**UNIT-1**

**Syllabus: Characterization of distributed systems-Introduction, examples of distributed systems, resource sharing and web, challenges. System Models: Introduction, Architectural models: S/w layers, system architecture and variants, Interface and Objects, Design requirements for distributed architectures, Fundamental Models: Interaction Model, Failure Model and Security Model**

## CHARACTERIZATION OF DISTRIBUTED SYSTEMS:

## INTRODUCTION

Networks of computers are everywhere. The Internet is one, as are the many networks of which it is composed. Mobile phone networks, corporate networks, factory networks, campus networks, home networks, in-car networks – all of these, both separately and in combination, share the essential characteristics that make them relevant subjects for study under the heading *distributed systems*.

Distributed system is the one in which hardware or software components located at networked computers communicate and coordinate their actions only by passing messages. This simple definition covers the entire range of systems in which networked computers can usefully be deployed.

Characteristics of Distributed Systems are,

***Concurrency*:** In a network of computers, concurrent program execution is the norm. I can do my work on my computer while you do your work on yours, sharing resources such as web pages or files when necessary. The capacity of the system to handle shared resources can be increased by adding more resources (for example. computers) to the network. The coordination of concurrently executing programs that share resources is also an important and recurring topic.

***No global clock*:** When programs need to cooperate they coordinate their actions by exchanging messages. Close coordination often depends on a shared idea of the time at which the programs' actions occur. But it turns out that there are limits to the accuracy with which the computers in a network can synchronize their clocks – there is no single global notion of the correct time. This is a direct consequence of the fact that the *only* communication is by sending messages through a network.

***Independent failures*:** All computer systems can fail, and it is the responsibility of system Designers to plan for the consequences of possible failures. Distributed systems can fail in new ways. Faults in the network result in the isolation of the computers that are connected to it, but that doesn't mean that they stop running. In fact, the programs on them may not be able to detect whether the network has failed or has become unusually slow. Similarly, the failure of a Computer, or the unexpected termination of a program somewhere in the system (a *crash*), is not immediately made known to the other components with which it communicates. Each component of the system can fail independently, leaving the others still running.

## EXAMPLES OF DISTRIBUTED SYSTEMS

Typical examples of Distributed systems are,

The

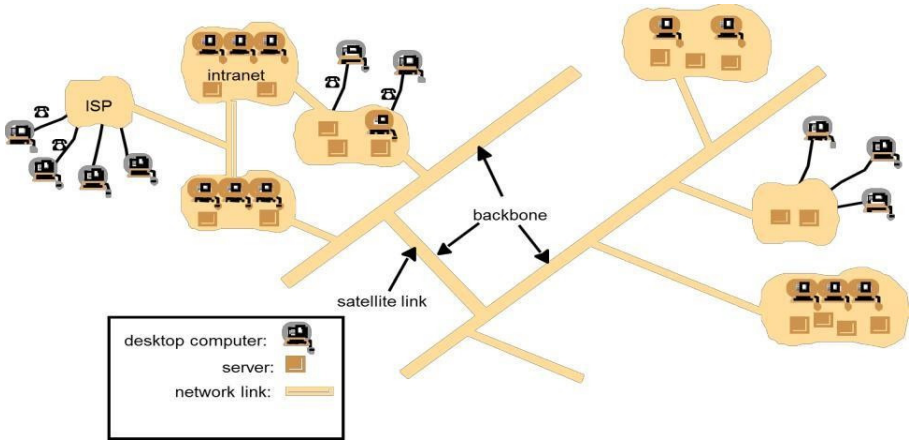
Internet

Intranets

Mobile and Ubiquitous computing.

### The Internet:

Internet is a very large distributed system. It enables users, wherever they are, to make use of services like www, email, file transfer. The set of services is open-ended. Refer figure below which shows a typical portion of internet. Internet connects millions of LANs and MANs to each other.



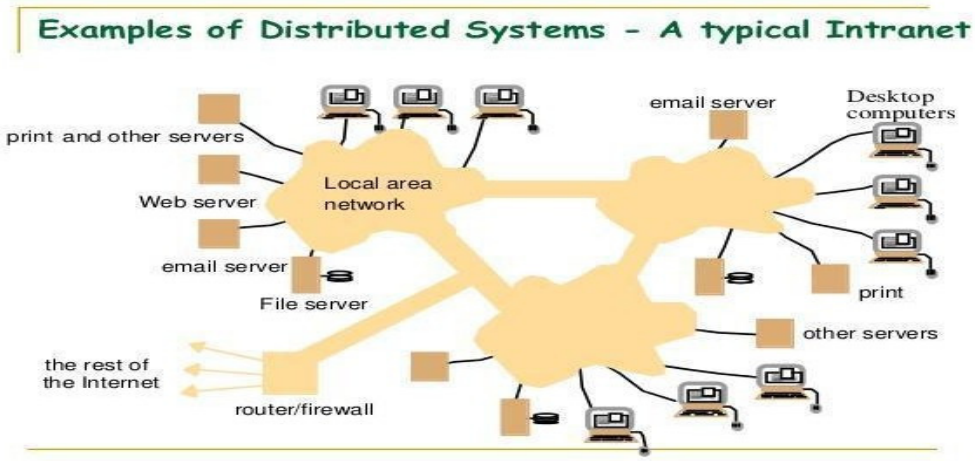
## Intranet

✓ An intranet is a portion of the internet that is separately administered and has a boundary that can be configured to enforce local security policies.

✓ It may be composed of several LANs linked by backbone connections.

✓ The n/w configuration of a particular intranet is the responsibility of the organization that administers it.

✓ An intranet is connected to the Internet via router, which allows the users to use the services available in the Internet.




✓ Firewall is used to protect intranet by preventing unauthorized messages leaving or entering.

✓ Some organizations do not wish to connect their internal networks to the Internet at all. E.g. police and other security and law enforcement agencies are likely to have at least some internal networks that are isolated from outside world.

✓ These organizations can be connected to Internet to avail the services by dispensing with the firewall.

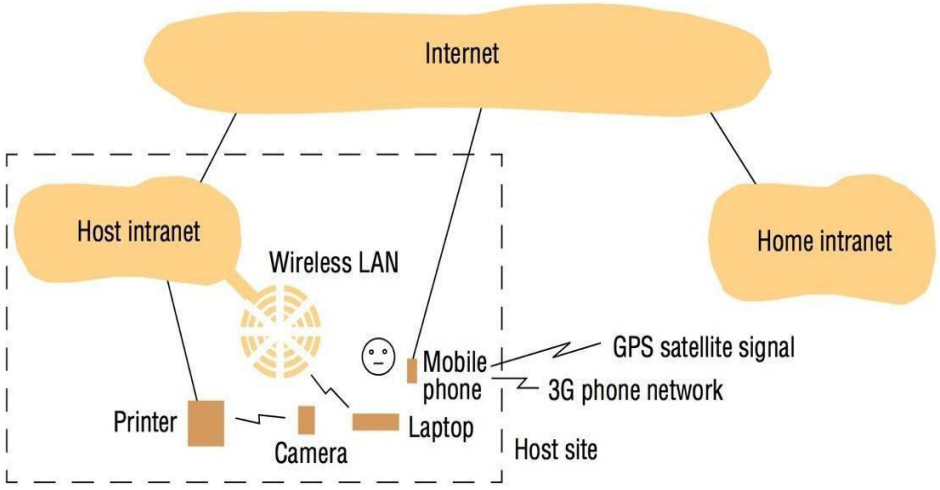
✓ The main issues arising in the design of components for use in intranets are, File services are needed to enable users to share data

Firewalls should ensure legitimate access to services.

Cost of installation and support should be minimum.

**Mobile and Ubiquitous computing:**

- ✓ Integration of portable computing devices like Laptops, smartphones, handheld devices, pagers, digital cameras, smart watches, devices embedded in appliances like refrigerators, washing machines, cars etc. with the distributed systems became possible because of the technological advances in device miniaturization and wireless networking.
- ✓ These devices can be connected to each other conveniently in different places, makes mobile computing possible.
- ✓ Figure below shows how a user from home intranet can access the resources at Host intranet using mobile devices.




- ✓ In mobile computing, users who are away from home intranet, are still allowed to access resources via the devices they carry.
- ✓ Ubiquitous computing is the harnessing of many small, cheap computational devices that are present in user's physical environments, including home, office and others.
- ✓ The term ubiquitous is intended to suggest that small computing devices will eventually become so pervasive in everyday objects that they are scarcely noticed.
- ✓ The presence of computers everywhere is useful only when they can communicate with one another.
- ✓ E.g. it would be convenient for users to control their washing machine and hi-fi system using "Universal remote control" device at home.
- ✓ The mobile user can get benefit from computers that are everywhere.

- ✓ Ubiquitous computing could benefit users while they remain in a single environment such as the home, office or hospital.
- ✓ Figure below shows a user who is visiting a host organization. The users home intranet and the host intranet at the site that the user is visiting. Both intranets are connected to the rest of the Internet.

**Resource Sharing and Web**

We routinely share hardware resources such as printers, data resources such as files, and resources with more specific functionality such as search engines.

Looked at from the point of view of hardware provision, we share equipment such as printers and disks to reduce costs.

But of far greater significance to users is the sharing of the higher-level resources that play a part in their applications and in their everyday work and social activities. For example, users are concerned with sharing data in the form of a shared database or a set of web pages – not the disks and processors on which they are implemented.

Similarly, users think in terms of shared resources such as a search engine or a currency converter, without regard for the server or servers that provide these.

In practice, patterns of resource sharing vary widely in their scope and in how closely users work together. At one extreme, a search engine on the Web provides a facility to users throughout the world, users who need never come into contact with one another directly. At the other extreme, in *computer-supported cooperative working* (CSCW), a group of users who cooperate directly share resources such as documents in a small, closed group. The pattern of sharing and the geographic distribution of particular users determines what mechanisms the system must supply to coordinate users' actions.

We use the term *service* for a distinct part of a computer system that manages a collection of related resources and presents their functionality to users and applications. For example, we access shared files through a file service; we send documents to printers through a printing service; we buy goods through an electronic payment service. The only access we have to the service is via the set of operations that it exports. For example, a file service provides *read*, *write* and *delete* operations on files.

The fact that services restrict resource access to a well-defined set of operations is in part standard software engineering practice. But it also reflects the physical organization of distributed systems. Resources in a distributed system are physically encapsulated within computers and can only be accessed from other computers by means of communication. For effective sharing, each resource must be managed by a program that offers a communication interface enabling the resource to be accessed and updated reliably and consistently.

The term *server* is probably familiar to most readers. It refers to a running program (a *process*) on a networked computer that accepts requests from programs running on other computers to perform a service and responds appropriately. The requesting processes are referred to as *clients,* and the overall approach is known as *client-server computing*. In this approach, requests are sent in messages from clients to a server and replies are sent in messages from the server to the clients. When the client sends a request for an operation to be carried out, we say that the client *invokes an operation* upon the server. A complete interaction between a client and a server, from the point when the client sends its request to when it receives the server's response, is called a *remote invocation*.

**World Wide Web**

key feature of the Web is that it provides a *hypertext* structure among the documents that it stores, reflecting the users' requirement to organize their knowledge. This means that documents contain *links* (or *hyperlinks*) – references to other documents and resources that are also stored in the Web.

The Web is an *open* system: it can be extended and implemented in new ways without disturbing its existing functionality. First, its operation is based on communication standards and document or content standards that are freely published and widely implemented. For example, there are many types of browser, each in many cases implemented on several platforms; and there are many implementations of web servers. Any conformant browser can retrieve resources from any conformant server. So users have access to browsers on the majority of the devices that they use, from mobile phones to desktop computers.

Second, the Web is open with respect to the types of resource that can be published and shared on it. At its simplest, a resource on the Web is a web page or some other type of *content* that can be presented to the user, such as media files and documents in Portable Document Format. If somebody invents, say, a new image-storage format, then images in this format can

immediately be published on the Web. Users require a means of viewing images in this new format, but browsers are designed to accommodate new content-presentation functionality in the form of 'helper' applications and 'plug-ins'.

The Web has moved beyond these simple data resources to encompass services, such as electronic purchasing of goods. It has evolved without changing its basic architecture. The Web is based on three main standard technological components:

- The Hypertext Markup Language (HTML), a language for specifying the contents and layout of pages as they are displayed by web browsers.
- Uniform Resource Locators (URLs), also known as Uniform Resource Identifiers (URIs), which identify documents and other resources stored as part of the Web.
- A client-server system architecture, with standard rules for interaction (the Hypertext Transfer Protocol – HTTP) by which browsers and other clients fetch documents and other resources from web servers.

**HTML:**

- It is used to specify text and images that make up the contents of a web page and to say how they are laid out and formatted for presentation to the user.
- Different tags are used in html.
- Either we can produce html by hand or using any HTML-aware editor.
- The html text is stored in a file that a web server can access.

**URL:**

- The purpose of URL is to identify a resource. Browsers looks up the corresponding URL when user clicks on a link or selects one of their bookmarks.
- Every URL has two top level components
- The first component "scheme" declares which type of URL this is.
  E.g. mailto: xyz@abc.com indicates a user's email address, or
  ftp://ftp.dowloadIt.com/software/aProg.exe identifies a file to be retrieved using FTP.
- The second component specifies the path of the resource.

**HTTP:**

- Hypertext Transfer protocol defines the ways in which browsers and other types of client interact with web servers.
- Main features are,

- Request-reply interactions:
- Content types
- One resource per request
- Simple access control.

## CHALLENGES IN DISTRIBUTED SYSTEMS

### HETEROGENEITY:

The Internet enables users to access services and run applications over a heterogeneous collection of computers and networks. Heterogeneity (that is, variety and difference) applies to all of the following:

- **Networks;**
- **Computer hardware;**
- **Operating systems;**
- **programming languages;**
- **Implementations by different developers.**

Although the Internet consists of many different sorts of network their differences are masked by the fact that all of the computers attached to them use the Internet protocols to communicate with one another. For example, a computer attached to an Ethernet has an implementation of the Internet protocols over the Ethernet, whereas a computer on a different sort of network will need an implementation of the Internet protocols for that network.

Data types such as integers may be represented in different ways on different sorts of hardware – for example, there are two alternatives for the byte ordering of integers. These differences in representation must be dealt with if messages are to be exchanged between programs running on different hardware.

Although the operating systems of all computers on the Internet need to include an implementation of the Internet protocols, they do not necessarily all provide the same application programming interface to these protocols. For example, the calls for exchanging messages in UNIX are different from the calls in Windows.

Different programming languages use different representations for characters and data structures such as arrays and records. These differences must be addressed if programs written in different languages are to be able to communicate with one another. Programs written by different developers cannot communicate with one another unless they use common standards, for example, for network communication and the representation of primitive data items and data

structures in messages. For this to happen, standards need to be agreed and adopted – as have the Internet protocols.

**OPENNESS:**

Openness cannot be achieved unless the specification and documentation of the Key software interfaces of the components of a system are made available to software developers. In a word, the key interfaces are *published*. This process is akin to the standardization of interfaces, but it often bypasses official standardization procedures, which are usually cumbersome and slow-moving.

However, the publication of interfaces is only the starting point for adding and extending services in a distributed system. The challenge to designers is to tackle the complexity of distributed systems consisting of many components engineered by different people.

Systems that are designed to support resource sharing in this way are termed *open distributed systems* to emphasize the fact that they are extensible. They may be extended at the hardware level by the addition of computers to the network and at the software level by the introduction of new services and the reimplementation of old ones, enabling application programs to share resources. A further benefit that is often cited for open systems is their independence from individual vendors.

**SECURITY:**

Many of the information resources that are made available and maintained in distributed systems have a high intrinsic value to their users. Their security is therefore of considerable importance. Security for information resources has three components: confidentiality (protection against disclosure to unauthorized individuals), integrity (protection against alteration or corruption), and availability (protection against interference with the means to access the resources).

In a distributed system, clients send requests to access data managed by servers, which involves sending information in messages over a network. For example:

1. A doctor might request access to hospital patient data or send additions to that data.

2. In electronic commerce and banking, users send their credit card numbers across the Internet.

In both examples, the challenge is to send sensitive information in a message over a network in a secure manner. But security is not just a matter of concealing the contents of messages – it also involves knowing for sure the identity of the user or other agent on whose behalf a message was sent. In the first example, the server needs to know that the
User is really a doctor, and in the second example, the user needs to be sure of the identity of the shop or bank with which they are dealing. The second challenge here is to identify a remote user or other agent correctly. Both of these challenges can be met by the use of encryption techniques developed for this purpose.

However, the following two security challenges have not yet been fully met: *Denial of service attacks*: *Security of mobile code*:

**SCALABILITY:**

Distributed systems operate effectively and efficiently at many different scales, ranging from a small intranet to the Internet. A system is described as *scalable* if it will remain effective when there is a significant increase in the number of resources and the number of users. The number of computers and servers in the Internet has increased dramatically. Figure below shows the increasing number of computers and web servers during the 12-year history of the Web up to 2005.

| *Date* | *Computers* | *Web servers* | *Percentage* |
|---|---|---|---|
| 1993, July | 1,776,000 | 130 | 0.008 |
| 1995, July | 6,642,000 | 23,500 | 0.4 |
| 1997, July | 19,540,000 | 1,203,096 | 6 |
| 1999, July | 56,218,000 | 6,598,697 | 12 |
| 2001, July | 125,888,197 | 31,299,592 | 25 |
| 2003, July | ~200,000,000 | 42,298,371 | 21 |
| 2005, July | 353,284,187 | 67,571,581 | 19 |

It is interesting to note the significant growth in both computers and web servers in this period, but also that the relative percentage is flattening out – a trend that is explained by the growth of fixed and mobile personal computing. One web server may also increasingly be hosted on multiple computers.

The design of scalable distributed systems presents the following challenges:

Controlling the cost of physical resources:

Controlling the performance loss:

Preventing software resources running out:

Avoiding performance bottlenecks:

**FAILURE HANDLING**

Computer systems sometimes fail. When faults occur in hardware or software, programs may produce incorrect results or may stop before they have completed the intended computation. Failures in a distributed system are partial – that is, some components fail while others continue to function. Therefore the handling of failures is particularly difficult. The following are techniques for dealing with failures.

***Detecting failures*:** Some failures can be detected. For example, checksums can be used to detect corrupted data in a message or a file. Chapter 2 explains that it is difficult or even impossible to detect some other failures, such as a remote crashed server in the Internet. The challenge is to manage in the presence of failures that cannot be detected but may be suspected.

***Masking failures*:** Some failures that have been detected can be hidden or made less severe. Two examples of hiding failures:

1. Messages can be retransmitted when they fail to arrive.
2. File data can be written to a pair of disks so that if one is corrupted, the other may still be correct.

Just dropping a message that is corrupted is an example of making a fault less severe – it could be retransmitted. The reader will probably realize that the techniques described for hiding failures are not guaranteed to work in the worst cases; for example, the data on the second disk may be corrupted too, or the message may not get through in a reasonable time however often it is retransmitted.

***Tolerating failures*:** Most of the services in the Internet do exhibit failures – it would not be practical for them to attempt to detect and hide all of the failures that might occur in such a large network with so many components. Their clients can be designed to tolerate failures, which generally involves the users tolerating them as well. For example, when a web browser cannot contact a web server, it does not make the user wait forever while it keeps on trying – it informs the user about the problem, leaving them free to try again later. Services that tolerate failures are discussed in the paragraph on redundancy below.

***Recovery from failures*:** Recovery involves the design of software so that the state of permanent data can be recovered or 'rolled back' after a server has crashed. In general, the computations performed by some programs will be incomplete when a fault occurs, and the permanent data that they update (files and other material stored in permanent storage) may not be in a consistent state.

***Redundancy*:** Services can be made to tolerate failures by the use of redundant components.

**CONCURRENCY**

Both services and applications provide resources that can be shared by clients in a distributed system. There is therefore a possibility that several clients will attempt to access a shared resource at the same time. For example, a data structure that records bids for an auction may be accessed very frequently when it gets close to the deadline time.

The process that manages a shared resource could take one client request at a time. But that approach limits throughput. Therefore services and applications generally allow multiple client requests to be processed concurrently. To make this more concrete, suppose that each resource is encapsulated as an object and that invocations are executed in concurrent threads. In this case it is possible that several threads may be executing concurrently within an object, in which case their operations on the object may conflict with one another and produce inconsistent results.

For example, if two concurrent bids at an auction are 'Smith: $122' and 'Jones: $111', and the corresponding operations are interleaved without any control, then they might get stored as 'Smith: $111' and 'Jones: $122'.

The moral of this story is that any object that represents a shared resource in a distributed system must be Responsible for ensuring that it operates correctly in a concurrent environment. This applies not only to servers but also to objects in applications. Therefore any programmer

who takes an implementation of an object that was not intended for use in a distributed system must do whatever is necessary to make it safe in a concurrent environment.

**TRANSPARENCY**

Transparency is defined as the concealment from the user and the application programmer of the separation of components in a distributed system, so that the system is perceived as a whole rather than as a collection of independent components. The implications of transparency are a major influence on the design of the system software.

***Access transparency*** enables local and remote resources to be accessed using identical operations.

***Location transparency*** enables resources to be accessed without knowledge of their physical or network location (for example, which building or IP address).

***Concurrency transparency*** enables several processes to operate concurrently using shared resources without interference between them.

***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.

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

***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.

The two most important transparencies are access and location transparency; their presence or absence most strongly affects the utilization of distributed resources. They are sometimes referred to together as *network transparency*.

**QUALITY OF SERVICE**

Once users are provided with the functionality that they require of a service, such as the file service in a distributed system, we can go on to ask about the quality of the service provided. The main nonfunctional properties of systems that affect the quality of the service experienced by clients and users are *reliability*, *security* and *performance*.

***Adaptability*** to meet changing system configurations and resource availability has been recognized as a further important aspect of service quality.

**Reliability** and security issues are critical in the design of most computer systems. The performance aspect of quality of service was originally defined in terms of responsiveness and

computational throughput, but it has been redefined in terms of ability to meet timeliness guarantees, as discussed in the following paragraphs.

Some applications, including multimedia applications, handle *time-critical data* – streams of data that are required to be processed or transferred from one process to another at a fixed rate. For example, a movie service might consist of a client program that is retrieving a film from a video server and presenting it on the user's screen. For a satisfactory result the successive frames of video need to be displayed to the user within some specified time limits.

In fact, the abbreviation QoS has effectively been commandeered to refer to the ability of systems to meet such deadlines. Its achievement depends upon the availability of the necessary computing and network resources at the appropriate times. This implies a requirement for the system to provide guaranteed computing and communication resources that are sufficient to enable applications to complete each task on time (for example, the task of displaying a frame of video).

The networks commonly used today have high performance – for example, BBC iPlayer generally performs acceptably – but when networks are heavily loaded their performance can deteriorate, and no guarantees are provided. QoS applies to operating systems as well as networks. Each critical resource must be reserved by the applications that require QoS, and there must be resource managers that provide guarantees. Reservation requests that cannot be met are rejected.

## SYSTEM MODELS:

### INTRODUCTION:

Systems that are intended for use in real-world environments should be designed to function correctly in the widest possible range of circumstances and in the face of many possible difficulties and threats.

***Different system models are,***

***Architectural models*** describe a system in terms of the computational and communication tasks performed by its computational elements; the computational elements being individual computers or aggregates of them supported by appropriate network interconnections.

***Fundamental models*** take an abstract perspective in order to examine individual aspects of a distributed system. In this chapter we introduce fundamental models that examine three important aspects of distributed systems: *interaction models*, which consider the structure and sequencing of the communication between the elements of the system;
*failure models*, which consider the ways in which a system may fail to operate correctly and; *security models*, which consider how the system is protected against attempts to interfere with its correct operation or to steal its data.

## ARCHITECTURAL MODEL

The architecture of a system is its structure in terms of separately specified components and their interrelationships. The overall goal is to ensure that the structure will meet present and likely future demands on it. Major concerns are to make the system reliable, manageable, adaptable and cost-effective. The architectural design of a building has similar aspects – it determines not only its appearance but also its general structure and architectural style (gothic, neo-classical, modern) and provides a consistent frame of reference for the design.

### Software Layers

- Software architecture referred to:
  - The structure of software as layers or modules in a single computer.
  - The services offered and requested between processes located in the same or different computers.
- Software architecture is breaking up the complexity of systems by designing them through layers and services.
  - Layer: a group of related functional components.
  - Service: functionality provided to the next layer.
- **Platform**

The lowest-level hardware and software layers are often referred to as a platform for distributed systems and applications.

→ These low-level layers provide services to the layers above them, which are implemented independently in each computer.

→ These low-level layers bring the system's programming interface up to a level that facilitates communication and coordination between processes.

- Common examples of platform are: Intel x86/Windows, Intel x86/Linux Intel x86/Solaris , SPARC/SunOS, PowePC/MacOS

### Middleware

It was a layer of software whose purpose is

→ To mask heterogeneity presented in distributed systems and provides interoperability between lower layer and upper layer.

→
→ To provide a convenient programming model to application developers.

Major Examples of middleware are:

- Sun RPC (Remote Procedure Calls)
- OMG CORBA (Common Request Broker Architecture)
- Microsoft D-COM (Distributed Component Object Model)
- Sun Java RMI

**System Architectures**

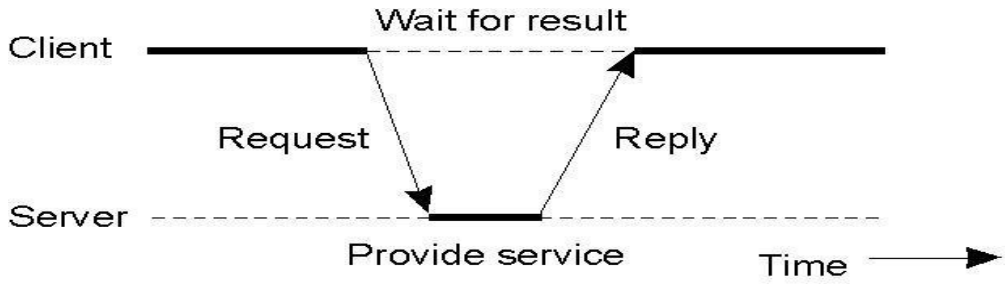
- The most evident aspect of distributed system design is the division of responsibilities between system components (applications, servers, and other processes) and the placement of the components on computers in the network.
- It has major implication for:
  - Performance
  - Reliability
  - Security

In a distributed system, processes with well-defined responsibilities interact with each other to perform a useful activity. The two major types of architectural models are described below.

**Client-server and peer-to-peer.**

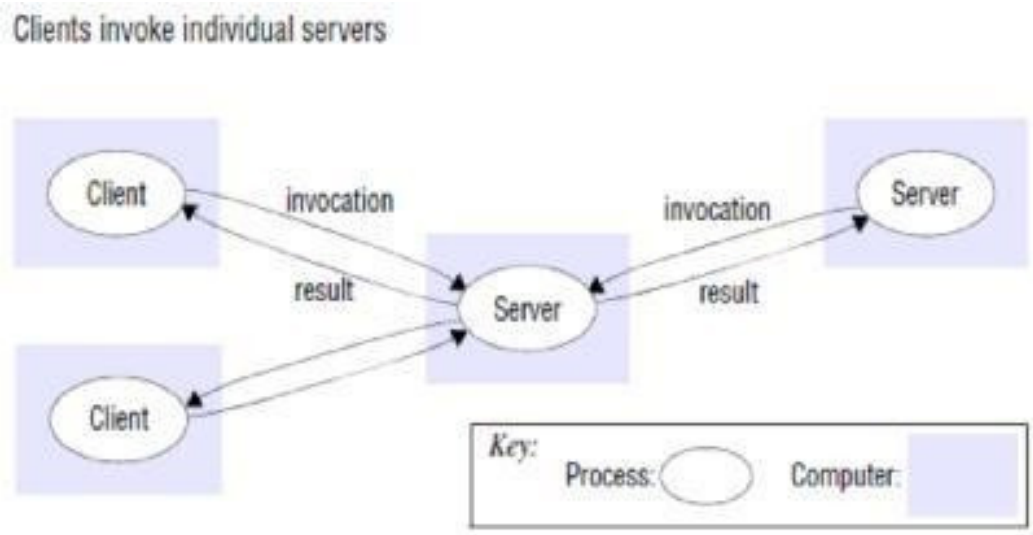
**Client Server:**

This is the architecture that is most often cited when distributed systems are discussed. It is historically the most important and remains the most widely employed.




In particular, client processes interact with individual server processes in potentially separate host computers in order to access the shared resources that they manage. Servers may in turn be clients of other servers, as the figure indicates. For example, a web server is often a client of a local file server that manages the files in which the web pages are stored. Web servers and most other Internet services are clients of the DNS service, which translates Internet domain names to network addresses. Another web-related example concerns *search engines*, which enable users to look up summaries of information available on web pages at sites throughout the Internet. These summaries are made by programs called *web crawlers*, which run in the background at a search

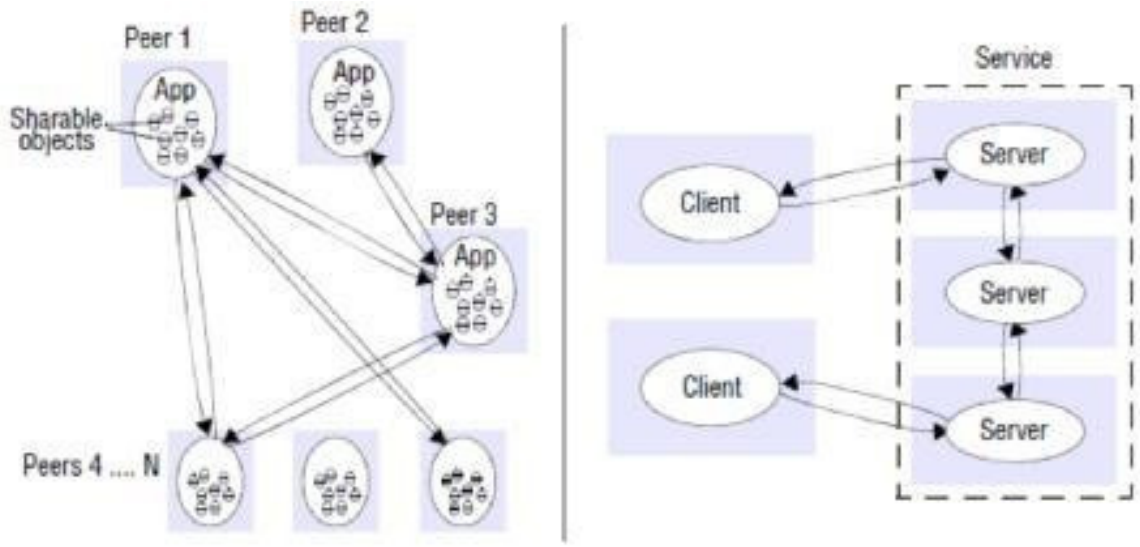
engine site using HTTP requests to access web servers throughout the Internet. Thus a search engine is both a server and a client: it responds to queries from browser clients and it runs web crawlers that act as clients of other web servers. In this example, the server tasks (responding to user queries) and the crawler tasks (making requests to other web servers) are entirely independent; there is little need to synchronize them and they may run concurrently. In fact, a typical search engine would normally include many concurrent threads of execution, some serving its clients and others running web crawlers.




**Peer to Peer :**

In this architecture all of the processes involved in a task or activity play similar roles, interacting cooperatively as *peers* without any distinction between client and server processes or the computers on which they run. In practical terms, all participating processes run the same program and offer the same set of interfaces to each other.

While the client-server model offers a direct and relatively simple approach to the sharing of data and other resources, it scales poorly. The centralization of service provision and management implied by placing a Service at a single address does not scale well beyond the capacity of the computer that hosts the service and the bandwidth of its network connections.




Above figure illustrates the form of a peer-to-peer application. Applications are composed of large numbers of peer processes running on separate computers and the pattern of communication between them depends entirely on application requirements. A large number of data objects are shared, an individual computer holds only a small part of the application database, and the storage, processing and communication loads for access to objects are distributed across many computers and network links. Each object is replicated in several computers to further distribute the load and to provide resilience in the event of disconnection of individual computers. The need to place individual objects and retrieve them and to maintain replicas amongst many computers renders this architecture substantially more complex than the client-server architecture.

## Variants of Client Server Model

The problem of client-server model is placing a service in a server at a single address that does not scale well beyond the capacity of computer host and bandwidth of network connections. To address this problem, several variations of client-server model have been proposed. Some of these variations are discussed below.

### Services provided by multiple servers

- Services may be implemented as several server processes in separate host computers interacting as necessary to provide a service to client processes.
- E.g. cluster that can be used for search engines.

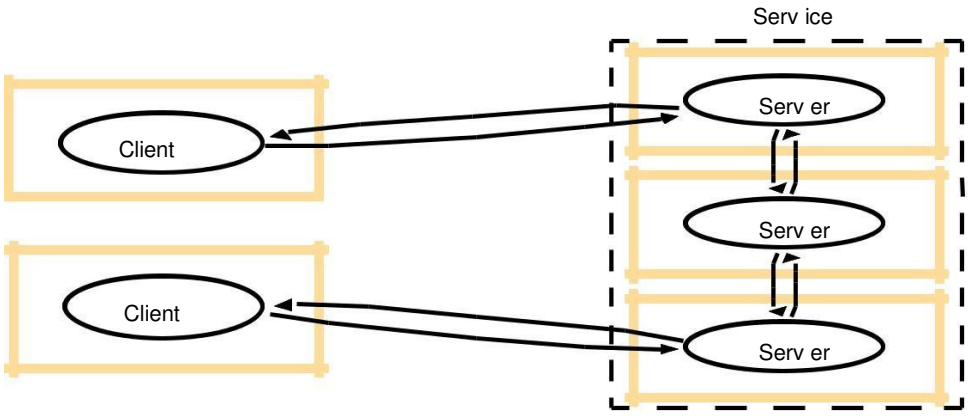
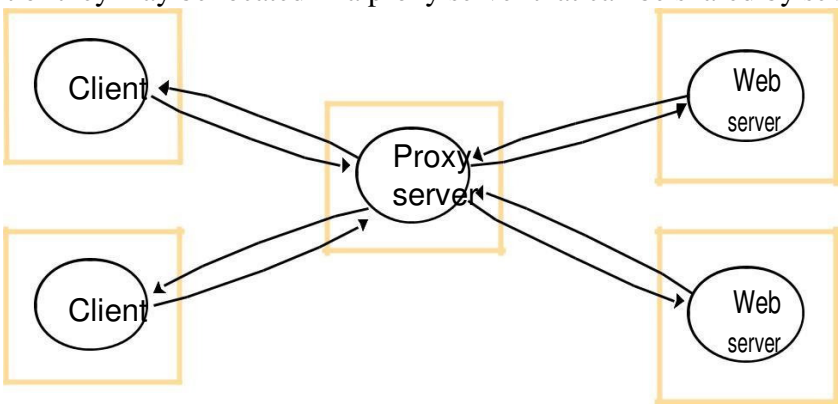



**Figure. A service provided by multiple servers** **Proxy servers and caches**

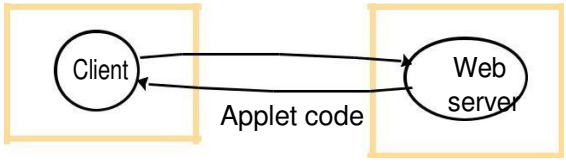
A cache is a store of recently used data objects. When a new object is received at a computer it is added to the cache store, replacing some existing objects if necessary. When an object is needed by a client process the caching service first checks the cache and supplies the object from there if an up-to-date copy is available. If not, an up-to-data copy is fetched. Caches may be collected with each client or they may be located in a proxy server that can be shared by several clients.




**Mobile code**

- Applets are a well-known and widely used example of mobile code.
- Applets downloaded to clients give good interactive response
- Mobile codes such as Applets are a potential security threat to the local resources in the destination computer.
- Browsers give applets limited access to local resources. For example, by providing no access to local user file system.
  - E.g. a stockbroker might provide a customized service to notify customers of changes in the prices of shares; to use the service, each customer would have to download a special applet that receives updates from the broker's server, display them to the user and perhaps performs automatic to buy and sell operations triggered by conditions set up by the customer and stored locally in the customer's computer.

a) client request results in the downloading of applet code




b) client interacts with the applet

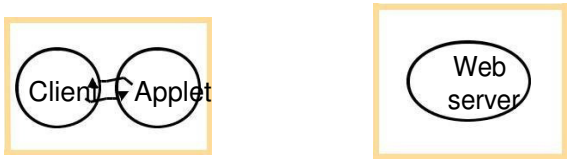



**Figure. Web applets**

## Mobile agents

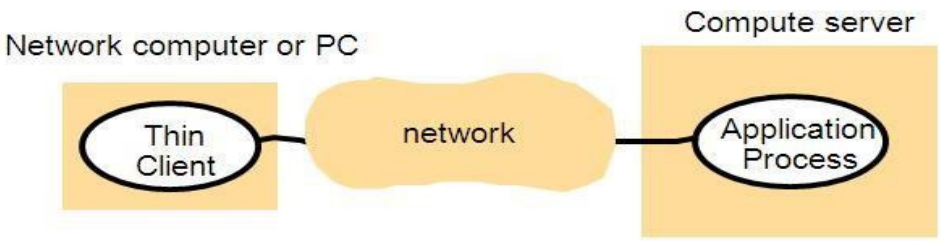
- A running program (code and data) that travels from one computer to another in a network carrying out of a task, usually on behalf of some other process.
- Examples of the tasks that can be done by mobile agents are:
  - To collecting information.
  - To install and maintain software maintain on the computers within an organization.

## Network computers

- It downloads its operating system and any application software needed by the user from a remote file server.
- Applications are run locally but the file are managed by a remote file server.
- Network applications such as a Web browser can also be run.

## Thin clients

- It is a software layer that supports a window-based user interface on a computer that is local to the user while executing application programs on a remote computer.
- This architecture has the same low management and hardware costs as the network computer scheme.
- Instead of downloading the code of applications into the user's computer, it runs them on a compute server.
- Compute server is a powerful computer that has the capacity to run large numbers of application simultaneously.



## Mobile devices and spontaneous interoperation

- Mobile devices are hardware computing components that move between physical locations and thus networks, carrying software component with them.
- Many of these devices are capable of wireless networking ranges of hundreds of meters such as WiFi (IEEE 802.11), or about 10 meters such as Bluetooth.
- Mobile devices include:
  - Laptops
  - Personal digital assistants (PDAs)
  - Mobile phones
  - Digital cameras
  - Wearable computers such as smart watches

## Design Requirements for distributed architectures

### Performance Issues

→ Performance issues arising from the limited processing and communication capacities of computers and networks are considered under the following subheading:

- Responsiveness
  - E.g. a web browser can access the cached pages faster than the non-cached pages.
- Throughput
- Load balancing
  - E.g. using applets on clients, remove the load on the server.

### Quality of service

→ The ability of systems to meet deadlines.

→It depends on availability of the necessary computing and network resources at the appropriate time.
→This implies a requirement for the system to provide guaranteed computing and communication resources that are sufficient to enable applications to complete each task on time.

- E.g. the task of displaying a frame of video

→

The main properties of the quality of the service are:

- Reliability
- Security
- Performance
- Adaptability

### Use of caching and replication

→

Distributed systems overcome the performance issues by the use of data replication and caching.

### Dependability issues

→

Dependability of computer systems is defined as:

- Correctness

❖ Security

→ Security is locating sensitive data and other resources only in computers that can be secured effectively against attack. E.g. a hospital database

**Fault tolerance**

→ Dependable applications should continue to function in the presence of faults in hardware, software, and networks.

→ Reliability is achieved by redundancy.

## FUNDAMENTAL MODELS

***Interaction*:** Computation occurs within processes; the processes interact by passing messages, resulting in communication (information flow) and coordination (synchronization and ordering of activities) between processes. In the analysis and design of distributed systems we are concerned especially with these interactions. The interaction model must reflect the facts that communication takes place with delays that are often of considerable duration, and that the accuracy with which independent processes can be coordinated is limited by these delays and by the difficulty of maintaining the same notion of time across all the computers in a distributed system.

***Failure*:** The correct operation of a distributed system is threatened whenever a fault occurs in any of the computers on which it runs (including software faults) or in the network that connects them. Our model defines and classifies the faults. This provides a basis for the analysis of their potential effects and for the design of systems that are able to tolerate faults of each type while continuing to run correctly.

***Security*:** The modular nature of distributed systems and their openness exposes them to attack by both external and internal agents. Our security model defines and classifies the forms that such attacks may take, providing a basis for the analysis of threats to a system and for the design of systems that are able to resist them.

## INTERACTION MODEL

The discussion of system architectures in indicates that fundamentally distributed systems are composed of many processes, interacting in complex ways. For example:

• Multiple server processes may cooperate with one another to provide a service; the examples mentioned above were the Domain Name System, which partitions and replicates its data at servers throughout the Internet, and Sun's Network Information Service, which keeps replicated copies of password files at several servers in a local area network.

Two significant factors affecting interacting processes in a distributed system:

• Communication performance is often a limiting characteristic.

• It is impossible to maintain a single global notion of time.

**Performance of communication channels**

→ The communication channels in our model are realized in a variety of ways in distributed systems, for example

- By an implementation of streams
- By simple message passing over a computer network

→

Communication over a computer network has the performance characteristics such as:

**Latency**
The delay between the start of a message's transmission from one process to the beginning of its receipt by another.
**Bandwidth**
The total amount of information that can be transmitted over a computer network in a given time. Communication channels using the same network, have to share the available bandwidth.
**Jitter**
The variation in the time taken to deliver a series of messages. It is relevant to multimedia data. For example, if consecutive samples of audio data are played with differing time intervals then the sound will be badly distorted.
**Interaction Model- Computer clocks and timing events**
Each computer in a distributed system has its own internal clock, which can be used by local processes to obtain the value of the current time. Two processes running on different computers can associate timestamp with their events. Even if two processes read their clock at the same time, their local clocks may supply different time. This is because computer clock drift from perfect time and their drift rates differ from one another. Clock drift rate refers to the relative amount that a computer clock differs from a perfect reference clock. Even if the clocks on all the computers in a distributed system are set to the same time initially, their clocks would eventually vary quite significantly unless corrections are applied. There are several techniques to correcting time on computer clocks. For example, computers may use radio signal receivers to get readings from GPS (Global Positioning System) with an accuracy about 1 microsecond.
**Interaction Model-Variations:**
Two variants of the interaction model are
**Synchronous distributed systems**
- It has a strong assumption of time
- The time to execute each step of a process has known lower and upper bounds.
- Each message transmitted over a channel is received within a known bounded time.
- Each process has a local clock whose drift rate from real time has a known bound.

**Asynchronous distributed system**
- It has no assumption about time.
- There is no bound on process execution speeds.
- Each step may take an arbitrary long time.
- There is no bound on message transmission delays.
- A message may be received after an arbitrary long time.
- There is no bound on clock drift rates.
- The drift rate of a clock is arbitrary.

**Event ordering**
In many cases, we are interested in knowing whether an event (sending or receiving a message) at one process occurred before, after, or concurrently with another event at another process. The execution of a system can be described in terms of events and their ordering despite the lack of accurate clocks.

❖ For example, consider a mailing list with users X, Y, Z, and A.

1. User X sends a message with the subject Meeting.
2. Users Y and Z reply by sending a message with the subject RE: Meeting.

- In real time, X's message was sent first, Y reads it and replies; Z reads both X's message and Y's reply and then sends another reply, which references both X's and Y's messages.
- But due to the independent delays in message delivery, the messages may be delivered in the order is shown in figure 10.
- It shows user A might see the two messages in the wrong order.

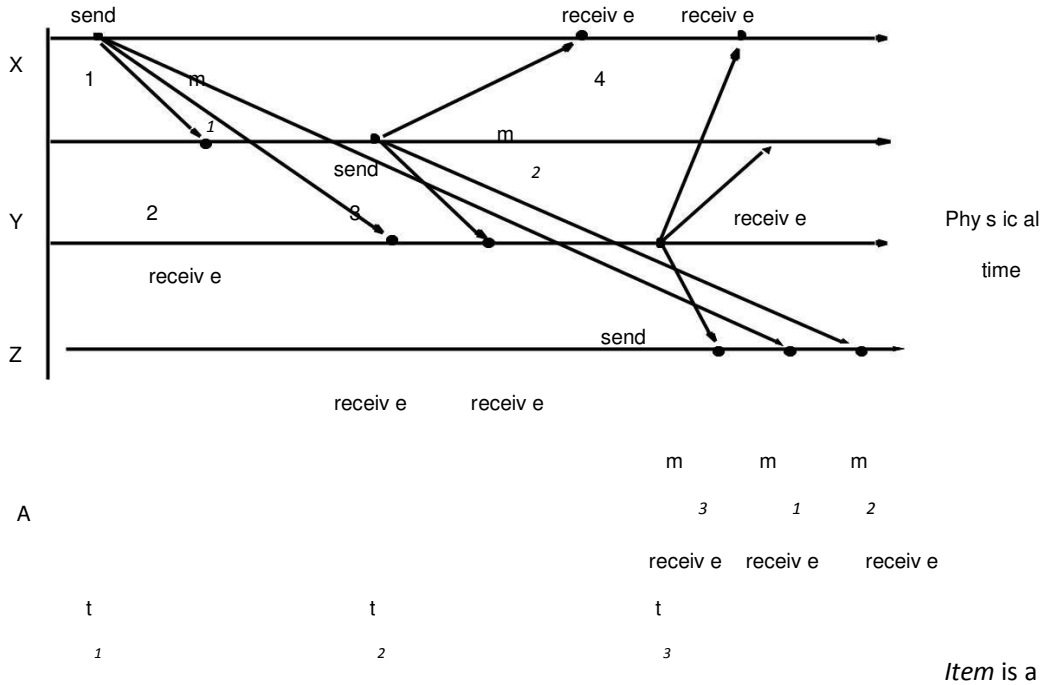



**Figure. Real-time ordering of events**

→ Some users may view two messages in the wrong order, for example, user A might see → *Item* is a sequence number that shows the order of receiving emails.

| *Item* | *From* | *Subject* |
|---|---|---|
| 23 | Z | Re: Meeting |
| 24 | X | Meeting |
| 26 | Y | Re: Meeting |

Since clocks cannot be synchronized perfectly across distributed system, Lamport proposed a model of logical time that provides ordering among events in a distributed system.
E.g. in the previous example we know that the message is received after it was sent. Hence a logical order can be derived here,
x sends m1 before y receives m1
Y sends m2(reply) before x receives m2(reply).

We also know that reply are send after receiving message.
Hence, we can say that,
Y receives m1 before sending m2.

**FAILURES MODEL**

In a distributed system both processes and communication channels may fail – that is, they may depart from what is considered to be correct or desirable behavior. The failure model defines the ways in which failure may occur in order to provide an understanding of the effects of failures.

**Omission failures** • The faults classified as *omission failures* refer to cases when a **process** or **communication Channel** fails to perform actions that it is supposed to do.

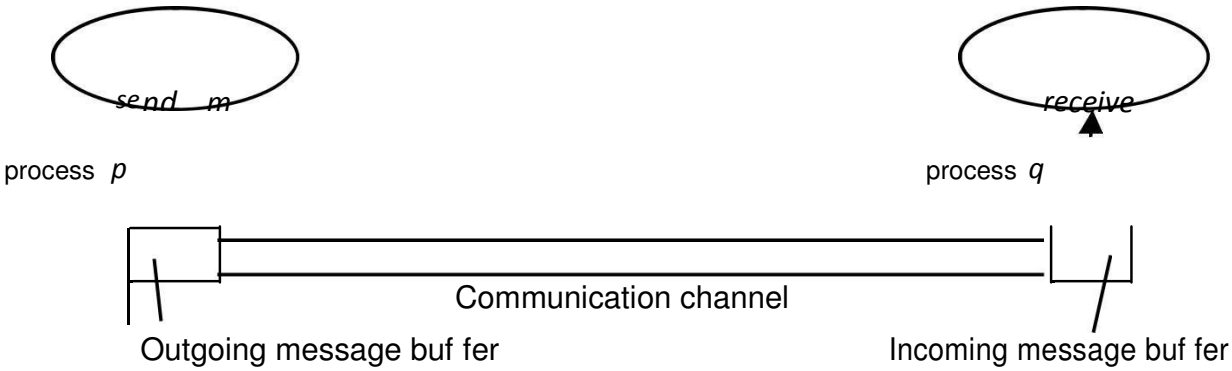
Process omission failures: The chief omission failure of a process is to crash. When we say that a process has crashed we mean that it has halted and will not execute any further steps of its program ever.

Other processes may be able to detect such a crash by the fact that the process repeatedly fails to respond to invocation messages. However, this method of crash detection relies on the use of *timeouts* – that is, a method in which one process allows a fixed period of time for something to occur. In an asynchronous system a timeout can indicate only that a process is not responding – it may have crashed or may be slow, or the messages may not have arrived.

A process crash is called *fail-stop* if other processes can detect certainly that the process has crashed. Fail-stop behavior can be produced in a synchronous system if the processes use timeouts to detect when other processes fail to respond and messages are guaranteed to be delivered. For example, if processes $p$ and $q$ are programmed for $q$ to reply to a message from $p$, and if process $p$ has received no reply from process $q$ in a maximum time measured on $p$'s local clock, then process $p$ may conclude that process $q$ has failed.

Communication omission failures: Consider the communication primitives *send* and *receive*. A process $p$ performs a *send* by inserting the message $m$ in its outgoing message buffer. The communication channel transports $m$ to $q$'s incoming message buffer. Process $q$ performs a *receive* by taking $m$ from its incoming message buffer and delivering it as shown below. The outgoing and incoming message buffers are typically provided by the operating system.

- ✓ The communication channel produces an omission failure if it does not transport a message from $p$'s outgoing message buffer to $q$'s incoming message buffer.
- ✓ This is known as 'dropping messages' and is generally caused by lack of buffer space at the receiver or at an intervening gateway, or by a network transmission error.
- ✓ The loss of messages between the sending process and the outgoing message buffer called as *send omission failures*,
- ✓ loss of messages between the incoming message buffer and the receiving process called as *receive-omission failures*,
- ✓ and to loss of messages in between is called as *channel omission failures*.




**Arbitrary failures** • The term *arbitrary* or *Byzantine* failure is used to describe the worst possible failure semantics, in which any type of error may occur. For example, a process may set

wrong values in its data items, or it may return a wrong value in response to an invocation. An arbitrary failure of a process is one in which it arbitrarily omits intended processing steps or takes unintended processing steps. Arbitrary failures in processes cannot be detected by seeing whether the process responds to invocations, because it might arbitrarily omit to reply.

Communication channels can suffer from arbitrary failures; for example, message contents may be corrupted, nonexistent messages may be delivered or real messages may be delivered more than once. Arbitrary failures of communication channels are rare because the communication software is able to recognize them and reject the faulty messages. For example, checksums are used to detect corrupted messages, and message sequence numbers can be used to detect nonexistent and duplicated messages.

The omission failures are classified together with arbitrary failures shown in Figure

| *Class of failure* | *Affects* | *Description* |
|---|---|---|
| Fail-stop | Process | Process halts and remains halted. Other processes may detect this state. |
| Crash | Process | Process halts and remains halted. Other processes may not be able to detect this state. |
| Omission | Channel | A message inserted in an outgoing message buffer never arrives at the other end's incoming message buffer. |
| Send-omission | Process | A process completes a *send*, but the message is not put in its outgoing message buffer. |
| Receive-omission | Process | A message is put in a process's incoming message buffer, but that process does not receive it. |
| Arbitrary (Byzantine) | Process or channel | Process/channel exhibits arbitrary behaviour: it may send/transmit arbitrary messages at arbitrary times, commit omissions; a process may stop or take an incorrect step. |

**Figure: Omission and arbitrary failures**

**Timing failures** • Timing failures are applicable in synchronous distributed systems where time limits are set on process execution time, message delivery time and clock drift rate.

| *Class of Failure* | *Affects* | *Description* |
|---|---|---|
| Clock | Process | Process's local clock exceeds the bounds on its rate of drift from real time. |
| Performance | Process | Process exceeds the bounds on the interval between two steps. |
| Performance | Channel | A message's transmission takes longer than the stated bound. |

**Figure: Timing failures**

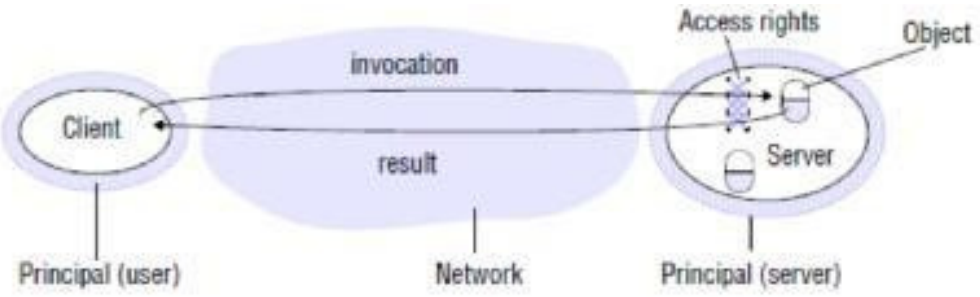
## SECURITY MODEL

Sharing of resources as a motivating factor for distributed systems, we described their architecture in terms of processes, potentially encapsulating higher-level abstractions such as objects, components or services, and providing access to them through interactions with other processes. That architectural model provides the basis for our security model: the security of a distributed system can be achieved by securing the processes and the channels used for their interactions and by protecting the objects that they encapsulate against unauthorized access. Protection is described in terms of objects, although the concepts apply equally well to resources of all types.

### Protecting objects:

Figure below shows a server that manages a collection of objects on behalf of some users. The users can run client programs that send invocations to the server to perform operations on the objects. The server carries out the operation specified in each invocation and sends the result to the client. Objects are intended to be used in different ways by different users. For example, some objects may hold a user's private data, such as their mailbox, and other objects may hold shared data such as web pages. To support this, *access rights* specify who is allowed to perform the operations of an object – for example, who is allowed to read or to write its state. Thus we must include users in our model as the beneficiaries of access rights. We do so by associating with each invocation and each result the authority on which it is issued. Such an authority is called a *principal*. A principal may be a user or a process. In our illustration, the invocation comes from a user and the result from a server.

The server is responsible for verifying the identity of the principal behind each invocation and checking that they have sufficient access rights to perform the requested operation on the particular object invoked, rejecting those that do not. The client may check the identity of the principal behind the server to ensure that the result comes from the required server.

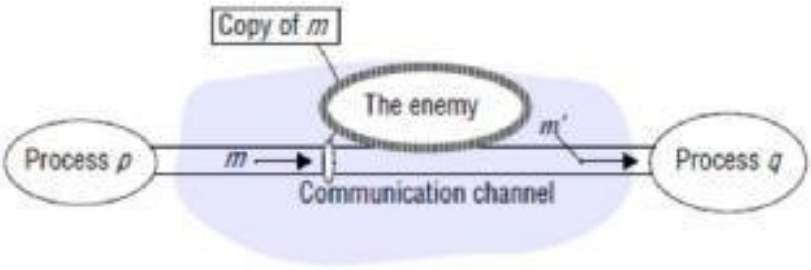



**Securing processes and their interactions** • Processes interact by sending messages. The messages are exposed to attack because the network and the communication service that they use

are open, to enable any pair of processes to interact. Servers and peer processes expose their interfaces, enabling invocations to be sent to them by any other process. Distributed systems are

often deployed and used in tasks that are likely to be subject to external attacks by hostile users. This is especially true for applications that handle financial transactions, confidential or classified information or any other information whose secrecy or integrity is crucial. Integrity is threatened by security violations as well as communication failures. So we know that there are likely to be threats to the processes of which such applications are composed and to the messages travelling between the processes. But how can we analyze these threats in order to identify and defeat them? The following discussion introduces a model for the analysis of security threats.

**The enemy** • To model security threats, we postulate an enemy (sometimes also known as the adversary) that is capable of sending any message to any process and reading or copying any message sent between a pair of processes, as shown in Figure below. Such attacks can be made simply by using a computer connected to a network to run a program that reads network messages addressed to other computers on the network, or a program that generates messages that make false requests to services, purporting to come from authorized users. The attack may come from a computer that is legitimately connected to the network or from one that is connected in an unauthorized manner.




The threats from a potential enemy include *threats to processes* and *threats to communication channels*.

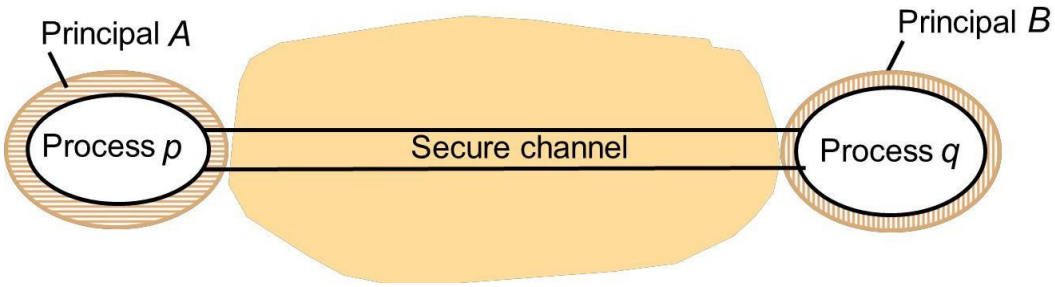
Threats to processes: A process that is designed to handle incoming requests may receive a message from any other process in the distributed system, and it cannot necessarily determine the identity of the sender. Communication protocols such as IP do include the address of the source computer in each message, but it is not difficult for an enemy to generate a message with a forged source address. This lack of reliable knowledge of the source of a message is a threat to the correct functioning of both servers and clients, as explained below:

***Servers*:** Since a server can receive invocations from many different clients, it cannot necessarily determine the identity of the principal behind any particular invocation. Even if a server requires the inclusion of the principal's identity in each invocation, an enemy might generate an invocation with a false identity. Without reliable knowledge of the sender's identity, a server cannot tell whether to perform the operation or to reject it.

***Clients*:** When a client receives the result of an invocation from a server, it cannot necessarily tell whether the source of the result message is from the intended server *Clients*: When a client receives the result of an invocation from a server, it cannot necessarily tell whether the source of

the result message is from the intended server or from an enemy, perhaps 'spoofing' the mail server. Thus the client could receive a result that was unrelated to the original invocation, such as a false mail item (one that is not in the user's mailbox).

Threats to communication channels: An enemy can copy, alter or inject messages as they travel across the network and its intervening gateways. Such attacks present a threat to the privacy and integrity of information as it travels over the network and to the integrity of the system. For example, a result message containing a user's mail item might be revealed to another user or it might be altered to say something quite different. Another form of attack is the attempt to save copies of messages and to replay them at a later time, making it possible to reuse the same message over and over again. For example, someone could benefit by resending an invocation message requesting a transfer of a sum of money from bank account to another. All these threats can be defeated by the use of *secure channels.*




**Important Questions:**

1. Define a distributed system and explain the same with two examples.
2. Analyse the different challenges of distributed system.
3. Discuss the types of hardware and software resources which can be shared in distributed system with an illustration.
4. Discuss the Software Layers of distributed system architectural model.
5. What are variations of client-server model?
6. Describe the interaction model of distributed system.
7. Write the design requirements for Distributed architectures.
8. Describe the failure model of distributed system.
9. Write about security model in distributed system.

**Syllabus:Interprocess Communication: Introduction, The API for the Internet Protocols- The Characteristics of Interprocess communication, Sockets, UDP Datagram Communication, TCP Stream Communication; External Data Representation and Marshalling; Client Server Communication; Group Communication- IP Multicast- an implementation of group communication, Reliability and Ordering of Multicast.**

# ΙΝΤΕΡΠΡΟΧΕΣΣ ΧΟΜΜΥΝΙΧΑΤΙΟΝ

Interposes communication in the Internet provides both datagram and stream communication. The Java APIs for these are presented, together with a discussion of their failure models. They provide alternative building blocks for communication protocols. This is complemented by a study of protocols for the representation of collections of data objects in messages and of references to remote objects.

Multicast is an important requirement for distributed applications and must be provided even if underlying support for IP multicast is not available. This is typically provided by an overlay network constructed on top of the underlying TCP/IP network. Overlay networks can also provide support for file sharing, enhanced reliability and content distribution.

## Τηε ΑΠΙ φορ τηε Ιντερνετ προτοχολσ

**The characteristics of intercrosses communication:**

Message passing between a pair of processes can be supported by two message communication operations, *send* and *receive*, defined in terms of destinations and messages. To communicate, one process sends a message (a sequence of bytes) to a destination and another process at the destination receives the message. This activity involves the communication of data from the sending process to the receiving process and may involve the synchronization of the two processes.

**Synchronous and asynchronous communication** • A queue is associated with each message destination. Sending processes cause messages to be added to remote queues and receiving processes remove messages from local queues. Communication between the sending and receiving processes may be either synchronous or asynchronous. In the ***synchronous***form of communication, the sending and receiving processes synchronize at very message. In this case, both *send* and *receive* are *blocking* operations. Whenever a *send* is issued the sending process (or thread) is blocked until the corresponding *receive* is issued. Whenever a *receive*is issued by a process (or thread), it blocks until a message arrives.

In the ***asynchronous***form of communication, the use of the *send* operation is *nonblocking* in that the sending process is allowed to proceed as soon as the message has been copied to a local buffer, and the transmission of the message proceeds in parallel with the sending process. The *receive* operation can have blocking and non-blocking variants. In the non-blocking variant, the receiving process proceeds

with its program after issuing a *receive* operation, which provides a buffer to be filled in the background, but it must separately receive notification that its buffer has been filled, by polling or interrupt.

## Μεσσαγε δεστινατιονσ

→A local port is a message destination within a computer, specified as an integer.

→A port has an exactly one receiver but can have many senders.

## Ρελιαβιλιτψ

→A reliable communication is defined in terms of validity and integrity.

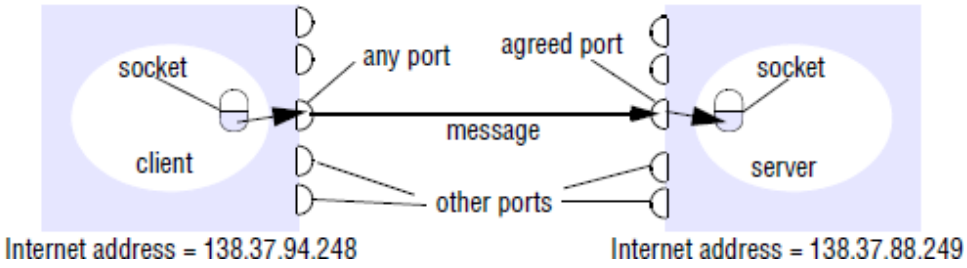
→A point-to-point message service is described as reliable if messages are guaranteed to be delivered despite a reasonable number of packets being dropped or lost.

→For integrity, messages must arrive uncorrupted and without duplication.

## Σοχκετσ

Both forms of communication (UDP and TCP) use the *socket* abstraction, which provides an endpoint for communication between processes. Sockets originate from BSD UNIX but are also present in most other versions of UNIX, including Linux as well as Windows and the Macintosh OS. Interprocess communication consists of transmitting a message between a socket in one process and a socket in another process, as illustrated in Figure below.

Sockets and ports




For a process to receive messages, its socket must be bound to a local port and one of the Internet addresses of the computer on which it runs. Messages sent to a particular Internet address and port number can be received only by a process whose socket is associated with that Internet address and port number. Processes may use the same socket for sending and receiving messages. Each computer has a large number (216) of possible port numbers for use by local processes forreceiving messages. Any process may make use of multiple ports to receive messages, but a process cannot share ports with other processes on the same computer. (Processes using IP multicast are an exception in that they do share ports However, any number of processes may send messages to the same port. Each socket is associated with a particular protocol – either UDP or TCP.

## ΥΔΠ δαταγραμ χομμυνιχατιον

Datagram sent by UDP is transmitted from a sending process to a receiving process without acknowledgement or retries. If a failure occurs, the message may not arrive. A datagram is transmitted between processes when one process *sends* it and another *receives* it. To send or receive messages a process must first create a socket bound to an Internet address of the local host and a local port. A

server will bind its socket to a *server port* – one that it makes known to clients so that they can send messages to it. A client binds its socket to any free local port. The *receive* method returns the Internet address and port of the sender, in addition to the message, allowing the recipient to send a reply. The following are some issues relating to datagram communication:

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  The receiving process needs to specify an array of bytes of a particular size in which to receive a message. If the message is too big for the array ,it is truncated on arrival. The underlying IP protocol allows packet lengths of upto$2^{16}$ bytes, which includes the headers as well as the message .However, most environments impose a size restriction of 8 kilobytes. Any application requiring messages larger than the maximum must fragment the min to chunks of that size.

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  Sockets normally provide non-blocking *sends* and blocking *receives* for datagram communication The *send* operation returns when it has handed the message to the underlying UDP and IP protocols ,which are responsible for transmitting it to its destination .On arrival ,the message is placed in a queue for the socket that is bound to the destination port. The method *receive* blocks until a datagram is received, unless a timeout has been set on the socket.If the process that invokes the *receive* method has other work to do while waiting for the message ,it should arrange to use a separate thread.

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  The *receive* that blocks for ever is suitable for use by a server that is waiting to receiver requests from its clients. But in some programs, it is not appropriate that a process that has invoked a *receive* operation should wait indefinitely in situations where the sending process may have crashed or the expected message may have been lost.To allow for such requirements, timeouts can be set on sockets. Choosing an appropriate timeout interval is difficult, but it should be fairly large incomparison with the time required to transmit a message.

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  The *receive* method does not specify an origin for messages. Instead ,an invocation of *receive* gets a message addressed to its socket from any origin.The *receive* method returns the Internetaddress and local port of the sender, allowing the recipient to check where the message came from.

## Φαιλυρε μοδελ φορ ΥΔΠ δαταγραμσ

Reliable communication in terms of two properties: integrity and validity. The integrity property requires that messages should not be corrupted or duplicated. The use of a checksum ensures that there is a negligible probability that any message received is corrupted. UDP datagrams suffer from the following failures:

***Omission failures*:** Messages may be dropped occasionally, either because of a checksum error or because no buffer space is available at the source or destination. To simplify the discussion, we regard send-omission and receive-omission failures as omission failures in the communication channel.

***Ordering*:** Messages can sometimes be delivered out of sender order.
Applications using UDP datagrams are left to provide their own checks to achieve the quality of reliable communication they require. A reliable delivery service may be constructed from one that suffers from omission failures by the use of acknowledgements.
**Use of UDP** • For some applications, it is acceptable to use a service that is liable to occasional omission failures. For example, the Domain Name System, which looks up DNS names in the Internet, is implemented over UDP. Voice over IP (VOIP) also runs over UDP. UDP datagrams are sometimes an attractive choice because they do not suffer from the overheads associated with guaranteed message delivery. There are three main sources of overhead:
• The need to store state information at the source and destination;
• The transmission of extra messages;
• Latency for the sender.

UDP clientsendsamessagetotheserverandgetsareply

```
importjava.net.*;
importjava.io.*;
publicclassUDPClient{

        publicstaticvoidmain(Stringargs[]){

    //
    argsgivemessagecontentsandserverhostname
    DatagramSocketaSocket= null;

    try{

        aSocket= newDatagramSocket();
        byte[]m=args[0].getBytes();

        InetAddressaHost= InetAddress.getByName(args[1]);
        intserverPort= 6789;

        DatagramPacketrequest=

                newDatagramPacket(m,m.length(),aHost,serverPort);
        aSocket.send(request);

        byte[]buffer=newbyte[1000];
        DatagramPacketreply=newDatagramPacket(buffer,buffer.length);
        aSocket.receive(reply);

        System.out.println("Reply:" + newString(reply.getData()));
```

```
        }catch(SocketExceptione){System.out.println("Socket:"+e.getMessage());
        }catch(IOExceptione){System.out.println("IO:"+e.getMessage());
        }finally{if(aSocket!=null)aSocket.close();}
    }
}
```

***DatagramSocket*:**This class supportssockets for sending and receiving UDP datagrams.Itprovidesaconstructorthattakesaportnumberasitsargument,foruse byprocessesthatneedtouseaparticular port.Italsoprovidesano-argument constructorthatallowsthesystemtochooseafreelocalport.

Theclass*DatagramSocket*providesmethodsthatincludethefollowing:

***send*and*receive*:**Thesemethodsarefortransmittingdatagramsbetweenapair ofsockets.Theargumentof*send*isaninstanceof*DatagramPacket*containing amessageanditsdestinatio n. Theargumentof*receive*isanempty *DatagramPacket* inwhichtoputthemessage,itslengthanditsorigin.The methods*send*and*receive*canthrow*IOExceptions*.

***setSoTimeout*:**Thismethodallowsatimeouttobeset.Withatimeoutset,the*receive*methodwillblockforthetimes pecifiedandthenthrowan*InterruptedIOException*.

***connect*:**Thismethodisusedforconnecting toaparticularremoteportand Internetaddress,inwhichcasethesocketisonlyabletosendmessagestoand receivemessagesfromthataddress.

UDP serverrepeatedlyreceivesarequestandsendsitbacktotheclient

```
importjava.net.*;
importjava.io.*;
publicclassUDPServer{

  publicstaticvoidmain(Stringargs[]){
    DatagramSocketaSocket= null;
    try{

        aSocket= newDatagramSocket(6789);
        byte[]buffer=newbyte[1000]; while(true){

          DatagramPacketrequest=newDatagramPacket(buffer,buffer.length);
           aSocket.receive(request);
           DatagramPacketreply=newDatagramPacket(request.getData(),

               request.getLength(),request.getAddress(),request.getPort())
          ; aSocket.send(reply);

        }

    }catch(SocketExceptione){System.out.println("Socket:"+e.getMessage());

    }catch(IOExceptione){System.out.println("IO:"+e.getMessage());

    } finally{if(aSocket!=null)aSocket.close();}

  }

}
```

## ΤΧΠ στρεαμ χομμυνιχατιον

The API to the TCP protocol, which originates from BSD 4.x UNIX, provides the abstraction of a stream of bytes to which data may be written and from which data may be read. The following characteristics of the network are hidden by the stream abstraction:

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The application can choose how much data it writes to a stream or reads from it. It may deal in very small or very large sets of data. The underlying implementation of a TCP stream decides how much data to collect before transmitting it as one or more IP packets. On arrival, the data is handed to the application as requested. Applications can, if necessary, force data to be sent immediately.

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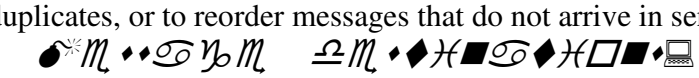
The TCP protocol uses an acknowledgement scheme. As an example of a simple scheme (which is not used in TCP), the sending end keeps a record of each IP packet sent and the receiving end acknowledges all the arrivals. If the sender does not receive an acknowledgement within a timeout, it retransmits the message. The more sophisticated sliding window scheme [Comer 2006] cuts down on the number of acknowledgement messages required

The TCP protocol attempts to match the speeds of the processes that read from and write to a stream. If the writer is too fast for the reader, then it is blocked until the reader has consumed sufficient data.

Message identifiers are associated with each IP packet, which enables the recipient to detect and reject duplicates, or to reorder messages that do not arrive in sender order.



A pair of communicating processes establish a connection before they can communicate over a stream. Once a connection is established, the processes simply read from and write to the stream without needing to use Internet addresses and ports. Establishing a connection involves a *connect* request from client to server followed by an *accept* request from server to client before any communication can take place.

**Failure model** • To satisfy the integrity property of reliable communication, TCP streams use checksums to detect and reject corrupt packets and sequence numbers to detect and reject duplicate packets. For the sake of the validity property, TCP streams use timeouts and retransmissions to deal with lost packets. Therefore, messages are guaranteed to be delivered even when some of the underlying packets are lost. But if the packet loss over a connection passes some limit or the network connecting a pair of communicating processes is severed or becomes severely congested, the TCP software responsible for sending messages will receive no acknowledgements and after a time will declare the connection to be broken. Thus TCP does not provide reliable communication, because it does not guarantee to deliver messages in the face of all possible difficulties.

**Use of TCP** • Many frequently used services run over TCP connections, with reserved port numbers. These include the following:

***HTTP*:** The Hypertext Transfer Protocol is used for communication between web browsers and web servers;

***FTP*:** The File Transfer Protocol allows directories on a remote computer to be browsed and files to be transferred from one computer to another over a connection.

***Telnet*:** Telnet provides access by means of a terminal session to a remote computer.

***SMTP*:** The Simple Mail Transfer Protocol is used to send mail between computers.

**JavaAPIforTCPstreams**•TheJavainterfacetoTCPstreamsisprovidedintheclasses*ServerSocket*and*Socket*:

***ServerSocket*:**Thisclassisintendedforusebyaservertocreateasocketataserver portforlisteningfor*connect*requestsfromclients.Its *accept*methodgetsa*connect* requestfromthe queueor, ifthe queueis empty,blocksuntilonearrives.Theresult ofexecuting*accept*isaninstanceof*Socket*– asockettouseforcommunicatingwith theclient.

TCPclientmakesconnection toserver,sendsrequestandreceivesreply

```
importjava.net.*;
importjava.io.*;
publicclassTCPClient{

        publicstaticvoidmain(Stringargs[]){

    //argumentssupplymessageandhostnameofdestinati
    on Sockets=null;

    try{

      intserverPort=7896;
      s=newSocket(args[1],serverPort);

      DataInputStreamin=newDataInputStream(s.getInputStream());
      DataOutputStreamout= □

            newDataOutputStream(s.getOutputStream());
      out.writeUTF(args[0]);      //UTFis astringencoding;seeSec4.3
      Stringdata= in.readUTF();
      System.out.println("Received:"+data);

    }catch(UnknownHostExceptione){
      System.out.println("Sock:"+e.getMessage());

    } catch(EOFExceptione){System.out.println("EOF:"+e.getMessage());

    } catch(IOExceptione){System.out.println("IO:"+e.getMessage());

    }finally{if(s!=null)try{s.close();}catch(IOExceptione){/*closefailed*/}}

  }
```

---

```
}
```

The***Socket***classprovidesthemethods*getInputStream*and*getOutputStream*foraccessingthetwostreams ass ociated withasocket.Thereturntypesofthese methodsare*InputStream*and*OutputStream*, respectively– abstractclassesthat definemethods forreading andwritingbytes.

TCPservermakesaconnection foreachclientandthenechoestheclient'srequest

```
importjava.net.*;
importjava.io.*;
publicclassTCPServer{
```

```
  publicstaticvoidmain(Stringargs[]){
            try{
      intserverPort= 7896;
      ServerSocketlistenSocket= newServerSocket(serverPort);
      while(true){
        SocketclientSocket=listenSocket.accept(); Connectionc
        = newConnection(clientSocket);
      }
    } catch(IOExceptione){System.out.println("Listen:"+e.getMessage());}
  }
}
```

```
classConnectionextendsThread{
    DataInputStreamin;
    DataOutputStreamout;
    SocketclientSocket;
    publicConnection(SocketaClientSocket){

      try{

        clientSocket=aClientSocket;
        in=newDataInputStream(clientSocket.getInputStream());
        out=newDataOutputStream(clientSocket.getOutputStream())
        ; this.start();

      }catch(IOExceptione){System.out.println("Connection:"+e.getMessage());}

    }

    publicvoidrun(){

      try{                    //
        anechoserver Stringdata=
        in.readUTF(); out.writeUTF(data);

      } catch(EOFExceptione){System.out.println("EOF:"+e.getMessage());

      } catch(IOExceptione){System.out.println("IO:"+e.getMessage());

      } finally{try{clientSocket.close();}catch(IOExceptione){/*closefailed*/}}

    }


}
```

## Εξτερναλ δατα ρεπρεσεντατιον ανδ μαρσηαλλινγ

The information stored in running programs is represented as data structures – for example, by sets of interconnected objects – whereas the information in messages consists of sequences of bytes. Irrespective of the form of communication used, the data structures must be flattened (converted to a sequence of bytes) before transmission and rebuilt on arrival. The individual primitive data items transmitted in messages can be data values of many different types, and not all computers store primitive values such as integers in the same order. The representation of floating-point numbers also differs between architectures. There are two variants for the ordering of integers: the so-called *big-endian* order, in which the most significant byte comes first; and *little-endian* order, in which it comes last. Another issue is the set of codes used to represent characters: for example, the majority of applications on systems such as UNIX use ASCII character Coding, taking one byte per character, whereas the Unicode standard allows for the representation of texts in many different languages and

takes two bytes per character. One of the following methods can be used to enable any two computers to Exchange binary data values:

• The values are converted to an agreed external format before transmission and converted to the local form on receipt; if the two computers are known to be the same type, the conversion to external format can be omitted.

• The values are transmitted in the sender's format, together with an indication of the format used, and the recipient converts the values if necessary.

Note, however, that bytes themselves are never altered during transmission. To support RMI or RPC, any data type that can be passed as an argument or returned as a result must be able to be flattened and the individual primitive data values represented in an agreed format. An agreed standard for the representation of data structures and primitive values
is called an ***external data representation*.**

***Marshalling*** is the process of taking a collection of data items and assembling them into a form suitable for transmission in a message. *Unmarshalling* is the process of disassembling them on arrival to produce an equivalent collection of data items at the destination. Thus marshalling consists of the translation of structured data items andPrimitive values into an external data representation. Similarly, Unmarshalling consists of the generation of primitive values from their external data representation and the rebuilding of the data structures.
Three alternative approaches to external data representation and marshalling are discussed
• **CORBA's common data representation**, which is concerned with an external representation for the structured and primitive types that can be passed as the arguments and results of remote method invocations in CORBA. It can be used by a variety of programming languages
• **Java's object serialization**, which is concerned with the flattening and external data representation of any single object or tree of objects that may need to be transmitted in a message or stored on a disk. It is for use only by Java.
• **XML (Extensible Markup Language),** which defines a textual format for representing structured data. It was originally intended for documents containing textual self-describing structured data – for example documents accessible on the Web – but it is now also used to represent the data sent in messages exchanged by clients and servers in web services.
Inthefirsttwocases,themarshallingandunmarshalling activitiesareintendedtobe carriedoutbyamiddlewarelayerwithoutanyinvolvementonthepartoftheapplication programmer.
Inthefirsttwoapproaches,theprimitivedatatypesaremarshalledintoabinary form.Inthethirdapproach(XML),theprimitivedatatypesarerepresented textually.

**CORBA'sCommonDataRepresentation (CDR)**
CORBACDRistheexternaldatarepresentationdefinedwithCORBA2.0.
Theseconsistof15primitivetypes,which include*short*(16-bit), *long*(32-bit),*unsigned short*,*unsigned long*,*float*(32-bit), *double*(64-bit),*char*,*boolean*(TRUE, FALSE), *octet*(8-bit),and*any.*

***Primitivetypes*:**CDRdefinesarepresentationforbothbig-endianandlittle-endian orderings.Valuesaretransmittedinthesender'sordering,whichisspecifiedineach message.Therecipienttranslatesifitrequiresadifferentordering.Forexample,a16-bit*short*occupiestwobytesinthemessage,andforbig-endianordering,themost significantbits occupythefirst byte and theleast significantbits occupythesecond byte.
***Constructedtypes*:**Theprimitivevaluesthatcompriseeachconstructedtypeare addedtoa sequenceofbytesinaparticularorder,asshownin following Figure.

CORBACDRforconstructedtypes

| *Type* | *Representation* |
|---|---|
| *sequence* | length(unsignedlong)followedbyelementsinorder |
| *string* | length(unsignedlong)followedbycharactersinorder(canalso havewidecharacters) |
| *array* | arrayelementsinorder(nolengthspecifiedbecauseitisfixed) |
| *struct* | intheorderofdeclarationofthecomponents |
| *enumerated* | unsignedlong(thevaluesarespecifiedbytheorderdeclared) |
| *union* | typetagfollowedbytheselectedmember |

The following figure showsamessageinCORBA CDRthatcontains thethreefieldsofa*struct*

| *index in sequence of bytes* | ←4 bytes→ | *notes on representation* |
|---|---|---|
| 0–3 | 5 | *length of string* |
| 4–7 | "Smit" | *'Smith'* |
| 8–11 | "h___" | |
| 12–15 | 6 | *length of string* |
| 16–19 | "Lond" | *'London'* |
| 20–23 | "on__" | |
| 24–27 | 1984 | *unsigned long* |

The flattened form represents a *Person* struct with value: {'Smith', 'London', 1984}

whoserespective typesare*string*,*string*and*unsignedlong*.

**MarshallinginCORBA•** Marshallingoperationscanbegeneratedautomaticallyfrom the specificationof the typesof dataitemstobetransmittedina message.

Forexample, wemightuseCORBA IDL(Interface Definition language)todescribethe datastructureinthemessageof above Figureasfollows:

```
structPerson{ stringname;
      stringplace;
      unsignedlongyear;

};
```

## ϑαϖαοβφεχτσεριαλιζατιον

InJavaRMI,bothobjectsandprimitivedatavaluesmaybepassedasarguments and resultsofmethodinvocations.Anobjectisaninstanceofa Javaclass.Forexample,the Javaclassequivalenttothe*Personstruct*definedinCORBAIDLmightbe:

```
publicclassPersonimplementsSerializable{
    privateStringname;
    privateStringplace;

    privateintyear;
    publicPerson(StringaName,StringaPlace,intaYear){
```

```
        name=aName;
        place=aPlace; year=
        aYear;
    }
    // followedbymethodsforaccessingtheinstancevariables
}
```

- ✓ The above class states that it implements serializable interface.
- ✓ In java, serialization means flattening an object or a set of objects into a serial form suitable for storing on a disk or transmitting in a message.
- ✓ Deserialization is the restoring of object from serialized form.
- ✓ Information about class(like name, version etc.) are included in serializable form so that it is helpful in deserialization process.
- ✓ Version numbers is intended to change when major changes are made to the class.(usually set by programmer).
- ✓ To serialize an object, its class information is written out followed by the types and names of its instance variables.
- ✓ Each class is given a handle( reference to an object within serialized form).
- ✓ Example, consider serialization of following object
- ✓ Person p=new Person("Smith","London",1934);

| *Serialized values* | | | | *Explanation* |
|---|---|---|---|---|
| Person | 8-byte version number | | h0 | *class name, version number* |
| 3 | int year | java.lang.String name | java.lang.String place | *number, type and name of instance variables* |
| 1984 | 5 Smith | 6 London | h1 | *values of instance variables* |

The true serialized form contains additional type markers; h0 and h1 are handles.

Extensible Markup Language (XML)

XML is a markup language that was defined by the World Wide Web Consortium(W3C) for general use on the Web. In general, the term *markup language* refers to atextual encoding that represents both a text and details as to its structure or itsappearance. Both XML and HTML were derived from SGML (StandardizedGeneralized Markup Language) [ISO 8879], a very complex markup language.

→XML data items are tagged with 'markup' strings. The tags are used to describethe logical structure of the data and to associate attribute-value pairs with logicalstructures.

→XML is used to enable clients to communicate with web services and for definingthe interfaces and other properties of web services.

→XML is *extensible* in the sense that users can define their own tags, in contrast toHTML, which uses a fixed set of tags. However, if an XML document is intended to beused by more than one application, then the names of the tags must be agreed betweenthem.

**XML elements and attributes** • The following Figure shows the XML definition of the *Person*structure that was used to illustrate marshalling in CORBA CDR and Java.

Φιγυρε ΞΜΛ δεφινιτιον οφ τηε Περσον στρυχτυρε

*<person id="123456789">*

*<name>Smith</name>*

*<place>London</place>*

*<year>1984</year>*

*<!-- a comment -->*

*</person >*

It shows thatXML consists of tags and character data. The character data, for example *Smith* or *1984*,is the actual data. As in HTML, the structure of an XML document is defined by pairsof tags enclosed in angle brackets. In above Figure, <*name*> and <*place*> are both tags.
Elements: An element in XML consists of a portion of character data surrounded bymatching start and end tags. For example, one of the elements in Figure consists ofthe data *Smith* contained within the <*name*> … </*name*> tag pair. Note that the elementwith the <*name*> tag is enclosed in the element with the <*person id="123456789"*> …</*person* > tag pair.

Attributes: A start tag may optionally include pairs of associated attribute names andvalues such as *id="123456789",* as shown above as attributes. An element is generally a container for data, whereas an attribute isused for labelling that data. In our example, *123456789* might be an identifier used bythe application, whereas *name*, *place* and *year* might be displayed.
Names: The names of tags and attributes in XML generally start with a letter, but canalso start with an underline or a colon. The names continue with letters, digits, hyphens,underscores, colons or full stops. Letters are case-sensitive. Names that start with *xml*are reserved.
Binary data: All of the information in XML elements must be expressed as characterdata.
**XML namespaces** • Traditionally, namespaces provide a means for scoping names. AnXML namespace is a set of names for a collection of element types and attributes that isreferenced by a URL. Any other XML document can use an XML namespace byreferring to its URL.
Any element that makes use of an XML namespace can specify that namespace asan attribute called *xmlns*, whose value is a URL referring to the file containing thenamespace definitions. For example:
*xmlns:pers = http://www.cdk5.net/person*
The name after *xmlns,* in this case *pers*can be used as a prefix to refer to the elements in a particular namespace, as shown in following Figure. The *pers*prefix is bound to*http://www.cdk4.net/person* for the *person* element.

Ιλλυστρατιον οφ τηε υσε οφ α ναμεσπαχε ιν τηε Περσον στρυχτυρε

*<person pers:id="123456789" xmlns:pers = "http://www.cdk5.net/person">*

*<pers:name> Smith </pers:name>*

*<pers:place> London </pers:place>*

*<pers:year> 1984 </pers:year>*

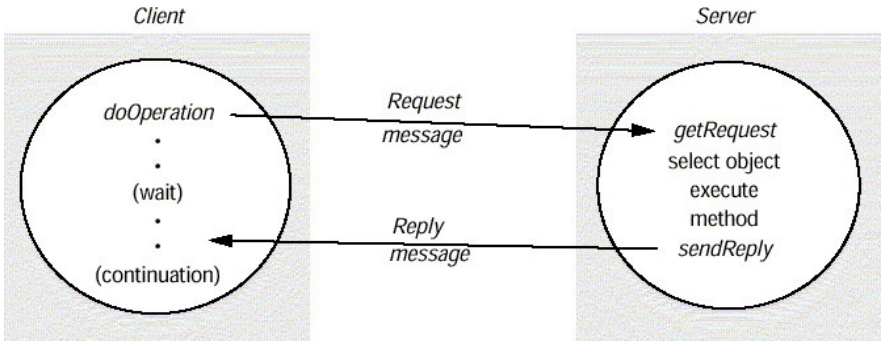
*</person>*

**Client-Server Communication**

The client-server communication is designed to support the roles and message exchanges in typical client-server interactions.In the normal case, request-reply communication is synchronous because the client process blocks until the reply arrives from the server. Asynchronous request-reply communication is an alternative that is useful where clients can afford to retrieve replies later.

**The request-reply protocol**

The request-reply protocol was based on a trio of communication primitives: doOperation, getRequest,




and sendReply shown in following Figure.

The designed request-reply protocol matches requests to replies. If UDP datagrams are used, the delivery guarantees must be provided by the request-reply protocol, which may use the server reply message as an acknowledgement of the client request message.

*public byte[] doOperation (RemoteObjectRef o, int methodId, byte[] arguments)*
sends a request message to the remote object and returns the reply.
The arguments specify the remote object, the method to be invoked and the arguments of that method.

*public byte[] getRequest ();*
acquires a client request via the server port.

*public void sendReply (byte[] reply, InetAddress clientHost, int clientPort);*
sends the reply message *reply* to the client at its Internet address and port.

The following Figureoutlines the three communication primitives.

The information to be transmitted in a request message or a reply message is shown in following Figure.

| | |
|---|---|
| messageType | *int (0=Request, 1= Reply)* |
| requestId | *int* |
| objectReference | *RemoteObjectRef* |
| methodId | *int or Method* |
| arguments | *// array of bytes* |

TheRequest-reply protocol message structure contains the following.

- The first field indicates whether the message is a request or a reply message.
- The second field request id contains a message identifier.
- The third field is a remote object reference.
- The fourth field is an identifier for the method to be invoked.

**Message identifier**

A message identifier consists of two parts:

→A requestId, which is taken from an increasing sequence of integers by the sending process

→An identifier for the sender process, for example its port and Internet address.

**Failure model of the request-reply protocol**

If the three primitive *dooperation, getRequest,* and*sendReply* are implemented over UDP datagram, they have some communication failures. Such as,

→omission failure

→Messages are not guaranteed to be delivered in sender order.

**RPC exchange protocols**

Three protocols are used for implementing various types of RPC.

- The request (R) protocol.
- The request-reply (RR) protocol.
- The request-reply-acknowledge (RRA) protocol.

| Name | Messages sent by | | |
|---|---|---|---|
| | Client | Server | Client |
| R | Request | | |
| RR | Request | Reply | |
| RRA | Request | Reply | Acknowledge reply |

→In the R protocol, a single request message is sent by the client to the server.

→The R protocol may be used when there is no value to be returned from the remote method.

→The RR protocol is useful for most client-server exchanges because it is based on request-reply protocol. Special acknowledgement messages are not required, because a server reply message is considered as an acknowledgement of the client's request message.

→RRA protocol is based on the exchange of three messages: request-reply-acknowledge reply. The acknowledgement reply message contains the requested from the reply message being acknowledged. This will enable the server to discard entries from its history.

**HTTP: an example of a request-reply protocol**

HTTP is a request-reply protocol for the exchange of network resources between web clients and web servers.

**HTTP protocol steps are:**

- Connection establishment between client and server at the default server port or at a port specified in the URL

- client sends a request message to the server
- server sends a reply message to the client
- connection is closed

HTTP request message is shown below.

| *method* | *URL* | *HTTP version* | *headers* | *message body* |
|---|---|---|---|---|
| GET | //www.dcs.qmw.ac.uk/index.html | HTTP/ 1.1 | | |

**Figure :. HTTP request message**

- **HTTP methods**
  - **GET**
    - Requests the resource, identified by URL as argument.
    - If the URL refers to data, then the web server replies by returning the data
    - If the URL refers to a program, then the web server runs the program and returns the output to the client.
  - **HEAD**
    - This method is similar to GET, but only meta data on resource is returned (like date of last modification, type, and size)
  - **POST**
    - Specifies the URL of a resource (for instance, a server program) that can deal with the data supplied with the request.
    - This method is designed to deal with:
      - Providing a block of data to a data-handling process
      - Posting a message to a bulletin board, mailing list or news group.
      - Extending a dataset with an append operation
  - **PUT**
    - Supplied data to be stored in the given URL as its identifier.
  - **DELETE**
    - The server deletes an identified resource by the given URL on the server.
  - **OPTIONS**
    - A server supplies the client with a list of methods.
    - It allows to be applied to the given URL
  - **TRACE**
    - The server sends back the request message

| *HTTP version* | *status code* | *reason* | *headers* | *message body* |
|---|---|---|---|---|
| HTTP/1.1 | 200 | OK | | resource data |

**HTTP reply message is shown below.**

Above reply message specifies

- The protocol version
- A status code
- Reason
- Some headers
- An optional message body

**Group Communication**

The pairwise exchange of messages is not the best model for communication from one process to a group of other processes, which may be necessary, for example, when a service is implemented as a number of different processes in different computers, perhaps to provide fault tolerance or to enhance availability. A *multicast operation* is more appropriate – this is an operation that sends a single message from one process to each of the members of a group of processes, usually in such a way that the membership of the group is transparent to the sender. There is a range of possibilities in the desired Behaviour of a multicast. The simplest multicast protocol provides no guarantees about message delivery or ordering.

Multicast messages provide a useful infrastructure for constructing distributed systems with the following characteristics:

**1.*Fault tolerance based on replicated services*:** A replicated service consists of a group of servers. Client requests are multicast to all the members of the group, each of which performs an identical operation. Even when some of the members fail, clients can still be served.

**2.*Discovering services in spontaneous networking***: Multicast messages can be used by servers and clients to locate available discovery services in order to register their interfaces or to look up the interfaces of other services in the distributed system.

**3. *Better performance through replicated data*:** Data are replicated to increase the performance of a service – in some cases replicas of the data are placed in users' computers. Each time the data changes,the new value is multicast to the processes managing the replicas.

**4. *Propagation of event notifications*:** Multicast to a group may be used to notify processes when something happens. For example, in Facebook, when someone changes their status, all their friends receive notifications. Similarly, publish subscribe protocols may make use of group multicast to disseminate events to subscribers.

## IP multicast An implementation of multicast communication

**IP multicast •** *IP multicast* is built on top of the Internet Protocol (IP). Note that IP packets are addressed to computers – ports belong to the TCP and UDP levels. IP multicast allows the sender to transmit a single IP packet to a set of computers that form a multicast group. The sender is unaware of the identities of the individual recipients and of the size of the group. A *multicast group* is specified by a Class D Internet address.

Being a member of a multicast group allows a computer to receive IP packets sent to the group. The membership of multicast groups is dynamic, allowing computers to join or leave at any time and to join an arbitrary number of groups. It is possible to send datagrams to a multicast group without being a member.

When a multicast message arrives at a computer, copies are forwarded to all of the local sockets that have joined the specified multicast address and are bound to the specified port number. The following details are specific to IPv4:

***Multicast routers*:** IP packets can be multicast both on a local network and on the wider Internet. Local multicasts use the multicast capability of the local network, for example, of an Ethernet. Internet multicasts make use of multicast routers, which forward single datagrams to routers on other networks, where they are again multicast to local members. To limit the distance of propagation of a multicast datagram, the sender can specify the number of routers it is allowed to pass – calledThe*time to live*, or TTL for short.

***Multicast address allocation*:** Class D addresses (that is,addresses in the range 224.0.0.0 to 239.255.255.255) are reserved for multicast trafficand managed globally by the Internet Assigned Numbers Authority (IANA).

**Failure model for multicast datagrams** • Datagrams multicast over IP multicast have the same failure characteristics as UDP datagrams – that is, they suffer from omission failures. The effect on a multicast is that messages are not guaranteed to be delivered to any particular group member in the face of even a single omission failure. That is, some but not all of the members of the group may receive it. This can be called *unreliable* multicast, because it does not guarantee that a message will be delivered to any member of a group.

**Java API to IP multicast** • The Java API provides a datagram interface to IP multicastthrough the class *MulticastSocket*, which is a subclass of *DatagramSocket* with theadditional capability of being able to join multicast groups. The class *MulticastSocket*provides two alternative constructors, allowing sockets to be created to use either aspecified local port (6789, in following figure) or any free local port. A process can join amulticast group with a given multicast address by invoking the *joinGroup()*method of itsmulticast socket. Effectively, the socket joins a multicast group at a given port and it willreceive datagrams sent by processes on other computers to that group at that port. Aprocess can leave a specified group by invoking the *leaveGroup()*method of its multicastsocket.

**Figure** Multicast peer joins a group and sends and receives datagrams

```
import
java.net.*;
import
java.io.*;

public class MulticastPeer{

public static void main(String args[]){

// args give message contents & destination multicast group (e.g.
"228.5.6.7") MulticastSocket s =null;

try {
```

```
InetAddress group =
InetAddress.getByName(args[1]); s = new
MulticastSocket(6789);

s.joinGroup(group);

byte [] m = args[0].getBytes();

DatagramPacket messageOut =

new DatagramPacket(m, m.length,
group, 6789); s.send(messageOut);

byte[] buffer = new byte[1000];

for(int i=0; i< 3; i++) { // get messages from others in
group DatagramPacket messageIn =

new DatagramPacket(buffer, buffer.length);
s.receive(messageIn);

System.out.println("Received:" +new String(messageIn.getData()));

}

                eaveGroup(group);
} catch (SocketException e){System.out.println("Socket: " + e.getMessage());

} catch (IOException e){System.out.println("IO: " + e.getMessage());

} finally { if(s != null) s.close();}

}

}
```

A datagram sent from one multicast router to another may be lost, thus preventing all recipients beyond that router from receiving the message. Also, when a multicast on a local area network uses the multicasting capabilities of the network to allow a single datagram to arrive at multiple recipients, any one of those recipients may drop the message because its buffer is full.

Another factor is that any process may fail. If a multicast router fails, the group members beyond that router will not receive the multicast message, although local members may do so. Ordering is another issue. IP packets sent over an internetwork do not necessarily arrive in the order in which they were sent, with the possible effect that some group members receive datagrams from a single sender in a different order from other group members. In addition, messages sent by two different processes will not necessarily arrive in the same order

at all the members of the group.

**Some examples of the effects of reliability and ordering** • We now consider the effect of the failure semantics of IP multicast as follows

1. ***Fault tolerance based on replicated services*:** Consider a replicated service that consists of the members of a group of servers that start in the same initial state and always perform the same operations in the same order, so as to remain consistent with one another. This application of multicast requires that either all of the replicas or none of them should receive each request to perform an operation – if one of them misses a request, it will become inconsistent with the others. In most cases, this service would require that all members receive request messages in the same order as one another.
2. ***Discovering services in spontaneous networking*:** One way for a process to discover services in spontaneous networking is to multicast requests at periodic intervals, and for the available services to listen for those multicasts and respond. An occasional lost request is not an issue when discovering services.
3. ***Better performance through replicated data***: Consider the case where the replicated data itself, rather than operations on the data, are distributed by means of multicast messages. The effect of lost messages and inconsistent ordering would depend on the method of replication and the importance of all replicas being totally up-to-date.
4. ***Propagation of event notifications*:** The particular application determines the qualities required of multicast.

Some applications require a multicast protocol that is more reliable than IP multicast. In particular, there is a need for *reliable multicast*, in which any message transmitted is either received by all members of a group or by none of them. The examples also suggest that some applications have strong requirements for ordering, the strictest of which is called *totally ordered multicast*, in which all of the messages transmitted to a group reach all of the members in the same order.

## UNIT – III

**Syllabus:** Distributed Objects and Remote Invocation: Introduction, Communication between Distributed Objects- Object Model, Distributed Object Modal, Design Issues for RMI, Implementation of RMI, Distributed Garbage Collection; Remote Procedure Call, Events and Notifications, Case Study: JAVA RMI

Distributed Objects and Remote Invocation:

Introduction communication between distributed objects

**Distributed objects**[ are objects that are distributed across different address spaces, either in multiple computers connected via a network or even indifferent processes on the same computer, but which work together by sharing data and invoking methods. This often involves location transparency, where remote objects appear the same as local objects.

The main method of distributed object communication is with remote method invocation

Invoking a method on a remote object is known as **remote method invocation**) generally by message-passing

Message-passing: one object sends a message to another object in a remote machine or process to perform some task. The results are sent back to the calling object.

The remote procedure call (RPC) approach extends the common programming Abstraction of the procedure call to distributed environments, allowing a calling Process to call a procedure in a remote node as if it is local.
Remote method invocation (RMI) is similar to RPC but for distributed objects,with
Added benefits in terms of using object-oriented programming concepts in Distributed systems and also extending the concept of an object reference to the Global distributed environments, and allowing the use of object references as Parameters in remote invocations
Remote procedure call – client calls the procedures in a server program that is running in a different process

Remote method invocation (RMI) – an object in one process can invoke methods of objects in another process

Event notification – objects receive notification of events at other objects for which they have registered
Middleware Roles

provide high-level abstractions such as RMI enable location transparency free from specifics of

communication protocols operating systems and communication hardware


Fig middle ware layer

Communication between distributed objects and other objects

Life cycle : Creation, migration and deletion of distributed objects is different from local objects

Reference : Remote references to distributed objects are more complex than simple pointers to memory addresses

Request Latency : A distributed object request is orders of magnitude slower than local method invocation

Object Activation : Distributed objects may not always be available to serve an object request at any point in time

Parallelism: Distributed objects may be executed in parallel.

Communication : There are different communication primitives available for distributed objects requests

Failure: Distributed objects have far more points of failure than typical local objects.

Security: Distribution makes them vulnerable to attack.

Distributed object model:

The term **distributed objects** usually refers to software modules that are designed to work together, but reside either in multiple computers connected via a network or in different processes inside the same computer.

## Διστριβυτεδ οβφεχτσ

The state of an object consists of the values of its instance variables since object-based programs are logically partitioned, the physical distribution of objects into different

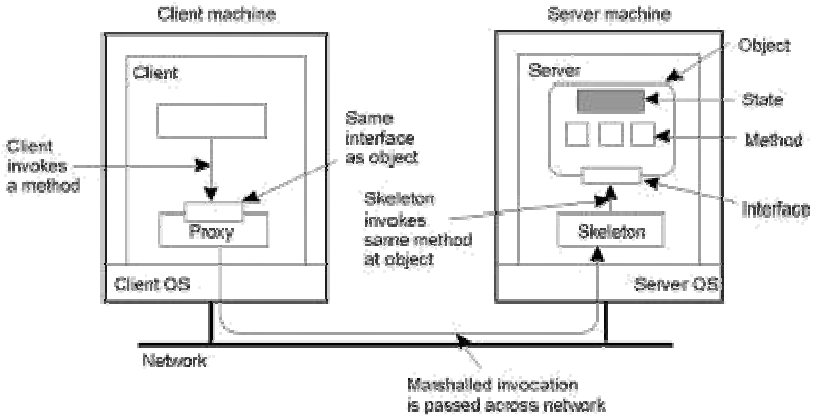
processes or computers in a distributed system. Distributed object systems may adopt the client-server architecture. objects are managed by servers and their clients invoke their methods using remote method invocation.

In RMI, the client's request to invoke a method of an object is sent in a message to the server managing the object. The invocation is carried out by executing a method of the object at the server and the result is returned to the client in another message

Distributed objects can assume other architectural models. For example, objects can be replicated in order to obtain the usual benefits of fault tolerance and enhanced performance, and objects can be migrated with a view to enhancing their performance and availability.

Another advantage of treating the shared state of a distributed program as a collection of objects is that an object may be accessed via RMI, or it may be copied into a local cache and accessed directly, provided that the class implementation is available locally.

Distributed Objects




**RMI Invocation Semantics:**

Invocation semantics depend upon implementation of Request Reply Protocol used by RMI

It maybe, used At-least-once, At-most-once
Transparency:

Partial failure, higher latency, Different semantics for remote objects,

For e.g. wait/notify Current consensus: remote invocations should be made transparent in the sense that syntax of a remote invocation is the same as the syntax of local invocation (access

transparency) but programmers should be able to distinguish between remote and local objects by looking at their interfaces, e.g. in Java RMI, remote objects implement the Remote interface

Issues in implementing RMI

Parameter passing

Request reply protocol (handling failures at client and server)

Supporting constant objects, object adapters, dynamic invocations, etc

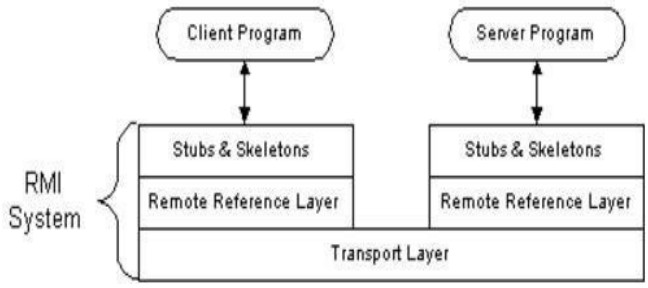
The design goal for the RMI architecture was to create a Java distributed object model that integrates naturally into the Java programming language and the local object model. RMI architects have succeeded; creating a system that extends the safety and robustness of the Java architecture to the distributed computing world.

The RMI architecture is based on one important principle: the definition of behavior and the implementation of that behavior are separate concepts. RMI allows the code that defines the behavior and the code that implements the behavior to remain separate and to run on separate JVMs.
This fits nicely with the needs of a distributed system where clients are concerned about the definition of a service and servers are focused on providing the service.
Specifically, in RMI, the definition of a remote service is coded using a Java interface. The implementation of the remote service is coded in a class.

Therefore, the key to understanding RMI is to remember that interfaces define behavior and classes

Implementation of RMI:

The RMI implementation is essentially built from three abstraction layers. The first is the Stub and Skeleton layer, which lies just beneath the view of the developer. This layer intercepts method calls made by the client to the interface reference variable and redirects these calls to a remote RMI service.
The next layer is the Remote Reference Layer. This layer understands how to interpret and manage references made from clients to the remote service objects. In JDK 1.1, this layer connects clients to remote service objects that are running and exported on a server. The connection is a one-to-one link. In the Java 2 SDK, this layer was enhanced to support the activation of dormant remote service objects via *Remote Object Activation*.
The transport layer is based on TCP/IP connections between machines in a network. It provides basic connectivity, as well as some firewall penetration strategies.



Distributed Garbage collection

**Distributed garbage collection** (DGC) in computing is a particular case of **garbage collection** where references to an object can be held by a remote client.

One of the joys of programming for the Java platform is not worrying about memory allocation. The JVM has an automatic garbage collector that will reclaim the memory from any object that has been discarded by the running program.

One of the design objectives for RMI was seamless integration into the Java programming language, which includes garbage collection. Designing an efficient single-machine garbage collector is hard; designing a distributed garbage collector is very hard.

The RMI system provides a reference counting distributed garbage collection algorithm based on Modula-3's Network Objects.

This system works by having the server keep track of which clients have requested access to remote objects running on the server. When a reference is made, the server marks the object as "dirty" and when a client drops the reference; it is marked as being "clean."

DGC uses some combination of the classical garbage collection (GC) techniques, tracing and reference counting. It has to cooperate with local garbage collectors in each process in order to keep global counts, or to globally trace accessibility of data.

In general, remote processors do not have to know about internal counting or tracing in a given process, and the relevant information is stored in interfaces associated with each process.

DGC is complex and can be costly and slow in freeing memory. One cheap way of avoiding DGC algorithms is typically to rely on a time lease set or configured on the remote object; it is the stub's task to periodically renew the lease on the remote object.

If the lease has expired, the server process (the process owning the remote object) can safely assume that either the client is no longer interested in the object, or that a network partition or crash obstructed lease renewal, in which case it is "hard luck" for the client if it is in fact still interested.

Hence, if there is only a single reference to the remote object on the server representing a remote reference from that client, that reference can be dropped, which will mean the object will be garbage collected by the local garbage collector on the server at some future point in time.

Distributed systems typically require distributed garbage collection. If a client holds a proxy to an object in the server, it is important that the server does not garbage-collect that object until the client releases the proxy. Most third-party distributed systems, such as RMI, handle the distributed garbage collection, but that does not necessarily mean it will be done efficiently. The overhead of distributed garbage collection and remote reference maintenance in RMI can slow network communications by a significant amount when many objects are involved.

Of course, if you need distributed reference maintenance, you cannot eliminate it, but you can reduce its impact. You can do this by reducing the number of temporary objects that may have

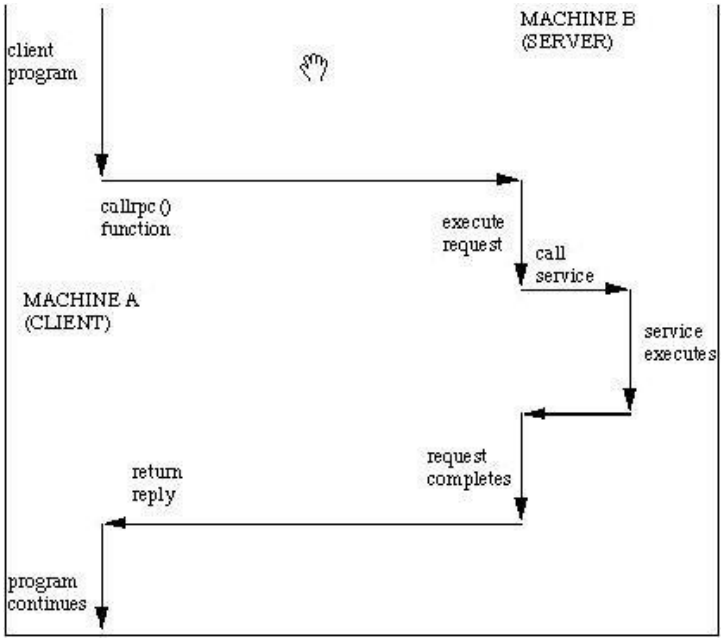
distributed references. The issue is considerably more complex in a multiuser distributed environment, and here you typically need to apply special optimizations related to the products you use in order to establish your multiuser environment.

**Remote Procedure Call** (**RPC**) is a protocol that one program can use to request a service from a program located in another computer in a network without having to understand network details. (A procedure call is also sometimes known as a function call or a subroutine call.) **RPC** uses the client/server model.

An RPC is analogous to a function call. Like a function call, when an RPC is made, the calling arguments are passed to the remote procedure and the caller waits for a response to be returned from the remote procedure.

The flow of activity that takes place during an RPC call between two networked systems. The client makes a procedure call that sends a request to the server and waits. The thread is blocked from processing until either a reply is received, or it times out.

When the request arrives, the server calls a dispatch routine that performs the requested service, and sends the reply to the client. After the RPC call is completed, the client program continues. RPC specifically supports network applications.



**Remote Procedure Calling Mechanism** A remote procedure is uniquely identified by the triple: (program number, version number, procedure number) the program number identifies a group of related remote procedures, each of which has a unique procedure number. A program may consist of one or more versions. Each version consists of a collection of procedures which are available to be called remotely. Version numbers enable multiple versions of an RPC protocol to be available simultaneously. Each version contains a number of procedures that can be called remotely. Each procedure has a procedure number.

Events and notification

Events of changes/updates...

notifications of events to parties interested in the events

publish events to send

subscribe events to receive

main characteristics in distributed event-based systems:

a way to standardize communication in heterogeneous systems (not designed to communicate directly)

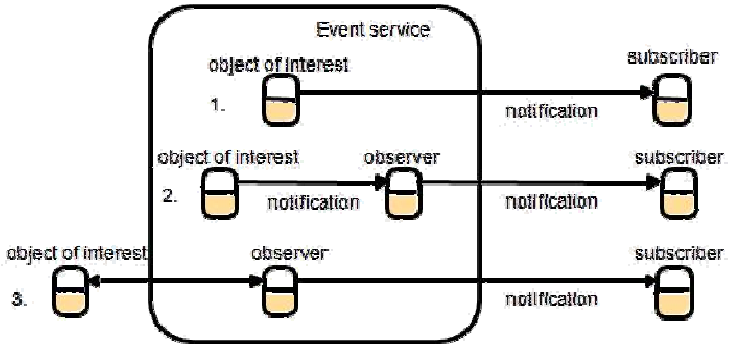
asynchronous communication (no need for a publisher to wait for each subscriber- - subscribers come and go)

event types

each type has attributes (information in it)

subscription filtering: focus on certain values in the attributes (e.g. "buy" events, but only "buy car" events)

## Events and Notifications (4):




Publish-subscribe paradigm: publisher sends notifications, i.e. objects representing events

‹ Subscriber registers interest to receive notifications

The object of interest: where events happen, change of state as a result of its operations being invoked „ Events: occurs in the object of interest „

Notification: an object containing information about an event

Subscriber: registers interest and receives notifications „

publisher: generate notifications, usually an object of interest

Observer objects: decouple an object of interest from its subscribers (not important)

Case study JAVA RMI

server program main program: binding instances of servant classes

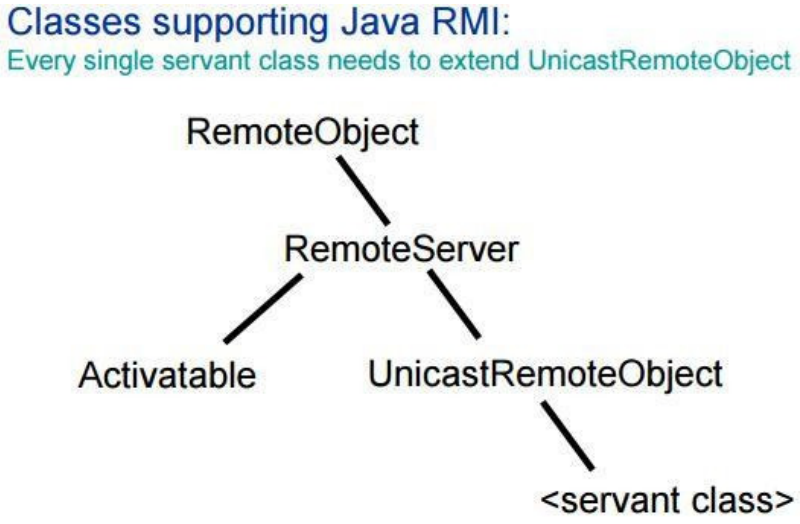
main method needs to create a security manager to enable Java security. A default security manager, RMISecurityManager, is provided

Note: if an RMI server sets no security manager, proxies and classes can only be loaded from the local classpath, in order to protect the program from code that is downloaded as a result of remote method invocations.

servant classes: ShapeList Servant and Shape Servant, implementing ShapeList and Shape interfaces respectively ‹ servant classes need to extend

UnicastRemoteObject, which provides remote object that live only as long as the process in which they are created

implementation of servant classes are straightforward, no concern of communication details




UnicastRemote Object:

automatically creates socket and listens for network requests, and make its services available by exporting them.

RMISecurityManager (): Needed to download objects from network. The downloaded objects are allowed to communicate only with sites they came from.

Default security manager, when none is explicitly set, allows only loading from local file system

Reflection: the class of an object can be determined at runtime, and this class can be examined to determine which methods are available, and even invoke these methods with dynamically created arguments „

The key to reflection is the java.lang.Class, which allows much information to be determined about a class. This leads onto the other reflection classes such as java.lang.reflect.Method

Heterogeneity is an important challenge to designers: ‹ Distributed systems must be constructed from a variety of different networks, operating systems, computer hardware and programming languages. The Internet communication protocols mask the difference in networks and middleware can deal with the other differences. „

External data representation and marshalling ‹
CORBA marshals data for use by recipients that have prior knowledge of the types of its components. It uses an IDL specification of the data types ‹

Java serializes data to include information about the types of its contents, allowing the recipient to reconstruct it. It uses reflection to do this. „ RMI ‹

Each object has a (global) remote object reference and a remote interface that specifies which of its operations can be invoked remotely. ‹

local method invocations provide exactly-once semantics; the best RMI can guarantee is at-most-once ‹

Middleware components (proxies, skeletons and dispatchers) hide details of marshalling, message passing and object location from programmers

## Unit-5 Distributed file Systems

**Syllabus:** Introduction, File service Architecture, PEER- to-PEER Systems, Napster and its Legacy, PEER-to-PEER, Middle ware, Routing Overlays

### Topic 01: INTRODUCTION

- File system were originally developed for centralized computer systems and desktop computers.
- File system was as an operating system facility providing a convenient programming interface to disk storage.
- Distributed file systems support the sharing of information in the form of files and hardware resources.
- With the advent of distributed object systems (CORBA, Java) and the web, the picture has become more complex.
- Figure 1 provides an overview of types of storage system.


- Distributed file systems support the sharing of information in the form of files and hardware resources.
- With the advent of distributed object systems (CORBA, Java) and the web, the picture has become more complex.
- Figure 1 provides an overview of types of storage system.


| | *Sharing* | *Persis-tence* | *Distributed cache replicas* | *Consistency maintenance* | *Example* |
|---|---|---|---|---|---|
| Main memory | ✗ | ✗ | ✗ | 1 | RAM |
| File system | ✗ | ✓ | ✗ | 1 | UNIX file system |
| Distributed file system | ✓ | ✓ | ✓ | ✓ | Sun NFS |
| Web | ✓ | ✓ | ✓ | ✗ | Web server |
| Distributed shared memory | ✓ | ✗ | ✓ | ✓ | Ivy (Ch. 18) |
| Remote objects (RMI ORB) | ✓ | ✗ | ✗ | 1 | CORBA |
| Persistent object store | ✓ | ✓ | ✗ | 1 | CORBA Persistent Object Service |
| Peer-to-peer storage system | ✓ | ✓ | ✓ | ✓ | OceanStore(Ch. 10) |

**Figure 1. Storage systems and their properties**

Types of consistency between copies: 1 - strict one-copy consistency
✓ - approximate consistency
X - no automatic consistency

- Figure 2 shows a typical layered module structure for the implementation of a non-distributed file system in a conventional operating system.

| | |
|---|---|
| Directory module: | relates file names to file IDs |
| File module: | relates file IDs to particular files |
| Access control module: | checks permission for operation requested |
| File access module: | reads or writes file data or attributes |
| Block module: | accesses and allocates disk blocks |
| Device module: | disk I/O and buffering |

**Figure 2. File system modules**

- File systems are responsible for the organization, storage, retrieval, naming, sharing and protection of files.
- Files contain both data and attributes.
- A typical attribute record structure is illustrated in Figure 3.

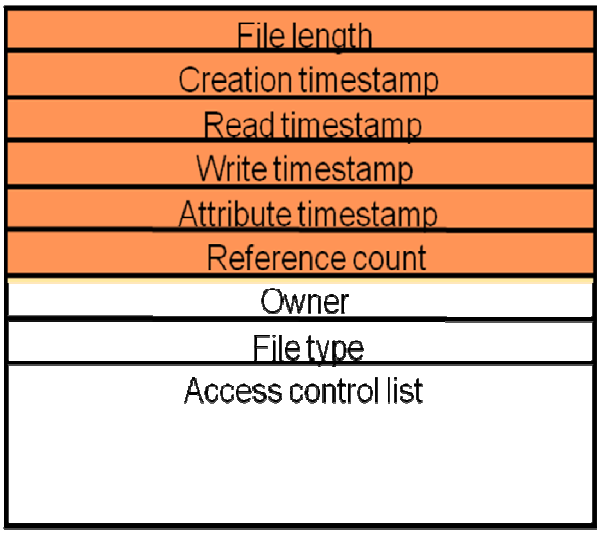



**Figure 3. File attribute record structure**

- Figure 4 summarizes the main operations on files that are available to applications in UNIX systems.

**Figure 4. UNIX file system operations**

| | |
|---|---|
| *filedes = open(name, mode)*<br>*filedes = creat(name, mode)* | Opens an existing file with the given *name*.<br>Creates a new file with the given *name*.<br>Both operations deliver a file descriptor referencing the open file. The *mode* is *read*, *write* or both. |
| *status = close(filedes)* | Closes the open file *filedes*. |
| *count = read(filedes, buffer, n)*<br>*count = write(filedes, buffer, n)* | Transfers *n* bytes from the file referenced by *filedes* to *buffer*.<br>Transfers *n* bytes to the file referenced by *filedes* from buffer.<br>Both operations deliver the number of bytes actually transferred and advance the read-write pointer. |
| *pos = lseek(filedes, offset, whence)* | Moves the read-write pointer to offset (relative or absolute, depending on *whence*). |
| *status = unlink(name)* | Removes the file *name* from the directory structure. If the file has no other names, it is deleted. |
| *status = link(name1, name2)* | Adds a new name (*name2*) for a file (*name1*). |
| *status = stat(name, buffer)* | Gets the file attributes for file *name* into *buffer*. |

- Distributed File system requirements
  - Related requirements in distributed file systems are:
    - Transparency
    - Concurrency
    - Replication
    - Heterogeneity
    - Fault tolerance
    - Consistency
    - Security
    - Efficiency

**Topic 02: File Service Architecture**

- An architecture that offers a clear separation of the main concerns in providing access to files is obtained by structuring the file service as three components:
  - A flat file service
  - A directory service
  - A client module.
- The relevant modules and their relationship is shown in Figure 5.

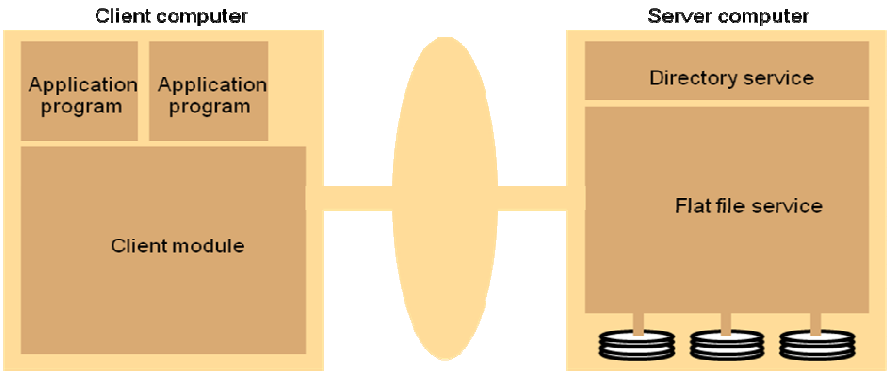



**Figure 5. File service architecture**

- The Client module implements exported interfaces by flat file and directory services on server side.
- Responsibilities of various modules can be defined as follows:
  - Flat file service:
    - Concerned with the implementation of operations on the contents of file. Unique File Identifiers (UFIDs) are used to refer to files in all requests for flat file service operations. UFIDs are long sequences of bits chosen so that each file has a unique among all of the files in a distributed system.
  - Directory service:
    - Provides mapping between text names for the files and their UFIDs. Clients may obtain the UFID of a file by quoting its text name to directory service. Directory service supports functions needed generate directories, to add new files to directories.
  - Client module:
    - It runs on each computer and provides integrated service (flat file and directory) as a single API to application programs. For example, in UNIX hosts, a client module emulates the full set of Unix file operations.
    - It holds information about the network locations of flat-file and directory server processes; and achieve better performance through implementation of a cache of recently used file blocks at the client.
  - Flat file service interface:
    - Figure 6 contains a definition of the interface to a flat file service.

| | |
|---|---|
| *Read(FileId, i, n) -> Data* -throws BadPosition | if *1≤i≤Length(File)*: Reads a sequence of up to n items from a file starting at item *i* and returns it in *Data*. |
| *Write(FileId, i, Data)* -throws BadPosition | if *1≤i≤Length(File)+1*: Write a sequence of *Data* to a file, starting at item *i*, extending the file if necessary. |
| *Create() -> FileId* | Creates a new file of length0 and delivers a UFID for it |
| *Delete(FileId)* | Removes the file from the file store. |
| *GetAttributes(FileId) -> Attr* | Returns the file attributes for the file. |
| *SetAttributes(FileId, Attr)* | Sets the file attributes (only those attributes that are not shaded in Figure 3.) |

**Figure 6. Flat file service operations**

- Access control
  - In distributed implementations, access rights checks have to be performed at the server because the server RPC interface is an otherwise unprotected point of access to files.
- Directory service interface
  - Figure 7 contains a definition of the RPC interface to a directory service.

| | |
|---|---|
| *Lookup(Dir, Name) -> FileId* -throws NotFound | Locates the text name in the directory and returns the relevant UFID. If *Name* is not in the directory, throws an exception. |
| *AddName(Dir, Name, File)* -throws NameDuplicate | If *Name* is not in the directory, adds(*Name*, *File*) to the directory and updates the file's attribute record. If *Name* is already in the directory: throws an exception. |
| *UnName(Dir, Name)* | If *Name* is in the directory, the entry containing *Name* is removed from the directory. If *Name* is not in the directory: throws an exception. |
| *GetNames(Dir, Pattern) -> NameSeq* | Returns all the text names in the directory that match the regular expression *Pattern*. |

**Figure 7. Directory service operations**

- Hierarchic file system
  - A hierarchic file system such as the one that UNIX provides consists of a number of directories arranged in a tree structure.
- File Group

- ❖ A file group is a collection of files that can be located on any server or moved between servers while maintaining the same names.
  - A similar construct is used in a UNIX file system.
  - It helps with distributing the load of file serving between several servers.
  - File groups have identifiers which are unique throughout the system (and hence for an open system, they must be globally unique).

To construct a globally unique ID we use some unique attribute of the machine on which it is created, e.g. IP number, even though the file group may move subsequently.


**Topic 03: PEER-TO-PEER SYSTEMS**

- Peer-to-peer systems aim to support useful distributed services and applications using data and computing resources available in the personal computers and workstations that are present in the Internet and other networks in ever-increasing numbers.

Peer-to-peer systems share these characteristics:

- Their design ensures that each user contributes resources to the system.
- Although they may differ in the resources that they contribute, all the nodes in a peer-to-peer system have the same functional capabilities and responsibilities.
- Their correct operation does not depend on the existence of any centrally Administered systems.
- They can be designed to offer a limited degree of anonymity to the providers and users of resources.
- A key issue for their efficient operation is the choice of an algorithm for the placement of data across many hosts and subsequent access to it in a manner that balances the workload and ensures availability without adding undue overheads.

**Peer-to-peer middleware**

The third generation is characterized by the emergence of middleware layers for the application-independent management of distributed resources on a global scale. Several research teams have now completed the development, evaluation and refinement of peer-to-peer middleware platforms and demonstrated or deployed them in a range of application services. The use of peer-to-peer systems for applications that demand a high level of

availability for the objects stored requires careful application design to avoid situations in which all of the replicas of an object are simultaneously unavailable. There is a risk of this for objects stored on computers with the same ownership, geographic location, administration, network connectivity, country or jurisdiction

| | *IP* | *Application-level routing overlay* |
|---|---|---|
| *Scale* | IPv4 is limited to 232 addressable nodes. The IPv6 name space is much more generous (2128), but addresses in both versions are hierarchically structured and much of the space is pre-allocated according to administrative requirements. | Peer-to-peer systems can address more objects. The GUID name space is very large and flat (>2128), allowing it to be much more fully occupied. |
| *Load balancing* | Loads on routers are determined by network topology and associated traffic patterns. | Object locations can be randomized and hence traffic patterns are divorced from the network topology. |
| *Network dynamics (addition/deletion of objects/nodes)* | IP routing tables are updated asynchronously on a best-efforts basis with time constants on the order of 1 hour. | Routing tables can be updated synchronously or asynchronously with fractions of a second delays. |
| *Fault tolerance* | Redundancy is designed into the IP network by its managers, ensuring tolerance of a single router or network connectivity failure. *n*-fold replication is costly. | Routes and object references can be replicated *n*-fold, ensuring tolerance of *n* failures of nodes or connections. |
| *Target identification* | Each IP address maps to exactly one target node. | Messages can be routed to the nearest replica of a target object. |
| *Security and anonymity* | Addressing is only secure when all nodes are trusted. Anonymity for the owners of addresses is not achievable. | Security can be achieved even in environments with limited trust. A limited degree of anonymity can be provided. |

**Figure: Distinctions between IP and overlay routing for peer-to-peer applications**

**Overlay routing versus IP routing:** At first sight, routing overlays share many characteristics with the IP packet routing infrastructure that constitutes the primary communication mechanism of the Internet. It is therefore legitimate to ask why an additional application-level routing mechanism is required in peer-to-peer systems.

**Distributed computation: The** exploitation of spare computing power on end-user computers has long been a subject of interest and experiment. More recently, much larger numbers of computers have been put to use to perform several scientific calculations that require almost unlimited quantities of computing power.

Topic 04: **Napster and its legacy**

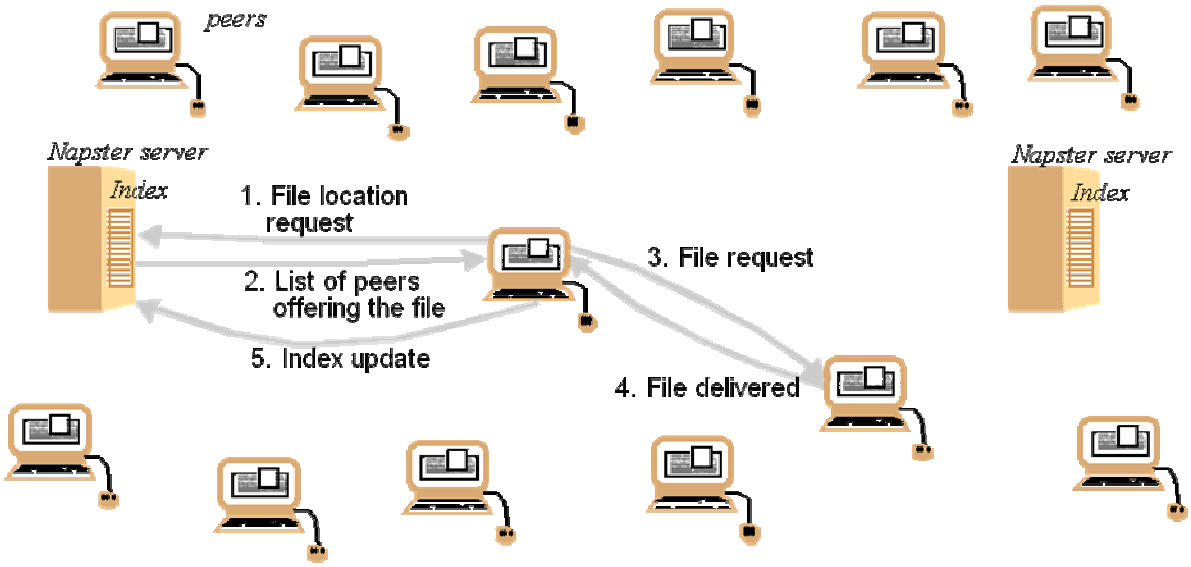



Figure : Napster: peer-to-peer file sharing with a centralized, replicated index

Napster's architecture included centralized indexes, but users supplied the files, which were stored and accessed on their personal computers. Napster's method of operation is illustrated by the sequence of steps shown in Figure (above figure) In step 5 clients are expected to add their own music files to the pool of shared resources by transmitting a link to the Napster indexing service for each available file. Thus the motivation for Napster and the key to its success was the making available of a large, widely distributed set of files to users throughout the Internet, by providing access to 'shared resources at the edges of the Internet'.

Napster was shut down as a result of legal proceedings instituted against the operators of the Napster service by the owners of the copyright in some of the material (i.e., digitally encoded music) that was made available on it .

**Lessons learned from Napster** • Napster demonstrated the feasibility of building a useful large-scale service that depends almost wholly on data and computers owned by ordinary Internet users. To avoid swamping the computing resources of individual users (for example, the first user to offer a chart-topping song) and their network connections, Napster took account of network locality – the number of hops between the client and the server – when allocating a server to a client requesting a song.

Limitations: Napster used a (replicated) unified index of all available music files. For the application in question, the requirement for consistency between the replicas was not strong, so this did not hamper performance, but for many applications it would constitute a limitation.

Application dependencies: Napster took advantage of the special characteristics of the application for which it was designed in other ways:

- Music files are never updated, avoiding any need to make sure all the replicas of files remain consistent after updates.

- No guarantees are required concerning the availability of individual files – if a music file is temporarily unavailable, it can be downloaded later. This reduces the requirement for dependability of individual computers and their connections to the Internet.

**Peer-to-peer middleware**

Peer-to-peer middleware systems are designed specifically to meet the need for the automatic placement and subsequent location of the distributed objects managed by peer-to-peer systems and applications.

**Functional requirements: The** function of peer-to-peer middleware is to simplify the construction of services that are implemented across many hosts in a widely distributed network.

- To achieve this it must enable clients to locate and communicate with any individual resource made available to a service, even though the resources are widely distributed amongst the hosts.
- Other important requirements include the ability to add new resources and to remove them at will and to add hosts to the service and remove them.

**Non-functional requirements:** To perform effectively, peer-to-peer middleware must t also address the following non-functional requirements:

- ***Global scalability*:** One of the aims of peer-to-peer applications is to exploit the hardware resources of very large numbers of hosts connected to the Internet. Peer-to-peer middleware must therefore be designed to support applications that access millions of objects on tens of thousands or hundreds of thousands of hosts.
- ***Load balancing*:** The performance of any system designed to exploit a large number of computers depends upon the balanced distribution of workload across them. For the systems we are considering, this will be achieved by a random placement of resources together with the use of replicas of heavily used resources.
- ***Optimization for local interactions between neighboring peers*:** The 'network distance' between nodes that interact has a substantial impact on the latency of individ- ual interactions, such as client requests for access to resources. Network traffic loadings are also impacted by it.
- ***Accommodating to highly dynamic host availability*:** Most peer-to-peer systems are constructed from host computers that are free to join or leave the system at any time. The hosts and network segments used in peer-to-peer systems are not owned or managed by any single authority; neither their reliability nor their continuous participation in the provision of a service is guaranteed.
- ***Security of data in an environment with heterogeneous trust*:** In global-scale systems with participating hosts of diverse ownership, trust must be built up by the use of

authentication and encryption mechanisms to ensure the integrity and privacy of information.

- ***Anonymity, deniability and resistance to censorship*:** An anonymity for the holders and recipients of data is a legitimate concern in many situations demanding resistance to censorship. A related requirement is that the hosts that hold data should be able to plausibly deny responsibility for holding or supplying it.

**Routing overlays**

- In peer-to-peer systems a distributed algorithm known as a *routing overlay* takes responsibility for locating nodes and objects.
- The name denotes the fact that the middleware takes the form of a layer that is responsible for routing requests from any client to a host that holds the object to which the request is addressed.
- The objects of interest may be placed at and subsequently relocated to any node in the network without client involvement.
- It is termed an overlay since it implements a routing mechanism in the application layer that is quite separate from any other routing mechanisms deployed at the network level such as IP routing.
- Peer-to-peer systems usually store multiple replicas of objects to ensure availability.
- In that case, the routing overlay maintains knowledge of the location of all the available replicas and delivers requests to the nearest 'live' node that has a copy of the relevant object.

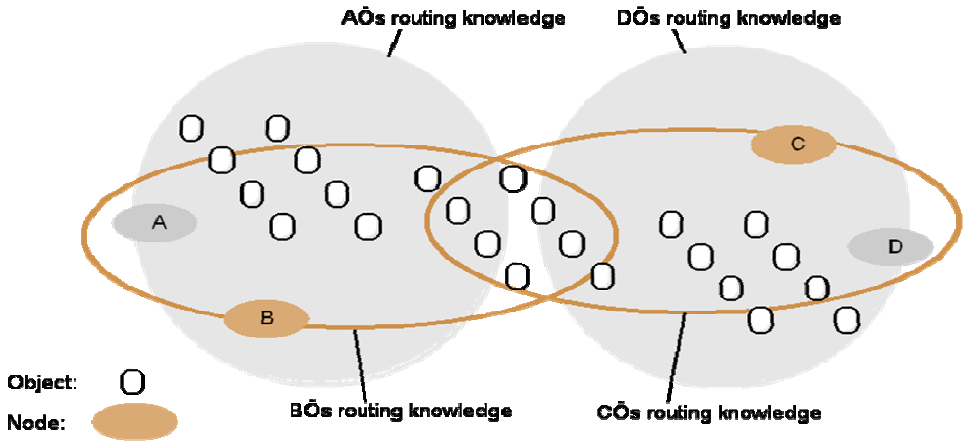



Fig: Distribution of information in a routing overlay

The main task of a routing overlay is the following:

*Routing of requests to objects*: A client wishing to invoke an operation on an object submits a request including the object's GUID to the routing overlay, which routes the request to a node at which a replica of the object resides.



But the routing overlay must also perform some other tasks:

- *Insertion of objects*: A node wishing to make a new object available to a peer-to-peer service computes a GUID for the object and announces it to the routing overlay, which then ensures that the object is reachable by all other clients.
- *Deletion of objects*: When clients request the removal of objects from the service the routing overlay must make them unavailable.
- *Node addition and removal*: Nodes (i.e., computers) may join and leave the service. When a node joins the service, the routing overlay arranges for it to assume some of the responsibilities of other nodes. When a node leaves (either voluntarily or as a result of a system or network fault), its responsibilities are distributed amongst the other nodes.

*put(GUID, data)*

The *data* is stored in replicas at all nodes responsible for the object identified by *GUID*.

*remove(GUID)*

Deletes all references to *GUID* and the associated data.

*value = get(GUID)*

The data associated with *GUID* is retrieved from one of the nodes responsible it.

Figure 6.4 : Basic programming interface for a distributed hash table (DHT) as implemented by the PAST API over Pastry

An object's GUID is computed from all or part of the state of the object using a function that delivers a value that is, with very high probability, unique. Uniqueness is verified by searching for another object with the same GUID. A hash function is used to generate the GUID from the object's value. Because these randomly distributed identifiers are used to determine the placement of objects and to retrieve them, overlay routing systems are sometimes described as *distributed hash tables* (DHT). This is reflected by the simplest form of API used to access them, as shown in Figure 6.4

With this API, the put() operation is used to submit a data item to be stored together with its GUID. A slightly more flexible form of API is provided by a distributed object location and routing (DOLR) layer, as shown in Figure 6.5. With this interface objects can be stored anywhere and the DOLR layer is responsible for maintaining a mapping between object identifiers (GUIDs) and the addresses of the nodes at which replicas of the objects are located. Objects may be replicated and stored with the same GUID at different hosts, and the routing overlay takes responsibility for routing requests.

*publish(GUID )*

*GUID* can be computed from the object (or some part of it, e.g. its name). This function makes the node performing a *publish* operation the host for the object corresponding to *GUID*.

*unpublish(GUID)*

Makes the object corresponding to *GUID* inaccessible.

*sendToObj(msg, GUID, [n])*

Figure 6.5 Basic programming interface for distributed object location and routing (DOLR) as implemented by Tapestry

Following the object-oriented paradigm, an invocation message is sent to an object in order to access it. This might be a request to open a TCP connection for data transfer or to return a message containing all or part of the object's state. The final optional parameter *[n]*, if present, requests the delivery of the same message to n replicas of the object.

# Unit-6 Transactions & Replications

**Syllabus:** Introduction, System Model and Group Communication, Concurrency Control in Distributed Transactions, Distributed Dead Locks, Transaction Recovery; Replication-Introduction, Passive (Primary) Replication, Active Replication

## Topic 01: INTRODUCTION

Introduction to replication

Replication of data: - the maintenance of copies of data at multiple computers

- performance enhancement
  - e.g. several web servers can have the same DNS name and the servers are selected in turn. To share the load.
  - replication of read-only data is simple, but replication of changing data has overheads
- fault-tolerant service
  - guarantees correct behaviour in spite of certain faults (can include timeliness)
  - if $f$ of $f$+1 servers crash then 1 remains to supply the service
  - if $f$ of 2$f$+1 servers have byzantine faults then they can supply a correct service
- availability is hindered by
  - server failures
    - Replicate data at failure- independent servers and when one fails, client may use another. Note that caches do not help with availability(they are incomplete).
  - network partitions and disconnected operation
    - Users of mobile computers deliberately disconnect, and then on re-connection, resolve conflicts

e.g. : a user on a train with a laptop with no access to a network will prepare by copying data to the laptop, e.g. a shared diary. If they update the diary they risk missing updates by other people.

Requirements for replicated data

- Replication transparency
  - clients see logical objects (not several physical copies)
    - they access one logical item and receive a single result
- Consistency
  - specified to suit the application,
    - e.g. when a user of a diary disconnects, their local copy may be inconsistent with the others and will need to be reconciled when they connect again. But connected clients using different copies should get consistent results. These issues are addressed in Bayou and Coda.

Topic 02: System model:

- each *logical* object is implemented by a collection of *physical* copies called *replicas*
  - the replicas are not necessarily consistent all the time (some may have received updates, not yet conveyed to the others)
- we assume an asynchronous system where processes fail only by crashing and generally assume no network partitions
- replica managers
  - an RM contains replicas on a computer and access them directly

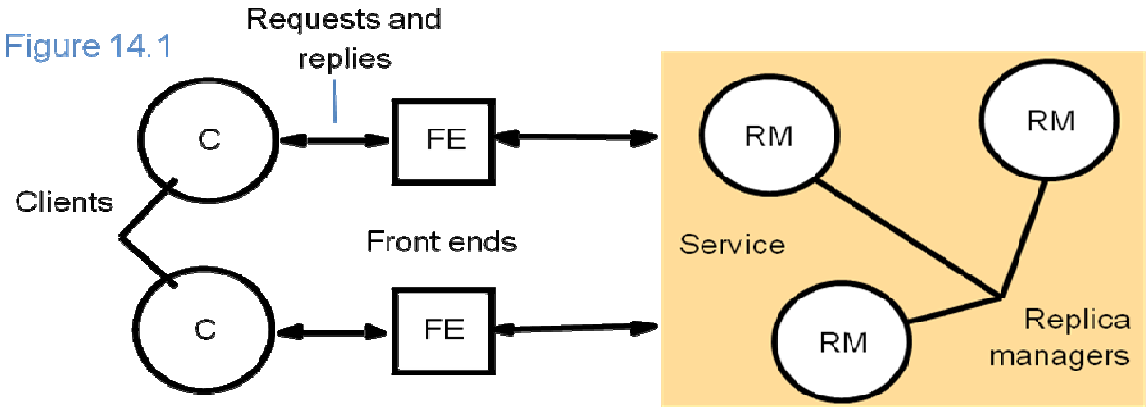
- RMs apply operations to replicas recoverably
  - i.e. they do not leave inconsistent results if they crash
- objects are copied at all RMs unless we state otherwise
- static systems are based on a fixed set of RMs
- in a dynamic system: RMs may join or leave (e.g. when they crash)
- an RM can be a *state machine*, which has the following properties:

**State machine**

- applies operations atomically
- its state is a deterministic function of its initial state and the operations applied
- all replicas start identical and carry out the same operations
- Its operations must not be affected by clock readings etc.

A basic architectural model for the management of replicated data

Figure 14.1




- A collection of RMs provides a service to clients
- Clients see a service that gives them access to logical objects, which are in fact replicated at the RMs
- Clients request operations: those without updates are called *read-only* requests the others are called *update* requests (they may include reads)
- Clients request are handled by front ends. A front end makes replication transparent.

Five phases in performing a request (What can the FE hide from a client?)

- issue request
  - the FE either
    - sends the request to a single RM that passes it on to the others
    - or multicasts the request to all of the RMs (in state machine approach)
- coordination
  - the RMs decide whether to apply the request; and decide on its ordering relative to other requests (according to FIFO, causal or total ordering)
- execution
  - the RMs execute the request (sometimes tentatively)
- agreement
  - RMs *agree* on the effect of the request, .e.g perform 'lazily' or immediately
- response
  - one or more RMs reply to FE. e.g.
    - for high availability give first response to client.
    - to tolerate byzantine faults, take a vote

FIFO ordering: if a FE issues r then *r'*, then any correct RM handles *r* before *r'*

Causal ordering: if r ® *r'*, then any correct RM handles *r* before *r'*

Total ordering: if a correct RM handles r before *r'*, then any correct RM handles *r* before *r'*

Bayou sometimes executes responses tentatively so as to be able to reorder them

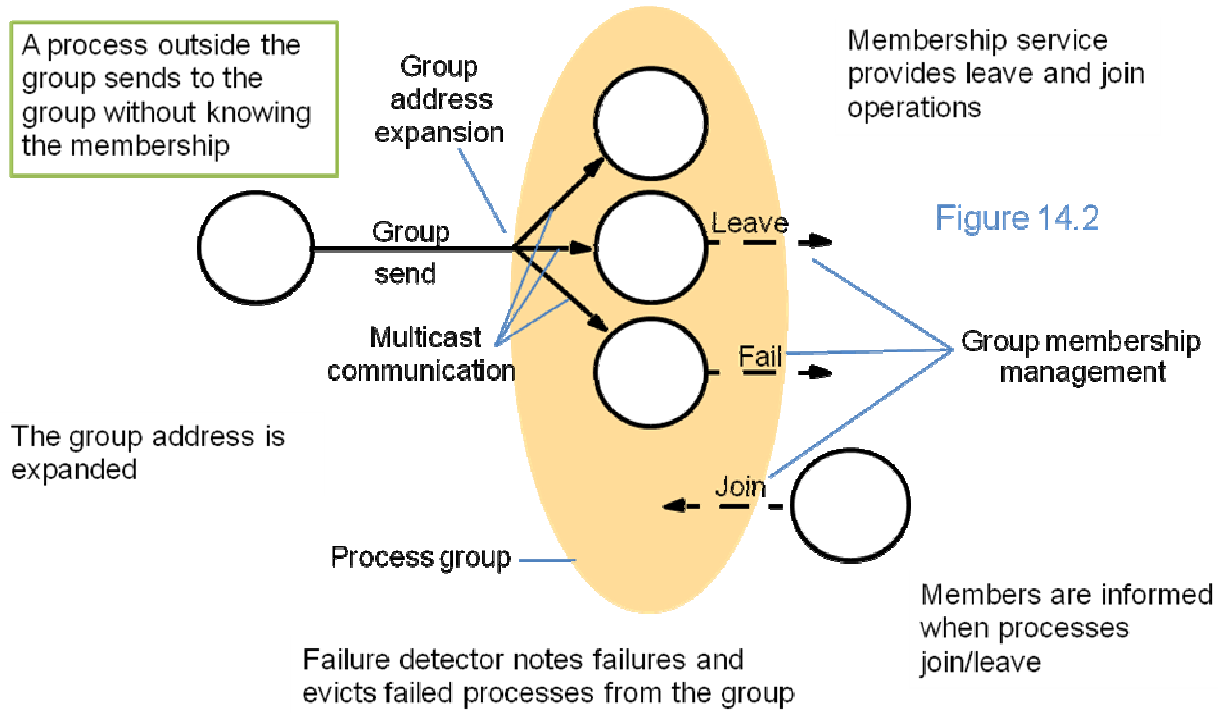
RMs agree - I.e. reach a consensus as to effect of the request. In Gossip, all RMs eventually receive updates.

Topic 03: Group Communication

We require a membership service to allow dynamic membership of groups

- process groups are useful for managing replicated data
  - but replication systems need to be able to add/remove RMs
- group membership service provides:
  - interface for adding/removing members
    - create, destroy process groups, add/remove members. A process can generally belong to several groups.
  - implements a failure detector (section 11.1 - not studied in this course)
    - which monitors members for failures (crashes/communication),
    - and excludes them when unreachable
  - notifies members of changes in membership
  - expands group addresses
    - multicasts addressed to group identifiers,
    - coordinates delivery when membership is changing
- e.g. IP multicast allows members to join/leave and performs address expansion, but not the other features

Services provided for process groups






We will leave out the details of view delivery and view synchronous group communication

- A full membership service maintains *group view*s, which are lists of group members, ordered e.g. as members join group.
- A new group view is generated each time a process joins or leaves the group.
- *View delivery* p 561. The idea is that processes can 'deliver views' (like delivering multicast messages).
  - ideally we would like all processes to get the same information in the same order relative to the messages.
- *view synchronous group communication* (p562) with reliability.
  - Illustrated in Fig below
  - all processes agree on the ordering of messages and membership changes,
  - a joining process can safely get state from another member.
  - or if one crashes, another will know which operations it had already performed
  - This work was done in the ISIS system (Birman)

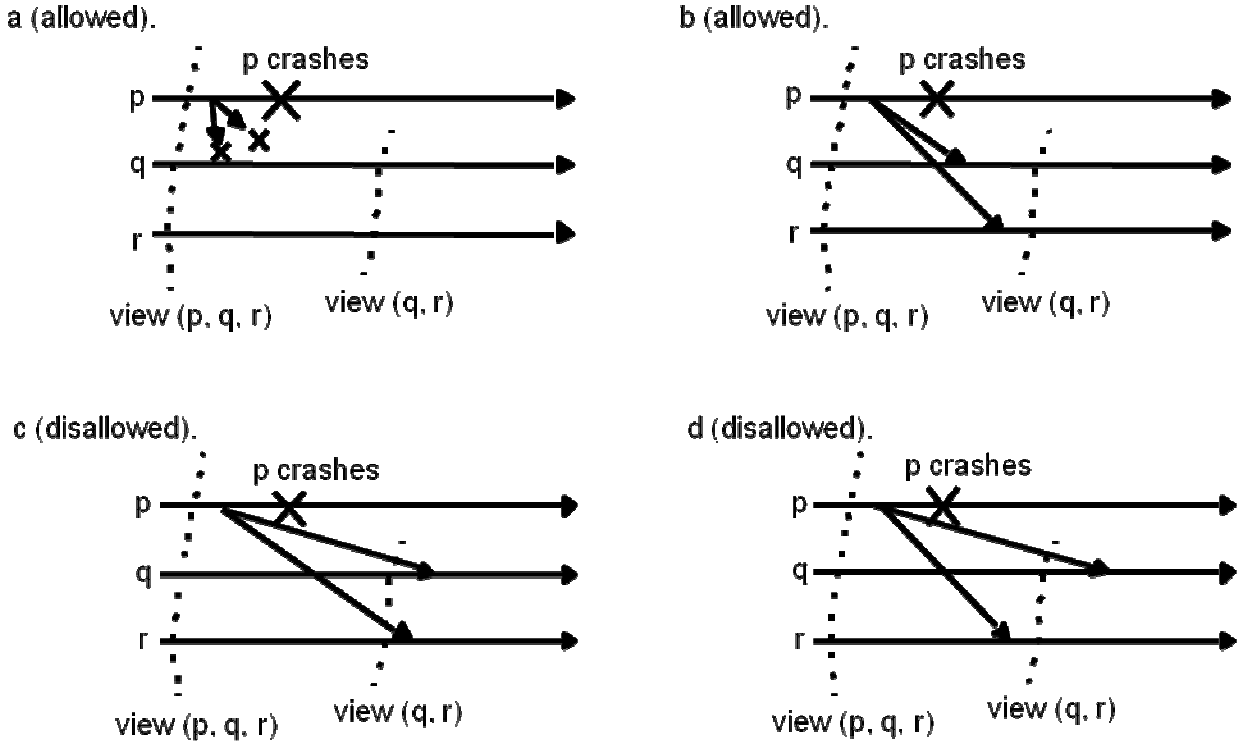



Figure : View-synchronous group communication

**Topic 04: Distributed transactions – introduction**

- a *distributed transaction* refers to a flat or nested transaction that accesses objects managed by multiple servers
- When a distributed transaction comes to an end
  - the either all of the servers commit the transaction
  - or all of them abort the transaction.
- one of the servers is *coordinator*, it must ensure the same outcome at all of the servers.
- the 'two-phase commit protocol' is the most commonly used protocol for achieving this



**Concurrency control in distributed transactions**

- Each server manages a set of objects and is responsible for ensuring that they remain consistent when accessed by concurrent transactions

- therefore, each server is responsible for applying concurrency control to its own objects.
- the members of a collection of servers of distributed transactions are jointly responsible for ensuring that they are performed in a serially equivalent manner
- therefore if transaction *T* is before transaction *U* in their conflicting access to objects at one of the servers then they must be in that order at all of the servers whose objects are accessed in a conflicting manner by both *T* and *U*

Sub Topic 4.1 : Locking

- In a distributed transaction, the locks on an object are held by the server that manages it.
  - The local lock manager decides whether to grant a lock or make the requesting transaction wait.
  - it cannot release any locks until it knows that the transaction has been committed or aborted at all the servers involved in the transaction.
  - the objects remain locked and are unavailable for other transactions during the atomic commit protocol
    - an aborted transaction releases its locks after phase 1 of the protocol.

Interleaving of transactions T and U at servers X and Y

- in the example on page 529, we have
  - *T* before *U* at server X and *U* before *T* at server Y
- different orderings lead to cyclic dependencies and distributed deadlock
  - detection and resolution of distributed deadlock in next section

| *T* | | | *U* | | |
|---|---|---|---|---|---|
| *Write*(A) | at *X* | locks *A* | | | |
| | | | *Write*(B) | at *Y* | locks *B* |
| *Read*(B) | at *Y* | waits for *U* | | | |
| | | | *Read*(A) | at *X* | waits for T |

**Sub topic 4.2 :Timestamp ordering concurrency control**

- Single server transactions
  - coordinator issues a unique timestamp to each transaction before it starts
  - serial equivalence ensured by committing objects in order of timestamps
- Distributed transactions
  - the first coordinator accessed by a transaction issues a globally unique timestamp
  - as before the timestamp is passed with each object access
  - the servers are jointly responsible for ensuring serial equivalence
    - that is if T access an object before U, then T is before U at all objects
  - coordinators agree on timestamp ordering
    - a timestamp consists of a pair <*local timestamp*, *server-id*>.
    - the agreed ordering of pairs of timestamps is based on a comparison in which the server-id part is less significant – they should relate to time

- The same ordering can be achieved at all servers even if their clocks are not synchronized
  - for efficiency it is better if local clocks are roughly synchronized
  - then the ordering of transactions corresponds roughly to the real time order in which they were started
- Timestamp ordering
  - conflicts are resolved as each operation is performed
  - if this leads to an abort, the coordinator will be informed
    - it will abort the transaction at the participants
  - any transaction that reaches the client request to commit should always be able to do so
    - participant will normally vote *yes*
    - unless it has crashed and recovered during the transaction

Optimistic concurrency control

Use backward validation

1. write/read, 2. read/write, 3. write/write

- each transaction is validated before it is allowed to commit
  - transaction numbers assigned at start of validation
  - transactions serialized according to transaction numbers
  - validation takes place in phase 1 of 2PC protocol

1. satisfied
2. checked
3. paralllel

- consider the following interleavings of *T* and *U*
  - *T* before *U* at *X* and *U* before *T* at *Y*

Suppose T & U start validation at about the same time

| *T* | | *U* | |
|---|---|---|---|
| *Read(A)* | at *X* | *Read(B)* | at *Y* |
| *Write(A)* | | *Write(B)* | |
| *Read(B)* | at *Y* | *Read(A)* | at *X* |
| *Write(B)* | | *Write(A)* | |

X does T first
Y does U first

No parallel Validation –. commitment deadlock

**Commitment deadlock in optimistic concurrency control**

- servers of distributed transactions do parallel validation
  - therefore rule 3 must be validated as well as rule 2
    - the write set of $T_v$ is checked for overlaps with write sets of earlier transactions
  - this prevents commitment deadlock
  - it also avoids delaying the 2PC protocol
- another problem - independent servers may schedule transactions in different orders
  - e.g. T before U at X and U before T at Y
  - this must be prevented - some hints as to how on page 531

**Topic 05: Distributed deadlocks**

- Single server transactions can experience deadlocks
  - prevent or detect and resolve
  - use of timeouts is clumsy, detection is preferable.
    - it uses wait-for graphs.
- Distributed transactions lead to distributed deadlocks
  - in theory can construct global wait-for graph from local ones
  - a cycle in a global wait-for graph that is not in local ones is a distributed deadlock

sub topic 5.1: **Interleavings of transactions *U*, *V* and *W***

- objects *A*, *B* managed by *X* and *Y* ; *C* and *D* by *Z*
  - next slide has global wait-for graph

| *U* | | *V* | | *W* | |
|---|---|---|---|---|---|
| *d.deposit(10)* | lock *D* | | | | |
| | | *b.deposit(10)* | lock *B* at *Y* | | |
| *a.deposit(20)* | lock *A* at *X* | | | | |
| $U \rightarrow V$ at *Y* | | | | *c.deposit(30)* | lock *C* at *Z* |
| *b.withdraw(30)* | wait at *Y* | $V \rightarrow W$ at *Z* | | | |
| | | *c.withdraw(20)* | wait at *Z* | $W \rightarrow U$ at *X* | |
| | | | | *a.withdraw(20)* | wait at *X* |

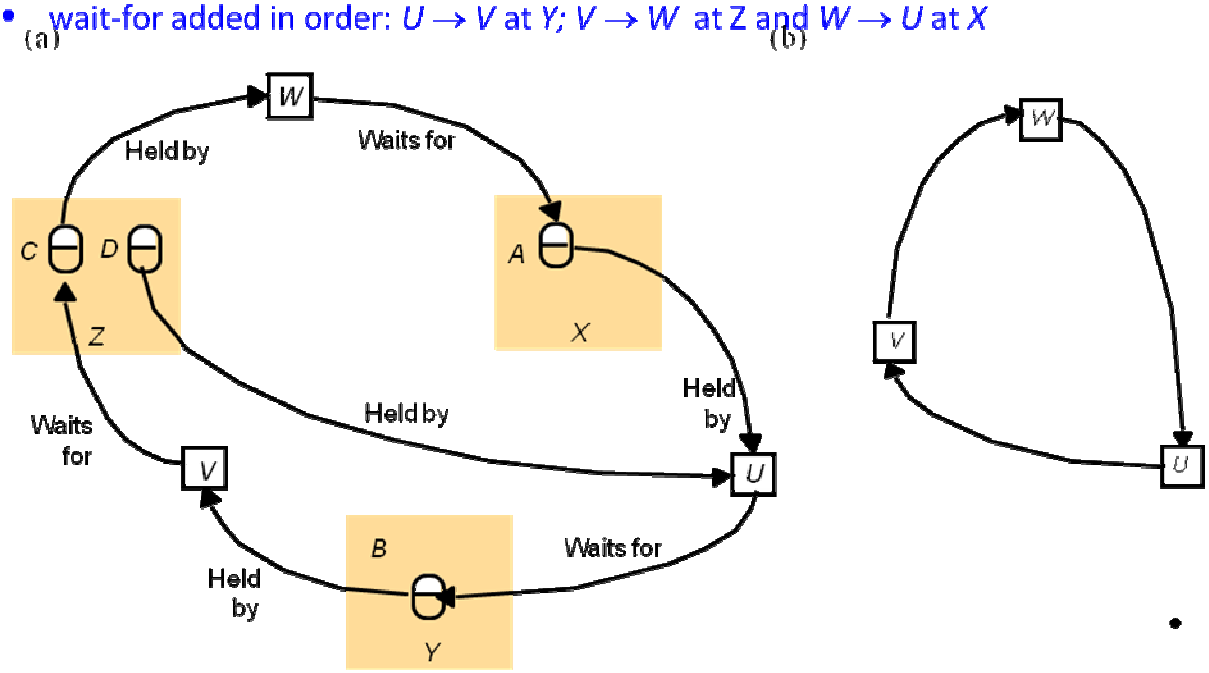
**Figure: Interleavings of transactions *U*, *V* and *W***

***Sub topic 5.2 Distributed deadlock***

*Deadlock detection - local wait-for graphs*

- *Local wait-for graphs can be built, e.g.*
  - *server Y: U ® V added when U requests b.withdraw(30)*
  - *server Z: V ® W added when V requests c.withdraw(20)*
  - *server X: W ® U added when W requests a.withdraw(20)*
- *to find a global cycle, communication between the servers is needed*
- *centralized deadlock detection*
  - *one server takes on role of global deadlock detector*
  - *the other servers send it their local graphs from time to time*
  - *it detects deadlocks, makes decisions about which transactions to abort and informs the other servers*
  - *usual problems of a centralized server - poor availability, lack of fault tolerance and no ability to scale*

- a deadlock cycle has alternate edges showing wait-for and held-by
- wait-for added in order: $U \rightarrow V$ at $Y$; $V \rightarrow W$ at Z and $W \rightarrow U$ at $X$




**Figure; Distributed deadlock**

Subtopic 5.3: Local and global wait-for graphs

- Phantom deadlocks
  - a 'deadlock' that is detected, but is not really one
  - happens when there appears to be a cycle, but one of the transactions has released a lock, due to time lags in distributing graphs
  - in the figure suppose U releases the object at X then waits for V at Y
    - and the global detector gets Y's graph before X's (T ® U ® V ® T)

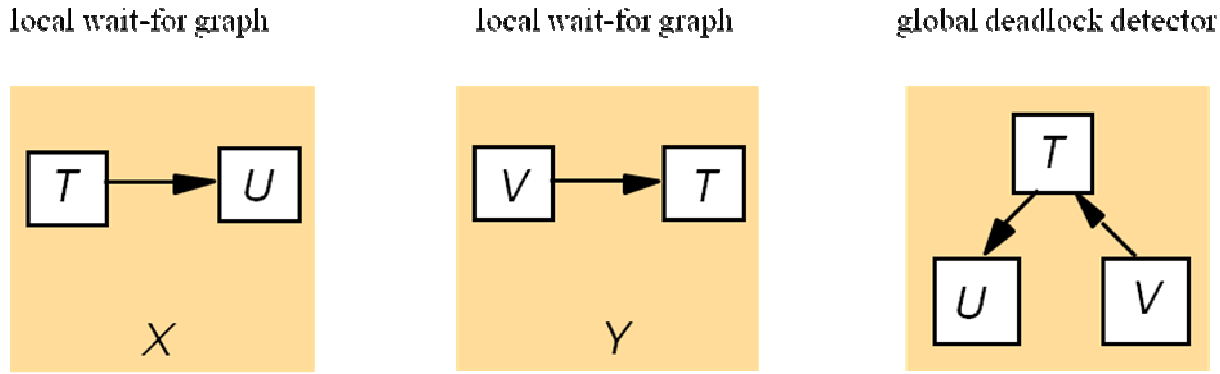



Figure: Local and global wait-for graphs

<u>Edge chasing - a distributed approach to deadlock detection</u>

- a global graph is not constructed, but each server knows about some of the edges
  - servers try to find cycles by sending *probes* which follow the edges of the graph through the distributed system
  - when should a server send a probe (go back to Fig 13.13)
  - edges were added in order $U$ ® $V$ at $Y$; $V$ ® $W$ at Z and $W$ ® $U$ at $X$
    - when $W$ ® $U$ at $X$ was added, U was waiting, but
    - when $V$ ® $W$ at $Z$, $W$ was not waiting

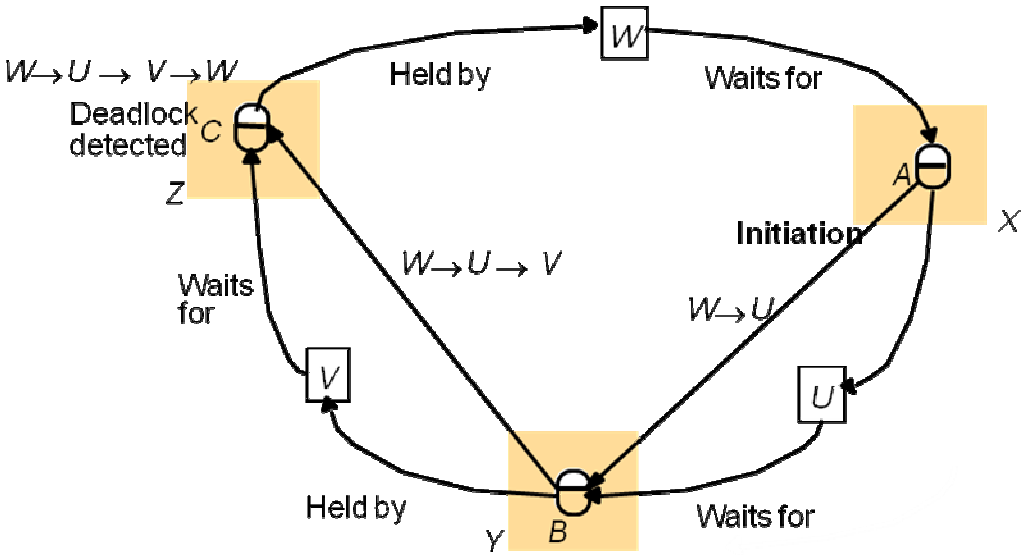
- send a probe when an edge $T1$ ® $T2$ when $T2$ is waiting
- each coordinator records whether its transactions are active or waiting
  - the local lock manager tells coordinators if transactions start/stop waiting
  - when a transaction is aborted to break a deadlock, the coordinator tells the participants, locks are removed and edges taken from wait-for graphs

Edge-chasing algorithms

- Three steps
  - Initiation:
    - When a server notes that T starts waiting for U, where U is waiting at another server, it initiates detection by sending a probe containing the edge < T ® U > to the server where U is blocked.
    - If U is sharing a lock, probes are sent to all the holders of the lock.
  - Detection:
    - Detection consists of receiving probes and deciding whether deadlock has occurred and whether to forward the probes.
      - e.g. when server receives probe < T ® U > it checks if U is waiting, e.g. U ® V, if so it forwards < T ® U ® V > to server where V waits
      - when a server adds a new edge, it checks whether a cycle is there
  - Resolution:
    - When a cycle is detected, a transaction in the cycle is aborted to break the deadlock.

Probes transmitted to detect deadlock

- example of edge chasing starts with $X$ sending $<W \rightarrow U>$, then $Y$ sends $<W \rightarrow U \rightarrow V>$, then $Z$ sends $<W \rightarrow U \rightarrow V \rightarrow W>$




Edge chasing conclusion



- probe to detect a cycle with $N$ transactions will require $2(N-1)$ messages.
  - Studies of databases show that the average deadlock involves 2 transactions.
- the above algorithm detects deadlock provided that

- waiting transactions do not abort
- no process crashes, no lost messages
- to be realistic it would need to allow for the above failures

- refinements of the algorithm
  - to avoid more than one transaction causing detection to start and then more than one being aborted
  - not time to study these now

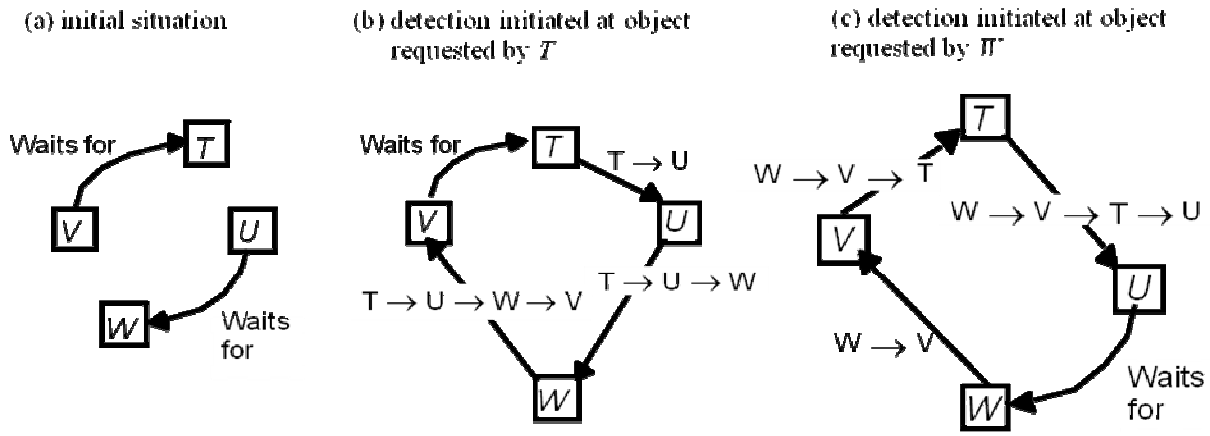



Figure: Two probes initiated

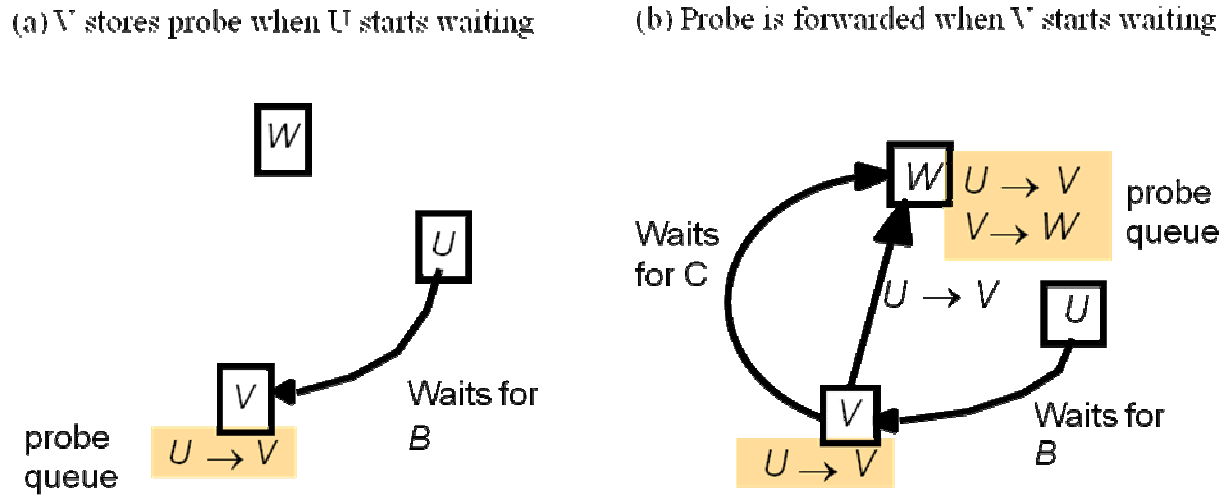



Figure: Probes travel downhill

**Topic 06: Transaction recovery**

- Atomicity property of transactions
  - durability and failure atomicity
  - durability requires that objects are saved in permanent storage and will be available indefinitely
  - failure atomicity requires that effects of transactions are atomic even when the server crashes

- Recovery is concerned with
  - ensuring that a server's objects are durable and
  - that the service provides failure atomicity.
  - for simplicity we assume that when a server is running, all of its objects are in volatile memory

- and all of its committed objects are in a *recovery file* in permanent storage
- recovery consists of restoring the server with the latest committed versions of all of its objects from its recovery file

**Recovery manager**

- The task of the Recovery Manager (RM) is:
  - to save objects in permanent storage (in a recovery file) for committed transactions;
  - to restore the server's objects after a crash;
  - to reorganize the recovery file to improve the performance of recovery;
  - to reclaim storage space (in the recovery file).
- media failures
  - i.e. disk failures affecting the recovery file
  - need another copy of the recovery file on an independent disk. e.g. implemented as stable storage or using mirrored disks

Recovery - intentions lists

- Each server records an intentions list for each of its currently active transactions
  - an intentions list contains a list of the object references and the values of all the objects that are altered by a transaction
  - when a transaction commits, the intentions list is used to identify the objects affected
    - the committed version of each object is replaced by the tentative one
    - the new value is written to the server's recovery file
  - in 2PC, when a participant says it is ready to commit, its RM must record its intentions list and its objects in the recovery file
    - it will be able to commit later on even if it crashes
    - when a client has been told a transaction has committed, the recovery files of all participating servers must show that the transaction is committed,
      - even if they crash between *prepare* to commit and *commit*

Types of entry in a recovery file

| *Type of entry* | *Description of contents of entry* |
|---|---|
| Object | A value of an object. |
| Transaction status | Transaction identifier, transaction status ( *prepared*, *committed*, *aborted*) and other status values used for the two-phase commit protocol. |
| Intentions list | Transaction identifier and a sequence of intentions, each of which consists of <identifier of object>, <position in recovery file of value of object>. |

Figure 13.18

Object state flattened to bytes

first entry says *prepared*

- For distributed transactions we need information relating to the 2PC as well as object values, that is:
  - transaction status (committed, prepared or aborted)
  - intentions list



Note that the objects need not be next to one another in the recovery file

Logging - a technique for the recovery file

- the recovery file represents a log of the history of all the transactions at a server
  - it includes objects, intentions lists and transaction status
  - in the order that transactions prepared, committed and aborted
  - a recent snapshot + a history of transactions after the snapshot
  - during normal operation the RM is called whenever a transaction prepares, commits or aborts
    - prepare - RM appends to recovery file all the objects in the intentions list followed by status (prepared) and the intentions list
    - commit/abort - RM appends to recovery file the corresponding status
    - assume *append* operation is atomic, if server fails only the last write will be incomplete
    - to make efficient use of disk, buffer *writes*. Note: sequential *writes* are more efficient than those to random locations
    - committed status is forced to the log - in case server crashes

Log for banking service

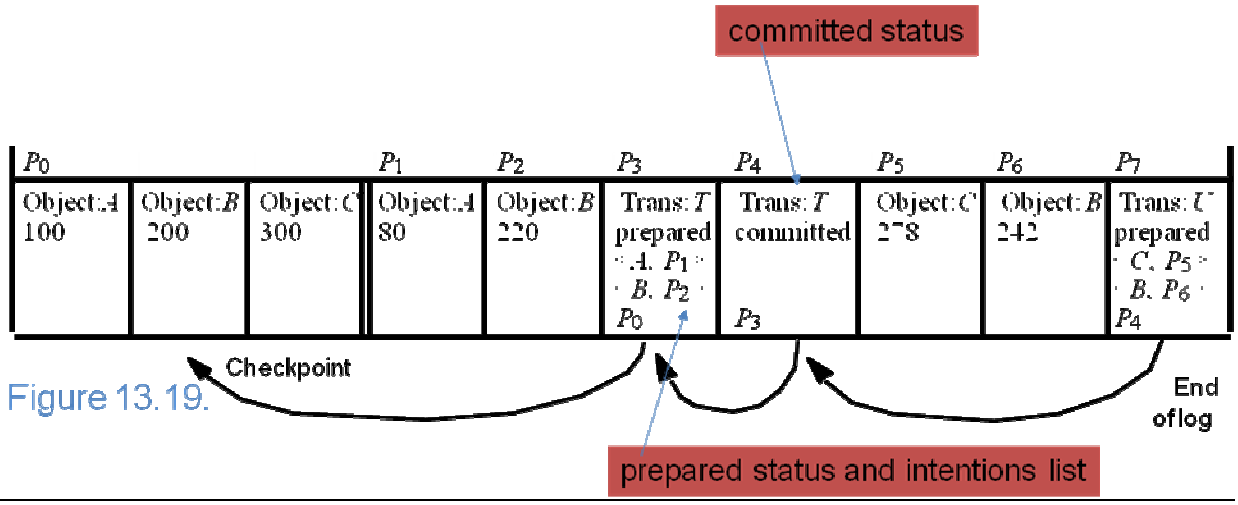


Figure 13.19.

- Logging mechanism (there would really be other objects in log file)
  - initial balances of *A*, *B* and *C* $100, $200, $300
  - *T* sets *A* and *B* to $80 and $220. *U* sets *B* and *C* to $242 and $278
  - entries to left of line represent a snapshot (checkpoint) of values of *A*, *B* and *C* before *T* started. *T* has committed, but *U* is prepared.
  - the RM gives each object a unique identifier (*A*, *B*, *C* in diagram)
  - each status entry contains a pointer to the previous status entry, then the checkpoint can follow transactions backwards through the file

Recovery of objects - with logging

- When a server is replaced after a crash
  - it first sets default initial values for its objects
  - and then hands over to its recovery manager.
- The RM restores the server's objects to include
  - all the effects of all the committed transactions in the correct order and
  - none of the effects of incomplete or aborted transactions
  - it 'reads the recovery file backwards' (by following the pointers)

        - restores values of objects with values from committed transactions
        - continuing until all of the objects have been restored
    - if it started at the beginning, there would generally be more work to do
    - to recover the effects of a transaction use the intentions list to find the value of the objects
        - e.g. look at previous slide (assuming the server crashed before T committed)
    - the recovery procedure must be idempotent

Logging - reorganising the recovery file

- RM is responsible for reorganizing its recovery file
    - so as to make the process of recovery faster and
    - to reduce its use of space
- checkpointing
    - the process of writing the following to a new recovery file
        - the current committed values of a server's objects,
        - transaction status entries and intentions lists of transactions that have not yet been fully resolved
        - including information related to the two-phase commit protocol (see later)
    - checkpointing makes recovery faster and saves disk space
        - done after recovery and from time to time
        - can use old recovery file until new one is ready, add a 'mark' to old file
        - do as above and then copy items after the mark to new recovery file
        - replace old recovery file by new recovery file

| *Map at start* | *Map when T commits* |
|---|---|
| $A \rightarrow P_0$<br>$B \rightarrow P_0'$<br>$C \rightarrow P_0''$ | $A \rightarrow P_1$<br>$B \rightarrow P_2$<br>$C \rightarrow P_0''$ |

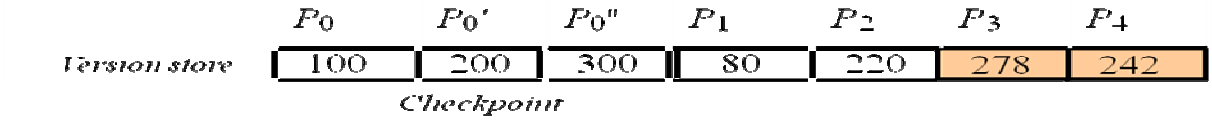



Figure: Shadow versions

Recovery of the two-phase commit protocol

- The above recovery scheme is extended to deal with transactions doing the 2PC protocol when a server fails
    - it uses new transaction status values *done*, *uncertain*
    - the coordinator uses *committed* when result is *Yes;*
    - *done* when 2PC complete ( if a transaction is *done* its information may be removed when reorganising the recovery file)
    - the participant uses *uncertain* when it has voted *Yes; committed* when told the result (*uncertain* entries must not be removed from recovery file)

– It also requires two additional types of entry:

| *Type of entry* | *Description of contents of entry* |
|---|---|
| *Coordinator* | Transaction identifier, list of participants<br>added by RM when coordinator prepared |
| *Participant* | Transaction identifier, coordinator<br>added by RM when participant votes yes |

Log with entries relating to two-phase commit protocol

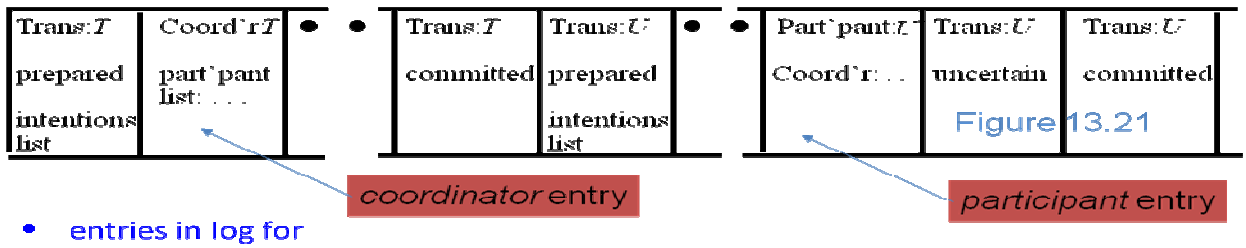



Figure 13.21

- entries in log for
  - *T* where server is coordinator (*prepared* comes first, followed by the coordinator entry, then *committed* *done* is not shown)
  - and *U* where server is participant (*prepared* comes first followed by the participant entry, then *uncertain* and finally *committed*)
  - these entries will be interspersed with values of objects
- recovery must deal with 2PC entries as well as restoring objects
  - where server was coordinator find *coordinator* entry and status entries.
  - where server was participant find *participant* entry and status entries

Start at end, for U find it is committed and a participant , We have T committed and coordinator, But if the server has crashed before the last entry we have U *uncertain* and participant, or if the server crashed earlier we have U *prepared* and participant

Recovery of the two-phase commit protocol

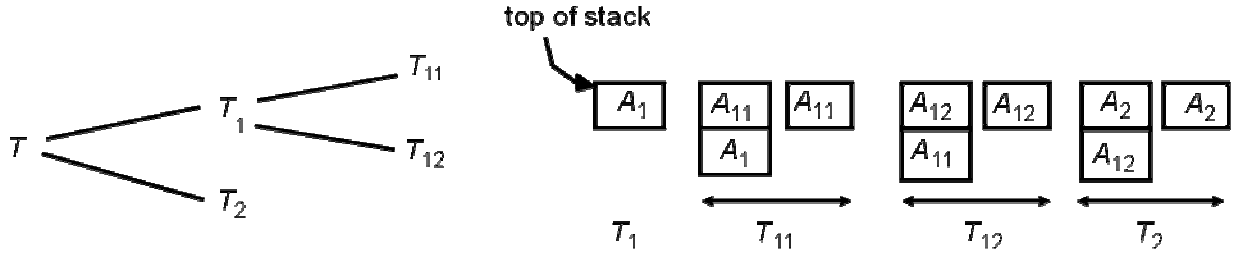
| *Role* | *Status* | *Action of recovery manager* |
|---|---|---|
| Coordinator | *prepared* | No decision had been reached before the server failed. It sends *abortTransaction* to all the servers in the participant list and adds the transaction status *aborted* in its recovery file. Same action for state *aborted*. If there is no participant list, the participants will eventually timeout and abort the transaction. |
| Coordinator | *committed* | A decision to commit had been reached before the server failed. It sends a *doCommit* to all the participants in its participant list (in case it had not done so before) and resumes the two-phase protocol at step 4 (Fig 13.5). |
| Participant | *committed* | The participant sends a *haveCommitted* message to the coordinator (in case this was not done before it failed). This will allow the coordinator to discard information about this transaction at the next checkpoint. |
| Participant | *uncertain* | The participant failed before it knew the outcome of the transaction. It cannot determine the status of the transaction until the coordinator informs it of the decision. It will send a *getDecision* to the coordinator to determine the status of the transaction. When it receives the reply it will commit or abort accordingly. |
| Participant | *prepared* | The participant has not yet voted and can abort the transaction. |
| Coordinator | *done* | No action is required. |

Figure 13.22

the most recent entry in the recovery file determines the status of the transaction at the time of failure

the RM action for each transaction depends on whether server was coordinator or participant and the status

Nested transactions:




Summary of transaction recovery

- Transaction-based applications have strong requirements for the long life and integrity of the information stored.
- Transactions are made durable by performing checkpoints and logging in a recovery file, which is used for recovery when a server is replaced after a crash.
- Users of a transaction service would experience some delay during recovery.
- It is assumed that the servers of distributed transactions exhibit crash failures and run in an asynchronous system,
  - but they can reach consensus about the outcome of transactions because crashed servers are replaced with new processes that can acquire all the relevant information from permanent storage or from other servers

**Topic 07: Fault-tolerant services**

- provision of a service that is correct even if *f* processes fail
  - by replicating data and functionality at RMs
  - assume communication reliable and no partitions
  - RMs are assumed to behave according to specification or to crash
  - intuitively, a service is correct if it responds despite failures and clients can't tell the difference between replicated data and a single copy
  - but care is needed to ensure that a set of replicas produce the same result as a single one would.

Example of a naive replication system

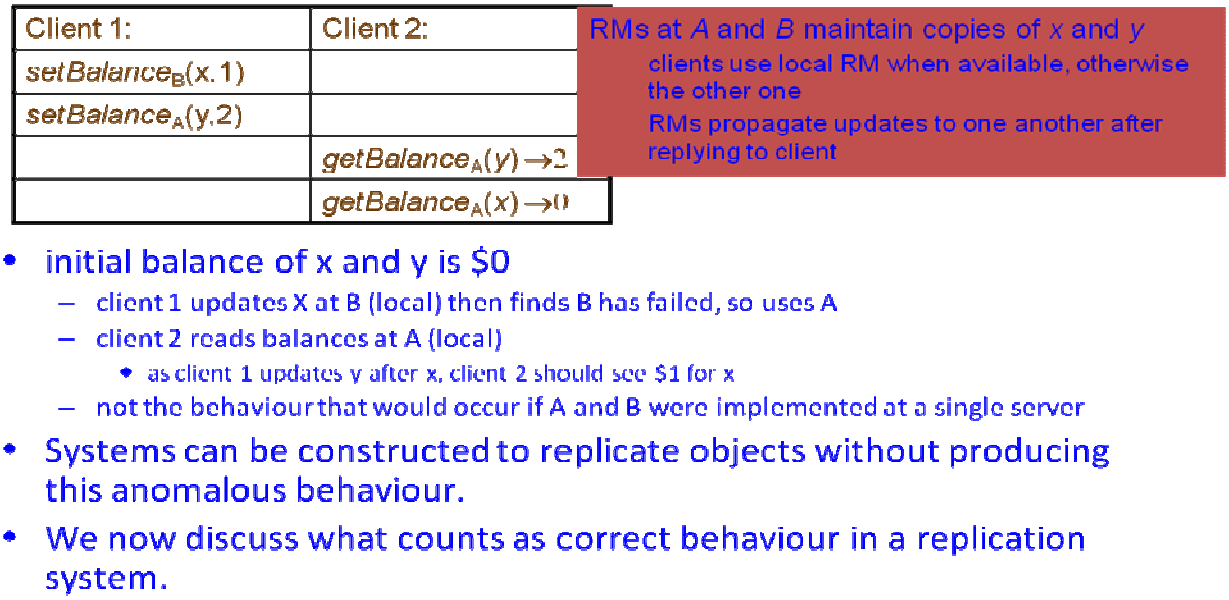



Figure: Native Replication System

*Linearizability* the strictest criterion for a replication system

Consider a replicated service with two clients, that perform read and update operations. A client waits for one operation to complete before doing another. Client operations $o_{10}$, $o_{11}$, $o_{12}$ and $o_{20}$, $o_{21}$, $o_{22}$ at a single server are interleaved in some order e.g. $o_{20}$, $o_{21}$, $o_{10}$, $o_{22}$ , $o_{11}$, $o_{12}$ (client 1 does $o_{10}$ etc)

- The correctness criteria for replicated objects are defined by referring to a virtual interleaving which would be correct

a replicated object service is *linearizable* if *for any execution* there is some interleaving of clients' operations such that:

  - the interleaved sequence of operations meets the specification of a (single) correct copy of the objects
  - the order of operations in the interleaving is consistent with the real time at which they occurred

- For any set of client operations there is a virtual interleaving (which would be correct for a set of single objects).
- Each client sees a view of the objects that is consistent with this, that is, the results of clients operations make sense within the interleaving

- the bank example did not make sense: if the second update is observed,the first update should be observed too.

– linearizability is not intended to be used with transactional replication systems

– The real-time requirement means clients should receive up-to-date information
  - but may not be practical due to difficulties of synchronizing clocks
  - a weaker criterion is sequential consistency

Sequential consistency

- a replicated shared object service is sequentially consistent if for any execution there is some interleaving of clients' operations such that:
  - the interleaved sequence of operations meets the specification of a (single) correct copy of the objects
  - the order of operations in the interleaving is consistent with the program order in which each client executed them

the following is sequentially consistent but not linearizable

| Client 1: | Client 2: |
|---|---|
| $setBalance_B(x,1)$ | |
| | $getBalance_A(y) \rightarrow 0$ |
| | $getBalance_A(x) \rightarrow 0$ |
| $setBalance_A(y,2)$ | |

this is possible under a naive replication strategy, even if neither *A* or *B* fails - the update at *B* has not yet been propagated to *A* when client 2 reads it

but the following interleaving satisfies both criteria for sequential consistency :

$getBalance_A(y) \rightarrow 0$; $getBalance_A(x) \rightarrow 0$; $setBalance_B(x,1)$; $setBalance_A(y,2)$

- it is not linearizable because client2's *getBalance* is after client 1's *setBalance* in real time.

The passive (primary-backup) model for fault tolerance

- There is at any time a single primary RM and one or more secondary (backup, slave) RMs
- FEs communicate with the primary which executes the operation and sends copies of the updated data to the result to backups
- if the primary fails, one of the backups is promoted to act as the primary

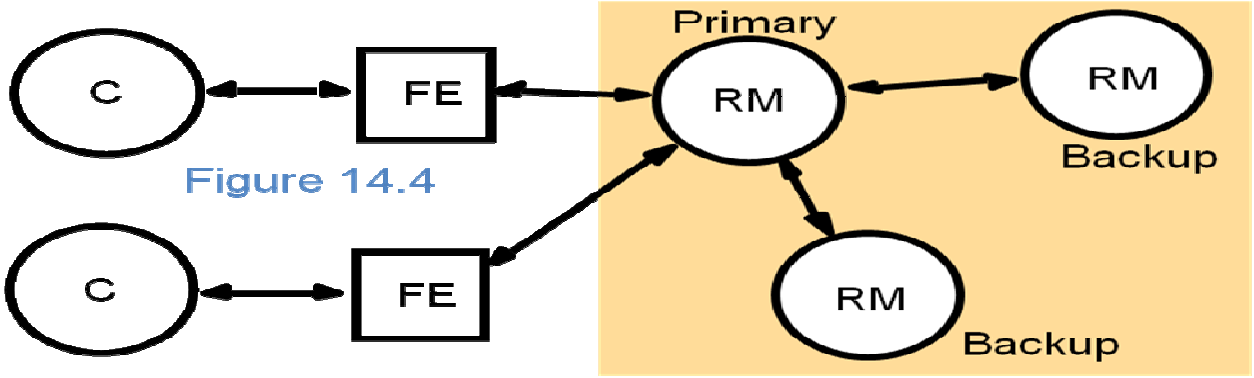


Figure 14.4

The FE has to find the primary, e.g. after it crashes and another takes over

Passive (primary-backup) replication. Five phases.

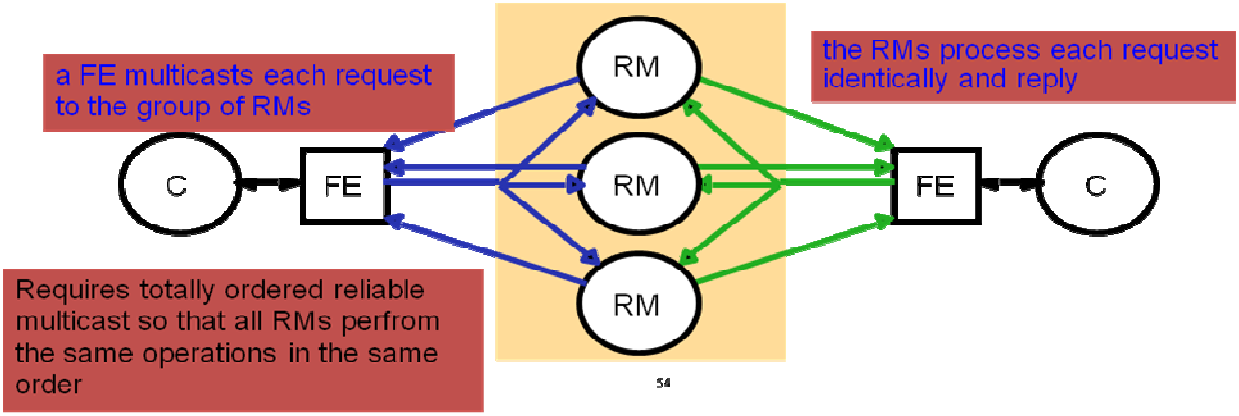
- The five phases in performing a client request are as follows:
- 1. Request:
  - a FE issues the request, containing a unique identifier, to the primary RM
- 2. Coordination:
  - the primary performs each request atomically, in the order in which it receives it relative to other requests
  - it checks the unique id; if it has already done the request it re-sends the response.
- 3. Execution:
  - The primary executes the request and stores the response.
- 4. Agreement:
  - If the request is an update the primary sends the updated state, the response and the unique identifier to all the backups. The backups send an acknowledgement.
- 5. Response:
  - The primary responds to the FE, which hands the response back to the client.

Discussion of passive replication

- To survive *f* process crashes, *f*+1 RMs are required
  - it cannot deal with byzantine failures because the client can't get replies from the backup RMs
- To design passive replication that is linearizable
  - View synchronous communication has relatively large overheads
  - Several rounds of messages per multicast
  - After failure of primary, there is latency due to delivery of group view
- variant in which clients can read from backups
  - which reduces the work for the primary
  - get sequential consistency but not linearizability
- Sun NIS uses passive replication with weaker guarantees
  - Weaker than sequential consistency, but adequate to the type of data stored
  - achieves high availability and good performance
  - Master receives updates and propagates them to slaves using 1-1 communication. Clients can uses either master or slave
  - updates are not done via RMs - they are made on the files at the master

Active replication for fault tolerance

- the RMs are *state machines* all playing the same role and organised as a group.
  - all start in the same state and perform the same operations in the same order so that their state remains identical
- If an RM crashes it has no effect on performance of the service because the others continue as normal
- It can tolerate byzantine failures because the FE can collect and compare the replies it receives




Active replication - five phases in performing a client request

- Request
  - FE attaches a unique *id* and uses *totally ordered reliable multicast* to send request to RMs. FE can at worst, crash. It does not issue requests in parallel
- Coordination
  - the multicast delivers requests to all the RMs in the same (total) order.
- Execution
  - every RM executes the request. They are state machines and receive requests in the same order, so the effects are identical. The *id* is put in the response
- Agreement
  - no agreement is required because all RMs execute the same operations in the same order, due to the properties of the totally ordered multicast.
- Response
  - FEs collect responses from RMs. FE may just use one or more responses. If it is only trying to tolerate crash failures, it gives the client the first response.

Active replication – discussion

- As RMs are state machines we have sequential consistency
  - due to reliable totally ordered multicast, the RMs collectively do the same as a single copy would do
  - it works in a synchronous system
  - in an asynchronous system reliable totally ordered multicast is impossible – but failure detectors can be used to work around this problem. How to do that is beyond the scope of this course.
- this replication scheme is not linearizable
  - because total order is not necessarily the same as real-time order
- To deal with byzantine failures
  - For up to *f* byzantine failures, use $2f+1$ RMs
  - FE collects f+1 identical responses
- To improve performance,
  - FEs send read-only requests to just one RM