Introduction of *Distributed System*

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Introduction

- **Computer Systems are under going a revolution**
- **From 1945 until about 1985,**
  - Computers were large & expensive
  - Lack of a way to connect them
    (operated independently from one another)
- **In the Mid-80'**
  - Powerful microprocessors are developed
  - High-speed computer networks are invented
  - Not only feasible, but easy to put together computing systems composed of large number of computers connected by a high-speed network
  - They are called computer networks or distributed systems
    (in contrast to the previous centralized systems)

1.1. Definition of a Distributed System

- **"A Distributed system is a collection of independent computers that appears to its users as a single coherent system"**
- **Two aspect**
  - Hardware: the machines are autonomous
  - Software: the users think they are dealing with a single system
- **Characteristics**
  - Differences between the various computers and the ways in which they communicate are hidden from users
  - Users and applications can interact with a distributed system in a consistent and uniform way, regardless of where and when interaction takes place

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1.1. Definition of a Distributed System

- **Characteristics**
  - Relatively easy to expand or scale
  - Normally be continuously available
    (although certain parts may be temporarily out of order)
  - Offering a single system view : → **Middleware**
    (in heterogeneous environments)

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1.2. Goals

- A distributed system should easily connect users to resources;
- it should hide the fact that resources are distributed across a network
- it should be open
- and it should be scalable

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1.2.1 Connecting Users and Resources

- Is to make it easy for users to access remote resources, and to share them with other users in a controlled way
  - Reason for sharing resources: economics
- Easier to collaborate and exchange information
  - Internet, groupware
- Security is becoming more and more important as connectivity and sharing increase
  - Tracking communication to build up a preference profile of a specific user

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1.2.2. Transparency

- Is to hide the fact that its processes and resources are physically distributed across multiple computers → transparent

① access transparency

: hiding differences in data representation and how a resource is accessed

- Ex) to send an integer from intel-based workstation to SUN SPARC machine
- Ex) different naming convention

② location transparency

: users cannot tell where a resource is physically located in the system → "naming"

- Ex) assigning only logical names to resources

1.2.2. Transparency

③ migration transparency

: resources can be moved without affecting how that resource can be accessed

④ relocation transparency

: resources can be relocated while they are being accessed without the user or application noticing anything

- Ex) when mobile users can continue to use their wireless laptop while moving from place to place without ever being (temporarily) disconnected

⑤ replication transparency

: resources may be replicated to increase availability or to improve performance by placing a copy close to the place where it is accessed

- All replicas have the same name
- Support location transparency

1.2.2. Transparency

⑥ concurrency transparency

: **hide that a resource may be shared by several competitive users**

- Issue: concurrent access to a shared resource leaves that resource in a consistent state
  - Consistency can be achived through locking mechanisms

⑦ failure transparent

: **a user does not notice that a resource fails to work properly, and that the system subsequently recovers from that failure**

- Difficulty in masking failures lies in the inability to distinguish between a dead resource and a painfully slow resource

1.2.2. Transparency

⑧ persistence transparency

: **masking whether a resource is in volatile memory or or perhaps somewhere on a disk**

- In object-oriented databases user is unaware that the server is moving state between primary and secondary memory

- **Degree of Transparency**
  - Trade-off between a high degree of transparency and the performance of a system

1.2.3. Openness

- **Open distributed system is a system that offers services according to standard rules that describe the syntax and semantics of these services**
  - In computer networks
    : standard rules govern the format contents, meaning of messages sent and received
    - Formalized in protocols
  - In Distributed system
    : services are specified through interfaces (IDL: interface Definition Language)
    - Specify the names of the functions that are available together with type of the parameters, return values, possible exceptions
    - Hard part: the semantics of interfaces (by means of natural language) → informal way

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1.2.3. Openness

- Once properly specified, an interface definition
  - Allows an arbitrary process to talk another process through that interface
  - Allows two independent parties to build different implementations of those interface
- **Proper specifications** are complete & neutral
  - Complete: everything that is necessary to make an implementation has indeed been specified (in real world not at all complete)
  - Neutral: specifications do not prescribe what the implementation should look like they should be neutral

Important for Interoperability and portability

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1.2.3. Openness

- **Interoperability**
  - Two implementations of systems or components from different manufacturers can co-exist and work together by merely relying on each other's services as specified by a common standard
- **Portability**
  - An application developed for a distributed system A can be executed, without modification, on a different distributed system B that implements the same interfaces as A
- **Flexibility**
  - It should be easy to configure the system out of different components prossibly from different developers
  - Easy to add new components or replace existing ones without affecting those components that stay in place

1.2.3. Openness

- **Separating Policy from Mechanism**
  - To achieve flexibility, the system in origanized as a collection of relatively small and easily replaceable or adaptable components
    - Implies that should provide definitions of the high-level interface and the internal parts of the system (how parts interact)
    - A component dose not provide the optional policy for a specific user or application
      ex : caching in WWW

1.2.3. Openness

- **Ex: caching policy**
  - Browsers allow a user to adapt their caching policy by specifying the size of cache, whether a cached document should always be checked for consistency, or only once per session
  - But, the user can not influence other caching parameters, how long a document may remain in the cache, or which document should be removed when the cache fills up. Impossible to make caching decisions based on the content of document.
- **We need a seperation between policy& mechanism**
  - Browser should ideally provide facilities for only storing documents (mechanism)
  - Allow users to decide which documents are stored and for how long (policy)
  - In practice, this can be implemented by offering a rich set of parameters that the use can set dynamically
  - Even better is the a user can implement his own policy in the form of a component that can be plugged into the browser. the component must have an interface that the browser can understand.

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1.2.4 Scalability

- **Measured 3 different dimensions**

① **Size : can easily add more users and resources to the system**

② **Geographically scalable system : the users and resources may lie for apart**

③ **Administratively scalable : it can be easy to manage even if it spans many independent administrative organizations.**

- Some loss of performance as the system scales up

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Scalability problems

- **1. Size**
: Confronted with the limitations of

① Centralized services : A single server for all users
  - problem : the server become a bottleneck as the number of user grows
  - Unavoidable using a single server : service for managing highly confidential information such as medical records, bank accounts......
  - Copying the server to several locations to enhance performance ➔ Vulnerable to security attack

② Centralized Data : A single on-line telephone book
  - problem : saturate all the communication lines into and out of a single database

③ Centralized Algorithm : Doing routing based on complete information.
  - Problem : theoretical point of view the optimal way to do routing in collect complete information about load on all machines and lines and then run a graph theory algorithm to compute all the optimal route.
  - Problem : messages would overload part of network
  - Solution : Decentralized Algorithms should be used

Characteristics
  ① No machine has complete information about the system state.
  ② Machines make decisions based only on local information.
  ③ Failure of one machine does not ruin the algorithms.
  ④ There are no implicit assumption that a global check exists.
  ➔ Clock synchronization in tricky in WAN

- **2. Geographical Scalability**
  - Problem
    - ① LAN used on synchronous communication.
      WAN had to use synchronous communication.
    - ② In WAN, inherently unreliable (point-to-point)
      In WAN, highly reliable communication (broad casting)
  - Geographical scalability is related to the problems of centralized solutions that hinder size scalability.

- **3. Administrative scalability**
  - How to scale a distributed system across multiple, independent administrative domains.
  - Problem needs to solved :
    - Conflicting policies with respect to resource usage management, and security.
    - ➔ The trust does not expand naturally across domain boundaries
    - If a distributed system expands to another domain, two types of security measures need to be taken.

  Distributed system

  ① Has at protect itself against malicious attacks from the new domain

  ② The new domain has to protect itself against malicious attack from the distributed system.

Scaling Techniques

① Hiding communication latencies

② Distribution

③ Replication

① Hiding communication latencies

- Solution : Try to avoid waiting for responses to remote service requests as much as possible.
  - Asynchronous communication is a solution.

In reality, many applications not use of asynchronous communication

- Example : Interactive applications.

  by moving part of computations which usably done at the server to the client process.

  Accessing DB case Figure 1-4.

Figure 1-4a

Normally, filling in forms is done by sending a separate message for each field, and waiting for an ACK form the server. The server check for syntactic error before accepting on entry.

Solution

Figure 1-4b

- **Ship the code for filling in the form to the client, and have the client return a complete form**

➔ Reduce overall communication overhead.

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② Distribution

- **Taking a component, splitting it into smaller parts, and subsequently spreading those parts across the system.**
- **Example : DNS (Domain Name System)**
  - The DNS name space in hierarchically organized into a tree of domains, which are divided into non overlapping zones.
  - The names in each zone are handled by a single name server

    Ex : xl, vu, cs, flits.

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③ Replication

- Scalability problems often appear in the form of performance degradation, it is a good idea to actually replicate components across a distributed system.
- Replication increases availability and load balance.
- Having a copy nearby can hide much of the communication latency problems.
- Caching is a special form of replication.
- Leads to consistency problems.

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1.3 Hardware Concept

- Even though distributed systems consist of multiple CPUs there are several ways the H/W can be organized => How they are interconnected & communicate

① Classification
- Shared Memory => multiprocessors :
  - a single physical address space that is shared by all CPUs
- Non shared Memory => Multicomputers :
  - Every machine has its own private memory.
  - Common example : a collection of PC connected by a network

memory

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② Architecture of the interconnection network base

- **Two categories**

Network interconnection

  - Bus :
    - There in a single network (back pane, bus, cable) that connects all the machines : example cable TV
  - Switch :
    - Do not use a single backbone like cable TV

    Instead, there are individual wires from machine to machine with different wiring patterns in use

    example : World wide public telephone.

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③ Only for multicomputer

- Homogeneous : only a single interconnection network that uses the dame technology every where. All processors are the same.

  =>tend to be used as parallel system

- Heterogeneous :
  - contain a variety of different, independent computers, which in turn are connected through different
  - Networks => Distributed computer system may be constructed from a collection of different local-area networks

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1.3.1 Multiprocessors

- Share a single key property : all the CPUs gave direct access to the shared memory.
- Coherent : since there in only one memory,

  if CPU A write a word to memory and then CPU B reads that word back a microsecond later, B will get the value just written.
- Problem : with as few as 4 or 5 CPUs, the bus will usually be overloaded and performance will drop drastically

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- Solution : is to add a high-speed cache memory between the CPU & the bus.

  [Fig 1-7] -> reduce bus traffic

  hitrate : the probability of success (the word requested is in the cache)

  ex: cache size : 512KB to 1MB are common

  hit rate 90% or more

cache

- Another problem of cache : memory incoherent

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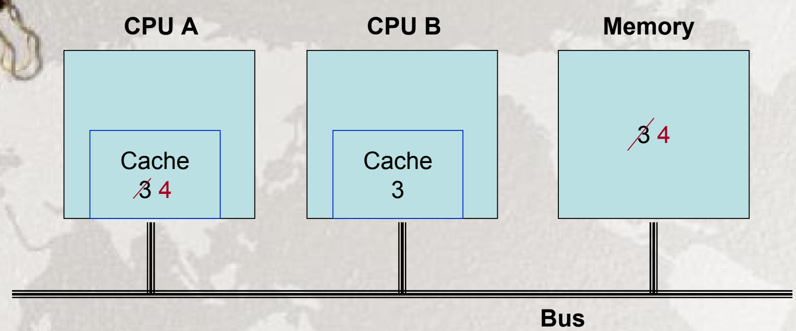

1. CPU A & B each read the same word into their respective caches
2. CPU A read 3 -> overwite 4
3. CPU B read 3 -> 3 in the oed value <- not the value A just wrote

∴ **incoherent** : the system is difficult to program

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- **Another problem of bus-based Multiprocessor**

limited scalability even when using "cache"

  – Crossbar switch [refer to Fig 5.8-3]
- **The virtue of the crossbar switch**
  – Many CPUs can be accessing memory at the same time although if two CPUs try to access the same memory simultaneously, one of them will have to wait
- **Downside of the crossbar switch**
  – Exponential growth of crosspoint switch number if # of CPU(n) grow large. (n^2)
- **Omega network (require fewer switch) [Fig 1-8-6]**
  – With proper settings of the switches, every CPU can access every memory

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- **Drawback of Switching Network**
  - There may be several switching stages between the CPU and Memory

    -> Consequently, to ensure low latency between CPU & memory, switching has to be extremely fast, which is expensive

    reduce the cost of switching

    Hierarchical system : NUMA (NonUniform Memory Access) machine
  - Some memory is associated with each CPU
  - Each CPU can access its own local memory quickly, but accessing anybody else memory is slower
  - Another complication :

    placement of the programs and data becomes critical in order to make access go to the local memory

1.3.2. Homogeneous Multicomputer Systems

- **Rlatively easy to build compare to Multiprocessors**
- **Each CPU has a direct connection to its own local memory**
- **How the CPUs communicate with each other (CPU-to-CPU communication)**

  Volume of traffic is much lower than that of CPU-to-memory
  - SAN (System Area Networks) : connected through a single interconnection network
  - Bus-based multicomputer
    - The processors are connected through a shared multiaccess network
    - Limited scalability
    - Broad-cast

– Switch-Based multicomputer
  - Messages between the processor are routed through an interconnection network.
  - Mesh / Hypercube topologies
  - MPP (massively parallel processors)
    - – Network design goal :
      - » low latency
      - » High-bandwidth
      - » Fault-tolerance
  - COWs (Cluster of Workstations)

1.3.3 Heterogeneous Multicomputer Systems

1.4. Software Concepts

- **Distributed system :**
  - Matter of software not matter of HW
  - Act as resource managers for the underlying H/W
  - Attempt to hide the intricacies and heterogeneous nature of underlying hardware by providing a virtual machine on which applications can be easily executed.
- **OS for distributed computers**
  - Tightly coupled system :
    - Try to maintain a single, global view of the resources it manages : DOS (Distributed OS)

    ->need for managing multiprocessors and homogeneous multicomputers
  - Loosely-coupled system : Collection of computers each running their own operating system : NOS (Network OS)

    ->local services are made available to remote clients

※Enhancements to the services of network OS are needed such that better support for distribution transparency ->middleware :

lie at the heart of modern distributed system

※Figure 1-10 : overview between DOS, NOS, and MW

System	Description	Main goal
DOS	Tightly-coupled OS for multiprocessr and homogeneous multicomputers	Hide & manage Hardware resource
NOS	Loosely-coupled OS for heterogeneous multicomputers (LAN and WAN)	Offer local services to remote clients
Middleware	Additional layer a top of NOS implementing general-purpose services	Provide distribution transparency

1.4.1. DOS

- Uniprocessor OS
- Multiprocessor OS
- Multicomputer OS
- Distributed Shared Memory Systems

Uniprocessor OS

- Allow uses/applications an easy way of sharing resources

  (CPU, Main Memory, Disks, peripheral device)
- Virtual machine : To an application, it appears as If it has its own resources, and that there may be several applications executing on the same system at the same time, each with their own set of resources

  sharing resources : applications are protected from each other

- Kernel mode : all instructions are permited to executed, and the whole memory and collection of all registers is accessible during execution

  ※ OS should be in full control of how the H/W resources are need & shared
- User mode : Memory & register access is restricted.
- Only way to switch from user mode to kernel mode is through “system call”.
- Monolitic OS :
  – Run in a single address space
  – Difficult to adapt the system
  – Not good idea for openness, SE, reliability or maintain ability

- Microkernel OS :
  – Containing only the code that must execute in kernel mode
  – Only contain the code for setting device registers, switching the CPU between processes, manipulating MMU, and capturing hardware interrupts.
  – Contains the code to pass system calls to calls on the appropriate user-level OS modules, and to return their results.

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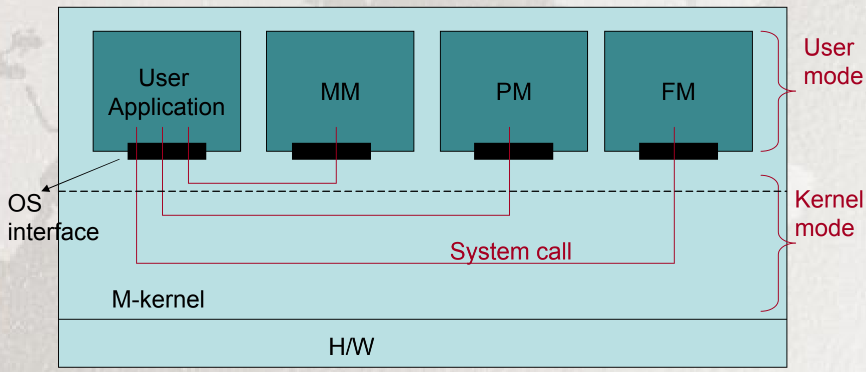

- **Main Benefits to using Microkernels**
  - Flexibility
    - A large part of OS is executed in user mode, it is relatively easy to recompile or re-install the entire system
    - User level modules can be place on different machines
  - Disadvantages
    - Different from the way current OS work (meets massive resistance)
    - Extra communication cost ->performance loss

Multiprocessor OS

- **An important is to support for multiple processors having access to a shared memory.**
- **Data have to be protected against concurrent access to guarantee consistency but can't eas~~ily h~~andle multiple CPUs since they have been designed as monolithic programs that can be executed only with a single thread of control => need redesigning and reimplementing the entire kernel**

- **Goal of multiprocessor OS :**
  - To support high performance through multiple CPUs
  - Is to make the # of CPUs transparent to the application.

    communication between different part of applications uses the same primitives as these in multitasking uniprocessor OS.

    All communication is done by manipulating data at shared memory locations =>protect that data against simultaneous access =>protection is done through synch primitives : semaphore / Monitor

  ※ Explain Semaphore / Monitor

- **Semaphore :**
  - Error-prone except when need for simply protecting shared data
  - Problem : easily lead to unstructured code (goto statement)
- **Monitor :**
  - Programming – language construct similar to an object in O-based programming
  - Problem : they are programming – language constructs

    java provides a notion of monitors by essentially allowing each object to protect itself against concurrent access through synchronized statements, and operations wait and notify on objects.

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Multicomputer OS

- **Different (totally) structure and complexity than multiprocessor OS**
- **Means of communication : Message passing (not enough for shared memory)**
- **[Fig 1-14]**
  - Each mode has its own kernel containing modules for managing local resources such as memory, the local CPU, a local disk, and soon.
- **Each kernel support parallel and concurrent execution of various tasks**
  - Software implementation of shared memory =>by means of message passing
  - Assigning a task to a processor
  - Masking transparent storage
  - General interprocess communication

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- **Message-passing**
  - Semantics of message-passing primitive vary between different systems
    - Differences:
      - Considering whether or not messages are buffered
      - Take into account when a sending or receiving process is blocked
- **Two places where messages can be buffered**
  - Sender's side
  - Receiver's side
- **4 synchronization points : at which a sender or receiver can block.**