – Ubiquitous computing (small embedded computers)

  – Services/resources encapsulated in and migrated as objects

Examples of DS - The Internet

- Interconnected computers/intranets, which communicate over backbone/medium via messages using the IP (Internet protocol)
- Medium:

  - wired: copper circuits, fibre optic

  - wireless: satellite

- A *backbone* is a network link with a high transmission capacity, employing satellite connections, fibre optic cables and other high-bandwidth circuits.

Examples of DS: Multiplayer Games

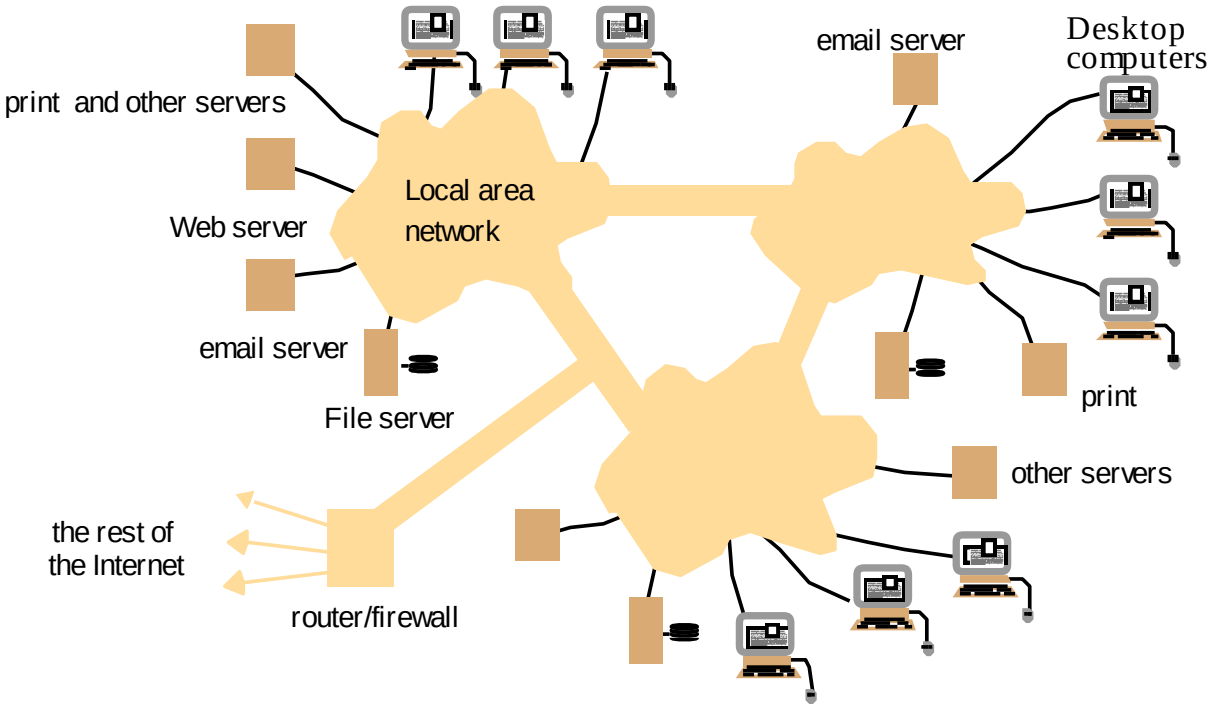
- Different players are doing different things
- Their actions must be consistent
  - Don't allow one person to be at different locations in views of different people
  - Don't let two people stand at the same spot
  - If X shoots Y, then everyone must know that Y is dead
- Made difficult by the fact that players are on different computers
- Sometimes network may be slow
- Sometimes messages can be lost

Examples of DS: Stock markets

- Everyone wants information quickly and to buy/sell without delay
- Updates must be sent to many clients fast
- Transactions must be executed in right order
- Specialized networks worth millions are installed to reduce latency

Examples of DS - Intranets

- Locally owned interconnected computers – *may be* a component of a DS, e.g., the Internet – if so, the intranet is connected via a router.
- Typically composed of LANs, with firewall (if connected to the Internet) for filtering incoming/outgoing transmissions



Example of DS - Mobile and ubiquitous computing

- Supported/spurred by advances in embedded system design – device miniaturization and wireless networking.
- *Mobile* computing – access to intranet resources/services on-the-move.
- *Ubiquitous* computing – transparent/intimate use of several, distributed and communicating small computing devices in *a given physical environment* (anywhere, anytime accessible) like office, hospital, home, classroom, …

The Web as an Internet Resource

- Transparent access to worldwide resources (databases, search engines, currency converters, web pages, programs/applications)

- Services - provided by distributed server *processes*: files/data,printing,computation; used by client *processes* via remote request invocation

Examples of DS: Web Search

- Google – a sophisticated distributed system infrastructure
  - A very large numbers of networked computers located at data centres all around the world;
  - A distributed file system designed to support very large files and heavily optimised for the style of usage required by search and other Google applications
  - An associated structured distributed storage system that offers fast access to very large datasets;
  - A lock service that offers distributed system functions such as distributed locking and agreement;
  - A programming model that supports the management of very large parallel and distributed computations across the underlying physical infrastructure.

Examples of DS: Massively multiplayer online games (MMOGs)

- A number of solutions
  - EVE Online (CPP Games)
    - Client-server architecture
    - A single copy of the state of the world is maintained
  - Other MMOGs (e.g. EverQuest) adopt
  - More distributed architecture with potentially large number of servers
  - Researchers are now looking at more radical architecture
    - Based on peer-to-peer technology

DS Challenges

- Fundamental issue
  - Different nodes have different knowledge. One node does know the status of other nodes in the network
- If each node knew exactly the status at all other nodes in the network, computing would be easy.
- But this is impossible, theoretically and practically

Theoretical issue: Knowledge cannot be perfectly up to date

- Information transmission speed
  - hardware and software limitations of the nodes & network
- New things can happen while information is traveling from node A to node B
- B can never be perfectly up to date about the status of A

Practical Challenges

- Communication is costly
  - It is not practical to transmit everything from A to B all the time
- There are many nodes
  - Transmitting updates to all nodes and receiving updates from all nodes are even more impractical

DS Challenges – Heterogeneity I

- Heterogeneity (variety and difference) applies to:
  - Networks- differences are masked by the fact that all of the computers use the Internet protocols to communicate.
  - Hardware – data types, such as integers, may be represented in different ways on different sorts of hardware (byte ordering: big-endian, little-endian)
  - Operating systems – do not provide the same application API to the Internet protocols.
  - Programming languages – used different representations for characters and data structures, such as arrays and records.
  - Developers – representation of primitive data items and data structures needs to be agreed upon (standards)

DS Challenges – Heterogeneity I

- Middleware
  - Software layer that provides a programming abstraction as well as masking the heterogeneity of the underlying networks, hardware, operating systems and programming languages (e.g. CORBA, Java RMI)
  - All middleware deals with the differences in operating systems and hardware.

- Mobile code
  - The code that can be sent from one computer to another and run at the destination (e.g. Java applets). Machine code suitable for running on one type of computer hardware is not suitable for running on another
  - Virtual machines approach – provides a way of making code executable on any hardware: the compiler for a particular language generates code for a virtual machine instead of a particular hardware order code.

DS Challenges - Openness

- The characteristic that determines whether the system can be extended and re-implemented in various ways.
- Can it be extended with new content/services without disruption to the underlying system?

- Key interfaces/standards are published

- Standards
  - Request For Comments (RFC)s
  - IETF
  - W3C
  - OMG (CORBA)

- Everything conforms to a standard!

DS Challenges – Openness I

- *Open systems* are characterized by the fact that their key interfaces are published.

- *Open distributed systems* are based on the provision of a uniform communication mechanism and published interfaces for access to shared resources.
  - They can be constructed from heterogeneous hardware and software, possibly from different vendors

DS Challenges - Security

- Three main issues
  - Confidentially
    - protection against disclosure to unauthorized individuals
  - Integrity
    - protection against alteration or corruption
  - Availability
    - protection against interference with the means to access the resources

DS Challenges – Security I

- Denial of Service
- Viruses/Worms
- Password Crackers
- Packet sniffers
- Trojan horses
- Spoofing
- Mobile Code

DS Challenges - Scalability

A system is scalable if it will remain effective if there is a significant increase in the number of resources and the number of users

- Control cost of physical resources
  - *For a system with n users to be scalable, the* quantity of physical resources required to support them should be at most O(*n*) – that is, proportional to n.
    - E.g., if a single file server can support 20 users, then two such servers should be able to support 40 users.
- Control performance loss
  - Maximum performance loss should be no worse than O(*log n*) where *n* is size of data.

DS Challenges – Scalability I

- Prevent software resources running out.
  - IP Addresses (initially 32 bits). New version 128-bit
- Avoid performance bottle neck
  - Algorithms should be decentralised to avoid having performance bottlenecks.

    Predecessor of the Domain Name System (DNS) kept the name table in a single master file that could be downloaded to any computers that needed it - fine with a few hundred computers.

    The DNS removed the bottleneck by partitioning the name table between servers located throughout the Internet and administered locally.
- Scalability techniques:
  - Replicated data, caching, multiple servers etc.

DS Challenges - Failure Handling

- Failures in distributed systems are mostly partial failures which can make failure handling more difficult

- Detecting failures
  - Checksums

- Masking failures
  - retransmission
  - duplicate files

DS Challenges - Failure Handling I

- Tolerating failures
  - Web pages (informing users about failure)
- Recovery

  - permanent data ‘rolled back’
- Redundancy (use of redundant components)
  - Duplication in routes, hardware,
  - DNS – every name table replicated in at least two different servers,
  - Databases – replicated in several servers
- Availability – measure of the proportion of time a system is available for use.
- DS provide a high degree of availability regarding hardware faults.

DS Challenges - Concurrency

- Resources can be shared by clients in a distributed system, therefore several clients may access a shared resource at the same time
- Not acceptable that each request be processed in turn, must be able to process requests concurrently
- For each ‘object’ that represents a shared resource, its operations must be synchronised in such a way that its data remains consistent

Transparencies

- The concealment from the user and application programmer of the separation of components in a distributed system:
  - Access transparency
  - Location transparency
  - Concurrency transparency
  - Replication transparency
  - Failure transparency
  - Mobility transparency
  - Performance transparency
  - Scaling transparency

DS Challenges – Transparency I

- Access transparency: enables local and remote resources to be accessed using identical operations.
  - A GUI with folders, which is the same whether the files are local or remote.
- Location transparency: enables resources to be accessed without knowledge of their location
  - Web resource names or URLs – because the part of the URL that identifies a web server domain name refers to a computer name in a domain, rather than to an Internet address.
- Concurrency transparency
  - Enables several processes to operate concurrently using shared resources without interference between them.

DS Challenges – Transparency II

- *Replication transparency*: enables multiple instances of resources to be used to increase reliability and performance without knowledge of the replicas by users or application programmers.

- *Failure transparency*: enables the concealment of faults, allowing users and application programs to complete their tasks despite the failure of hardware or software components.

  - Email is eventually delivered, even when servers or communication links fail.

DS Challenges – Transparency III

- *Mobility transparency*: allows the movement of resources and clients within a system without affecting the operation of users or programs.

  - Mobile phone users (client – resource)

- *Performance transparency*: allows the system to be reconfigured to improve performance as loads vary.

- *Scaling transparency*: allows the system and applications to expand in scale without change to the system structure or the application algorithms.

Distributed Systems - Issues I

- Remote Method Invocation – dispatching method requests, marshalling of parameters etc.
- Load balancing – directing clients to servers with light loads
- Transparent failover – server crashes, how fast can clients be rerouted to other servers without interruption
- Backend integration – legacy systems

Distributed Systems - Issues II

- Transactions – simultaneous updates in database when it crashes
- Clustering – server contains state when it crashes, is that state replicated across all servers?
- Dynamic redeployment – how do you perform updates with the system is running?

Distributed Systems - More Issues III

- Clean shutdown – can you shutdown a server without disruption to a client?
- Logging and Auditing – if something goes wrong are their logs available for debugging purposes?
- System Management – if there is a catastrophic error who is notified and how?

Distributed Systems - Issues IV

- Threading – how do we implement threading to facilitate concurrency
- Object lifecycle – when do objects in the system need to be created/destroyed
- Resource pooling – if a client is not using a resource, it should be returned to the pool of resources
- Caching – if particular information is being requested constantly, should and how can we cache it?

Summary

- A distributed system is one in which component systems are networked for communication and coordination through
  - Message passing only - allowing transparency of independent failure and lack of global clocks)
- Resource sharing is the main motivating factor for constructing distributed systems.
- Make it easier to integrate different applications running on different computers
- If designed properly, they can scale well
- Often comes at the cost of more complex software, degradation of performance and weaker security
- Middleware is a key facility for the building of distributed systems