

Cloud Computing

Unit – 1

UNIT I: Systems modeling, Clustering and virtualization:

Scalable Computing over the Internet, Technologies for Network based systems, System models for Distributed and Cloud Computing, Software environments for distributed systems and clouds, Performance, Security And Energy Efficiency.

SCALABLE COMPUTING OVER THE INTERNET

Over the past 60 years, computing technology has undergone a series of platform and environment changes. In this section, we assess evolutionary changes in machine architecture, operating system platform, network connectivity, and application workload. Instead of using a centralized computer to solve computational problems, a parallel and distributed computing system uses multiple computers to solve large-scale problems over the Internet. Thus, distributed computing becomes data-intensive and network-centric.

The Age of Internet Computing

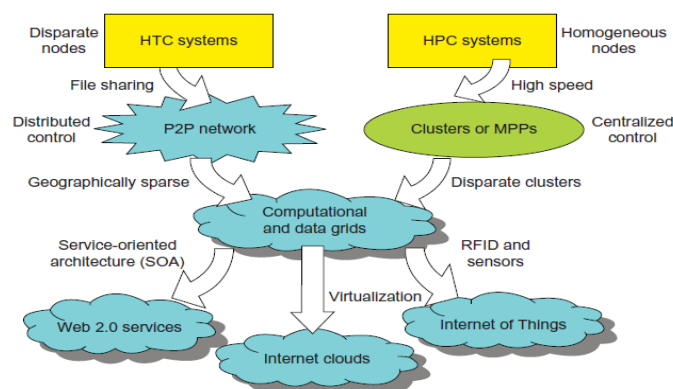
Billions of people use the Internet every day. As a result, supercomputer sites and large data centers must provide high-performance computing services to huge numbers of Internet users concurrently. Because of this high demand, the Linpack Benchmark for high-performance computing (HPC) applications is no longer optimal for measuring system performance.

The emergence of computing clouds instead demands high-throughput computing (HTC) systems built with parallel and distributed computing technologies

High-Performance Computing

For many years, HPC systems emphasize the raw speed performance. The speed of HPC systems has increased from Gflops in the early 1990s to now Pflops in 2010.

This improvement was driven mainly by the demands from scientific, engineering, and manufacturing communities. For example, the Top 500 most powerful computer systems in the world are measured by floating-point speed in Linpack benchmark results. However, the number of supercomputer users is limited to less than 10% of all computer users. Today, the majority of computer users are using desktop computers or large servers when they conduct Internet searches and market-driven computing tasks.



High-Throughput Computing

The development of market-oriented high-end computing systems is undergoing a strategic change from an HPC paradigm to an HTC paradigm.

This HTC paradigm pays more attention to high-flux computing. The main application for high-flux computing is in Internet searches and web services by millions or more users simultaneously.

The performance goal thus shifts to measure high throughput or the number of tasks completed per unit of time. HTC technology needs to not only improve in terms of batch processing speed, but also address the acute problems of cost, energy savings, security, and reliability at many data and enterprise computing centers. This book will address both HPC and HTC systems to meet the demands of all computer users.

Three New Computing Paradigms

With the introduction of SOA, Web 2.0 services become available. Advances in virtualization make it possible to see the growth of Internet clouds as a new computing paradigm. The maturity of radio-frequency identification (RFID), Global Positioning System (GPS), and sensor technologies has triggered the development of the Internet of Things (IoT).

When the Internet was introduced in 1969, Leonard Klienrock of UCLA declared: “As of now, computer networks are still in their infancy, but as they grow up and become sophisticated, we will probably see the spread of computer utilities, which like present electric and telephone utilities, will service individual homes and offices across the country.” Many people have redefined the term “computer” since that time. In 1984, John Gage of Sun Microsystems created the slogan, “The network is the computer.”

In 2008, David Patterson of UC Berkeley said, “The data center is the computer. There are dramatic differences between developing software for millions to use as a service versus distributing software to run on their PCs.” Recently, Rajkumar Buyya of Melbourne University simply said: “The cloud is the computer.”

Computing Paradigm Distinctions

The high-technology community has argued for many years about the precise definitions of centralized computing, parallel computing, distributed computing, and cloud computing. In general, distributed computing is the opposite of centralized computing.

The field of parallel computing overlaps with distributed computing to a great extent, and cloud computing overlaps with distributed, centralized, and parallel computing.

- **Centralized computing** This is a computing paradigm by which all computer resources are centralized in one physical system. All resources (processors, memory, and storage) are fully shared and tightly coupled within one integrated OS. Many data centers and supercomputers are centralized systems, but they are used in parallel, distributed, and cloud computing applications.
- **Parallel computing** In parallel computing, all processors are either tightly coupled with centralized shared memory or loosely coupled with distributed memory. Some authors refer to this discipline as parallel processing. Interprocessor communication is accomplished through shared memory or via message passing.

A computer system capable of parallel computing is commonly known as a parallel computer. Programs running in a parallel computer are called parallel programs. The process of writing parallel programs is often referred to as parallel programming.

- **Distributed computing** This is a field of computer science/engineering that studies distributed systems. A distributed system consists of multiple autonomous computers, each having its own private memory, communicating through a computer network.

Information exchange in a distributed system is accomplished through message passing. A computer program that runs in a distributed system is known as a distributed program. The process of writing distributed programs is referred to as distributed programming.

- **Cloud computing** An Internet cloud of resources can be either a centralized or a distributed computing system. The cloud applies parallel or distributed computing, or both. Clouds can be built with physical or virtualized resources over large data centers that are centralized or distributed. Some authors consider cloud computing to be a form of utility computing or service computing.

Distributed System Families

Since the mid-1990s, technologies for building P2P networks and networks of clusters have been consolidated into many national projects designed to establish wide area computing infrastructures, known as computational grids or data grids.

Meeting these goals requires to yield the following design objectives:

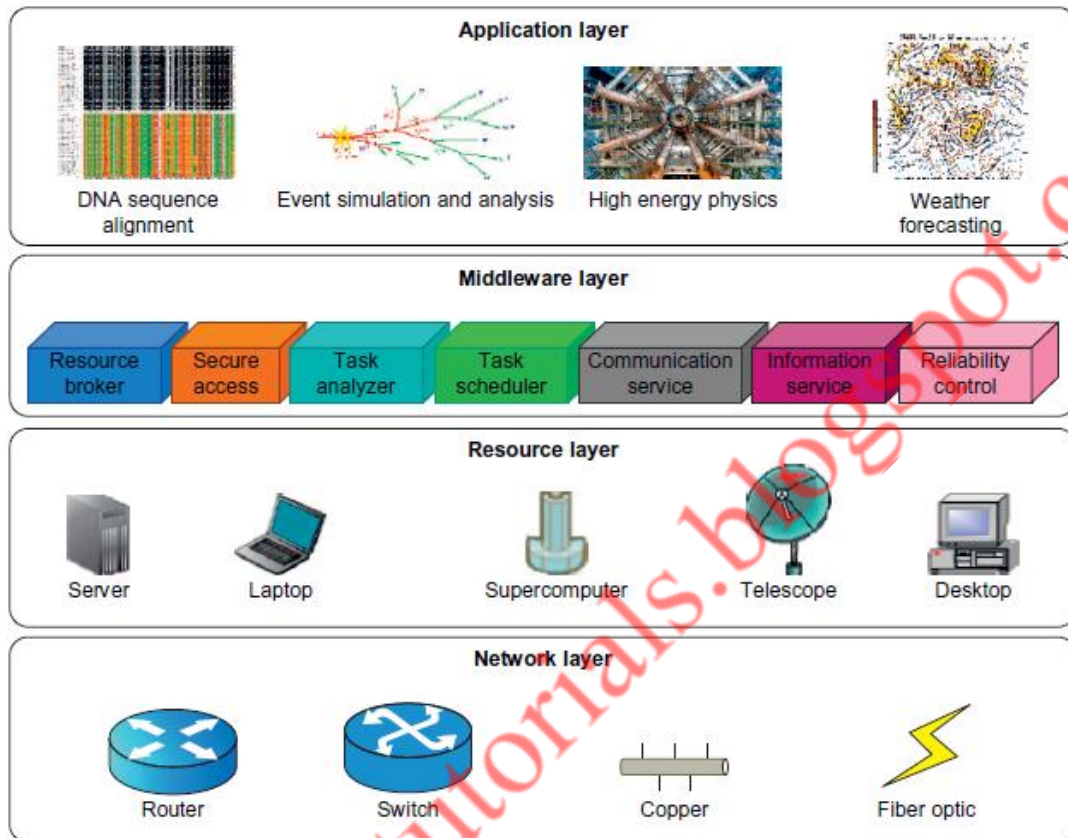
- **Efficiency** measures the utilization rate of resources in an execution model by exploiting massive parallelism in HPC. For HTC, efficiency is more closely related to job throughput, data access, storage, and power efficiency.
- **Dependability** measures the reliability and self-management from the chip to the system and application levels. The purpose is to provide high-throughput service with Quality of Service (QoS) assurance, even under failure conditions.
- **Adaptation** in the programming model measures the ability to support billions of job requests over massive data sets and virtualized cloud resources under various workload and service models.
- **Flexibility** in application deployment measures the ability of distributed systems to run well in both HPC (science and engineering) and HTC (business) applications.

Degrees of Parallelism

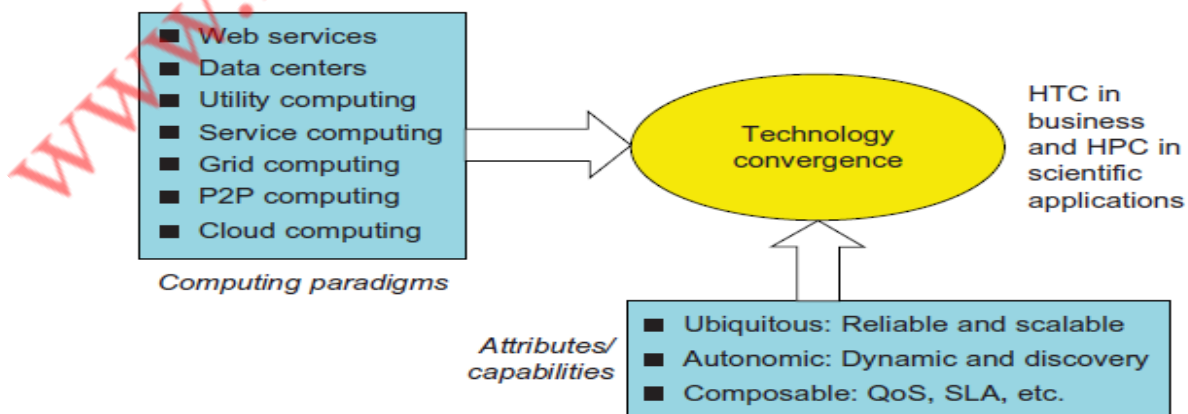
Fifty years ago, when hardware was bulky and expensive, most computers were designed in a bit-serial fashion. In this scenario, bit-level parallelism (BLP) converts bit-serial processing to word-level processing gradually. Over the years, users graduated from 4-bit microprocessors to 8-, 16-, 32-, and 64-bit CPUs. This led us to the next wave of improvement, known as instruction-level parallelism (ILP), in which the processor executes multiple instructions simultaneously rather than only one instruction at a time.

For the past 30 years, we have practiced ILP through pipelining, superscalar computing, VLIW (very long instruction word) architectures, and multithreading. ILP requires branch prediction, dynamic scheduling, speculation, and compiler support to work efficiently. Data-level parallelism (DLP) was made popular through SIMD (single instruction, multiple data) and vector machines using vector or array types of instructions. DLP requires even more hardware support and compiler assistance to work properly.

Ever since the introduction of multicore processors and chip multiprocessors (CMPs), we have been exploring task-level parallelism (TLP). A modern processor explores all of the aforementioned parallelism types. In fact, BLP, ILP, and DLP are well supported by advances in hardware and compilers. However, TLP is far from being very successful due to difficulty in programming and compilation of code for efficient execution on multicore CMPs.



Utility computing focuses on a business model in which customers receive computing resources from a paid service provider. All grid/cloud platforms are regarded as utility service providers. However, cloud computing offers a broader concept than utility computing. Distributed cloud applications run on any available servers in some edge networks. Major technological challenges include all aspects of computer science and engineering.



The Internet of Things

The concept of the IoT was introduced in 1999 at MIT [40]. The IoT refers to the networked interconnection of everyday objects, tools, devices, or computers. One can view the IoT as a wireless network of sensors that interconnect all things in our daily life. These things can be large or small and they vary with respect to time and place. The idea is to tag every object using RFID or a related sensor or electronic technology such as GPS.

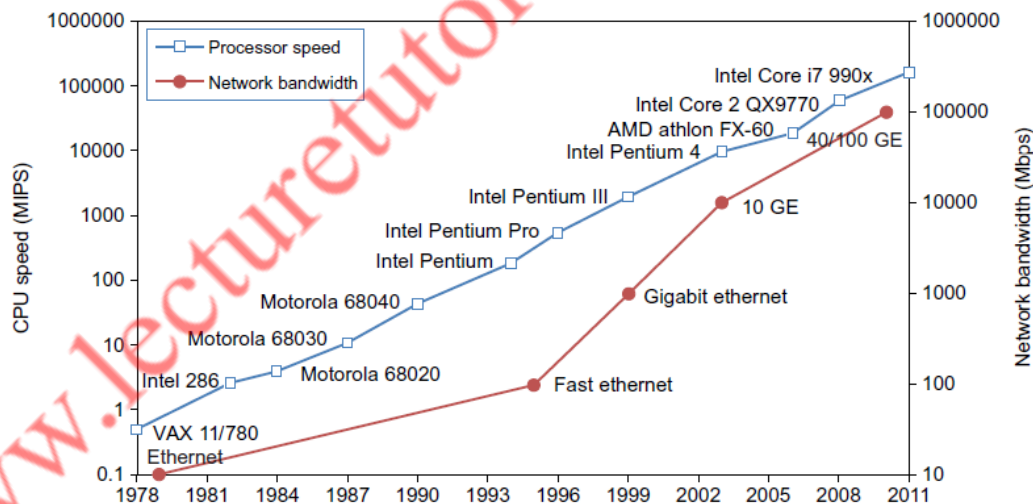
TECHNOLOGIES FOR NETWORK-BASED SYSTEMS

Multicore CPUs and Multithreading Technologies

Consider the growth of component and network technologies over the past 30 years. They are crucial to the development of HPC and HTC systems. In Figure 1.4, processor speed is measured in millions of instructions per second (MIPS) and network bandwidth is measured in megabits per second (Mbps) or gigabits per second (Gbps). The unit GE refers to 1 Gbps Ethernet bandwidth.

Advances in CPU Processors

Advanced CPUs or microprocessor chips assume a multicore architecture with dual, quad, six, or more processing cores. These processors exploit parallelism at ILP and TLP levels. Processor speed growth is plotted in the upper curve in across generations of microprocessors or CMPs.



Multicore CPU and Many-Core GPU Architectures

Multicore CPUs may increase from the tens of cores to hundreds or more in the future. But the CPU has reached its limit in terms of exploiting massive DLP due to the aforementioned memory wall problem. This has triggered the development of many-core GPUs with hundreds or more thin cores. Both IA-32 and IA-64 instruction set architectures are built into commercial CPUs. Now, x-86 processors have been extended to serve HPC and HTC systems in some high-end server processors.

Multithreading Technology & How GPUs Work

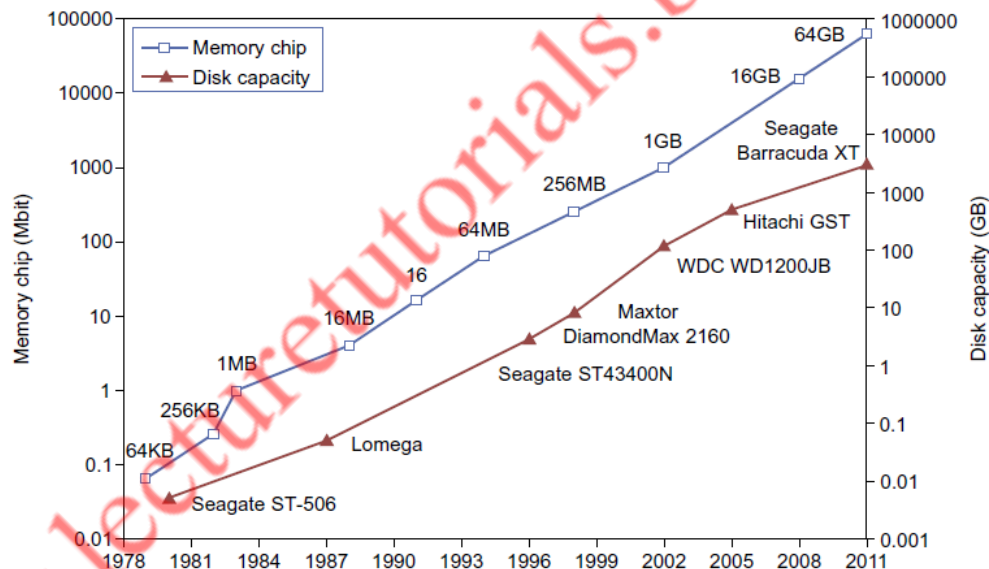
Memory, Storage, and Wide-Area Networking

Memory Technology

The growth of DRAM chip capacity from 16 KB in 1976 to 64 GB in 2011. This shows that memory chips have experienced a 4x increase in capacity every three years. Memory access time did not improve much in the past. In fact, the memory wall problem is getting worse as the processor gets faster. For hard drives, capacity increased from 260 MB in 1981 to 250 GB in 2004. The Seagate Barracuda XT hard drive reached 3 TB in 2011.

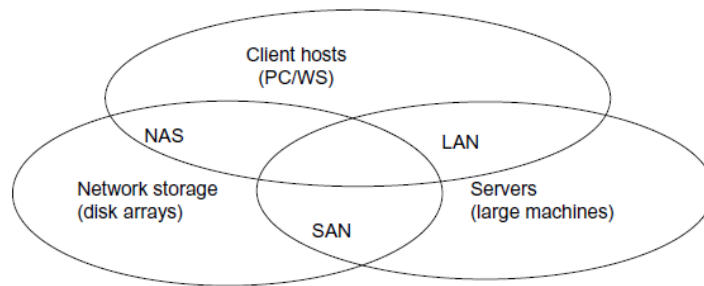
Disks and Storage Technology

Beyond 2011, disks or disk arrays have exceeded 3 TB in capacity. The lower curve in Figure shows the disk storage growth in 7 orders of magnitude in 33 years. The rapid growth of flash memory and solid-state drives (SSDs) also impacts the future of HPC and HTC systems. The mortality rate of SSD is not bad at all. A typical SSD can handle 300,000 to 1 million write cycles per block. So the SSD can last for several years, even under conditions of heavy write usage. Flash and SSD will demonstrate impressive speedups in many applications.



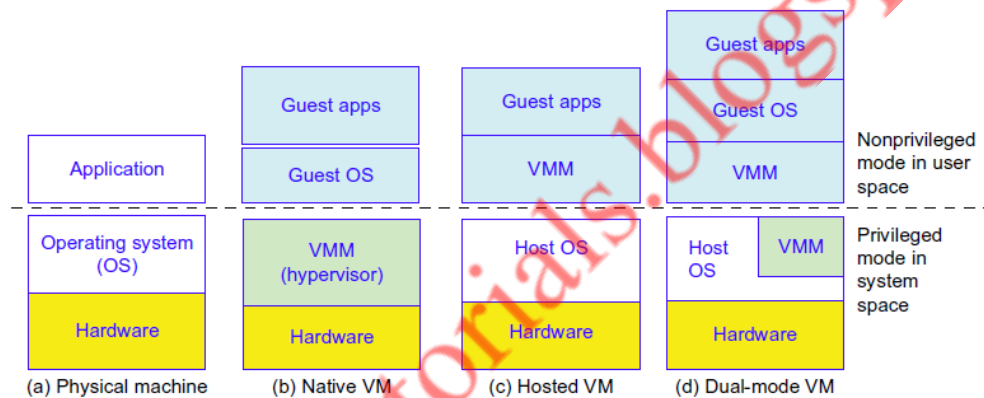
System-Area Interconnects

The nodes in small clusters are mostly interconnected by an Ethernet switch or a local area network (LAN). As Figure 1.11 shows, a LAN typically is used to connect client hosts to big servers. A storage area network (SAN) connects servers to network storage such as disk arrays. Network attached storage (NAS) connects client hosts directly to the disk arrays. All three types of networks often appear in a large cluster built with commercial network components.



Virtual Machines and Virtualization Middleware

A conventional computer has a single OS image. This offers a rigid architecture that tightly couples application software to a specific hardware platform. Some software running well on one machine may not be executable on another platform with a different instruction set under a fixed OS. Virtual machines (VMs) offer novel solutions to underutilized resources, application inflexibility, software manageability, and security concerns in existing physical machines.



Virtual Machines

The host machine is equipped with the physical hardware, as shown at the bottom of the figure. An example is an x-86 architecture desktop running its installed Windows OS, as shown in part (a) of the figure.

The VM can be provisioned for any hardware system. The VM is built with virtual resources managed by a guest OS to run a specific application. Between the VMs and the host platform, one needs to deploy a middleware layer called a virtual machine monitor (VMM). Figure 1.12(b) shows a native VM installed with the use of a VMM called a hypervisor in privileged mode. For example, the hardware has x-86 architecture running the Windows system.

The guest OS could be a Linux system and the hypervisor is the XEN system developed at Cambridge University. This hypervisor approach is also called bare-metal VM, because the hypervisor handles the bare hardware (CPU, memory, and I/O) directly. Another architecture is the host VM shown in Figure 1.12(c). Here the VMM runs in nonprivileged mode. The host OS need not be modified. The VM can also be implemented with a dual mode, as shown in Figure 1.12(d).

Part of the VMM runs at the user level and another part runs at the supervisor level. In this case, the host OS may have to be modified to some extent. Multiple VMs can be ported to a given hardware system to support the virtualization process. The VM approach offers hardware independence of the OS and applications. The user application running on its dedicated OS could be bundled together as a virtual

appliance that can be ported to any hardware platform. The VM could run on an OS different from that of the host computer.

VM Primitive Operations

The VMM provides the VM abstraction to the guest OS. With full virtualization, the VMM exports a VM abstraction identical to the physical machine so that a standard OS such as Windows 2000 or Linux can run just as it would on the physical hardware. Low-level VMM operations are indicated by Mendel Rosenblum [41] and illustrated in Figure 1.13.

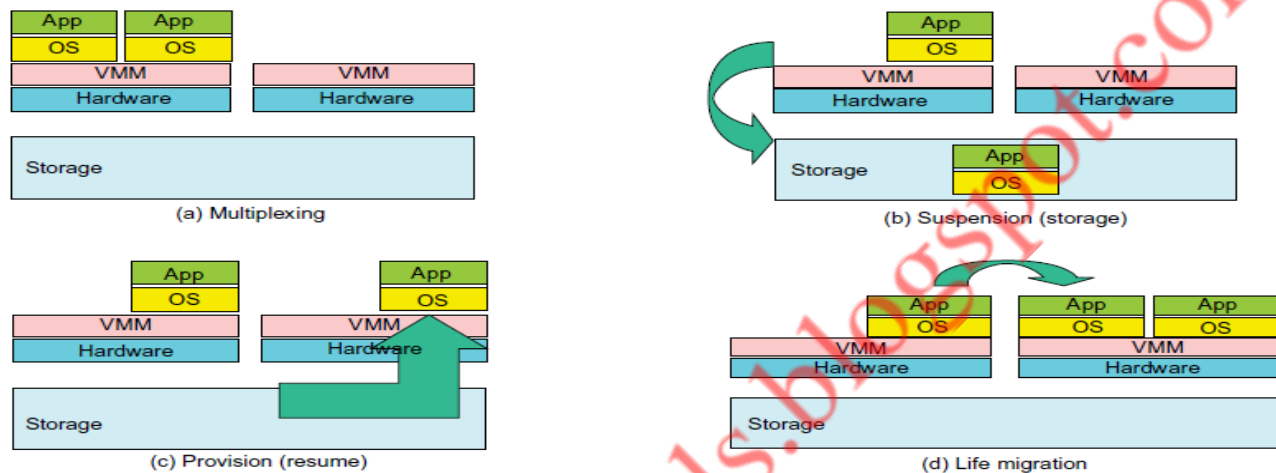


FIGURE 1.13

VM multiplexing, suspension, provision, and migration in a distributed computing environment.

First, the VMs can be multiplexed between hardware machines, as shown in Figure (a). Second, a VM can be suspended and stored in stable storage, as shown in Figure (b). Third, a suspended VM can be resumed or provisioned to a new hardware platform, as shown in Figure (c). Finally, a VM can be migrated from one hardware platform to another, as shown in Figure (d).

Virtual Infrastructures

Physical resources for compute, storage, and networking at the bottom of Figure are mapped to the needy applications embedded in various VMs at the top. Hardware and software are then separated. Virtual infrastructure is what connects resources to distributed applications. It is a dynamic mapping of system resources to specific applications. The result is decreased costs and increased efficiency and responsiveness. Virtualization for server consolidation and containment is a good example of this.

Data Center Virtualization for Cloud Computing

Data Center Growth and Cost Breakdown

A large data center may be built with thousands of servers. Smaller data centers are typically built with hundreds of servers. The cost to build and maintain data center servers has increased over the years. According to a 2009 IDC report, typically only 30 percent of data center costs goes toward purchasing IT equipment (such as servers and disks), 33 percent is attributed to the chiller, 18 percent to the uninterruptible power supply (UPS), 9 percent to computer room air conditioning (CRAC), and the remaining 7 percent to power distribution, lighting, and transformer costs. Thus, about 60 percent of the cost to run a data center is allocated to management and maintenance. The server purchase cost did not

increase much with time. The cost of electricity and cooling did increase from 5 percent to 14 percent in 15 years.

SYSTEM MODELS FOR DISTRIBUTED AND CLOUD COMPUTING

Distributed and cloud computing systems are built over a large number of autonomous computer nodes. These node machines are interconnected by SANs, LANs, or WANs in a hierarchical manner. With today's networking technology, a few LAN switches can easily connect hundreds of machines as a working cluster. A WAN can connect many local clusters to form a very large cluster of clusters. In this sense, one can build a massive system with millions of computers connected to edge networks.

Massive systems are considered highly scalable, and can reach web-scale connectivity, either physically or logically. In Table 1.2, massive systems are classified into four groups: clusters, P2P networks, computing grids, and Internet clouds over huge data centers. In terms of node number, these four system classes may involve hundreds, thousands, or even millions of computers as participating nodes.

| Functionality, Applications | Computer Clusters [10,28,38] | Peer-to-Peer Networks [34,46] | Data/Computational Grids [6,18,51] | Cloud Platforms [1,9,11,12,30] |
|--|--|--|--|---|
| Architecture, Network Connectivity, and Size | Network of compute nodes interconnected by SAN, LAN, or WAN hierarchically | Flexible network of client machines logically connected by an overlay network | Heterogeneous clusters interconnected by high-speed network links over selected resource sites | Virtualized cluster of servers over data centers via SLA |
| Control and Resources Management | Homogeneous nodes with distributed control, running UNIX or Linux | Autonomous client nodes, free in and out, with self-organization | Centralized control, server-oriented with authenticated security | Dynamic resource provisioning of servers, storage, and networks |
| Applications and Network-centric Services | High-performance computing, search engines, and web services, etc. | Most appealing to business file sharing, content delivery, and social networking | Distributed supercomputing, global problem solving, and data center services | Upgraded web search, utility computing, and outsourced computing services |
| Representative Operational Systems | Google search engine, SunBlade, IBM Road Runner, Cray XT4, etc. | Gnutella, eMule, BitTorrent, Napster, KaZaA, Skype, JXTA | TeraGrid, GriPhyN, UK EGEE, D-Grid, ChinaGrid, etc. | Google App Engine, IBM Bluecloud, AWS, and Microsoft Azure |

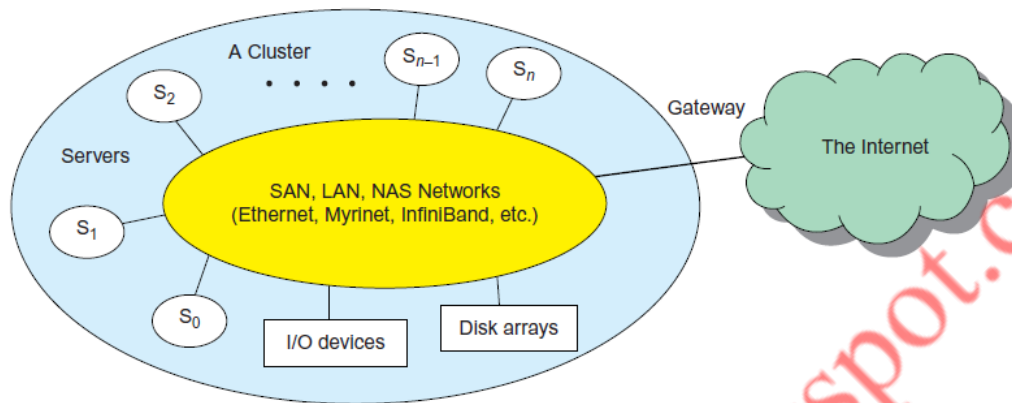
Clusters of Cooperative Computers

A computing cluster consists of interconnected stand-alone computers which work cooperatively as a single integrated computing resource. In the past, clustered computer systems have demonstrated impressive results in handling heavy workloads with large data sets.

Cluster Architecture

Figure 1.15 shows the architecture of a typical server cluster built around a low-latency, high bandwidth interconnection network. This network can be as simple as a SAN (e.g., Myrinet) or a LAN (e.g., Ethernet). To build a larger cluster with more nodes, the interconnection network can be built with multiple levels of Gigabit Ethernet, Myrinet, or InfiniBand switches. Through hierarchical construction using a SAN, LAN, or WAN, one can build scalable clusters with an increasing number of nodes. The cluster is connected to

the Internet via a virtual private network (VPN) gateway. The gateway IP address locates the cluster. The system image of a computer is decided by the way the OS manages the shared cluster resources. Most clusters have loosely coupled node computers. All resources of a server node are managed by their own OS. Thus, most clusters have multiple system images as a result of having many autonomous nodes under different OS control.



Single-System Image

Greg Pfister [38] has indicated that an ideal cluster should merge multiple system images into a single-system image (SSI). Cluster designers desire a cluster operating system or some middleware to support SSI at various levels, including the sharing of CPUs, memory, and I/O across all cluster nodes.

Hardware, Software, and Middleware Support

Clusters exploring massive parallelism are commonly known as MPPs. Almost all HPC clusters in the Top 500 list are also MPPs. The building blocks are computer nodes (PCs, workstations, servers, or SMP), special communication software such as PVM or MPI, and a network interface card in each computer node. Most clusters run under the Linux OS. The computer nodes are interconnected by a high-bandwidth network (such as Gigabit Ethernet, Myrinet, InfiniBand, etc.). Special cluster middleware supports are needed to create SSI or high availability (HA). Both sequential and parallel applications can run on the cluster, and special parallel environments are needed to facilitate use of the cluster resources.

Grid Computing Infrastructures

Internet services such as the Telnet command enables a local computer to connect to a remote computer. A web service such as HTTP enables remote access of remote web pages. Grid computing is envisioned to allow close interaction among applications running on distant computers simultaneously.

Computational Grids

Like an electric utility power grid, a computing grid offers an infrastructure that couples computers, software/middleware, special instruments, and people and sensors together. The grid is often constructed across LAN, WAN, or Internet backbone networks at a regional, national, or global scale. Enterprises or organizations present grids as integrated computing resources. They can also be viewed as virtual platforms to support virtual organizations. The computers used in a grid are primarily workstations, servers, clusters, and supercomputers. Personal computers, laptops, and PDAs can be used as access devices to a grid system.

Grid Families

Grid technology demands new distributed computing models, software/middleware support, network protocols, and hardware infrastructures. National grid projects are followed by industrial grid platform development by IBM, Microsoft, Sun, HP, Dell, Cisco, EMC, Platform Computing, and others. New grid

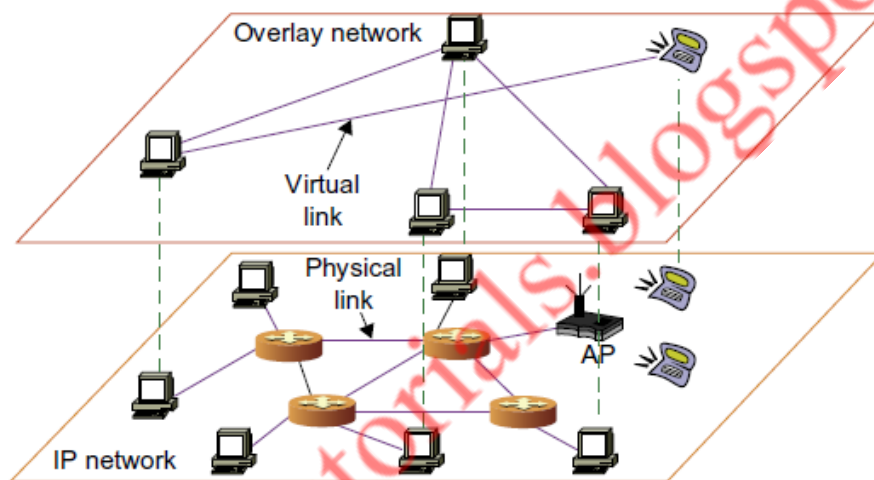
service providers (GSPs) and new grid applications have emerged rapidly, similar to the growth of Internet and web services in the past two decades.

Peer-to-Peer Network Families

An example of a well-established distributed system is the client-server architecture. In this scenario, client machines (PCs and workstations) are connected to a central server for compute, e-mail, file access, and database applications. The P2P architecture offers a distributed model of networked systems. First, a P2P network is client-oriented instead of server-oriented. In this section, P2P systems are introduced at the physical level and overlay networks at the logical level.

Overlay Networks

Data items or files are distributed in the participating peers. Based on communication or file-sharing needs, the peer IDs form an overlay network at the logical level.



Cloud Computing over the Internet

“A cloud is a pool of virtualized computer resources. A cloud can host a variety of different workloads, including batch-style backend jobs and interactive and user-facing applications.” Based on this definition, a cloud allows workloads to be deployed and scaled out quickly through rapid provisioning of virtual or physical machines. The cloud supports redundant, self-recovering, highly scalable programming models that allow workloads to recover from many unavoidable hardware/software failures. Finally, the cloud system should be able to monitor resource use in real time to enable rebalancing of allocations when needed.

Internet Clouds

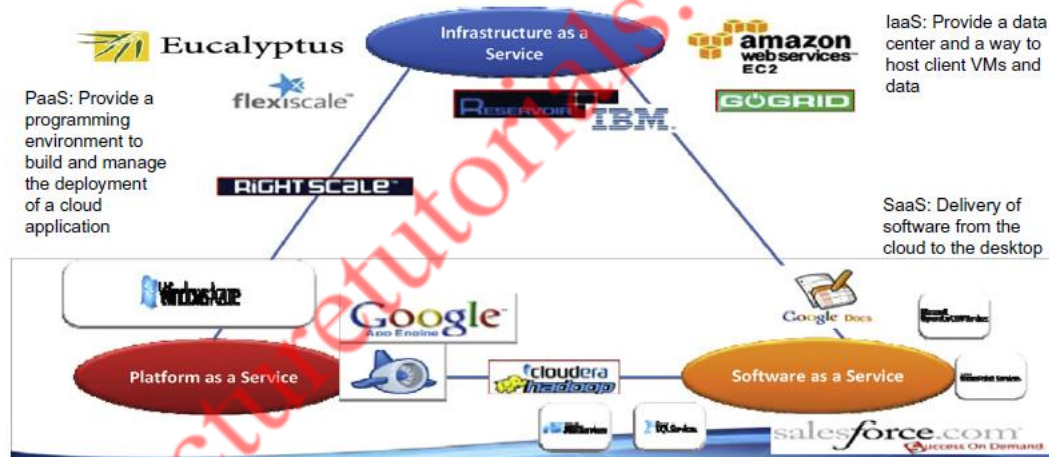
Cloud computing applies a virtualized platform with elastic resources on demand by provisioning hardware, software, and data sets dynamically. The idea is to move desktop computing to a service-oriented platform using server clusters and huge databases at data centers. Cloud computing leverages its low cost and simplicity to benefit both users and providers.

The Cloud Landscape

Traditionally, a distributed computing system tends to be owned and operated by an autonomous administrative domain (e.g., a research laboratory or company) for on-premises computing needs. However, these traditional systems have encountered several performance bottlenecks: constant system

maintenance, poor utilization, and increasing costs associated with hardware/software upgrades. Cloud computing as an on-demand computing paradigm resolves or relieves us from these problems.

- **Infrastructure as a Service (IaaS)** This model puts together infrastructures demanded by users—namely servers, storage, networks, and the data center fabric. The user can deploy and run on multiple VMs running guest OSES on specific applications. The user does not manage or control the underlying cloud infrastructure, but can specify when to request and release the needed resources.
- **Platform as a Service (PaaS)** This model enables the user to deploy user-built applications onto a virtualized cloud platform. PaaS includes middleware, databases, development tools, and some runtime support such as Web 2.0 and Java. The platform includes both hardware and software integrated with specific programming interfaces. The provider supplies the API and software tools (e.g., Java, Python, Web 2.0, .NET). The user is freed from managing the cloud infrastructure.
- **Software as a Service (SaaS)** This refers to browser-initiated application software over thousands of paid cloud customers. The SaaS model applies to business processes, industry applications, consumer relationship management (CRM), enterprise resources planning (ERP), human resources (HR), and collaborative applications. On the customer side, there is no upfront investment in servers or software licensing. On the provider side, costs are rather low, compared with conventional hosting of user applications.



SOFTWARE ENVIRONMENTS FOR DISTRIBUTED SYSTEMS AND CLOUDS

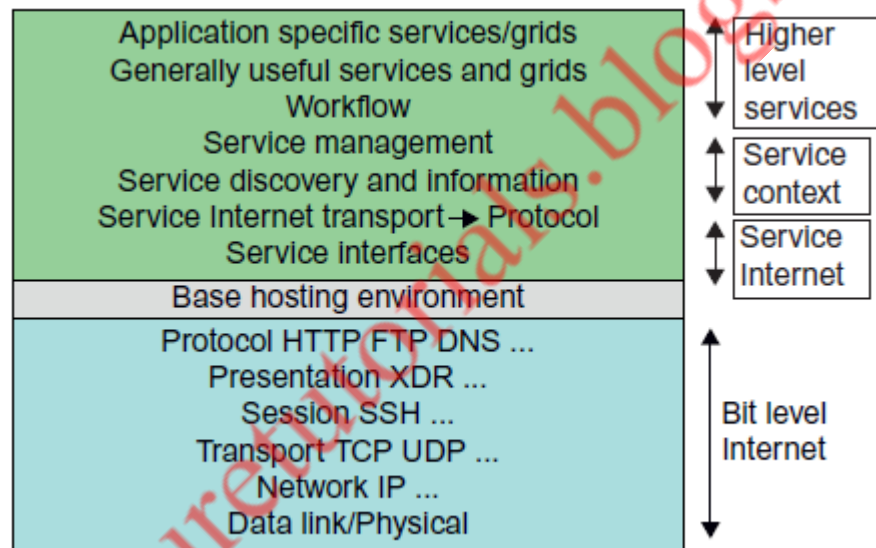
Service-Oriented Architecture (SOA)

In grids/web services, Java, and CORBA, an entity is, respectively, a service, a Java object, and a CORBA distributed object in a variety of languages. These architectures build on the traditional seven Open Systems Interconnection (OSI) layers that provide the base networking abstractions. On top of this we have a base software environment, which would be .NET or Apache Axis for web services, the Java Virtual Machine for Java, and a broker network for CORBA. On top of this base environment one would build a higher level environment reflecting the special features of the distributed computing environment.

Layered Architecture for Web Services and Grids

The entity interfaces correspond to the Web Services Description Language (WSDL), Java method, and CORBA interface definition language (IDL) specifications in these example distributed systems. These interfaces are linked with customized, high-level communication systems: SOAP, RMI, and IIOP in the three examples. These communication systems support features including particular message patterns (such as Remote Procedure Call or RPC), fault recovery, and specialized routing. Often, these communication systems are built on message-oriented middleware (enterprise bus) infrastructure such as Web-Sphere MQ or Java Message Service (JMS) which provide rich functionality and support virtualization of routing, senders, and recipients.

In the case of fault tolerance, the features in the Web Services Reliable Messaging (WSRM) framework mimic the OSI layer capability (as in TCP fault tolerance) modified to match the different abstractions (such as messages versus packets, virtualized addressing) at the entity levels. Security is a critical capability that either uses or reimplements the capabilities seen in concepts such as Internet Protocol Security (IPsec) and secure sockets in the OSI layers. Entity communication is supported by higher level services for registries, metadata, and management.



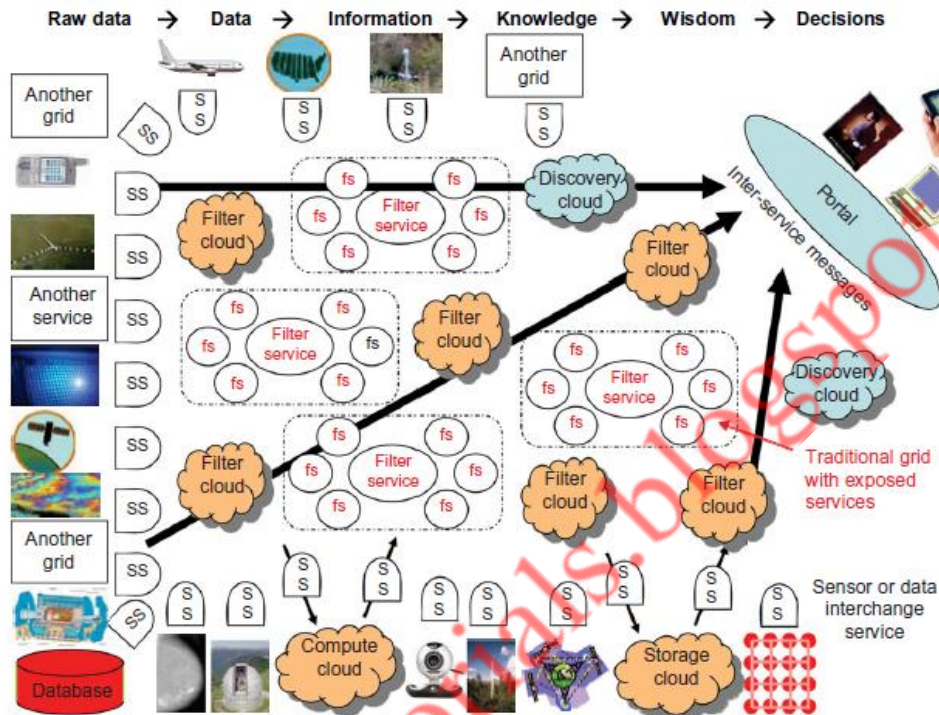
Web Services and Tools

Loose coupling and support of heterogeneous implementations make services more attractive than distributed objects. The above picture corresponds to two choices of service architecture: web services or REST systems. Both web services and REST systems have very distinct approaches to building reliable interoperable systems. In web services, one aims to fully specify all aspects of the service and its environment. This specification is carried with communicated messages using Simple Object Access Protocol (SOAP). The hosting environment then becomes a universal distributed operating system with fully distributed capability carried by SOAP messages. This approach has mixed success as it has been hard to agree on key parts of the protocol and even harder to efficiently implement the protocol by software such as Apache Axis.

The Evolution of SOA

As shown in Figure 1.21, service-oriented architecture (SOA) has evolved over the years. SOA applies to building grids, clouds, grids of clouds, clouds of grids, clouds of clouds (also known as interclouds), and systems of systems in general. A large number of sensors provide data-collection services, denoted in the

figure as SS (sensor service). A sensor can be a ZigBee device, a Bluetooth device, a WiFi access point, a personal computer, a GPA, or a wireless phone, among other things. Raw data is collected by sensor services. All the SS devices interact with large or small computers, many forms of grids, databases, the compute cloud, the storage cloud, the filter cloud, the discovery cloud, and so on. Filter services (fs in the figure) are used to eliminate unwanted raw data, in order to respond to specific requests from the web, the grid, or web services.



Grids versus Clouds

The boundary between grids and clouds are getting blurred in recent years. For web services, workflow technologies are used to coordinate or orchestrate services with certain specifications used to define critical business process models such as two-phase transactions.

In general, a grid system applies static resources, while a cloud emphasizes elastic resources. For some researchers, the differences between grids and clouds are limited only in dynamic resource allocation based on virtualization and autonomic computing. One can build a grid out of multiple clouds. This type of grid can do a better job than a pure cloud, because it can explicitly support negotiated resource allocation. Thus one may end up building with a system of systems: such as a cloud of clouds, a grid of clouds, or a cloud of grids, or inter-clouds as a basic SOA architecture.

Trends toward Distributed Operating Systems

A distributed system inherently has multiple system images. This is mainly due to the fact that all node machines run with an independent operating system. To promote resource sharing and fast communication among node machines, it is best to have a distributed OS that manages all resources coherently and efficiently. Such a system is most likely to be a closed system, and it will likely rely on message passing and RPCs for internode communications. It should be pointed out that a distributed OS is crucial for upgrading the performance, efficiency, and flexibility of distributed applications.

PERFORMANCE, SECURITY, AND ENERGY EFFICIENCY

Performance Metrics and Scalability Analysis

Performance metrics are needed to measure various distributed systems. In this section, we will discuss various dimensions of scalability and performance laws. Then we will examine system scalability against OS images and the limiting factors encountered.

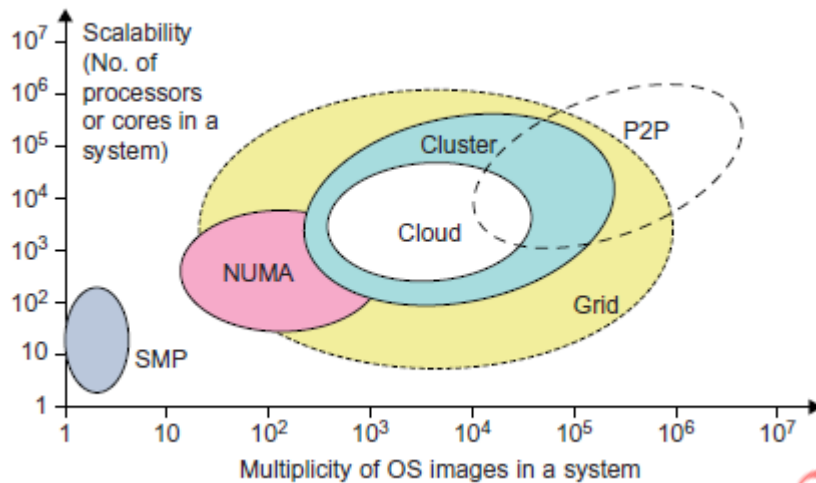
Performance Metrics

In a distributed system, performance is attributed to a large number of factors. System throughput is often measured in MIPS, Tflops (tera floating-point operations per second), or TPS (transactions per second). Other measures include job response time and network latency. An interconnection network that has low latency and high bandwidth is preferred. System overhead is often attributed to OS boot time, compile time, I/O data rate, and the runtime support system used. Other performance-related metrics include the QoS for Internet and web services; system availability and dependability; and security resilience for system defense against network attacks.

Dimensions of Scalability

Users want to have a distributed system that can achieve scalable performance. Any resource upgrade in a system should be backward compatible with existing hardware and software resources.

- **Size scalability** This refers to achieving higher performance or more functionality by increasing the machine size. The word “size” refers to adding processors, cache, memory, storage, or I/O channels. The most obvious way to determine size scalability is to simply count the number of processors installed. Not all parallel computer or distributed architectures are equally sizescalable. For example, the IBM S2 was scaled up to 512 processors in 1997. But in 2008, the IBM BlueGene/L system scaled up to 65,000 processors.
- **Software scalability** This refers to upgrades in the OS or compilers, adding mathematical and engineering libraries, porting new application software, and installing more user-friendly programming environments. Some software upgrades may not work with large system configurations. Testing and fine-tuning of new software on larger systems is a nontrivial job.
- **Application scalability** This refers to matching problem size scalability with machine size scalability. Problem size affects the size of the data set or the workload increase. Instead of increasing machine size, users can enlarge the problem size to enhance system efficiency or cost-effectiveness.
- **Technology scalability** This refers to a system that can adapt to changes in building technologies, such as the component and networking technologies discussed in Section 3.1. When scaling a system design with new technology one must consider three aspects: time, space, and heterogeneity. (1) Time refers to generation scalability. When changing to new-generation processors, one must consider the impact to the motherboard, power supply, packaging and cooling, and so forth. Based on past experience, most systems upgrade their commodity processors every three to five years. (2) Space is related to packaging and energy concerns. Technology scalability demands harmony and portability among suppliers. (3) Heterogeneity refers to the use of hardware components or software packages from different vendors. Heterogeneity may limit the scalability.



Amdahl's Law

Consider the execution of a given program on a uniprocessor workstation with a total execution time of T minutes. Now, let's say the program has been parallelized or partitioned for parallel execution on a cluster of many processing nodes. Assume that a fraction α of the code must be executed sequentially, called the *sequential bottleneck*. Therefore, $(1 - \alpha)$ of the code can be compiled for parallel execution by n processors. The total execution time of the program is calculated by $\alpha T + (1 - \alpha)T/n$, where the first term is the sequential execution time on a single processor and the second term is the parallel execution time on n processing nodes.

All system or communication overhead is ignored here. The I/O time or exception handling time is also not included in the following speedup analysis. Amdahl's Law states that the *speedup factor* of using the n -processor system over the use of a single processor is expressed by:

$$\text{Speedup} = S = T / [\alpha T + (1 - \alpha)T/n] = 1 / [\alpha + (1 - \alpha)/n]$$

Fault Tolerance and System Availability - System Availability

HA (high availability) is desired in all clusters, grids, P2P networks, and cloud systems. A system is highly available if it has a long mean time to failure (MTTF) and a short mean time to repair (MTTR). System availability is formally defined as follows:

$$\text{System Availability} = \text{MTTF} / (\text{MTTF} + \text{MTTR})$$

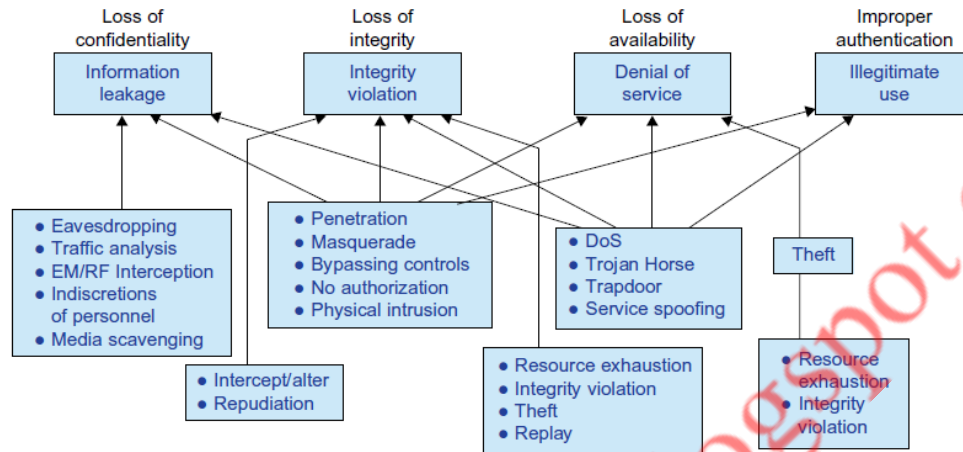
System availability is attributed to many factors. All hardware, software, and network components may fail. Any failure that will pull down the operation of the entire system is called a single point of failure. The rule of thumb is to design a dependable computing system with no single point of failure. Adding hardware redundancy, increasing component reliability, and designing for testability will help to enhance system availability and dependability.

Network Threats and Data Integrity - Threats to Systems and Networks

Network viruses have threatened many users in widespread attacks. These incidents have created a worm epidemic by pulling down many routers and servers, and are responsible for the loss of billions of dollars

in business, government, and services. Figure 1.25 summarizes various attack types and their potential damage to users. As the figure shows, information leaks lead to a loss of confidentiality.

Loss of data integrity may be caused by user alteration, Trojan horses, and service spoofing attacks. A denial of service (DoS) results in a loss of system operation and Internet connections.



Copyright Protection

Collusive piracy is the main source of intellectual property violations within the boundary of a P2P network. Paid clients (colluders) may illegally share copyrighted content files with unpaid clients (pirates). Online piracy has hindered the use of open P2P networks for commercial content delivery.

Energy Efficiency in Distributed Computing

Primary performance goals in conventional parallel and distributed computing systems are high performance and high throughput, considering some form of performance reliability (e.g., fault tolerance and security). However, these systems recently encountered new challenging issues including energy efficiency, and workload and resource outsourcing. These emerging issues are crucial not only on their own, but also for the sustainability of large-scale computing systems in general. This section reviews energy consumption issues in servers and HPC systems, an area known as distributed power management (DPM).

Energy Consumption of Unused Servers

To run a server farm (data center) a company has to spend a huge amount of money for hardware, software, operational support, and energy every year. Therefore, companies should thoroughly identify whether their installed server farm (more specifically, the volume of provisioned resources) is at an appropriate level, particularly in terms of utilization. It was estimated in the past that, on average, one-sixth (15 percent) of the full-time servers in a company are left powered on without being actively used (i.e., they are idling) on a daily basis. This indicates that with 44 million servers in the world, around 4.7 million servers are not doing any useful work.

Reducing Energy in Active Servers

In addition to identifying unused/underutilized servers for energy savings, it is also necessary to apply appropriate techniques to decrease energy consumption in active distributed systems with negligible influence on their performance.

