UNIT 4 Cloud Computing

- **8.1 What Is Cloud Computing?**
- **8.2 Grid/SOA and Cloud Computing**
- **8.3 Cloud Middleware**
- **8.4 NIST's SPI Architecture and Cloud Standards**
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8.1 What Is Cloud Computing?

"It starts with the principle that the data services and architecture should be on servers. We call it cloud computing—they should be in a 'cloud' somewhere. And that if you have the right kind of browser or the right kind of access, it doesn't matter whether you have a PC or a Mac or a mobile phone or a BlackBerry or what have you—or new devices still to be developed—you can get access to the cloud." Cloud computing is the on-demand availability of computer system resources, especially data storage and computing power, without direct active management by the user. This is the vision of Google chief executive officer Eric Schmidt, speaking at a search engine conference in 2006. Since then, *cloud computing* has been a buzzword worldwide. This was the first high-profile usage of the term; however, the first mention of cloud computing was in a 1997 paper entitled "Intermediaries in Cloud-Computing: A New Computing Paradigm" by R. Chellappa.

The term *cloud* was used as a metaphor(symbol) for the Internet, based on the cloud drawing used in the past to represent the telephone network, and later to depict the Internet in computer network diagrams as an abstraction of the underlying infrastructure it represents. Much like the Internet of Things (IoT), cloud computing is a natural evolution of related, existing, and new concepts in the information and communications technologies (ICT) arena, based on the widespread adoption of virtualization, web services, parallel and distributed file systems, load balance and batch scheduling, autonomic, and utility computing technologies.

In fact, the cloud computing term collided with many other terms that were already catchword in the ICT industry, such as SaaS (software as a service), grid computing, utility computing, PaaS (platform as a service), on-demand services, pervasive computing, and so on. Cloud computing provides computation, software, data access, and storage services that do not require end-user knowledge of the physical location and configuration of the system that delivers the services.

Details are abstracted from end-users, who no longer have the need for expertise in, or control over, the technology infrastructure "in the cloud" that supports them. The underlying concept of cloud computing dates back to 1961, when John McCarthy proposed the concept of utility computing and IBM started to rent its mainframe computing resources as "electric utility" to Wall Street via remotely connected dumb terminals.

Amazon played a key role in the development of cloud computing. After the dot-com bubble, most data centers were using as little as 10 percent of their capacity at any one time, just to leave room for occasional spikes. Having found that the new Amazon infrastructure resulted in significant internal efficiency improvements, Jeff Bezos initiated a new product development effort to provide cloud computing to external customers, and launched Amazon Web Service on a utility computing basis in 2006, which is now categorized as IaaS (infrastructure as a service).

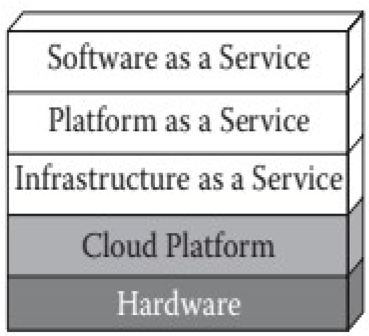


Figure 8.1 Cloud hierarchy. (From Ralf Teckelmann, Anthony Sulistio, and Christoph Reich, "A Taxonomy of Interoperability for IaaS," in Lizhe Wang, Rajiv Ranjan, Jinjun Chen, and Boualem Benatallah (Eds.), *Cloud Computing: Methodology, Systems, and Applications*, Boca Raton, FL: CRC Press, 2011.)

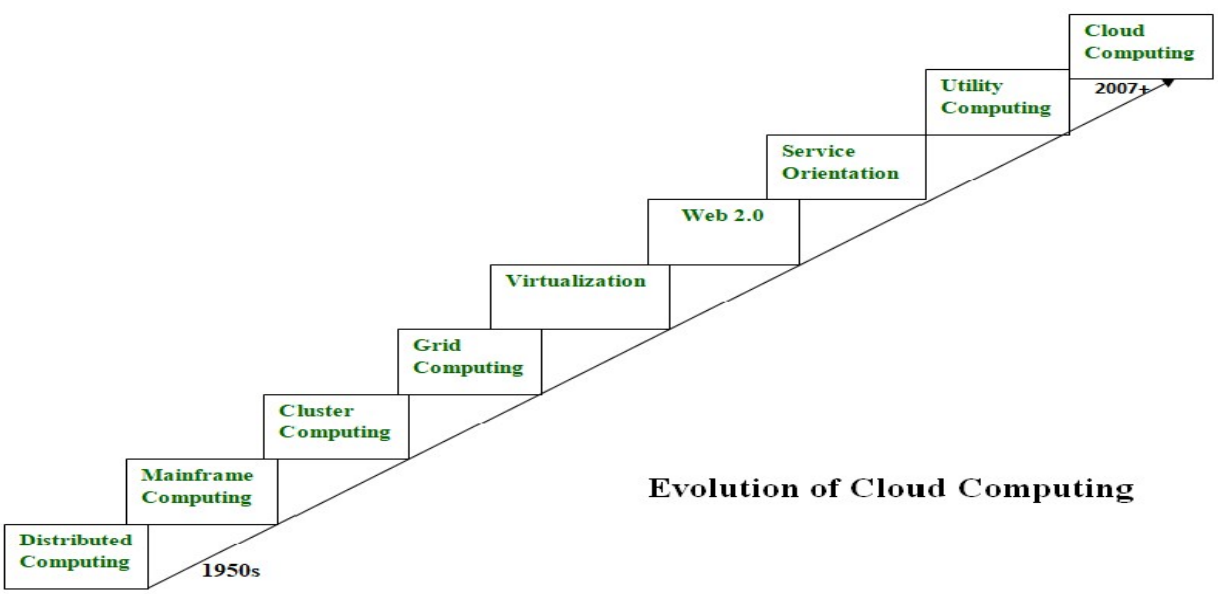
Salesforce was founded in 1999 by Marc Benioff,. In 2001, salesforce.com pioneered the multitenant SaaS model, a new application-delivering mechanism. SaaS provides immediate benefits at reduced risks and costs, thanks to the rapid development and maturity of the Internet infrastructure, among other factors (as shown in Figure 8.1). In 2008, the force.com PaaS on-demand development platform was launched and became a new pillar of cloud computing, which has three pillars: IaaS, PaaS, and SaaS. All three pillars can provide services.

EVOLUTION OF CLOUD COMPUTING:

Distributed Systems:

- It is a composition of multiple independent systems but all of them are depicted as a single entity to the users.
- The purpose of distributed systems is to share resources and also use them effectively and efficiently.
- Distributed systems possess characteristics such as scalability, concurrency, continuous availability, heterogeneity, and independence in failures.
- But the main problem with this system was that all the systems were required to be present at the same geographical location.

Thus to solve this problem, distributed computing led to three more types of computing and they were-Mainframe computing, cluster computing, and grid computing.



Evolution of Cloud Computing

Mainframe computing:

- Mainframes which first came into existence in 1951 are highly powerful and reliable computing machines.
- These are responsible for handling large data such as massive input-output operations.
- Even today these are used for bulk processing tasks such as online transactions etc.
- These systems have almost no downtime with high fault tolerance.
- After distributed computing, these increased the processing capabilities of the system.
- But these were very expensive.
- To reduce this cost, cluster computing came as an alternative to mainframe technology.

Cluster computing:

- In 1980s, cluster computing came as an alternative to mainframe computing.
- Each machine in the cluster was connected to each other by a network with high bandwidth.
- These were way cheaper than those mainframe systems. These were equally capable of high computations.
- Also, new nodes could easily be added to the cluster if it was required.
- Thus, the problem of the cost was solved to some extent but the problem related to geographical restrictions still pertained.
- To solve this, the concept of grid computing was introduced.

Grid computing:

- In 1990s, the concept of grid computing was introduced.
- It means that different systems were placed at entirely different geographical locations and these all were connected via the internet.
- These systems belonged to different organizations and thus the grid consisted of heterogeneous nodes.
- Although it solved some problems but new problems emerged as the distance between the nodes increased.

- The main problem which was encountered was the low availability of high bandwidth connectivity and with it other network associated issues.
- Thus. cloud computing is often referred to as “Successor of grid computing”.

Virtualization:

- It was introduced nearly 40 years back.
- It refers to the process of creating a virtual layer over the hardware which allows the user to run multiple instances simultaneously on the hardware.
- It is a key technology used in cloud computing.
- It is the base on which major cloud computing services such as Amazon EC2, VMware vCloud, etc work on.
- Hardware virtualization is still one of the most common types of virtualization.

Web 2.0:

- It is the interface through which the cloud computing services interact with the clients.
- It is because of Web 2.0 that we have interactive and dynamic web pages.
- It also increases flexibility among web pages.
- Popular examples of web 2.0 include Google Maps, Facebook, Twitter, etc.
- Needless to say, social media is possible because of this technology only.
- It gained major popularity in 2004.

Service orientation:

- It acts as a reference model for cloud computing.
- It supports low-cost, flexible, and evolvable applications.
- Two important concepts were introduced in this computing model.
- These were Quality of Service (QoS) which also includes the SLA (Service Level Agreement) and Software as a Service (SaaS).

Utility computing:

- It is a computing model that defines service provisioning techniques for services such as compute services along with other major services such as storage, infrastructure, etc which are provisioned on a pay-per-use basis.
- Thus, the above technologies contributed to the making of cloud computing.

8.2 Grid/SOA and Cloud Computing

Much like the Internet of Things, the technological foundation of cloud computing is distributed computing based on communication networks. One of the most directly related works is the use of cluster of workstations (COWs) and networks of workstations.

Google's server farms were based on the same philosophy of COW. In fact, the MapReduce system is a batch processing extension of the scatter–barrier–reduce primitives of MPI/PVM(Message Passing Interface/Parallel Virtual Machine). The well-known Hadoop is an open-source implementation of Google's Bigtable, GFS, and MapReduce by Doug Cutting et al. in 2004. Hadoop is a high-throughput computing batch processing system, a niche application customized for embarrassingly parallel Internet-based massive data processing, as shown in Figure 8.2.

However, as the Internet-related data and users increase rapidly, Hadoop has been widely used and become almost a nickname of cloud computing.Grid computing is the direct technological ancestor of cloud computing, which also has roots in the COW technology; some of the well-known cloud systems such as Eucalyptus and OpenNebula are directly transformed from earlier grid computing research and development systems.

The grid computing concept was credited to Ian Foster of Argonne National Laboratory when he initiated the Globus project in 1994 based on the works of PVM/MPI, PBS(Portable Batch System)/Condor (as job schedulers of high-performance computing or parallel supercomputing systems), and so on. Besides the basic parallel and distributed computing environments provided by middleware such as PVM and MPI, the job scheduler plays an important role as workload and resource management systems in building the grid and cloud computing/clustering infrastructure.

BATCH Processing: Batch processing is **the method computers use to periodically complete high-volume, repetitive data jobs**. Certain data processing tasks, such as backups, filtering, and sorting, can be compute intensive and inefficient to run on individual data transactions.

Nutshell: Nutshell is a web and mobile customer relationship management (CRM) and email marketing automation service. It is composed of a web application, as well as mobile applications for the iOS and Android platforms.

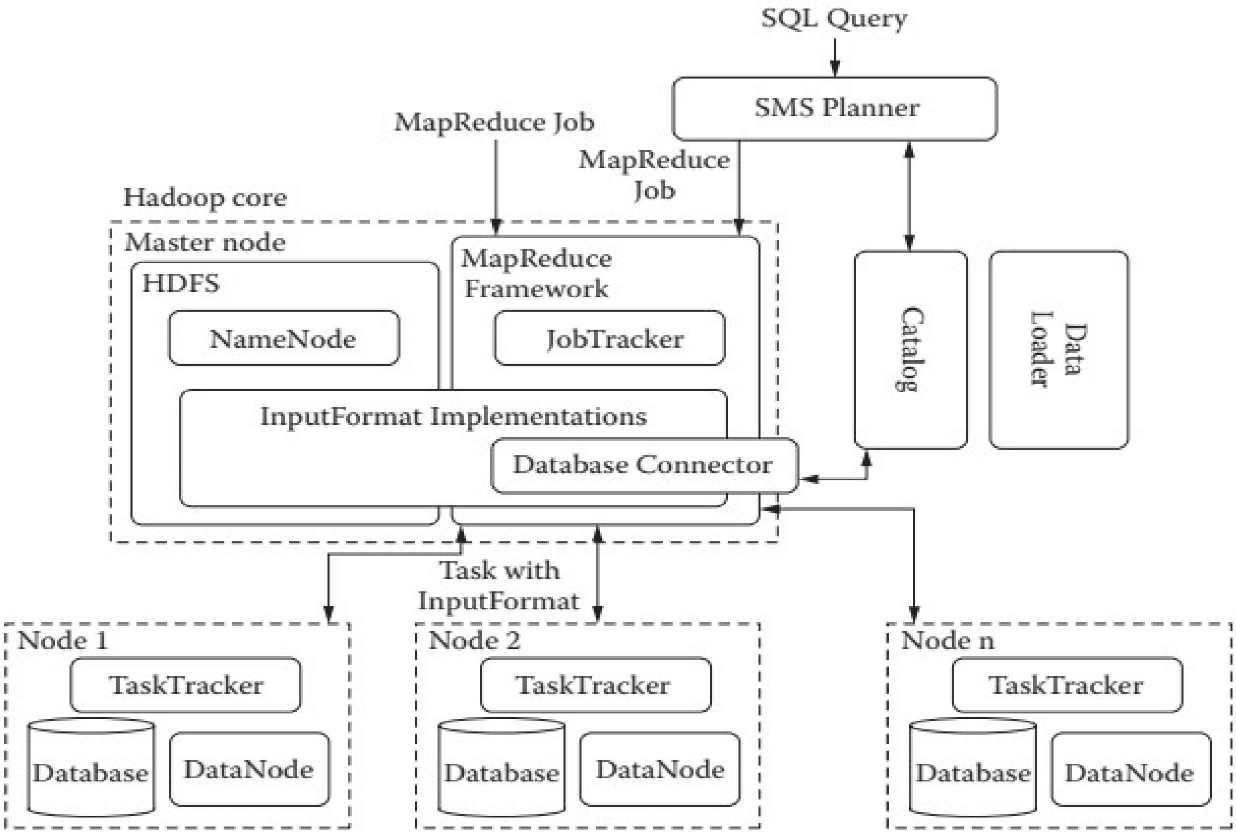


Figure 8.2 Hadoop is a batch system for embarrassingly parallel niche applications.

For example, the Condor scheduler can be used in the Amazon system as shown in Figure 8.3. One of the key features or functionalities of grid and cloud computing is providing a single system image (or a single parallel virtual machine) that hides the underlying scalable elastic infrastructure (such as the Amazon backend server and storage farms) based on clustering technologies (as shown in Figure 8.4) and provisions a unified user interface via web services (such as the Amazon Web Services) and SOA over the Internet.

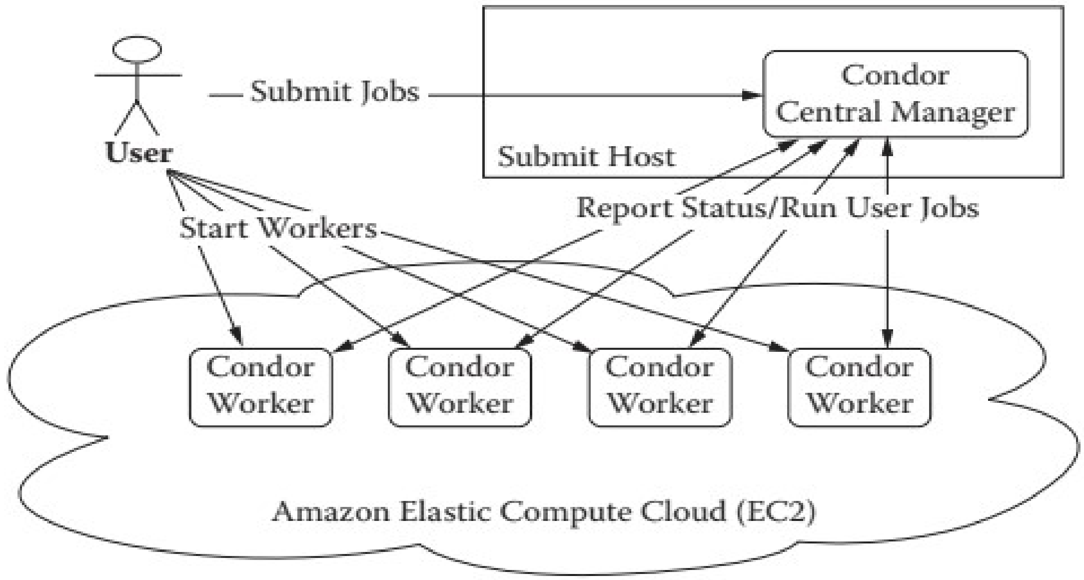


Figure 8.3 Condor scheduler in Amazon Web Services.

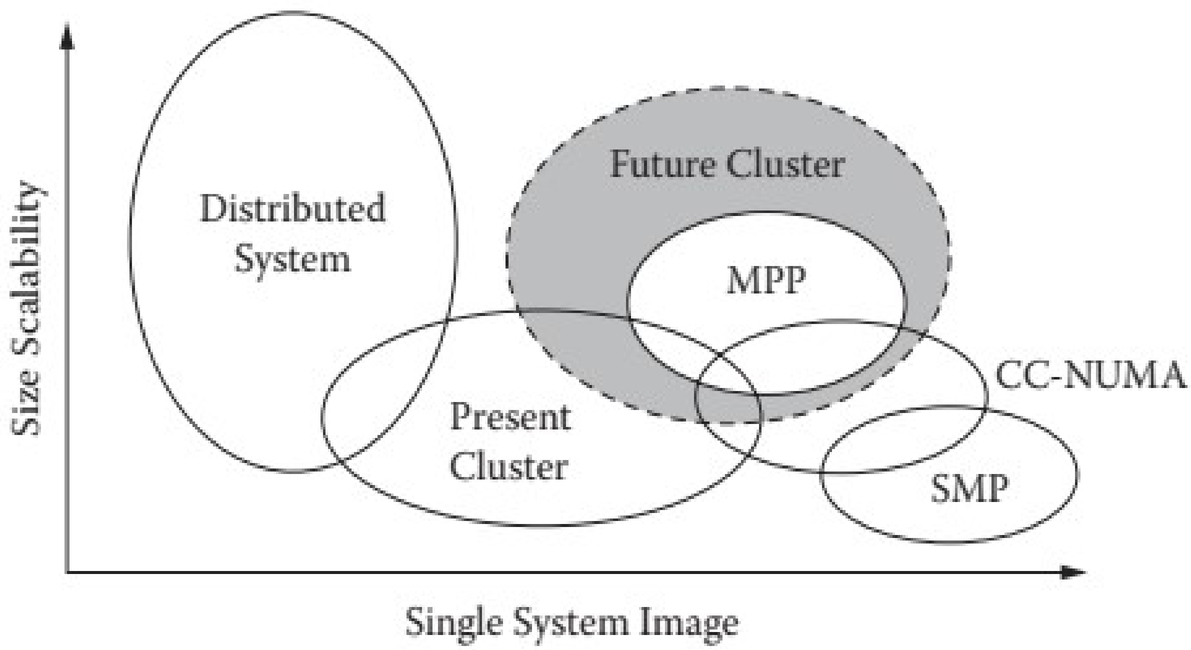


Figure 8.4 Single system image is the core.

Virtualization is another important concept often mentioned in the cloud computing context. There are two sides of the virtualization coin:

- single system virtualization (SSV, i.e., oneto-many virtualization)

- Multi system virtualization (MSV, i.e., many-to-one virtualization).

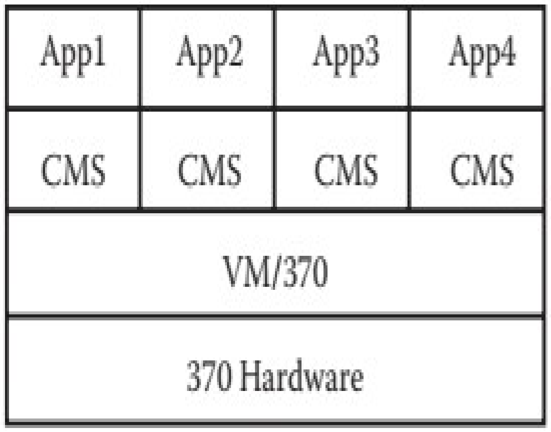


Figure 8.5 Earliest hypervisor.

Utility computing started with SSV when IBM provided computing resources for rent via networked dumb terminals to Wall Street in the 1970s as mentioned before. A mainframe computer was virtualized into multiple virtual computers (as shown in Figure 8.5) via *hypervisor* technology so that enterprise users feel like a dedicated computer is providing services to them.

hypervisor?

A **hypervisor**, also known as a virtual machine monitor or VMM, is software that creates and runs virtual machines (VMs). A hypervisor allows one host computer to support multiple guest VMs by virtually sharing its resources, such as memory and processing.

Benefits of hypervisors

There are several benefits to using a hypervisor that hosts multiple virtual machines:

- **Speed**: Hypervisors allow virtual machines to be created instantly, unlike bare-metal servers. This makes it easier to provision resources as needed for dynamic workloads.
- **Efficiency**: Hypervisors that run several virtual machines on one physical machine's resources also allow for more efficient utilization of one physical server. It is more cost- and energy-efficient to run several virtual machines on one physical machine than to run multiple underutilized physical machines for the same task.
- **Flexibility**: Bare-metal hypervisors allow operating systems and their associated applications to run on a variety of hardware types because the hypervisor separates the OS from the underlying hardware, so the software no longer relies on specific hardware devices or drivers.

- **Portability**: Hypervisors allow multiple operating systems to reside on the same physical server (host machine). Because the virtual machines that the hypervisor runs are independent from the physical machine, they are portable. IT teams can shift workloads and allocate networking, memory, storage and processing resources across multiple servers as needed, moving from machine to machine or platform to platform. When an application needs more processing power, the virtualization software allows it to seamlessly access additional machines.

Modern SSV technologies are similar to the hypervisor technologies that IBM used decades ago. The purpose is to simulate multiple computers on top of one computer run multiple operating systems on one computer hardware to enable maximum usage of the ever-increasing power of a single computer such as a PC and increase efficiency of overall resources.

For example, one of the most important uses of SSV in earlier times was to simulate all the operating systems on a few servers so that a startup company in Silicon Valley could test their software products on all operating systems without having to buy all kinds of computers.

SSV can be further categorized as three types of virtual machine monitors:

- Type 1 (hypervisor),
- Type 2, and hybrid.

The virtualization (currently almost a synonym of VMWare) talked about in the context of cloud computing currently is SSV, which makes many believe that SSV is a must for cloud computing. In fact, one-to-many virtualization is not required to build a cloud computing system, although it enables new platforms to run on legacy environments, and it helps to consolidate and simplify the management of the system by making the nodes of the system homogenous, thus simplifying the handling of issues such as (fault tolerance) check-pointing and migration (e.g., VMWare vMotion) when some of the nodes run into failures.

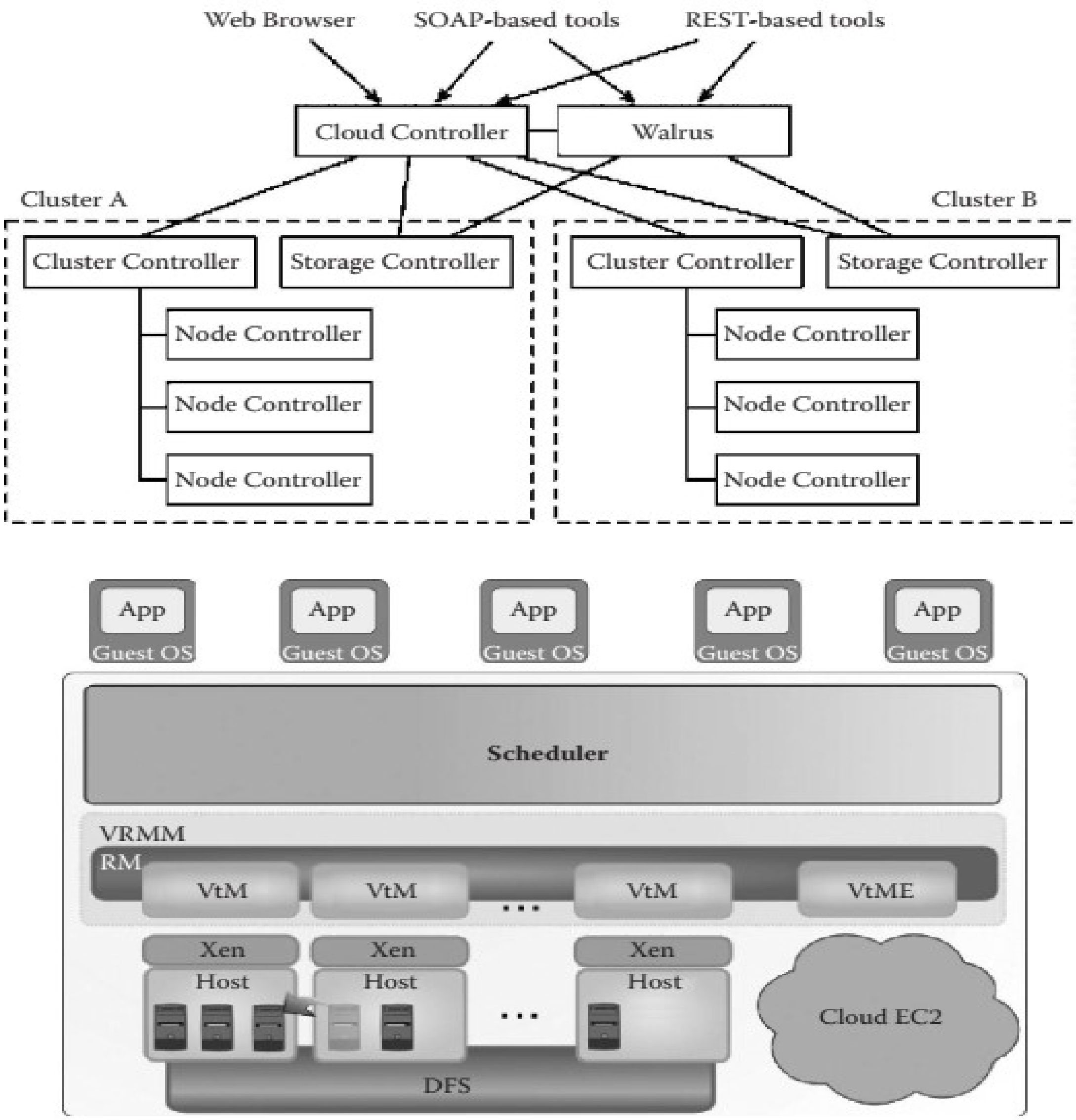


Figure 8.6 Many-to-one virtualization is the foundation of cloud computing.

On the other hand, many-to-one virtualization is the foundation of cloud computing. MSV refers aggregately to the use of the abovementioned distributed and parallel clustering technologies such as COW, high-performance computing (HPC), grid computing, high-throughput computing, high-availability computing, and so forth to build a single, gigantic, parallel virtual computer or a single centralized service-providing virtual resource that serves many users for a shortage of applications. Some sample MSV architectures are shown in Figure 8.6. SSV technologies can be used at the node level of MSV but are not required.

The computing and storage resource are delivered to the end users using SOA (including SOAP(Simple Object Access Protocol) or REST (Representational State Transfer)-based web services, SaaS, EAI, etc.) via the Internet, sometimes via intranet and extranet for private cloud applications. Many of the technologies and protocols of the SOA standard stack can be used in all of the three layers: IaaS, PaaS, and SaaS. To summarize, cloud computing is the fusion of grid computing and SOA technologies to provide everything as utility-style services, as shown in Figure 8.7.

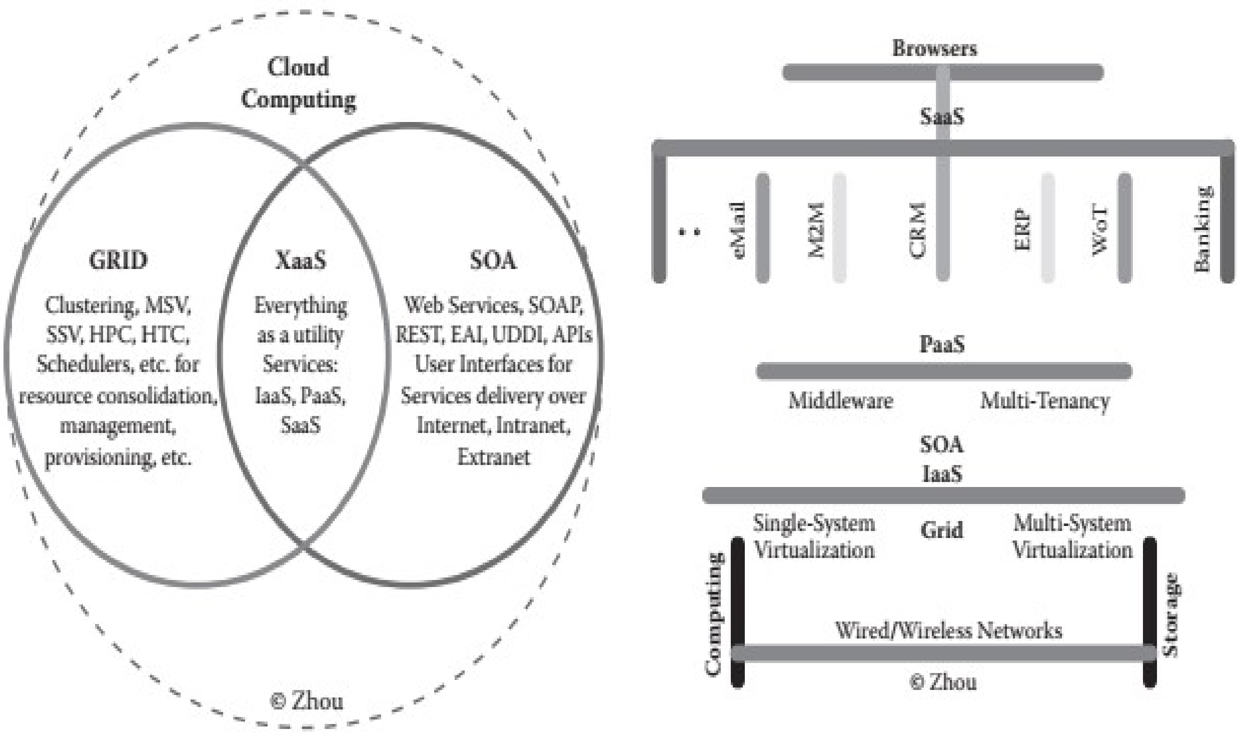


Figure 8.7 Cloud computing is the fusion of grid and SOA.

8.3 Cloud Middleware

the cloud computing system is also a multi-tiered architecture built on a middleware stack as shown in Figure 8.8. At the lowest machine virtualization (SSV) level, there are middleware that help reduce the overhead of virtualization. SSV is useful and widely used, but it does not come cheap. The performance cost of virtualization, for I/O-intensive workloads in particular, can be heavy. Common approaches to solve the I/O virtualization overhead focus on the I/O stack, thereby missing optimization opportunities in the overall stack.

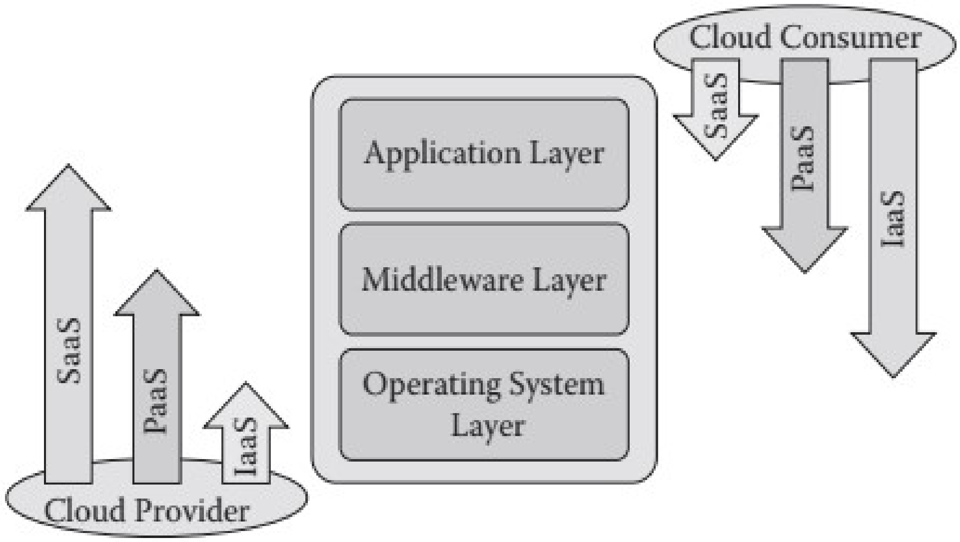


Figure 8.8 Multitiered cloud architecture based on middleware.

As an example, VAMOS(Voice services over Adaptive Multi-user channels on One Slot), built by IBM, is a novel middleware architecture that runs its middleware modules at the hypervisor level. VAMOS reduces I/O virtualization overhead by cutting down on the overall number of guest/ hypervisor switches for I/O intensive workloads. Applying VAMOS to a database application improved its performance by up to 32 percent. Here, the middleware concept is extended to include software that does inter-process communication not necessary over a network.

At the cluster computing or grid computing level, many types of work are done by middleware.

- The parallel computing environments such as PVM and MPI are (HPC) middleware by definition; the Hadoop system and the job scheduler such as Condor, LoadLeveler, and others are all middleware.
- The HPC(High Performance Computing) middleware fills the gap that the operating systems and the programming languages lack to support parallel computing.
- A number of grid middleware initiatives (such as http:// www.eu-emi.eu/) have been formed by interested members, mostly in the scientific computing community.

Some of those middleware are aggregately referred to as grid middleware and listed as follows:

Low-level middleware

- MPI, Open MPI
- PVM (parallel virtual machine)
- POE (parallel operating environment, IBM)
- Middleware for file systems and resources
- MPI-IP
- PVFS/GPFS (parallel virtual file system/general parallel file system IBM)
- Sector-Sphere
- Condor/PBS/LoadLeveler (IBM)
- High-level middleware
- Beowolf
- Globus Toolkit
- Gridbus
- Legion
- Unicore
- OSCAR/CAOS/Rocks
- OpenMosix/NSA/Perceus

Many research works demonstrate a typical grid computing system (other similar systems include Distributed European Infrastructure for Supercomputing Application [DEISA], Teragrid, Enabling Grids for E-Science [EGEE], NorduGrid, SEE-GRID, OSG, etc.) and its components based on grid middleware before cloud computing gained momentum. A grid computing system aims to serve all kinds of applications as a more generic cloud computing system than Hadoop.

As discussed before, grid computing is the foundation of cloud computing infrastructure, so grid middleware is the basis of IaaS middleware. In addition, the IaaS middleware (part of cloud middleware) may include components such as system management, network management, billing and operation support systems, provision, configuration, automation, orchestration, service level agreement (SLA) management, and so on.

From the distributed enterprise computing standpoint, almost all of the EAI (Enterprise application integration) and business-to-business (B2B) middleware described in the previous chapters are needed to build cloud computing systems for enterprise and commercial applications. They all are part of cloud middleware, particularly part of the PaaS middleware. Multitenancy is one of the basic functions of PaaS middleware, evolving from the traditional platform middleware. The multitenant efficiency functionalities of a PaaS platform are often required and implemented in a traditional middleware such as the three-tiered application servers described in the previous chapters and as shown in Figure 8.9.

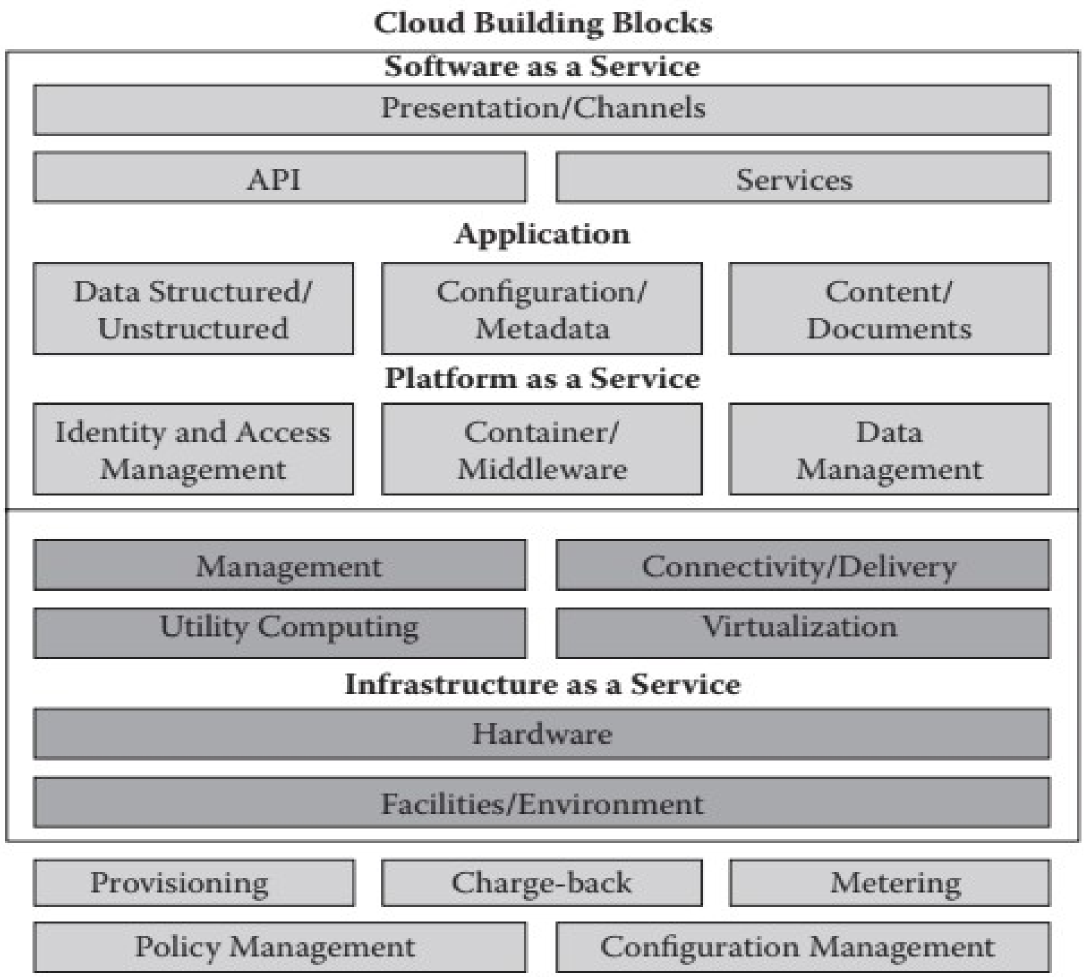


Figure 8.9 PaaS and cloud middleware.

The PaaS middleware is often referred to as the cloud middleware that underpins and supports the SaaS applications. The graphic in depicts the different deployment options of a PaaS middleware in cloud systems: the more middleware is shared, the cloud systems scale to larger numbers of tenants and with lower operational costs. The well-known middleware quadrant from Gartner depicts the market landscape of middleware vendors.

Salesforce.com was included for the first time in 2010, most likely because its foundational platform (force.com) is recognized as one of the most important cloud (PaaS) middleware vendors. To summarize, the cloud middleware consists of two kinds of middleware—IaaS and PaaS middleware—and their relation is shown in Figure 8.10. (Note: SaaS are not middleware, they are applications on top of middleware.) In cloud computing, **multitenancy** means that multiple customers of a cloud vendor are using the same computing resources.

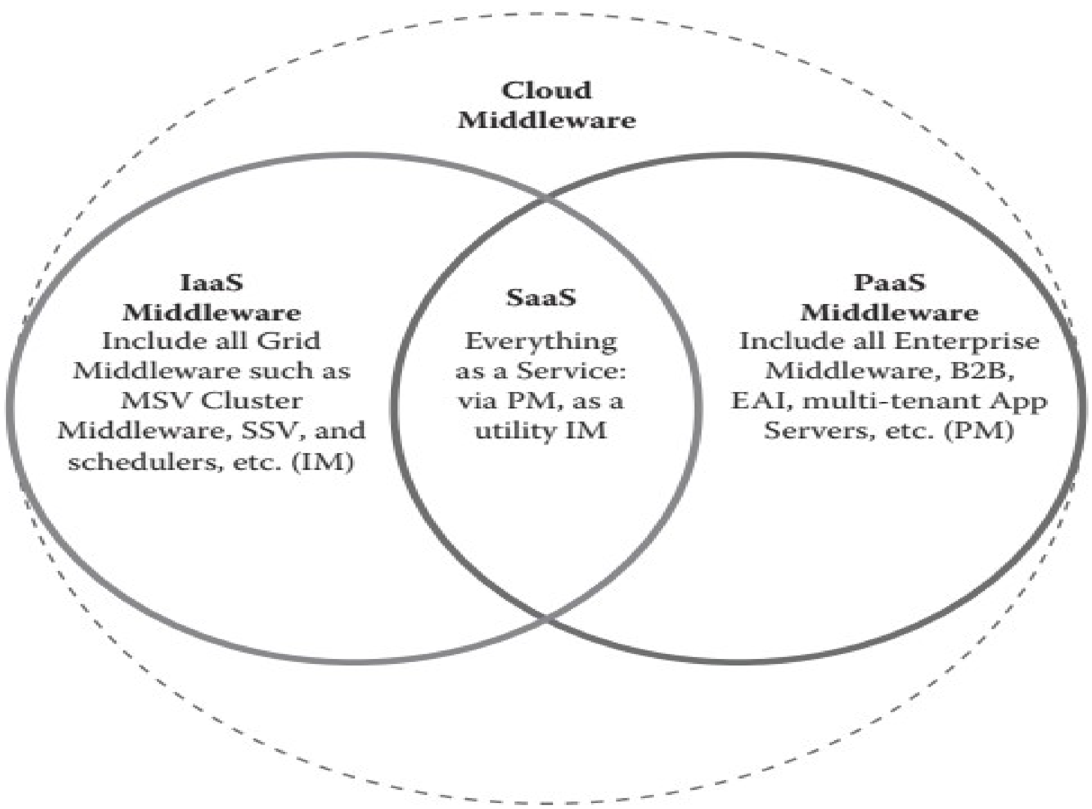


Figure 8.10 Cloud middleware.

8.4 NIST's SPI Architecture and Cloud Standards

The U.S. National Institute of Standards and Technology (NIST) has come up with a widely accepted definition that characterizes important aspects of cloud computing:

> Cloud computing is a model for enabling everywhere, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.

This cloud model is composed of the following:

- Three service models: IaaS, PaaS, and SaaS
- Four deployment models: private cloud, public cloud, community cloud, and hybrid cloud
- Five essential characteristics: on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service.

Cloud computing is an evolving paradigm. The comparative benefits of the different service models of cloud computing are compared in http://itcandor.net/2010/11/22/cloud-computing -benefits-q410/. The NIST specification is a milestone that clarifies and settles most of the confusion and arguments about cloud computing. It can be used as a starting point for standardization.

Electronics and Telecommunications Research Institute (ETRI) of Korea proposed to address standards on nine aspects (http://www.etri.re.kr/eng/res/res_0102020301.etri):

- Definition, taxonomy, terminologies
- Provisioning model
- Business process
- Security
- Interoperability
- Legality
- Environmental issues
- Architecture
- Availability

The NIST specification covers a few of the aspects, such as the standardization of definition, taxonomy, and terminologies.Some of the standardization in the grid computing domain provided a foundation for extended work, such as the MPI, openMP standards, as well as job description language standards (such as Job Submission and Description Language and Basic Execution Service of Open Grid Forum—Open Grid Services Architecture) for job scheduling.

Table 8.1 lists some of the cloud computing standardization organizations and their websites. The following are some of the works done by those standards organizations:

NIST: Working definition of cloud computing

- Distributed Management Task Force: Open Virtualization Format, Open Cloud Standards Incubator, DSP-IS0101 Cloud Interoperability White Paper V1.0.0
- Cloud Management Working Group: DSP-IS0102 Architecture for Managing Clouds White Paper V1.0.0, and DSP-IS0103 Use Cases and Interactions for Managing Clouds White Paper V1.0.0
- European Telecommunications Standards Institute: TC cloud definition
- Standards Acceleration to Jumpstart Adoption of Cloud Computing: 25 use cases
- Open Cloud Consortium: Open Cloud Testbed, Open Science Data Cloud, benchmarks, reference implementation.

Table 8.1 List of Standardization Efforts

National Institute of Standards and Technology (http://csrc.nist.gov/groups/SNS/cloud-computing/index.cfm)
Distributed Management Task Force (http://www.dmtf.org)
The European Telecommunications Standards Institute (http://www.etsi.org)
Open Grid Forum (http://www.ogf.org)
Open Cloud Computing Interface Working Group (http://www.occi-wg.org)
Object Management Group (http://www.omg.org)
Storage Networking Industry Association (http://www.snia.org)
Open Cloud Consortium (http://www.opencloudconsortium.org)
Organization for the Advancement of Structured Information Standards (http://www.oasis-open.org)
Association for Retail Technology Standards (http://www.nrf-arts.org)
The Open Group (http://www.opengroup.org)
Cloud Security Alliance (http://www.cloudsecurityalliance.org)

The Cloud Computing Interoperability Forum: framework/ ontology, semantic web/resource description framework, unified cloud interface.

- The Open Group: SOA, The Open Group Architecture Framework
- Association for Retail Technology Standards: Cloud Computing White Paper V1.0
- TM Forum: Cloud Services Initiative, Enterprise Cloud Leadership Council Goals, Future Collaborative Programs, BSS/OSS/SLA
- ITU-T FG Cloud: Introduction to the Cloud Ecosystem: Definitions, Taxonomies and Use Cases;
- Global Inter-Cloud Technology Forum: Japan, Interoperability.

Cloud Standards Coordination: Standards Development Organization Collaboration on Networked Resources Management

- Open Cloud Manifesto (http://www.opencloudmanifesto .org/)
- Open Grid Forum: Open Cloud Computing Interface, Open Grid Services Architecture
- Cloud Security Alliance: Security Guidance for Critical Areas of Focus in Cloud Computing, Cloud Controls Matrix, Top Threats to Cloud Computing, CloudAudit
- Storage Networking Industry Association: Cloud Storage Technical Work Group, Cloud Data Management Interface.

8.5 Cloud Providers and Systems

In five short years, cloud computing has gone from being a charming technology to being a major catchphrase. It started in 2006 when Amazon began offering its Simple Storage Service and soon following up with its Elastic Compute service, and Google's CEO Eric Schmidt's speech about cloud computing. Just like the Internet of Things, the market potential is huge. Many vendors, old and new, have joined the gold rush to provide cloud services and products. There are many forecasts about market size of cloud computing. For example, Gartner estimated that, among the three SPI segments, SaaS generates most of the revenue, because it directly creates value for the end users. IaaS helps reduce the costs of organizational users, which has the fastest growth.

Gartner predicts the change of revenue on percentage among the three SPI segments between 2010 (SaaS: 72%, PaaS: 26%, IaaS: 2%) and 2014 (SaaS: 61%, PaaS: 36%, IaaS: 3%). However, this prediction may not count the revenue of PaaS as a middleware product sold independently, but only the part of the revenue of PaaS as a hosted service, in which case PaaS is sold as part of SaaS most of the times. Revenue generated by cloud technology companies, excluding the larger, more mature SaaS segment, is forecast to grow from $984 million in 2010 to $4 billion in 2013, according to The 451 Group, representing a compound annual growth rate of 60 percent.

Including SaaS, total cloud technology vendor revenue was $8.5 billion in 2010, expected to grow to $16.3 billion in 2013, a compound annual growth rate of 24 percent. Of course, the amount spent by companies on cloud products and services is much larger, with Gartner estimating worldwide cloud services revenue in 2010 of $68.3 billion, an increase of 16.6 percent from $58.6 billion of 2009. Gartner estimates that the cloud services revenue will reach $148.8 billion in 2014.

We will give an overview of the current cloud providers based on their participation in providing the building blocks as depicted in the graphics noted below that include the services and products for the three SPI pillars, as well as additional products such as development tools, security frameworks, system management software, adaptor frameworks, and so on. There are many top 10, top 20, and top 50 listings of cloud providers on the web that can be easily found with Google search. The graphic at http://www.opencrowd.com/assets/ images/views/views_cloud-tax-lrg.png lists some of the top cloud providers in the SPI and general software categories.

The cloud computing boom has brought a surge of opportunity to the open-source world. Open-source developers and users are taking advantage of these opportunities. Many open-source applications are now available on a SaaS basis. Other open-source projects have taken the steps necessary to make them easy to use in the cloud, for example, by making preconfigured images available through Amazon Web Services or other public clouds. However, most open-source developers are contributing to the growth of cloud computing by creating the tools that make cloud computing feasible. They offer infrastructure, middleware, and other software that make it easier for companies to develop and run their applications in the cloud.

The following is a list of open-source projects:

- Open-source IaaS and PaaS projects: OpenStack, cloud. com Cloud Stack, OpenNebula, Eucalyptus, AppScale, Scalr, Traffic Server, RedHat Cloud, Cloudera (Hadoop), Puppet, Enomaly, Joyent, Globus Nimbus, Reservoir, Amanda/Zmanda, XCP, TPlatform, and so forth.

- Open-source SaaS projects: Zoho, Phreebooks, Pentaho, Palo BI Suite, Jaspersoft, Processmaker, eyeOS, Alfresco, SugarCRM, SourceTap, KnowledgeTree, OpenKM, Collabtive, Zimbra, Feng Office, Open ERP, Openbravo, Compiere, Orange HRM, JStock, Ubuntu, OpenProj, openSIS, TimeTrex, GlobaSight, and others.

To summarize, the author has created a free-style panoramic view graphic of existing cloud providers and their products and services in five layers (including vendors and products in China that are mostly at the PaaS and SaaS layers):

- Chip and hardware supports for virtualization: Intel-VT (VT-x, VT-x2), AMD-V (SVM), SUN/Oracle UltraSPARC T1, T2, T2+, SPARC T3, and others
- Hypervisors (one-to-many SSV virtualization) vendors and products
- IaaS (many-to-one MSV virtualization) grid/cluster computing, web services–based delivery vendors and products
- PaaS (multitiered middleware) vendors and products
- SaaS vendors and products (due to the vastly large number of SaaS vendors and products, only some of them are listed; some of the IoT SaaS services such as Pachube are also listed. See Figure 8.11.)

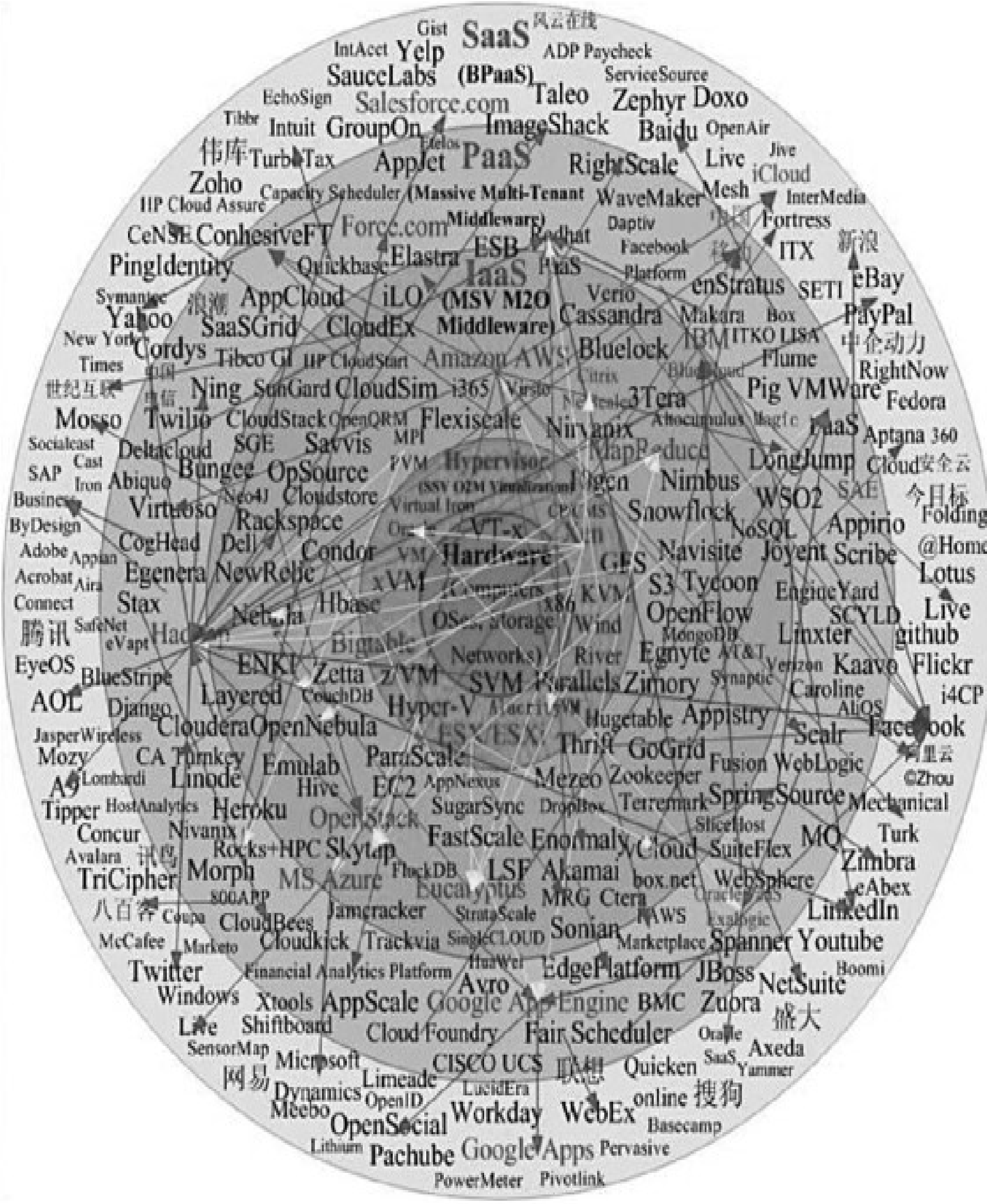


Figure 8.11 Five-layer panoramic view of cloud vendors and products.