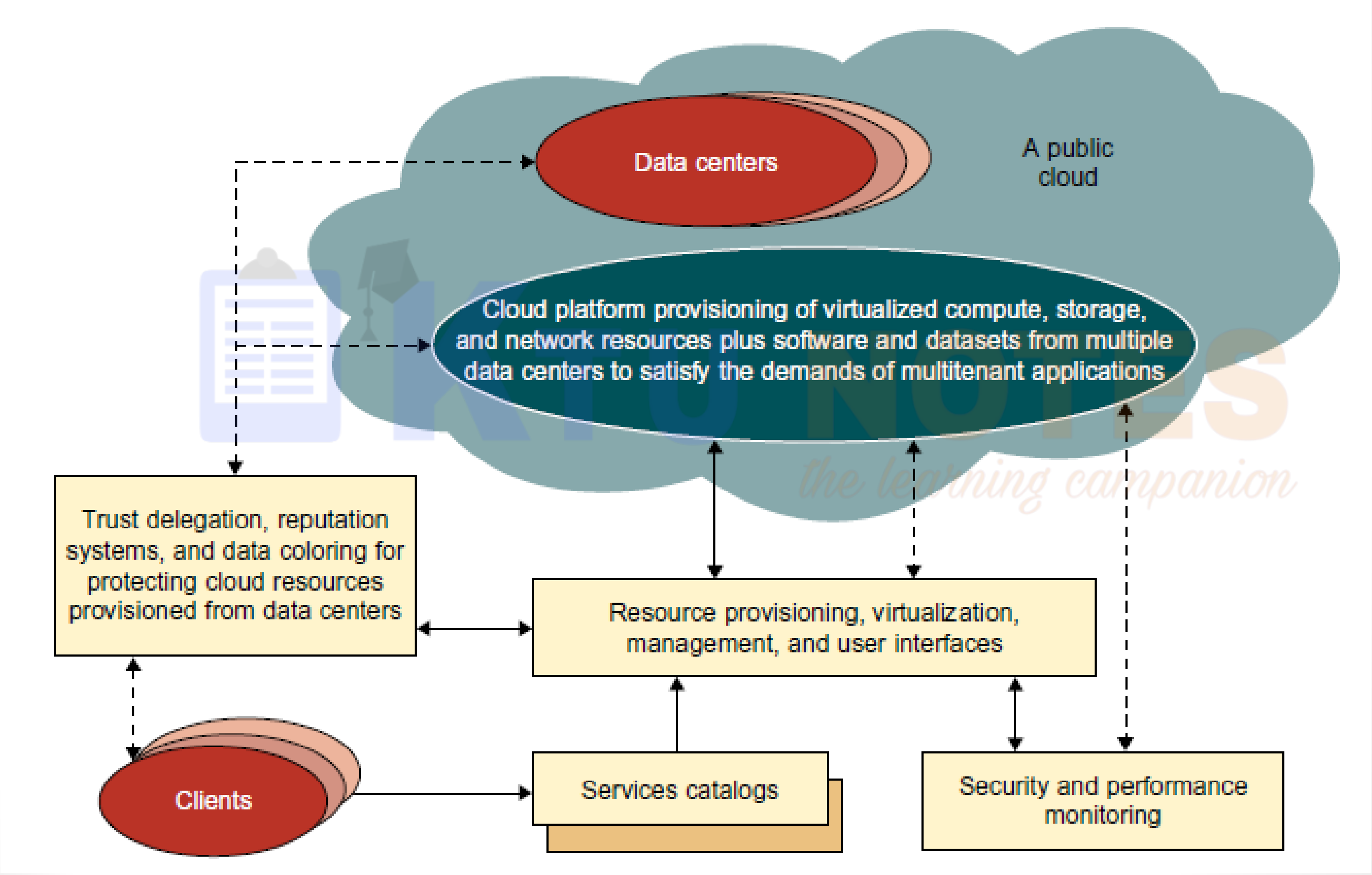
Module 3

CLOUD ARCHITECTURE AND RESOURCE MANAGEMENT

Architectural Design of Compute and Storage Clouds

- **Generic Cloud Architecture Design:**
  - **Scalability, virtualization, efficiency, and reliability** are four major design goals of a cloud computing platform.
  - System scalability and reliability can benefit from cluster architecture.
  - Cloud management software needs to support both physical and virtual machines.
  - Security in shared resources and shared access of data centers also pose another design challenge

- **Security-aware cloud architecture**:



- Internet cloud is envisioned as a massive cluster of servers.
- Servers are provisioned on demand to perform collective web services or distributed applications using data-center resources.
- The cloud platform is formed dynamically by provisioning or deprovisioning servers, software, and database resources.
- Servers in the cloud can be **physical machines or VMs**.
- User interfaces are applied to request services.
- The provisioning tool carves out the cloud system to deliver the requested service.

- The cloud computing resources are built into the data centers, which are typically owned and operated by a third-party provider.
- The cloud demands a high degree of trust of massive amounts of data retrieved from large data centers.
- A framework is needed to process large-scale data stored in the storage system :- a distributed file system over the database system.
- Other cloud resources are added into a cloud platform, including **storage area networks (SANs), database systems, firewalls, and security devices**.
- Web service providers offer special APIs that enable developers to exploit Internet clouds.
- Monitoring and metering units are used to track the usage and performance of provisioned resources.

- The software infrastructure of a cloud platform must handle all resource management and do most of the maintenance automatically.
- Software must detect the status of each node server joining and leaving, and perform relevant tasks accordingly.
- Cloud computing providers, such as Google and Microsoft, have built a large number of data centers all over the world.
- Each data center may have thousands of servers.
- The location of the data center is chosen to reduce power and cooling costs.
- Thus, the data centers are often built around hydroelectric power.

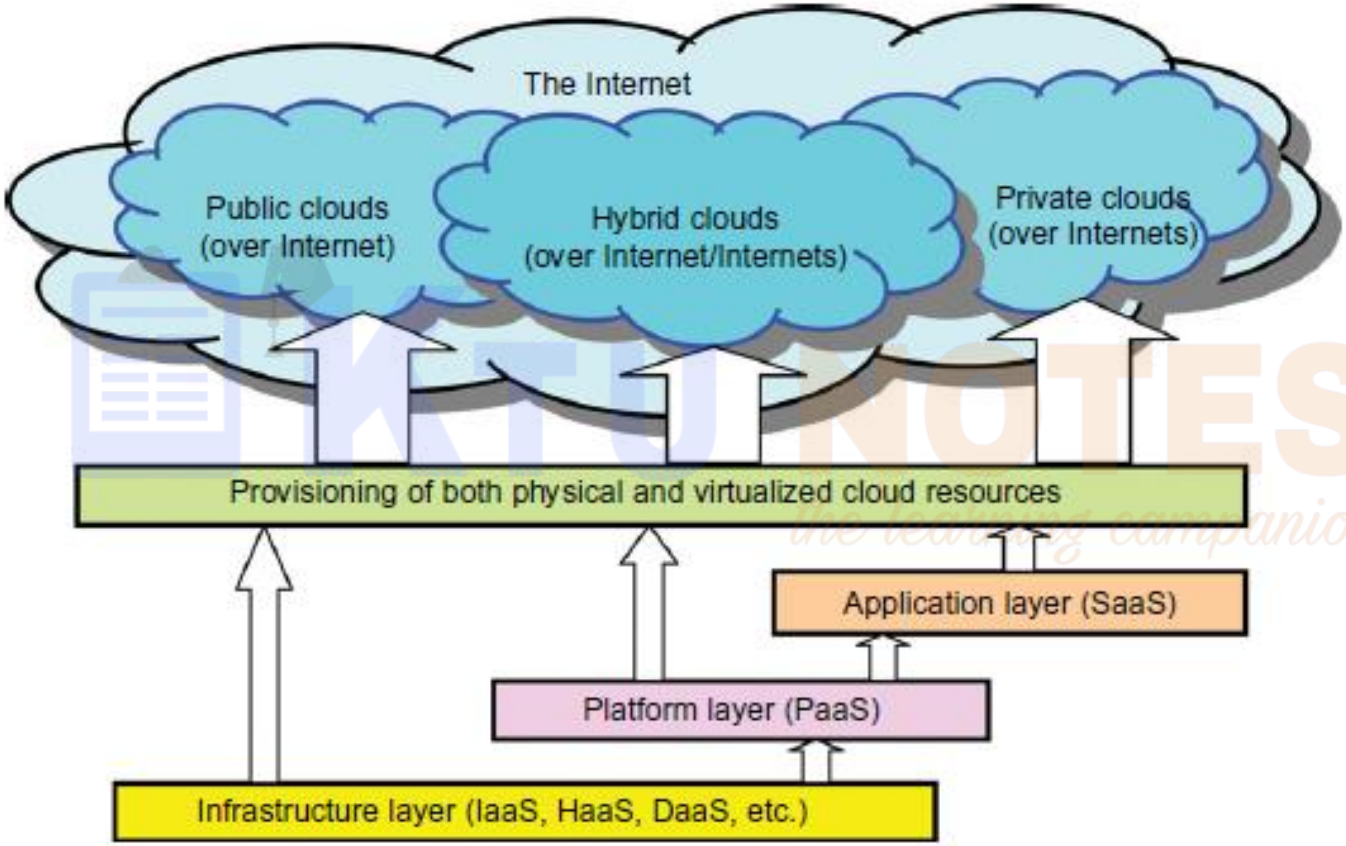
- **Layered Cloud Architectural Development**:

- The architecture of a cloud is developed at three layers:
  - Infrastructure
  - Platform
  - Application.

- The services to public, private, and hybrid clouds are conveyed to users through networking support over the Internet and intranets involved.

- This infrastructure layer serves as the foundation for building the platform layer of the cloud for supporting PaaS services.

- In turn, the platform layer is a foundation for implementing the application layer for SaaS applications


The Internet
Public clouds
(over Internet)
Hybrid clouds
(over Internet/Internets)
Private clouds
(over Internets)
Provisioning of both physical and virtualized cloud resources
Application layer (SaaS)
Platform layer (PaaS)
Infrastructure layer (IaaS, HaaS, DaaS, etc.)

- The **infrastructure layer** is built with virtualized compute, storage, and network resources.

- Virtualization realizes automated provisioning of resources and optimizes the infrastructure management process.

- The **platform layer** provides users with an environment to develop their applications, to test operation flows, and to monitor execution results and performance.

- The platform should be able to assure users that they have scalability, dependability, and security protection.

- In a way, the **virtualized cloud platform** serves as a "**system middleware**" between the infrastructure and application layers of the cloud.

- **Application layer** is formed with a collection of all needed software modules for SaaS applications.

- Service applications in this layer include daily office management work, such as **information retrieval, document processing, and calendar and authentication services**.

- The application layer is also heavily used by **enterprises in business marketing and sales, consumer relationship management (CRM), financial transactions, and supply chain management**.

- All cloud services are **not restricted** to a single layer. Many applications may apply resources at mixed layers.

- The services at various layers demand different amounts of functionality support and resource management by providers.

- SaaS demands the most work from the provider, PaaS is in the middle, and IaaS demands the least.

- **Market-Oriented Cloud Architecture**:

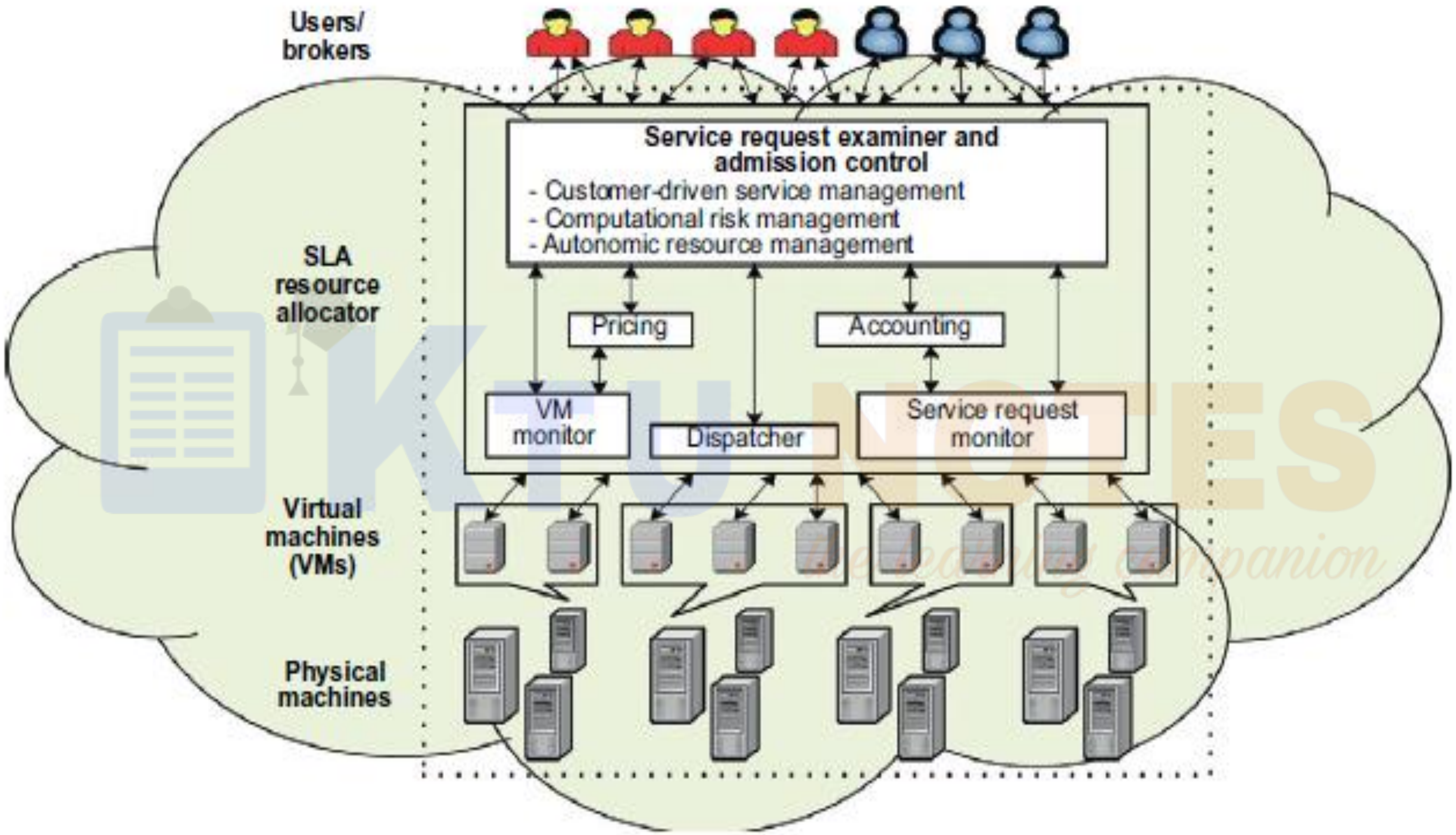
- Cloud providers consider and meet the different **QoS (Quality of Service)** parameters of each individual consumer as negotiated in specific **SLAs (Service Level Agreements)**.

- To achieve this market-oriented resource management is necessary to regulate the supply and demand of cloud resources.

- The designer needs to provide feedback on economic incentives for both consumers and providers.

- The purpose is to promote QoS-based resource allocation mechanisms.

- In addition, clients can benefit from the potential cost reduction of providers, which could lead to a more competitive market, and thus lower prices.



Users/ brokers
SLA resource allocator
Service request examiner and admission control
- Customer-driven service management
- Computational risk management
- Autonomic resource management
Pricing
Accounting
VM monitor
Dispatcher
Service request monitor
Virtual machines (VMs)
Physical machines

- Users or brokers acting on user's behalf submit service requests from anywhere in the world to the data center and cloud to be processed.
- The SLA resource allocator acts as the interface between the data center/cloud service provider and external users/brokers.
- It requires the interaction of the following mechanisms to support SLA-oriented resource management.
- When a service request is first submitted the service request examiner interprets the submitted request for QoS requirements before determining whether to accept or reject the request.
- The request examiner ensures that there is no overloading of resources whereby many service requests cannot be fulfilled successfully due to limited resources.
- It also needs the latest status information regarding resource availability (from the VM Monitor mechanism) and workload processing (from the Service Request Monitor mechanism) in order to make resource allocation decisions effectively.

- Then it assigns requests to VMs and determines resource entitlements for allocated VMs.

- The Pricing mechanism decides how service requests are charged.

- The Accounting mechanism maintains the actual usage of resources by requests so that the final cost can be computed and charged to users

- The VM Monitor mechanism keeps track of the availability of VMs and their resource entitlements.

- The Dispatcher mechanism starts the execution of accepted service requests on allocated VMs.

- The Service Request Monitor mechanism keeps track of the execution progress of service requests.

- **Quality of Service Factors**:

- Critical QoS parameters to consider in a service request, such as time, cost, reliability, and trust/security.

- QoS requirements cannot be static and may change over time due to continuing changes in business operations and operating environments.

- Greater importance on customers since they pay to access services in clouds.

- The state of the art in cloud computing has no or limited support for dynamic negotiation of SLAs between participants and mechanisms for automatic allocation of resources to multiple competing requests.

- Negotiation mechanisms are needed to respond to alternate offers protocol for establishing SLAs

- **Virtualization Support and Disaster Recovery:**

- One very distinguishing feature of cloud computing infrastructure is the use of system virtualization and the modification to provisioning tools.

- As the VMs are the containers of cloud services, the provisioning tools will first find the corresponding physical machines and deploy the VMs to those nodes before scheduling the service to run on the virtual nodes.

- In cloud computing, virtualization also means the resources and fundamental infrastructure are virtualized.

- The user will not care about the computing resources that are used for providing the services.

- Application developers focus on service logic.

- **Hardware Virtualization:**

- Virtualization software is used to virtualize the hardware.

- System virtualization software is a special kind of software which simulates the execution of hardware and runs even unmodified operating systems.

- VMs provide flexible runtime services to free users from worrying about the system environment.

- As the computing resources are shared by many users, a method is required to maximize the users' privileges and still keep them separated safely.

- Virtualization allows users to have full privileges while keeping them separate.

- The virtualized resources form a resource pool.
- The virtualization is carried out by special servers dedicated to generating the virtualized resource pool.
- The virtualized infrastructure (black box in the middle) is built with many virtualizing integration managers.
- These managers handle loads, resources, security, data, and provisioning functions.
- Each platform carries out a virtual solution to a user job.
- All cloud services are managed in the boxes at the top.

- **VM Cloning for Disaster Recovery:**

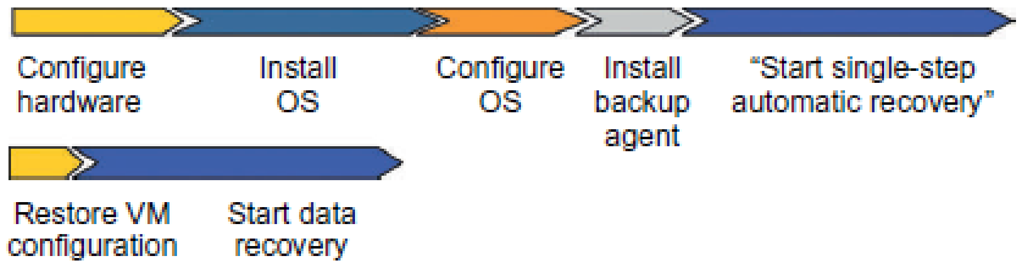
- VM technology requires an advanced disaster recovery scheme.

- One scheme is to recover one physical machine by another physical machine.

- The second scheme is to recover one VM by another.

- Traditional disaster recovery from one physical machine to another is rather slow, complex, and expensive.

- To recover a VM platform, the installation and configuration times for the OS and backup agents are eliminated.



- This results in a much shorter disaster recovery time, about 40 percent of that to recover the physical machines.
- The cloning of VMs offers an effective solution.
- The idea is to make a clone VM on a remote server for every running VM on a local server.
- Among all the clone VMs, only one needs to be active. The remote VM should be in a suspended mode.
- A cloud control center should be able to activate this clone VM in case of failure of the original VM, taking a snapshot of the VM to enable live migration in a minimal amount of time.
- Only updated data and modified states are sent to the suspended VM to update its state.
- Security of the VMs should be enforced during live migration of VMs.

- **Architectural Design Challenges:**

- **Challenge 1—Service Availability and Data Lock-in Problem**

- The management of a cloud service by a single company is often the source of single points of failure.

- Using multiple cloud providers may provide more protection from failures.

- Another availability obstacle is distributed denial of service (DDoS) attacks.

- Criminals threaten to cut off the incomes of SaaS providers by making their services unavailable.

- Some utility computing services offer SaaS providers the opportunity to defend against DDoS attacks by using quick scale-ups.

- Software stacks have improved interoperability among different cloud platforms, but the APIs itself are still proprietary.
- So customers cannot easily extract their data and programs from one site to run on another.
- The solution is to standardize the APIs so that a SaaS developer can deploy services and data across multiple cloud providers.
- This will rescue the loss of all data due to the failure of a single company.
- Standardization of APIs enables a new usage model in which the same software infrastructure can be used in both public and private clouds.
- Such an option could enable “surge computing,” in which the public cloud is used to capture the extra tasks that cannot be easily run in the data center of a private cloud.

- **Challenge 2—Data Privacy and Security Concerns**

- Current cloud offerings are essentially public (rather than private) networks, exposing the system to more attacks.

- Many obstacles can be overcome immediately with well-understood technologies such as encrypted storage, virtual LANs, and network middleboxes (e.g., firewalls, packet filters).

- For example, you could encrypt your data before placing it in a cloud.

- Many nations have laws requiring SaaS providers to keep customer data and copyrighted material within national boundaries.

- Traditional network attacks include buffer overflows, DoS attacks, spyware, malware, rootkits, Trojan horses, and worms.

- In a cloud environment, newer attacks may result from hypervisor malware, guest hopping and hijacking, or VM rootkits

- Another type of attack is the man-in-the-middle attack for VM migrations.
- In general, passive attacks steal sensitive data or passwords.
- Active attacks may manipulate kernel data structures which will cause major damage to cloud servers.
- **Challenge 3—Unpredictable Performance and Bottlenecks**
- Multiple VMs can share CPUs and main memory in cloud computing, but I/O sharing is problematic.
- One solution is to improve I/O architectures and operating systems to efficiently virtualize interrupts and I/O channels.

- Cloud users and providers have to think about the implications of placement and traffic at every level of the system, if they want to minimize costs.

- Therefore, data transfer bottlenecks must be removed, bottleneck links must be widened, and weak servers should be removed.

- **Challenge 4—Distributed Storage and Widespread Software Bugs**

- The database is always growing in cloud applications.

- A storage system should not only meet this growth, but also combine it with the cloud advantage of scaling arbitrarily up and down on demand.

- This demands the design of efficient distributed SANs.

- Data centers must meet programmers' expectations in terms of scalability, data durability, and HA.

- Data consistence checking in SAN-connected data centers is a major challenge in cloud computing.

- Large-scale distributed bugs cannot be reproduced, so the debugging must occur at a scale in the production data centers.

- No data center will provide such a convenience.

- One solution may be a reliance on using VMs in cloud computing.

- The level of virtualization may make it possible to capture valuable information in ways that are impossible without using VMs.

- Debugging over simulators is another approach to attacking the problem, if the simulator is well designed.

- **Challenge 5 - Cloud Scalability, Interoperability, and Standardization**
- The pay-as-you-go model applies to storage and network bandwidth; both are counted in terms of the number of bytes used.
- Computation is different depending on virtualization level.
- GAE automatically scales in response to load increases and decreases; users are charged by the cycles used.
- AWS charges by the hour for the number of VM instances used, even if the machine is idle.
- The opportunity here is to scale quickly up and down in response to load variation, in order to save money, but without violating SLAs.

- Open Virtualization Format (OVF) describes an open, secure, portable, efficient, and extensible format for the packaging and distribution of VMs.
- The approach is to address virtual platform-agnostic packaging with certification and integrity of packaged software.
- The package supports virtual appliances to span more than one VM.
- OVF also defines a transport mechanism for VM templates, and can apply to different virtualization platforms with different levels of virtualization.
- In terms of cloud standardization:- the ability for virtual appliances to run on any virtual platform and the ability of VMs to run on heterogeneous hardware platform hypervisors is needed

- **Challenge 6—Software Licensing and Reputation Sharing**

- Many cloud computing providers originally relied on open source software because the licensing model for commercial software is not ideal for utility computing.

- The primary opportunity is either for open source to remain popular or simply for commercial software companies to change their licensing structure to better fit cloud computing.

- One customer's bad behavior can affect the reputation of the entire cloud.

- For instance, blacklisting of EC2 IP addresses by spam-prevention services may limit smooth VM installation.

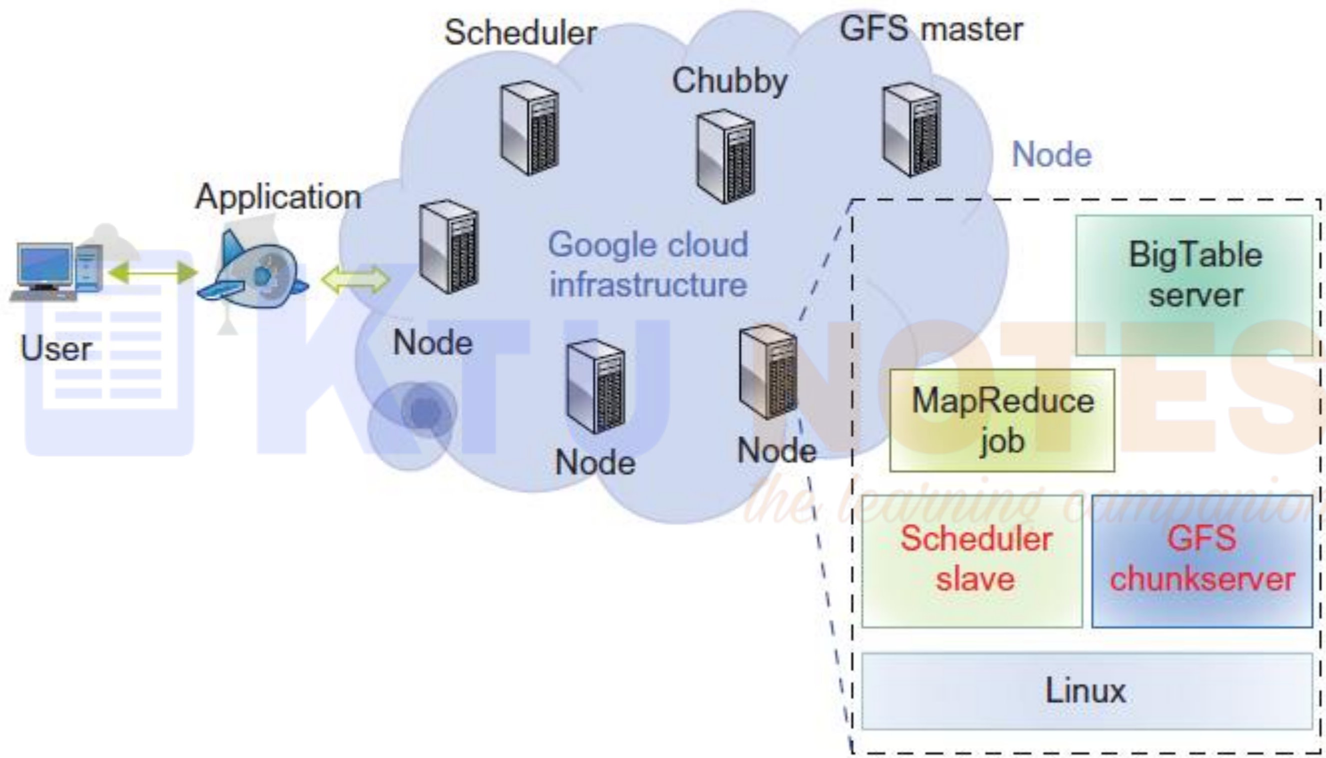
- Hence reputation-guarding services similar to the "trusted e-mail" services may be given to service hosted on smaller ISPs.

- Another legal issue concerns the transfer of legal liability.
- Cloud providers want legal liability to remain with the customer, and vice versa.
- This problem must be solved at the SLA level

Public Cloud Platforms

- **Google App Engine:**
- Offers a PaaS platform supporting various cloud and web applications.
- Google pioneered cloud services in Gmail, Google Docs, and Google Earth
- Notable technology achievements include the Google File System (GFS), MapReduce, BigTable, and Chubby.
- In 2008, Google announced the GAE web application platform which is becoming a common platform for many small cloud service providers.
- This platform specializes in supporting scalable (elastic) web applications.
- GAE enables users to run their applications on a large number of data centers associated with Google's search engine operations.

- **GAE Architecture:**



- The figure shows the major building blocks of the Google cloud platform which has been used to deliver the cloud services highlighted earlier.

- **GFS** is used for storing large amounts of data. **MapReduce** is for use in application program development.

- **Chubby** is used for distributed application lock services. **BigTable** offers a storage service for accessing structured data.

- Users can interact with Google applications via the web interface provided by each application.

- Third-party application providers can use GAE to build cloud applications for providing services.

- GAE runs the user program on Google's infrastructure.

- The frontend is an application framework which is similar to other web application frameworks such as ASP, J2EE, and JSP.

- **Functional Modules of GAE:**

- The GAE platform comprises the following five major components:

- The **datastore** offers object-oriented, distributed, structured data storage services based on BigTable techniques. The datastore secures data management operations.

- The **application runtime environment** offers a platform for scalable web programming and execution. It supports two development languages: Python and Java.

- The **software development kit (SDK)** is used for local application development. The SDK allows users to execute test runs of local applications and upload application code.

- The **administration console** is used for easy management of user application development cycles, instead of for physical resource management.

- The **GAE web service infrastructure** provides special interfaces to guarantee flexible use and management of storage and network resources by GAE.

- Google offers essentially free GAE services to all Gmail account owners within a quota.
- If you exceed the quota, the page instructs you on how to pay for the service.
- GAE only accepts Python, Ruby, and Java programming languages.
- The platform does not provide any IaaS services, unlike Amazon, which offers Iaas and PaaS.
- This model allows the user to deploy user-built applications on top of the cloud infrastructure that are built using the programming languages and software tools supported by the provider (e.g., Java, Python).
- The user does not manage the underlying cloud infrastructure.
- The cloud provider facilitates support of application development, testing, and operation support on a well-defined service platform.

- **GAE Applications:**
- Well-known GAE applications include the Google Search Engine, Google Docs, Google Earth, and Gmail.
- These applications can support large numbers of users simultaneously.
- Users can interact with Google applications via the web interface provided by each application.
- Third-party application providers can use GAE to build cloud applications for providing services. The applications are all run in the Google data centers.
- GAE supports many web applications. One is a storage service to store application-specific data in the Google infrastructure.
- GAE also provides Google-specific services, such as the Gmail account service

- **Amazon Web Services:**

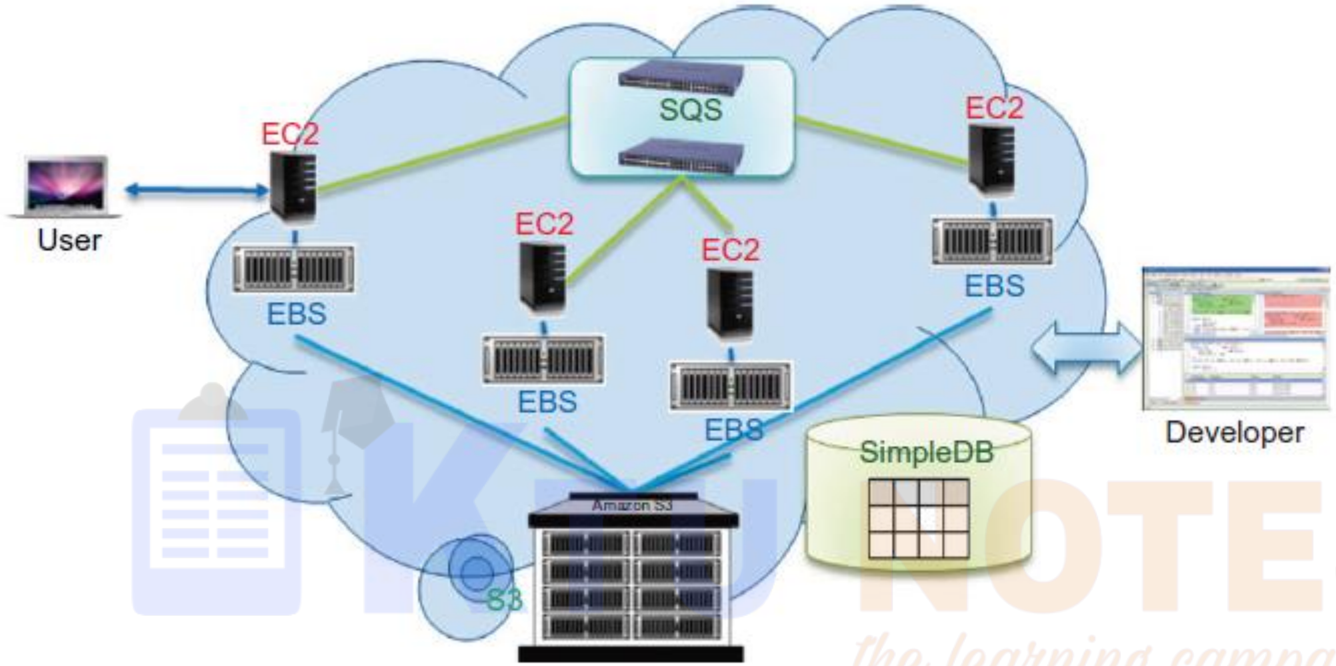
- Amazon has been a leader in providing public cloud services and applies the IaaS model in providing its services.

- **Amazon Web Services (AWS)** provides on-demand cloud computing platforms to individuals, companies and governments, on a paid subscription basis.

- **Service offerings by AWS:**

Service Area	Service Modules and Abbreviated Names
Compute	Elastic Compute Cloud (EC2), Elastic MapReduce, Auto Scaling
Messaging	Simple Queue Service (SQS), Simple Notification Service (SNS)
Storage	Simple Storage Service (S3), Elastic Block Storage (EBS), AWS Import/Export
Content Delivery	Amazon CloudFront
Monitoring	Amazon CloudWatch
Support	AWS Premium Support
Database	Amazon SimpleDB, Relational Database Service (RDS)
Networking	Virtual Private Cloud (VPC)

- **AWS architecture:**



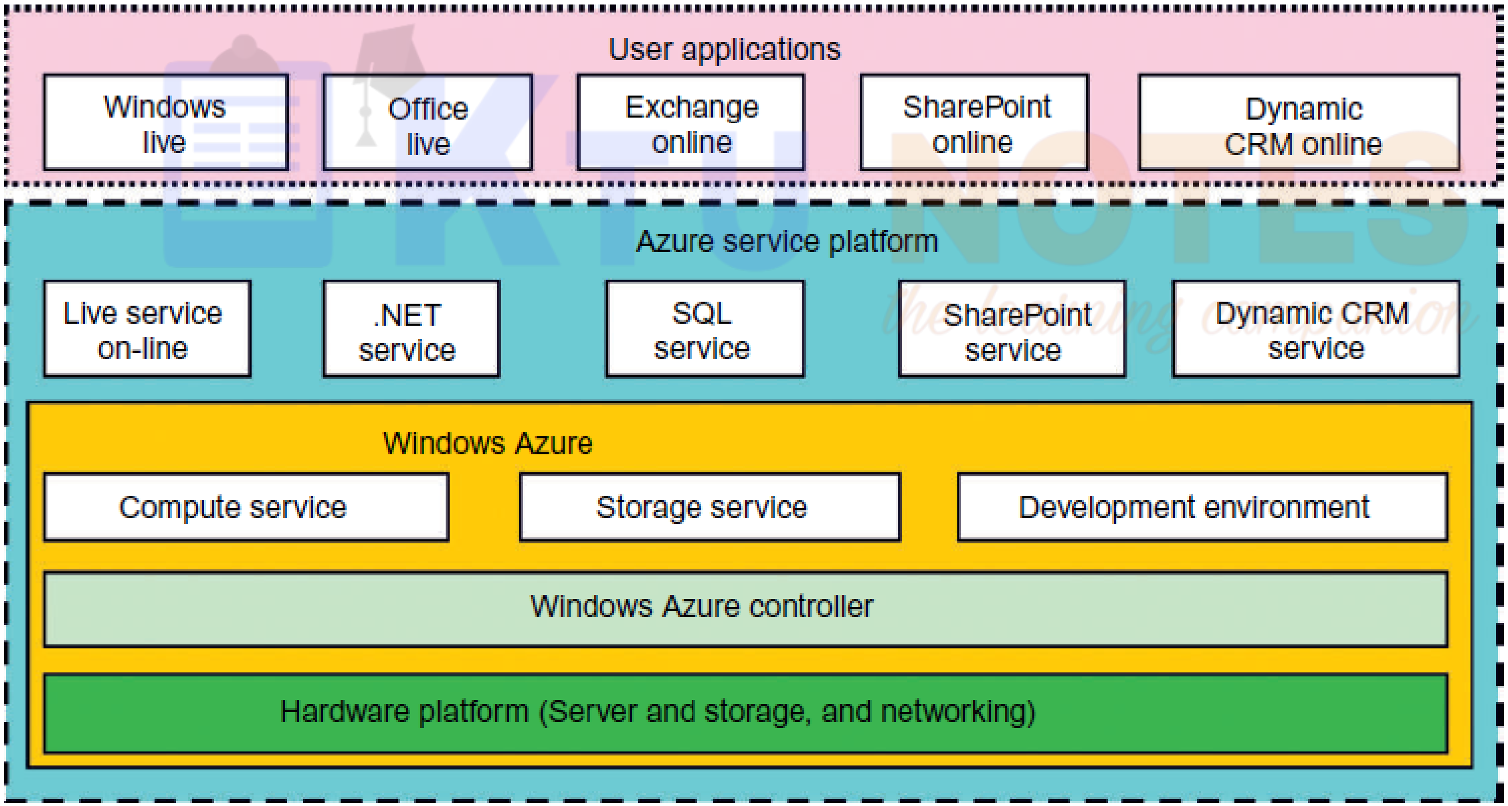
- EC2 provides the virtualized platforms to the host virtual machines where the cloud application can run.
- S3 (Simple Storage Service) provides the object-oriented storage service for users.

- EBS (Elastic Block Service) provides the block storage interface which can be used to support traditional applications.
- SQS stands for Simple Queue Service, and its job is to ensure a reliable message service between two processes.
- Amazon offers queuing and notification services (SQS and SNS), which are implemented in the AWS cloud.
- Amazon offers a Relational Database Service (RDS) with a messaging interface.
- Amazon CloudFront implements a content distribution network.
- Amazon DevPay is a simple-to-use online billing and account management service that makes it easy for businesses to sell applications that are built into or run on top of AWS.

Microsoft:

- Microsoft launched a Windows Azure platform built over Microsoft data centers to meet the challenges in cloud computing.

- **Overall architecture of Microsoft's cloud platform:**



- Windows Azure offers a cloud platform built on Windows OS and based on Microsoft virtualization technology.
- Applications are installed on VMs deployed on the data-center servers.
- Azure manages all servers, storage, and network resources of the data center.
- On top of the infrastructure are the various services for building different cloud applications.
- Cloud-level services provided by the Azure platform are introduced below:
- **Live service -** Users can visit Microsoft Live applications and apply the data involved across multiple machines concurrently.
- **.NET service -** This package supports application development on local hosts and execution on cloud machines.

- **SQL Azure -** This function makes it easier for users to visit and use the relational database associated with the SQL server in the cloud.

- **SharePoint service -** This provides a scalable and manageable platform for users to develop their special business applications in upgraded web services.

- **Dynamic CRM service -** This provides software developers a business platform in managing CRM applications in financing, marketing, and sales and promotions.

- All these cloud services in Azure can interact with traditional Microsoft software applications, such as Windows Live, Office Live, Exchange online, SharePoint online, and dynamic CRM online.

- The Azure platform applies the standard web communication protocols SOAP and REST.

- The Azure service applications allow users to integrate the cloud application with other platforms or third-party clouds.

Emerging Cloud Software Environments

- **Eucalyptus:**

- Provides an AWS-compliant EC2-based web service interface for interacting with the cloud service.

- Also Eucalyptus provides services, such as the AWS-compliant Walrus, and a user interface for managing users and images.

- The Eucalyptus system is an open software environment.

- The system has been extended to support the development of both the compute cloud and storage cloud.

- Image management system of Eucalyptus is similar to EC2.

- Eucalyptus stores images in Walrus, the block storage system that is analogous to the Amazon S3 service.
- Any user can bundle her own root file system, and upload and then register this image and link it with a particular kernel and ramdisk image.
- This image is uploaded into a user-defined bucket within Walrus, and can be retrieved anytime from any availability zone.
- This allows users to create specialty virtual appliances and deploy them within Eucalyptus with ease.
- The Eucalyptus system is available in a commercial proprietary version, as well as the open source version

- **Nimbus:**

- A set of open source tools that together provide an IaaS cloud computing solution.

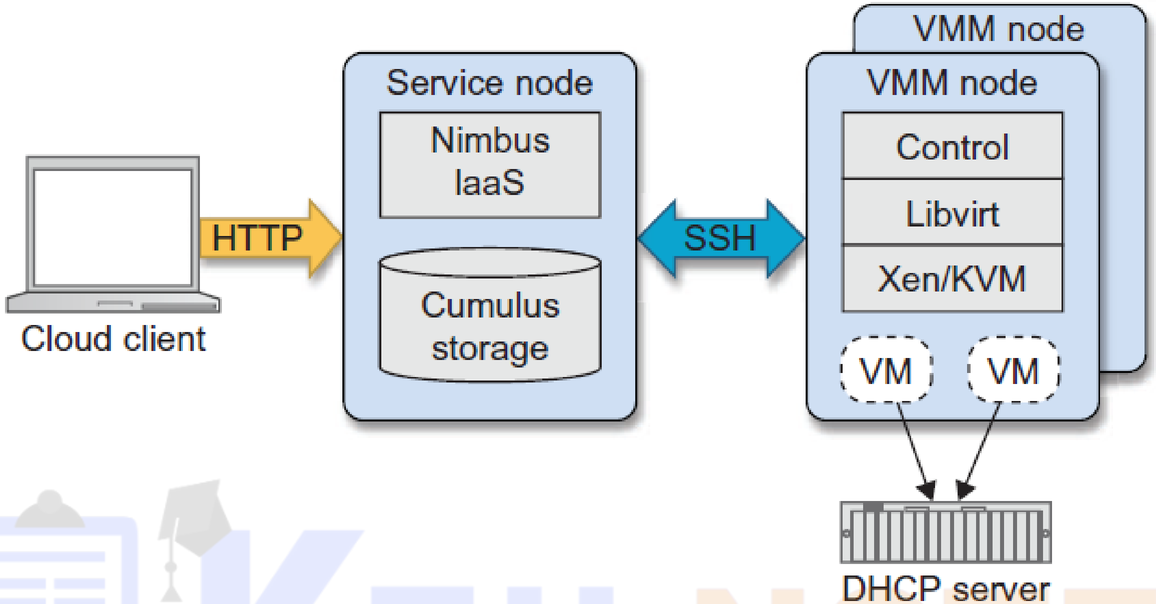
- Allows a client to lease remote resources by deploying VMs on those resources and configuring them to represent the environment desired by the user.

- Provides a special web interface known as Nimbus Web aimed to provide administrative and user functions in a friendly interface.

- Nimbus Web is centered around a Python Django web application that is intended to be deployable completely separate from the Nimbus service.

- It also has a storage cloud implementation called Cumulus.

- It is compatible with the Amazon S3 REST API, but extends its capabilities by including features such as quota management.



- Nimbus supports two resource management strategies.
- Resource pool mode –Default mode, the service has direct control of a pool of VM manager nodes and it assumes it can start VMs.
- Pilot mode - Here, the service makes requests to a cluster's Local Resource Management System (LRMS) to get a VM manager available to deploy VMs.
- Nimbus also provides an implementation of Amazon's EC2 interface that allows users to use clients developed for the real EC2 system against Nimbus-based clouds.

- **OpenStack:**

- OpenStack was introduced by Rackspace and NASA in July 2010.

- It is a free and open-source software platform for cloud computing, mostly deployed as infrastructure-as-a-service (IaaS), whereby virtual servers and other resources are made available to customers.

- OpenStack focuses on the development of two aspects of cloud computing to address compute and storage aspects with the **OpenStack Compute** and **OpenStack Storage** solutions.

- **OpenStack Compute** is the internal fabric of the cloud creating and managing large groups of virtual private servers.

- **OpenStack Object Storage** is software for creating redundant, scalable object storage using clusters of commodity servers to store terabytes or even petabytes of data.

- **OpenStack Compute:**

- OpenStack is developing a cloud computing fabric controller, a component of an IaaS system, known as Nova.

- The architecture for Nova is built on the concepts of shared-nothing and messaging-based information exchange.

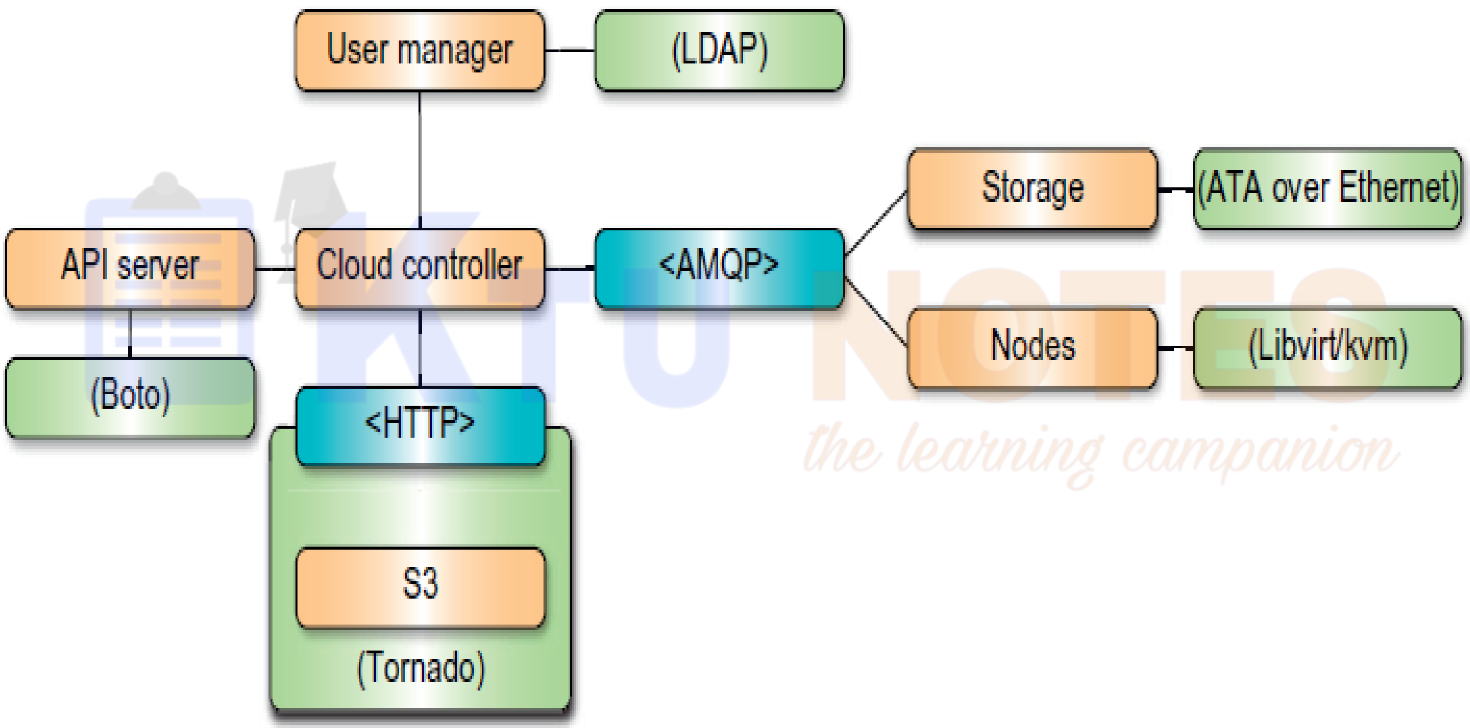
- Hence, most communication in Nova is facilitated by message queues.

- To achieve the shared-nothing paradigm, the overall system state is kept in a distributed data system.

- State updates are made consistent through atomic transactions.

- Nova is implemented in Python while utilizing a number of externally supported libraries and components.

- **The main architecture of Open Stack Compute:**



- This includes boto, an Amazon API provided in Python, and Tornado, a fast HTTP server used to implement the S3 capabilities in OpenStack.

- The API Server receives HTTP requests from boto, converts the commands to and from the API format, and forwards the requests to the cloud controller.

- The cloud controller maintains the global state of the system, ensures authorization while interacting with the User Manager via Lightweight Directory Access Protocol (LDAP), interacts with the S3 service, and manages nodes, as well as storage workers through a queue (AQMP).

- Additionally, Nova integrates networking components to manage private networks, public IP addressing, virtual private network (VPN) connectivity, and firewall rules.

Extended Cloud Computing Services

- Six layers of cloud services, ranging from hardware, network, and collocation to infrastructure, platform, and software applications.
- The top three service layers are SaaS, PaaS, and IaaS, respectively.
- The cloud platform provides PaaS, which sits on top of the IaaS infrastructure. The top layer offers SaaS.
- The bottom three layers are more related to physical requirements.
- The bottommost layer provides Hardware as a Service (HaaS).
- The next layer is for interconnecting all the hardware components, and is simply called Network as a Service (NaaS).

Cloud application (SaaS)	Concur, RightNOW, Teleo, Kenexa, Webex, Blackbaud, salesforce.com, Netsuite, Kenexa, etc.
Cloud software environment (PaaS)	Force.com, App Engine, Facebook, MS Azure, NetSuite, IBM BlueCloud, SGI Cyclone, eBay
Cloud software infrastructure: Computational resources (IaaS); Storage (DaaS); Communications (Caas)	Amazon AWS, OpSource Cloud, IBM Ensembles, Rackspace cloud, Windows Azure, HP, Banknorth
Collocation cloud services (LaaS)	Savvis, Internap, NTTCommunications, Digital Realty Trust, 365 Main
Network cloud services (NaaS)	Owest, AT&T, AboveNet
Hardware/Virtualization cloud services (HaaS)	VMware, Intel, IBM, XenEnterprise

- The next layer up offers Location as a Service (LaaS), which provides a collocation service to house, power, and secure all the physical hardware and network resources.

- Also known as Security as a Service ("SaaS").

- The cloud infrastructure layer can be further subdivided as Data as a Service (DaaS) and Communication as a Service (CaaS) in addition to compute and storage in IaaS.

- **Cloud Differences in Perspectives of Providers, Vendors, and Users**

Cloud Players	IaaS	PaaS	SaaS
IT administrators/cloud providers	Monitor SLAs	Monitor SLAs and enable service platforms	Monitor SLAs and deploy software
Software developers (vendors)	To deploy and store data	Enabling platforms via configurators and APIs	Develop and deploy software
End users or business users	To deploy and store data	To develop and test web software	Use business software

- **Software Stack for Cloud Computing**

- The overall software stack structure of cloud computing software can be viewed as layers.

- Each layer has its own purpose and provides the interface for the upper layers just as the traditional software stack does.

- The platform for running cloud computing services can be either physical servers or virtual servers.

- Using VMs, the platform can be flexible, that is, the running services are not bound to specific hardware platforms. This brings flexibility to cloud computing platforms.

- The software layer on top of the platform is the layer for storing massive amounts of data. This layer acts like the file system in a traditional single machine.

- Other layers running on top of the file system are the layers for executing cloud computing applications.
- They include the database storage system, programming for large-scale clusters, and data query language support.
- **Runtime Support Services:**
- The distributed scheduler for the cloud application has special characteristics that can support cloud applications, such as scheduling the programs written in MapReduce style.
- The runtime support system keeps the cloud cluster working properly with high efficiency.

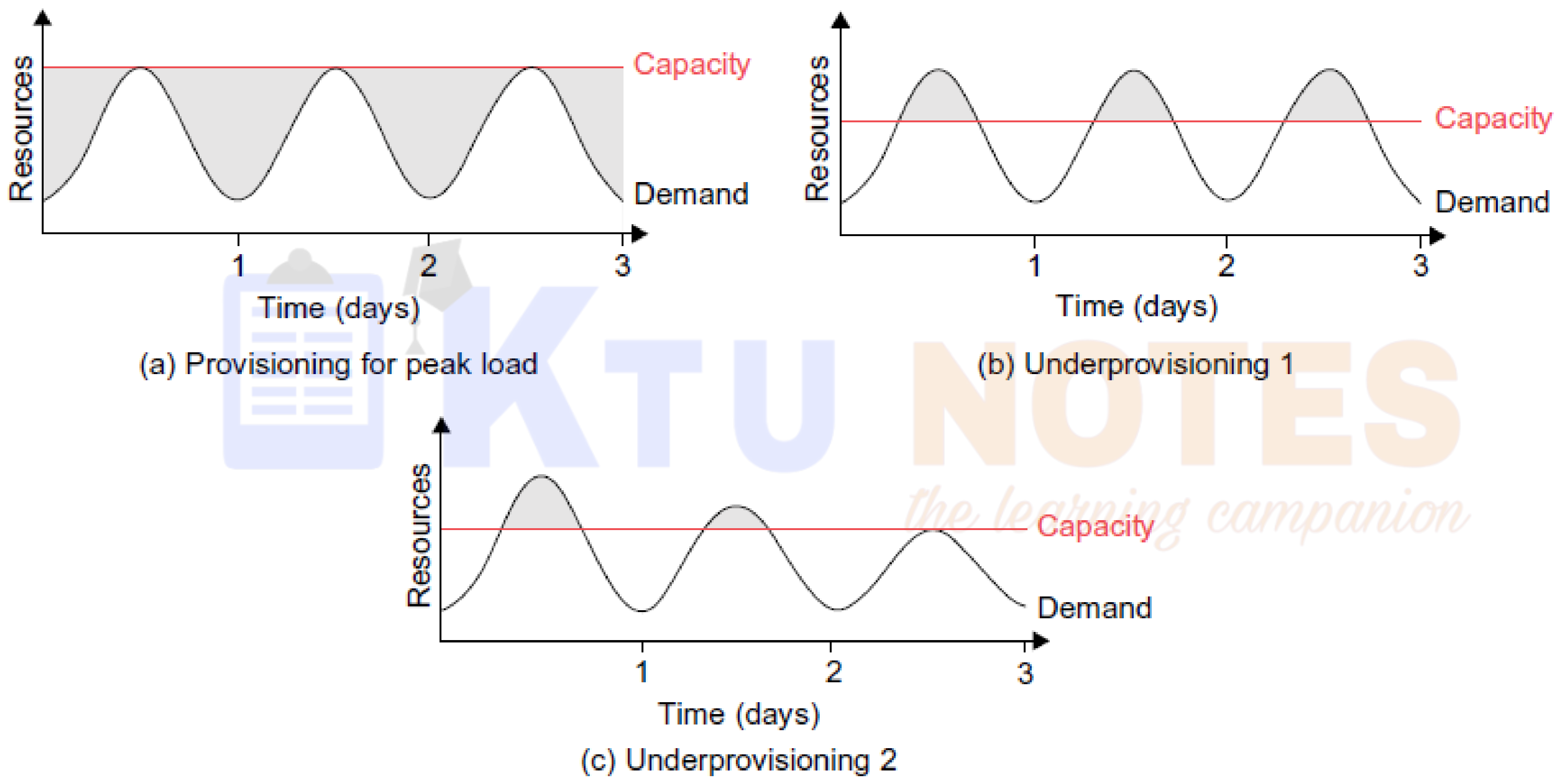
- Runtime support is software needed in browser-initiated applications applied by thousands of cloud customers.
- The SaaS model provides the software applications as a service, rather than letting users purchase the software.
- As a result, on the customer side, there is no upfront investment in servers or software licensing.
- On the provider side, costs are rather low, compared with conventional hosting of user applications.
- The customer data is stored in the cloud that is either vendor proprietary or a publicly hosted cloud supporting PaaS and IaaS

Resource Provisioning and Platform Deployment

- **Provisioning of Compute Resources (VMs):**
- Providers supply cloud services by signing SLAs with end users.
- The SLAs must commit sufficient resources such as CPU, memory, and bandwidth that the user can use for a preset period.
- Underprovisioning of resources will lead to broken SLAs and penalties.
- Overprovisioning of resources will lead to resource underutilization, and consequently, a decrease in revenue for the provider.
- Deploying an autonomous system to efficiently provision resources to users is a challenging problem.
- The difficulty comes from the unpredictability of consumer demand, software and hardware failures, heterogeneity of services, power management, and conflicts in signed SLAs between consumers and service providers.

- Efficient VM provisioning depends on the cloud architecture and management of cloud infrastructures.
- In a virtualized cluster of servers, this demands efficient installation of VMs, live VM migration, and fast recovery from failures.
- In the EC2 platform, some predefined VM templates are also provided. Users can choose different kinds of VMs from the templates.
- The provider should offer resource-economic services.
- Power-efficient schemes for caching, query processing, and thermal management are mandatory due to increasing energy waste by heat dissipation from data centers.

- **Resource Provisioning Methods:**
- 3 cases of static cloud resource provisioning policies.
- Overprovisioning with the peak load causes heavy resource waste.
- Underprovisioning of resources results in losses by both user and provider.
- Demand by the users is not served and wasted resources still exist for those demanded areas below the provisioned capacity.
- The constant provisioning of resources with fixed capacity to a declining user demand could result in even worse resource waste.
- The user may give up the service by canceling the demand, resulting in reduced revenue for the provider.
- Both the user and provider may be losers in resource provisioning without elasticity.


Resources
Capacity
Demand
1
2
3
Time (days)
(a) Provisioning for peak load
Resources
Capacity
Demand
1
2
3
Time (days)
(b) Underprovisioning 1
Resources
Capacity
Demand
1
2
3
Time (days)
(c) Underprovisioning 2

- **Demand-Driven Resource Provisioning:**

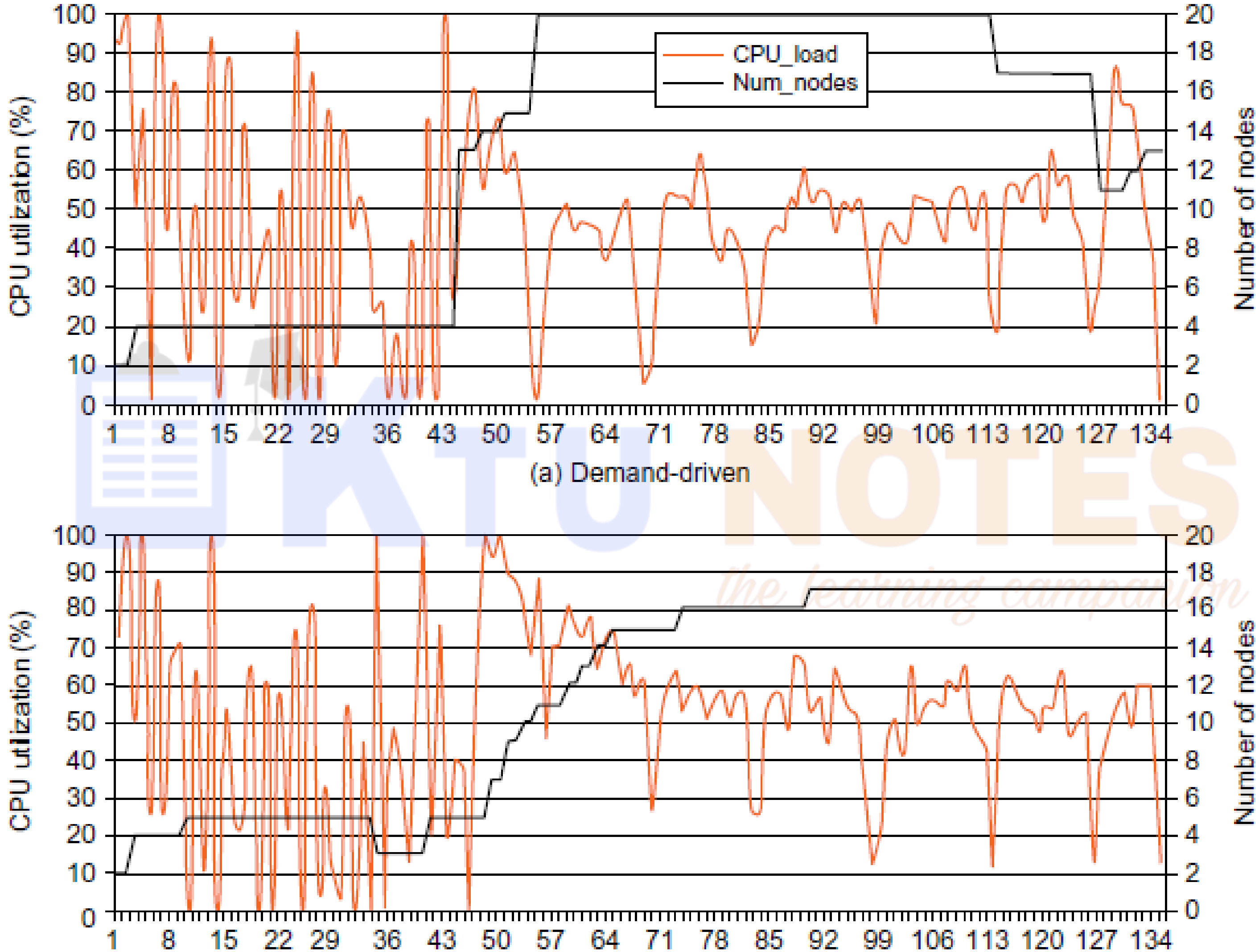
- This method adds or removes computing instances based on the current utilization level of the allocated resources

- When a resource has surpassed a threshold for a certain amount of time, the scheme increases that resource based on demand.

- When a resource is below a threshold for a certain amount of time, that resource could be decreased accordingly.

- Amazon implements such an auto-scale feature in its EC2 platform.

- This method is easy to implement. The scheme does not work out right if the workload changes abruptly.



(a) Demand-driven

(b) Event-driven

- **Event-Driven Resource Provisioning:**

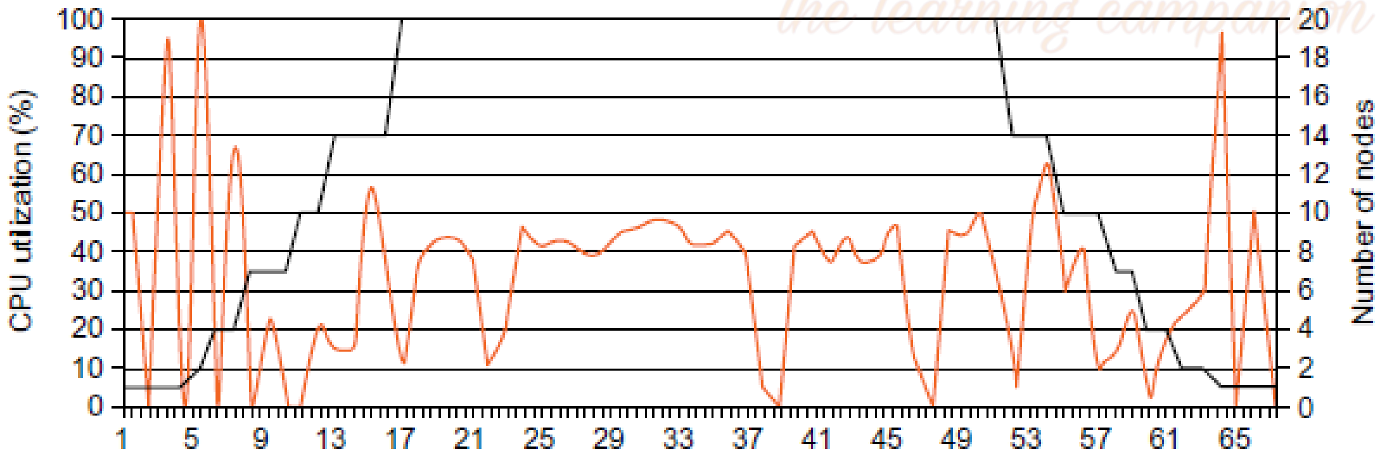
- This scheme adds or removes machine instances based on a specific time event.
- The scheme works better for seasonal or predicted events such as Christmastime in the West and the Lunar New Year in the East.
- During these events, the number of users grows before the event period and then decreases during the event period.
- This scheme anticipates peak traffic before it happens.
- The method results in a minimal loss of QoS, if the event is predicted correctly.
- Otherwise, wasted resources are even greater due to events that do not follow a fixed pattern.

- **Popularity-Driven Resource Provisioning:**

- In this method, the Internet searches for popularity of certain applications and creates the instances by popularity demand.

- The scheme anticipates increased traffic with popularity. Again, the scheme has a minimal loss of QoS, if the predicted popularity is correct.

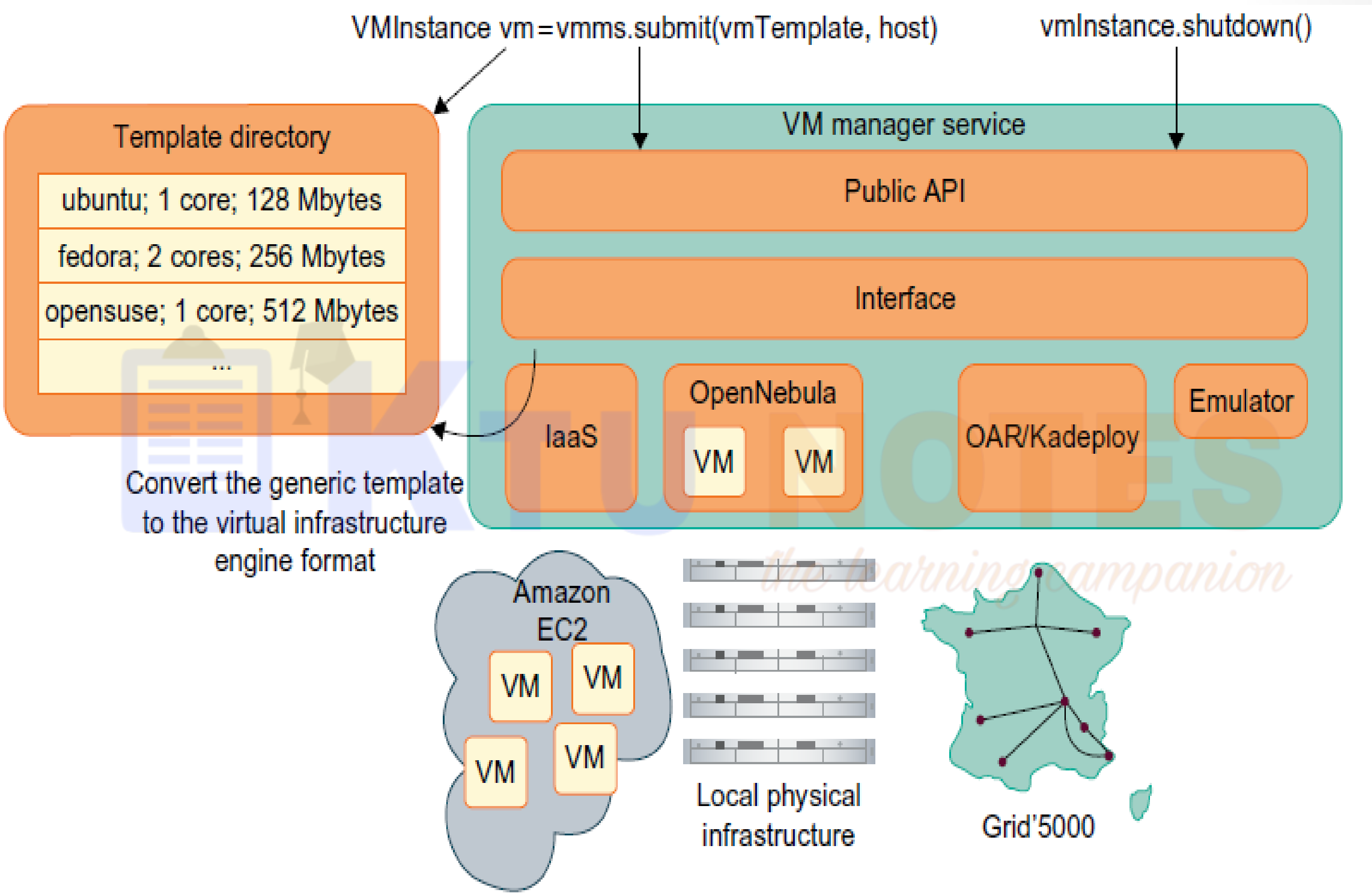
- Resources may be wasted if traffic does not occur as expected.



(c) Popularity-driven

Virtual Machine Creation and Management

- Cloud-loading experiments are used by a Melbourne research group on the French Grid’5000 system.
- This experimental setting illustrates VM creation and management.
- The figure shows the interactions among VM managers for cloud creation and management.
- The managers provide a public API for users to submit and control the VMs.
- The VM manager is the link between the gateway and resources.
- The manager manage VMs deployed on a set of physical resources.


VMInstance vm=vmms.submit(vmTemplate, host)
vmInstance.shutdown()
Template directory
ubuntu; 1 core; 128 Mbytes
fedora; 2 cores; 256 Mbytes
opensuse; 1 core; 512 Mbytes
...
Convert the generic template to the virtual infrastructure engine format
VM manager service
Public API
Interface
IaaS
OpenNebula
VM
VM
OAR/Kadeploy
Emulator
Amazon EC2
VM
VM
VM
VM
Local physical infrastructure
Grid'5000

- **Virtual Machine Templates:**

- A VM template is analogous to a computer's configuration and contains a description for a VM with the following static information:
  - The number of cores or processors to be assigned to the VM
  - The amount of memory the VM requires
  - The kernel used to boot the VM's operating system
  - The disk image containing the VM's file system
  - The price per hour of using a VM

- The gateway administrator provides the VM template information when the infrastructure is set up.

- The administrator can update, add, and delete templates at any time.

- To deploy an instance of a given VM, the VMM generates a descriptor from the template.

- This descriptor contains the same fields as the template and additional information related to a specific VM instance.

- Typically the additional information includes:
  - The disk image that contains the VM's file system
  - The address of the physical machine hosting the VM
  - The VM's network configuration
  - The required information for deployment on an IaaS provider

- Before starting an instance, the scheduler gives the network configuration and the host's address; it then allocates MAC and IP addresses for that instance.

- The template specifies the disk image field.

- To deploy several instances of the same VM template in parallel, each instance uses a temporary copy of the disk image.

- The descriptor's fields are different for deploying a VM on an IaaS provider.

- Network information is not needed, because Amazon EC2 automatically assigns a public IP to the instances.