Subject Name: High Performance Computing

Module Number: 04

Module Name: Cluster Computing

Syllabus

Cluster Computing :

The Role of Clusters, Definition and Taxonomy, Distributed Computing, Scalable Parallel Computer Architecture, Cluster Computer and its Architecture, Cluster Classification, Components for Clusters, Network Services/Communication SW, Cluster Middleware. Resource Management and Scheduling, Heterogeneous Clusters, Chef server, Deploying Chef clusters, Puppet server, Deploying cluster using puppet.

Issues in cluster design: performance, single- system-image, fault tolerance, manageability, programmability, load balancing, security, storage.

Aim

The aim of this module is to study cluster computing, Hardware technologies for cluster computing, including a survey of the possible node hardware and high-speed networking hardware and software. Software for cluster computing, Software and software architectures for cluster computing, including Issues in cluster design.

Objectives

The Objectives of this module are

- Identify the technical foundations of cluster computing architectures.
- Analyze the problems and solutions to cluster computing
- Apply principles of best practice in cluster computing application design and management.
- Identify and define technical challenges for cluster computing applications and assess their importance

Outcome

At the end of this module, you are expected to:

- Understand the fundamental principles of cluster computing
- Understand the importance of cluster computing
- Analyze the performance of cluster computing
- Recognize Issues in cluster design.

Contents

The Role of Clusters, Definition and Taxonomy,

Distributed Computing, Scalable Parallel Computer Architecture

Cluster Computer and its Architecture ,Cluster Classification,

Components for Clusters, Network Services/Communication SW,

Cluster Middleware. Resource Management and Scheduling,

Heterogeneous Clusters, Chef server, Deploying Chef clusters,

Puppet server, Deploying cluster using puppet.

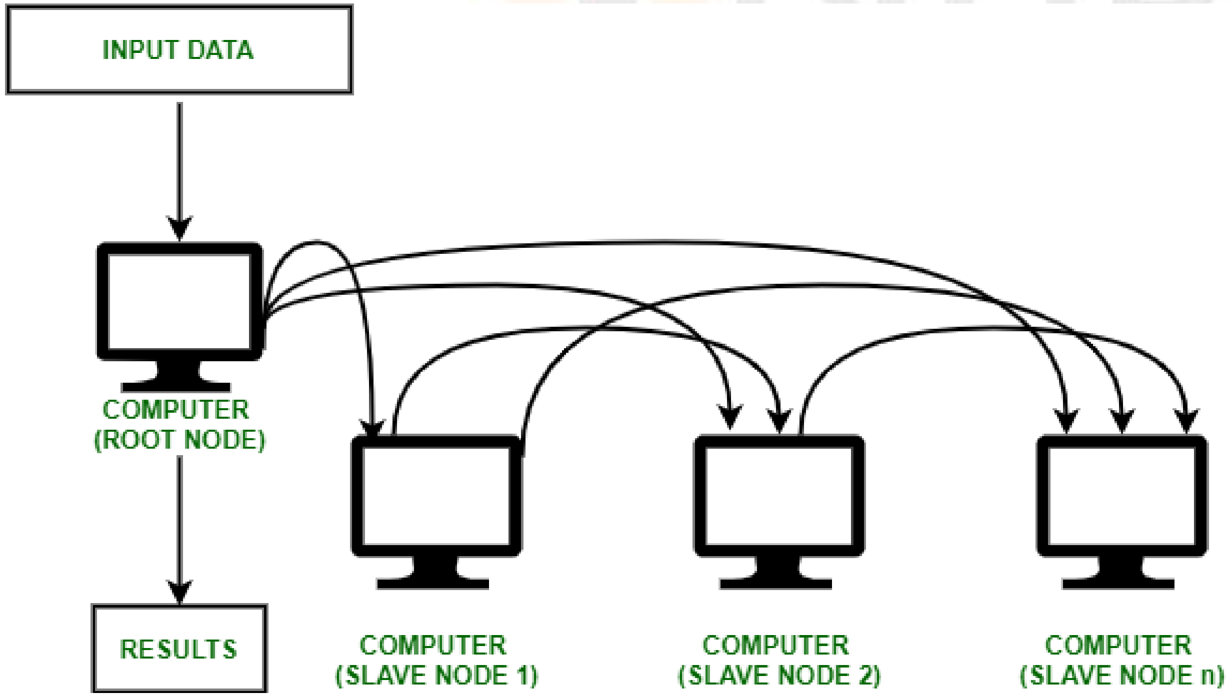
Issues in cluster design: performance, single- system-image, fault tolerance,

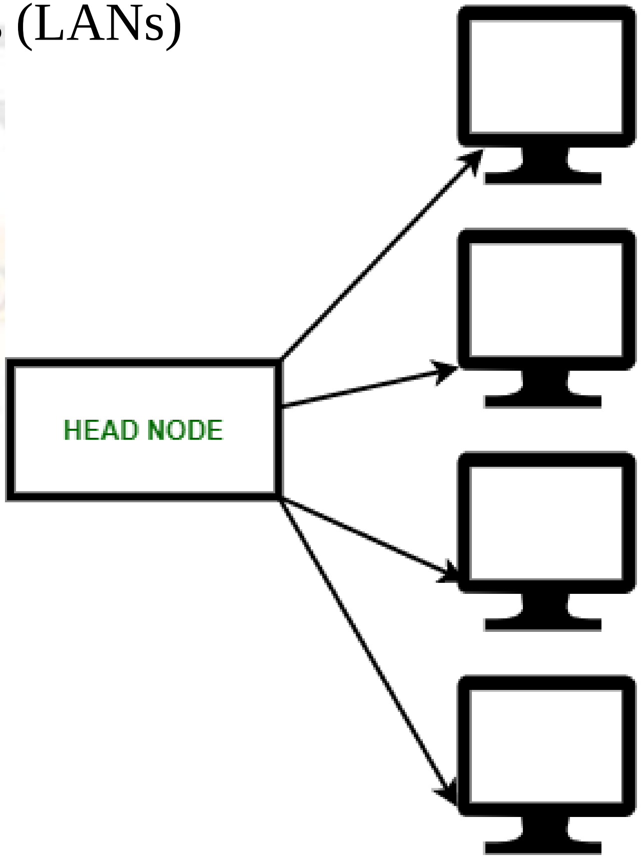
manageability, programmability, load balancing, security, storage.

Cluster Computing

The Role of Clusters, Definition and Taxonomy

Cluster computing is a collection of tightly or loosely connected computers that work together so that they act as a single entity. The connected computers execute operations all together thus creating the idea of a single system. The clusters are generally connected through fast local area networks (LANs)





Cluster Computing

The Role of Clusters, Definition and Taxonomy

Why is Cluster Computing important?

Cluster computing, also known as high-performance computing (HPC), is the use of interconnected computers or servers to work together as a single system.

Cluster computing is important for several reasons:

- Increased Computational Power
- Scalability
- Resource Efficiency
- Fault Tolerance and High Availability
- Cost-effectiveness:
- Complex Problem Solving

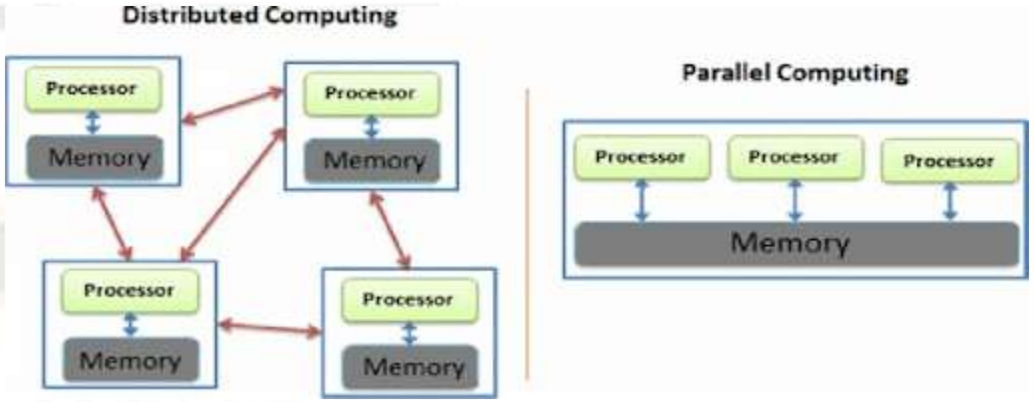
In summary, cluster computing provides significant computational power, scalability, resource efficiency, fault tolerance, and cost-effectiveness. It enables organizations and researchers to solve complex problems, process large datasets, and perform advanced simulations, leading to scientific advancements, improved productivity, and technological innovation.

Cluster Computing

Distributed Computing, Scalable Parallel Computer Architecture

Distributed computing

Distributed computing is the process of connecting multiple computers via a local network or wide area network so that they can act together as a single ultra-powerful computer capable of performing computations that no single computer within the network would be able to perform on its own.



Distributed computers offer two key advantages:

•**Easy scalability:** Just add more computers to expand the system.

•**Redundancy:** Since many different machines are providing the same service, that service can keep running even if one (or more) of the computers goes down.

Cluster Computing

Distributed Computing, Scalable Parallel Computer Architecture

S.NO	PARALLEL COMPUTING	DISTRIBUTED COMPUTING
1.	In a parallel system, many operations can be performed at the same time, or simultaneously.	In a distributed system, the various components are located at different locations or places.
2.	Single computer is required.	Uses multiple computers.
3.	Multiple operations are performed by multiple processors.	Several computers carry out multiple operations.
4.	Communication between processors occurs through a bus.	Communication between computers occurs through message passing.
5.	It may have shared or distributed memory	It has only distributed memory
6.	Enhances the efficiency of the system.	Enhances the system's ability to handle more workload, recover from failures, and share resources effectively.

Cluster Computing

Distributed Computing, Scalable Parallel Computer Architecture

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Distributed Computing, Scalable Parallel Computer Architecture

What Is Parallel Computing?

Parallel computing is the process of performing computational tasks across multiple processors at once to improve computing speed and efficiency. It divides tasks into sub-tasks and executes them simultaneously through different processors.

There are three main types, or “levels,” of parallel computing: bit, instruction, and task.

Bit-level parallelism: Uses larger “words,” which is a fixed-sized piece of data handled as a unit by the instruction set or the hardware of the processor, to reduce the number of instructions the processor needs to perform an operation.

Instruction-level parallelism: Employs a stream of instructions to allow processors to execute more than one instruction per clock cycle (the oscillation between high and low states within a digital circuit).

Task-level parallelism: Runs computer code across multiple processors to run multiple tasks at the same time on the same data.

Distributed Computing, Scalable Parallel Computer Architecture

Key Differences Between Parallel Computing and Distributed Computing

While parallel and distributed computers are both important technologies, there are several key differences between them.

Difference 1: Number of Computers Required

Parallel computing typically requires one computer with multiple processors. Distributed computing, on the other hand, involves several autonomous (and often geographically separate and/or distant) computer systems working on divided tasks.

Difference 2: Scalability

Parallel computing systems are less scalable than distributed computing systems because the memory of a single computer can only handle so many processors at once. A distributed computing system can always scale with additional computers.

Distributed Computing, Scalable Parallel Computer Architecture

Key Differences Between Parallel Computing and Distributed Computing

Difference 3: Memory

In parallel computing, all processors share the same memory and the processors communicate with each other with the help of this shared memory. Distributed computing systems, on the other hand, have their own memory and processors.

Difference 4: Synchronization

In parallel computing, all processors share a single master clock for synchronization, while distributed computing systems use synchronization algorithms.

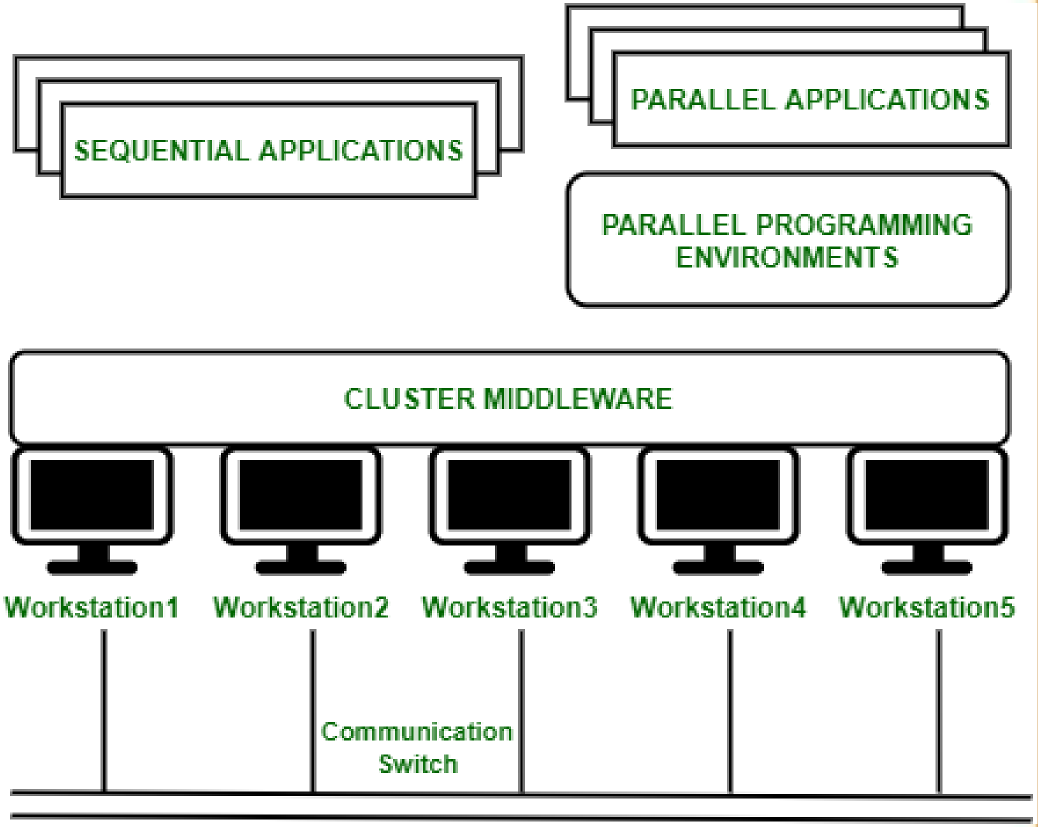
Difference 5: Usage

Parallel computing is used to increase computer performance and for scientific computing, while distributed computing is used to share resources and improve scalability.

Cluster Computing

Cluster Computer and its Architecture

- it is designed with an array of interconnected individual computers and the computer systems operating collectively as a single standalone system.
- It is a group of workstations or computers working together as a single, integrated computing resource connected via high speed interconnects.
- A node – Either a single or a multiprocessor network having memory, input and output functions and an operating system.
- Two or more nodes are connected on a single line or every node might be connected individually through a LAN connection.



Cluster Computing

Cluster Computer and its Architecture

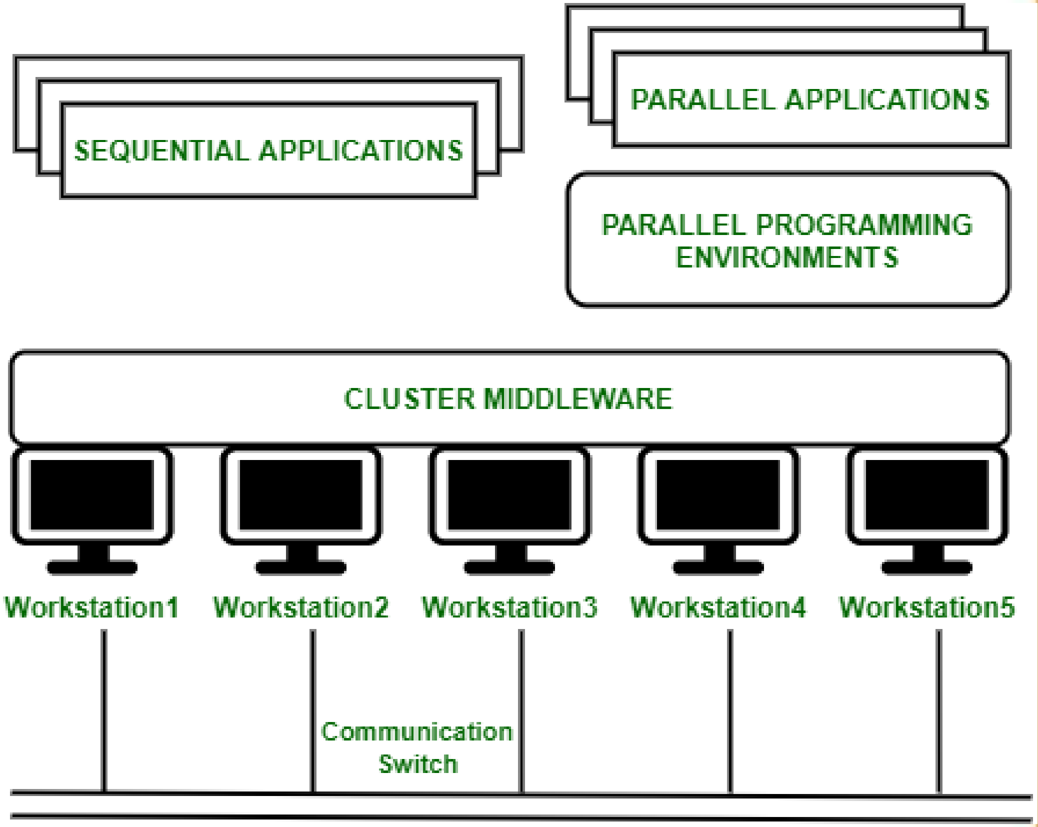
Components of a Cluster Computer :

Cluster Nodes

Cluster Operating System

The switch or node interconnect

Network switching hardware

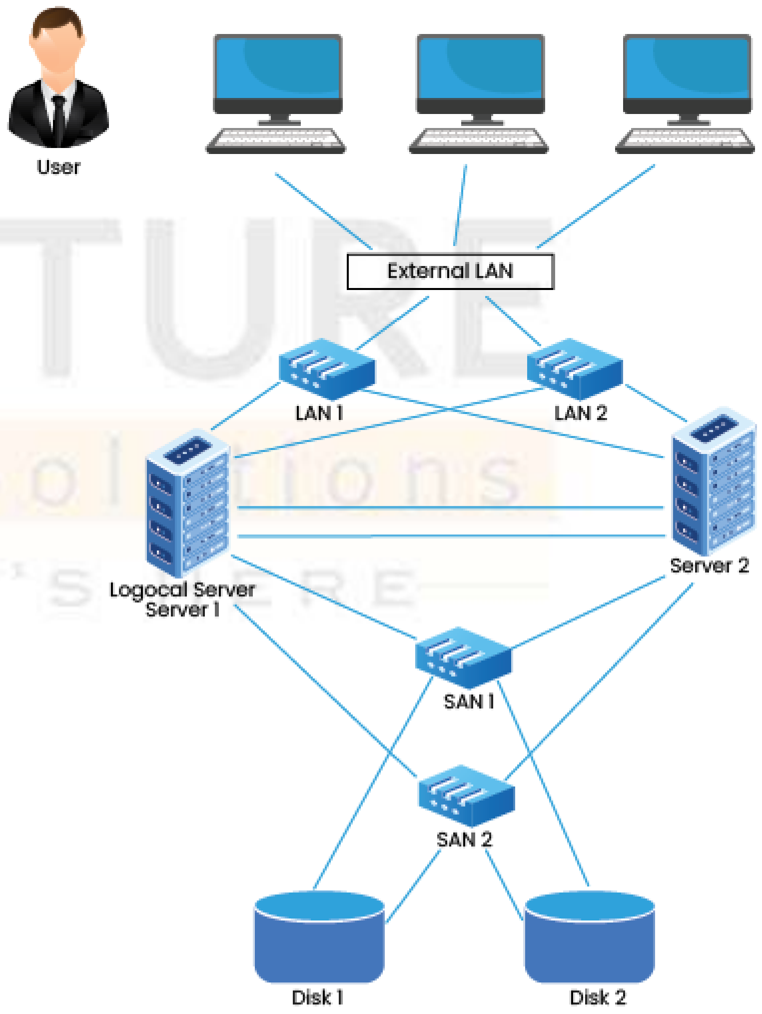


Cluster Computing

Cluster Computer and its Architecture

Types of Cluster computing :

1. High Availability (HA) and Failover Clusters: These cluster models create availability of services and resources in an uninterrupted method using the system's implicit redundancy. The basic idea in this form of Cluster is that if a node fails, then applications and services can be made available to other nodes. These types of Clusters serve as the base for critical missions, mails, files, and application servers.

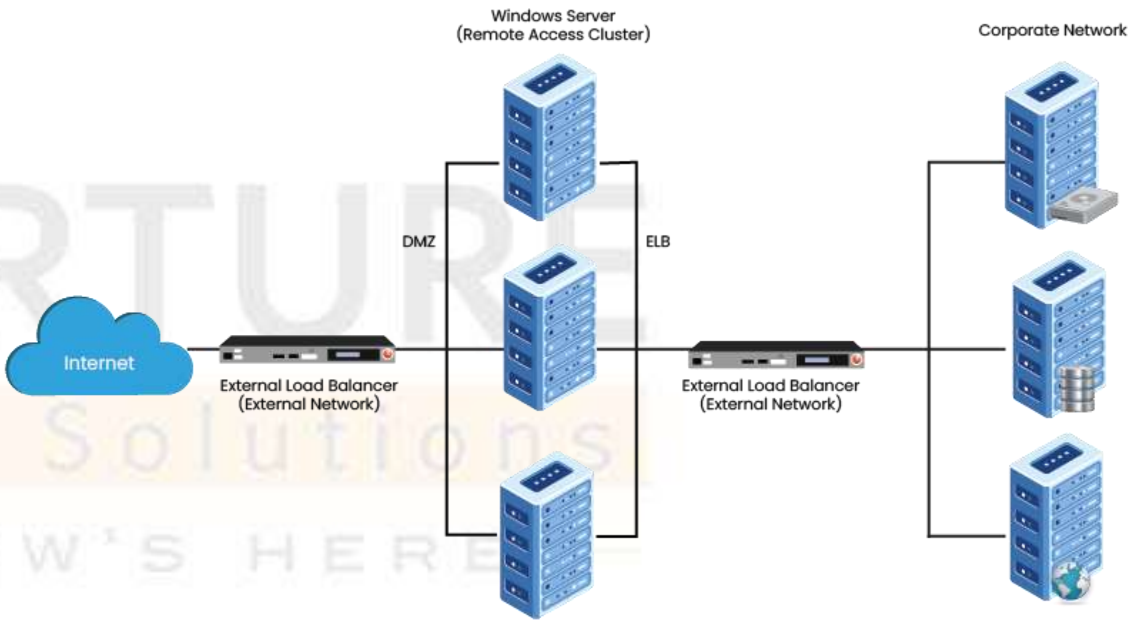


Cluster Computer and its Architecture

Types of Cluster computing :

2. Load-balancing clusters :

This Cluster distributes all the incoming traffic/requests for resources from nodes that run the same programs and machines. In this Cluster model, all the nodes are responsible for tracking orders, and if a node fails, then the requests are distributed amongst all the nodes available. Such a solution is usually used on web server farms.



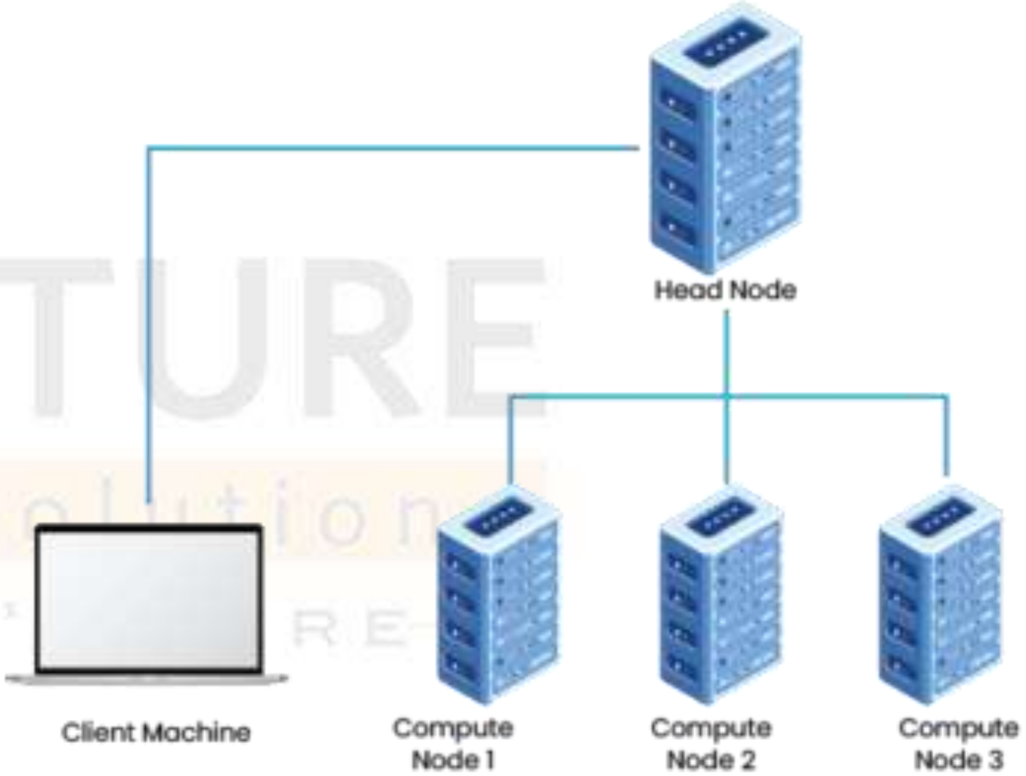
Cluster Computing

Cluster Computer and its Architecture

Types of Cluster computing :

3. Distributed & Parallel Processing Clusters:

This Cluster model enhances availability and performance for applications that have large computational tasks. A large computational task gets divided into smaller tasks and distributed across the stations. Such Clusters are usually used for scientific computing or financial analysis that require high processing power.



Cluster Computer and its Architecture

Cluster computer architecture refers to the design and structure of a computer cluster, which is a collection of interconnected computers or servers that work together as a unified computing resource. The architecture of a cluster computer is based on an array of interconnected individual computers or nodes, which operate collectively as a single standalone system

Cluster computer architecture typically consists of several key components that work together to form a cohesive system. The specific components may vary depending on the type and purpose of the cluster. Here are the common components associated with cluster computer architecture:

Cluster Computing

Cluster Computer and its Architecture

Cluster Nodes: These are individual computers or servers that constitute the cluster. Each node within the cluster performs computing tasks and contributes to the overall processing power of the system .

Cluster Operating System: Each node in a cluster typically runs its own instance of an operating system, which enables coordination, resource sharing, and task scheduling among the nodes .

Network Interconnect: The components of a cluster are usually connected through fast local area networks (LAN) or high-speed interconnects. These network connections facilitate communication and data transfer between the nodes, allowing them to work together seamlessly

Cluster Computer and its Architecture

Cluster Nodes: These are individual computers or servers that constitute the cluster. Each node within the

Network Switching Hardware: Cluster architectures often involve the use of network switching hardware, such as switches or routers, to manage the flow of data between the nodes. These devices ensure efficient and reliable communication within the cluster

Managing Nodes: In some cluster architectures, there are dedicated servers known as managing nodes or control nodes. These nodes handle the management and coordination of the cluster, including load balancing, fault detection, and scheduling tasks among the compute nodes .

High-Performance Computing (HPC) Scheduler: HPC clusters often employ a centralized scheduler that manages the parallel computing workload across the cluster. The scheduler allocates resources, assigns tasks to available nodes, and optimizes the utilization of computing resources

Cluster Component

Multiple High Performance Computers

- PCs
- Workstations
- SMPs (CLUMPS)
- Distributed HPC Systems leading to Metacomputing

State of the art Operating Systems

- Linux (MOSIX, Beowulf, and many more)
- Microsoft NT (Illinois HPVM, Cornell Velocity)
- SUN Solaris (Berkeley NOW, C-DAC PARAM)

High Performance Networks/Switches

- Ethernet (10Mbps),
- Fast Ethernet (100Mbps),
- Gigabit Ethernet (1Gbps) etc.

Cluster Computing

Cluster Component

Network Interface Card

- Myrinet has NIC
- User-level access support

Fast Communication Protocols and Services

- Active Messages (Berkeley)
- Fast Messages (Illinois)
- U-net (Cornell)
- XTP (Virginia)
- Virtual Interface Architecture (VIA)

Cluster Computing

Cluster Component

Cluster Middleware

- Single System Image (SSI)
- System Availability (SA) Infrastructure

Hardware

- DEC Memory Channel, DSM (Alewife, DASH), SMP Techniques

Operating System Kernel/Gluing Layers

- Solaris MC, Unixware, GLUnix, MOSIX

Applications and Subsystems

- Applications (system management and electronic forms)
- Runtime systems (software DSM, PFS etc.)
- Resource management and scheduling (RMS) software
    - SGE (Sun Grid Engine), LSF, PBS, Libra: Economy Cluster Scheduler, NQS, etc.

Cluster Computing

Cluster Component

Parallel Programming Environments and Tools

- Threads (PCs, SMPs, NOW..)
  - POSIX Threads
  - Java Threads
- MPI (Message Passing Interface)
  - Linux, NT, on many Supercomputers
- PVM (Parallel Virtual Machine)
- Parametric Programming
- Software DSMs (Shmem)
- Compilers
  - C/C++/Java
  - Parallel programming with C++ (MIT Press book)
- RAD (rapid application development tools)
  - GUI based tools for PP modeling
- Debuggers
- Performance Analysis Tools
- Visualization Tools

Cluster Component

Applications

- Sequential
- Parallel / Distributed (Cluster-aware app.)
  - Grand Challenging applications
    - Weather Forecasting
    - Quantum Chemistry
    - Molecular Biology Modeling
    - Engineering Analysis (CAD/CAM)
    - ……………….
  - PDBs, web servers,data-mining

Network Services/Communication SW

- Communication infrastructure support protocol for
  - Bulk-data transport
  - Streaming data
  - Group communications
- Communication service provide cluster with important QoS parameters
  - Latency
  - Bandwidth
  - Reliability
  - Fault-tolerance
  - Jitter control
- Network service are designed as hierarchical stack of protocols with relatively low-level communication API, provide means to implement wide range of communication methodologies
  - RPC
  - DSM
  - Stream-based and message passing interface (e.g., MPI, PVM)

Cluster Computing

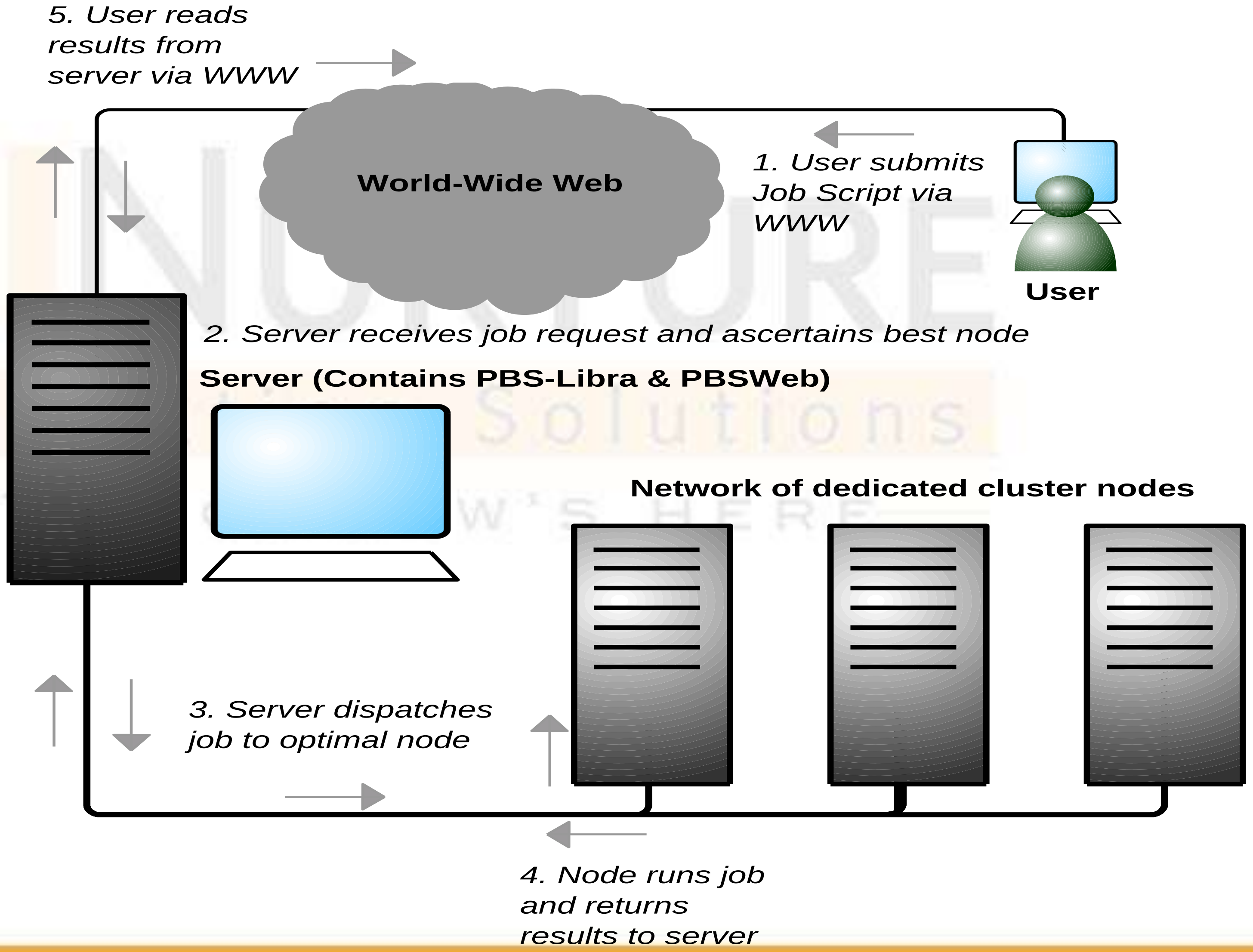
Resource Management and Scheduling

- RMS is the act of distributing applications among computers to maximize their throughput
- Enable the effective and efficient utilization of the resources available
- Software components
  - Resource manager
    - Locating and allocating computational resource, authentication, process creation and migration
  - Resource scheduler
    - Queuing applications, resource location and assignment. It instructs resource manager what to do when (policy)
- Reasons for using RMS
  - Provide an increased, and reliable, throughput of user applications on the systems
  - Load balancing
  - Utilizing spare CPU cycles
  - Providing fault tolerant systems
  - Manage access to powerful system, etc
- Basic architecture of RMS: client-server system

Cluster Computing

Resource Management and Scheduling

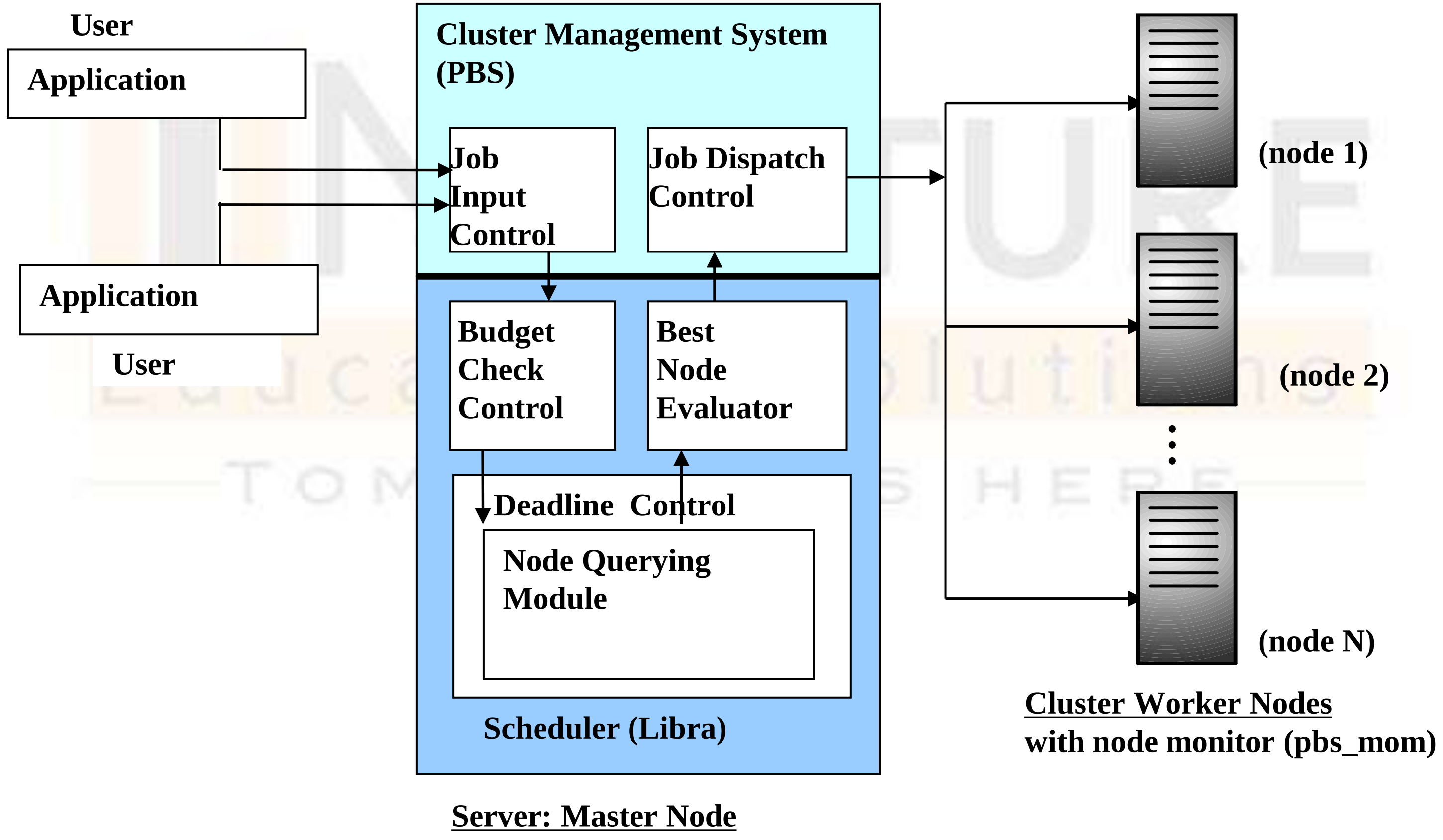
RMS Components



Cluster Computing

Resource Management and Scheduling

Libra: An example cluster scheduler



Cluster Computing

Resource Management and Scheduling

Services provided by RMS

- Process Migration
  - Computational resource has become too heavily loaded
  - Fault tolerant concern
- Checkpointing
- Scavenging Idle Cycles
  - 70% to 90% of the time most workstations are idle
- Fault Tolerance
- Minimization of Impact on Users
- Load Balancing
- Multiple Application Queues

Cluster Computing

Issues in cluster design:

- Enhanced Performance (performance @ low cost)
- Enhanced Availability (failure management)
- Single System Image (look-and-feel of one system)
- Size Scalability (physical & application)
- Fast Communication (networks & protocols)
- Load Balancing (CPU, Net, Memory, Disk)
- Security and Encryption (clusters of clusters)
- Distributed Environment (Social issues)
- Manageability (admin. And control)
- Programmability (simple API if required)
- Applicability (cluster-aware and non-aware app.)

Issues in cluster design:

Single System Image (SSI) ?

- A single system image is the illusion, created by software or hardware, that presents a collection of resources as one, more powerful resource.
- SSI makes the cluster appear like a single machine to the user, to applications, and to the network.
- A cluster without a SSI is not a cluster.

Cluster Middleware & SSI

- SSI
  - Supported by a middleware layer that resides between the OS and user-level environment
  - Middleware consists of essentially 2 sublayers of SW infrastructure
    - SSI infrastructure
      - Glue together OSs on all nodes to offer unified access to system resources
    - System availability infrastructure
      - Enable cluster services such as checkpointing, automatic failover, recovery from failure, & fault-tolerant support among all nodes of the cluster

Issues in cluster design:

Single System Image Benefits

- Provide a simple, straightforward view of all system resources and activities, from any node of the cluster
- Free the end user from having to know where an application will run
- Free the operator from having to know where a resource is located
- Let the user work with familiar interface and commands and allows the administrators to manage the entire clusters as a single entity
- Reduce the risk of operator errors, with the result that end users see improved reliability and higher availability of the system

Issues in cluster design:
Fault tolerance

Fault tolerance refers to the ability of a system (computer, network, cloud cluster, etc.) to continue operating without interruption when one or more of its components fail.

The objective of creating a fault-tolerant system is to prevent disruptions arising from a single point of failure, ensuring the high availability and business continuity of mission-critical applications or systems.

Fault-tolerant systems use backup components that automatically take the place of failed components, ensuring no loss of service. These include:

- **Hardware systems** that are backed up by identical or equivalent systems. For example, a server can be made fault tolerant by using an identical server running in parallel, with all operations mirrored to the backup server.
- **Software systems** that are backed up by other software instances. For example, a database with customer information can be continuously replicated to another machine. If the primary database goes down, operations can be automatically redirected to the second database.

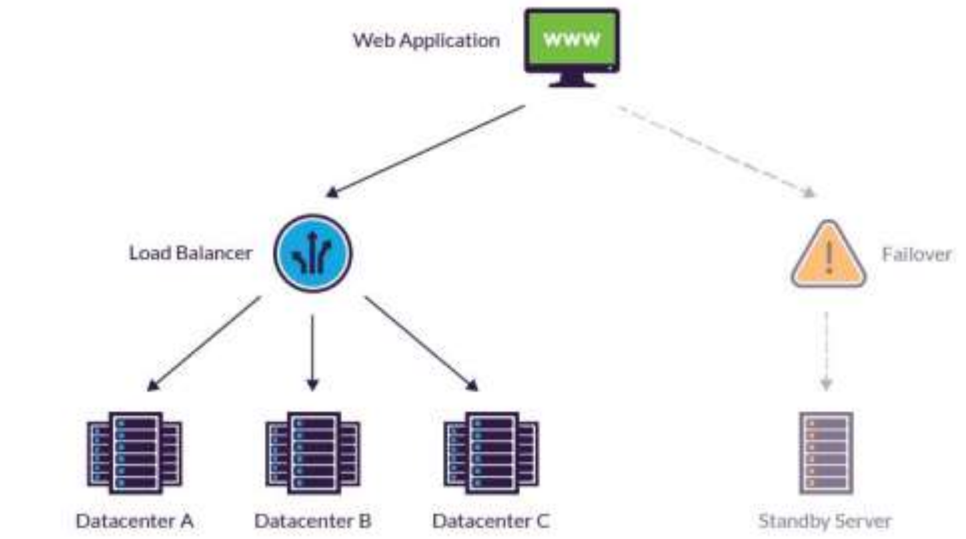
Cluster Computing

Issues in cluster design:

Fault tolerance

Power sources that are made fault tolerant using alternative sources. For example, many organizations have power generators that can take over in case main line electricity fails.

In similar fashion, any system or component which is a single point of failure can be made fault tolerant using redundancy. Fault tolerance can play a role in a disaster recovery strategy. For example, fault-tolerant systems with backup components in the cloud can restore mission-c nan-induced disaster destroys on-premise IT infrastructure.



Cluster Computing

Summery

- Cluster computing is a collection of tightly or loosely connected computers that work together
- The clusters are generally connected through fast local area networks (LANs)
- Distributed computing is the process of connecting multiple computers via a local network
- Runs computer code across multiple processors to run multiple tasks at the same time on the same data is called Task-level parallelism.
- Fault tolerance refers to the ability of a system to continue operating without interruption when one or more of its components fail.
- SSI makes the cluster appear like a single machine to the user, to applications, and to the network

Self Assessment Questions

Q.1 Clustered systems have ____________ CPUs.

A. zero

B. one

C. two

D. multiple

Answer: D multiple

Self Assessment Questions

Q.2 Clustered systems are created by _________ individual computer systems.

A. one

B. two

C. two or more

D. None of the above

Answer: C. two or more

Self Assessment Questions

Q.3 The clustered systems are a combination of hardware clusters and software clusters

A. TRUE

B. FALSE

C. Can be true or false

D. Can not say

Answer: A. TRUE

Self Assessment Questions

Q.4 Which of the following are Benefits of Clustered Systems?

A. Clustered systems result in high performance

B. Clustered systems are quite fault tolerant

C. Clustered systems are quite scalable

D. All of the above

Answer: D. All of the above

Self Assessment Questions

Q.5 In which type of clusters, the nodes in the system share the workload to provide a better performance?

A. High Availability Clusters

B. Load Balancing Clusters

C. Both A and B

D. None of the above

Answer: C. Both A and B

Self Assessment Questions

Q.6 Each node in the clustered systems contains the cluster?

A. Hardware

B. software

C. Both A and B

D. Can not say

Answer: B. software

Document Links

Topic	URL	Notes
Scalable Parallel Computer Architecture	https://ebrary.net/206306/computer_science/scalable_parallel_computer_architecture	This link explain Scalable Parallel Computer Architecture
Components of a cluster	https://www.ibm.com/docs/en/ibm-mq/7.5?topic=cluster-components	This link explains Components of a cluster

Cluster Computing

Video Links

Topic	URL	Notes
Cluster Computing	https://www.youtube.com/watch?v=GlobK-eWDSo	Explains about cluster computing
Issues in Mainstream Clusters	https://www.youtube.com/watch?v=_lDSPPZVVQg	This video talks about Issues in Mainstream Clusters

E-Book Links

Topic	URL	Notes
Cluster Computing	https://doc.lagout.org/science/0_Computer%20Science/5_Parallel%20and%20Distributed/Cluster%20Computing%20-%20Architectures%2C%20Operating%20Systems%2C%20Parallel%20Processing%20%26%20Programming%20Languages.pdf	Ebook gives an comprehensive knowledge on Cluster Computing