ANNAMACHARYA INSTITUTE OF TECHNOLOGY AND SCIENCES, TIRUPATI
(AUTONOMOUS)

DEPARTMENT OF COMPUTER SCIENCEAND ENGINEERING

COURSE MATERIAL

15A05701- GRID AND CLOUD COMPUTING

B. Tech IV-I Sem. (CSE)

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DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

SYLLABUS (THEORY)

Sub. Code	: 15A05701	**Branch/Year/Sem**	: CSE/IV/I
Sub Name	: GRID AND CLOUD COMPUTING		:
Staff Name	: Mr B .Sunil Kumar	**Academic Year**	: 2021-2022

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UNIT I INTRODUCTION

Evolution of Distributed computing: Scalable computing over the Internet – Technologies for network based systems – clusters of cooperative computers- Grid computing Infrastructures – cloud computing - service oriented architecture – Introduction to Grid Architecture and standards – Elements of Grid – Overview of Grid Architecture.

UNIT II GRID SERVICE

Introduction to Open Grid Services Architecture (OGSA) – Motivation – Functionality Requirements – Practical & Detailed view of OGSA/OGSI – Data intensive grid service models – OGSA services.

UNIT III VIRTUALIZATION

Cloud deployment models: public, private, hybrid, community – Categories of cloud computing: Everything as a service: Infrastructure, platform, software - Pros and Cons of cloud computing – Implementation levels of virtualization – virtualization structure – virtualization of CPU, Memory and I/O devices – virtual clusters and Resource Management – Virtualization for data center automation.

UNIT IV PROGRAMMING MODEL

Open source grid middleware packages – Globus Toolkit (GT4) Architecture , Configuration – Usage of Globus – Main components and Programming model - Introduction to Hadoop Framework - Mapreduce, Input splitting, map and reduce functions, specifying input and output parameters, configuring and running a job – Design of Hadoop file system, HDFS concepts, command line and java interface, dataflow of File read & File write.

UNIT V SECURITY

Trust models for Grid security environment – Authentication and Authorization methods – Grid security infrastructure – Cloud Infrastructure security: network, host and application level – aspects of data security, provider data and its security, Identity and access management architecture, IAM practices in the cloud, SaaS, PaaS, IaaS availability in the cloud, Key privacy issues in the cloud.

TEXT BOOK:

1. Kai Hwang, Geoffery C. Fox and Jack J. Dongarra, ┤Distributed and Cloud Computing: Clusters, Grids, Clouds and the Future of Internet┤, First Edition, Morgan Kaufman Publisher, an Imprint of Elsevier, 2012.

REFERENCES:

1. Jason Venner, ┤Pro Hadoop- Build Scalable, Distributed Applications in the Cloud┤, A Press, 2009
2. Tom White, ┤Hadoop The Definitive Guide┤, First Edition. O'Reilly, 2009.
3. Bart Jacob (Editor), ┤Introduction to Grid Computing┤, IBM Red Books, Vervante, 2005
4. Ian Foster, Carl Kesselman, ┤The Grid: Blueprint for a New Computing Infrastructure┤, 2nd Edition, Morgan Kaufmann.
5. Frederic Magoules and Jie Pan, ┤Introduction to Grid Computing┤ CRC Press, 2009.
6. Daniel Minoli, ┤A Networking Approach to Grid Computing┤, John Wiley Publication, 2005.
7. Barry Wilkinson, ┤Grid Computing: Techniques and Applications┤, Chapman and Hall, CRC, Taylor and Francis Group, 2010.

SUBJECT IN-CHARGE **HOD/CSE**

Annamacharya Institute of Technology & Sciences, Tirupati

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DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Sub. Code	: 15A05701	**Branch/Year/Sem**	: CSE/IV/I
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COURSE OBJECTIVE

1. Understand how Grid computing helps in solving large scale scientific problems.
2. Gain knowledge on the concept of virtualization that is fundamental to cloud computing.
3. Learn how to program the grid and the cloud
4. Understand the security issues in the grid and the cloud environment.

COURSE OUTCOMES

1. Apply the security models in the grid and the cloud environment
2. Use the grid and cloud tool kits.
3. Understand the concept of virtualization
4. Apply grid computing techniques to solve large scale scientific problems

Prepared by
STAFF NAME

Verified By
HOD

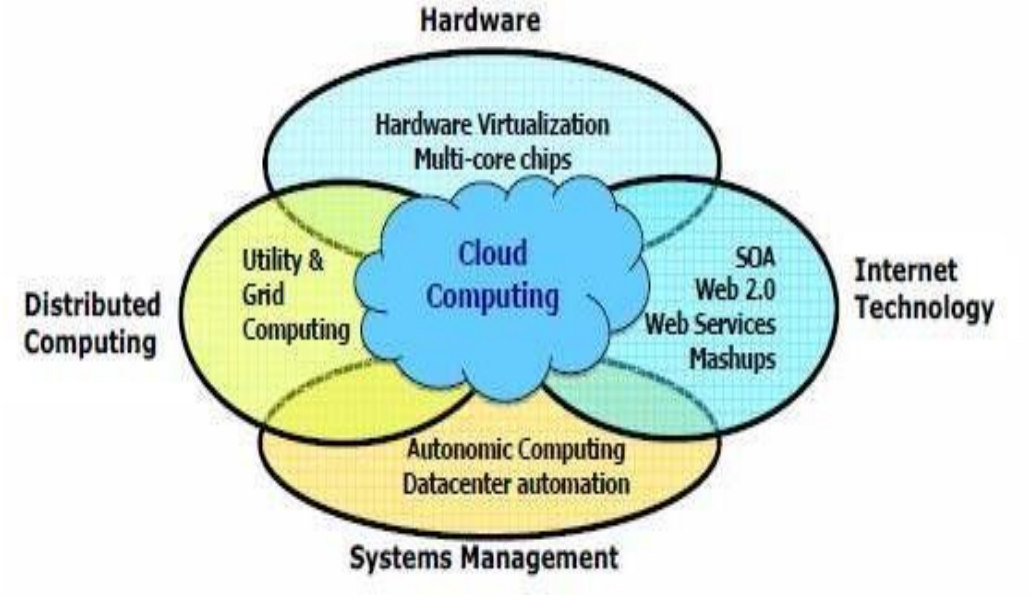
UNIT-I

INTRODUCTION:

Evolution of Distributed computing:

Scalable computing over the Internet:

Data Deluge enabling new challenges:

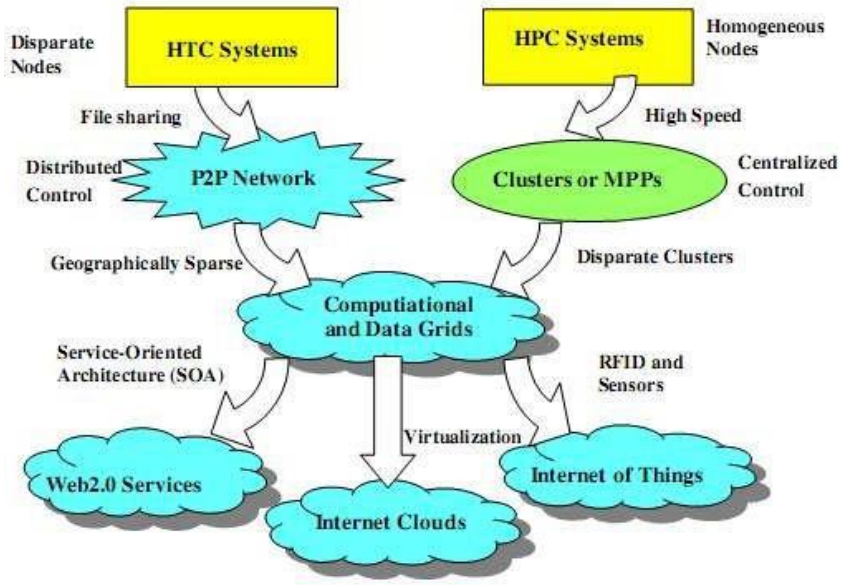


From Desktop/HPC/Grids to Internet Clouds in 30 Years

- HPC moving from centralized supercomputers to geographically distributed desktops, desk sides, clusters, and grids to clouds over last 30 years
- Location of computing infrastructure in areas with lower costs in hardware, software, datasets, space, and power requirements – moving from desktop computing to datacenter-based clouds

Interactions among 4 technical challenges: Data Deluge, Cloud Technology, eScience, and Multicore/Parallel Computing

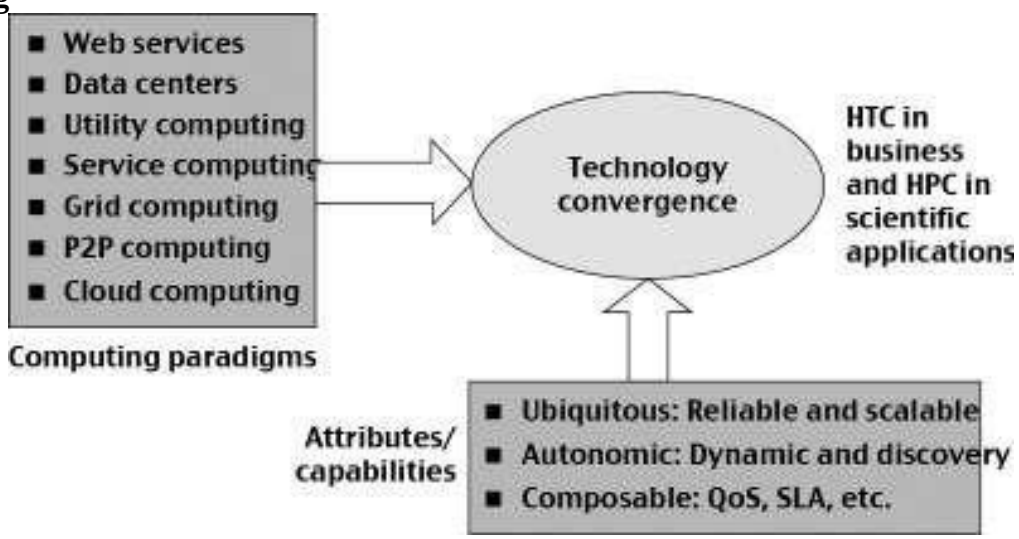
Clouds and Internet of Things



Computing Paradigm Distinctions

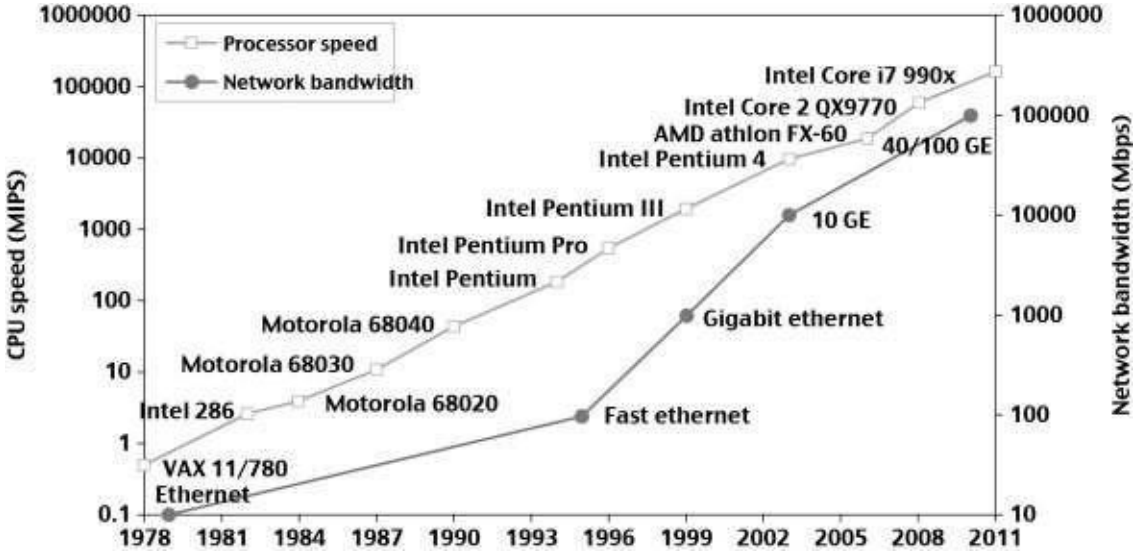
- Centralized Computing
  - All computer resources are centralized in one physical system.
- Parallel Computing
  - All processors are either tightly coupled with central shared memory or loosely coupled with distributed memory
- Distributed Computing
  - A distributed system consists of multiple autonomous computers, each with its own private memory, communicating over a network.
- Cloud Computing
  - An Internet cloud of resources that may be either centralized or decentralized. The cloud apples to parallel or distributed computing or both. Clouds may be built from physical or virtualized resources.

Technology Convergence toward HPC for Science and HTC for Business: Utility Computing

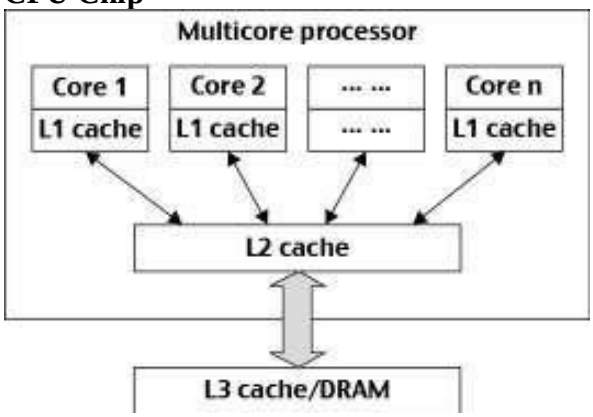


Technologies for Network-based Systems

33 year Improvement in Processor and Network Technologies



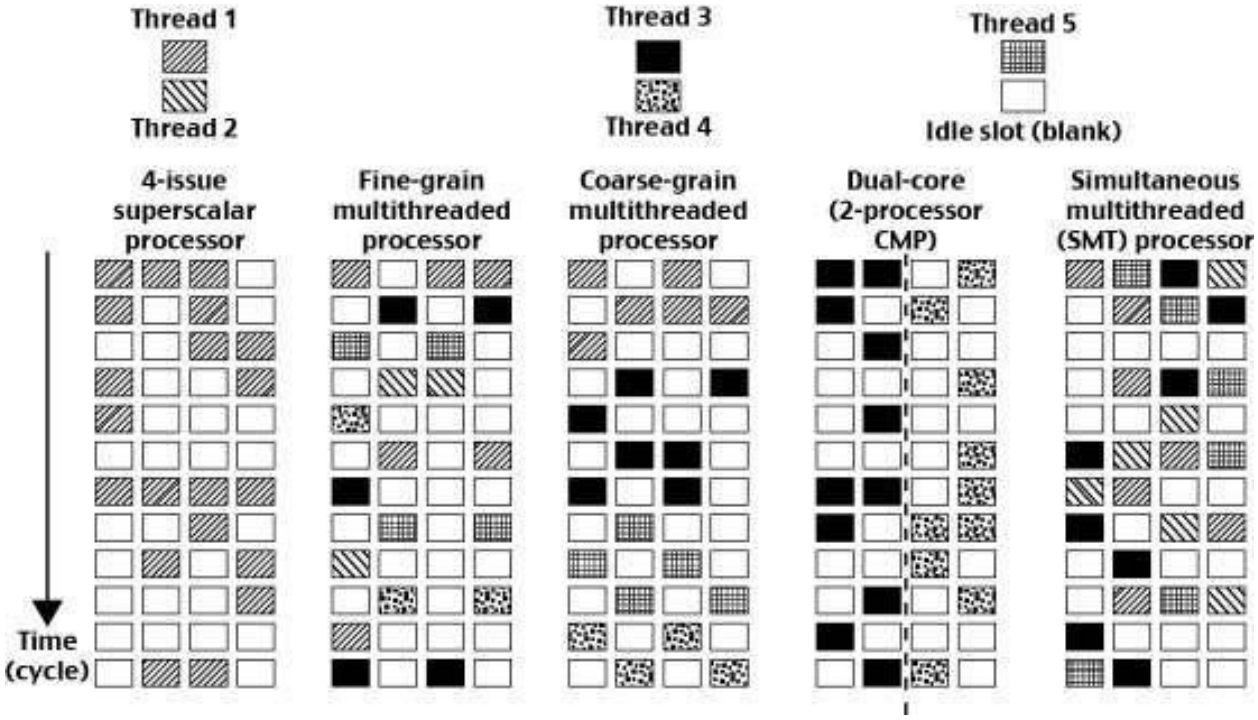
Modern Multi-core CPU Chip



Multi-threading Processors

- Four-issue superscalar (e.g. Sun Ultras arc I)
  - Implements instruction level parallelism (ILP) within a single processor.
  - Executes more than one instruction during a clock cycle by sending multiple instructions to redundant functional units.
- Fine-grain multithreaded processor
  - Switch threads after each cycle
  - Interleave instruction execution
  - If one thread stalls, others are executed
- Coarse-grain multithreaded processor
  - Executes a single thread until it reaches certain situations
- Simultaneous multithread processor (SMT)
  - Instructions from more than one thread can execute in any given pipeline stage at a time.

5 Micro-architectures of CPUs

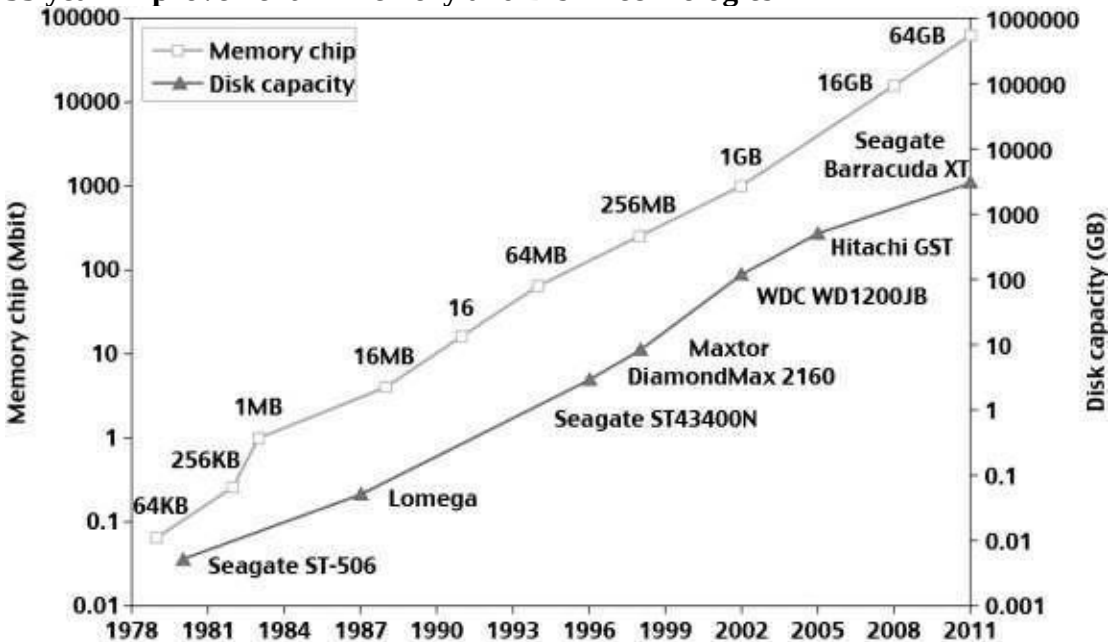


Each row represents the issue slots for a single execution cycle:

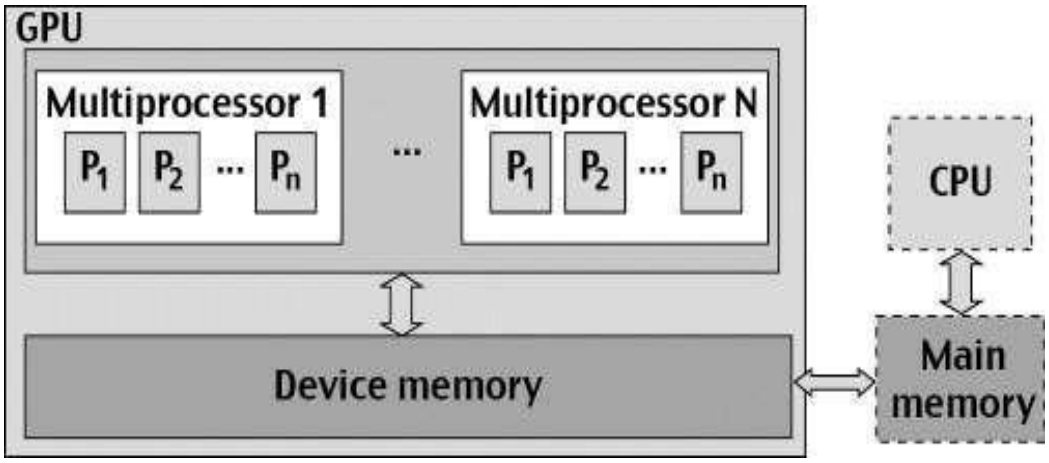
- A filled box indicates that the processor found an instruction to execute in that issue slot on that cycle;

An empty box denotes an unused slot.

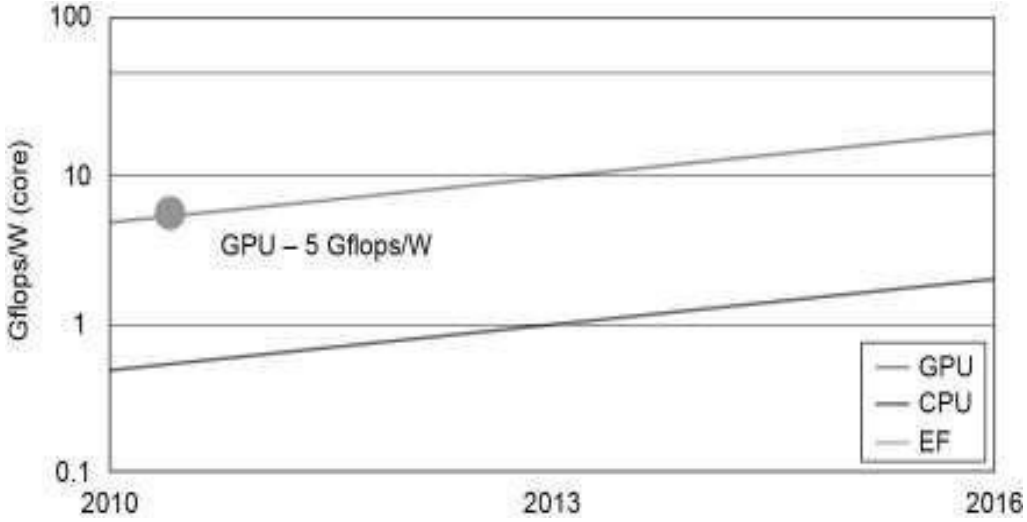
33 year Improvement in Memory and Disk Technologies



Architecture of A Many-Core Multiprocessor GPU interacting with a CPU Processor

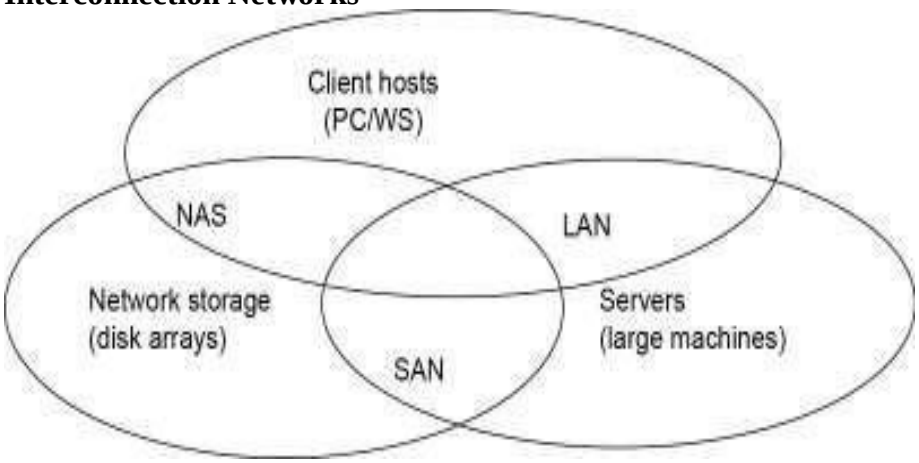


GPU Performance



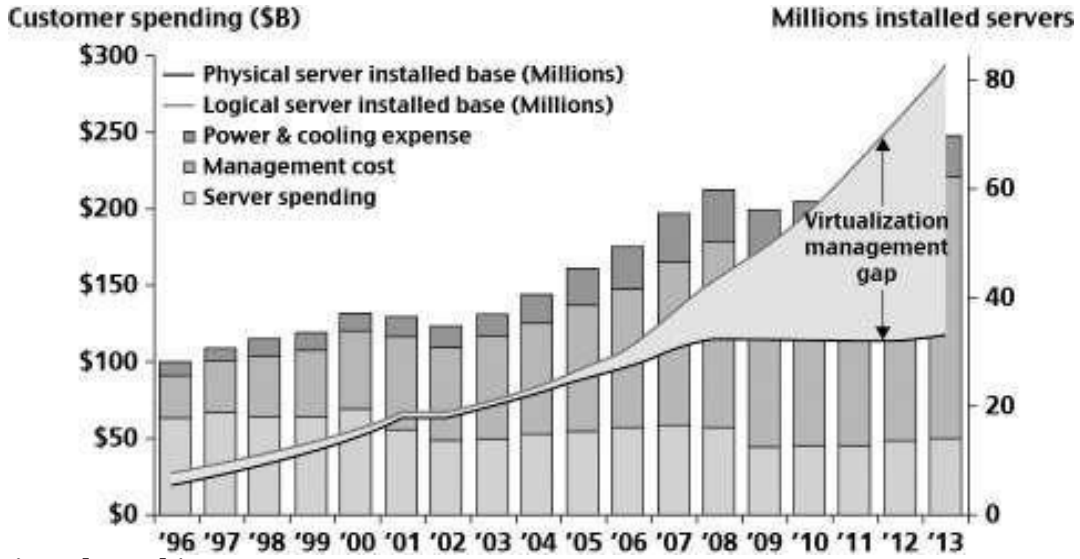
Bottom – CPU - 0.8 Gflops/W/Core (2011)
Middle – GPU - 5 Gflops/W/Core (2011)
Top - EF – Exascale computing (10^18 Flops)

Interconnection Networks



- SAN (storage area network) - connects servers with disk arrays
- LAN (local area network) – connects clients, hosts, and servers
- NAS (network attached storage) – connects clients with large storage systems

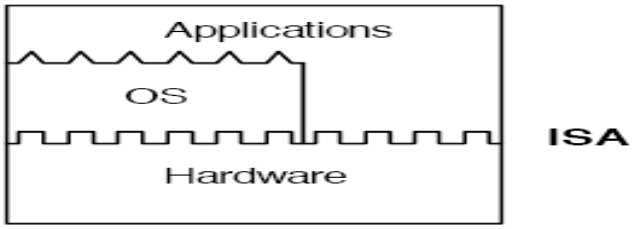
Datacenter and Server Cost Distribution:



Virtual Machines

- Eliminate real machine constraint
  - Increases portability and flexibility
- Virtual machine adds software to a physical machine to give it the appearance of a different platform or multiple platforms.
- Benefits
  - Cross platform compatibility
  - Increase Security
  - Enhance Performance
  - Simplify software migration

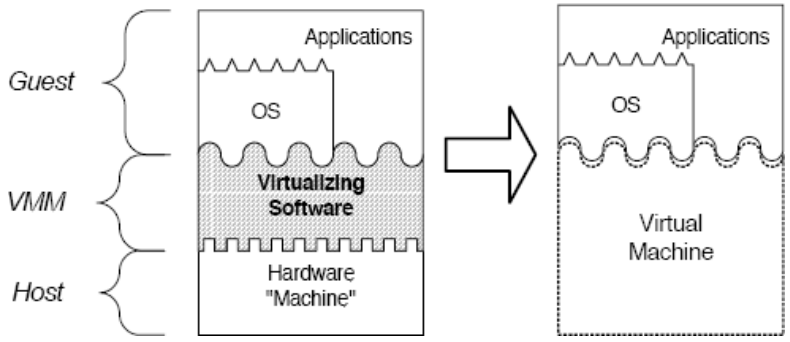
Initial Hardware Model



- All applications access hardware resources (i.e. memory, i/o) through system calls to operating system (privileged instructions)
- Advantages
  - Design is decoupled (i.e. OS people can develop OS separate of Hardware people developing hardware)
  - Hardware and software can be upgraded without notifying the Application programs

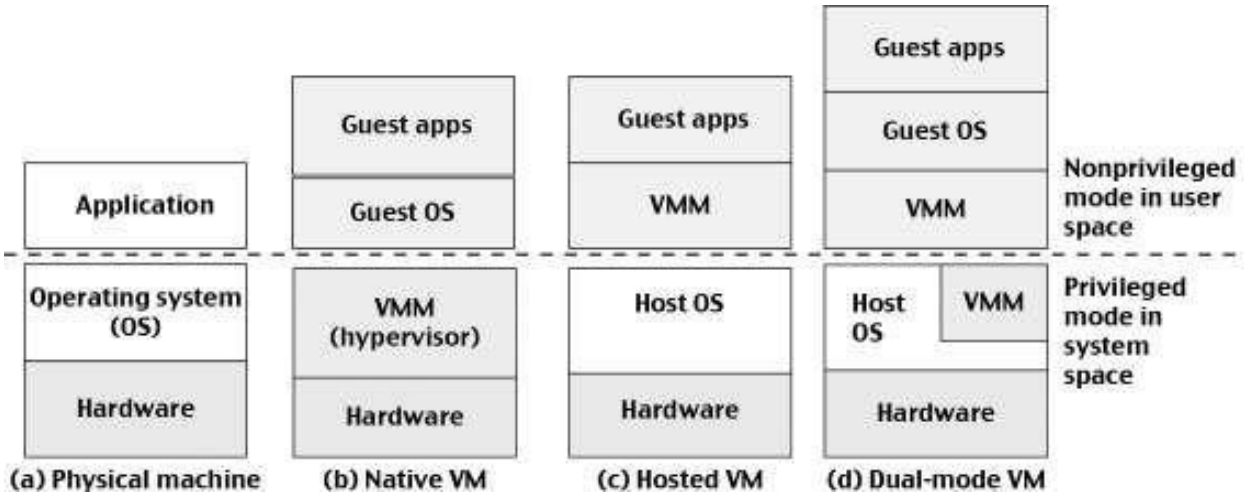
- Disadvantage
  - Application compiled on one ISA will not run on another ISA.
    - Applications compiled for Mac use different operating system calls then application designed for windows.
  - ISA's must support old software
    - Can often be inhibiting in terms of performance
  - Since software is developed separately from hardware… Software is not necessarily optimized for hardware.

Virtual Machine Basics



- Virtual software placed between underlying machine and conventional software
  - Conventional software sees different ISA from the one supported by the hardware
- Virtualization process involves:
  - Mapping of virtual resources (registers and memory) to real hardware resources
  - Using real machine instructions to carry out the actions specified by the virtual machine instructions

Three VM Architectures

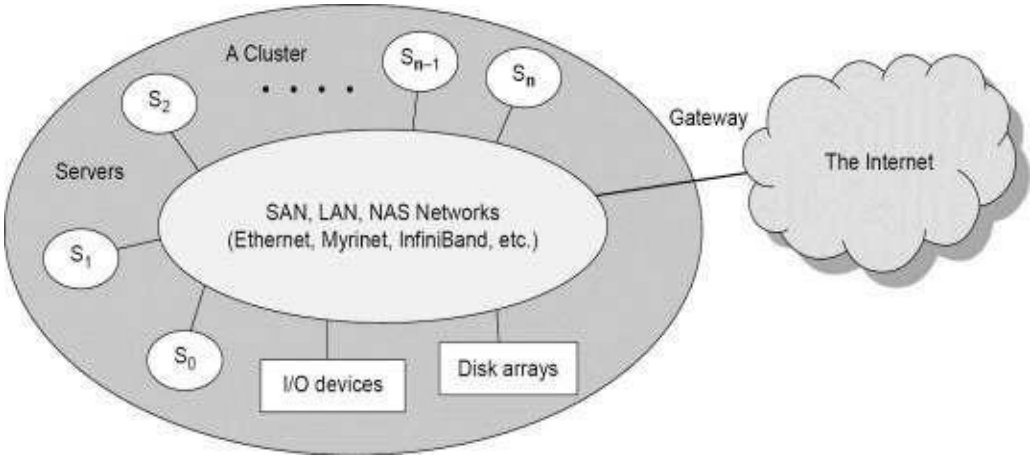


System Models for Distributed and Cloud Computing

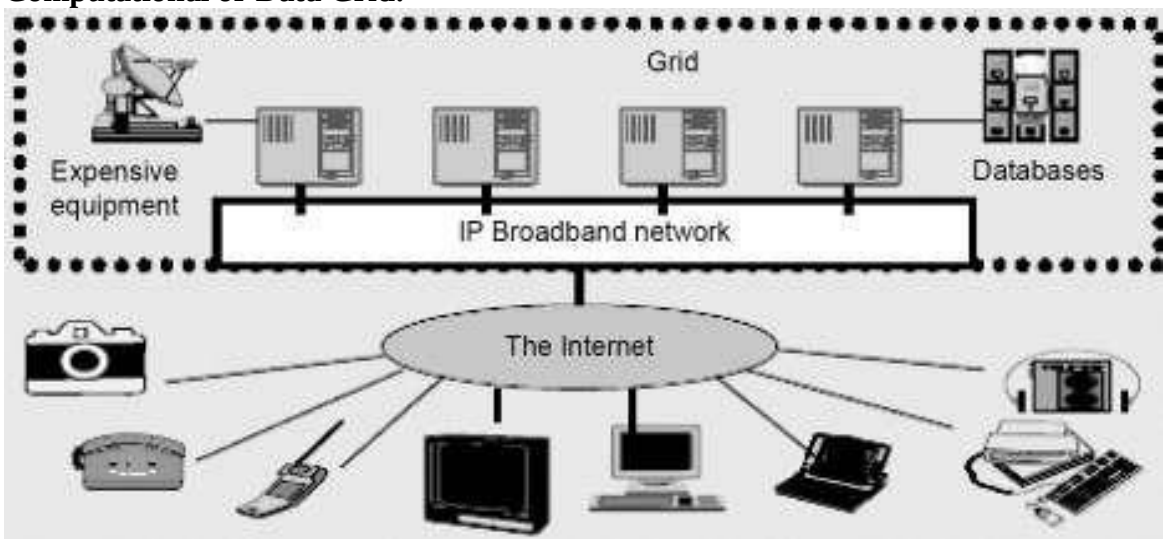
Table 1.2 Classification of Distributed Parallel Computing Systems

Functionality, Applications	Multicomputer Clusters [27, 33]	Peer-to-Peer Networks [40]	Data/Computational Grids [6, 42]	Cloud Platforms [1, 9, 12, 17, 29]
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 datacenters via service-level agreement
Control and Resources Management	Homogeneous nodes with distributed control, running Unix or Linux	Autonomous client nodes, free in and out, with distributed self-organization	Centralized control, server oriented with authenticated security, and static resources	Dynamic resource provisioning of servers, storage, and networks over massive datasets
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 super-computing, global problem solving, and datacenter 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, and .NET	TeraGrid, GriPhyN, UK EGEE, D-Grid, ChinaGrid, etc.	Google App Engine, IBM Bluecloud, Amazon Web Service(AWS), and Microsoft Azure,

Clusters of cooperative computersA
Typical Cluster Architecture

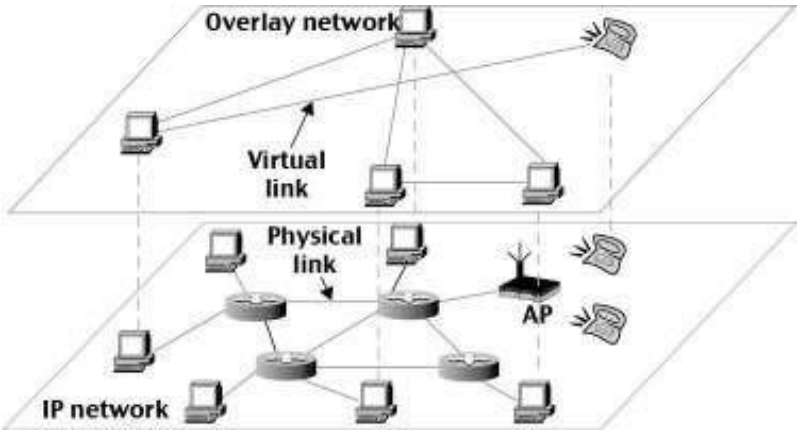


Computational or Data Grid:



Peer-to-Peer (P2P) Network

- A distributed system architecture
- Each computer in the network can act as a client or server for other network computers.
- No centralized control
- Typically many nodes, but unreliable and heterogeneous
- Nodes are symmetric in function
- Take advantage of distributed, shared resources (bandwidth, CPU, storage) on peer-nodes
- Fault-tolerant, self-organizing
- Operate in dynamic environment, frequent join and leave is the norm



Overlay network - computer network built on top of another network.

- Nodes in the overlay can be thought of as being connected by virtual or logical links, each of which corresponds to a path, perhaps through many physical links, in the underlying network.
- For example, distributed systems such as cloud computing, peer-to-peer networks, and client-server applications are overlay networks because their nodes run on top of the Internet.

Grid computing Infrastructures

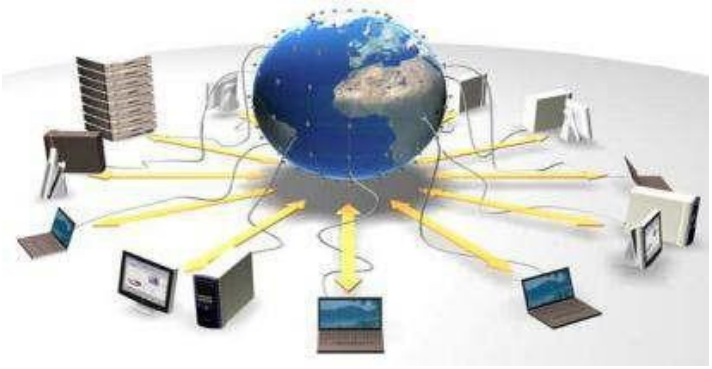
Grid Computing is based on the concept of information and electricity sharing, which allowing us to access to another type of heterogeneous and geographically separated resources.

Grid gives the sharing of:

1. Storage elements
2. Computational resources
3. Equipment
4. Specific applications
5. Other

Thus, Grid is based on:

- Internet protocols.
- Ideas of parallel and distributed computing.



A Grid is a system that,

1) Coordinates resources that may not subject to a centralized control.
2) Using standard, open, general-purpose protocols and interfaces.
3) To deliver nontrivial qualities of services.

Flexible, secure, coordinated resource sharing among individuals and institutions.

Enable communities (virtual organizations) to share geographically distributed resources in order to achieve a common goal.

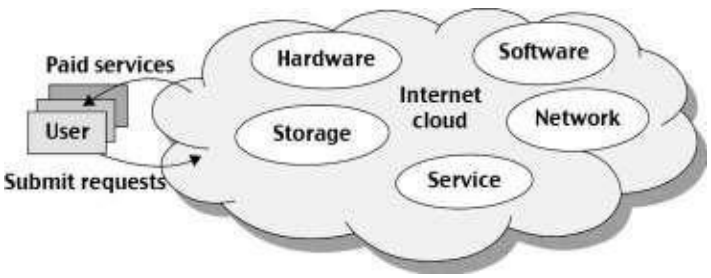
In applications which can't be solved by resources of an only institution or the results can be achieved faster and/or cheaper.

The Cloud

- Historical roots in today's Internet apps
    - Search, email, social networks
    - File storage (Live Mesh, Mobile Me, Flicker, …)
- A cloud infrastructure provides a framework to manage scalable, reliable, on-demand access to applications
- A cloud is the "invisible" backend to many of our mobile applications
- A model of computation and data storage based on "pay as you go" access to "unlimited" remote data center capabilities

Basic Concept of Internet Clouds

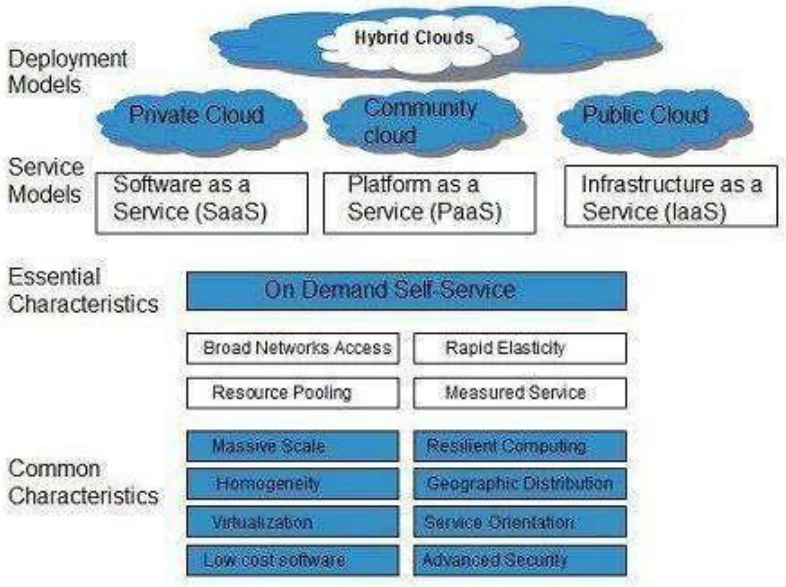
- Cloud computing is the use of computing resources (hardware and software) that are delivered as a service over a network (typically the Internet).
- The name comes from the use of a cloud-shaped symbol as an abstraction for the complex infrastructure it contains in system diagrams.
- Cloud computing entrusts remote services with a user's data, software and computation.



Cloud computing supports platform independency, as the software is not required to be installed locally on the PC. Hence, the Cloud Computing is making our business applications mobile and collaborative.

Characteristics of Cloud Computing

There are four key characteristics of cloud computing. They are shown in the following diagram:



On Demand Self Service

Cloud Computing allows the users to use web services and resources on demand. One can logon to a website at any time and use them.

Broad Network Access

Since cloud computing is completely web based, it can be accessed from anywhere and at any time.

Resource Pooling

Cloud computing allows multiple tenants to share a pool of resources. One can share single physical instance of hardware, database and basic infrastructure.

Rapid Elasticity

It is very easy to scale the resources vertically or horizontally at any time. Scaling of resources means the ability of resources to deal with increasing or decreasing demand.
The resources being used by customers at any given point of time are automatically monitored.

Measured Service

In this service cloud provider controls and monitors all the aspects of cloud service. Resource optimization, billing capacity planning etc. depend on it.

Benefits

1. One can access applications as utilities, over the Internet.
2. One can manipulate and configure the applications online at any time.
3. It does not require to install a software to access or manipulate cloud application.
4. Cloud Computing offers online development and deployment tools, programming runtime environment through PaaS model.
5. Cloud resources are available over the network in a manner that provide platform independent access to any type of clients.

6. Cloud Computing offers on-demand self-service. The resources can be used without interaction with cloud service provider**.**

Disadvantages of cloud computing

• Requires a high-speed internet connection
• Security and confidentiality of data
• Not solved yet the execution of HPC apps in cloud computing Interoperability between cloud based systems

Cloud Service Models

Infrastructure as a service (IaaS)

- Most basic cloud service model
- Cloud providers offer computers, as physical or more often as virtual machines, and other resources.
- Virtual machines are run as guests by a hypervisor, such as Xen or KVM.
- Cloud users deploy their applications by then installing operating system images on the machines as well as their application software.
- Cloud providers typically bill IaaS services on a utility computing basis, that is, cost will reflect the amount of resources allocated and consumed.
- Examples of IaaS include: Amazon Cloud Formation (and underlying services such as Amazon EC2), Rackspace Cloud, Terre mark, and Google Compute Engine.

Platform as a service (PaaS)

- Cloud providers deliver a computing platform typically including operating system, programming language execution environment, database, and web server.
- Application developers develop and run their software on a cloud platform without the cost and complexity of buying and managing the underlying hardware and software layers.
- Examples of PaaS include: Amazon Elastic Beanstalk, Cloud Foundry, Heroku, Force.com, Engine Yard, Mendix, Google App Engine, Microsoft Azure and OrangeScape.

Software as a service (SaaS)

- Cloud providers install and operate application software in the cloud and cloud users access the software from cloud clients.
- The pricing model for SaaS applications is typically a monthly or yearly flat fee per user, so price is scalable and adjustable if users are added or removed at any point.
- Examples of SaaS include: Google Apps, innkeypos, QuickBooks Online, Limelight Video Platform, Salesforce.com, and Microsoft Office 365.

Service-oriented architecture (SOA)

- SOA is an evolution of distributed computing based on the request/reply design paradigm for synchronous and asynchronous applications.
- An application's business logic or individual functions are modularized and presented as services for consumer/client applications.

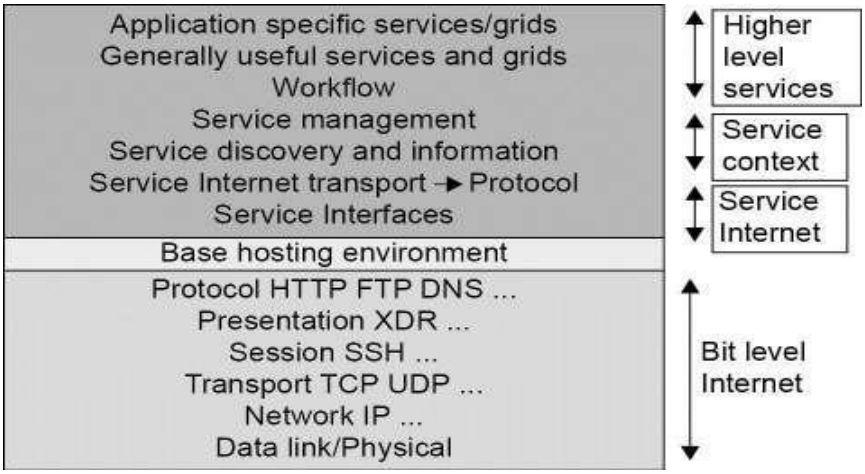
- Key to these services - their loosely coupled nature;
  - i.e., the service interface is independent of the implementation.
- Application developers or system integrators can build applications by composing one or more services without knowing the services' underlying implementations.

For example, a service can be implemented either in .Net or J2EE, and the application consuming the service can be on a different platform or language

SOA key characteristics:

- SOA services have self-describing interfaces in platform-independent XML documents.
  - Web Services Description Language (WSDL) is the standard used to describe the services.
- SOA services communicate with messages formally defined via XML Schema (also called XSD).
  - Communication among consumers and providers or services typically happens in heterogeneous environments, with little or no knowledge about the provider.
  - Messages between services can be viewed as key business documents processed in an enterprise.
- SOA services are maintained in the enterprise by a registry that acts as a directory listing.
  - Applications can look up the services in the registry and invoke the service.
  - Universal Description, Definition, and Integration (UDDI) is the standard used for service registry.
- Each SOA service has a quality of service (QoS) associated with it.
  - Some of the key QoS elements are security requirements, such as authentication and authorization, reliable messaging, and policies regarding who can invoke services.

Layered Architecture for Web Services



Introduction to Grid Architecture and Standards

- **Grid computing** is a form of distributed computing whereby a "super and virtual computer" is composed of a cluster of networked, loosely coupled computers, acting in concert to perform very large tasks.
- Grid computing (Foster and Kesselman, 1999) is a growing technology that facilitates the executions of large-scale resource intensive applications on geographically distributed computing resources.
- Facilitates flexible, secure, coordinated large scale resource sharing among dynamic collections of individuals, institutions, and resource
- Enable communities ("virtual organizations") to share geographically distributed resources as they pursue common goals

Criteria for a Grid:

- Coordinates resources that are not subject to centralized control.
- Uses standard, open, general-purpose protocols and interfaces.
- Delivers nontrivial qualities of service.

Benefits

- Exploit Underutilized resources
- Resource load Balancing
- Virtualize resources across an enterprise
  - Data Grids, Compute Grids
- Enable collaboration for virtual organizations

Grid Applications

Data and computationally intensive applications:

This technology has been applied to computationally-intensive scientific, mathematical, and academic problems like drug discovery, economic forecasting, seismic analysis back office data processing in support of e-commerce

- A chemist may utilize hundreds of processors to screen thousands of compounds per hour.
- Teams of engineers worldwide pool resources to analyze terabytes of structural data.
- Meteorologists seek to visualize and analyze petabytes of climate data with enormous computational demands.

Resource sharing

- Computers, storage, sensors, networks, …
- Sharing always conditional: issues of trust, policy, negotiation, payment, …

Coordinated problem solving

- Distributed data analysis, computation, collaboration…

Elements of Grid Computing

- Resource sharing
  - Computers, data, storage, sensors, networks, …
  - Sharing always conditional: issues of trust, policy, negotiation, payment, …
- Coordinated problem solving
  - Beyond client-server: distributed data analysis, computation, collaboration, …
- Dynamic, multi-institutional virtual organizations
  - Community overlays on classic org structures
  - Large or small, static or dynamic

Grid Topologies

• Intragrid
  – Local grid within an organization
  – Trust based on personal contracts
• Extragrid
  – Resources of a consortium of organizations
    Connected through a (Virtual) Private Network
  – Trust based on Business to Business contracts
• Intergrid
  – Global sharing of resources through the internet
  – Trust based on certification

Computational Grid

"A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities."

Example: Science Grid (US Department of Energy)

Data Grid

- A **data grid** is a grid computing system that deals with data — the **controlled sharing and management of large amounts of distributed data**.
- Data Grid is the storage component of a grid environment. Scientific and engineering applications require access to large amounts of data, and often this data is widely distributed. A data grid provides seamless access to the local or remote data required to complete compute intensive calculations.

Example:
Biomedical informatics Research Network (BIRN),
The Southern California earthquake Center (SCEC)

Methods of Grid Computing

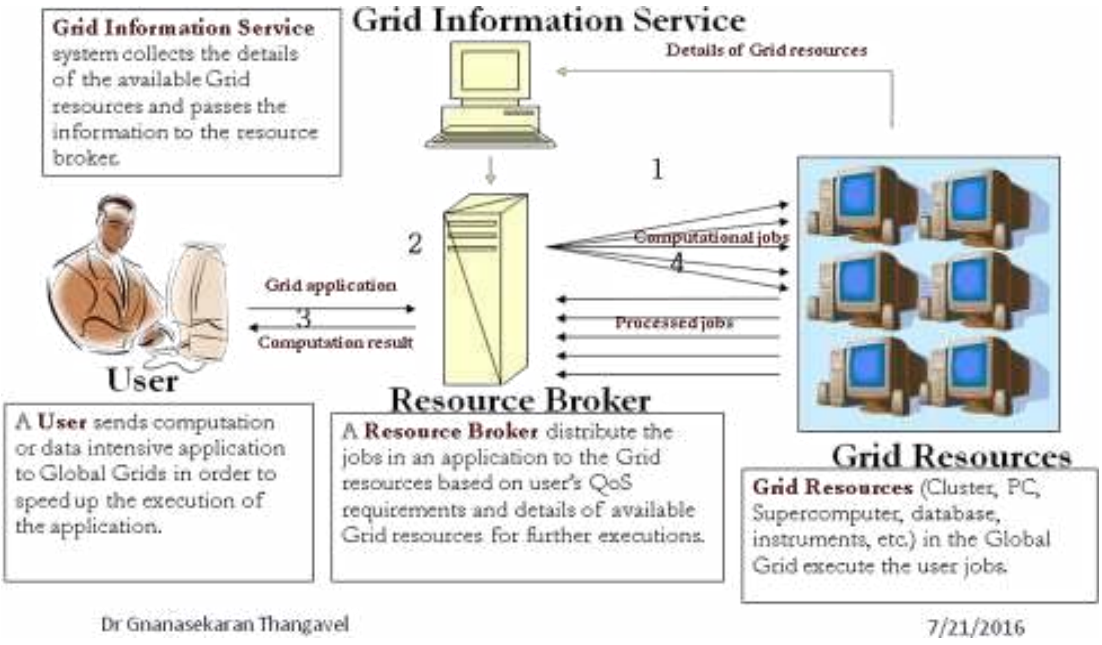
- Distributed Supercomputing
- High-Throughput Computing
- On-Demand Computing
- Data-Intensive Computing
- Collaborative Computing
- Logistical Networking

Grid Standards and Middleware

Table 1.9 Grid Standards and Toolkits for scientific and Engineering Applications

Grid Standards	Major Grid Service Functionalities	Key Features and Security Infrastructure
OGSA Standard	Open Grid Service Architecture offers common grid service standards for general public use	Support heterogeneous distributed environment, bridging CA, multiple trusted intermediaries, dynamic policies, multiple security mechanisms, etc.
Globus Toolkits	Resource allocation, Globus security infrastructure (GSI), and generic security service API	Sign-in multi-site authentication with PKI, Kerberos, SSL, Proxy, delegation, and GSS API for message integrity and confidentiality
IBM Grid Toolbox	AIX and Linux grids built on top of Globus Toolkit, autonomic computing, Replica services	Using simple CA, granting access, grid service (ReGS), supporting Grid application for Java (GAF4J), GridMap in IntraGrid for security update.

A typical view of Grid environment



- Grids are typically managed by grid ware - a special type of middleware that enable sharing and manage grid components based on user requirements and resource attributes (e.g., capacity, performance)

- Software that connects other software components or applications to provide the following functions:

  - Run applications on suitable available resources

– Brokering, Scheduling

  - Provide uniform, high-level access to resources

– Semantic interfaces
– Web Services, Service Oriented Architectures

  - Address inter-domain issues of security, policy, etc.

-Monitoring and control

Middleware

- Globus –chicago Univ
- Condor – Wisconsin Univ – High throughput computing
- Legion – Virginia Univ – virtual workspaces- collaborative computing
- IBP – Internet back pane – Tennesse Univ – logistical networking
- NetSolve – solving scientific problems in heterogeneous env – high throughput & data intensive

Grid Architecture

The Hourglass Model

- Focus on architecture issues
  - Propose set of core services as basic infrastructure
  - Used to construct high-level, domain-specific solutions (diverse)
- Design principles
  - Keep participation cost low
  - Enable local control
  - Support for adaptation
  - "IP hourglass" model

An Overview of Grid Architecture

The Computing Element (CE) is a set of gLite services that provide access for Grid jobs to a local resource management system (LRMS, batch system) running on a computer farm, or possibly to computing resources local to the CE host. Typically the CE provides access to a set of job queues within the LRMS.

Utilization Period

Booking Conditions

No particular booking is required to use this service. However, the user MUST have a valid grid certificate of an accepted Certificate Authority and MUST be member of a valid Virtual Organization (VO).

The service is initiated by respective commands that can be submitted from any gLite User Interface either interactively or through batch submission.

To run a job on the cluster the user must install an own or at least have access to a gLite User Interface. Certificates can be requested for example at the German Grid Certificate Authority.

Deregistration

No particular deregistration is required for this service. A user with an expired Grid certificate or VO membership is automatically blocked from accessing the CE.

IT-Security

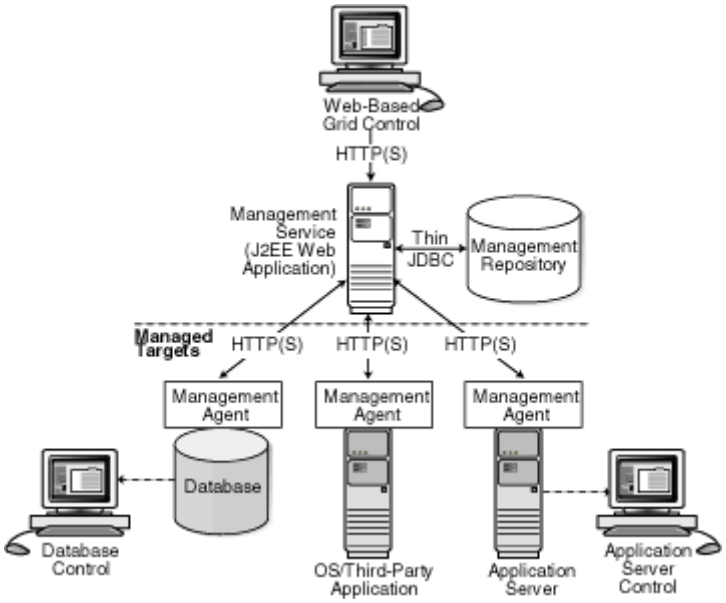
The database and log files of the CEs contain information on the status and results of the jobs and the certificate that was used to initiate the task.

The required data files themselves are stored on the worker nodes or in the Grid Storage Elements (SEs). No other personal data is stored.

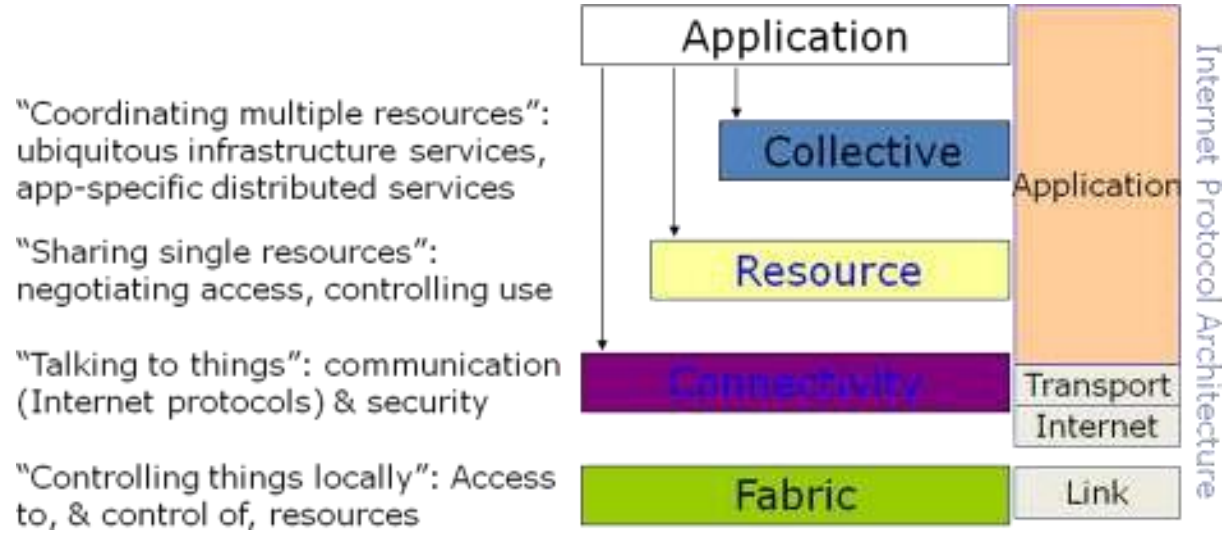
Technical requirements

To run a job at the Grid cluster of the Steinbuch Centre for Computing (SCC) the user needs:

1. A valid Grid user certificate.
2. Membership in a Virtual Organization (VO).
3. An own or at least access to a User Interface.



Layered Grid Architecture



Data Grid Architecture

App	Discipline-Specific Data Grid Application
Collective (App)	Coherency control, replica selection, task management, virtual data catalog, virtual data code catalog, …
Collective (Generic)	Replica catalog, replica management, co-allocation, certificate authorities, metadata catalogs,
Resource	Access to data, access to computers, access to network performance data, …
Connect	Communication, service discovery (DNS), authentication, authorization, delegation
Fabric	Storage systems, clusters, networks, network caches, …

Simulation tools

- GridSim – job scheduling
- SimGrid – single client multiserver scheduling
- Bricks – scheduling
- GangSim- Ganglia VO
- OptoSim – Data Grid Simulations
- G3S – Grid Security services Simulator – security services

UNIT-II
GRID SERVICES

Introduction to Open Grid Services Architecture (OGSA)

OGSA defines what Grid services are, what they should be capable of, what type of technologies they should be based on. OGSA does not give a technical and detailed specification. It uses WSDL

- It is a formal and technical specification of the concepts described in OGSA.
- The Globus Toolkit 3 is an implementation of OGSI.

The OGSA is an open source grid service standard jointly developed by academia and the IT industry under coordination of a working group in the Global Grid Forum (GGF). The standard was specifically developed for the emerging grid and cloud service communities. The OGSA is extended from web service concepts and technologies. The standard defines a common framework that allows businesses to build grid platforms across enterprises and business partners. The intent is to define the standards required for both open source and commercial software to support a global grid infrastructure

OGSA Framework

The OGSA was built on two basic software technologies: the Globus Toolkit widely adopted as a grid technology solution for scientific and technical computing, and web services (WS 2.0) as a popular standards-based framework for business and network applications. The OGSA is intended to support the creation, termination, management, and invocation of stateful, transient grid services via standard interfaces and conventions

OGSA Interfaces

The OGSA is centered on grid services. These services demand special well-defined application interfaces.

These interfaces provide resource discovery, dynamic service creation, lifetime management, notification, and manageability. These properties have significant implications regarding how a grid service is named, discovered, and managed

Port Type	Operation	Brief Description
Grid service	Find service data	Query a grid service instance, including the handle, reference, primary key, home handle map, interface information, and service-specific information. Extensible support for various query languages.
	Termination time	Set (and get) termination time for grid service instance.
	Destroy	Terminate grid service instance.
Notification source	Subscribe to notification topic	Subscribe to notifications of service events. Allow delivery via third-party messaging services.
Notification sink	Deliver notification	Carry out asynchronous delivery of notification messages.
Registry	Register service	Conduct soft-state registration of Grid Service Handles (GSHs).
	Unregister service	Unregister a GSH.
Factory	Create service	Create a new grid service instance.
Handle map	Find by handle	Return the Grid Service Reference (GSR) associated with the GSH.

Grid Service Handle

A GSH is a globally unique name that distinguishes a specific grid service instance from all others. The status of a grid service instance could be that it exists now or that it will exist in the future.

These instances carry no protocol or instance-specific addresses or supported protocol bindings. Instead, these information items are encapsulated along with all other instance-specific information. In order to interact with a specific service instance, a single abstraction is defined as a GSR.

Grid Service Migration

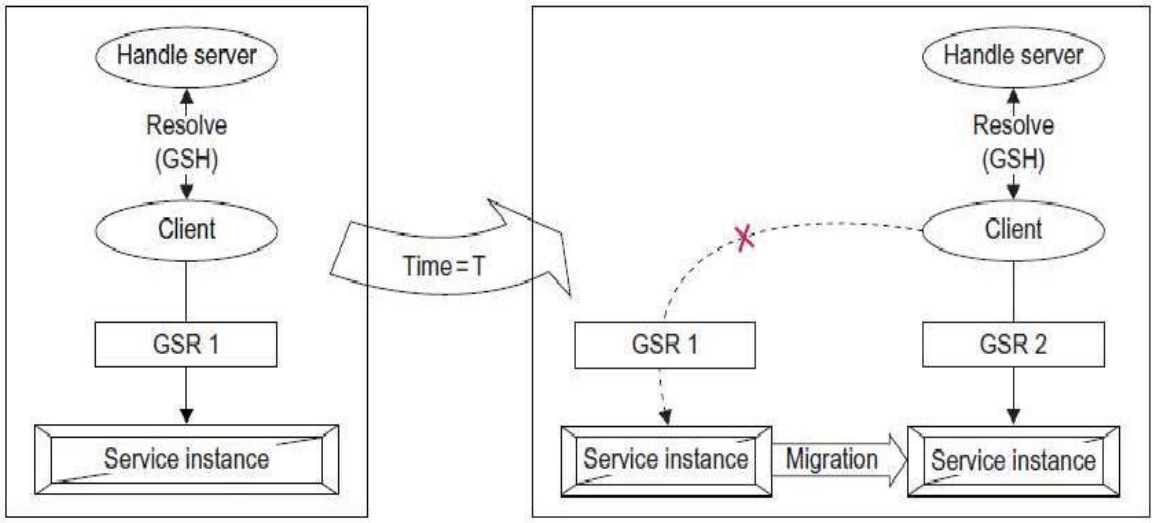
This is a mechanism for creating new services and specifying assertions regarding the lifetime of a service. The OGSA model defines a standard interface, known as a factor, to implement this reference. This creates a requested grid service with a specified interface and returns the GSH and initial GSR for the new service instance.

If the time period expires without having received a reaffirmed interest from a client, the service instance can be terminated on its own and release the associated resources accordingly

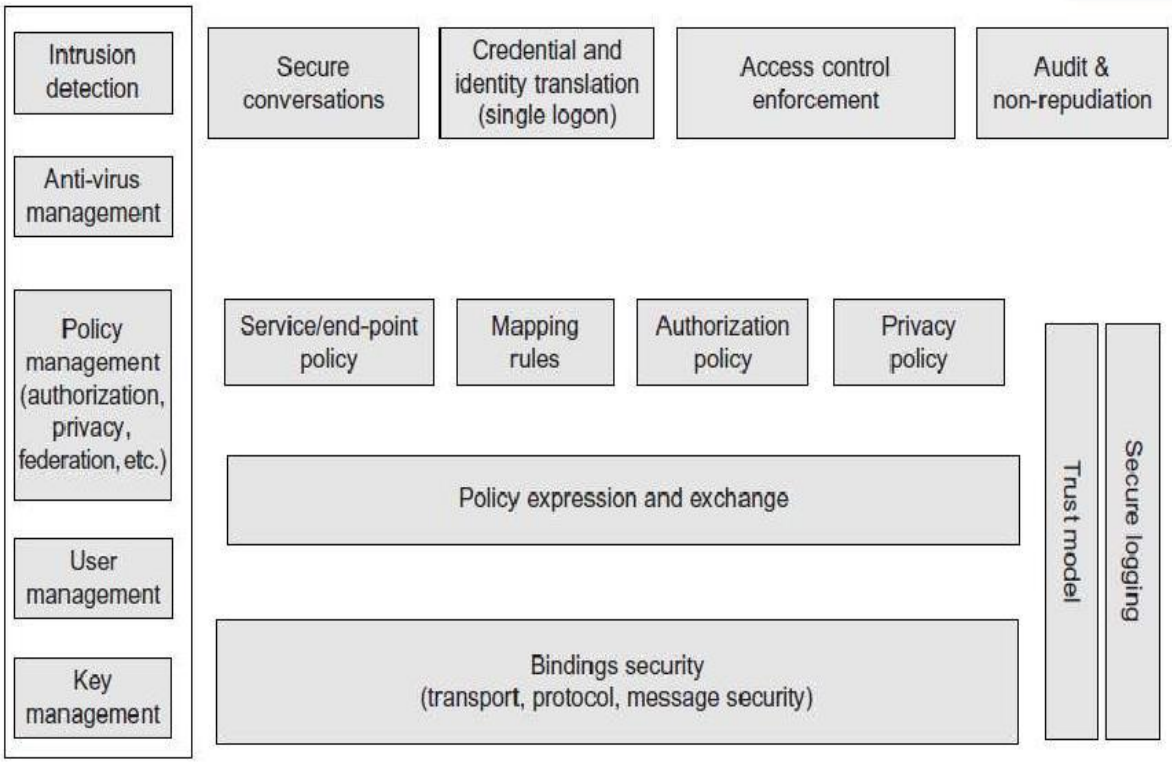
OGSA Security Models

The grid works in a heterogeneous distributed environment, which is essentially open to the general public. We must be able to detect intrusions or stop viruses from spreading by implementing secure conversations, single logon, access control, and auditing for nonrepudiation.

At the security policy and user levels, we want to apply a service or endpoint policy, resource mapping rules, authorized access of critical resources, and privacy protection. At the Public Key Infrastructure (PKI) service level, the OGSA demands security binding with the security protocol stack and bridging of certificate authorities (CAs), use of multiple trusted intermediaries, and so on.



A GSH resolving to a different GSR for a migrated service instance before (shown on the left) and after (on the right) the migration at time T.



The OGSA security model implemented at various protection levels.

Motivation

Grid Evolution: Open Grid Services Architecture

Four largely orthogonal goals

1)Refactor Globus protocol suite to enable common base and expose key capabilities

2) Extend for new technical requirements

3) Service orientation to virtualize resources and unify resources/services/information

4) Embrace key Web services technologies for standard IDL, leverage commercial efforts

Result

Standard interfaces & behaviors for building distributed systems: the Grid service

Refactor Globus Protocol Suite

Extract, generalize, allow modular use of protocols and mechanisms for

- Reliable invocation
- Service description & information access
- Notification
- Policy management
- Lifetime management
- Service naming
- Authentication

Designed in an integrated, uniform fashion and Extend into New Areas

Extend core protocol suite to address

- Manageability
- Concurrency control
- Others

Service Orientation

Define all entities by interface & behavior, so that Resources and programs are treated in the same manner & accessed in the same way Virtualization easy to achieve: e.g. "compute service" may be computer or network

Embrace Standards:

Two Distinct (But Interrelated) Issues

Standard means of defining, discovering, and invoking interfaces

Addressed by Web services

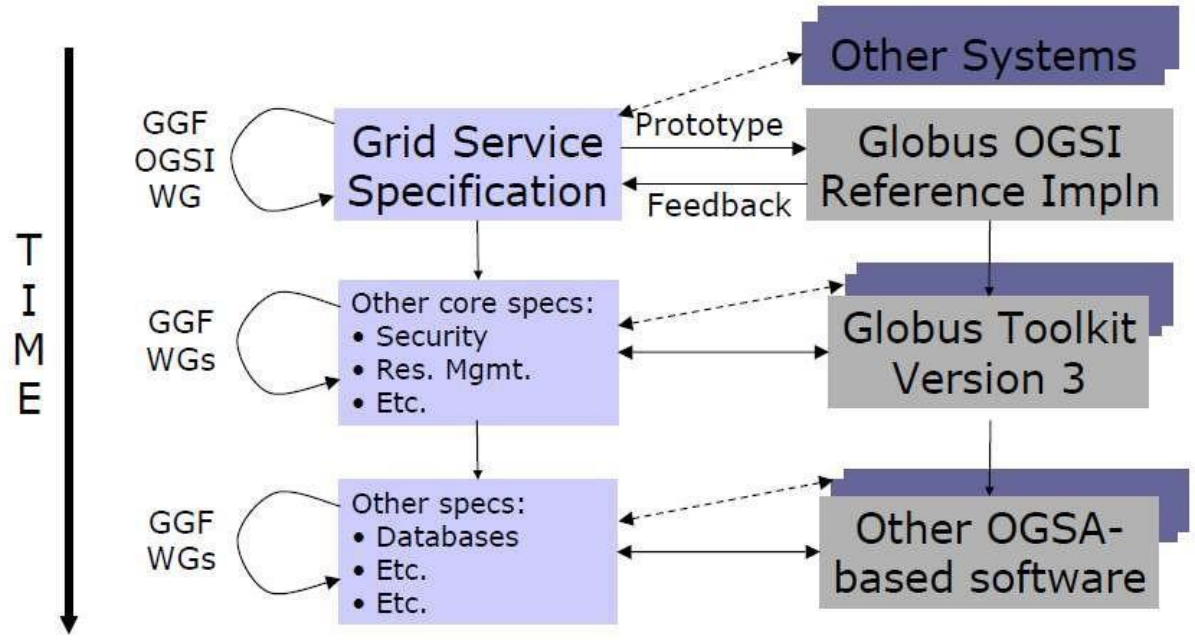
Standard means of customizing computer systems to application requirements

Addressed by hosting environments: J2EE, .NET, ...

OGSA System Structure

A standard substrate: the Grid service Standard interfaces and behaviors that address key distributed system issues.

- The "Grid Service Specification"
- supports standard service specifications
- Resource management, databases, workflow, security, diagnostics, etc., etc.
- Target of current & planned GGF efforts
- Arbitrary application-specific services based on these & other definitions



Functionality requirements and System Properties Requirements

Basic functionality requirements

Discovery and brokering. Mechanisms are required for discovering and/or allocating services, data, and resources with desired properties. For example, clients need to discover network services before they are used, service brokers need to discover hardware and software availability, and service brokers must identify codes and platforms suitable for execution requested by the client

Metering and accounting. Applications and schemas for metering, auditing, and billing for IT infrastructure and management use cases. The metering function records the usage and duration, especially metering the usage of licenses. The auditing function audits usage and application profiles on machines, and the billing function bills the user based on metering.

Data sharing. Data sharing and data management are common as well as important grid applications. chanisms are required for accessing and managing data archives, for caching data and managing its consistency, and for indexing and discovering data and metadata.

Deployment. Data is deployed to the hosting environment that will execute the job (or made available in or via a high-performance infrastructure). Also, applications (executable) are migrated to the computer that will execute them

Virtual organizations (VOs). The need to support collaborative VOs introduces a need for mechanisms to support VO creation and management, including group membership services [58]. For the commercial data center use case [55], the grid creates a VO in a data center that provides IT resources to the job upon the customer's job request.

Monitoring. A global, cross-organizational view of resources and assets for project and fiscal planning, troubleshooting, and other purposes. The users want to monitor their applications running on the grid. Also, the resource or service owners need to surface certain states so that the user of those resources or services may manage the usage using the state information

Policy. An error and event policy guides self-controlling management, including failover and provisioning. It is important to be able to represent policy at multiple stages in hierarchical systems, with the goal of automating the enforcement of policies that might otherwise be implemented as organizational processes or managed manually

System Properties Requirements

Fault tolerance. Support is required for failover, load redistribution, and other techniques used to achieve fault tolerance. Fault tolerance is particularly important for long running queries that can potentially return large amounts of data, for dynamic scientific applications, and for commercial data center applications.

Disaster recovery. Disaster recovery is a critical capability for complex distributed grid infrastructures. For distributed systems, failure must be considered one of the natural behaviors and disaster recovery mechanisms must be considered an essential component of the design.

Self-healing capabilities of resources, services and systems are required. Significant manual effort should not be required to monitor, diagnose, and repair faults.

Legacy application management. Legacy applications are those that cannot be changed, but they are too valuable to give up or to complex to rewrite. Grid infrastructure has to be built around them so that they can continue to be used

Administration. Be able to ―codify‖ and ―automate‖ the normal practices used to administer the environment. The goal is that systems should be able to self-organize and self-describe to manage low-level configuration details based on higher-level configurations and management policies specified by administrators.

Agreement-based interaction. Some initiatives require agreement-based interactions capable of specifying and enacting agreements between clients and servers (not necessarily human) and then composing those agreements into higher-level end-user structures

Grouping/aggregation of services. The ability to instantiate (compose) services using some set of existing services is a key requirement. There are two main types of composition techniques: selection and aggregation. Selection involves choosing to use a particular service among many services with the same operational interface.

Security requirements

Grids also introduce a rich set of security requirements; some of these requirements are:

Multiple security infrastructures. Distributed operation implies a need to interoperate with and manage multiple security infrastructures. For example, for a commercial data center application, isolation of customers in the same commercial data center is a crucial requirement; the grid should provide not only access control but also performance isolation.

Perimeter security solutions. Many use cases require applications to be deployed on the other side of firewalls from the intended user clients. Intergrade collaboration often requires crossing institutional firewalls.

Authentication, Authorization, and Accounting. Obtaining application programs and deploying them into a grid system may require authentication/authorization. In the commercial data center use case, the commercial data center authenticates the customer and authorizes the submitted request when the customer submits a job request.

Encryption. The IT infrastructure and management use case requires encrypting of the communications, at least of the payload

Application and Network-Level Firewalls. This is a long-standing problem; it is made particularly difficult by the many different policies one is dealing with and the particularly harsh restrictions at international sites.

Certification. A trusted party certifies that a particular service has certain semantic behavior. For example, a company could establish a policy of only using e-commerce services certified by Yahoo

Resource Management Requirements

Resource management is another multilevel requirement, encompassing SLA negotiation, provisioning, and scheduling for a variety of resource types and activities

Provisioning. Computer processors, applications, licenses, storage, networks, and instruments are all grid resources that require provisioning. OGSA needs a framework that allows resource provisioning to be done in a uniform, consistent manner.

Resource virtualization. Dynamic provisioning implies a need for resource virtualization mechanisms that allow resources to be transitioned flexibly to different tasks as required; for example, when bringing more Web servers on line as demand exceeds a threshold..

Optimization of resource usage while meeting cost targets (i.e., dealing with finite resources). Mechanisms to manage conflicting demands from various organizations, groups, projects, and users and implement a fair sharing of resources and access to the grid

Transport management. For applications that require some form of real-time scheduling, it can be important to be able to schedule or provision bandwidth dynamically for data transfers or in support of the other data sharing applications. In many (if not all) commercial applications, reliable transport management is essential to obtain the end-to-end QoS required by the application

Management and monitoring. Support for the management and monitoring of resource usage and the detection of SLA or contract violations by all relevant parties. Also, conflict management is necessary;

Processor scavenging is an important tool that allows an enterprise or VO to use to aggregate computing power that would otherwise go to waste

Scheduling of service tasks. Long recognized as an important capability for any information processing system, scheduling becomes extremely important and difficult for distributed grid systems.

Load balancing. In many applications, it is necessary to make sure make sure deadlines are met or resources are used uniformly. These are both forms of load balancing that must be made possible by the underlying infrastructure.

Advanced reservation. This functionality may be required in order to execute the application on reserved resources.

Notification and messaging. Notification and messaging are critical in most dynamic scientific problems.

Logging. It may be desirable to log processes such as obtaining/deploying application programs because, for example, the information might be used for accounting. This functionality is represented as ―metering and accounting.‖

Workflow management. Many applications can be wrapped in scripts or processes that require licenses and other resources from multiple sources. Applications coordinate using the file system based on events

Pricing. Mechanisms for determining how to render appropriate bills to users of a grid.

Practical and detailed view of OGSA/OGSI

OGSA aims at addressing standardization (for interoperability) by defining the basic framework of a grid application structure. Some of the mechanisms employed in the standards formulation of grid computing

The objectives of OGSA are

Manage resources across distributed heterogeneous platforms

Support QoS-oriented Service Level Agreements (SLAs). The topology of grids is often complex; the interactions between/among grid resources are almost invariably dynamic.

Provide a common base for autonomic management. A grid can contain a plethora of resources, along with an abundance of combinations of resource

MPICH-G2: Grid-enabled message passing (Message Passing Interface)

_ CoG Kits, GridPort: Portal construction, based on N-tier architectures

_ Condor-G: workflow management

_ Legion: object models for grid computing

_ Cactus: Grid-aware numerical solver framework

Portals

- N-tier architectures enabling thin clients, with middle tiers using grid functions
- Thin clients = web browsers
- Middle tier = e.g., Java Server Pages, with Java CoG Kit, GPDK, Grid Port utilities
- Bottom tier = various grid resources
- Numerous applications and projects, e.g.,

- Unicore, Gateway, Discover, Mississippi Computational Web Portal, NPACI Grid

Port, Lattice Portal, Nimrod-G, Cactus, NASA IPG Launchpad, Grid Resource Broker

High-Throughput Computing and Condor

- High-throughput computing
- Processor cycles/day (week, month, year?) under non ideal circumstances
- How many times can I run simulation X in a month using all available machines?
- Condor converts collections of distributive owned workstations and dedicated clusters into a distributed high-throughput computing facility
- Emphasis on policy management and reliability

Object-Based Approaches

- Grid-enabled CORBA
- NASA Lewis, Rutgers, ANL, others
- CORBA wrappers for grid protocols
- Some initial successes
- Legion
- University of Virginia
- Object models for grid components (e.g., ―vault‖ = storage, ―host‖ = computer)

Cactus: Modular, portable framework for parallel, multidimensional simulations
Construct codes by linking

- Small core: management services

Selected modules: Numerical methods, grids and domain decamps, visualization and Steering, etc.

- Custom linking/configuration tools
- Developed for astrophysics, but not astrophysics specific

Table 4.6 Proposed OGSA grid service interfaces*

Port type	Operation	Description
GridService	FindServiceData	Query a variety of information about the grid service instance, including basic introspection information (handle, reference, primary key, home handle map: terms to be defined), richer per-interface information, and service-specific information (e.g., service instances known to a registry). Extensible support for various query languages.
	SetTermination Time	Set (and get) termination time for grid service instance
	Destroy	Terminate grid service instance.
Notification-Source	SubscribeTo-NotificationTopic	Subscribe to notifications of service-related events, based on message type and interest statement. Allows for delivery via third-party messaging services.
Notification-Sink	Deliver Notification	Carry out asynchronous delivery of notification messages.
Registry	RegisterService UnregisterService	Conduct soft-state registration of grid service handles. Deregister a grid service handle.
Factory	CreateService	Create new grid service instance.
Handle Map	FindByHandle	Return grid service reference currently associated

There are two fundamental requirements for describing Web services based on the OGSI
1. The ability to describe interface inheritance—a basic concept with most of the distributed object systems.
2. The ability to describe additional information elements with the interface definitions.

Detailed view of OGSA/OGSI

It provides a more detailed view of OGSI based on the OGSI specification itself. For a more comprehensive description of these concepts, the reader should consult the specification OGSI defines a component model that extends WSDL and XML schema definition to incorporate the concepts of Stateful Web services

- Extension of Web services interfaces
- Asynchronous notification of state change
- References to instances of services
- Collections of service instances
- Service state data that augment the constraint capabilities of XML schema definition

Setting the Context

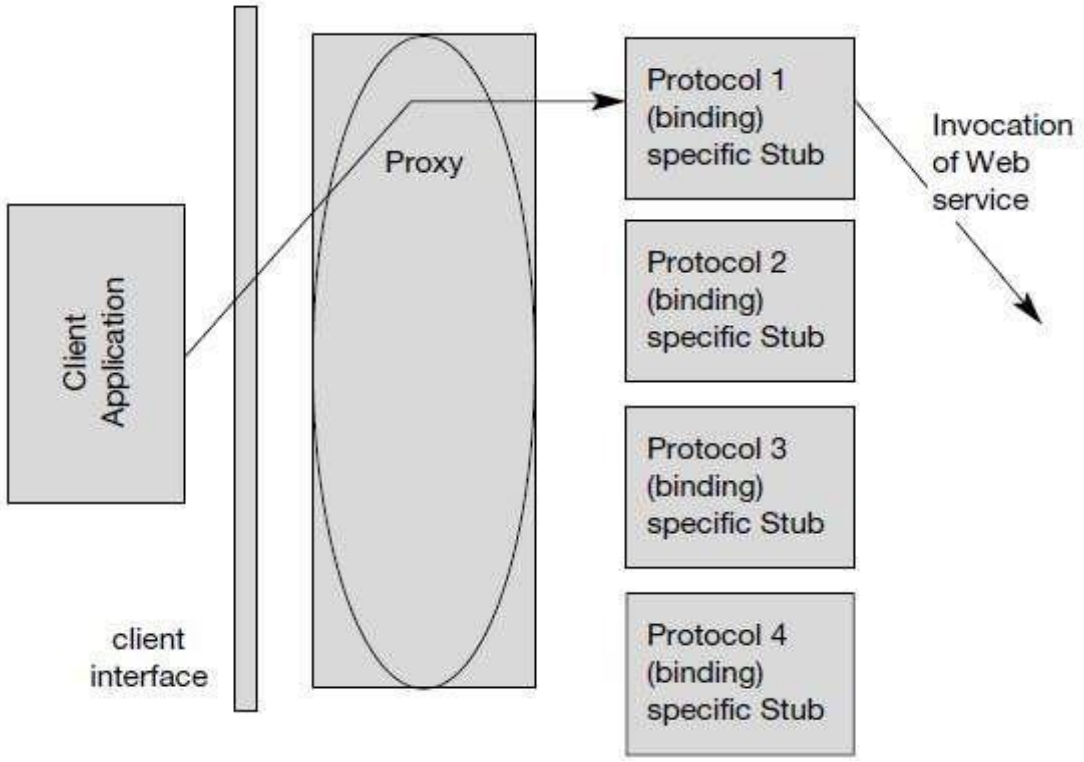
GGF calls OGSI the ―base for OGSA.‖ Specifically, there is a relationship between OGSI and distributed object systems and also a relationship between OGSI and the existing (and evolving) Web services framework

Relationship to Distributed Object Systems

Given grid service implementation is an addressable and potentially stateful instance that implements one or more interfaces described by WSDL port Types. Grid service factories can be used to create instances implementing a given set of port Type(s).

Client-Side Programming Patterns

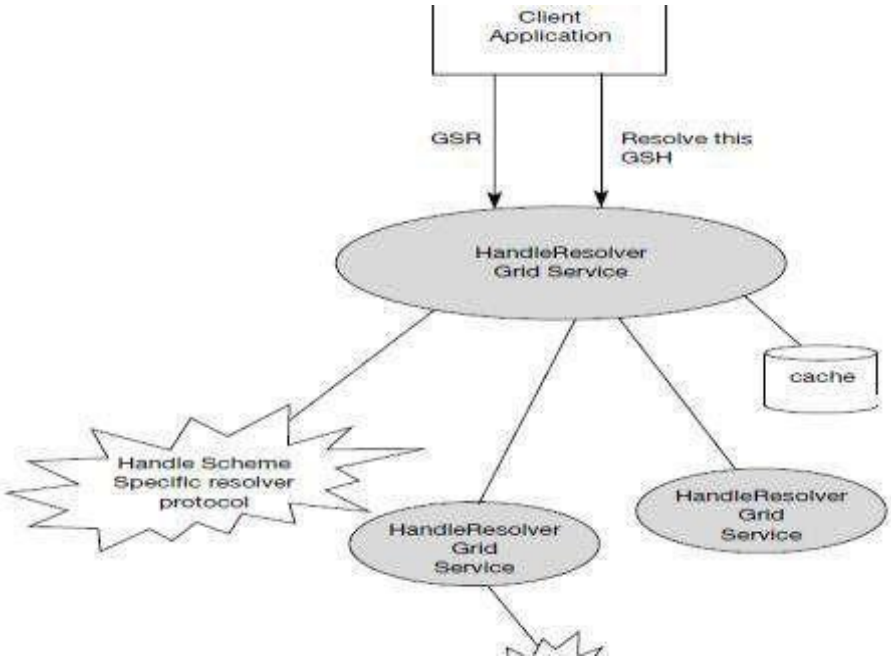
Another important issue is how OGSI interfaces are likely to be invoked from client applications. OGSI exploits an important component of the Web services framework: the use of WSDL to describe multiple protocol bindings, encoding styles, messaging styles (RPC versus document oriented), and so on, for a given Web service.



Possible client-side runtime architecture.

Client Use of Grid Service Handles and References

Client gains access to a grid service instance through grid service handles and grid service references. A grid service handle (GSH) can be thought of as a permanent network pointer to a particular grid service instance.



Resolving a GSH.

Relationship to Hosting Environment

OGSI does not dictate a particular service-provider-side implementation architecture. A variety of approaches are possible, ranging from implementing the grid service instance directly as an operating system process to a sophisticated server-side component model such as J2EE. In the former case, most or even all support for standard grid service behaviors (invocation, lifetime management, registration, etc.)

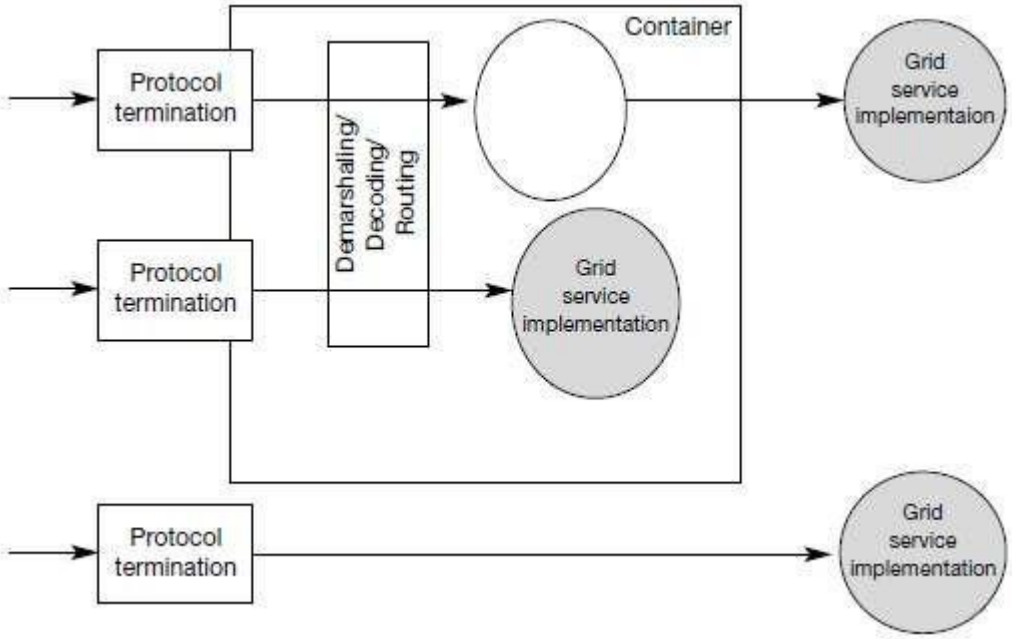


Figure 4.16 Two approaches to the implementation of argument demarshaling functions in a grid service hosting environment.

The Grid Service

The purpose of the OGSI document is to specify the (standardized) interfaces and behaviors that define a grid service

WSDL Extensions and Conventions

OGSI is based on Web services; in particular, it uses WSDL as the mechanism to describe the public interfaces of grid services.

Service Data

The approach to stateful Web services introduced in OGSI identified the need for a common mechanism to expose a service instance's state data to service requestors for query, update, and change notification.

Motivation and Comparison to JavaBean Properties

OGSI specification introduces the service Data concept to provide a flexible, properties- style approach to accessing state data of a Web service. The service Data concept is similar to the notion of a public instance variable or field in object-oriented programming languages such as Java, Smalltalk, and C++.

Extending port Type with service Data

Service Data defines a Newport Type child element named service Data, used to define service Data elements, or SDEs, associated with that port Type. These service Data element definitions are referred to as service Data declarations, or SDDs.

Service Data Values.

Each service instance is associated with a collection of service Data elements: those service Data elements defined within the various port Types that form the service's interface, and also, potentially, additional service

SDE Aggregation within a port Type Interface Hierarchy

WSDL 1.2 has introduced the notion of multiple port Type extension, and one can model that construct within the GWSDL namespace. A port Type can extend zero or more other port Types.

Dynamic service Data Elements

Although many service Data elements are most naturally defined in a service's interface definition, situations can arise in which it is useful to add or move service Data elements dynamically to or from an instance.

Core Grid Service Properties

Service Description and Service Instance

One can distinguish in OGSI between the description of a grid service and an instance of a grid service:

A grid service description describes how a client interacts with service instances.

This description is independent of any particular instance. Within a WSDL document, the grid service description is embodied in the most derived port Type

A grid service description may be simultaneously used by any number of grid service instances, each of which

_ embodies some state with which the service description describes how to interact

_ Has one or more grid service handles

_ Has one or more grid service references to it

Modeling Time in OGSI

The need arises at various points throughout this specification to represent time that is meaningful to multiple parties in the distributed Grid.

The GMT global time standard is assumed for grid services, allowing operations to refer unambiguously to absolute times. However, assuming the GMT time standard to represent time does not imply any particular level of clock synchronization between clients and services in the grid. In fact, no specific accuracy of synchronization is specified or expected by OGSI, as this is a service-quality issue

XML Element Lifetime Declaration Properties

Service Data elements may represent instantaneous observations of the dynamic state of a service instance, it is critical that consumers of service Data be able to understand the valid lifetimes of these observations.

The three lifetime declaration properties are:

1.ogsi:goodFrom. Declares the time from which the content of the element is said to be valid. This is typically the time at which the value was created.

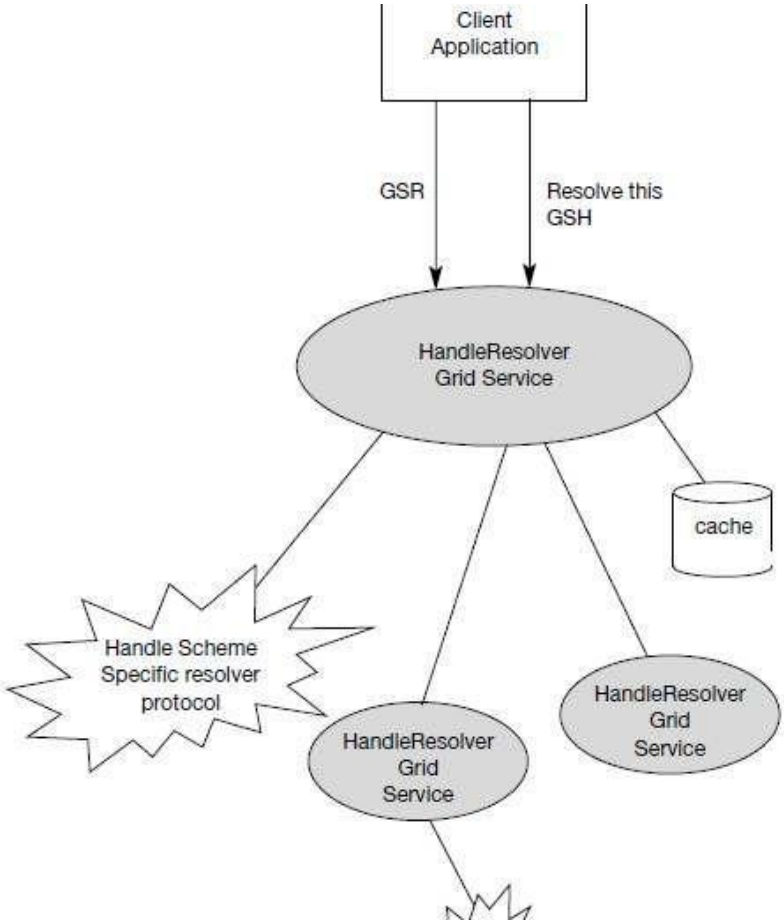
2. ogsi:goodUntil. Declares the time until which the content of the element is said to be valid. This property must be greater than or equal to the good From time

3.ogsi:availableUntil. Declares the time until which this element itself is expected to be available, perhaps with updated values. Prior to this time, a client should be able to obtain an updated copy of this element

b) Grid Service Handles and Grid Service References

Client gains access to a grid service instance through grid service handles and grid service references. A grid service handle (GSH) can be thought of as a permanent network pointer to a particular grid service instance.

The client resolves a GSH into a GSR by invoking a Handle Resolver grid service instance identified by some out-of-band mechanism. The Handle Resolver can use various means to do the resolution.



Data-Intensive Grid Service Models

Applications in the grid are normally grouped into two categories: computation-intensive and data intensive. For data-intensive applications, we may have to deal with massive amounts of data. For example, the data produced annually by a Large Hadron Collider may exceed several petabytes (1015 bytes). The grid system must be specially designed to discover, transfer, and manipulate these massive data sets. Transferring massive data sets is a time-consuming task. Efficient data management demands low-cost storage and high-speed data movement

Data Replication and Unified Namespace

This data access method is also known as caching, which is often applied to enhance data efficiency in a grid environment. By replicating the same data blocks and scattering them in multiple regions of a grid, users can access the same data with locality of references. Replication strategies determine when and where to create a replica of the data. The factors to consider include data demand, network conditions, and transfer cost

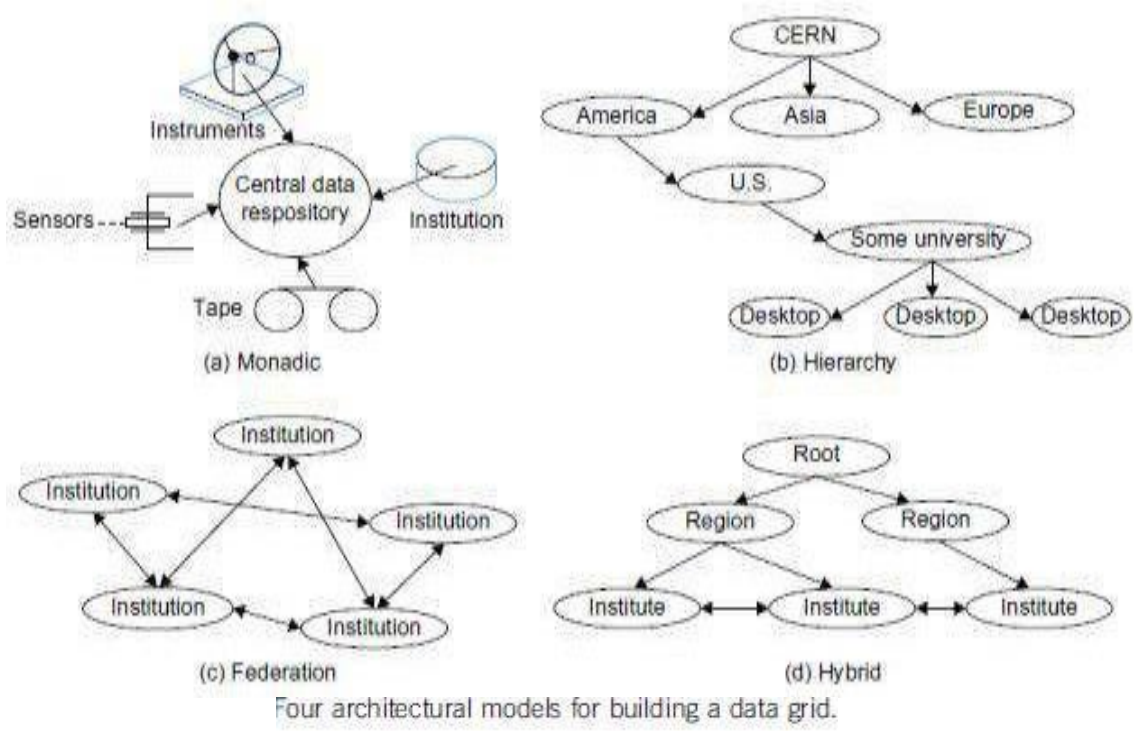
Grid Data Access Models

Multiple participants may want to share the same data collection. To retrieve any piece of data, we need a grid with a unique global namespace. Similarly, we desire to have unique file names. To achieve these, we have to resolve inconsistencies among multiple data objects bearing the same name Monadic model: This is a centralized data repository model, All the data is saved in a central data repository. When users want to access some data they have to submit requests directly to the central repository.

Hierarchical model: The hierarchical model, is suitable for building a large data grid which has only one large data access directory. The data may be transferred from the source to a second-level center.

Federation model: This data access model is better suited for designing a data grid with multiple sources of data supplies. Sometimes this model is also known as a mesh model.

Hybrid model: This data access model. The model combines the best features of the hierarchical and mesh models. Traditional data transfer technology, such as FTP, applies for networks with lower bandwidth.



Four architectural models for building a data grid.

Parallel versus Striped Data Transfers

Compared with traditional FTP data transfer, parallel data transfer opens multiple data streams for passing subdivided segments of a file simultaneously. Although the speed of each stream is the same as in sequential streaming, the total time to move data in all streams can be significantly reduced compared to FTP transfer**.**

OGSA Service

a) Metering Service

Different grid deployments may integrate different services and resources and feature different underlying economic motivations and models; however, regardless of these differences, it is a quasiuniversal requirement that resource utilization can be monitored, whether for purposes of cost allocation (i.e., charge back), capacity and trend analysis, dynamic provisioning, grid-service pricing, fraud and intrusion detection, and/or billing.

A grid service may consume multiple resources and a resource may be shared by multiple service instances. Ultimately, the sharing of underlying resources is managed by middleware and operating systems.

A metering interface provides access to a standard description of such aggregated data (metering service Data). A key parameter is the time window over which measurements are aggregated. In commercial UNIX systems, measurements are aggregated at administrator-defined intervals (chronological entry), usually daily, primarily for the purpose of accounting. Several use cases require metering systems that support multitier, end-to-end flows involving multiple services. An OGSA metering service must be able to meter the resource consumption of configurable classes of these types of flows executing on widely distributed, loosely coupled server, storage, and network resources. Configurable classes should support, for example, a departmental charge-back scenario where incoming requests and their subsequent flows are partitioned into account classes determined by the department providing the service.

b) Service Groups and Discovery Services

GSHs and GSRs together realize a two-level naming scheme, with Handle Resolver services mapping from handles to references; however, GSHs are not intended to contain semantic information and indeed may be viewed for most purposes as opaque. Thus, other entities (both humans and applications) need other means for

Discovering services with particular properties, whether relating to interface, function, availability, location, policy

Attribute naming schemes associate various metadata with services and support retrieval via queries on attribute values. A registry implementing such a scheme allows service providers to publish the existence and properties of the services that they provide, so that service consumers can discover them

A Service Group is a collection of entries, where each entry is a grid service implementing the service Group Entry interface. The Service Group interface also extends the Grid Service interface

It is also envisioned that many registries will inherit and implement the notification Source interface so as to facilitate client subscription to register state changes

Path naming or directory schemes (as used, for example, in file systems) represent an alternative approach to attribute schemes for organizing services into a hierarchical name space that can be navigated. The two approaches can be combined, as in LDAP.

c) Rating Service

A rating interface needs to address two types of behaviors. Once the metered information is available, it has to be translated into financial terms. That is, for each unit of usage, a price has to be associated with it. This step is accomplished by the rating interfaces, which provide operations that take the metered information and a rating package as input and output the usage in terms of chargeable amounts.

For example,

A commercial UNIX system indicates that 10 hours of prime-time resource and 10 hours on nonprime-time resource are consumed, and the rating package indicates that each hour of prime-time resource is priced at 2 dollars and each hour of nonprime- time resource is priced at 1 dollar, a rating service will apply the pricing indicated in the rating package

Furthermore, when a business service is developed, a rating service is used to aggregate the costs of the components used to deliver the service, so that the service owner can determine the pricing, terms, and conditions under which the service will be offered to subscribe

d) Other Data Services

A variety of higher-level data interfaces can and must be defined on top of the base

Data interfaces, to address functions such as:

_ Data access and movement

_ Data replication and caching

_ Data and schema mediation

_ Metadata management and looking

Data Replication. Data replication can be important as a means of meeting performance objectives by allowing local computer resources to have access to local data. Although closely related to caching (indeed, a ―replica store‖ and a ―cache may differ only in their policies), replicas may provide different interfaces

Data Caching. In order to improve performance of access to remote data items, caching services will be employed. At the minimum, caching services for traditional flat file data will be employed. Caching of other data types, such as views on RDBMS data, streaming data, and application binaries, are also envisioned

Consistency—Is the data in the cache the same as in the source? If not, what is the coherence window? Different applications have very different requirements. _ Cache invalidation protocols—How and when is cached data invalidated? _ Write through or write back? When are writes to the cache committed back to the original data source?

Security—How will access control to cached items be handled? Will access control enforcement be delegated to the cache, or will access control be somehow enforced by the original data source? _ Integrity of cached data—Is the cached data kept in memory or on disk? How is it protected from unauthorized access? Is it encrypted?

Schema Transformation. Schema transformation interfaces support the transformation of data from one schema to another. For example, XML transformations as specified in XSLT.

Open Grid Services Infrastructure and Distributed Logging

The OGSI defines fundamental mechanisms on which OGSA is constructed. These mechanisms address issues relating to the creation, naming, management, and exchange of information among entities called grid services. The following list recaps the key OGSI features and briefly discusses their relevance to OGSA.

Grid Service descriptions and instances. OGSI introduces the twin concepts of the grid service description and grid service instance as organizing principles of distributed systems.

Grid Service descriptions and instances. OGSI introduces the twin concepts of the grid service description and grid service instance as organizing principles of distributed systems.

Naming and name resolution. OGSI defines a two-level naming scheme for grid service instances based on abstract, long-lived grid service handles that can be mapped by Handle Mapper services to concrete but potentially less long- lived grid service references.

Fault model. OGSI defines a common approach for conveying fault information from operations.

Life cycle. OGSI defines mechanisms for managing the life cycle of a grid service instance, including both explicit destruction and soft-state lifetime management functions for grid service instances, and grid service factories that can be used to create instances implementing specified interfaces

Service groups. OGSI defines a means of organizing groups of service instances.

Distributed Logging

Distributed logging can be viewed as a typical messaging application in which message producers generate log artifacts, (atomic expressions of diagnostic information) that may or may not be used at a later time by other independent message consumers. OGSA-based logging can leverage the notification mechanism available in OGSI as the transport for messages.

Logging services provide the extensions needed to deal with the following issues: Decoupling. The logical separation of logging artifact creation from logging artifact consumption. The ultimate usage of the data (e.g., logging, tracing, management) is determined by the message consumer

Transformation and common representation. Logging packages commonly annotate the data that they generate with useful common information such as category, priority, time stamp, and location

Filtering and aggregation. The amount of logging data generated can be large, whereas the amount of data actually consumed can be small. Therefore, it can be desirable to have a mechanism for controlling the amount of data generated and for filtering out what is actually kept and where.

Configurable persistency. Depending on consumer needs, data may have different durability characteristics. For example, in a real-time monitoring application, data may become irrelevant quickly, but be needed as soon as it is generated; data for an auditing program may be needed months or even years after it was generated.

Consumption patterns. Consumption patterns differ according to the needs of the consumer application. For example, a real-time monitoring application needs to be notified whenever a particular event occurs, whereas a postmortem problem determination program queries historical data, trying to find known patterns.

a) Job Agreement Service

The job agreement service is created by the agreement factory service with a set of job terms, including command line, resource requirements, execution environment, data staging, job control, scheduler directives, and accounting and notification term.

The job agreement service provides an interface for placing jobs on a resource manager (i.e., representing a machine or a cluster), and for interacting with the job once it has been dispatched to the resource manager. The job agreement service provides basic matchmaking capabilities between the requirements of the job and the underlying resource manager available for running the job.

The interfaces provided by the job agreement service are:
_ Manageability interface
_ Supported job terms: defines a set of service data used to publish the job terms supported by this job service, including the job definition (command line and application name), resource requirements, execution requirement, data staging, job control, scheduler directives, and accounting and notification terms.
_ Workload status: total number of jobs, statuses such as number of jobs running or pending and suspended jobs.
_ Job control: control the job after it has been instantiated. This would include the ability to suspend/resume, checkpoint, and kill the job.

b) Reservation Agreement Service
The reservation agreement service is created by the agreement factory service with a set of terms including time duration, resource requirement specification, and authorized user/project agreement terms. The reservation agreement service allows end users or a job agreement service to reserve resources under the control of a resource manager to guarantee their availability to run a job. The service allows reservations on any type of resource (e.g., hosts, software licenses, or network bandwidth). Reservations can be specific (e.g., provide access to host ―A‖ from noon to 5 PM), or more general (e.g., provide access to 16 Linux cpus on Sunday).
The reservation service makes use of information about the existing resource managers available and any policies that might be defined at the VO level, and will make use of a logging service to log reservations. It will use the resource manager adapter interfaces to make reservations and to delete existing reservations.

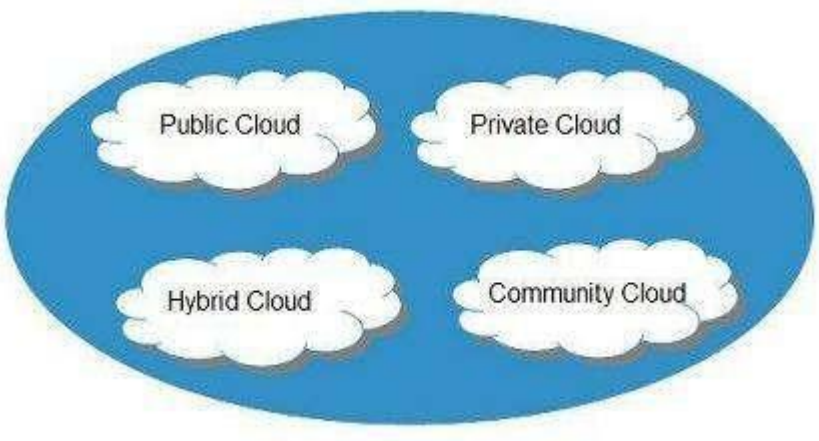
c) Base Data Services
OGSA data interfaces are intended to enable a service-oriented treatment of data so that data can be treated in the same way as other resources within the Web/grid services architecture
Four base data interfaces (WSDL port Types) can be used to implement a variety of different data service behaviors:
1. **Data Description** defines OGSI service data elements representing key parameters of the data virtualization encapsulated by the data service.
2. **Data Access** provides operations to access and/or modify the contents of the data virtualization encapsulated by the data service.
3. **Data Factory** provides an operation to create a new data service with a data virtualization derived from the data virtualization of the parent (factory) data service.
4. **Data Management** provides operations to monitor and manage the data service's data virtualization, including (depending on the implementation) the data sources (such as database management systems) that underlie the data service.

UNIT-III

VIRTUALIZATION

Cloud deployment models

Deployment models define the type of access to the cloud, i.e., how the cloud is located? Cloud can have any of the four types of access: Public, Private, Hybrid, and Community.



1. PUBLIC CLOUD

The **public cloud** allows systems and services to be easily accessible to the general public. Public cloud may be less secure because of its openness.

2. PRIVATE CLOUD

The **private cloud** allows systems and services to be accessible within an organization. It is more secured because of its private nature.

3. COMMUNITY CLOUD

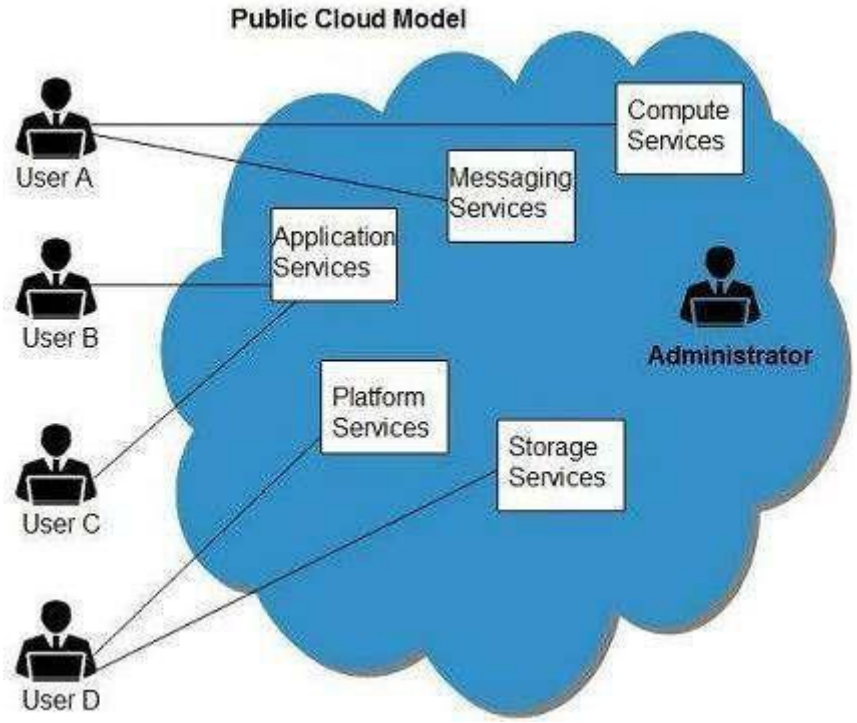
The **community cloud** allows systems and services to be accessible by a group of organizations.

4. HYBRID CLOUD

The **hybrid cloud** is a mixture of public and private cloud, in which the critical activities are performed using private cloud while the non-critical activities are performed using public cloud.

Public cloud

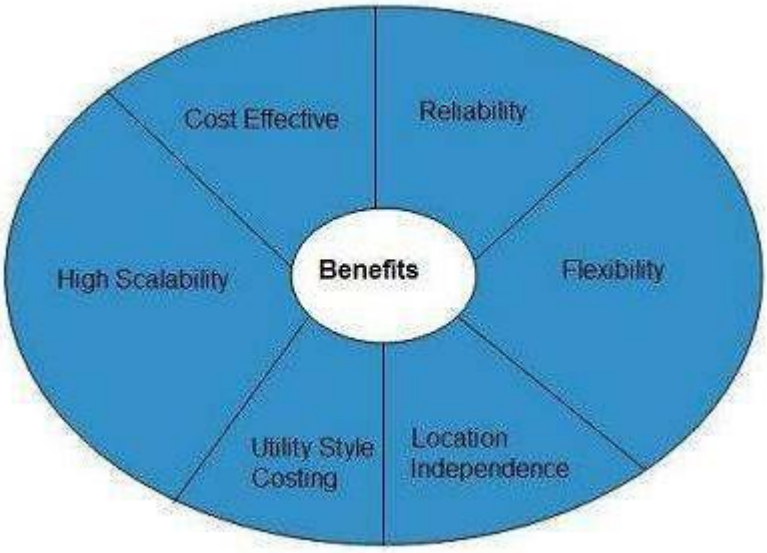
Public Cloud allows systems and services to be easily accessible to general public. The IT giants such as **Google**, **Amazon** and **Microsoft** offer cloud services via Internet. The Public Cloud Model is shown in the diagram below.



Public cloud Model

Benefits

There are many benefits of deploying cloud as public cloud model. The following diagram shows some of those benefits:



Cost Effective

Since **public cloud** shares same resources with large number of customers it turns out inexpensive.

Reliability

The **public cloud** employs large number of resources from different locations. If any of the resources fails, public cloud can employ another one.

Flexibility

The public cloud can smoothly integrate with private cloud, which gives customers a flexible approach.

Location Independence

Public cloud services are delivered through Internet, ensuring location independence.

Utility Style Costing

Public cloud is also based on **pay-per-use** model and resources are accessible whenever customer needs them.

High Scalability

Cloud resources are made available on demand from a pool of resources, i.e., they can be scaled up or down according the requirement.

Disadvantages

Here are some disadvantages of public cloud model:

Low Security

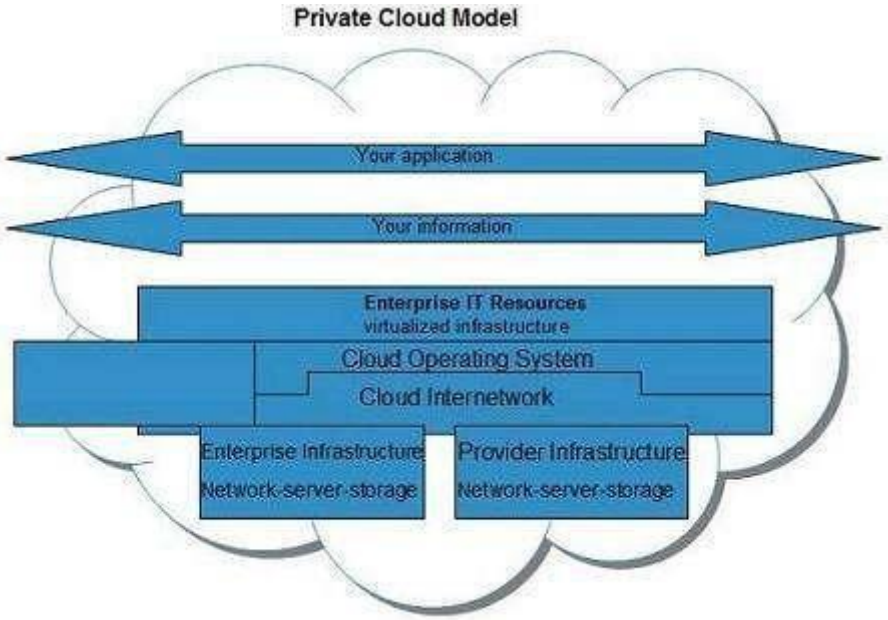
In **public cloud model**, data is hosted off-site and resources are shared publicly, therefore does not ensure higher level of security.

Less Customizable

It is comparatively less customizable than private cloud.

3.3. Private cloud

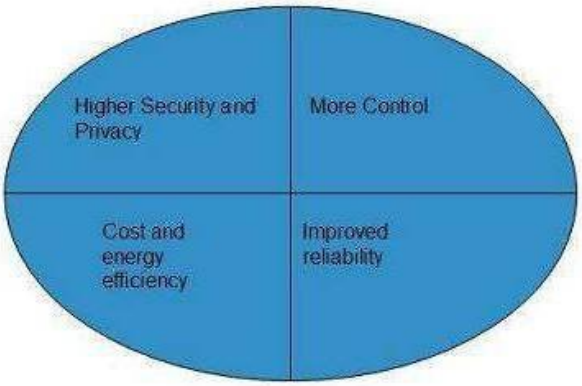
Private Cloud allows systems and services to be accessible within an organization. The Private Cloud is operated only within a single organization. However, it may be managed internally by the organization itself or by third-party. The private cloud model is shown in the diagram below.



Public cloud model

Benefits

There are many benefits of deploying cloud as private cloud model. The following diagram shows some of those benefits:



High Security and Privacy

Private cloud operations are not available to general public and resources are shared from distinct pool of resources. Therefore, it ensures high **security** and **privacy**.

More Control

The **private cloud** has more control on its resources and hardware than public cloud because it is accessed only within an organization.

Cost and Energy Efficiency

The **private cloud** resources are not as cost effective as resources in public clouds but they offer more efficiency than public cloud resources.

Disadvantages

Here are the disadvantages of using private cloud model:

Restricted Area of Operation

The private cloud is only accessible locally and is very difficult to deploy globally.

High Priced

Purchasing new hardware in order to fulfill the demand is a costly transaction.

Limited Scalability

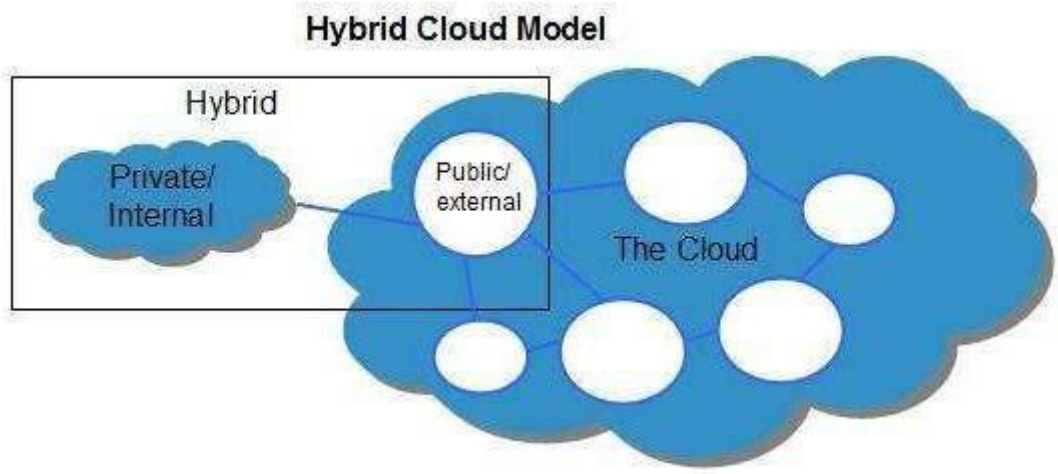
The private cloud can be scaled only within capacity of internal hosted resources.

Additional Skills

In order to maintain cloud deployment, organization requires skilled expertise.

Hybrid cloud

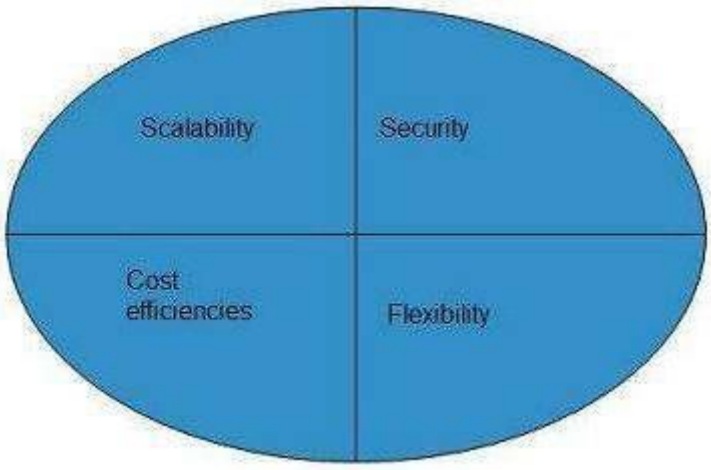
Hybrid Cloud is a mixture of **public** and **private cloud**. Non-critical activities are performed using public cloud while the critical activities are performed using private cloud. The Hybrid Cloud Model is shown in the diagram below.



Hybrid cloud model

Benefits

There are many benefits of deploying cloud as hybrid cloud model. The following diagram shows some of those benefits:



Scalability

It offers features of both, the public cloud scalability and the private cloud scalability.

Flexibility

It offers secure resources and scalable public resources.

Cost Efficiency
Public clouds are more cost effective than private ones. Therefore, hybrid clouds can be cost saving.

Security
The private cloud in hybrid cloud ensures higher degree of security.

Disadvantages
Networking Issues
Networking becomes complex due to presence of private and public cloud.

Security Compliance
It is necessary to ensure that cloud services are compliant with security policies of the organization.

Infrastructure Dependency
The hybrid cloud model is dependent on internal IT infrastructure, therefore it is necessary to ensure redundancy across data centers.

Community cloud

Community Cloud allows system and services to be accessible by group of organizations. It shares the infrastructure between several organizations from a specific community. It may be managed internally by organizations or by the third-party. The Community Cloud Model is shown in the diagram below.

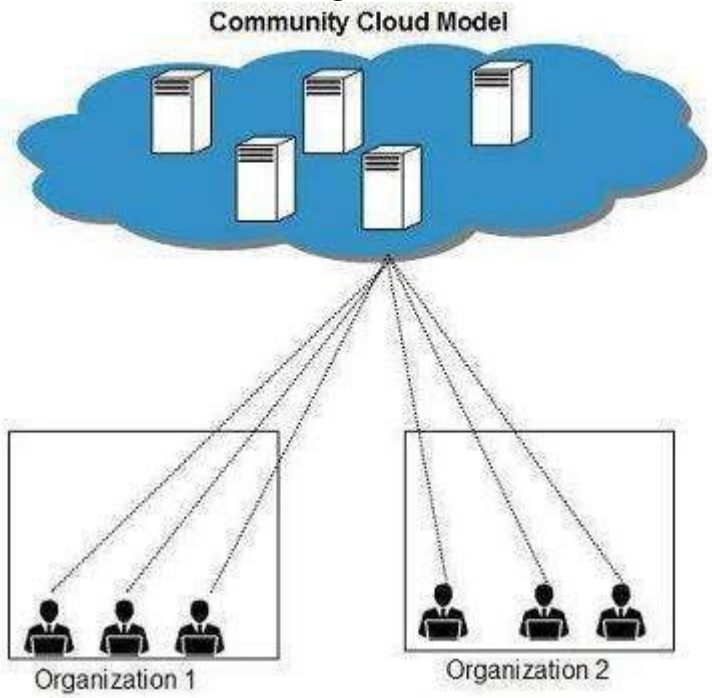


Fig: Community cloud model

Benefits
There are many benefits of deploying cloud as **community cloud model**.

Cost Effective

Community cloud offers same advantages as that of private cloud at low cost.

Sharing Among Organizations

Community cloud provides an infrastructure to share cloud resources and capabilities among several organizations.

Security

The community cloud is comparatively more secure than the public cloud but less secured than the private cloud.

Issues

Since all data is located at one place, one must be careful in storing data in community cloud because it might be accessible to others.

It is also challenging to allocate responsibilities of governance, security and cost among organizations.

Categories of cloud computing

Cloud is made feasible through the deployment and interoperability of three platform types. These three layers are:

IaaS - Infrastructure as a Service

PaaS - Platform as a Service

SaaS - Software as a Service

Now this stack is easily broken down as follows: Think of the "Infrastructure-as-a-Service" as the road. It's the basis for communication. It's the bottom layer that we build our platform on. The platform are the cars traveling on the infrastructure. PaaS rides on IaaS. But on the top of that, the goods and passengers inside the cars are the SaaS. It's the end user experience. It's the end result. Let's take that a step further.

Infrastructure-as-a-Service (IaaS)

Cloud Providers offering Infrastructure as a Service tout data-center space and servers; as well as network equipment such as routers/switches and software for businesses. These data-centers are fully outsourced, we need not lift a finger, upgrade an IOS or re-route data. Although this is the base layer, it allows for scalability and reliability; as well as better security than an organization may have in a local co-lo or local data center. In addition, these services are charged as utilities, so we pay for what we use, like our water, electric and gas. Depending on our capacity or usage, our payment is a variable.

Because the IaaS vendors purchase equipment in such bulk, we, Mr. Customer, get the best gear for the lowest price. Hence, the financial benefits of IaaS are cheaper access to infrastructure.

With the pay-as-we-go model, instead of investing in a fixed capacity infrastructure, which will either fall short or exceed the organizational need, customers are able to save quite a bit of coin. Buying hardware that's barely used is a waste of hardware, air conditioning, space and power.

Operational expenses versus Capital expenses: Cloud is better. Because these computing resources are basically used and paid for like a utility they can be paid via the operating expenditures budget versus being paid for via capital investments. In other words, instead of depreciating the gear over three years, we're able to expense the monthly charge this year. And the year after that. It's an elastic service.

Platform-as-a-Service (Paas)

Provisioning a full hardware architecture and software framework to allow applications to run is the essence of Platform-as-a-Service. There's a huge market for customers who require flexible, robust web-based applications. But, in order for these applications to run, there needs to be platform supporting it that is just as robust and flexible. Cloud providers offer this environment and framework as a service. Their developers can write their code regardless of the OS behind it. So instead of software being written for Apple, Linux or Windows, it's being written for a development environment provided by Cloud Providers such as Amazon, Microsoft and Google.

Software-as-a-Service (SaaS)

Software-as-a-Service is the process of provisioning commercially available software but giving access over the net. The customer doesn't have to worry about software licenses, since they are handled by the service provider. The provider also handles upgrades, patches or bug fixes. Some examples of this software might be office productivity software, which we may access online, like Google Docs.

We can also essentially rent contact management software, content management software, email software (Google mail?), project management software and scheduling software. It's all online. All easily available on the internet. Why is this a big deal? Well, we no longer have to pay for expensive hardware to host the software, or get to the software (VPNs, dedicated links, etc.), we don't need the employees (and their associated salaries, benefits, office costs, etc.) to install, configure or maintain the software. The application is handled on the back end by the SaaS provider. That's sort of a big deal regardless the size of our business. Money is money. Our IT staff is then able to use its time and resources to work on other projects or we can simply eliminate unnecessary IT staff.

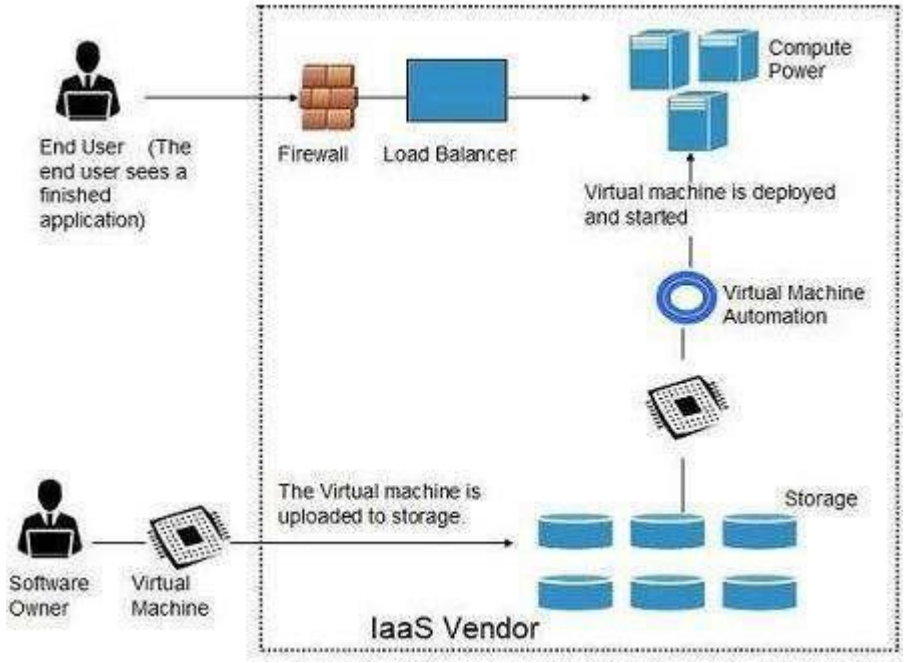
Everything as a service

Infrastructure as a service

Infrastructure-as-a-Service provides access to fundamental resources such as physical machines, virtual machines, virtual storage, etc. Apart from these resources, the IaaS also offers:

a. Virtual machine disk storage
b. Virtual local area network (VLANs)
c. Load balancers
d. IP addresses
e. Software bundles

All of the above resources are made available to end user via **server virtualization**. Moreover, these resources are accessed by the customers as if they own them.



Benefits

IaaS allows the cloud provider to freely locate the infrastructure over the Internet in a cost-effective manner. Some of the key benefits of IaaS are listed below:

Full control of the computing resources through administrative access to VMs.

Flexible and efficient renting of computer hardware.

Portability, interoperability with legacy applications.

Full control over computing resources through administrative access to VMs

IaaS allows the customer to access computing resources through administrative access to virtual machines in the following manner:

Customer issues administrative command to cloud provider to run the virtual machine or to save data on cloud server.

Customer issues administrative command to virtual machines they owned to start web server or to install new applications.

Flexible and efficient renting of computer hardware

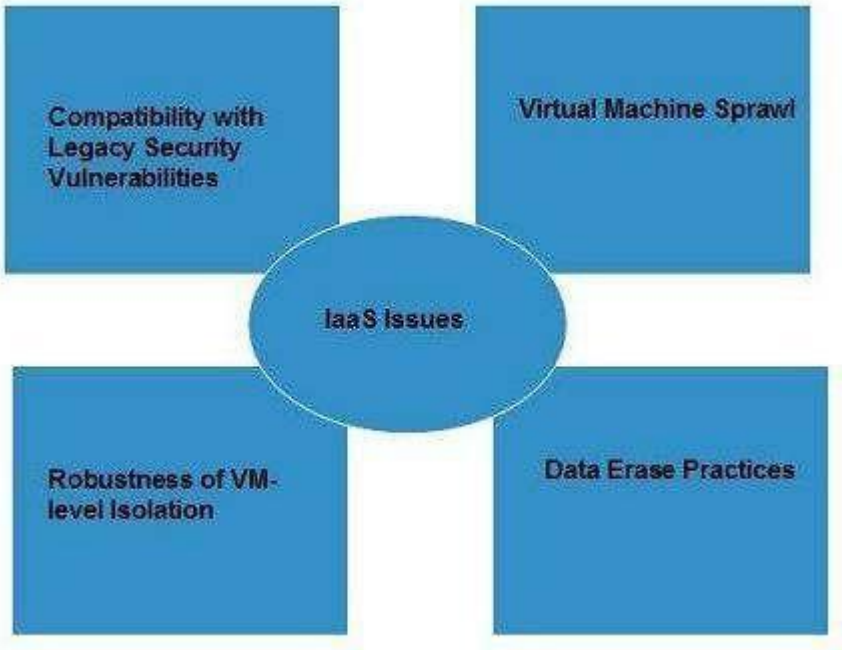
IaaS resources such as virtual machines, storage devices, bandwidth, IP addresses, monitoring services, firewalls, etc. are made available to the customers on rent. The payment is based upon the amount of time the customer retains a resource. Also with administrative access to virtual machines, the customer can run any software, even a custom operating system.

Portability, interoperability with legacy applications

It is possible to maintain legacy between applications and workloads between IaaS clouds. For example, network applications such as web server or e-mail server that normally runs on customer-owned server hardware can also run from VMs in IaaS cloud.

Issues

IaaS shares issues with PaaS and SaaS, such as Network dependence and browser based risks. It also has some specific issues, which are mentioned in the following diagram:



Compatibility with legacy security vulnerabilities

Because IaaS offers the customer to run legacy software in provider's infrastructure, it exposes customers to all of the security vulnerabilities of such legacy software.

Virtual Machine sprawl

The VM can become out-of-date with respect to security updates because IaaS allows the customer to operate the virtual machines in running, suspended and off state. However, the provider can automatically update such VMs, but this mechanism is hard and complex.

Robustness of VM-level isolation

IaaS offers an isolated environment to individual customers through hypervisor. Hypervisor is a software layer that includes hardware support for virtualization to split a physical computer into multiple virtual machines.

Data erase practices

The customer uses virtual machines that in turn use the common disk resources provided by the cloud provider. When the customer releases the resource, the cloud provider must ensure that next customer to rent the resource does not observe data residue from previous customer.

Characteristics

Here are the characteristics of IaaS service model:

- Virtual machines with pre-installed software.
- Virtual machines with pre-installed operating systems such as Windows, Linux, and Solaris.
- On-demand availability of resources.
- Allows storing copies of particular data at different locations.
- The computing resources can be easily scaled up and down.

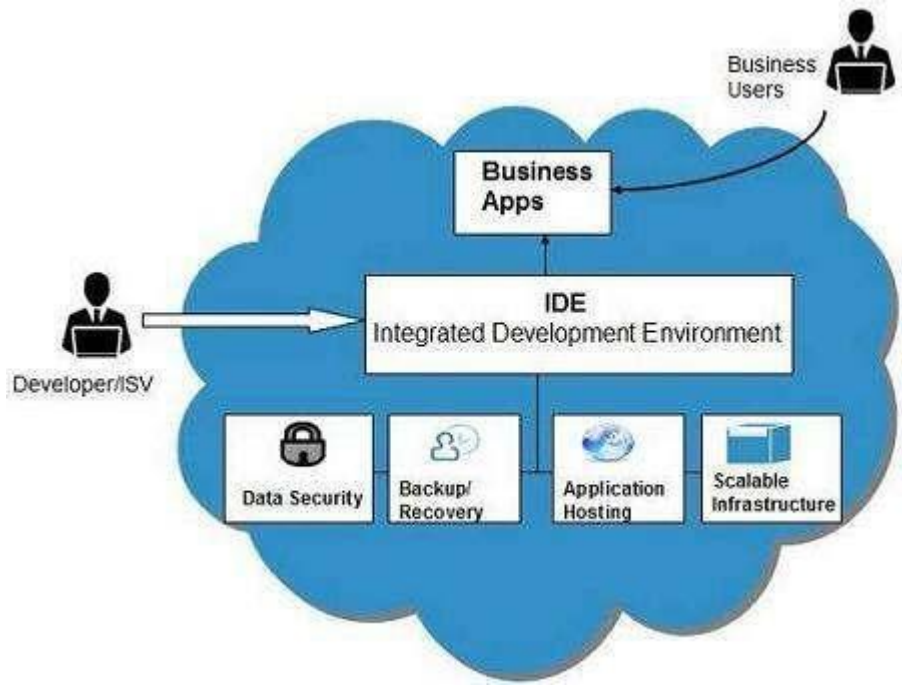
Platform as a service

Platform-as-a-Service offers the runtime environment for applications. It also offers development and deployment tools required to develop applications. PaaS has a feature of **point-and-click** tools that enables non-developers to create web applications.

App Engine of Google and **Force.com** are examples of PaaS offering vendors. Developer may log on to these websites and use the **built-in API** to create web-based applications.

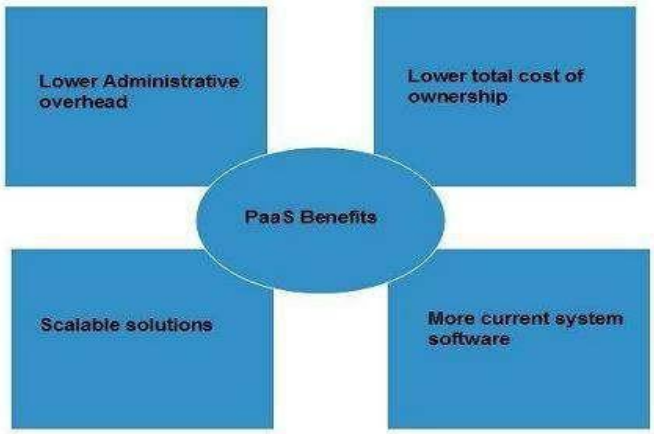
But the disadvantage of using PaaS is that, the developer **locks-in** with a particular vendor. For example, an application written in Python against API of Google, and using App Engine of Google is likely to work only in that environment.

The following diagram shows how PaaS offers an API and development tools to the developers and how it helps the end user to access business applications.



Benefits

Following are the benefits of PaaS model:



Lower administrative overhead

Customer need not bother about the administration because it is the responsibility of cloud provider.

Lower total cost of ownership

Customer need not purchase expensive hardware, servers, power, and data storage.

Scalable solutions

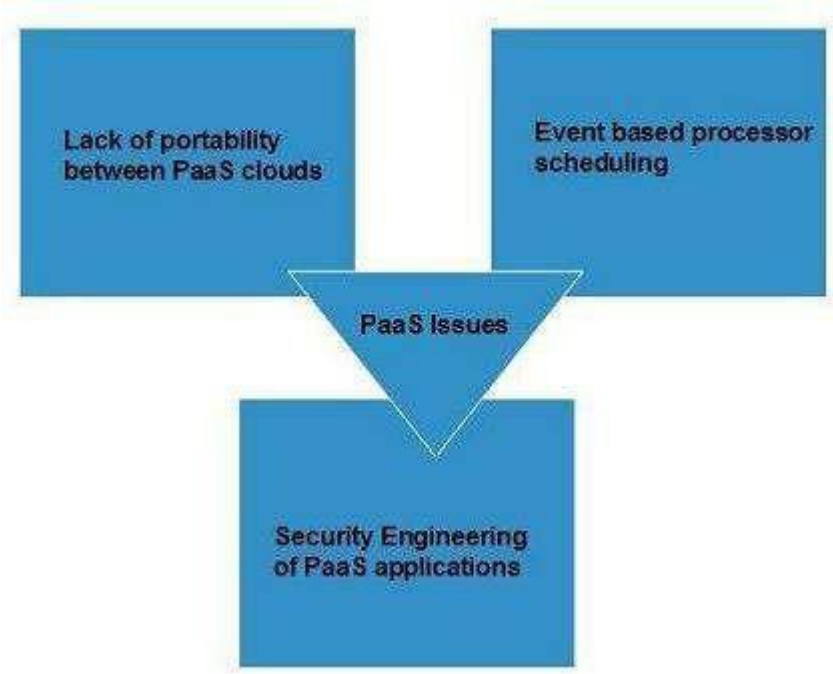
It is very easy to scale the resources up or down automatically, based on their demand.

More current system software

It is the responsibility of the cloud provider to maintain software versions and patch installations.

Issues

Like **SaaS**, **PaaS** also places significant burdens on customer's browsers to maintain reliable and secure connections to the provider's systems. Therefore, PaaS shares many of the issues of SaaS. However, there are some specific issues associated with PaaS as shown in the following diagram:



Lack of portability between PaaS clouds

Although standard languages are used, yet the implementations of platform services may vary. For example, file, queue, or hash table interfaces of one platform may differ from another, making it difficult to transfer the workloads from one platform to another.

Event based processor scheduling

The PaaS applications are event-oriented which poses resource constraints on applications, i.e., they have to answer a request in a given interval of time.

Security engineering of PaaS applications

Since PaaS applications are dependent on network, they must explicitly use cryptography and manage security exposures.

Characteristics

Here are the characteristics of PaaS service model:

PaaS offers **browser based development environment**. It allows the developer to create database and edit the application code either via Application Programming Interface or point-and-click tools.

PaaS provides **built-in security, scalability,** and **web service interfaces**.

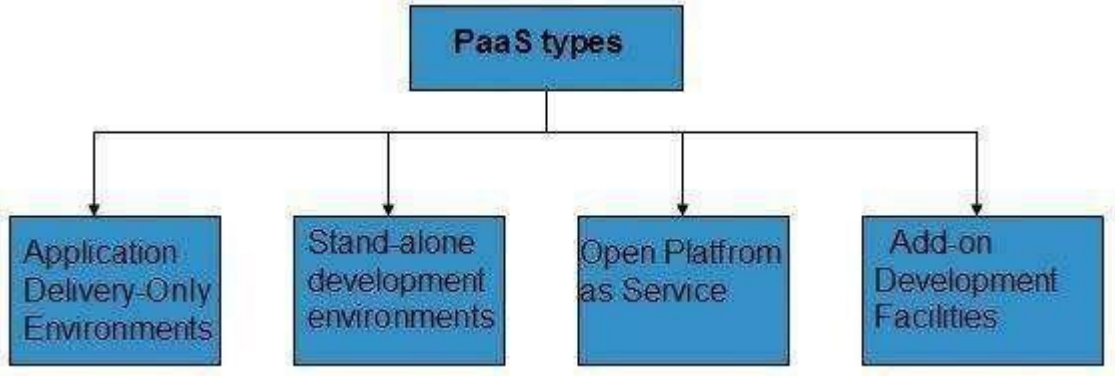
PaaS provides built-in tools for defining **workflow, approval processes,** and business rules.

It is easy to integrate PaaS with other applications on the same platform.

PaaS also provides web services interfaces that allow us to connect the applications outside the platform.

PaaS Types

Based on the functions, PaaS can be classified into four types as shown in the following diagram:



Stand-alone development environments

The **stand-alone PaaS** works as an independent entity for a specific function. It does not include licensing or technical dependencies on specific SaaS applications.

Application delivery-only environments

The **application delivery PaaS** includes **on-demand scaling** and **application security**.

Open platform as a service

Open PaaS offers an **open source software** that helps a PaaS provider to run applications.

Add-on development facilities

The **add-on PaaS** allows to customize the existing SaaS platform.

3.10. Software as a service

Software-as-a-Service (SaaS) model allows to provide software application as a service to the end users. It refers to a software that is deployed on a host service and is accessible via Internet. There are several SaaS applications listed below:

a. Billing and invoicing system
b. Customer Relationship Management (CRM) applications
c. Help desk applications
d. Human Resource (HR) solutions

Some of the SaaS applications are not customizable such as **Microsoft Office Suite**. But SaaS provides us **Application Programming Interface (API)**, which allows the developer to develop a customized application.

Characteristics

Here are the characteristics of SaaS service model:

- SaaS makes the software available over the Internet.
- The software applications are maintained by the vendor.
- The license to the software may be subscription based or usage based. And it is billed on recurring basis.
- SaaS applications are cost-effective since they do not require any maintenance at end user side.
- They are available on demand.
- They can be scaled up or down on demand.
- They are automatically upgraded and updated.
- SaaS offers shared data model. Therefore, multiple users can share single instance of infrastructure. It is not required to hard code the functionality for individual users.
- All users run the same version of the software.

Benefits

Using SaaS has proved to be beneficial in terms of scalability, efficiency and performance. Some of the benefits are listed below:

a. Modest software tools
b. Efficient use of software licenses
c. Centralized management and data
d. Platform responsibilities managed by provider
e. Multitenant solutions

Modest software tools

The SaaS application deployment requires a little or no client side software installation, which results in the following benefits:

a. No requirement for complex software packages at client side
b. Little or no risk of configuration at client side
c. Low distribution cost

Efficient use of software licenses

The customer can have single license for multiple computers running at different locations which reduces the licensing cost. Also, there is no requirement for license servers because the software runs in the provider's infrastructure.

Centralized management and data

The cloud provider stores data centrally. However, the cloud providers may store data in a decentralized manner for the sake of redundancy and reliability.

Platform responsibilities managed by providers

All platform responsibilities such as backups, system maintenance, security, hardware refresh, power management, etc. are performed by the cloud provider. The customer does not need to bother about them.

Multitenant solutions

Multitenant solutions allow multiple users to share single instance of different resources in virtual isolation. Customers can customize their application without affecting the core functionality.

Issues

There are several issues associated with SaaS, some of them are listed below:

a) Browser based risks

b) Network dependence

c) Lack of portability between SaaS clouds

Browser based risks

If the customer visits malicious website and browser becomes infected, the subsequent access to SaaS application might compromise the customer's data.

To avoid such risks, the customer can use multiple browsers and dedicate a specific browser to access SaaS applications or can use virtual desktop while accessing the SaaS applications.

Network dependence

The SaaS application can be delivered only when network is continuously available. Also network should be reliable but the network reliability cannot be guaranteed either by cloud provider or by the customer.

Lack of portability between SaaS clouds

Transferring workloads from one SaaS cloud to another is not so easy because work flow, business logics, user interfaces, support scripts can be provider specific.

Open SaaS and SOA

Open SaaS uses those SaaS applications, which are developed using open source programming language. These SaaS applications can run on any open source operating system and database. Open SaaS has several benefits listed below:

i. No License Required

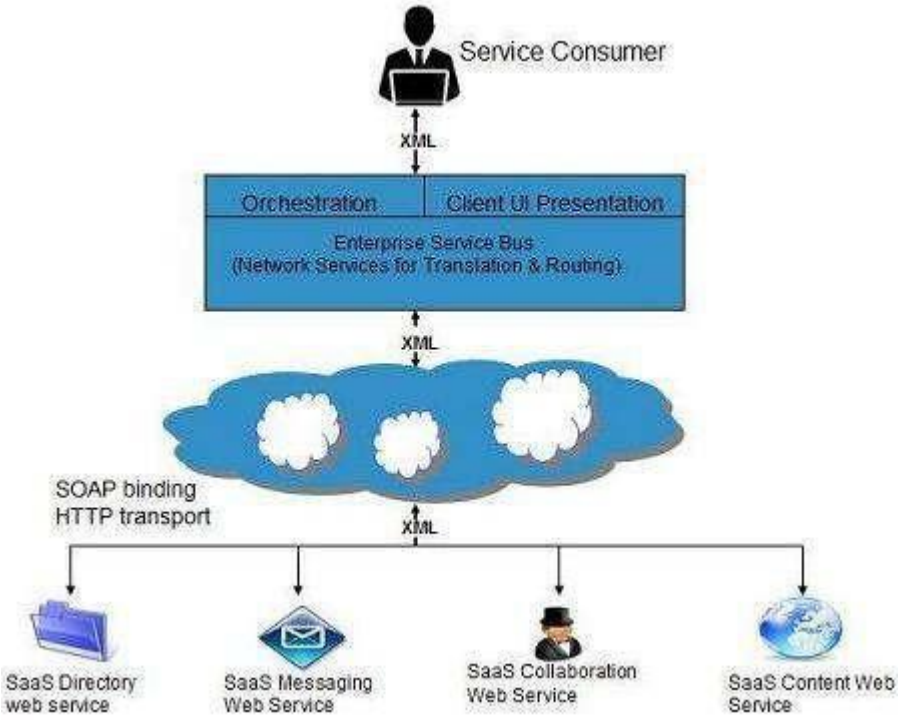
ii. Low Deployment Cost

iii. Less Vendor Lock-in

iv. More portable applications

v. More Robust Solution

The following diagram shows the SaaS implementation based on SOA:



Pros and Cons of cloud computing

Cloud Computing: 3 Pros

1. Improved Disaster Recovery

Moving our business data to the cloud can make disaster recovery (DR)—i.e., retrieving data in the event of a hardware compromise—easier and less expensive. We can even set up our system to back up data automatically to ensure we will be able to recover the most up-to-date information in case of emergency.

2. Increased Collaboration and Flexibility

For many businesses, moving to the cloud increases opportunities for collaboration between employees. Colleagues can sync and work on documents or shared apps with ease, often simultaneously, receiving updates in real time.

Additionally, cloud computing allows each team member to work from anywhere. The cloud centralizes our data, which means that we, our employees and even our clients can access our company data from any location with Internet access.

3. Environmentally Friendly

Cloud computing decreases a business carbon footprint by reducing energy consumption and carbon emissions by more than 30 percent. For small companies, the decreased energy usage can reach 90 percent—a huge money saver. It can also help a business project an environmentally sound image.

Cloud Computing: 3 Cons

1. Internet Connectivity

Running all or some of our business applications in the cloud is great, as long as we can maintain a consistent Internet connection. If any one of our cloud-based service providers loses connectivity or if our ISP experiences an outage, we are out of business until that Internet connection returns. Even the best servers go down occasionally, so if we decide to use this method, it's important to implement a backup plan.

2. Ongoing Costs

While cloud computing is relatively inexpensive to start up, depending on our needs, an in-house solution may cost less in the long run. Buying an in-house server and installing a network system is definitely a large, up-front capital investment, and we also need to consider ongoing IT maintenance costs.

With cloud computing, we pay the same amount each month to maintain not only our server, but also all our data. The choice we make may depend on whether we have a lot of start-up capital to invest in a private network. Be sure to compare all the costs for supporting both an in-house server and cloud-based server to see which option works best for our situation.

3. Security

It boils down to whom do we trust with our business data? Not every business should place its data in the cloud. Companies with highly sensitive data—or that must meet stringent compliance regulations—may well need their own IT department to keep data secure. When we store data in the cloud, we trust a third party to keep it safe.

Implementation levels of virtualization

Virtualization is a technique, which allows to share single physical instance of an application or resource among multiple organizations or tenants (customers). It does so by **assigning a logical name** to a physical resource and providing a **pointer to that physical resource** on demand.

Virtualization Concept

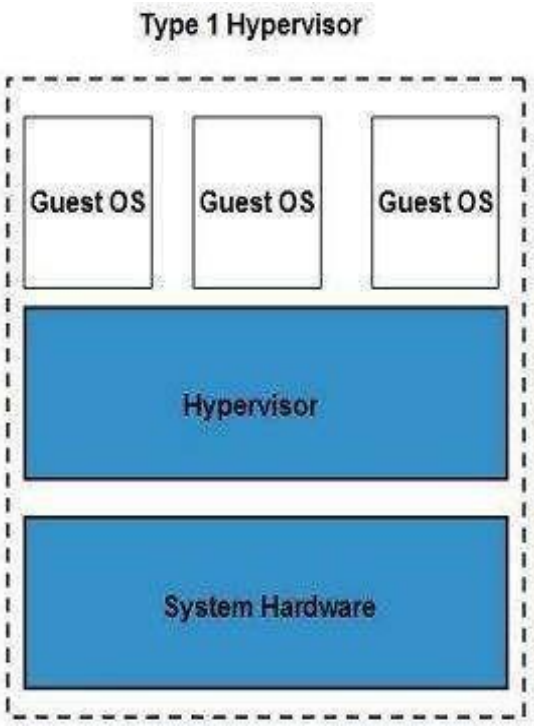
Creating a virtual machine over existing operating system and hardware is referred as Hardware Virtualization. Virtual Machines provide an environment that is logically separated from the underlying hardware.

The machine on which the virtual machine is created is known as **host machine** and **virtual machine** is referred as a **guest machine**. This virtual machine is managed by a software or firmware, which is known as **hypervisor**.

Hypervisor

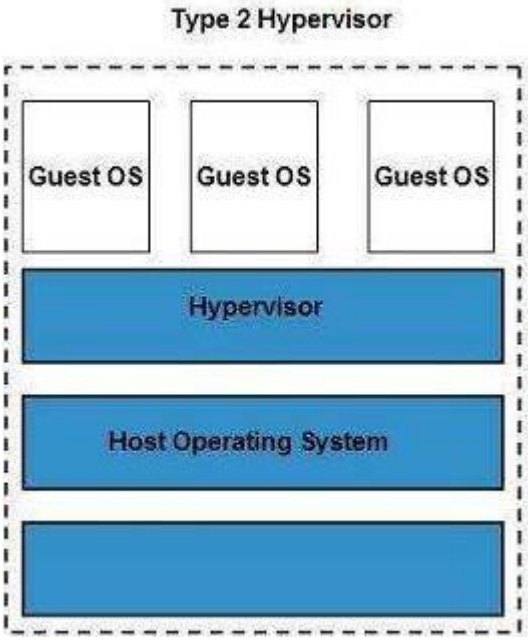
The **hypervisor** is a firmware or low-level program that acts as a Virtual Machine Manager. There are two types of hypervisor:

Type 1 hypervisor executes on bare system. Lynx Secure, RTS Hypervisor, Oracle VM, Sun xVM Server, Virtual Logic VLX are examples of Type 1 hypervisor. The following diagram shows the Type 1 hypervisor.



The **type1 hypervisor** does not have any host operating system because they are installed on a bare system.

Type 2 hypervisor is a software interface that emulates the devices with which a system normally interacts. Containers, KVM, Microsoft Hyper V, VMWare Fusion, Virtual Server 2005 R2, Windows Virtual PC and **VMW are workstation 6.0** are examples of Type 2 hypervisor. The following diagram shows the Type 2 hypervisor.



Virtualization structure

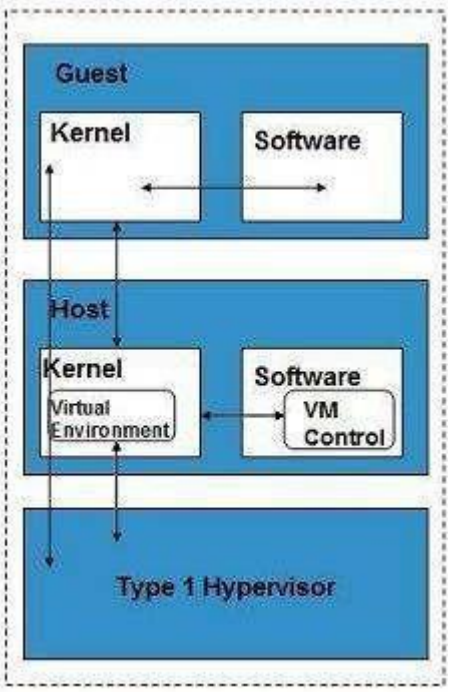
Types of Hardware Virtualization

Here are the three types of hardware virtualization:

I. Full Virtualization
II. Emulation Virtualization
III. Par virtualization

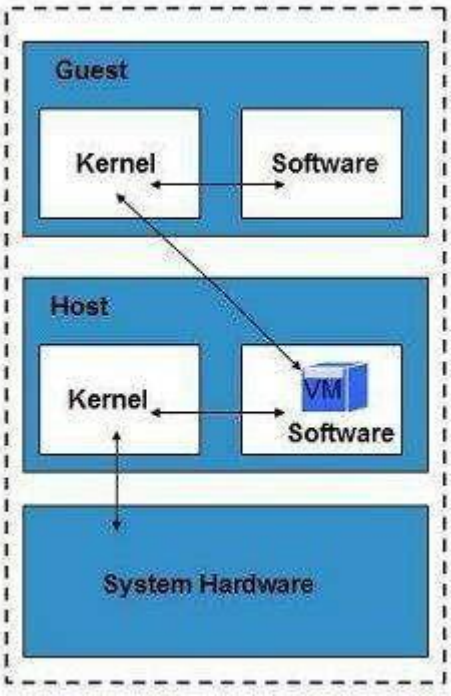
Full Virtualization

In **full virtualization**, the underlying hardware is completely simulated. Guest software does not require any modification to run.



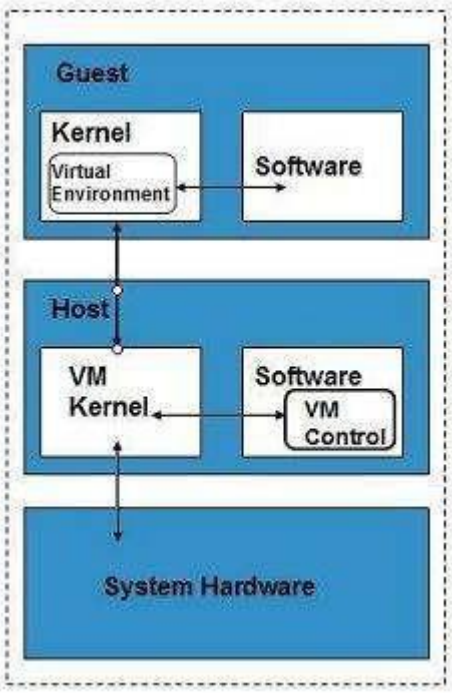
Emulation Virtualization

In **Emulation**, the virtual machine simulates the hardware and hence becomes independent of it. In this, the guest operating system does not require modification.



Par virtualization

In **Par virtualization**, the hardware is not simulated. The guest software run their own isolated domains.



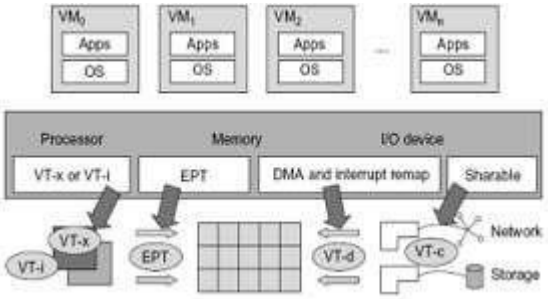
VMware vSphere is highly developed infrastructure that offers a management infrastructure framework for virtualization. It virtualizes the system, storage and networking hardware.

Virtualization of CPU, Memory and I/O devices

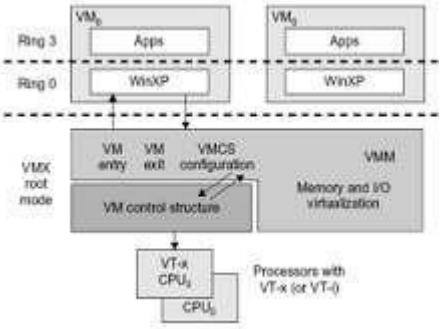
1. Hardware Support for Virtualization
2. CPU Virtualization
3. Memory Virtualization
4. I/O Virtualization
5. Virtualization in Multi-Core Processors

Hardware Support for Virtualization:

EPT (Extended Page Table); VT-x (Intel's Virtualization Technology)



VMCS (Virtual Machine Control Structure):



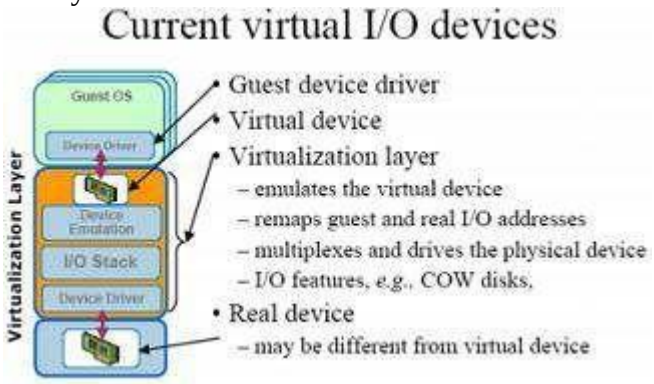
3.14 Virtualization of CPU:

Intel Hardware-assisted CPU Virtualization:

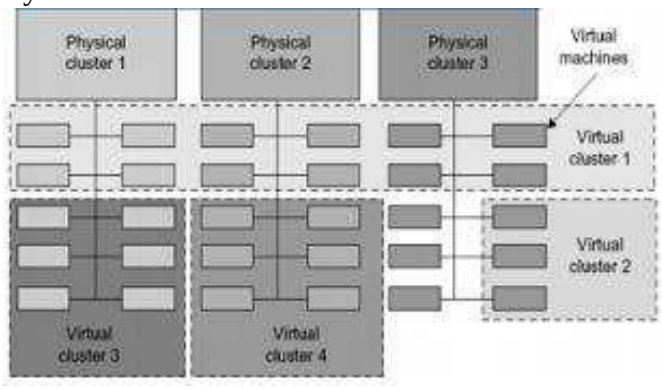
A VM is a duplicate of an existing computer system in which a majority of the VM instructions are executed on the host processor in native mode. Thus, unprivileged instructions of VMs run directly on the host machine for higher efficiency. Other critical instructions should be handled carefully for correctness and stability. The critical instructions are divided into three categories: privileged instructions, control-sensitive instructions, and behavior-sensitive instructions.

Privileged instructions execute in a privileged mode and will be trapped if executed outside this mode. Control-sensitive instructions attempt to change the configuration of resources used. Behavior-sensitive instructions have different behaviors depending on the configuration of resources, including the load and store operations over the virtual memory.

A CPU architecture is virtualizable if it supports the ability to run the VM's privileged and unprivileged instructions in the CPU's user mode while the VMM runs in supervisor mode. When the privileged instructions including control- and behavior-sensitive instructions of a VM are executed, they are trapped in the VMM. In this case, the VMM acts as a unified mediator for hardware access from different VMs to guarantee the correctness and stability of the whole system.



Virtual Clusters vs. Physical Clusters:



3.15. Virtualization of memory and I/O devices

Memory Virtualization

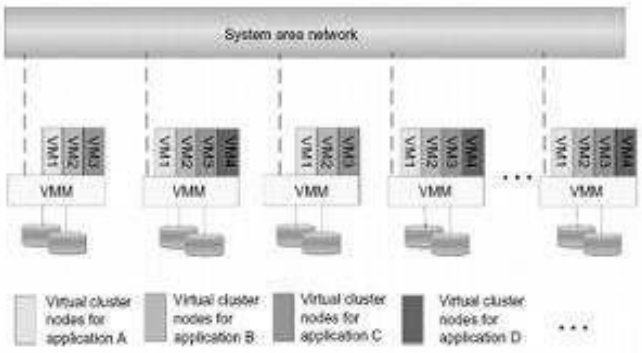
Virtual memory virtualization is similar to the virtual memory support provided by modern operating systems. In a traditional execution environment, the operating system maintains mappings of virtual memory to machine memory using page tables, which is a one-stage mapping from virtual memory to machine memory. All modern x86 CPUs include a memory management unit (MMU) and a translation look aside buffer (TLB) to optimize virtual memory performance.

However, in a virtual execution environment, virtual memory virtualization involves sharing the physical system memory in RAM and dynamically allocating it to the physical memory of the VMs.That means a two-stage mapping process should be maintained by the guest OS and the VMM, respectively: virtual memory to physical memory and physical memory to machine memory.

Furthermore, MMU virtualization should be supported, which is transparent to the guest OS. The guest OS continues to control the mapping of virtual addresses to the physical memory addresses of VMs. But the guest OS cannot directly access the actual machine memory. The VMM is responsible for mapping the guest physical memory to the actual machine memory, shows the two-level memory mapping procedure.

Two-level memory mapping procedure. Courtesy of R. Rblig, et al. Since each page table of the guest OSes has a separate page table in the VMM corresponding to it, the VMM page table is called the shadow page table. Nested page tables add another layer of indirection to virtual memory.

A Virtual Clusters based on Application Partitioning:



Virtual Clusters Projects:

Project Name	Design Objectives	Reported Results and References
Cluster-on-Demand at Duke Univ.	Dynamic resource allocation with a virtual cluster management system	Sharing of VMs by multiple virtual clusters using Sun GridEngine [12]
Cellular Disco at Stanford Univ.	To deploy a virtual cluster on a shared-memory multiprocessor	VMs deployed on multiple processors under a VMM called Cellular Disco [8]
VIOLIN at Purdue Univ.	Multiple VM clustering to prove the advantage of dynamic adaptation	Reduce execution time of applications running VIOLIN with adaptation [25,55]
GRAAL Project at INRIA in France	Performance of parallel algorithms in Xen-enabled virtual clusters	75% of max. performance achieved with 30% resource slacks over VM clusters

The MMU already handles virtual-to-physical translations as defined by the OS. Then the physical memory addresses are translated to machine addresses using another set of page tables defined by the hypervisor. Since modern operating systems maintain a set of page tables for every process, the shadow page tables will get flooded.

Consequently, the performance overhead and cost of memory will be very high. VMware uses shadow page tables to perform virtual memory- to-machine-memory address translation. Processors use TLB hardware to map the virtual memory directly to the machine memory to avoid the two levels of translation on every access. When the guest OS changes the virtual memory to a physical memory mapping, the VMM updates the shadow page tables to enable a direct lookup.

The AMD Barcelona processor has featured hardware-assisted memory virtualization since 2007. It provides hardware assistance to the two-stage address translation in a virtual execution environment by using a technology called nested paging.

I/O Virtualization

I/O virtualization involves managing the routing of I/O requests between virtual devices and the shared physical hardware. At the time of this writing, there are three ways to implement I/O virtualization: full device emulation, para-virtualization, and direct I/Full device emulation is the first approach for I/O virtualization. Generally, this approach emulates well-known, real-world devices. All the functions of a device or bus infrastructure, such as device enumeration, identification, interrupts, and DMA, are replicated in software. This software is located in the VMM and acts as a virtual device. The I/O access requests of the guest OS are trapped in the VMM which interacts with the I/O devices. Device emulation for I/O virtualization implemented inside the middle layer that maps real I/O devices into the virtual devices for the guest device driver to use. Courtesy of V. Chadha, et al. and Y. Dong, et al. A single hardware device can be shared by multiple VMs that run concurrently. However, software emulation runs much slower than the hardware it emulates.

The para-virtualization method of I/O virtualization is typically used in Xen. It is also known as the split driver model consisting of a frontend driver and a backend driver. The frontend driver is running in Domain U and the backend driver is running in Domain 0. They interact with each other via a block of shared memory.

The frontend driver manages the I/O requests of the guest OSes and the backend driver is responsible for managing the real I/O devices and multiplexing the I/O data of different VMs. Although para-I/O-virtualization achieves better device performance than full device emulation, it comes with a higher CPU overhead.

Direct I/O virtualization lets the VM access devices directly. It can achieve close-to-native performance without high CPU costs. However, current direct I/O virtualization implementations focus on networking for mainframes. There are a lot of challenges for commodity hardware devices.

For example, when a physical device is reclaimed (required by workload migration) for later reassignment, it may have been set to an arbitrary state (e.g., DMA to some arbitrary memory locations) that can function incorrectly or even crash the whole system.

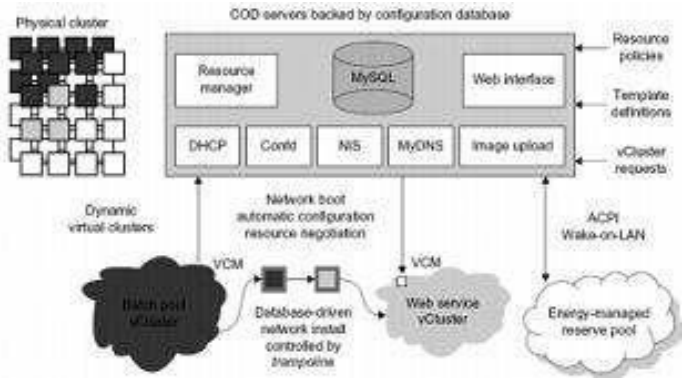
Since software based I/O virtualization requires a very high overhead of device emulation, hardware-assisted I/O virtualization is critical. Intel VT-d supports the remapping of I/O DMA transfers and device-generated interrupts. The architecture of VT-d provides the flexibility to support multiple usage models that may run unmodified, special-purpose, or ―virtualization-aware‖ guest OSes.

Another way to help I/O virtualization is via self-virtualized I/O (SV-IO) . The key idea of SVIO is to harness the rich resources of a multicore processor. All tasks associated with virtualizing an I/O device are encapsulated in SV-IO. It provides virtual devices and an associated access API to VMs and a management API to the VMM. SV-IO defines one virtual interface (VIF) for every kind of virtualized I/O device, such as virtual network interfaces, virtual block devices (disk), virtual camera devices, and others.

The guest OS interacts with the VIFs via VIF device drivers. Each VIF consists of two message queues. One is for outgoing messages to the devices and the other is for incoming messages from the devices. In addition, each VIF has a unique ID for identifying it in SV-IO.

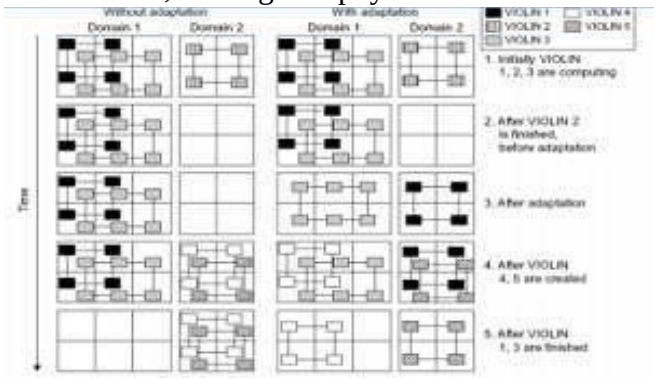
COD (Cluster-on-Demand) Project at Duke University:

DHCP (Dynamic Host Configuration Protocol); VCM (configuration Manager); NIS (Network Information Service)



VIOLIN Project at Purdue University

• Live VM migration to reconfigure a virtual cluster environment, Five concurrent virtual environment, labeled VIOLIN 1-5, sharing two physical clusters.



Virtualization Support at Intel

Virtual clusters and Resource Management

A physical cluster is a collection of servers (physical machines) interconnected by a physical network such as a LAN.

Let us study three critical design issues of virtual clusters: live migration of VMs, memory and file migrations, and dynamic deployment of virtual clusters.

When a traditional VM is initialized, the administrator needs to manually write configuration information or specify the configuration sources. When more VMs join a network, an inefficient configuration always causes problems with overloading or underutilization.

Amazon's Elastic Compute Cloud (EC2)is a good example of a web service that provides elastic computing power in a cloud. EC2 permits customers to create VMs and to manage user accounts over the time of their use.

Most virtualization platforms, including XenServer and VMware ESX Server, support a brid-ging mode which allows all domains to appear on the network as individual hosts. By using this mode, VMs can communicate with one another freely through the virtual network interface card and configure the network automatically.

Physical versus Virtual Clusters

Virtual clusters are built with VMs installed at distributed servers from one or more physical clusters. The VMs in a virtual cluster are interconnected logically by a virtual network across several physical networks.

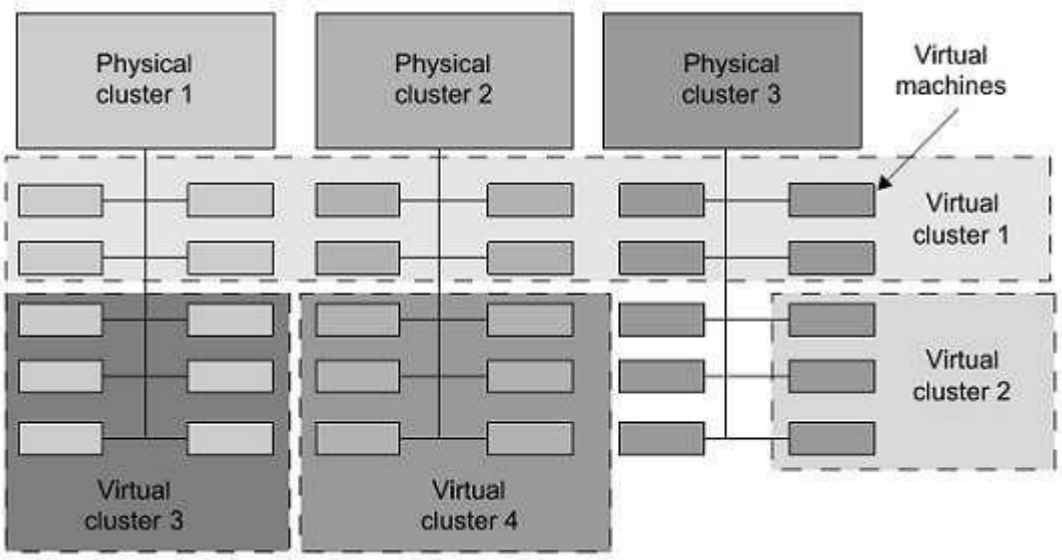
The below figure illustrates the concepts of virtual clusters and physical clusters. Each virtual cluster is formed with physical machines or a VM hosted by multiple physical clusters. The virtual cluster boundaries are shown as distinct boundaries.

The provisioning of VMs to a virtual cluster is done dynamically to have the following interesting properties:

• The virtual cluster nodes can be either physical or virtual machines. Multiple VMs running with different OSes can be deployed on the same physical node.

• A VM runs with a guest OS, which is often different from the host OS, that manages the resources in the physical machine, where the VM is implemented.

• The purpose of using VMs is to consolidate multiple functionalities on the same server. This will greatly enhance server utilization and application flexibility.



A cloud platform with four virtual clusters over three physical clusters shaded differently

• VMs can be colonized (replicated) in multiple servers for the purpose of promoting distributed parallelism, fault tolerance, and disaster recovery.
• The size of a virtual cluster can grow or shrink dynamically, similar to the way an overlay network varies in size in a peer-to-peer (P2P) network.
• The failure of any physical nodes may disable some VMs installed on the failing nodes. But the failure of VMs will not pull down the host system.

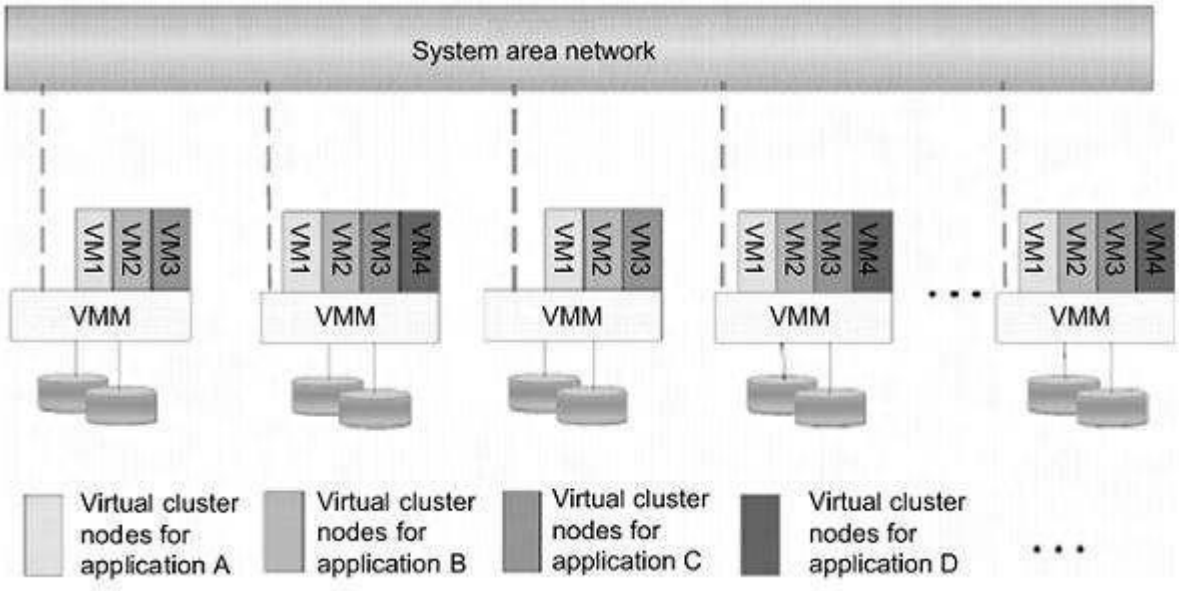
Since system virtualization has been widely used, it is necessary to effectively manage VMs running on a mass of physical computing nodes (also called virtual clusters) and consequently build a high-performance virtualized computing environment. This involves virtual cluster deployment, monitoring and management over large-scale clusters, as well as resource scheduling, load balancing, server consolidation, fault tolerance, and other techniques.

The different node colors in the figure above refer to different virtual clusters. In a virtual cluster system, it is quite important to store the large number of VM images efficiently.

The below figure shows the concept of a virtual cluster based on application partitioning or customization. The different colors in the figure represent the nodes in different virtual clusters. As a large number of VM images might be present, the most important thing is to determine how to store those images in the system efficiently. There are common installations for most users or applications, such as operating systems or user-level programming libraries. These software packages can be preinstalled as templates.

With these templates, users can build their own software stacks. New OS instances can be copied from the template VM. User-specific components such as programming libraries and applications can be installed to those instances.

Three physical clusters are shown on the left side of figure below. Four virtual clusters are created on the right, over the physical clusters. The physical machines are also called host systems.



Concept of a virtual cluster based on application partitioning

In contrast, the VMs are guest systems. The host and guest systems may run with different operating systems. Each VM can be installed on a remote server or replicated on multiple servers belonging to the same or different physical clusters. The boundary of a virtual cluster can change as VM nodes are added, removed, or migrated dynamically over time.

Fast Deployment and Effective Scheduling

The system should have the capability of fast deployment. Here, deployment means two things: to construct and distribute software stacks (OS, libraries, applications) to a physical node inside clusters as fast as possible, and to quickly switch runtime environments from one user's virtual cluster to another user's virtual cluster.

If one user finishes using his system, the corresponding virtual cluster should shut down or suspend quickly to save the resources to run other VMs for other users.

The concept of "green computing "has attracted much attention recently. However, previous approaches have focused on saving the energy cost of components in a single workstation without a global vision.

Consequently, they do not necessarily reduce the power consumption of the whole cluster. Other cluster-wide energy-efficient techniques can only be applied to homogeneous workstations and specific applications. The live migration of VMs allows workloads of one node to transfer to another node. However, it does not guarantee that VMs can randomly migrate among themselves.

In fact, the potential overhead caused by live migrations of VMs cannot be ignored. The overhead may have serious negative effects on cluster utilization, throughput and QoS issues. Therefore, the challenge is to determine how to design migration strategies to implement green computing without influencing the performance of clusters. Another advantage of virtualization is load balancing of applications in a virtual cluster. Load balancing can be achieved using the load index and frequency of user logins. The automatic scale-up and scale-down mechanism of a virtual cluster can be implemented based on this model.

Consequently, we can increase the resource utilization of nodes and shorten the response time of systems. Mapping VMs onto the most appropriate physical node should promote performance. Dynamically adjusting loads among nodes by live migration of VMs is desired, when the loads on cluster nodes become quite unbalanced.

High-Performance Virtual Storage

The template VM can be distributed to several physical hosts in the cluster to customize the VMs. In addition, existing software packages reduce the time for customization as well as switching virtual environments. It is important to efficiently manage the disk spaces occupied by template software packages.

Some storage architecture design can be applied to reduce duplicated blocks in a distributed file system of virtual clusters. Hash values are used to compare the contents of data blocks. Users have their own profiles which store the identification of the data blocks for corresponding VMs in a user-specific virtual cluster. New blocks are created when users modify the corresponding data.

Newly created blocks are identified in the users 'profiles. Basically, there are four steps to deploy a group of VMs onto a target cluster: preparing the disk image, conuring the VMs, choosing the destination nodes and executing the VM deployment command on every host. Many systems use templates to simplify the disk image preparation process.

A template is a disk image that includes a preinstalled operating system with or without certain application software. Users choose a proper template according to their requirements and make a duplicate of it as their own disk image. Templates could implement the COW (Copy on Write) format.

A new COW backup file is very small and easy to create and transfer. Therefore, it definitely reduces disk space consumption. In addition, VM deployment time is much shorter than that of copying the whole raw image file.

Every VM is configured with a name, disk image, network setting and allocated CPU and memory. One needs to record each VM configuration into a file. However, this method is inefficient when managing a large group of VMs. VMs with the same configurations could use predicted profiles to simplify the process.

In this scenario, the system configures the VMs according to the chosen pro-file. Most configuration items use the same settings, while some of them, such as UUID, VM name and IP address, are assigned with automatically calculated values. Normally, users do not care which host is running their VM.

A strategy to choose the proper destination host for any VM is needed. The deployment principle is to fulfil the VM requirement and to balance workloads among the whole host network.

Live VM Migration Steps and Performance Effects

In a cluster built with mixed nodes of host and guest systems, the normal method of operation is to run everything on the physical machine. When a VM fails, its role could be replaced by another VM on a different node, as long as they both run with the same guest OS.

In other words, a physical node can fail over to a VM on another host. This is different from physical-to-physical failover in a traditional physical cluster. The advantage is enhanced failover flexibility. The potential drawback is that a VM must stop playing its role if its residing host node fails. However, this problem can be mitigated with VM life migration.

The figure below shows the process of life migration of a VM from host A to host B. The migration copies the VM state file from the storage area to the host machine. There are four ways to manage a virtual cluster. First, we can use a guest-based manager, by which the cluster manager resides on a guest system. In this case, multiple VMs form a virtual cluster.

For example, openMosix is an open source Linux cluster running different guest systems on top of the Xen hypervisor. Another example is Sun's cluster Oasis, an experimental Solar is cluster of VMs supported by a VM ware VMM. Second, we can build a cluster manager on the host systems. The host-based manager supervises the guest systems and can restart the guest system on another physical machine.

A good example is the VMware HA system that can restart a guest system after failure. These two cluster management systems are either guest-only or host-only, but they do not mix. A third way to manage a virtual cluster is to use an independent cluster manager on both the host and guest systems. This will make infrastructure management more complex, however.

Finally, we can use an integrated cluster on the guest and host systems. This means the manager must be designed to distinguish between virtualized resources and physical resources. Various cluster management schemes can be greatly enhanced when VM life migration is enabled with minimal overhead.

VMs can be live-migrated from one physical machine to another; in case of failure, one VM can be replaced by another VM. Virtual clusters can be applied in computational grids, cloud platforms and high-performance computing (HPC) systems.

The major attraction of this scenario is that virtual clustering provides dynamic resources that can be quickly put together upon user demand or after a node failure.

In particular, virtual clustering plays a key role in cloud computing. When a VM runs a live service, it is necessary to make a trade-off to ensure that the migration occurs in a manner that minimizes all three metrics. The motivation is to design a live VM migration scheme with negligible downtime, the lowest network bandwidth consumption possible and a reasonable total migration time.

Furthermore, we should ensure that the migration will not disrupt other active services residing in the same host through resource contention (e.g., CPU, network bandwidth). A VM can be in one of the following four states. An inactive state is defined by the virtualization platform, under which the VM is not enabled.

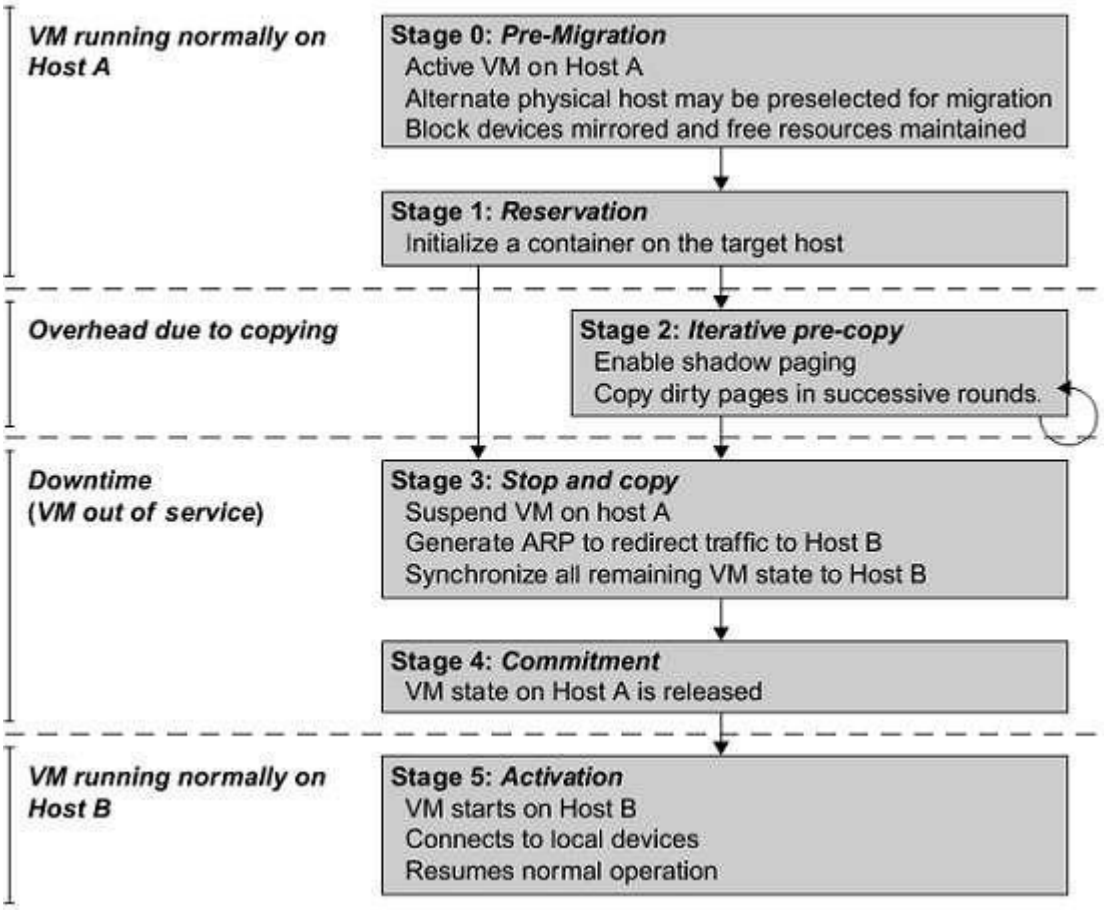
An active state refers to a VM that has been instantiated at the virtualization platform to perform a real task. A paused state corresponds to a VM that has been instantiated but disabled to process a task or paused in a waiting state. A VM enters the suspended state if its machine file and virtual resources are stored back to the disk.

As shown in the figure below, live migration of a VM consists of the following six steps:

Steps 0 and 1: Start migration. This step makes preparations for the migration, including determining the migrating VM and the destination host. Although users could manually make a VM migrate to an appointed host, in most circumstances, the migration is automatically started by strategies such as load balancing and server consolidation.

Steps 2: Transfer memory. Since the whole execution state of the VM is stored in memory, sending the VM's memory to the destination node ensures continuity of the service provided by the VM. All of the memory data is transferred in the first round, and then the migration controller recopies the memory data which is changed in the last round.

These steps keep iterating until the dirty portion of the memory is small enough to handle the final copy. Although precopying memory is performed iteratively, the execution of programs is not obviously interrupted.



Live migration process of a VM from one host to another

Step 3: Suspend the VM and copy the last portion of the data. The migrating VM's execution is suspended when the last round's memory data is transferred. Other non-memory data such as CPU and network states should be sent as well.

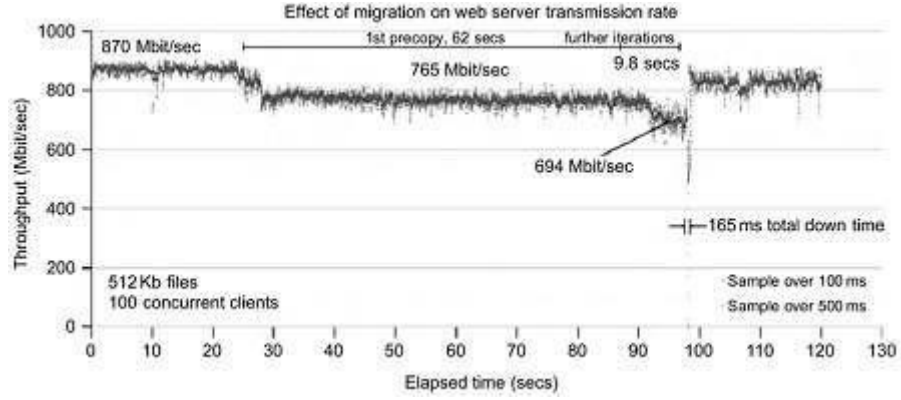
During this step, the VM is stopped and its applications will no longer run. This "service unavailable "time is called the "downtime "of migration, which should be as short as possible so that it can be negligible to users.

Steps 4 and 5: Commit and activate the new host. After all the needed data is copied, on the destination host, the VM reloads the states and recovers the execution of programs in it and the service provided by this VM continues. Then the network connection is redirected to the new VM and the dependency to the source host is cleared. The whole migration process finishes by removing the original VM from the source host.

The bellow figure shows the effect on the data transmission rate (Mbit/second) of live migration of a VM from one host to another. Before copying the VM with 512 KB files for 100 clients, the data throughput was 870 MB/second.

The first precopy takes 63 seconds, during which the rate is reduced to 765 MB/second. Then the data rate reduces to 694 MB/second in 9.8 seconds for more iterations of the copying process. The system experiences only 165 ms of downtime, before the VM is restored at the destination host. This experimental result shows a very small migration overhead in live transfer of a VM between host nodes. This is critical to achieve dynamic cluster reconfiguration and disaster recovery as needed in cloud computing.

With the emergence of widespread cluster computing more than a decade ago, many cluster configuration and management systems have been developed to achieve a range of goals. These goals naturally influence individual approaches to cluster management. VM technology has become a popular method for simplifying management and sharing of physical computing resources. Platforms such as VMware and Xen allow multiple VMs with different operating systems and configurations to coexist on the same physical host in mutual isolation. Clustering inexpensive computers is an effective way to obtain reliable, scalable computing power for network services and compute-intensive applications.



Effect on data transmission rate of a VM migrated from one failing web server to another

Migration of Memory, Files, and Network Resources

Since clusters have a high initial cost of ownership, including space, power conditioning, and cooling equipment, leasing or sharing access to a common cluster is an attractive solution when demands vary over time. Shared clusters offer economies of scale and more effective utilization of resources by multiplexing.

Early configuration and management systems focus on expressive and scalable mechanisms for defining clusters for specific types of service, and physically partition cluster nodes among those types. When one system migrates to another physical node, we should consider the following issues.

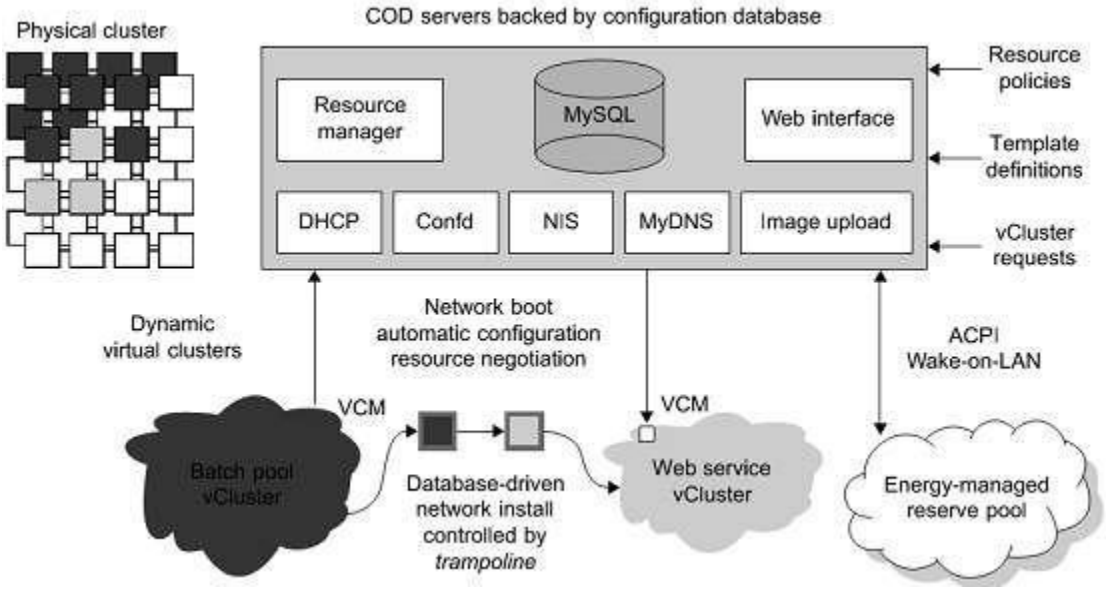
1. Memory Migration
2. File System Migration
3. Network Migration
4. Live Migration of VM Using Xen

Dynamic Deployment of Virtual Clusters

The below table summarizes four virtual cluster research projects. We briefly introduce them here just to identify their design objectives and reported results. The Cellular Disco at Stanford is a virtual cluster built in a shared-memory multiprocessor system. The INRIA virtual cluster was built to test parallel algorithm performance. The COD and VIOLIN clusters are studied in forthcoming examples.

Experimental Results on Four Research Virtual Clusters

Project Name	Design Objectives	Reported Results and References
Cluster-on-Demand at Duke Univ.	Dynamic resource allocation with a virtual cluster management system	Sharing of VMs by multiple virtual clusters using Sun GridEngine [12]
Cellular Disco at Stanford Univ.	To deploy a virtual cluster on a shared-memory multiprocessor	VMs deployed on multiple processors under a VMM called Cellular Disco [8]
VIOLIN at Purdue Univ.	Multiple VM clustering to prove the advantage of dynamic adaptation	Reduce execution time of applications running VIOLIN with adaptation [25,55]
GRAAL Project at INRIA in France	Performance of parallel algorithms in Xen-enabled virtual clusters	75% of max. performance achieved with 30% resource slacks over VM clusters

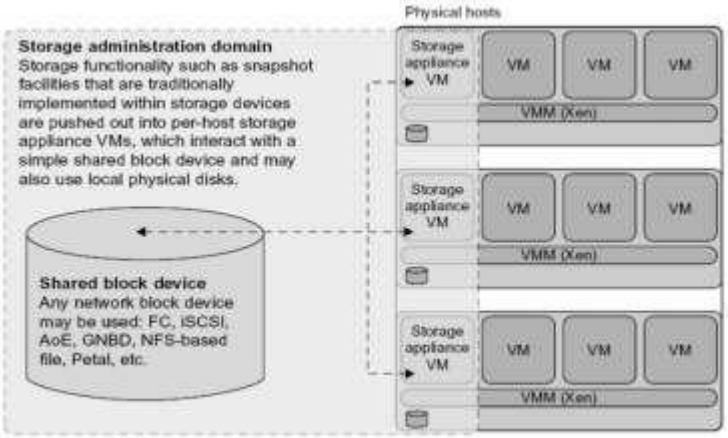


COD partitioning a physical cluster into multiple virtual clusters

Virtualization for data center automation

1. Virtual Storage Management
2. Cloud OS for Virtualized Data Centers
3. Trust Management in Virtualized Data Centers
4. VM-based Intrusion Detection

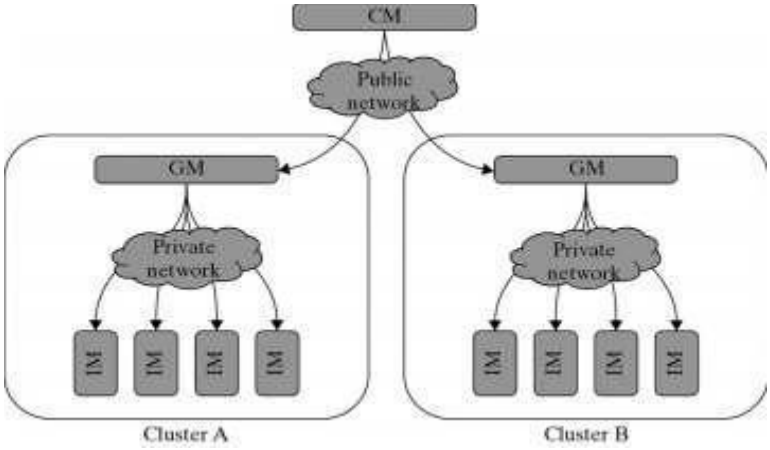
Parallax Providing Virtual Disks to Clients VMs from a Large Common Shared Physical Disk.



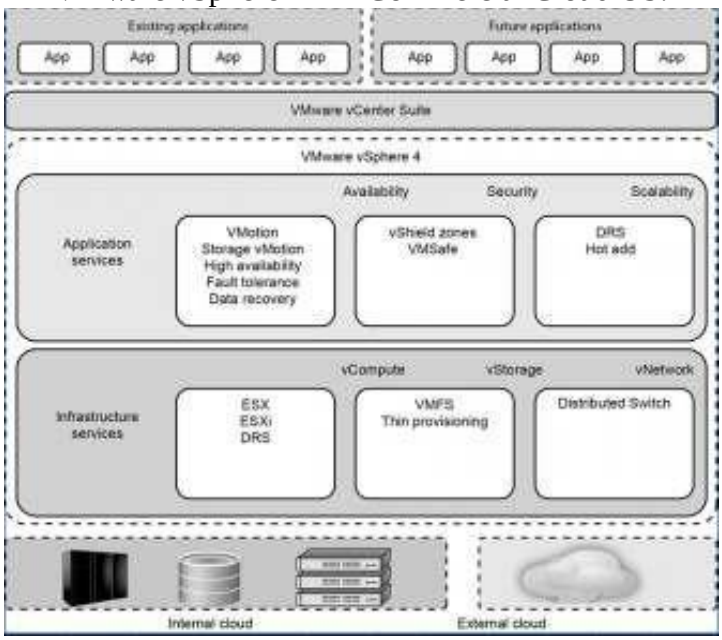
Cloud OS for Building Private Clouds (VI: Virtual Infrastructure, EC2: Elastic Compute Cloud).

Manager/ OS, Platforms, License	Resources Being Virtualized, Web Link	Client API, Language	Hypervisors Used	Public Cloud Interface	Special Features
Nimbus Linux, Apache v2	VM creation, virtual cluster, www .nimbusproject.org/	EC2 WS, WSRF, CLI	Xen, KVM	EC2	Virtual networks
Eucalyptus Linux, BSD	Virtual networking (Example 3.12 and [41]), www .eucalyptus.com/	EC2 WS, CLI	Xen, KVM	EC2	Virtual networks
OpenNebula Linux, Apache v2	Management of VM, host, virtual network, and scheduling tools, www.opennebula.org/	XML-RPC, CLI, Java	Xen, KVM	EC2, Elastic Host	Virtual networks, dynamic provisioning
vSphere 4 Linux, Windows, proprietary	Virtualizing OS for data centers (Example 3.13), www .vmware.com/ products/vsphere/ [66]	CLI, GUI, Portal, WS	VMware ESX, ESXi	VMware vCloud partners	Data protection, vStorage, VMFS, DRM, HA

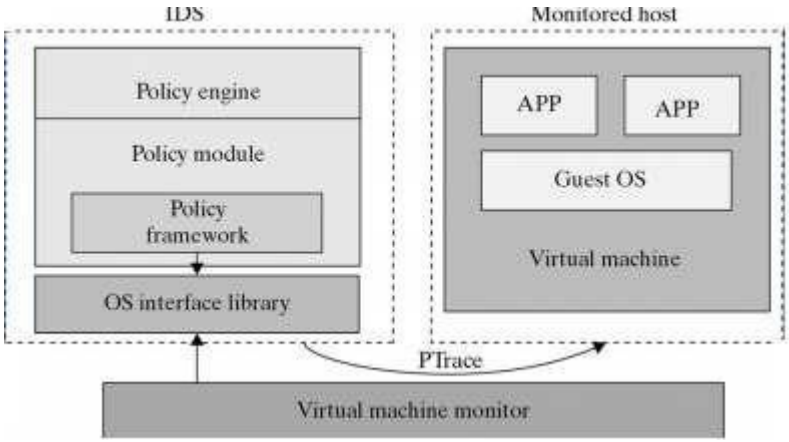
Eucalptus: An Open-Source OS for Setting Up and Managing Private Clouds (IaaS)
Three Resource Managers: CM (Cloud Manager), GM (Group Manager), and IM (Instance Manager)
Works like AWS APIs



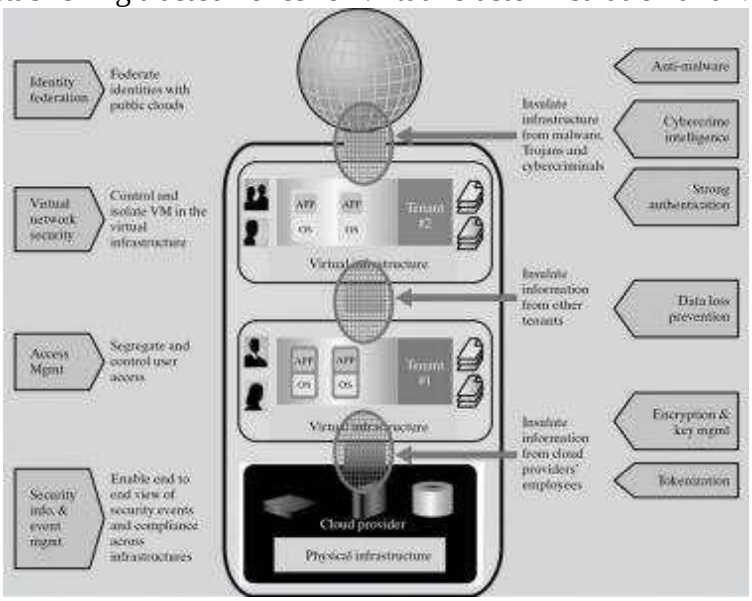
VMware vSphere 4 – A Commercial Cloud OS.



VM-based Intrusion Detection.



Techniques for establishing trusted zones for virtual cluster insulation and VM isolation.



UNIT-IV

PROGRAMMING MODEL

OPEN SOURCE GRID MIDDLEWARE PACKAGES

As reviewed in Berman, Fox, and Hey , many software, middleware, and programming environments have been developed for grid computing over past 15 years. Below we assess their relative strength and limitations based on recently reported applications. We first introduce some grid standards and popular APIs. Then we present the desired software support and middleware developed for grid computing includesfour grid middleware packages.

Grid Software Support and Middleware Packages
BOINC Berkeley Open Infrastructure for Network Computing.
UNICORE Middleware developed by the German grid computing community.

Globus (GT4) A middleware library jointly developed by Argonne National Lab., Univ. of Chicago, and USC Information Science Institute, funded by DARPA, NSF, and NIH. CGSP in ChinaGrid

The CGSP (ChinaGrid Support Platform) is a middleware library developed by 20 top universities in China as part of the ChinaGridProject .
Condor-G Originally developed at the Univ. of Wisconsin for general distributed computing, and later extended to Condor-G for grid job management. .

Sun Grid Engine (SGE)

Developed by Sun Microsystems for business grid applications.Applied to private grids and local clusters within enterprises or campuses.

Grid Standards and APIs

Grid standards have been developed over the years. The Open Grid Forum (formally Global Grid Forum) and Object Management Group are two well-formed organizations behind those standards. We have already introduced the OGSA (Open Grid Services Architecture) in standards including the GLUE for resource representation, SAGA (Simple API for Grid Applications), GSI (Grid Security Infrastructure), OGSI (Open Grid Service Infrastructure), and WSRE (Web Service Resource Framework).

The grid standards have guided the development of several middleware libraries and API tools for grid computing. They are applied in both research grids and production grids today. Research grids tested include the EGEE, France Grilles, D-Grid (German), CNGrid (China), TeraGrid (USA), etc. Production grids built with the standards include the EGEE, INFN grid (Italian), NorduGrid, Sun Grid, Techila, and Xgrid . We review next the software environments and middleware implementations based on these standards.

Software Support and Middleware

Grid middleware is specifically designed a layer between hardware and the software. The middleware products enable the sharing of heterogeneous resources and managing virtual organizations created around the grid. Middleware glues the allocated resources with specific user applications. Popular grid middleware tools include the Globus Toolkits (USA), gLight, UNICORE (German), BOINC (Berkeley), CGSP (China), Condor-G, and Sun Grid Engine, etc. summarizes the grid software support and middleware packages developed for grid systems since 1995. In subsequent sections, we will describe the features in Condor-G, SGE, GT4, and CGSP.

The Globus Toolkit Architecture (GT4)

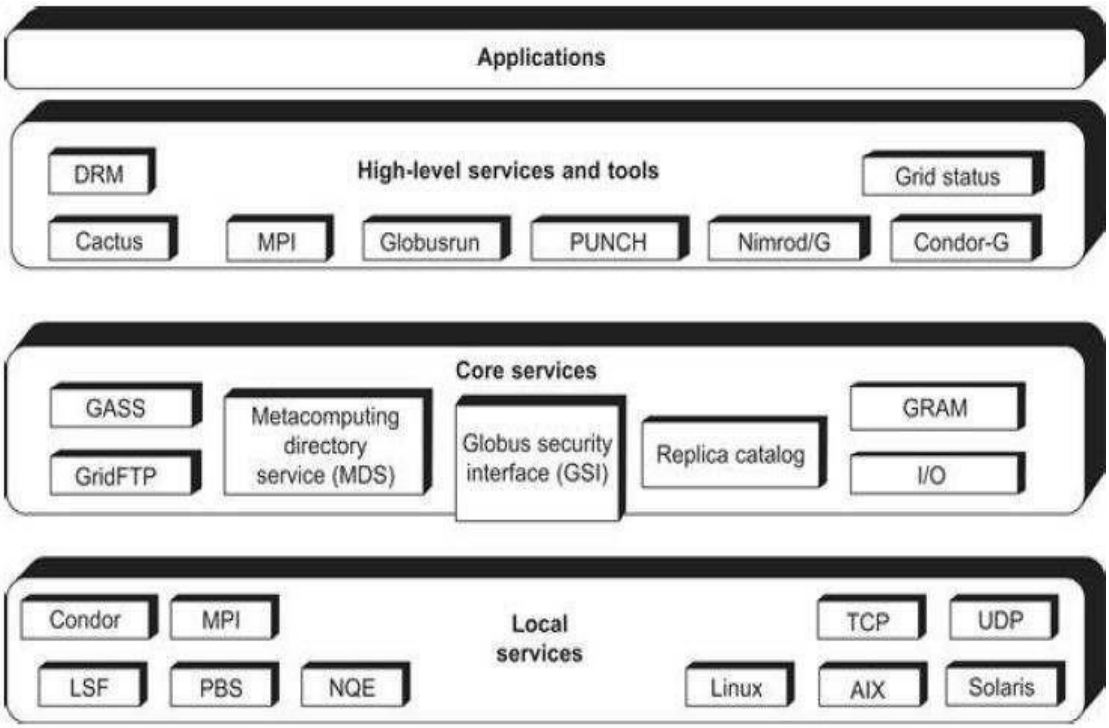
The Globus Toolkit, is an open middleware library for the grid computing communities. These open source software libraries support many operational grids and their applications on an international basis. The toolkit addresses common problems and issues related to grid resource discovery, management, communication, security, fault detection, and portability. The software itself provides a variety of components and capabilities. The library includes a rich set of service implementations.

The implemented software supports

- Grid infrastructure management,
- Provides tools for building new web services in Java, C, and Python,
- Builds a powerful std-based security infrastructure and client APIs (in diff languages)
- Offers comprehensive command-line programs for accessing various grid services.

The Globus Toolkit was initially motivated by a desire to remove obstacles that prevent seamless

Collaboration and thus sharing of resources and services, in scientific and engineering applications. The shared resources can be computers, storage, data, services, networks, science instruments (e.g., sensors), and so on. The Globus library version GT4, is conceptually shown in Figure



The GT4 Library

Globus Toolkit 4 provides components in the following five categories:

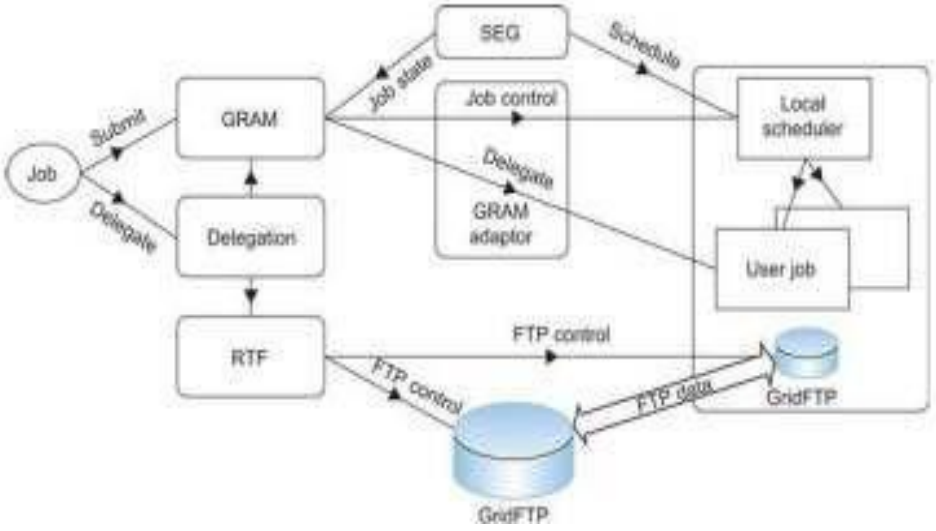
_ Common runtime components
_ Security
_ Data management
_ Information services
_ Execution management

Service Functionality	Module Name	Functional Description
Global Resource Allocation Manager	GRAM	Grid Resource Access and Management (HTTP-based)
Communication	Nexus	Unicast and multicast communication
Grid Security Infrastructure	GSI	Authentication and related security services
Monitory and Discovery Service	MDS	Distributed access to structure and state information
Health and Status	HBM	Heartbeat monitoring of system components
Global Access of Secondary Storage	GASS	Grid access of data in remote secondary storage
Grid File Transfer	GridFTP	Inter-node fast file transfer

GT4 offers the middle-level core services in grid applications. The high-level services and tools, such as MPI, Condor-G, and Nimrod/G, are developed by third parties for general purpose distributed computing applications. The local services, such as LSF, TCP, Linux, and Condor, are at the bottom level and are fundamental tools supplied by other developers. Nexus is used for collective communications and HBM for heartbeat monitoring of resource nodes. Grid FTP is for speeding up internode file transfers. The module GASS is used for global access of secondary storage. GSI (grid security infrastructure)

Globus Job Workflow

Figure shows the typical job workflow when using the Globus tools. A typical job execution sequence proceeds as follows: The user delegates his credentials to a delegation service. The user submits a job request to GRAM with the delegation identifier as a parameter. GRAM parses the request, retrieves the user proxy certificate from the delegation service, and then acts on behalf of the user. GRAM sends a transfer request to the RFT (Reliable File Transfer), which applies Grid FTP to bring in the necessary files.



Globus job workflow among interactive functional modules

GRAM invokes a local scheduler via a GRAM adapter and the SEG (Scheduler Event Generator) initiates a set of user jobs. The local scheduler reports the job state to the SEG. Once the job is complete, GRAM uses RFT and Grid FTP to stage out the resultant files. The grid monitors the progress of these operations and sends the user a notification when they succeed, fail, or are delayed.

Configuration Installing

Globus Toolkit 4

You may install Globus Toolkit 4 in many ways.
In this section, we introduce both binary and source package installation.
Installation of the binary package is extremely fast, while installation using the Source package will take longer, as would be expected

Installation from binary package

To install from a binary package:

1. Obtain the Globus Toolkit 4 binary package from the Globus site
2. 2. Extract the binary package as the Globus user
3. 3. Set environmental variables for the Globus location
4. 4. Create and change the ownership of directory for user and group Globus.
5. 5. Configure and install Globus Toolkit 4

Configuration and testing of grid environment
After the installation of the Globus Toolkit, each element of your grid environment Must be configured.

Configuring environmental variables
Before starting the configuration process, it is useful to set up the GLOBUS_LOCATION environmental variables in either /etc/profile or (User home)/.bash profile.

Security set up
In this book, we use Simple CA, which is a wrapper of Open SSL CA functionality.
Important: Before setting up a certificate authority (CA), make sure to Synchronize the system time of all the machines in your environment

Setting up security in each grid node
After performing the steps above, a package file has been created that needs to be used on other nodes, as described in this section. In order to use certificates from this CA in other grid nodes, you need to copy and install the CA setup package to each grid node.

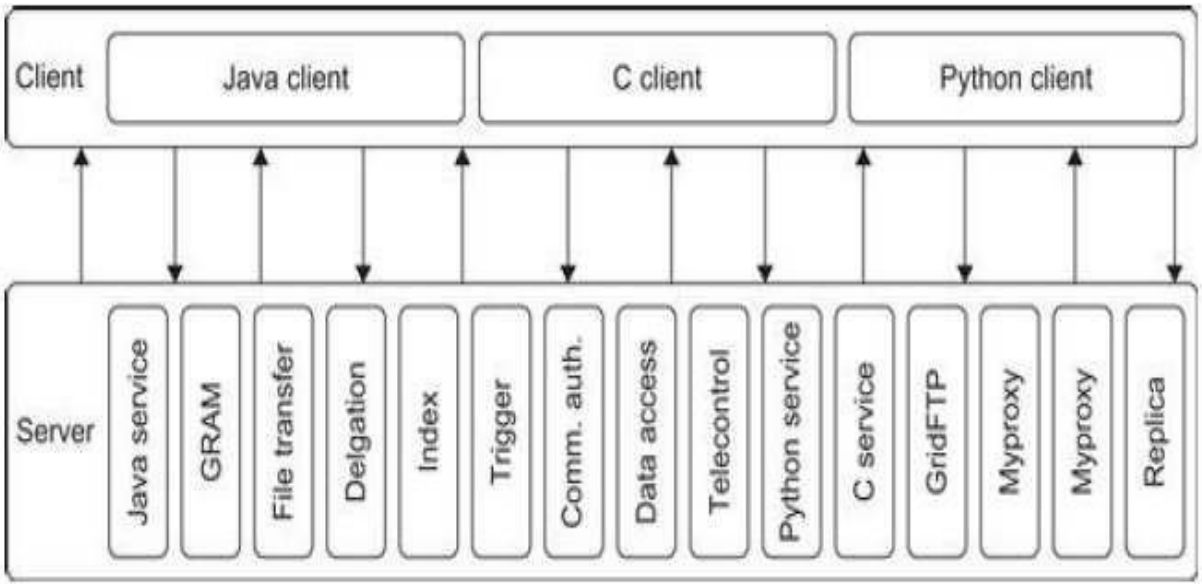
Obtain and sign a host certificate
In order to use some of the services provided by Globus Toolkit 4, such as Grid FTP, you need to have a CA signed host certificate and host key in the appropriate directory.
Set mapping information between a grid user and a local user
Globus Toolkit 4 requires a mapping between an authenticated grid user and a local user.
Configuration of Java WS Core
The Java WS Core container is installed as a part of the default Globus Toolkit 4 installation.

Usage of Globus

Client-Globus Interactions

GT4 service programs are designed to support user applications as illustrated in Figure. There are strong interactions between provider programs and user code. GT4 makes heavy use of industry-standard web service protocols and mechanisms in service description, discovery, access, authentication, authorization, and the like. GT4 makes extensive use of Java, C, and Python to write user code. Web service mechanisms define specific interfaces for grid computing. Web services provide flexible, extensible, and widely adopted XML-based interfaces.

Three containers are used to host user-developed services written in Java, Python, and C, respectively. These containers provide implementations of security, management, discovery, state management, and other mechanisms frequently required when building services. They



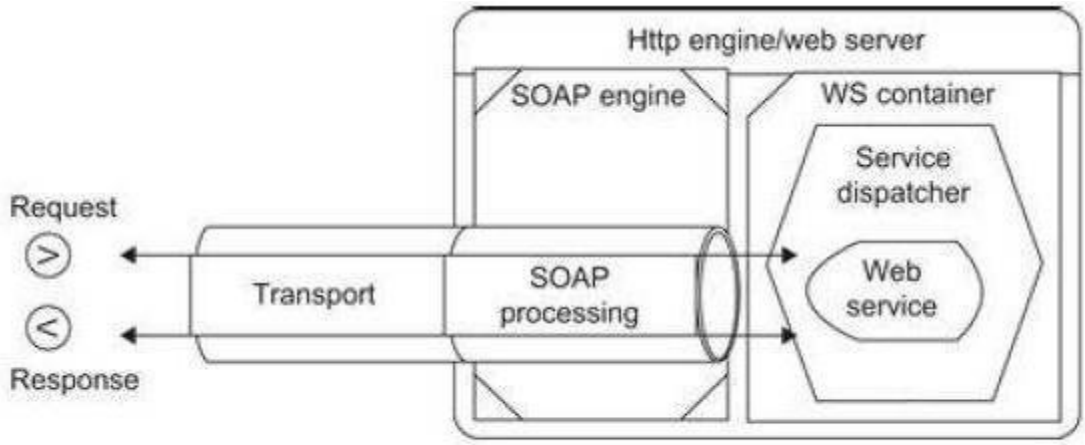
Extend open source service hosting environments with support for a range of useful web service specifications, including WSRF, WS-Notification, and WS-Security.

Containers and Resources/Data Management

GRAM supports dynamic job execution with coordinated file staging. MDS is used for monitoring and discovery of available grid resources in a grid execution environment.

Globus Container: A Runtime Environment

The Globus Container (also called a web service core or WS container) provides a basic runtime environment for hosting the web services needed to execute grid jobs. The container is built with heavy use of SOAP engines. The WS-addressing, WSRF, and WS-Notification functions are implemented.



(a) The globus container

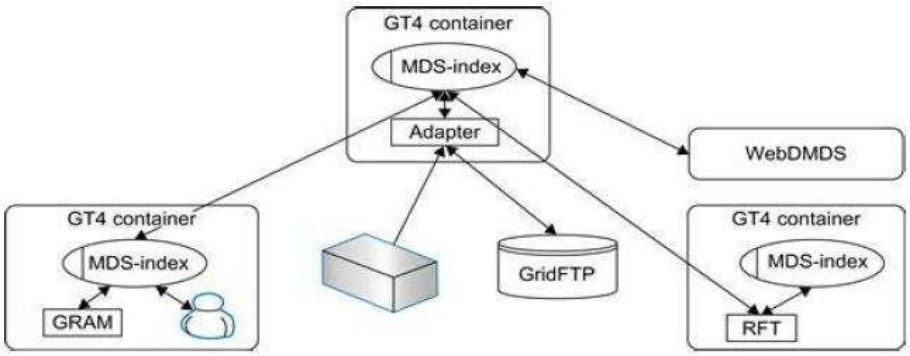
The main SOAP functions performed include the transport of incoming job requests and corresponding responses.
To implement the SOAP commands over the HTTP engine as a message transport protocol.
Both transport-level and message-level security is enforced in all communications.. GT4 container can host many services to multiple jobs simultaneously.
The container also hosts advanced services provided by GT4, such as GRAM, MDS, and RFT. The application clients use the Globus container registry interfaces to determine which services are hosted in a particular container.
The container administration interfaces are used to perform routine management functions. Web service containers written in Java, C, and Python in the GT4 suite.

Data Management Using GT4

Grid applications often need to provide access to and/or integrate large quantities of data at multiple sites. The following list briefly
Introduces these GT4 tools:
1. **Grid FTP** supports reliable, secure, and fast memory-to-memory and disk-to-disk data movement over high-bandwidth WANs. Based on the popular FTP protocol for Internet file transfer, Grid FTP adds additional features such as parallel data transfer, third-party data transfer, and striped data transfer. In addition, Grid FTP benefits from using the strong Globus Security Infrastructure (GSI to be studied in Section 7.5.5) for securing data channels with authentication and reusability. It has been reported that the grid has achieved 27 Gbit/second end-to-end transfer speeds over some WANs.
2. **RFT** provides reliable management of multiple Grid FTP transfers. It has been used to orchestrate the transfer of millions of files among many sites simultaneously.
3. **RLS** (Replica Location Service) is a scalable system for maintaining and providing access to information about the location of replicated files and data sets.
4. **OGSA-DAI** (Globus Data Access and Integration) tools were developed by the UK e-Science program and provide access to relational and XML databases.

The MDS Services

Monitoring and discovery are two vital functions in any distributed system. Both tasks require the ability to collect information from multiple distributed information sources.GT4 provides monitoring and discovery support at a fundamental level. GT4 enables the association of XML-based resource properties t to carry out MDS indexing, Grid FTP, and other functions needed to conduct monitoring and discovery of available resources. Grid services can be registered with distributed containers.



MDS4 consists of two higher-level services, an Index service and a Trigger Service

Index service:

_ Index services can be configured in hierarchies, but there is no single global index that provides information about every resource on the Grid.

_ The presence of a resource in an Index service makes no guarantee about the availability of the resource for users of that Index.

_ Information published with MDS is recent but not the absolute latest.

_ Each registration into an Index service has a lifetime and requires periodic renewal of registrations to indicate the continued existence of a resource or a service.

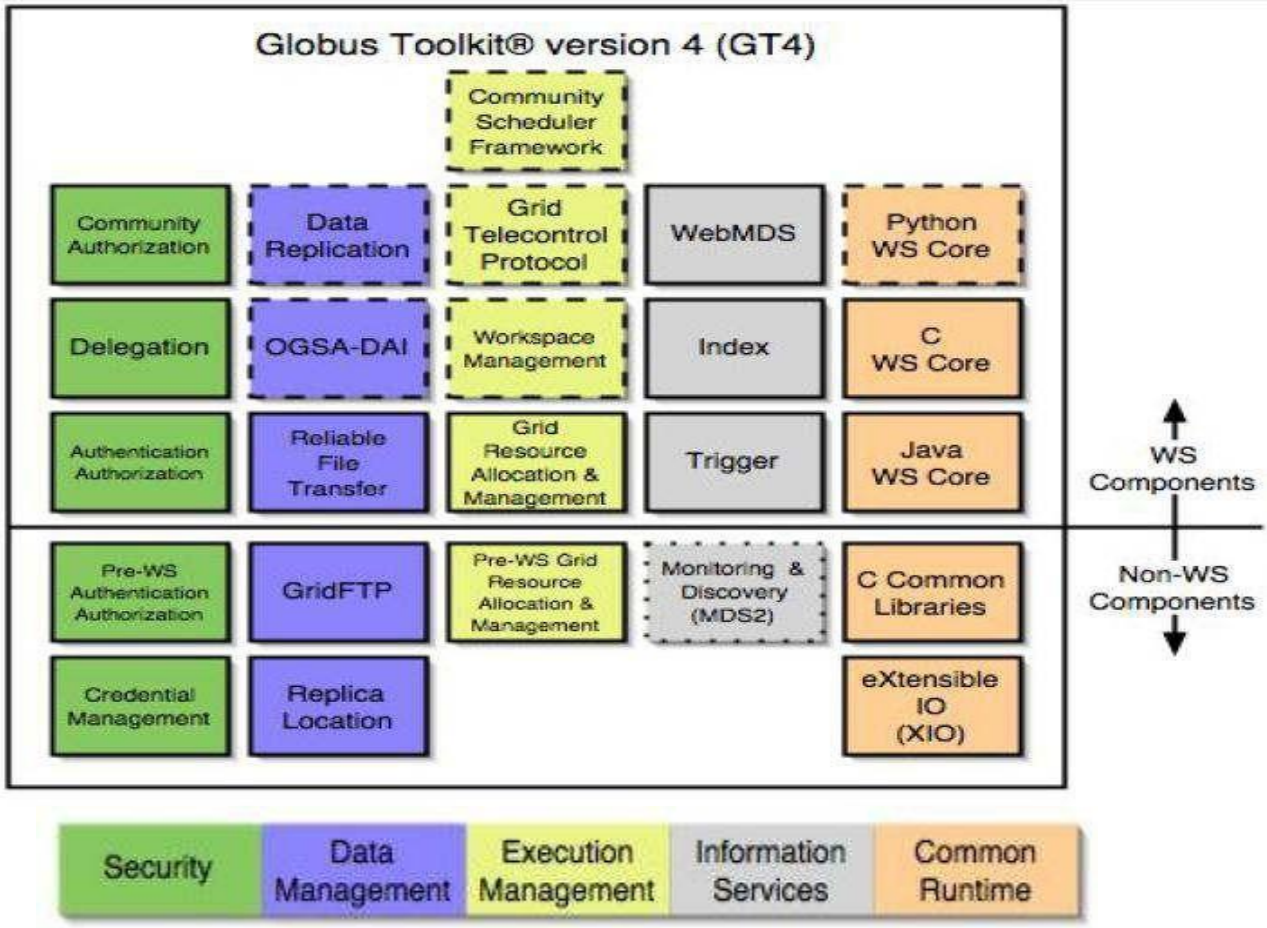
Trigger service

The MDS Trigger service collects information and compares that data against a set of conditions defined in a configuration file. When a condition is met an action is executed.

Web MDS

Web MDS is a Web-based interface to WS-RF resource property information that can be used as a user-friendly front-end to the Index service. Web MDS uses standard resource property requests to query resource property data and transforms data for a user-friendly display.

Main components and Programming Model



It is important to realize that the Globus Toolkit includes a lot of other components which can help us build Grid systems. Even so, the Java WS Core component is especially interesting because it is the base for most of the WS components. Note that we do not need to have in-depth knowledge about Java WS Core to use many GT4 components like GRAM, MDS, etc. However, if we want to build aGrid system that integrates all of these components with our own services, we will need to know about Java WS Core to actually "glue" all those services together and to program our own services.

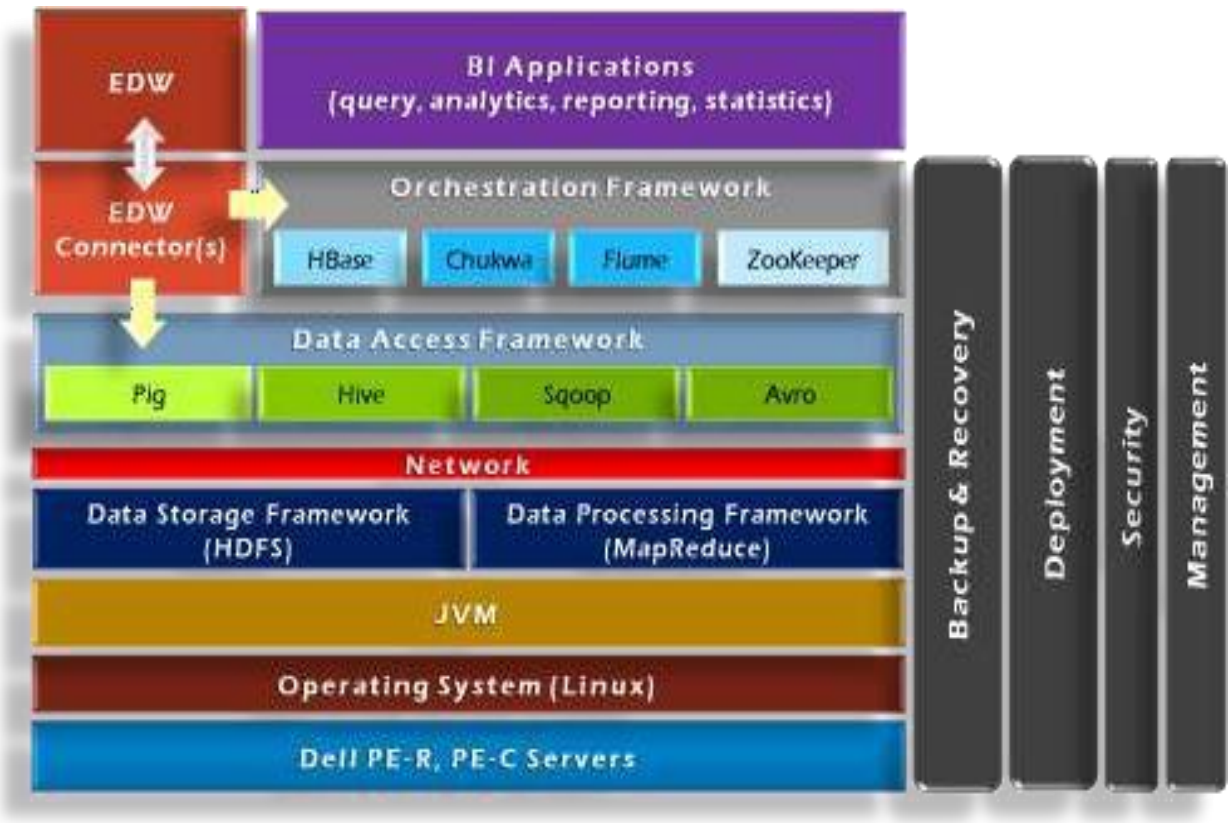
Introduction to Hadoop Framework

Apache Hadoop and the Hadoop Ecosystem

Although Hadoop is best known for Map Reduce and its distributed file system (HDFS,
Renamed from NDFS),

Map Reduce is a programming model for data processing. The model is simple, yet not
Too simple to express useful programs in. Hadoop can run Map Reduce programs written in various languages; in this chapter, we shall look at the same program expressed in Java, Ruby, Python, and C++. Most important, Map Reduce programs are inherently parallel, thus putting very large-scale data analysis into the hands of anyone with enough machines at their disposal. Map Reduce comes into its own for large datasets, so let's start by looking at one.
Analyzing the Data with Hadoop

To take advantage of the parallel processing that Hadoop provides, we need to express our query as a Map Reduce job. After some local, small-scale testing, we will be able torun it on a cluster of machines.



- Distributed, with some centralization
- Main nodes of cluster are where most of the computational power and storage of the system lies
- Main nodes run Task Tracker to accept and reply to Map Reduce tasks, and also Data Node to store needed blocks closely as possible
- Central control node runs Name Node to keep track of HDFS directories & files, and Job Tracker to dispatch compute tasks to Task Tracker
- Written in Java, also supports Python and Ruby

Map and Reduce

Map Reduce works by breaking the processing into two phases: the map phase and the reduce phase. Each phase has key-value pairs as input and output, the types of which may be chosen by the programmer. The programmer also specifies two functions: the map function and the reduce function

Anatomy of a Map Reduce Job Run

You can run a Map Reduce job with a single line of code: Job Client .run Job(conf). It's very short, but it conceals a great deal of processing behind the scenes. This section uncovers the steps Hadoop takes to run a job.

The whole process is illustrated in Figure. At the highest level, there are fourindependent entities:

- The client, which submits the Map Reduce job.
- The job tracker, which coordinates the job run. The job tracker is a Java application whose main class is Job Tracker.
- The task trackers, which run the tasks that the job has been split into. Task trackers are Java applications whose main class is Task Tracker.
- The distributed file system, which is usedfor sharing job files between the other entities.

Job Submission

The run Job () method on Job Client is a convenience method that creates a new Job Client instance and calls submit Job() on it (step 1). Having submitted the job, run Job() polls the job's progress once a second and reports the progress to the console if it has changed since the last report. When the job is complete, if it was successful, the job counters are displayed. Otherwise, the error that caused the job to fail is logged to the console.

The job submission process implemented by Job Client's submit Job() method does the following:

- Asks the job tracker for a new job ID (by calling get New Job Id () on Job Tracker) (step2).
- Checks the output specification of the job. For example, if the output directory has not been specified or it already exists, the job is not submitted and an error is thrown to the Map Reduce program.
- Computes the input splits for the job. If the splits cannot be computed, because the input paths don't exist, for example, then the job is not submitted and an error is thrown to the Map Reduce program.

• Copies the resources needed to run the job, including the job JAR file, the configuration file, and the computed input splits, to the job tracker's file system in a directory named after the job ID. The job JAR is copied with a high replication factor (controlled by the mapped. submit .replication property, which defaults to10) so that there are lots of copies across the cluster for the task trackers to access when they run tasks for the job (step 3).
• Tells the job tracker that the job is ready for execution (by calling submit Job() on Job Tracker) (step 4).

Job Initialization

When the Job Tracker receives a call to its submit Job() method, it puts it into an internal queue from where the job scheduler will pick it up and initialize it. Initialization involves creating an object to represent the job being run, which encapsulates its tasks, and bookkeeping information to keep track of the tasks' status and progress (step 5).

To create the list of tasks to run, the job scheduler first retrieves the input splits computed
by the Job Client from the shared file system (step 6). It then creates one map task for each split. The number of reduce tasks to create is determined by the mapped. Reduce. Tasks property in the Job Conf, which is set by the set Num Reduce Tasks() method, and the scheduler simply creates this number of reduce tasks to be run. Tasks are given IDs at this point.
• Tells the job tracker that the job is ready for execution (by calling submit Job() on Job Tracker) (step 4).

Input Splitting

Task Assignment

Task trackers run a simple loop that periodically sends heartbeat method calls to the job tracker. Heartbeats tell the job tracker that a task tracker is alive, but they also double as a channel for messages. As a part of the heartbeat, a task tracker will indicate whether it is ready to run a new task, and if it is, the job tracker will allocate it a task, which it communicates to the task tracker using the heartbeat return value (step 7).
Before it can choose a task for the task tracker, the job tracker must choose a job to select the task from.

Task Execution

Now that the task tracker has been assigned a task, the next step is for it to run the task. First, it localizes the job JAR by copying it from the shared file system to the task tracker's file system. It also copies any files needed from the distributed cache by the application to the local disk. Second, it creates a local working directory for the task, and un-jars the contents of the JAR into this directory. Third, it creates an instance of Task Runner to run the task. Task Runner launches a new Java Virtual Machine (step 9) to run each task in (step 10),so that any bugs in the user-defined map and reduce functions don't affect the task tracker(by causing it to crash or hang, for example). It is, however, possible to reuse the JVM between tasks.
The child process communicates with its parent through the umbilical interface. This way it informs the parent of the task's progress every few seconds until the task is complete.

Job Completion

When the job tracker receives a notification that the last task for a job is complete, it changes the status for the job to "successful." Then, when the Job Client polls for status, it learns that the job has completed successfully, so it prints a message to tell the user and then returns from the run Job() method.

Java Map Reduce

Having run through how the Map Reduce program works, the next step is to express it in code. We need three things: a map function, a reduce function, and some code to run the job. The map function is represented by an implementation of the Mapper interface, which declares a map() method.

Analyzing the Data with Hadoop

To take advantage of the parallel processing that Hadoop provides, we need to express our query as a Map Reduce job. After some local, small-scale testing, we will be able to run it on a cluster of machines.

HADOOP LIBRARY FROM APACHE

Hadoop is an open source implementation of Map Reduce coded and released in Java (rather than C) by Apache. The Hadoop implementation of Map Reduce uses the Hadoop Distributed File System (HDFS) as its underlying layer rather than GFS. The Hadoop core is divided into two fundamental layers: the Map Reduce engine and HDFS. The Map Reduce engine is the computation engine running on top of HDFS as its data storage manager. The following two sections cover the details of these two fundamental layers.

HDFS: HDFS is a distributed file system inspired by GFS that organizes files and stores their data on a distributed computing system.

HDFS Architecture: HDFS has a master/slave architecture containing a single Name Node as the master and a number of Data Nodes as workers (slaves). To store a file in this architecture, HDFS splits the file into fixed-size blocks (e.g., 64 MB) and stores them on workers (Data Nodes). The mapping of blocks to Data Nodes is determined by the Name Node. The Name Node (master) also manages the file system's metadata and namespace. In such systems, the namespace is the area maintaining the metadata, and metadata refers to all the information stored by a file system that is needed for overall management of all files. For example, Name Node in the metadata stores all information regarding the location of input splits/blocks in all Data Nodes. Each Data Node, usually one per node in a cluster, manages the storage attached to the node. Each Data Node is responsible for storing and retrieving its file blocks.

HDFS Features: Distributed file systems have special requirements, such as performance, scalability, concurrency control, fault tolerance, and security requirements, to operate efficiently. However, because HDFS is not a general-purpose file system, as it only executes specific types of applications, it does not need all the requirements of a general distributed file system. For example, security has never been supported for HDFS systems. The following discussion highlights two important characteristics of HDFS to distinguish it from other generic distributed file systems.

HDFS Fault Tolerance: One of the main aspects of HDFS is its fault tolerance characteristic. Since Hadoop is designed to be deployed on low-cost hardware by default, a hardware failure in this system is considered to be common rather than an exception. Therefore, Hadoop considers the following issues to fulfill reliability requirements of the file system:

• Block replication to reliably store data in HDFS, file blocks are replicated in this system. In other words, HDFS stores a file as a set of blocks and each block is replicated and distributed across the whole cluster. The replication factor is set by the user and is three by default.

• Replica placement the placement of replicas is another factor to fulfill the desired fault tolerance in HDFS. Although storing replicas on different nodes (Data Nodes) located in different racks across the whole cluster provides more reliability, it is sometimes ignored as the cost of communication between two nodes in different racks is relatively high in comparison with that of different nodes located in the same rack. Therefore, sometimes HDFS compromises its reliability to achieve lower communication costs. For example, for the default replication factor of three, HDFS stores one replica in the same node the original data is stored, one replica on a different node but in the same rack, and one replica on a different node in a different rack to provide three copies of the data .

• Heartbeat and Block report messages Heartbeats and Block reports are periodic messages sent to the Name Node by each Data Node in a cluster. Receipt of a Heartbeat implies that the Data Node is functioning properly, while each Block report contains a list of all blocks on a Data Node. The Name Node receives such messages because it is the sole decision maker of all replicas in the system.

HDFS High-Throughput Access to Large Data Sets (Files): Because HDFS is primarily designed for batch processing rather than interactive processing, data access throughput in HDFS is more important than latency. Also, because applications run on HDFS typically have large data sets, individual files are broken into large blocks (e.g., 64 MB) to allow HDFS to decrease the amount of metadata storage required per file. This provides two advantages: The list of blocks per file will shrink as the size of individual blocks increases, and by keeping large amounts of data sequentially within a block, HDFS provides fast streaming reads of data.

HDFS Operation: The control flow of HDFS operations such as write and read can properly highlight roles of the Name Node and Data Nodes in the managing operations. In this section, the control flow of the main operations of HDFS on files is further described to manifest the interaction between the user, the Name Node, and the Data Nodes in such systems.

• Reading a file to read a file in HDFS, a user sends an ―open‖ request to the Name Node to get the location of file blocks. For each file block, the Name Node returns the address of a set of Data Nodes containing replica information for the requested file. The number of addresses depends on the number of block replicas. Upon receiving such information, the user calls the read function to connect to the closest Data Node containing the first block of the file. After the first block is streamed from the respective Data Node to the user, the established connection is terminated and the same process is repeated for all blocks of the requested file until the whole file is streamed to the user.

• Writing to a file To write a file in HDFS, a user sends a ―create‖ request to the Name Node to create a new file in the file system namespace. If the file does not exist, the Name Node notifies the user and allows him to start writing data to the file by calling the write function. The first block of the file is written to an internal queue termed the data queue while a data streamer monitors its writing into a Data Node. Since each file block needs to be replicated by a predefined factor, the data streamer first sends a request to the Name Node to get a list of suitable Data Nodes to store replicas of the first block.

The steamer then stores the block in the first allocated Data Node. Afterward, the block is forwarded to the second Data Node by the first Data Node. The process continues until all allocated Data Nodes receive a replica of the first block from the previous Data Node.

Once this replication process is finalized, the same process starts for the second block and continues until all blocks of the file are stored and replicated on the file system.

Architecture of Map Reduce in Hadoop

The topmost layer of Hadoop is the Map Reduce engine that manages the data flow and control flow of Map Reduce jobs over distributed computing systems shows the Map Reduce engine architecture cooperating with HDFS. Similar to HDFS, the Map Reduce engine also has a master/slave architecture consisting of a single Job Tracker as the master and a number of Task Trackers as the slaves (workers). The Job Tracker manages the Map Reduce job over a cluster and is responsible for monitoring jobs and assigning tasks to Task Trackers. The Task Tracker manages the execution of the map and/or reduce tasks on a single computation node in the cluster. HDFS and Map Reduce architecture in Hadoop where boxes with different shadings refer to different functional nodes applied to different blocks of data.

Each Task Tracker node has a number of simultaneous execution slots, each executing either a map or a reduce task. Slots are defined as the number of simultaneous threads supported by CPUs of the Task Tracker node. For example, a Task Tracker node with N CPUs, each supporting M threads, has M * N simultaneous execution slots. It is worth noting that each data block is processed by one map task running on a single slot. Therefore, there is a one-to-one correspondence between map tasks in a Task Tracker and data blocks in the respective Data Node.

Map and Reduce functions

Map Reduce works by breaking the processing into two phases: the map phase and the reduce phase. Each phase has key-value pairs as input and output, the types of which may be chosen by the programmer. The programmer also specifies two functions: the map function and the reduce function.

The input to our map phase is the raw NCDC data. We choose a text input format that gives us each line in the dataset as a text value. The key is the offset of the beginning of the line from the beginning of the file, but as we have no need for this, we ignore it.

Our map function is simple. We pull out the year and the air temperature, since these are the only fields we are interested in. In this case, the map function is just a data preparation phase, setting up the data in such a way that the reducer function can do its work on it: finding the maximum temperature for each year. The map function is also a good place to drop bad records: here we filter out temperatures that are missing, suspect, or erroneous.
These lines are presented to the map function as the key-value pairs:

The keys are the line offsets within the file, which we ignore in our map function. The map function merely extracts the year and the air temperature (indicated in bold text),and emits them as its output (the temperature values have been interpreted as integers):

The output from the map function is processed by the Map Reduce framework before being sent to the reduce function. This processing sorts and groups the key-value pairs by key. So, continuing the example, our reduce function sees the following input:

Java Map Reduce

Having run through how the Map Reduce program works, the next step is to express it in code. We need three things: a map function, a reduce function, and some code to run the job. The map function is represented by an implementation of the Mapper interface, which declares a map() method.

The implementation of four map function.

```
public class Max Temperature Mapper extends Map Reduce Base
implements Mapper<Long Writable, Text, Text, Int Writable> {
private static final int MISSING = 9999;
public void map(Long Writable key, Text value,
Output Collector<Text, Int Writable> output, Reporter reporter)
throwsIOException {
String line = value.toString();
String year = line.substring(15, 19);
intairTemperature;
if (line.charAt(87) == '+') { // parseInt doesn't like leading plus signs
airTemperature = Integer.parseInt(line.substring(88, 92));
} else {
airTemperature = Integer.parseInt(line.substring(87, 92));
}
String quality = line.substring(92, 93);
if (airTemperature != MISSING &&quality.matches("[01459]")) {
output.collect(new Text(year), new IntWritable(airTemperature));
}
}
}
```

The Mapper interface is a generic type, with four formal type parameters that specify the input key, input value, output key, and output value types of the map function.

Hadoop provides its own set of basic types that are optimized for network serialization. These are found in the org.apache.hadoop.io package. Here we use Long Writable, which corresponds to a Java Long, Text (like Java String),and Int Writable(like Java Integer).

The map() method is passed a key and a value. We convert the Text value containing the line of input into a Java String, then use its substring() method to extract the columns we are interested in.

The map() method also provides an instance of Output Collector to write the output to.In this case, we write the year as a Text object (since we are just using it as a key), and the temperature is wrapped in an Int Writable. We write an output record only if the temperature is present and the quality code indicates the temperature reading is OK. The reduce function is similarly defined using a Reducer, as illustrated in Example 2-4.

Example 2-4. Reducer for maximum temperature example

```
importjava.io.IOException;
importjava.util.Iterator;
importorg.apache.hadoop.io.IntWritable;
importorg.apache.hadoop.io.Text;
importorg.apache.hadoop.mapred.MapReduceBase;
importorg.apache.hadoop.mapred.OutputCollector;
importorg.apache.hadoop.mapred.Reducer;
importorg.apache.hadoop.mapred.Reporter;
public class MaxTemperatureReducer extends MapReduceBase
implements Reducer<Text, IntWritable, Text, IntWritable> {
public void reduce(Text key, Iterator<IntWritable> values,
OutputCollector<Text, IntWritable> output, Reporter reporter)
throwsIOException {
intmaxValue = Integer.MIN_VALUE;
while (values.hasNext()) {
maxValue = Math.max(maxValue, values.next().get());
}
output.collect(key, new IntWritable(maxValue));}}
```

Again, four formal type parameters are used to specify the input and output types, this time for the reduce function. The input types of the reduce function must match the output types of the map function: Text and In Writable. And in this case, the output types of the reduce function are Text and Int Writable, for a year and its maximum The third piece of code runs the Map Reduce job (see Example 2-5).

Example 2-5. Application to find the maximum temperature in the weather dataset

```
importjava.io.IOException;
importorg.apache.hadoop.fs.Path;
importorg.apache.hadoop.io.IntWritable;
importorg.apache.hadoop.io.Text;
importorg.apache.hadoop.mapred.FileInputFormat;
importorg.apache.hadoop.mapred.FileOutputFormat;
importorg.apache.hadoop.mapred.JobClient;
importorg.apache.hadoop.mapred.JobConf;
public class MaxTemperature {
public static void main(String[] args) throws IOException {
if (args.length != 2) {
System.err.println("Usage: MaxTemperature<input path><output path>");
System.exit(-1);
}
JobConfconf = new JobConf(MaxTemperature.class);
conf.setJobName("Max temperature");
FileInputFormat.addInputPath(conf, new Path(args[0]));
FileOutputFormat.setOutputPath(conf, new Path(args[1]));
conf.setMapperClass(MaxTemperatureMapper.class);
conf.setReducerClass(MaxTemperatureReducer.class);
conf.setOutputKeyClass(Text.class);
conf.setOutputValueClass(IntWritable.class);
JobClient.runJob(conf);
}
}
```

A Job Conf object forms the specification of the job. It gives you control over how the job is run. When we run this job on a Hadoop cluster, we will package the code into a JAR file (which Hadoop will distribute around the cluster). Rather than explicitly specify the name of the JAR file, we can pass a class in the Job Conf constructor, which Hadoop will use to locate the relevant JAR file by looking for the JAR file containing this class.

Having constructed a Job Conf object, we specify the input and output paths. An input path is specified by calling the static add Input Path() method on File Input Format, and it can be a single file, a directory (in which case, the input forms all the files in that directory), or a file pattern. As the name suggests, add Input Path() can be called more than once to use input from multiple paths.

The output path (of which there is only one) is specified by the static set Output Path() method on File Output Format. It specifies a directory where the output files from the reducer functions are written. The directory shouldn't exist before running the job, as Hadoop will complain and not run the job. This precaution is to prevent data loss(it can be very annoying to accidentally overwrite the output of a long job with another).

Next, we specify the map and reduce types to use via the set Mapper Class() and Set Reducer Class() methods.

The set Output Key Class() and set Output Value Class() methods control the output types for the map and the reduce functions, which are often the same, as they are in our case. If they are different, then the map output types can be set using the methods set Map Output Key Class() and set Map Output Value Class().

The input types are controlled via the input format, which we have not explicitly set since we are using the default Text Input Format.

After setting the classes that define the map and reduce functions, we are ready to run the job. The static run Job() method on Job Client submits the job and waits for it to finish, writing information about its progress to the console.

Data Flow

First, some terminology. A Map Reduce job is a unit of work that the client wants to be performed: it consists of the input data, the Map Reduce program, and configuration information. Hadoop runs the job by dividing it into tasks, of which there are two types: map tasks and reduce tasks.

There are two types of nodes that control the job execution process: a job tracker and a number of task trackers. The job tracker coordinates all the jobs run on the system by scheduling tasks to run on task trackers. Task trackers run tasks and send progress reports to the job tracker, which keeps a record of the overall progress of each job. If a task fails, the job tracker can reschedule it on a different task tracker.

Hadoop divides the input to a Map Reduce job into fixed-size pieces called input splits, or just splits. Hadoop creates one map task for each split, which runs the user defined map function for each record in the split.

Having many splits means the time taken to process each split is small compared to the time to process the whole input. So if we are processing the splits in parallel, the processing is better load-balanced if the splits are small, since a faster machine will be able to process proportionally more splits over the course of the job than a slower machine. Even if the machines are identical, failed processes or other jobs running concurrently make load balancing desirable, and the quality of the load balancing increases as the splits become more fine-grained.

On the other hand, if splits are too small, then the overhead of managing the splits and of map task creation begins to dominate the total job execution time. For most jobs, a good split size tends to be the size of an HDFS block, 64 MB by default, although this can be changed for the cluster (for all newly created files), or specified when each file is created.

Hadoop does its best to run the map task on a node where the input data resides in HDFS. This is called the data locality optimization. It should now be clear why the optimal split size is the same as the block size: it is the largest size of input that can be guaranteed to be stored on a single node. If the split spanned two blocks, it would be unlikely that any HDFS node stored both blocks, so some of the split would have to be transferred across the network to the node running the map task, which is clearly less efficient than running the whole map task using local data.

Map tasks write their output to the local disk, not to HDFS. Why is this? Map output is intermediate output: it's processed by reduce tasks to produce the final output, and once the job is complete the map output can be thrown away. So storing it in HDFS, with replication, would be overkill. If the node running the map task fails before the map output has been consumed by the reduce task, then Hadoop will automatically run.

Specifying Input Output ParametersMap

Parameters

A record emitted from a map will be serialized into a buffer and metadata will be stored into accounting buffers. As described in the following options, when either the serialization buffer or the metadata exceed a threshold, the contents of the buffers will be sorted and written to disk in the background while the map continues to output records. If either buffer fills completely while the spill is in progress, the map thread will block. When the map is finished, any remaining records are written to disk and all on-disk segments are merged into a single file. Minimizing the number of spills to disk can decrease map time, but a larger buffer also decreases the memory available to the mapper.

Name	Type	Description
io.sort.mb	int	The cumulative size of the serialization and accounting buffers storing records emitted from the map, in megabytes.
io.sort.record.percent	float	The ratio of serialization to accounting space can be adjusted. Each serialized record requires 16 bytes of accounting information in addition to its serialized size to effect the sort. This percentage of space allocated from io.sort.mb affects the probability of a spill to disk being caused by either exhaustion of the serialization buffer or the accounting space. Clearly, for a map outputting small records, a higher value than the default will likely decrease the number of spills to disk.
io.sort.spill.percent	float	This is the threshold for the accounting and serialization buffers. When this percentage of either buffer has filled, their contents will be spilled to disk in the background. Let io.sort.record.percent be r, io.sort.mb be x, and this value be q. The maximum number of records collected before the collection thread will spill is r * x * q * 2^16. Note that a higher value may decrease the number of- or even eliminate- merges, but will also increase the probability of the map task getting blocked. The lowest average map times are usually obtained by accurately estimating the size of the map output and preventing multiple spills.

Other notes

- If either spill threshold is exceeded while a spill is in progress, collection will continue until the spill is finished. For example, if io.sort.buffer.spill.percent is set to 0.33, and the remainder of the buffer is filled while the spill runs, the next spill will include all the collected records, or 0.66 of the buffer, and will not generate additional spills. In other words, the thresholds are defining triggers, not blocking.
- A record larger than the serialization buffer will first trigger a spill, then be spilled to a separate file. It is undefined whether or not this record will first pass through the combiner.

Shuffle/Reduce Parameters

As described previously, each reduce fetches the output assigned to it by the Partitioner via HTTP into memory and periodically merges these outputs to disk. If intermediate compression of map outputs is turned on, each output is decompressed into memory. The following options affect the frequency of these merges to disk prior to the reduce and the memory allocated to map output during the reduce.

Name	Type	Description
io.sort.factor	int	Specifies the number of segments on disk to be merged at the same time. It limits the number of open files and compression codecs during the merge. If the number of files exceeds this limit, the merge will proceed in several passes. Though this limit also applies to the map, most jobs should be configured so that hitting this limit is unlikely there.

mapred.inmem.merge.threshold	int	The number of sorted map outputs fetched into memory before being merged to disk. Like the spill thresholds in the preceding note, this is not defining a unit of partition, but a trigger. In practice, this is usually set very high (1000) or disabled (0), since merging in-memory segments is often less expensive than merging from disk (see notes following this table). This threshold influences only the frequency of in-memory merges during the shuffle.
mapred.job.shuffle.merge.percent	float	The memory threshold for fetched map outputs before an in-memory merge is started, expressed as a percentage of memory allocated to storing map outputs in memory. Since map outputs that can't fit in memory can be stalled, setting this high may decrease parallelism between the fetch and merge. Conversely, values as high as 1.0 have been effective for reduces whose input can fit entirely in memory. This parameter influences only the frequency of in-memory merges during the shuffle.
mapred.job.shuffle.input.buffer.percent	float	The percentage of memory- relative to the maximum heapsize as typically specified in mapred.reduce.child.java.opts- that can be allocated to storing map outputs during the shuffle. Though some memory should be set aside for the framework, in general it is advantageous to set this high enough to store large and numerous map outputs.
mapred.job.reduce.input.buffer.percent	float	The percentage of memory relative to the maximum heapsize in which map outputs may be retained during the reduce. When the reduce begins, map outputs will be merged to disk until those that remain are under the resource limit this defines. By default, all map outputs are merged to disk before the reduce begins to maximize the memory available to the reduce. For less memory-intensive reduces, this should be increased to avoid trips to disk.

Configuring and Running a Job

Running a Job in Hadoop

Three components contribute in running a job in this system: a user node, a Job Tracker, and several Task Trackers. The data flow starts by calling the runJob(conf) function inside a user program running on the user node, in which conf is an object containing some tuning parameters for the Map Reduce framework and HDFS.

The runJob(conf) function and conf are comparable to the Map Reduce(Spec, &Results) function and Spec in the first implementation of Map Reduce by Google, depicts the data flow of running a Map Reduce job in Hadoop . Data flow in running a Map Reduce job at various task trackers using the Hadoop library.

• Job Submission Each job is submitted from a user node to the Job Tracker node that might be situated in a different node within the cluster through the following procedure:

• A user node asks for a new job ID from the Job Tracker and computes input file splits.

• The user node copies some resources, such as the job's JAR file, configuration file, and computed input splits, to the Job Tracker's file system.

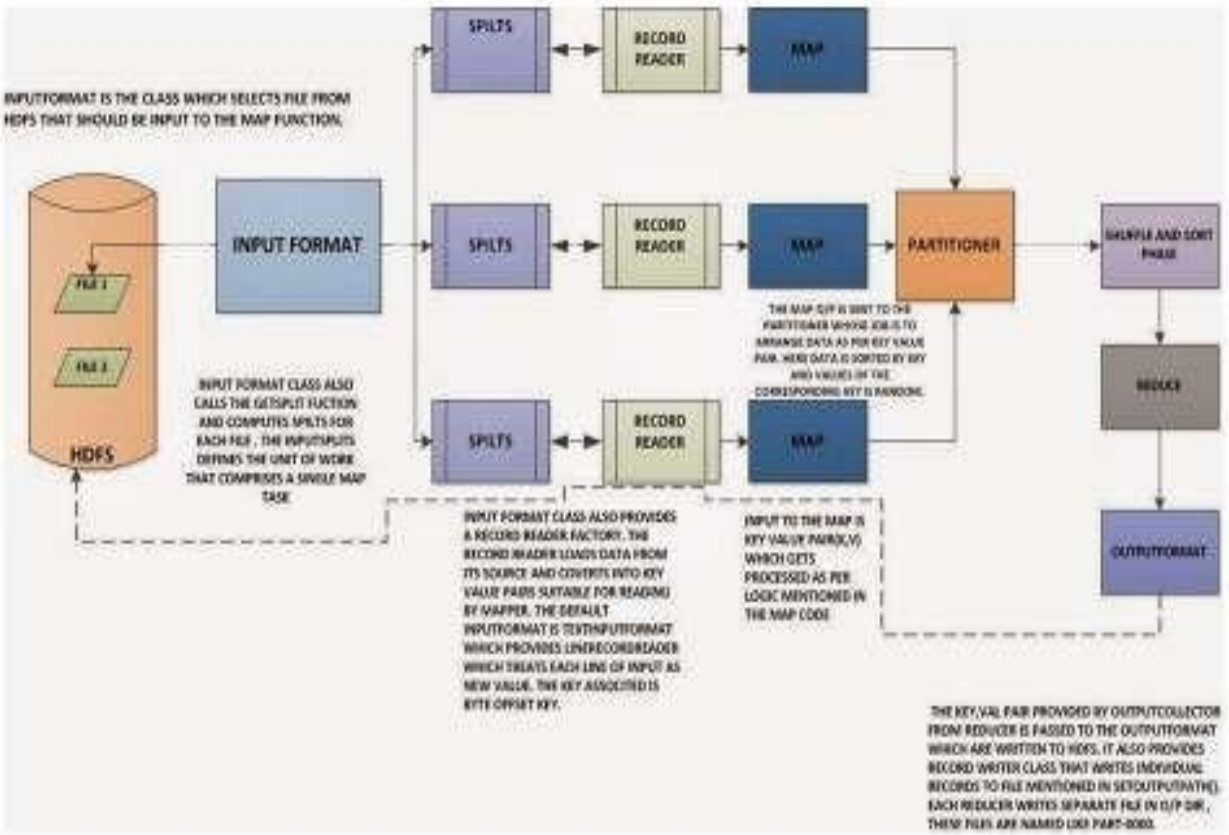
• The user node submits the job to the Job Tracker by calling the submitJob() function.

• Task assignment The Job Tracker creates one map task for each computed input split by the user node and assigns the map tasks to the execution slots of the Task Trackers.

The Job Tracker considers the localization of the data when assigning the map tasks to the Task Trackers. The Job Tracker also creates reduce tasks and assigns them to the Task Trackers. The number of reduce tasks is predetermined by the user, and there is no locality consideration in assigning them.

• Task execution The control flow to execute a task (either map or reduce) starts inside the Task Tracker by copying the job JAR file to its file system. Instructions inside the job JAR file are executed after launching a Java Virtual Machine (JVM) to run its map or reduce task.

• Task running check A task running check is performed by receiving periodic heartbeat messages to the Job Tracker from the Task Trackers. Each heartbeat notifies the Job Tracker that the sending Task Tracker is alive, and whether the sending Task Tracker is ready to run a new task.



Design of Hadoop file system

Basic File system Operations

The file system is ready to be used, and we can do all of the usual file system operations such as reading files, creating directories, moving files, deleting data, and listing directories. You can type hadoop fs -help to get detailed help on every command.

Start by copying a file from the local file system to HDFS:
% **hadoop fs –copy From Local input/docs/quangle.txt hdfs://localhost/user/tom/quangle.txt**

This command invokes Hadoop's file system shell command fs, which supports a number of subcommands—in this case, we are running –copy From Local. The local file quangle.txt is copied to the file /user/tom/quangle.txt on the HDFS instance running on local host. In fact, we could have omitted the scheme and host of the URI and picked

up the default, hdfs://localhost, as specified in core-site.xml.
% **hadoopfs -copyFromLocal input/docs/quangle.txt /user/tom/quangle.txt**

We could also have used a relative path, and copied the file to our home directory in HDFS, which in this case is /user/tom:

% **hadoopfs -copyFromLocal input/docs/quangle.txt quangle.txt**

Let's copy the file back to the local filesystem and check whether it's the same:
% **hadoopfs -copyToLocal quangle.txt quangle.copy.txt**
% **md5 input/docs/quangle.txt quangle.copy.txt**
MD5 (input/docs/quangle.txt) = a16f231da6b05e2ba7a339320e7dacd9
MD5 (quangle.copy.txt) = a16f231da6b05e2ba7a339320e7dacd9

The MD5 digests are the same, showing that the file survived its trip to HDFS and is back intact.

Finally, let's look at an HDFS file listing. We create a directory first just to see how it is displayed in the listing:
% **hadoopfs -mkdir books**
% **hadoopfs -ls .**
Found 2 items
drwxr-xr-x - tom supergroup 0 2009-04-02 22:41 /user/tom/books
-rw-r--r-- 1 tom supergroup 118 2009-04-02 22:29 /user/tom/quangle.txt

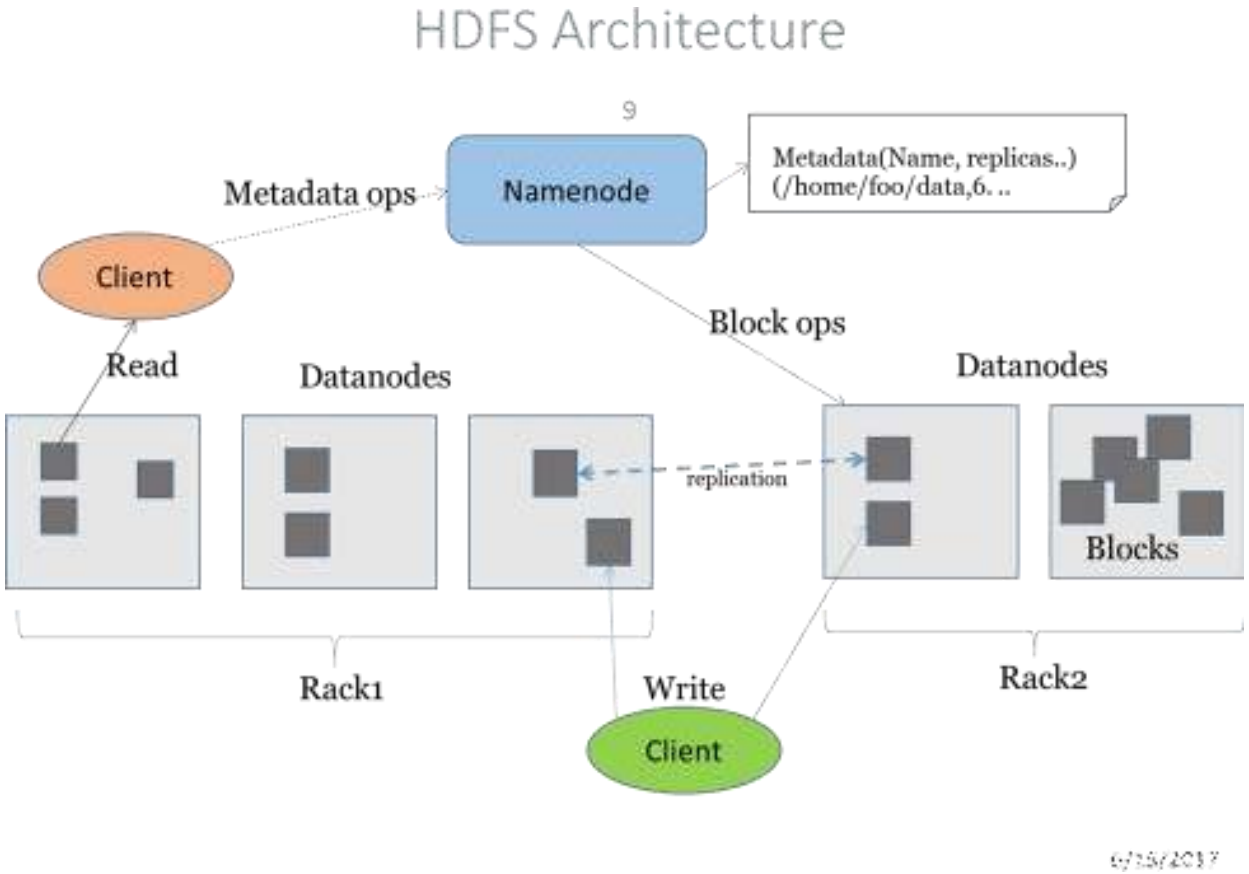
The information returned is very similar to the Unix command ls -l, with a few minor differences. The first column shows the file mode. The second column is the replication factor of the file (something a traditional Unixfilesystems does not have). Remember we set the default replication factor in the site-wide configuration to be 1, which is why we see the same value here. The entry in this column is empty for directories since the concept of replication does not apply to them—directories are treated as metadata and stored by the namenode, not the datanodes. The third and fourth columns show the file owner and group. The fifth column is the size of the file in bytes, or zero for directories. The six and seventh columns are the last modified date and time. Finally, the eighth column is the absolute name of the file or directory.

HDFS concepts

- Master/slave architecture
- HDFS cluster consists of a single Name node, a master server that manages the file system namespace and regulates access to files by clients.
- There are a number of Data Nodes usually one per node in a cluster.
- The Data Nodes manage storage attached to the nodes that they run on.
- HDFS exposes a file system namespace and allows user data to be stored in files.
- A file is split into one or more blocks and set of blocks are stored in Data Nodes.
- Data Nodes: serves read, write requests, performs block creation, deletion, and replication upon instruction from Name node.
- Hierarchical file system with directories and files
- Create, remove, move, rename etc.
- Name node maintains the file system
- Any meta information changes to the file system recorded by the Name node.
- An application can specify the number of replicas of the file needed: replication factor of the file. This information is stored in the Name node

Data Replication

- HDFS is designed to store very large files across machines in a large cluster.
- Each file is a sequence of blocks.
- All blocks in the file except the last are of the same size.
- Blocks are replicated for fault tolerance.
- Block size and replicas are configurable per file.
- The Name node receives a Heartbeat and a Block Report from each Data Node in the cluster.
- Block Report contains all the blocks on a Data node.



Command line interface in HDFS

There are many other interfaces to HDFS, but the command line is one of the simplest, and to many developers the most familiar. We are going to run HDFS on one machine, so first follow the instructions for setting up Hadoop in pseudo-distributed mode .Later you'll see how to run on a cluster of machines to give us scalability and fault tolerance.

There are two properties that we set in the pseudo-distributed configuration that deserve further explanation. The first is fs.default.name, set to hdfs://localhost/, which is used to set a default file system for Hadoop. File systems are specified by a URI, and here we have used a hdfs URI to configure Hadoop to use HDFS by default. The HDFS daemons will use this property to determine the host and port for the HDFS name node. We'll be running it on local host, on the default HDFS port, 8020. And HDFS clients will use this property to work out where the name node is running so they can connect to it.

We set the second property, dfs.replication, to one so that HDFS doesn't replicate file system blocks by the usual default of three. When running with a single data node, HDFS can't replicate blocks to three data nodes, so it would perpetually warn about blocks being under-replicated. This setting solves that problem.

The HDFS can be manipulated through a Java API or through a command line interface. ll commands for manipulating HDFS through Hadoop's command line interface begin with "hadoop", a space, and "fs". This is the file system shell. This is followed by the command name as an argument to "hadoop fs". These commands start with a dash. For example, the "ls" command for listing a directory is a common UNIX command and is preceded with a dash. As on UNIX systems, ls can take a path as an argument.

In this example, the path is the current directory, represented by a single dot. Let's begin looking at these HDFS commands by starting up Hadoop. We'll run the start.sh script to bring up each of the Hadoop nodes: first the Name Node, the Secondary Name Node, a Data Node, the Job Tracker, and a Task Tracker. Now we'll run the -ls command to give us the current directory.

As we saw for the "ls" command, the file system shell commands can take paths as arguments. These paths can be expressed in the form of uniform resource identifiers or URIs. The URI format consists of a scheme, an authority, and path. There are multiple schemes support. The local file system has a scheme of "file". HDFS has a scheme called "hdfs".

For example, let us say you wish to copy a file called "myfile.txt" from your local file system to an HDFS file system on the loca host. You can do this by issuing the command shown. The copy From Local command takes a URI for the source and a URI for the destination. The scheme and the authority do not always need to be specified. Instead you may rely on their default values. These defaults can be overridden by specifying them in a file named core-site.xml in the conf directory of your Hadoop installation.

Now let's examine the cop From Local command. We will copy a file named myfile.txt to the HDFS. Now we can just examine the HDFS with the -ls command and see that our file has been copied. And there it is. HDFS supports many POSIX-like commands. HDFS is not a fully POSIX compliant file system, but it supports many of the commands. The HDFS commands are mostly easily-recognized UNIX commands like cat and chmod. There are also a few commands that are specific to HDFS such as copy From Local.

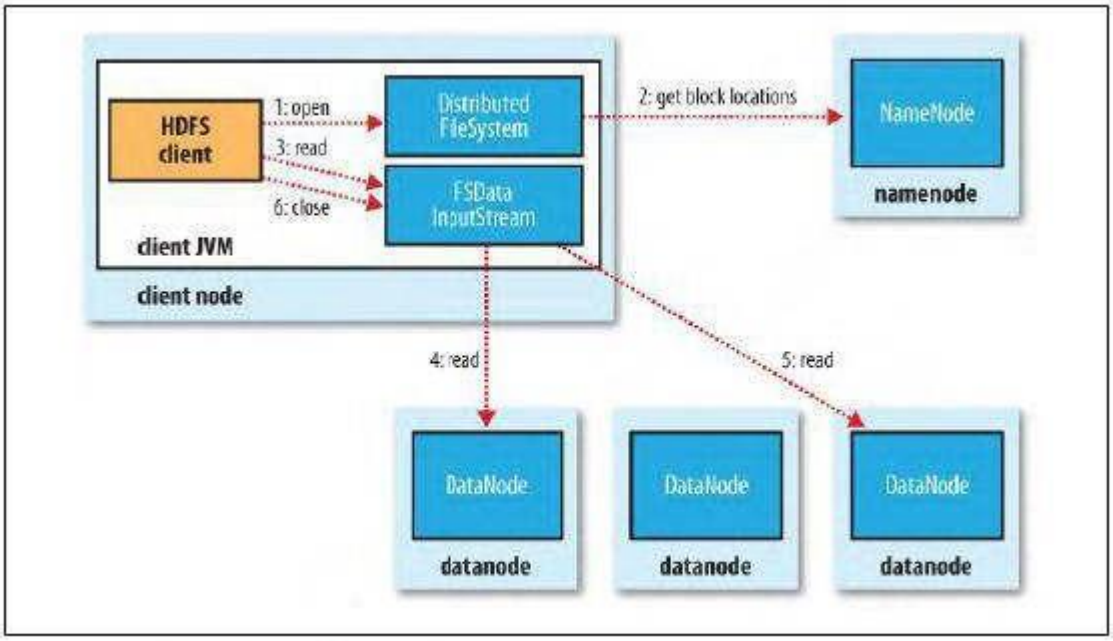
Copy from Local and put are two HDFS-specific commands that do the same thing - copy files from the local file system to a location on another file system. Their opposite is the copy To Local command which can also be referred to as get. This command copies files out of the file system you specify and into the local file system. Get merge is an enhanced form of get that can merge the files from multiple locations into a single local file.

Now let's try out the get merge command. First we will copy the myfile.txt into a second copy on the HDFS called myfile2.txt. Then we will use the get merge command to combine the two and write them as one file in the local file system called myfiles.txt. Now if we cat out the value, we see the text twice. setrep lets you override the default level of replication to a level you specify. You can do this for one file or, with the -R option, to an entire tree. This command returns immediately after requesting the new replication level. If you want the command to block until the job is done, pass the -w option.

Dataflow of file read and write in HDFS

Dataflow of file read in HDFS

To get an idea of how data flows between the client interacting with HDFS, the name node and the data node, consider the below diagram, which shows the main sequence of events when reading a file.



A client reading data from HDFS

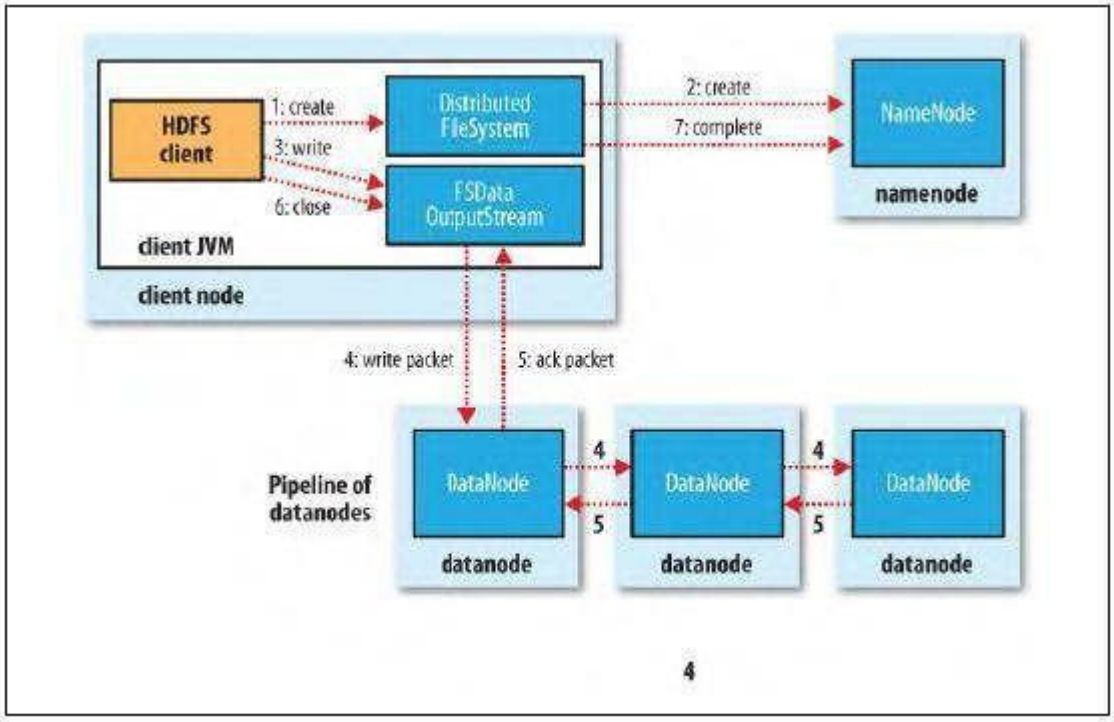
The client opens the file it wishes to read by calling open() on the File System object, which for HDFS is an instance of Distributed File System (step 1). Distributed File System calls the name node, using RPC, to determine the locations of the blocks for the first few blocks in the file (step 2). For each block, the name node returns the addresses of the data nodes that have a copy of that block. Furthermore, the data nodes are sorted according to their proximity to the client. If the client is itself a data node (in the case of a Map Reduce task, for instance), then it will read from the local data node.

The Distributed File System returns a FS Data Input Stream to the client for it to read data from. FS Data Input Stream in turn wraps a DFS Input Stream, which manages the data node and name node I/O. The client then calls read() on the stream (step 3). DFS Input Stream, which has stored the data node addresses for the first few blocks in the file, then connects to the first (closest) data node for the first block in the file. Data is streamed from the data node back to the client, which calls read() repeatedly on the stream (step 4). When the end of the block is reached, DFS Input Stream will close the connection to the data node, then find the best data node for the next block (step 5). This happens transparently to the client, which from its point of view is just reading a continuous stream. Blocks are read in order with the DFS Input Stream opening new connections to data nodes as the client reads through the stream. It will also call the name node to retrieve the data node locations for the next batch of blocks as needed. When the client has finished reading, it calls close() on the FS Data Input Stream (step 6).

One important aspect of this design is that the client contacts data nodes directly to retrieve data, and is guided by the name node to the best data node for each block. This design allows HDFS to scale to large number of concurrent clients, since the data traffic is spread across all the data nodes in the cluster. The name node meanwhile merely has to service block location requests (which it stores in memory, making them very efficient), and does not, for example, serve data, which would quickly become a bottleneck as the number of clients grew.

Dataflow of file write in HDFS

The case we're going to consider is the case of creating a new file, writing data to it, then closing the file.



A client writing data to HDFS

The client creates the file by calling create() on Distributed File System (step 1). Distributed File System makes an RPC call to the name node to create a new file in the file system's namespace, with no blocks associated with it (step 2). The name node performs various checks to make sure the file doesn't already exist, and that the client has the right permissions to create the file. If these checks pass, the name node makes a record of the new file; otherwise, file creation fails and the client is thrown an IO Exception. The Distributed File System returns a FS Data Output Stream for the client to start writing data to. Just as in the read case, FS Data Output Stream wraps a DFS Output Stream, which handles communication with the data nodes and name node.

As the client writes data (step 3), DFS Output Stream splits it into packets, which it writes to an internal queue, called the data queue. The data queue is consumed by the Data Streamer, whose responsibility it is to ask the name node to allocate new blocks by picking a list of suitable data nodes to store the replicas. The list of data nodes forms a pipeline—we'll assume the replication level is 3, so there are three nodes in the pipeline. The Data Streamer streams the packets to the first data node in the pipeline, which stores the packet and forwards it to the second data node in the pipeline. Similarly, the second data node stores the packet and forwards it to the third (and last) data node in the pipeline (step 4). DFS Output Stream also maintains an internal queue of packets that are waiting to be acknowledged by data nodes, called the ack queue. A packet is removed from the ack queue only when it has been acknowledged by all the data nodes in the pipeline (step 5).

If a data node fails while data is being written to it, then the following actions are taken, which are transparent to the client writing the data. First the pipeline is closed, and any packets in the ack queue are added to the front of the data queue so that data nodes that are downstream from the failed node will not miss any packets. The current block on the good data nodes is given a new identity, which is communicated to the name node, so that the partial block on the failed data node will be deleted if the failed data node recovers later on. The failed data node is removed from the pipeline and the remainder of the block's data is written to the two good data nodes in the pipeline. The name node notices that the block is under-replicated, and it arranges for a further replica to be created on another node. Subsequent blocks are then treated as normal.

When the client has finished writing data it calls close() on the stream (step 6). This action flushes all the remaining packets to the data node pipeline and waits for acknowledgments before contacting the name node to signal that the file is complete (step7). The name node already knows which blocks the file is made up of (via Data Streamer asking for block allocations), so it only has to wait for blocks to be minimally replicated before returning successfully.

Reading Data from a Hadoop URL and Deleting Data

The Hadoop's File System class: the API for interacting with one of Hadoop's file systems. While we focus mainly on the HDFS implementation, Distributed File System, in general you should strive to write your code against the File System abstract class, to retain portability across file systems. This is very useful when testing your program.

One of the simplest ways to read a file from a Hadoop file system is by using a java.net.URL object to open a stream to read the data from. The general idiom is:

```
try {
in = new URL("hdfs://host/path").openStream();
// process in
} finally {
IOUtils.closeStream(in);
}
```

There's a little bit more work required to make Java recognize Hadoop'shdfs URL scheme. This is achieved by calling the set URL Stream Handler Factory method on URL with an instance of Fs Url Stream Handler Factory. This method can only be called once per JVM, so it is typically executed in a static block. This limitation means that if some other part of your program perhaps a third-party component outside your control sets RL Stream Handler Factory, you won't be able to use this approach for reading data from Hadoop. The next section discusses an alternative. A program for displaying files from Hadoop file systems on standard output, like the Unix cat command.

We make use of the handy IOUtils class that comes with Hadoop for closing the stream in the finally clause, and also for copying bytes between the input stream and the output stream (System.out in this case). The last two arguments to the copyBytes method are the buffer size used for copying, and whether to close the streams when the copy is complete. We close the input stream ourselves, and System.out doesn't need to be closed.

Displaying files from a Hadoop filesystem on standard output using a URLStreamHandler

```
public class URLCat {

  static {
    URL.setURLStreamHandlerFactory(new FsUrlStreamHandlerFactory());
  }

  public static void main(String[] args) throws Exception {
    InputStream in = null;
    try {
      in = new URL(args[0]).openStream();
      IOUtils.copyBytes(in, System.out, 4096, false);
    } finally {
      IOUtils.closeStream(in);
    }
  }
}
```

Deleting Data

Use the delete() method on File System to permanently remove files or directories: public Boolean delete(Path f, boolean recursive) throws IOException. If f is a file or an empty directory, then the value of recursive is ignored. A nonempty directory is only deleted, along with its contents, if recursive is true (otherwise an IOException is thrown).

File pattern in HDFS

It is a common requirement to process sets of files in a single operation. For example, a Map Reduce job for log processing might analyze a month worth of files, contained in a number of directories. Rather than having to enumerate each file and directory to specify the input, it is convenient to use wildcard characters to match multiple files with a single expression, an operation that is known as globing. Hadoop provides two File System methods for processing globs:

publicFileStatus[] globStatus(Path pathPattern) throws IOException
publicFileStatus[] globStatus(Path pathPattern, PathFilter filter) throws IOException

The globStatus() methods returns an array of FileStatus objects whose paths match the supplied pattern, sorted by path. An optional PathFilter can be specified to restrict the matches further.

Glob characters and their meanings

Glob	Name	Matches
*	*asterisk*	Matches zero or more characters
?	*question mark*	Matches a single character
[ab]	*character class*	Matches a single character in the set {a, b}
[^ab]	*negated character class*	Matches a single character that is not in the set {a, b}
[a-b]	*character range*	Matches a single character in the (closed) range [a, b], where a is lexicographically less than or equal to b
[^a-b]	*negated character range*	Matches a single character that is not in the (closed) range [a, b], where a is lexicographically less than or equal to b
{a,b}	*alternation*	Matches either expression a or b
\c	*escaped character*	Matches character c when it is a metacharacter

Hadoop supports the same set of glob characters as Unixbash.

Imagine that logfiles are stored in a directory structure organized hierarchically by date. So, for example, logfiles for the last day of 2007 would go in a directory named /2007/12/31. Suppose that the full file listing is:

/2007/12/30
/2007/12/31
/2008/01/01
/2008/01/02

UNIT-V
SECURITY

Trust models for Grid security environment

Many potential security issues may occur in a grid environment includes network sniffers, out-of-control access, faulty operation, malicious operation, integration of local security mechanisms, delegation, dynamic resources and services, attack provenance, and so on. Computational grids are motivated by the desire to share processing resources among many organizations to solve large-scale problems. Indeed, grid sites may exhibit unacceptable security conditions and system vulnerabilities.

User job demands the resource site to provide security assurance by issuing a security demand (SD),trust index (TI). These two parameters must satisfy a security assurance condition: TI $\geq$ SD during the job mapping process. These attributes and their values are dynamically changing and depend heavily on the trust model, security policy, accumulated reputation, self-defense capability, attack history, and site vulnerability.

Three challenges are outlined below to establish the trust among grid sites.

1. Integration with existing systems and technologies. The resources sites in a grid are usually heterogeneous and autonomous.
2. Interoperability with different "hosting environments. "Services are often invoked across multiple domains, and need to be able to interact with one another.

Resource sharing among entities is one of the major goals of grid computing. A trust relationship must be established before the entities in the grid interoperate with one another. The grid aims to construct a large-scale network computing system by integrating distributed, heterogeneous, and autonomous resources.

The security challenges faced by the grid are much greater than other computing systems. Before any effective sharing and cooperation occurs, a trust relationship has to be established among participants.

Generalized Trust Model

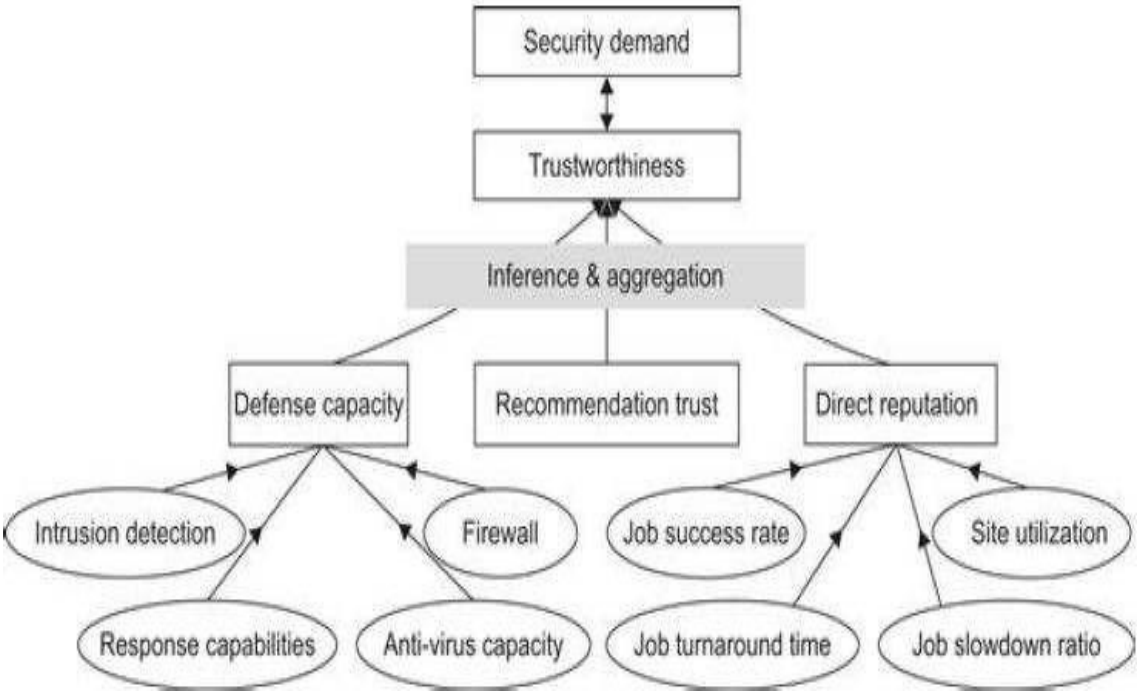


Figure shows a general trust model.

At the bottom, we identify three major factors which influence the trustworthiness of a resource site. An inference module is required to aggregate these factors. Followings are some existing inference or aggregation methods.

1. Defense capability is decided by the firewall, intrusion detection system (IDS), intrusion response capability, and anti-virus capacity of the individual resource site.
2. Direct reputation is decided based on the job success rate, site utilization, job turnaround time, and job slowdown ratio measured.
3. Recommended trust is also known as secondary trust and is obtained indirectly over the grid network

Reputation-Based Trust Model

In a reputation-based model, jobs are sent to a resource site only when the site is trustworthy to meet users' demands. The site trustworthiness is usually calculated from the following information:
1. Defense capability
2. Direct reputation, and
3. Recommendation trust.

The defense capability refers to the site's ability to protect itself from danger. It is assessed according to such factors as intrusion detection, firewall, response capabilities, anti-virus capacity, and so on.

Direct reputation is based on experiences of prior jobs previously submitted to the site. The reputation is measured by many factors such as prior job execution success rate, cumulative site utilization, job turnaround time, jobs lowdown ratio, and so on. A positive experience associated with a site will improve its reputation. On the contrary, a negative experience with a site will decrease its reputation.

A Fuzzy-Trust Model

In this model, the job security demand (SD) is supplied by the user programs. The trust index (TI) of a resource site is aggregated through the fuzzy-logic inference process over all related parameters.

The TI is normalized as a single real number with 0 representing the condition with the highest risk at a site and 1 representing the condition which is totally risk-free or fully trusted.

The fuzzy inference is accomplished through four steps: fuzzification, inference, aggregation, and defuzzification. The second salient feature of the trust model is that if a site's trust index cannot match the job security demand (i.e., SD > TI), the trust model could deduce detailed security features to guide the site security upgrade as a result of tuning the fuzzy system.

Authentication and Authorization Methods

The major authentication methods in the grid include

- ✓ Passwords, PKI, and Kerberos.

- The password is the simplest method to identify users, but the most vulnerable one to use.
- The PKI is the most popular method supported by GSI. To implement PKI, we use a trusted third party, called the certificate authority (CA). Each user applies a unique pair of public and private keys. The public keys are issued by the CA by issuing a certificate, after recognizing a legitimate user. The private key is exclusive for each user to use, and is unknown to any other users.
- A digital certificate in IEEE X.509 format consists of the username, user public key, CA name, and a secrete signature of the user. The following example illustrates the use of a PKI service in a grid environment.

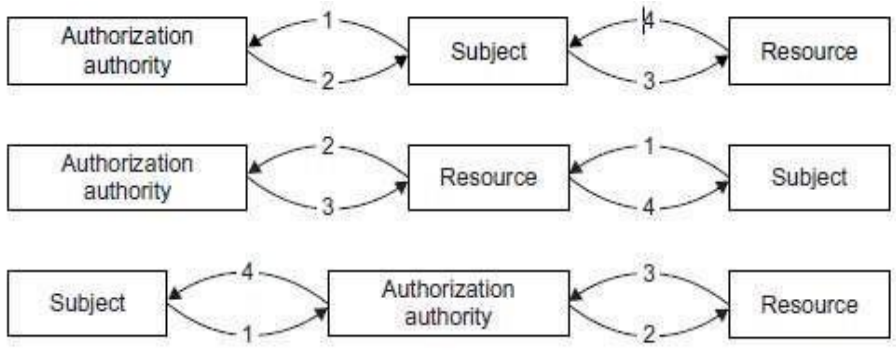
Authorization for Access Control

The authorization is a process to exercise access control of shared resources. Decisions can be made either at the access point of service or at a centralized place. Typically, there source is a host that provides processors and storage for services deployed on it. Based on a set predefined policies or rules, the resource may enforce access for local services.

The central authority is a special entity which is capable of issuing and revoking polices of access rights granted to remote accesses. The authority can be classified into three categories:

- attribute authorities,
- policy authorities, and
- Density authorities.

Attribute authorities issue attribute assertions; policy authorities issue authorization policies; identity authorities issue certificates. The authorization server makes the final authorization decision.



Three authorization models: the subject-push model, resource-pulling model, and the authorization agent model.

Three Authorization Models

The subject is the user and the resource refers to the machine side. The subject-push model is shown at the top diagram.
The user conducts handshake with the authority first and then with the resource site in a sequence. The resource-pulling model puts the resource in the middle.
The user checks there source first.
Then the resource contacts its authority to verify the request, and the authority authorizes at step the resource accepts or rejects the request from the subject at step 4.
The authorization agent model puts the authority in the middle. The subject check with the authority at step 1 and the authority makes decisions on the access of the requested resources.
The authorization process is complete at steps 3 and 4 in the reverse direction.

Grid Security Infrastructure (GSI)

The grid requires a security infrastructure with the following properties:
Easy to use;
Conforms to the VO's security needs while working well with site policies of each resource provider site;
Provides appropriate authentication and encryption of all interactions.
The GSI is an important step toward satisfying these requirements. As a well-known security solution in the grid environment,

GSI is a portion of the Globus Toolkit and provides fundamental security services needed to support grids, including supporting for

- message protection
- authentication and
- delegation,
- Authorization.

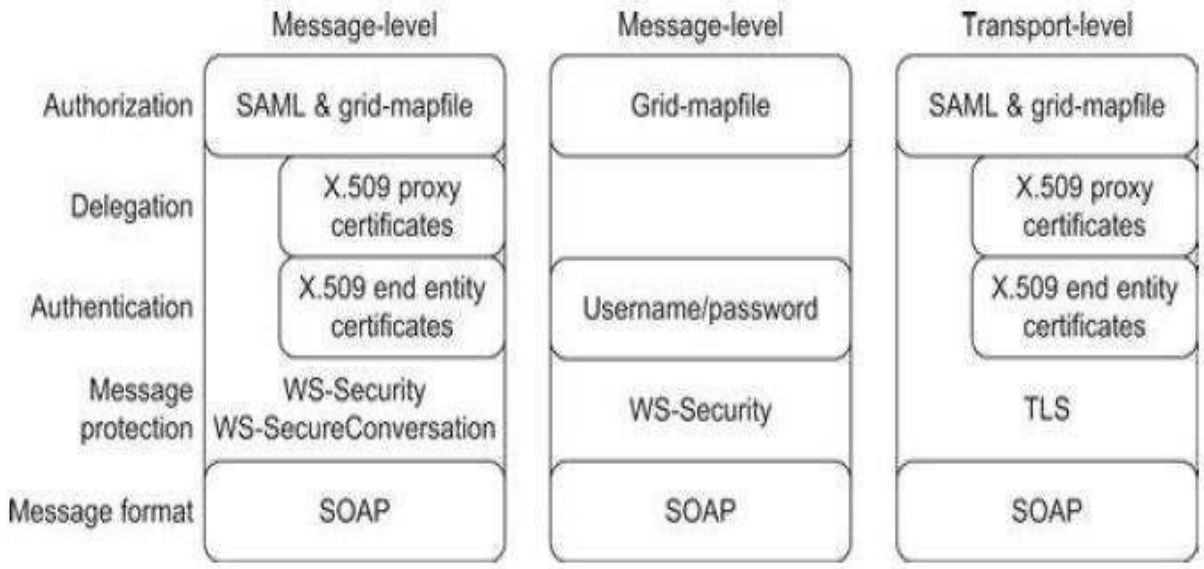
GSI enables secure authentication and communication over an open network, and permits mutual authentication across and among distributed sites with single sign-on capability. No centrally managed security system is required, and the grid maintains the integrity of its members' local policies. GSI supports both message-level security, which supports the WS-Security standard and the WS-Secure Conversation specification to provide message protection for SOAP messages, and transport-level security, which means authentication via TLS with support for X.509 proxy certificates.

GSI Functional Layers

GT4 provides distinct WS and pre-WS authentication and authorization capabilities. Both build on the same base, namely the

X.509 standard
Entity certificates
Proxy certificates

Which are used to identify persistent entities such as users and servers and to support the temporary delegation of privileges to other entities, respectively.



Message protection

TLS (transport-level security) or WS-Security and WS-Secure Conversation (message level)are used as mechanisms in combination with SOAP. X.509

Authentication

End Entity Certificates or Username and Password are used as authentication credentials.

Delegation

X.509 Proxy Certificates and WS-Trust are used for delegation.

Authorization

ACL, an ACL defined by a service, a custom authorization handler, and access to an authorization service via the SAML protocol.

The remainder of this section reviews both the GT implementations of each of these functions and the standards that are used in these implementations. The web services portions of GT4 use SOAP as their message protocol for communication. Message protection can be provided either by transport-level security, which transports SOAP messages over TLS, or by message-level security, which is signing and/or encrypting portions of the SOAP message using the WS-Security standard. Here we describe these two methods.

Transport-Level Security

Transport-level security entails SOAP messages conveyed over a network connection protected by TLS. TLS provides for both integrity protection and privacy (via encryption).

Transport-level security is normally used in conjunction with X.509 credentials for authentication.

Message-Level Security

GSI also provides message-level security for message protection for SOAP messages by implementing the WS-Security standard and the WS-Secure Conversation specification.
The WS-Security standard from OASIS defines a framework for applying security to individual SOAP messages;

WS-Secure Conversation is a proposed standard from IBM and Microsoft that allows for an initial exchange of messages to establish a security context which can then be used to protect subsequent messages in a manner that requires less computational overhead.
GSI, as described further in the subsequent section on authentication, allows for both X.509public key credentials and the combination of username and password for authentication;

GSI allows three additional protection mechanisms.

- The first is integrity protection, by which a receiver can verify that messages were not altered in transit from the sender.
- The second is encryption, by which messages can be protected to provide confidentiality.
- The third is replay prevention, by which a receiver can verify that it has not received the same message previously.

These protections are provided between WS-Security and WS-Secure Conversation. The former applies the keys associated with the sender and receiver'sX.509 credentials. The X.509 credentials are used to establish a session key that is used to provide the message protection.

Authentication and Delegation

GSI has traditionally supported authentication and delegation through the use of X.509certificates and public keys. As a new feature in GT4, GSI also supports authentication through plain usernames and passwords as a deployment option.
As a central concept in GSI authentication, a certificate includes four primary pieces of information:
(1) A subject name, which identifies the person or object that the certificate represents;
(2) The public key belonging to the subject;
(3) The identity of a CA that has signed the certificate to certify that the public key and the identity both belong to the subject; and
(4) The digital signature of the named CA. X.509 provides each entity with a unique identifier (i.e., a distinguished name) and a method to assert that identifier to another party through the use of an asymmetric key pair bound to the identifier by the certificate.

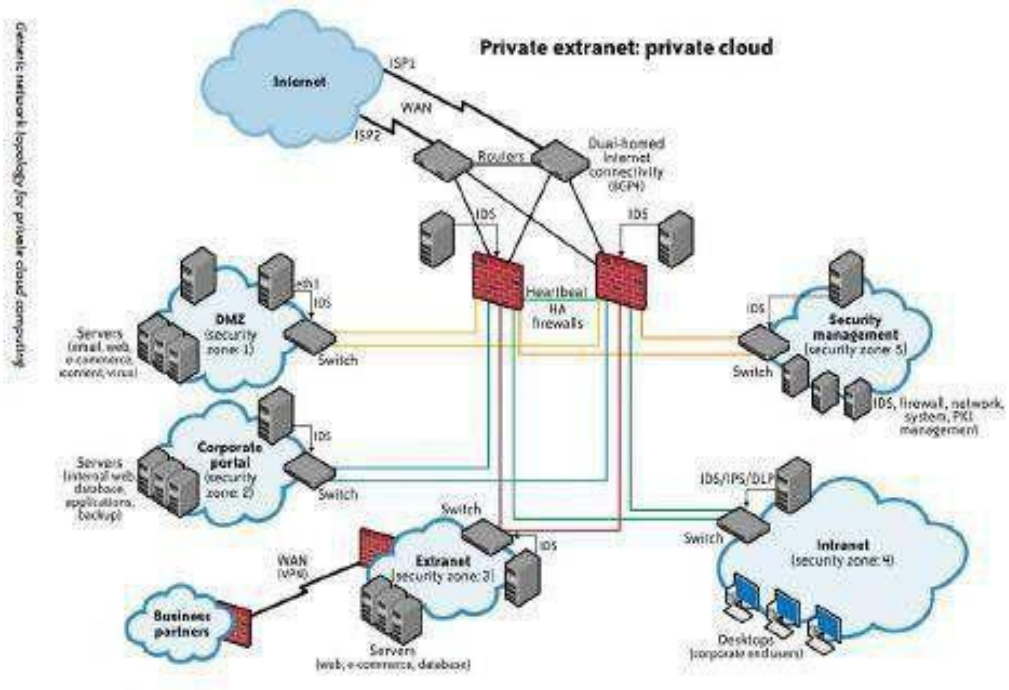
Trust Delegation

To reduce or even avoid the number of times the user must enter his passphrase when several grids are used or have agents (local or remote) requesting services on behalf of a user, GSI provides a delegation capability and a delegation service that provides an interface to allow clients to delegate (and renew) X.509 proxy certificates to a service. The interface to this service is based on the WS-Trust specification. A proxy consists of a new certificate and a private key. The key pair that is used for the proxy, that is, the public key embedded in the certificate and the private key, may either be regenerated for each proxy or be obtained by other means. The new certificate contains the owner's identity, modified slightly to indicate that it is a proxy. The new certificate is signed by the owner, rather than a CA.

Cloud infrastructure security

Network level

Although your organization's IT architecture may change with the implementation of a private cloud, your current network topology will probably not change significantly. If you have a private extranet in place (e.g., for premium customers or strategic partners), for practical purposes you probably have the network topology for a private cloud in place already. The security considerations you have today apply to a private cloud infrastructure, too. And the security tools you have in place (or should have in place) are also necessary for a private cloud and operate in the same way.



If you choose to use public cloud services, changing security requirements will require changes to your network topology. You must address how your existing network topology interacts with your cloud provider's network topology. There are four significant risk factors in this use case:

- Ensuring the confidentiality and integrity of your organization's data-in-transit to and from your public cloud provider
- Ensuring proper access control (authentication, authorization, and auditing) to whatever resources you are using at your public cloud provider
- Ensuring the availability of the Internet-facing resources in a public cloud that are being used by your organization, or have been assigned to your organization by your public cloud providers
- Replacing the established model of network zones and tiers with domains

Ensuring Data Confidentiality and Integrity

Some resources and data previously confined to a private network are now exposed to the Internet, and to a shared public network belonging to a third-party cloud provider. Although use of HTTPS (instead of HTTP) would have mitigated the integrity risk, users not using HTTPS (but using HTTP) did face an increased risk that their data could have been altered in transit without their knowledge.

Ensuring Proper Access Control

Since some subset of these resources (or maybe even all of them) is now exposed to the Internet, an organization using a public cloud faces a significant increase in risk to its data. The ability to audit the operations of your cloud provider's network (let alone to conduct any real time monitoring, such as on your own network), even after the fact, is probably non-existent. You will have decreased access to relevant network-level logs and data, and a limited ability to thoroughly conduct investigations and gather forensic data.

However, the issue of ―non-aged‖ IP addresses and unauthorized network access to resources does not apply only to routable IP addresses (i.e., resources intended to be reachable directly from the Internet). The issue also applies to cloud providers' internal networks for customer use and the assignment of non-routable IP addresses.

Host Level

Ensuring the Availability of Internet-Facing Resources

There are deliberate attacks as well. Although prefix hijacking due to deliberate attacks is far less common than misconfigurations, it still occurs and can block access to data. According to the same study presented to NANOG, attacks occur fewer than 100 times per month. Although prefix hijackings are not new, that attack figure will certainly rise, and probably significantly, along with a rise in cloud computing.

DNS attacks are another example of problems associated with this third risk factor. In fact, there are several forms of DNS attacks to worry about with regard to cloud computing. Although DNS attacks are not new and are not directly related to the use of cloud computing, the issue with DNS and cloud computing is an increase in an organization's risk at the network level because of increased external DNS querying.

Cloud infrastructure security at application level

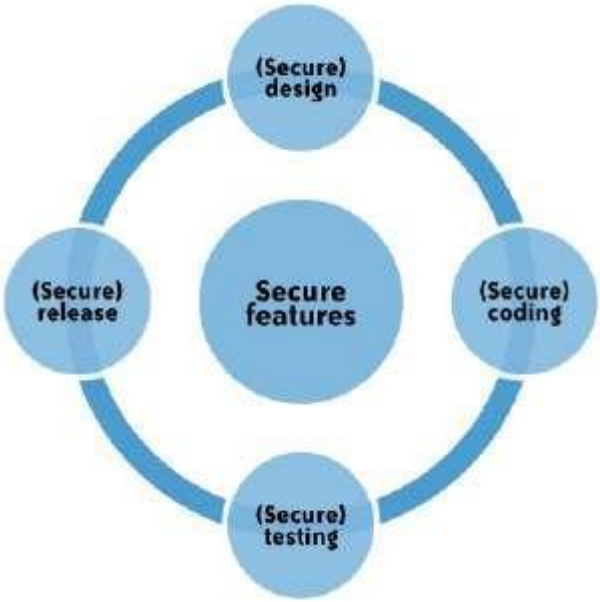
We will limit our discussion to web application security: web applications in the cloud accessed by users with standard Internet browsers, such as Firefox, Internet Explorer, or Safari, from any computer connected to the Internet.

Application-Level Security Threats

The existing threats exploit well-known application vulnerabilities including cross-site scripting (XSS), SQL injection, malicious file execution, and other vulnerabilities resulting from programming errors and design flaws. Armed with knowledge and tools, hackers are constantly scanning web applications (accessible from the Internet) for application vulnerabilities.

It has been a common practice to use a combination of perimeter security controls and network- and host-based access controls to protect web applications deployed in a tightly controlled environment, including corporate intranets and private clouds, from external hackers.

Web applications built and deployed in a public cloud platform will be subjected to a high threat level, attacked, and potentially exploited by hackers to support fraudulent and illegal activities. In that threat model, web applications deployed in a public cloud (the SPI model) must be designed for an Internet threat model, and security must be embedded into the Software Development Life Cycle (SDLC).



DoS and EDoS

Additionally, you should be cognizant of application-level DoS and EDDoS attacks that can potentially disrupt cloud services for an extended time. These attacks typically originate from compromised computer systems attached to the Internet.

Application-level DoS attacks could manifest themselves as high-volume web page reloads, XML* web services requests (over HTTP or HTTPS), or protocol-specific requests supported by a cloud service. Since these malicious requests blend with the legitimate traffic, it is extremely difficult to selectively filter the malicious traffic without impacting the service as a whole

DoS attacks on pay-as-you-go cloud applications will result in a dramatic increase in your cloud utility bill: you'll see increased use of network bandwidth, CPU, and storage consumption. This type of attack is also being characterized as economic denial of sustainability (EDoS)

Aspects of Data Security

End User Security

A customer of a cloud service, are responsible for end user security tasks—security procedures to protect your Internet-connected PC—and for practicing ―safe surfing.‖ Protection measures include use of security software, such as anti-malware, antivirus, personal firewalls, security patches, and IPS-type software on your Internet-connected computer.

The new mantra of ―the browser is your operating system‖ appropriately conveys the message that browsers have become the ubiquitous ―operating systems‖ for consuming cloud services. All Internet browsers routinely suffer from software vulnerabilities that make them vulnerable to end user security attacks. Hence, our recommendation is that cloud customers take appropriate steps to protect browsers from attacks. To achieve end-to-end security in a cloud, it is essential for customers to maintain good browser hygiene. The means keeping the browser (e.g., Internet Explorer, Firefox, Safari) patched and updated to mitigate threats related to browser vulnerabilities.

Currently, although browser security add-ons are not commercially available, users are encouraged to frequently check their browser vendor's website for security updates, use the auto-update feature, and install patches on a timely basis to maintain end user security.

SaaS Application Security

The SaaS model dictates that the provider manages the entire suite of applications delivered to users. Therefore, SaaS providers are largely responsible for securing the applications and components they offer to customers. Customers are usually responsible for operational security functions, including user and access management as supported by the provider.

Extra attention needs to be paid to the authentication and access control features offered by SaaS CSPs. Usually that is the only security control available to manage risk to information. Most services, including those from Salesforce.com and Google, offer a web-based administration user interface tool to manage authentication and access control of the application.

Cloud customers should try to understand cloud-specific access control mechanisms— including support for strong authentication and privilege management based on user roles and functions—and take the steps necessary to protect information hosted in the cloud. Additional controls should be implemented to manage privileged access to the SaaS administration tool, and enforce segregation of duties to protect the application from insider threats. In line with security standard practices, customers should implement a strong password policy—one that forces users to choose strong passwords when authenticating to an application.

PaaS Application Security

PaaS vendors broadly fall into the following two major categories:

• Software vendors (e.g., Bungee, Etelos, GigaSpaces, Eucalyptus)

• CSPs (e.g., Google App Engine, Salesforce.com's Force.com, Microsoft Azure, Intuit Quick Base)

A PaaS cloud (public or private) offers an integrated environment to design, develop, test, deploy, and support custom applications developed in the language the platform supports.

PaaS application security encompasses two software layers:

• Security of the PaaS platform itself (i.e., runtime engine)

• Security of customer applications deployed on a PaaS platform

PaaS CSPs (e.g., Google, Microsoft, and Force.com) are responsible for securing the platform software stack that includes the runtime engine that runs the customer applications. Since PaaS applications may use third-party applications, components, or web services, the third-party application provider may be responsible for securing their services. Hence, customers should understand the dependency of their application on all services and assess risks pertaining to third-party service providers.

IaaS Application Security

IaaS cloud providers (e.g., Amazon EC2, GoGrid, and Joyent) treat the applications on customer virtual instances as a black box, and therefore are completely agnostic to the operations and management of the customer's applications.

The entire stack—customer applications, runtime application platform (Java, .NET, PHP, Ruby on Rails, etc.), and so on— runs on the customer's virtual servers and is deployed and managed by customers. To that end, customers have full responsibility for securing their applications deployed in the IaaS cloud.

Web applications deployed in a public cloud must be designed for an Internet threat model, embedded with standard security countermeasures against common web vulnerabilities. In adherence with common security development practices, they should also be periodically tested for vulnerabilities, and most importantly, security should be embedded into the SDLC. Customers are solely responsible for keeping their applications and runtime platform patched to protect the system from malware and hackers scanning for vulnerabilities to gain unauthorized access to their data in the cloud. It is highly recommended that you design and implement applications with a ”least-privileged” runtime model.

Developers writing applications for IaaS clouds must implement their own features to handle authentication and authorization. In line with enterprise identity management practices, cloud applications should be designed to leverage delegated authentication service features supported by an enterprise Identity Provider (e.g., OpenSSO, Oracle IAM, IBM, CA) or third-party identity service provider (e.g., Ping Identity, Simplified, TriCipher). Any custom implementations of Authentication, Authorization, and Accounting (AAA) features can become a weak link if they are not properly implemented, and you should avoid them when possible.

Provider data and its security:

Customers should also be concerned about what data the provider collects and how the CSP protects that data. Additionally, your provider collects and must protect a huge amount of security-related data.

Storage

For data stored in the cloud (i.e., storage-as-a-service), we are referring to IaaS and not data associated with an application running in the cloud on PaaS or SaaS. The same three information security concerns are associated with this data stored in the cloud (e.g., Amazon’s S3) as with data stored elsewhere: confidentiality, integrity, and availability.

Confidentiality

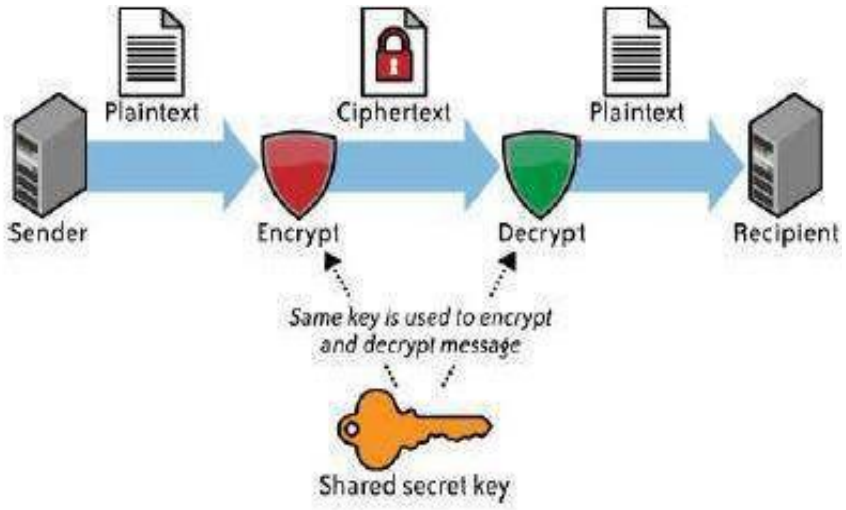
When it comes to the confidentiality of data stored in a public cloud, you have two potential concerns. First, what access control exists to protect the data? Access control consists of both authentication and authorization.

CSPs generally use weak authentication mechanisms (e.g., username + password), and the authorization (―access‖) controls available to users tend to be quite coarse and not very granular. For large organizations, this coarse authorization presents significant security concerns unto itself. Often, the only authorization levels cloud vendors provide are administrator authorization (i.e., the owner of the account itself) and user authorization (i.e., all other authorized users)—with no levels in between (e.g., business unit administrators, who are authorized to approve access for their own business unit personnel).

If a CSP does encrypt a customer’s data, the next consideration concerns what encryption algorithm it uses. Not all encryption algorithms are created equal. Cryptographically, many algorithms provide insufficient security. Only algorithms that have been publicly vetted by a formal standards body (e.g., NIST) or at least informally by the cryptographic community should be used. Any algorithm that is proprietary should absolutely be avoided.

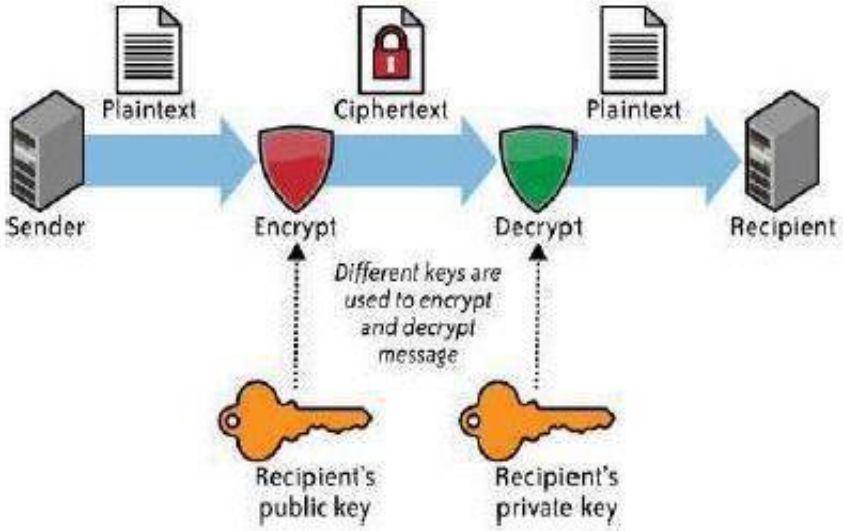
Symmetric encryption involves the use of a single secret key for both the encryption and decryption of data. Only symmetric encryption has the speed and computational efficiency to handle encryption of large volumes of data. It would be highly unusual to use an asymmetric algorithm for this encryption use case.

Although the example in diagram is related to email, the same concept (i.e., a single shared, secret key) is used in data storage encryption.



Symmetric encryption

Although the example in diagram is related to email, the same concept (i.e., a public key and a private key) is not used in data storage encryption.



Asymmetric encryption

Integrity

Confidentiality does not imply integrity; data can be encrypted for confidentiality purposes, and yet you might not have a way to verify the integrity of that data. Encryption alone is sufficient for confidentiality, but integrity also requires the use of message authentication codes (MACs). The simplest way to use MACs on encrypted data is to use a block symmetric algorithm (as opposed to a streaming symmetric algorithm) in cipher block chaining (CBC) mode, and to include a one-way hash function.

Another aspect of data integrity is important, especially with bulk storage using IaaS. Once a customer has several gigabytes (or more) of its data up in the cloud for storage, how does the customer check on the integrity of the data stored there? There are IaaS transfer costs associated with moving data into and back down from the cloud,* as well as network utilization (bandwidth) considerations for the customer's own network. What a customer really wants to do is to validate the integrity of its data while that data remains in the cloud—without having to download and reload that data.

Availability

Assuming that a customer's data has maintained its confidentiality and integrity, you must also be concerned about the availability of your data. There are currently three major threats in this regard—none of which are new to computing, but all of which take on increased importance in cloud computing because of increased risk.

The first threat to availability is network-based attacks

The second threat to availability is the CSP's own availability.

Cloud storage customers must be certain to ascertain just what services their provider is actually offering. Cloud storage does not mean the stored data is actually backed up. Some cloud storage providers do back up customer data, in addition to providing storage. However, many cloud storage providers do not back up customer data, or do so only as an additional service for an additional cost.

All three of these considerations (confidentiality, integrity, and availability) should be encapsulated in a CSP's service-level agreement (SLA) to its customers. However, at this time, CSP SLAs are extremely weak—in fact, for all practical purposes, they are essentially worthless. Even where a CSP appears to have at least a partially sufficient SLA, how that SLA actually gets measured is problematic. For all of these reasons, data security considerations and how data is actually stored in the cloud should merit considerable attention by customers.

Identity and access management functional architecture:

The basic concepts and definitions of IAM functions for any service:

Authentication

Authentication is the process of verifying the identity of a user or system. Authentication usually connotes a more robust form of identification. In some use cases, such as service-to-service interaction, authentication involves verifying the network service requesting access to information served by another service.

Authorization

Authorization is the process of determining the privileges the user or system is entitled to once the identity is established. —in other words, authorization is the process of enforcing policies.

Auditing

In the context of IAM, auditing entails the process of review and examination of authentication, authorization records, and activities to determine the adequacy of IAM system controls, to verify compliance with established security policies and procedures (e.g., separation of duties), to detect breaches in security services (e.g., privilege escalation), and to recommend any changes that are indicated for countermeasures.

IAM Architecture

Standard enterprise IAM architecture encompasses several layers of technology, services, and processes. At the core of the deployment architecture is a directory service (such as LDAP or Active Directory) that acts as a repository for the identity, credential, and user attributes of the organization's user pool. The directory interacts with IAM technology components such as authentication, user management, provisioning, and federation services that support the standard IAM practice and processes within the organization. It is not uncommon for organizations to use several directories that were deployed for environment-specific reasons (e.g., Windows systems using Active Directory, UNIX systems using LDAP) or that were integrated into the environment by way of business mergers and acquisitions.

The IAM processes to support the business can be broadly categorized as follows:

User management

Activities for the effective governance and management of identity life cycles

Authentication management

Activities for the effective governance and management of the process for determining that an entity is who or what it claims to be

Authorization management

Activities for the effective governance and management of the process for determining entitlement rights that decide what resources an entity is permitted to access in accordance with the organization's policies.

Access management

Enforcement of policies for access control in response to a request from an entity (user, services) wanting to access an IT resource within the organization

Data management and provisioning

Propagation of identity and data for authorization to IT resources via automated or manual processes

Monitoring and auditing

Monitoring, auditing, and reporting compliance by users regarding access to resources within the organization based on the defined policies.

IAM processes support the following operational activities:

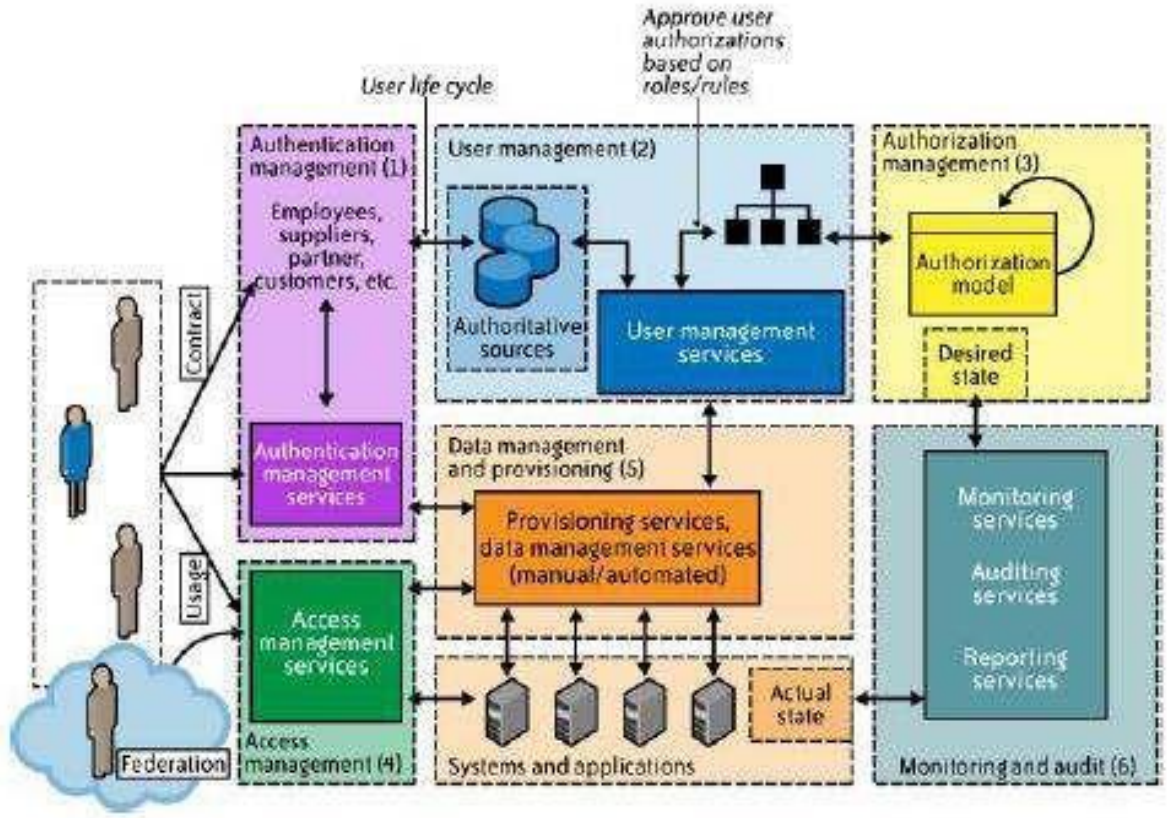
Provisioning

This is the process of on-boarding users to systems and applications. These processes provide users with necessary access to data and technology resources. The term typically is used in reference to enterprise-level resource management.

Credential and attribute management

These processes are designed to manage the life cycle of credentials and user attributes— create, issue, manage, revoke—to minimize the business risk associated with identity impersonation and inappropriate account use. Credentials are usually bound to an individual and are verified during the authentication process.

The processes include provisioning of attributes, static (e.g., standard text password) and dynamic (e.g., one-time password) credentials that comply with a password standard (e.g., passwords resistant to dictionary attacks), handling password expiration, and encryption management of credentials during transit and at rest, and access policies of user attributes



Enterprise IAM functional architecture

Entitlement management

Entitlements are also referred to as authorization policies. The processes in this domain address the provisioning and DE provisioning of privileges needed for the user to access resources including systems, applications, and databases.

Compliance management

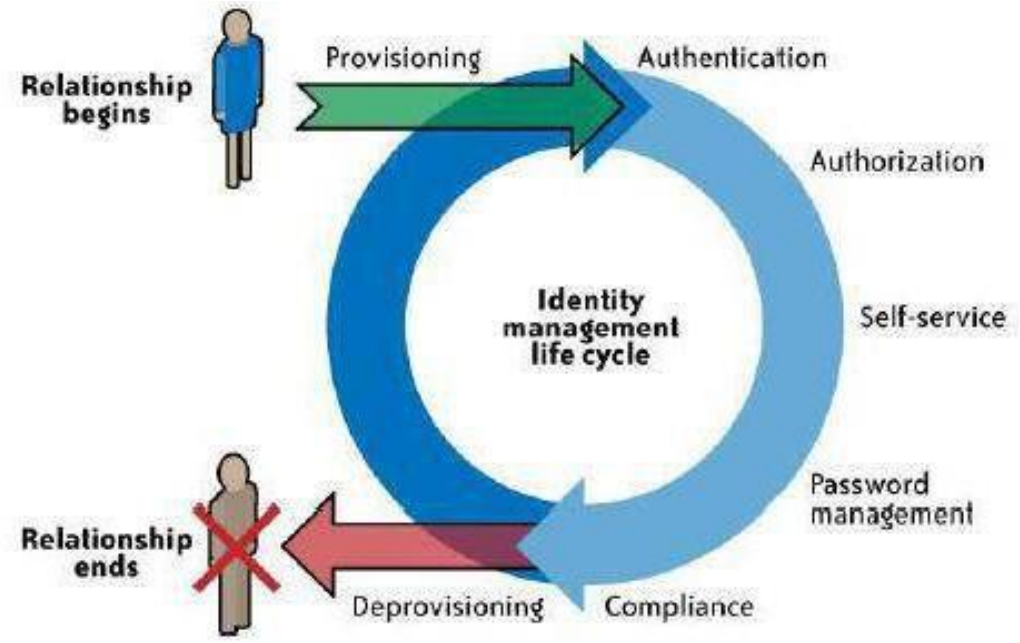
This process implies that access rights and privileges are monitored and tracked to ensure the security of an enterprise's resources. The process also helps auditors verify compliance to various internal access control policies, and standards that include practices such as segregation of duties, access monitoring, periodic auditing, and reporting.

Identity federation management

Federation is the process of managing the trust relationships established beyond the internal network boundaries or administrative domain boundaries among distinct organizations. A federation is an association of organizations that come together to exchange information about their users and resources to enable collaborations and transactions

Centralization of authentication (authN) and authorization (authZ)

A central authentication and authorization infrastructure alleviates the need for application developers to build custom authentication and authorization features into their applications. Furthermore, it promotes a loose coupling architecture where applications become agnostic to the authentication methods and policies. This approach is also called an "externalization of authN and authZ" from applications.



Identity life cycle

IAM practices in cloud:

User management functions in the cloud

User management functions in the cloud can be categorized as follows:
1. Cloud identity administration
2. Federation or SSO
3. Authorization management
4. Compliance management

Cloud Identity Administration

Cloud identity administrative functions should focus on life cycle management of user identities in the cloud—provisioning, DE provisioning, identity federation, SSO, password or credentials management, profile management, and administrative management. Organizations that are not capable of supporting federation should explore cloud-based identity management services.

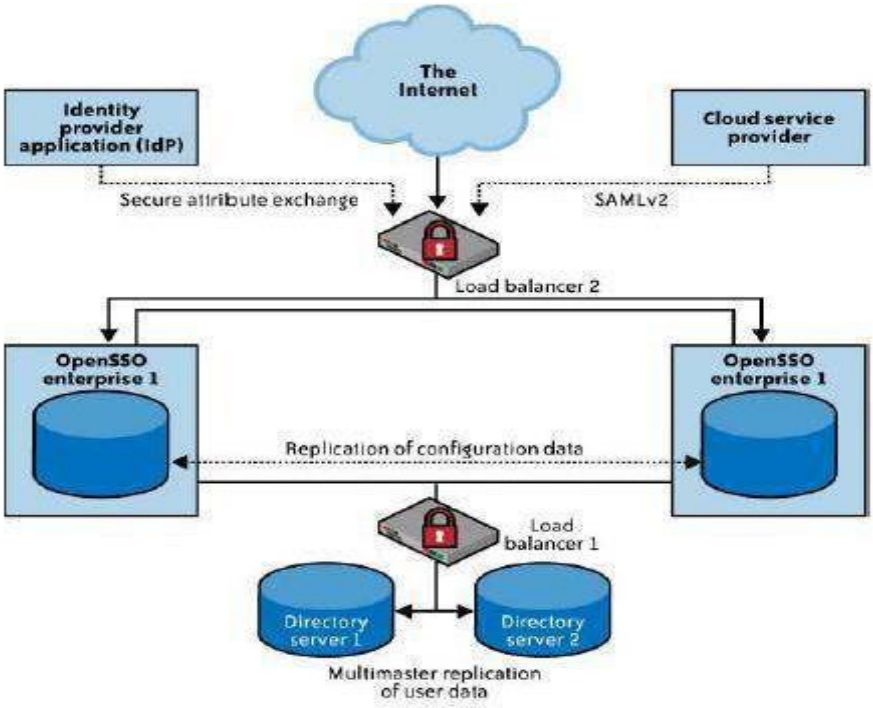
By federating identities using either an internal Internet-facing IdP or a cloud identity management service provider, organizations can avoid duplicating identities and attributes and storing them with the CSP. Given the inconsistent and sparse support for identity standards among CSPs, customers may have to devise custom methods to address user management functions in the cloud. Provisioning users when federation is not supported can be complex and laborious.

Federated Identity (SSO)

Organizations planning to implement identity federation that enables SSO for users can take one of the following two paths (architectures):
1. Implement an enterprise IdP within an organization perimeter.
2. Integrate with a trusted cloud-based identity management service provider.

Enterprise identity provider

In this architecture, cloud services will delegate authentication to an organization's IdP. In this delegated authentication architecture, the organization federates identities within a trusted circle of CSP domains. A circle of trust can be created with all the domains that are authorized to delegate authentication to the IdP. In this deployment architecture, where the organization will provide and support an IdP, greater control can be exercised over user identities, attributes, credentials, and policies for authenticating and authorizing users to a cloud service.

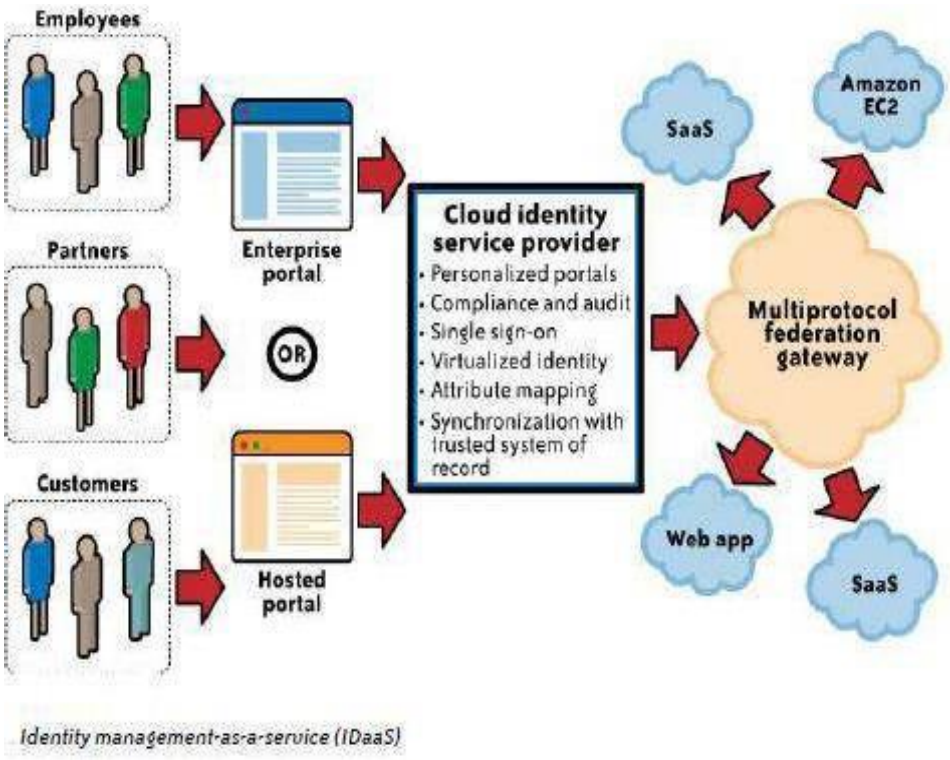


Identity provider deployment architecture

Identity management-as-a-service

In this architecture, cloud services can delegate authentication to an identity management-as-a- service (IDaaS) provider. In this model, organizations outsource the federated identity management technology and user management processes to a third-party service provider. In essence, this is a SaaS model for identity management, where the SaaS IdP stores identities in a ―trusted identity store‖ and acts as a proxy for the organization's users accessing cloud services.

The identity store in the cloud is kept in sync with the corporate directory through a provider proprietary scheme (e.g., agents running on the customer's premises synchronizing a subset of an organization's identity store to the identity store in the cloud using SSL VPNs). Once the IdP is established in the cloud, the organization should work with the CSP to delegate authentication to the cloud identity service provider. The cloud IdP will authenticate the cloud users prior to them accessing any cloud services



Identity management-as-a-service (IDaaS)

Cloud Authorization Management

Most cloud services support at least dual roles (privileges): administrator and end user. It is a normal practice among CSPs to provision the administrator role with administrative privileges. These privileges allow administrators to provision and DE provision identities, basic attribute profiles, and, in some cases, to set access control policies such as password strength and trusted networks from which connections are accepted.

As we mentioned earlier, XACML is the preferred standard for expressing and enforcing authorization and user authentication policies. As of this writing, we are not aware of any cloud services supporting XACML to express authorization policies for users.

IAM Support for Compliance Management

As much as cloud IAM architecture and practices impact the efficiency of internal IT processes, they also play a major role in managing compliance within the enterprise. Properly implemented IAM practices and processes can help improve the effectiveness of the controls identified by compliance frameworks.

IAM practices and processes offer a centralized view of business operations and an automated process that can stop insider threats before they occur. However, given the sparse support for IAM standards such as SAML (federation), SPML (provisioning), and XACML (authorization) by the CSP, you should assess the CSP capabilities on a case-by-case basis and institute processes for managing compliance related to identity (including attribute) and access management.

PaaS Availability management

In a typical PaaS service, customers (developers) build and deploy PaaS applications on top of the CSP-supplied PaaS platform. The PaaS platform is typically built on a CSP owned and managed network, servers, operating systems, storage infrastructure, and application components (web services). Given that the customer PaaS applications are assembled with CSP-supplied application components and, in some cases, third-party web services components (mash-up applications), availability management of the PaaS application can be complicated

PaaS applications may rely on other third-party web services components that are not part of the PaaS service offerings; hence, understanding the dependency of your application on third-party services, including services supplied by the PaaS vendor, is essential. PaaS providers may also offer a set of web services, including a message queue service, identity and authentication service, and database service, and your application may depend on the availability of those service components.

App Engine resource is measured against one of two kinds of quotas: a billable quota or a fixed quota.

Billable quotas are resource maximums set by you, the application's administrator, to prevent the cost of the application from exceeding your budget. Every application gets an amount of each billable quota for free. You can increase billable quotas for your application by enabling billing, setting a daily budget, and then allocating the budget to the quotas. You will be charged only for the resources your app actually uses, and only for the amount of resources used above the free quota thresholds.

Fixed quotas are resource maximums set by the App Engine to ensure the integrity of the system. These resources describe the boundaries of the architecture, and all applications are expected to run within the same limits. They ensure that another app that is consuming too many resources will not affect the performance of your app.

Customer Responsibility

The PaaS application customer should carefully analyze the dependencies of the application on the third-party web services (components) and outline a holistic management strategy to manage and monitor all the dependencies.

PaaS platform service levels

Customers should carefully review the terms and conditions of the CSP's SLAs and understand the availability constraints.

Third-party web services provider service levels

When your PaaS application depends on a third-party service, it is critical to understand the SLA of that service.

PaaS Health Monitoring

The following options are available to customers to monitor the health of their service:

- Service health dashboard published by the CSP
- CSP customer mailing list that notifies customers of occurring and recently occurred outages
- RSS feed for RSS readers with availability and outage information
- Internal or third-party-based service monitoring tools that periodically check your PaaS application, as well as third-party web services that monitor your application

IaaS Availability management

Availability considerations for the IaaS delivery model should include both a computing and storage (persistent and ephemeral) infrastructure in the cloud. IaaS providers may also offer other services such as account management, a message queue service, an identity and authentication service, a database service, a billing service, and monitoring services.

Managing your IaaS virtual infrastructure in the cloud depends on five factors:

- Availability of a CSP network, host, storage, and support application infrastructure.

This factor depends on the following:

1. CSP data center architecture, including a geographically diverse and fault-tolerance architecture.
2. Reliability, diversity, and redundancy of Internet connectivity used by the customer and the CSP.
3. Reliability and redundancy architecture of the hardware and software components used for delivering compute and storage services.

4. Availability management process and procedures, including business continuity processes established by the CSP.

- Availability of your virtual servers and the attached storage (persistent and ephemeral) for compute services
- Availability of virtual storage that your users and virtual server depend on for storage service. This includes both synchronous and asynchronous storage access use cases. Synchronous storage access use cases demand low data access latency and continuous availability, whereas asynchronous use cases are more tolerant to latency and availability.
- Availability of your network connectivity to the Internet or virtual network connectivity to IaaS services. In some cases, this can involve virtual private network (VPN) connectivity between your internal private data center and the public IaaS cloud
- Availability of network services, including a DNS, routing services, and authentication services required to connect to the IaaS service.

IaaS Health Monitoring

- Service health dashboard published by the CSP.
- CSP customer mailing list that notifies customers of occurring and recently occurred outages.
- Web console or API that publishes the current health status of your virtual servers and network.

Key Privacy Concerns in the Cloud:

These concerns typically mix security and privacy. Here are some additional considerations to be aware of:

Access

Data subjects have a right to know what personal information is held and, in some cases, can make a request to stop processing it. This is especially important with regard to marketing activities; in some jurisdictions, marketing activities are subject to additional regulations and are almost always addressed in the end user privacy policy for applicable organizations. In the cloud, the main concern is the organization's ability to provide the individual with access to all personal information, and to comply with stated requests.

Compliance

What are the privacy compliance requirements in the cloud? What are the applicable laws, regulations, standards, and contractual commitments that govern this information, and who is responsible for maintaining the compliance? How are existing privacy compliance requirements impacted by the move to the cloud? Clouds can cross multiple jurisdictions;

Storage

Where is the data in the cloud stored? Was it transferred to another data center in another country? Is it commingled with information from other organizations that use the same CSP? Privacy laws in various countries place limitations on the ability of organizations to transfer some types of personal information to other countries. When the data is stored in the cloud, such a transfer may occur without the knowledge of the organization, resulting in a potential violation of the local law.

Retention

How long is personal information (that is transferred to the cloud) retained? Which retention policy governs the data? Does the organization own the data, or the CSP? Who enforces the retention policy in the cloud, and how are exceptions to this policy (such as litigation holds) managed?

Destruction

How does the cloud provider destroy PII at the end of the retention period? How do organizations ensure that their PII is destroyed by the CSP at the right point and is not available to other cloud users? How do they know that the CSP didn't retain additional copies? Cloud storage providers usually replicate the data across multiple systems and sites—increased availability is one of the benefits they provide. This benefit turns into a challenge when the organization tries to destroy the data—can you truly destroy information once it is in the cloud? Did the CSP really destroy the data, or just make it inaccessible to the organization? Is the CSP keeping the information longer than necessary so that it can mine the data for its own use?

Audit and monitoring

How can organizations monitor their CSP and provide assurance to relevant stakeholders that privacy requirements are met when their PII is in the cloud?

Privacy breaches

How do you know that a breach has occurred, how do you ensure that the CSP notifies you when a breach occurs, and who is responsible for managing the breach notification process (and costs associated with the process)? If contracts include liability for breaches resulting from negligence of the CSP, how is the contract enforced and how is it determined who is at fault?

SaaS Availability Management

SaaS service providers are responsible for business continuity, application, and infrastructure security management processes. This means the tasks your IT organization once handled will now be handled by the CSP. Some mature organizations that are aligned with industry standards, such as ITIL, will be faced with new challenges of governance of SaaS services as they try to map internal service-level categories to a CSP.

Customer Responsibility

Customers should understand the SLA and communication methods (e.g., email, RSS feed, website URL with outage information) to stay informed on service outages. When possible, customers should use automated tools such as Nagios or Siteuptime.com to verify the availability of the SaaS service. As of this writing, customers of a SaaS service have a limited number of options to support availability management. Hence, customers should seek to understand the availability management factors, including the SLA of the service, and clarify with the CSP any gaps in SLA exclusions and service credits when disruptions occur.

SaaS Health Monitoring

The following options are available to customers to stay informed on the health of their service:

- Service health dashboard published by the CSP. Usually SaaS providers, such as Salesforce.com, publish the current state of the service, current outages that may impact customers, and upcoming scheduled maintenance services on their website
- The Cloud Computing Incidents Database (CCID).
- Customer mailing list that notifies customers of occurring and recently occurred outages.
- Internal or third-party-based service monitoring tools that periodically check SaaS provider health and alert customers when service becomes unavailable
- RSS feed hosted at the SaaS service provider.