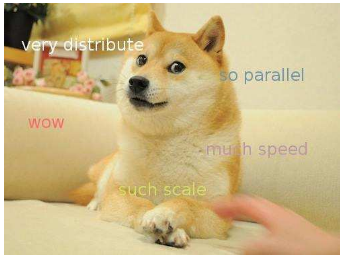
Slide 1

Distributed Systems (COMP9243)



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Slide 2

DISTRIBUTED SYSTEMS (COMP9243)

Introduction

① Distributed Systems - what and why
② Hardware and Software
③ Goals
④ Overview - principles and paradigms

Slide 3

DISTRIBUTED SYSTEMS

What is a *distributed system?*

➜ Andrew Tannenbaum defines it as follows:

> *A distributed system is a collection of independent computers that appear to its users as a single coherent system.*

➜ Is there any such system? ~~Hardly!~~ Kind of

➜ We will learn about the challenges in building "true" distributed systems

For the time being, we go by a weaker definition of distributed system:

> *A distributed system is a collection of independent computers that are used jointly to perform a single task or to provide a single service.*

Slide 4

Examples of distributed systems

➜ Cray XK7 & CLE (massive multiprocessor)

➜ Distributed file system on a LAN

➜ Domain Name Service (DNS)

➜ Collection of Web servers: distributed database of hypertext and multimedia documents

Slide 5

Find more examples of distributed systems:

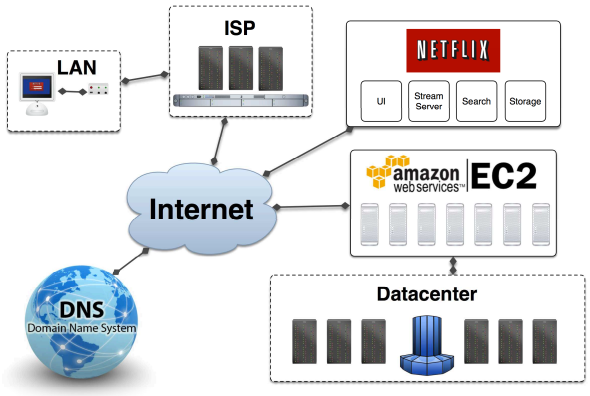
Remember

> *A distributed system is a collection of independent computers that are used jointly to perform a single task or to provide a single service.*

What's the difference between a distributed application and distributed system?

Slide 6

Interdependence of Distributed Systems



Slide 7

The Advantages of Distributed Systems

What are economic and technical reasons for having distributed systems?

Cost. Better price/performance as long as commodity hardware is used for the component computers

Performance. By using the combined processing and storage capacity of many nodes, performance levels can be reached that are out of the scope of centralised machines

Scalability. Resources such as processing and storage capacity can be increased incrementally

Reliability. By having redundant components, the impact of hardware and software faults on users can be reduced

Inherent distribution. Some applications like the Web are naturally distributed

Slide 8

The Disadvantages of Distributed Systems

What problems are there in the use and development of distributed systems?

New component: network. Networks are needed to connect independent nodes, are subject to performance limits

Software complexity. Distributed software is more complex and harder to develop than conventional software; hence, it is more expensive and harder to get right

Failure. More elements that can fail, and the failure must be dealt with

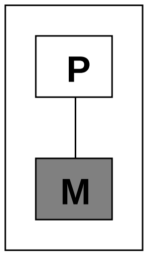
Security. Easier to compromise distributed systems

Distributed systems are hard to build and understand
➸ this course is going to be very challenging!

Slide 9

Hardware Architecture

Uniprocessor:

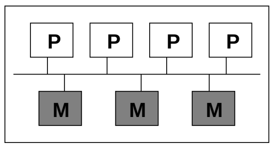


Properties:

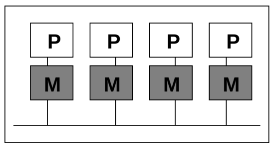
- ➜ Single processor
- ➜ Direct memory access

Slide 10

Multiprocessor:



Uniform



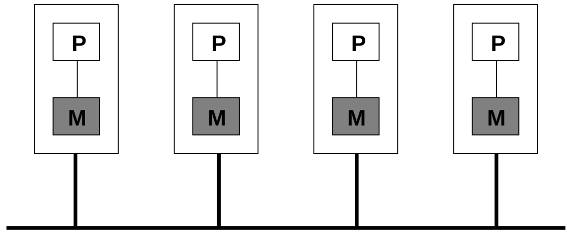
Nonuniform

Properties:

- ➜ Multiple processors
- ➜ Direct memory access
  - Uniform memory access (e.g., SMP, multicore)
  - Nonuniform memory access (e.g., NUMA)

Slide 11

Multicomputer:



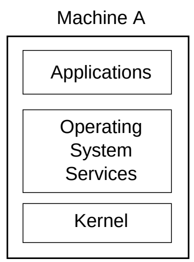
Properties:

- ➜ Multiple computers
- ➜ No direct memory access
- ➜ Network
- ➜ Homogeneous vs. Heterogeneous

Slide 12

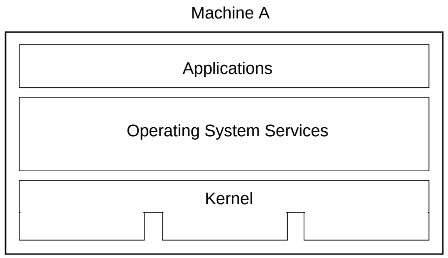
Software Architecture

Uniprocessor OS:



Slide 13

Multiprocessor OS:



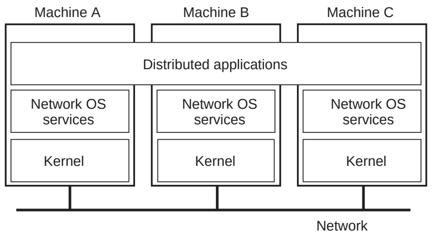
Similar to a uniprocessor OS but:

- ➜ Kernel designed to handle multiple CPUs
- ➜ Number of CPUs is transparent
- ➜ Communication uses same primitives as uniprocessor OS
- ➜ Single system image

What's the limitation here?

Slide 14

Network OS:



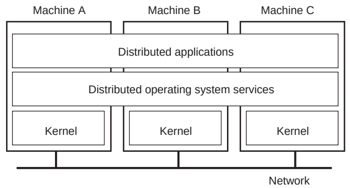
Properties:

- ➜ No single system image. Individual nodes are highly autonomous
- ➜ All distribution of tasks is explicit to the user
- ➜ Examples: Linux, Windows

What's the challenge with this approach?

Slide 15

Distributed OS:



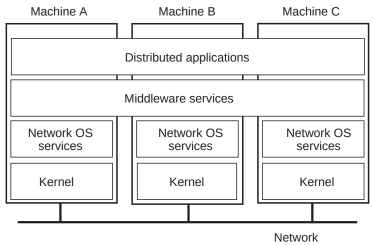
Properties:

- ➜ High degree of transparency
- ➜ Single system image (FS, process, devices, etc.)
- ➜ Homogeneous hardware
- ➜ Examples: Amoeba, Plan 9, Chorus, Mungi

Are there any problems with this approach?

Slide 16

Middleware:



Properties:

- ➜ System independent interface for distributed programming
- ➜ Improves transparency (e.g., hides heterogeneity)
- ➜ Provides services (e.g., naming service, transactions, etc.)
- ➜ Provides programming model (e.g., distributed objects)

Slide 17

Why is Middleware 'Winning'?:

- ➜ Builds on commonly available abstractions of network OSes (processes and message passing)
- ➜ Examples: RPC, NFS, CORBA, MQSeries, SOAP, REST, MapReduce
- ➜ Also languages (or language modifications) specially designed for distributed computing
- ➜ Examples: Erlang, Ada, Limbo, Go, etc.
- ✓ Usually runs in user space
- ✓ Raises level of abstraction for programming ➽ less error-prone
- ✓ Independence from OS, network protocol, programming language, etc. ➽ Flexibility
- ✗ Feature dump and bloated interfaces

Slide 18

Distributed Systems and Parallel Computing

- ➜ Parallel computing: improve performance by using multiple processors per application
- ➜ There are two flavours:
  1. Shared-memory systems:
     - Multiprocessor (multiple processors share a single bus and memory unit)
     - SMP support in OS
     - Much simpler than distributed systems
     - Limited scalability
  2. Distributed memory systems:
     - Multicomputer (multiple nodes connected via a network)
     - These are a form of distributed systems
     - Share many of the challenges discussed here
     - Better scalability & cheaper

Slide 19

Distributed Systems in Context

Networking:

- ➜ Network protocols, routing protocols, etc.
- ➜ Distributed Systems: make use of networks

Operating Systems:

- ➜ Resource management for single systems
- ➜ Distributed Systems: management of distributed resources

This Course:

- ➜ Generalised solutions to distributed systems problems and challenges
- ➜ Infrastructure software to help build distributed applications

Slide 20

Basic Goals of Distributed Systems

We want distributed systems to have the following properties:

- ➜ Transparency
- ➜ Dependability
- ➜ Scalability
- ➜ Performance
- ➜ Flexibility

This course will examine approaches and techniques for designing and building distributed systems that achieve these goals.

Slide 21

Transparency

Concealment of the separation of the components of a distributed system (single image view).

There are a number of forms of transparency

Access: Local and remote resources accessed in same way

Location: Users unaware of location of resources

Migration: Resources can migrate without name change

Replication: Users unaware of existence of multiple copies

Failure: Users unaware of the failure of individual components

Concurrency: Users unaware of sharing resources with others

Is transparency always desirable? Is it always possible?

Slide 22

Dependability

- ➜ Dependability of distributed systems is a double-edged sword:
  - Distributed systems promise higher availability:
    - Replication
  - But availability may degrade:
    - More components ➽ more potential points of failure
- ➜ Dependability requires consistency, security, and fault tolerance

Slide 23

Scalability

A system is said to be scalable if it can handle the addition of users and resources without suffering a noticeable loss of performance or increase in administrative complexity

(B. Clifford Neuman)

Scale has three dimensions:

Size: number of users and resources (problem: overloading)

Geography: distance between users and resources (problem: communication)

Administration: number of organisations that exert administrative control over parts of the system (problem: administrative mess)

Note:

- ➜ Scalability often conflicts with (small system) performance
- ➜ Claim of scalability is often abused

Slide 24

Scaling Up or Out?

Vertical Scaling: Scaling UP Increasing the resources of a single machine

Horizontal Scaling: Scaling OUT Adding more machines

Slide 25

Techniques for scaling:

- ➜ Hiding communication latencies (asynchronous communication, reduce communication)
- ➜ Distribution (spreading data and control around)
- ➜ Replication (making copies of data and processes)
- ➜ Decentralisation

Slide 26

Decentralisation

Avoid centralising:

- ➜ Services (e.g., single server)
- ➜ Data (e.g., central directories)
- ➜ Algorithms (e.g., based on complete information).

With regards to algorithms:

- ➜ Do not require machine to hold complete system state Why?
- ➜ Allow nodes to make decisions based on local info Why?
- ➜ Algorithms must survive failure of nodes Why?
- ➜ No assumption of a global clock Why?

Decentralisation is *hard*

Slide 27

PERFORMANCE

- ➜ Any system should strive for maximum performance
- ➜ In distributed systems, performance directly conflicts with some other desirable properties
  - Transparency
  - Security
  - Dependability
  - Scalability

How?

Slide 28

NUMBERS EVERY PROGRAMMER SHOULD KNOW

```
L1 cache reference ...................... 0.5 ns
Branch mispredict ......................... 5 ns
L2 cache reference ........................ 7 ns
Mutex lock/unlock ........................ 25 ns
Main memory reference ................... 100 ns
Compress 1K bytes with Zippy ......... 3,000 ns = 3 us
Send 2K bytes over 1 Gbps network .... 20,000 ns = 20 us
Read 1 MB sequentially from memory .. 250,000 ns = 250 us
Round trip within same datacenter ... 500,000 ns = 0.5 ms
Disk seek ....................... 10,000,000 ns = 10 ms
Read 1 MB sequentially from disk . 20,000,000 ns = 20 ms
Send packet CA->Netherlands->CA . 150,000,000 ns = 150 ms
```

(from Peter Norvig, Jeff Dean, see also http://www.eecs.berkeley.edu/~rcs/research/interactive_latency.html)

Slide 29

Flexibility

- ➜ Build a system out of (only) required components
- ➜ Extensibility: Components/services can be changed or added
- ➜ Openness of interfaces and specification
  - allows reimplementation and extension
- ➜ Interoperability
- ➜ Separation of policy and mechanism
  - standardised internal interfaces

Slide 30

Common Mistakes

False assumptions commonly made:

1. Reliable network
2. Zero latency
3. Infinite bandwidth
4. Secure network
5. Topology does not change
6. One administrator
7. Zero transport cost
8. Everything is homogeneous

Slide 31

Principles

Several key principles underlying the functioning of all distributed systems

- ➜ System Architecture
- ➜ Communication
- ➜ Partitioning, Replication and Consistency
- ➜ Synchronisation & Coordination
- ➜ Naming
- ➜ Fault Tolerance
- ➜ Security

Discussion of these principles will form the core content of the course

Slide 32

Paradigms

Most distributed systems are built based on a particular paradigm (or model)

- ➜ Shared memory
- ➜ Distributed objects
- ➜ Distributed file system
- ➜ Distributed coordination
- ➜ Service Oriented Architecture and Web Services
- ➜ Distributed Database
- ➜ Shared documents
- ➜ Agents

This course will cover the first five in detail.

Slide 33

Miscellaneous 'Rules of Thumb'

Trade-offs Many of the challenges provide conflicting requirements. For example better scalability can cause worse overall performance. Have to make trade-offs - what is more important?

Separation of Concerns Split a problem into individual concerns and address each separately

End-to-End Argument Some communication functions can only be reliably implemented at the application level

Policy vs. Mechanism A system should build mechanisms that allow flexible application of policies. Avoid built-in policies.

Keep It Simple, Stupid make things as simple as possible, *but no simpler*.

Slide 34

Reading List

End-to-end Arguments in System Design A classic paper arguing the end-to-end argument with excellent examples.

A Note on Distributed Computing Another classic paper showing the dangers of too much transparency in RPC-based distributed systems.

Fallacies of Distributed Computing Explained A good explanation of the 8 common mistakes made by architects and designers of distributed systems.

Scale in Distributed Systems A really good paper to read if you are interested in understanding more about scalability in distributed systems.

Slide 35

Overview of Course

① Introduction and Erlang
② System Architecture and Communication
③ Replication and Consistency, Distributed Shared Memory
④ Synchronisation and Coordination
⑤ Dependability and Fault Tolerance
⑥ Security
⑦ Naming
⑧ Distributed File Systems
⑨ Middleware, Distributed Objects, Publish/Subscribe, SOA, Web Services
⑩ Cloud Computing

Extras:

① Distributed Systems in Practice
② Blockchain

Slide 36

Homework

Examples of Distributed Systems:

➜ Choose an existing distributed system and
  ① Research its structure (i.e. what is its internal architecture?)
  ② Evaluate how it satisfies each of the goals discussed

Hacker's edition:

➜ For your chosen system:
  ① Are there any obvious mistakes in the architecture and design?
  ② Are there any strange design decisions? Why might they have been made?