

Cloud Computing



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These slides and audio/video recordings of this class lecture are at:

<http://www.cse.wustl.edu/~jain/cse570-18/>



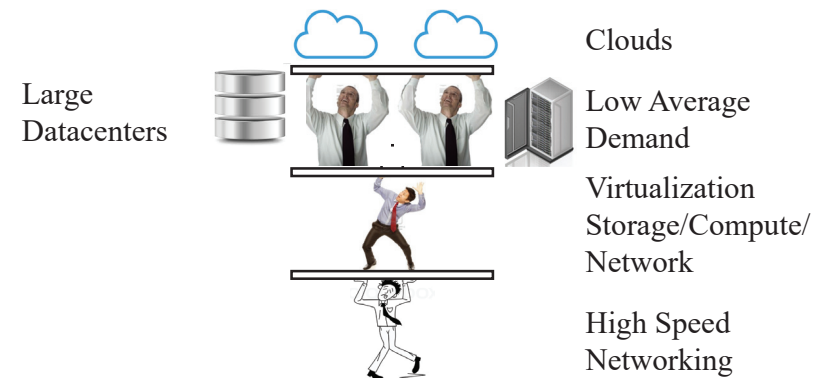
1. Genesis of Cloud Computing
2. What is Cloud Computing?
3. Why Use Clouds?
4. Cloud Deployment Models
5. Cloud Software and Standards
6. Software Defined Intelligence

Genesis of Cloud Computing

- ❑ August 25, 2006: Amazon announced EC2
⇒ Birth of Cloud Computing in reality
(Prior theoretical concepts of computing as a utility)
- ❑ Amazon's CEO was amazed by the number of computers in their datacenter and their low utilization
- ❑ Computing facilities are designed for peak load (Christmas)
- ❑ Needed a way to rent unused capacity, like renting their warehouses and other infrastructure
⇒ Develop an application programming interfaces (APIs) to remotely use computers.
- ❑ So began the computer rental business that we now call cloud computing.
- ❑ Sharing an underutilized resource is good for cloud service customers as well as for the cloud service providers.

Ref: Raj Jain and Subharthi Paul, "Network Virtualization and Software Defined Networking for Cloud Computing - A Survey," IEEE Communications Magazine, Nov 2013, pp. 24-31, ISSN: 01636804, DOI: 10.1109/MCOM.2013.6658648,
http://www.cse.wustl.edu/~jain/papers/net_virt.htm
<http://www.cse.wustl.edu/~jain/cse570-18/>

Cloud Enabled by Networking



What is Cloud Computing?

- ❑ *Cloud computing is a model for enabling 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.*

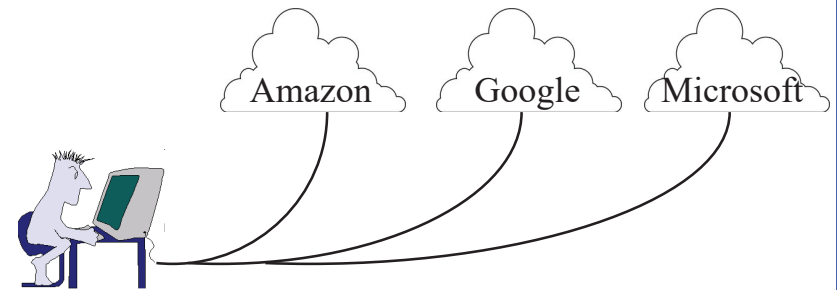
-National Institute of Standards and Technology (NIST)

<http://www.nist.gov/itl/cloud/>

- ❑ **Key Characteristics:**
 - On-Demand self-service
 - Scalable
 - Shared
 - Ubiquitous access
 - Rapid provisioning/released
 - Minimal management

Cloud Computing as a Utility

- ❑ Cloud computing is a utility like water, electricity, telephone
- ❑ Just turn on your computer and get computing storage and other resources as you need it and pay for it by usage.
- ❑ Computers include smart phones, tablets, laptops, desktops, ...



Attributes of a Cloud Service

- ❑ **Off-Premise:** Out-side the company firewall.
Connected via Internet
Belongs to a service provider
- ❑ **Elasticity:** Scalable up or down rapidly.
- ❑ **Flexible Billing:** Usage or flat rate. Payment or advertising-paid (as in Google docs)
- ❑ **Multi-tenancy:** Cost optimization of sharing
- ❑ **Universal Access:** Available to anyone
- ❑ **Virtualization:** Easier allocation of resources
- ❑ **Service:** Provides both management and computational APIs.
- ❑ **Service level agreement:** Different levels

Networking Services

- ❑ One DHCP assigned address per VM is standard.
Static/global IP addresses are provided at an extra cost
- ❑ Load balancing
- ❑ Virtual firewalls
- ❑ Private VLANs
- ❑ Access control lists of IP addresses that can access
- ❑ VPN connecting enterprise to the cloud
- ❑ Round-robin DNS for load balancing
- ❑ Content compression
- ❑ Geographical load distribution, e.g., Big-IP global traffic manager

Cloud Computing Statistics

By 2020:

- ❑ 11/12th of workload in **clouds**, 1/12th in traditional data center
- ❑ 92% Data center IP traffic in clouds, 8% in traditional data center
- ❑ 3X growth in cloud workload in 5 years
3X growth in IP traffic in 5 years
- ❑ 5X growth in data center **storage**
7/8th in cloud, 1/8th in traditional data centers
2/3rd in public clouds, 1/3rd in private clouds
- ❑ 59% of consumers will use cloud storage (Under estimate)
- ❑ **SDN/NFV** transporting 22% of datacenter traffic to 44% by 2020

Ref: Cisco, "Cisco Global Cloud Index: Forecast and Methodology, 2015-2020," 2016,
<https://www.cisco.com/c/dam/en/us/solutions/collateral/service-provider/global-cloud-index-gci/white-paper-c11-738085.pdf>
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Gray's Economy

- ❑ Jim Gray observed in 2003 that one dollar equates to:
 - > 1 GB sent over the WAN
 - > 10 Tera CPU operations
 - > 8 hours of CPU time
 - > 1 GB of disk space
 - > 10 M Databases accesses
 - > 10 TB of disk bandwidth
 - > 10 TB of LAN bandwidth
 - ⇒ WAN bandwidth is 10000 times more expensive than LAN
 - ⇒ Move program to the data not data to the programs
- ❑ In the last 10 years, networks have become faster but not at the same speed as processors ⇒ Networks are economic bottleneck
⇒ Remote (Cloud) computing is good for processor intensive jobs, e.g., image processing

Ref: Jim Gray, Microsoft Large Databases and Grid Computing, 21 May 2003,
http://research.microsoft.com/~Gray/talks/WebServices_Grid.ppt
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Why Cloud?

- ❑ Clouds are better than private data center, because of they are on-demand, large-scale, and dispersed.

10 Laws of Clouconomics

1. Utility services cost less even though they cost more.
(Customers don't pay when they don't use it).
2. On-Demand trumps forecasting. (Forecasting is often wrong.)
3. The peak of the sum is never greater than the sum of the peaks.
4. Aggregate demand is smoother than individual.
5. Average unit costs are reduced by distributing fixed costs over more units of output.

Ref: Joe Weinman, "The 10 Laws of Clouconomics," Sep 7, 2008, <http://gigaom.com/2008/09/07/the-10-laws-of-clouconomics>
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10 Laws of Clouconomics (Cont)

6. Superiority in numbers is the most important factor in the result of a combat
(Numerical superiority is the key to winning battles.)
7. Space-time is a continuum.
(You can reduce time by having more VMs)
8. Dispersion is the inverse square of the latency.
9. Don't put all your eggs in one basket.
(High reliability with many data centers per CSP).
10. An object at rest tends to stay at rest.
(Private datacenters are located in suboptimal locations: headquarters).
While cloud data centers are located optimally)

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Barriers to Cloud Adoption

1. Security:

- Is our data secure?
- How can we audit security?
- Will my data be erased on deletion?
- ...

2. Compliance:

- Will we be compliant with risk, security, privacy laws?

3. Interoperability:

- Can I take my workload from provider to provider?
- Not easily

4. Service Level Management: Is the billing accurate? What happens on failures? Is the capacity sufficient?

Ref: https://en.wikipedia.org/wiki/Cloud_computing_issues, https://en.wikipedia.org/wiki/Cloud_computing_security
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Barriers to Cloud Adoption (Cont)

5. Tools:

- How can I automate provisioning, monitoring, management

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Cloud Deployment Models



- ❑ National Institute of Science and Technology (NIST) classification
- ❑ **Public Cloud:** Offered by large companies for use by anyone who pays. Least expensive and least secure.
- ❑ **Private Cloud:** Owned by a specific entity and used only by that entity. More expensive and more secure.
- ❑ **Community Cloud:** Shared by multiple organizations who share a common cause. Did not materialize in practice.
- ❑ **Hybrid Cloud:** Cloud consisting of two or more Public, Private cloud. E.g., Private cloud for sensitive data and public cloud for less sensitive data

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Cloud Deployment Models (Cont)

- ❑ **Virtual Private Cloud:** Private cloud within a public cloud
- ❑ **Multi-Cloud:** Multiple cloud providers, e.g., Amazon, Google, and Azure
- ❑ **Distributed Cloud:** Combine machines in many different locations
- ❑ **Edge Cloud:** Cloud on the carrier networks edge, e.g., cell towers or central offices

Ref: https://en.wikipedia.org/wiki/Virtual_private_cloud

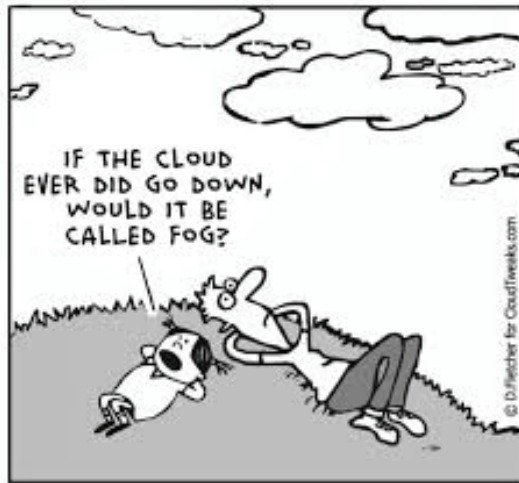
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Fog Computing



Ref: <http://community.spiceworks.com/topic/254392-fog-computing-replaces-cloud-as-new-tech-buzzword>
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Fog Computing (Cont)

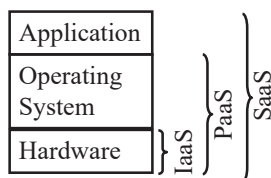
- Location Aware and Location Sensitive
 - ⇒ Low latency ⇒ Computing in micro clouds
 - ⇒ Computing in the edge ⇒ Computing everywhere
 - ⇒ Fog
- Geographically distributed ⇒ Everywhere/Anywhere
- Large Scale
- Mobility
- Real-Time

Ref: F. Bonomi, et al., "Fog Computing and Its Role in the Internet of Things," ACM MCC'12, August 17, 2012, Helsinki, Finland
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Cloud Service Models



- **Infrastructure as a service (IaaS):** Provide virtual machines, storage, and network facilities that users can manage. Users install their own operating systems and software, e.g., Amazon Web Services
- **Platform as a service (PaaS):** Includes hardware and operating systems, development and administrative tools. Users develop and deploy their software, e.g., Microsoft Azure
- **Software as a service (SaaS):** Complete application with a user interface, e.g., Google Docs, Gmail, Salesforce.com

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Everything As A Service

- https://en.wikipedia.org/wiki/Banking_as_a_Service
- https://en.wikipedia.org/wiki/Content_as_a_service
- https://en.wikipedia.org/wiki/Data_as_a_service
- https://en.wikipedia.org/wiki/Function_as_a_service
- https://en.wikipedia.org/wiki/IT_as_a_service
- https://en.wikipedia.org/wiki/Location_as_a_service
- https://en.wikipedia.org/wiki/Mobile_backend_as_a_service
- https://en.wikipedia.org/wiki/Network_as_a_service
- https://en.wikipedia.org/wiki/Payments_as_a_service
- https://en.wikipedia.org/wiki/Recovery_as_a_service
- https://en.wikipedia.org/wiki/Security_as_a_service
- https://en.wikipedia.org/wiki/Unified_communications_as_a_service
- https://en.wikipedia.org/wiki/As_a_service
- https://en.wikipedia.org/wiki/Category:As_a_service

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Bridges, Brokers, Gateways

- ❑ **Bridge:** Connecting private data center networks to clouds
- ❑ **Brokers:** Connecting services between private data centers and clouds. E.g., authentication (identity), access (authorization), delivery (server/cloud selection)
- ❑ **Gateways:** Connecting private storage to cloud storage. Thereby, increasing the size of storage pool. Using cloud storage for overflow, backup, and disaster recovery.

Ref: L. MacVittie, "Integrating the Cloud: Bridges, Brokers, and Gateways," 2012,
<http://www.f5.com/pdf/white-papers/f5-vmware-integrating-cloud-white-paper.pdf>

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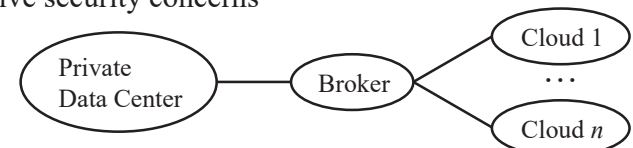
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Cloud Service Brokers

- ❑ Too many cloud service providers (like airlines)
- ❑ Cloud service brokers help you find the right subset of cloud providers for your needs
- ❑ May provide their own cloud services
- ❑ Provide simplified/unified interface to multiple providers with a single sign on
- ❑ Help negotiate cloud contracts
- ❑ Help resolve security concerns



Ref: W. Bumpus, Cloud Service Brokers: What You Need to Know, <http://www.infoq.com/articles/cloud-service-brokers>

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Open Source Cloud Management Software

- ❑ **OpenStack:** Open source software to build/manage private/public clouds
 - Initiated by NASA and Rackspace Hosting
 - Many components: Nova (Compute), Neutron (Networking), Cinder (Storage), Glance (image), Horizon (dashboard), Heat (Orchestration),
 - Utilizes plugins.
- ❑ **CloudStack:** Open Source Sw to manage cloud services
 - Supports AWS API and OCCI API
 - Similar to OpenStack
 - Also under Apache Foundation

Ref: <http://www.openstack.org>, <https://en.wikipedia.org/wiki/OpenStack>, https://en.wikipedia.org/wiki/Apache_CloudStack

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Open Source Cloud Management (Cont)

- ❑ **Cloud Foundry:** Multi-Cloud Application platform under Linux Foundation
- ❑ **Scalr:** Manage multi-cloud infrastructure
- ❑ **Eucalyptus:** Build AWS-compatible private and hybrid clouds
- ❑ **oVirt:** Management platform to manage virtual nodes, storage, and network resources.
 - Similar to VMware's vSphere.
 - Allows allocating VMs to host: manual, optimized, pinned
 - Live migration of VMs
 - Monitor resource usage
 - Manage quota for use of resources

Ref: https://en.wikipedia.org/wiki/Cloud_Foundry, <https://en.wikipedia.org/wiki/Scalr>,

[https://en.wikipedia.org/wiki/Eucalyptus_\(software\)](https://en.wikipedia.org/wiki/Eucalyptus_(software)), <https://en.wikipedia.org/wiki/OVirt>, <http://www.ovirt.org>

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Open Source Cloud Management (Cont)

- ❑ **OpenVZ:** Open Virtuozzo
 - Allows multiple containers on Linux
- ❑ **Open Virtual Alliance (OVA):**
 - Linux Foundation project for KVM hypervisor
- ❑ **openQRM:** Cloud computing management platform
 - Bare metal and VM deployment
 - Supports KVM, Linux Vserver, OpenVZ, Xen, ...
- ❑ **Proxmox Virtual Environment (Proxmox VE):**
 - Server virtualization environment
 - VMs and Containers
 - Web console with REST API

Ref: https://en.wikipedia.org/wiki/Open_Virtualization_Alliance, <https://en.wikipedia.org/wiki/OpenQRM>, https://en.wikipedia.org/wiki/Proxmox_Virtual_Environment,

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Open Source Cloud Management (Cont)

- ❑ **OpenNebula:** Manage data center infrastructure
 - Offer cloud services in a data center
- ❑ **BOSCH:** Life-cycle management of large scale distributed services
- ❑ **AppScale:** Deploy unmodified Google App Engine applications over other clouds
- ❑ **Nimbus:** Toolkit to provide IaaS via Amazon EC2 APIs
- ❑ **NextCloud:** Client-Server software to create file hosting cloud services, like Dropbox

Ref: <https://en.wikipedia.org/wiki/OpenNebula>, https://en.wikipedia.org/wiki/List_of_commercial_open-source_applications_and_services,

[https://en.wikipedia.org/wiki/BOSH_\(software\)](https://en.wikipedia.org/wiki/BOSH_(software)), <https://en.wikipedia.org/wiki/AppScale>,

[https://en.wikipedia.org/wiki/Nimbus_\(cloud_computing\)](https://en.wikipedia.org/wiki/Nimbus_(cloud_computing)), <https://en.wikipedia.org/wiki/Nextcloud>,

https://en.wikipedia.org/wiki/Category:Free_software_for_cloud_computing, https://en.wikipedia.org/wiki/Category:Open-source_cloud_applications

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Cloud Data Management Interface (CDMI)

- ❑ Standard interface to create, retrieve, update and delete data elements from the cloud
- ❑ Developed by Storage Networking Industry Association (SNIA) and now ISO/IEC standard
- ❑ Clients can discover the capabilities of the cloud storage Used by administrative and management applications to manage containers, accounts, security access, and monitoring and billing information
- ❑ Example: GET Container (List objects in a container)
GET Container `cdmi_geographic_placement_provided` metadata item (Discover the geographic locations) in which the container is stored)

Ref: SNIA, "Cloud Data Management Interface (CDMI)," <http://www.snia.org/cdmi>

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Cloud APIs

- ❑ Open Grid Forum, "Open Cloud Computing Interface (OCCI)," http://www.ogf.org/gf/group_info/view.php?group=occi-wg
- ❑ VMware Virtual Cloud Director (vCD) API: http://www.vmware.com/pdf/vcd_10_api_guide.pdf
- ❑ Amazon Web Services (AWS) API: <http://aws.amazon.com/developertools/Amazon-EC2/351>
- ❑ ElasticHosts API: <http://www.elastichosts.com/cloud-hosting/api>
- ❑ FlexiScale (Cloud management and orchestration software for private clouds) API: <http://www.flexiant.com/reference/api>
- ❑ GoGrid API: <http://www.gogrid.com/cloud-hosting/cloud-api.php>
- ❑ Sun Cloud API: <http://kenai.com/projects/suncloudapis/pages/Home>
- ❑ OpenStack APIs: <http://docs.openstack.org/api/api-specs.html>
- ❑ Cloud Application Management for Platforms (CAMP): Managing PaaS. https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=camp

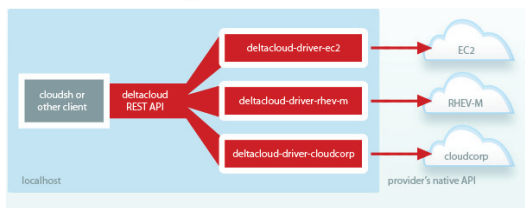
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Apache Deltacloud



- ❑ Open source project to provides API server and drivers necessary for connecting to various cloud providers
- ❑ Supports 3 APIs: Deltacloud classic, CIMI standard, EC2
- ❑ Translates the input API to cloud specific API
Takes care of δ = difference
- ❑ Allows moving applications to various clouds.
- ❑ HTML interface allows controlling cloud infrastructure using a browser on a computer, mobile phone or tablet

Ref: <http://deltacloud.apache.org/about.html>

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Software Defined Intelligence

- ❑ SDI = SDN + Machine Learning
- ❑ **Predictive Operation:** Discover new relationships from network data
 - **Predictive Security:** Predict security attacks rather than react to attacks
 - Detect Spam Sources/Prefixes
- ❑ Network data generated by too many sources
⇒ Too much to process by humans
- ❑ Analytics = Brute force style of data analysis

Ref: David Meyer, "Software Defined Intelligence: A New Interdisciplinary Approach to Intelligent Infrastructure," Networking Field Day 8, Sept 11, 2014, <http://www.1-4-5.net/~dmm/talks/nfd8.pptx>

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Google's SDI Applications

- ❑ Beyond short snippets: deep networks for video classification
- ❑ Diagnosing automatic white-listing for dynamic remarking ads using hybrid ASP
- ❑ Grapheme-to-Phoneme conversion using long short-term memory recurrent neural networks
- ❑ Cicada: predictive guarantees for cloud network bandwidth
- ❑ Show and Tell: a neural image caption generator
- ❑ Large scale video classification with convolutional neural networks
- ❑ Measuring online audiences
- ❑ Ad-click prediction
- ❑ Modeling of eye-mouse behavior

Ref: Google, "Artificial Intelligence and Machine Learning,"

<http://research.google.com/pubs/ArtificialIntelligenceandMachineLearning.html>

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Summary



1. Computing resources are designed for peak load
⇒ Cloud computing started with need to rent-out excess computing resources
2. Network virtualization allowed datacenters to be shared => Cloud computing
3. Clouds can be public or private. Now mostly hybrid.
4. Many service models: IaaS, PaaS, SaaS
5. Many APIs ⇒ Need for standardization.
Open source software is becoming the standard by default.

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- ❑ David Meyer, "Software Defined Intelligence: A New Interdisciplinary Approach to Intelligent Infrastructure," Networking Field Day 8, Sept 11, 2014, <http://www.1-4-5.net/~dmm/talks/nfd8.pptx>
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https://en.wikipedia.org/wiki/Power_usage_effectiveness
- ❑ Google, "Artificial Intelligence and Machine Learning," <http://research.google.com/pubs/ArtificialIntelligenceandMachineLearning.html>
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Open Source Software

- ❑ <http://www.openstack.org>
- ❑ <http://www.cloudstack.org>
- ❑ <http://deltacloud.apache.org/about.html>
- ❑ <http://opennebula.org/>
- ❑ <http://openvirtualizationalliance.org/resources>
- ❑ <http://www.openqrm-enterprise.com/openqrm-tour.html>
- ❑ <http://www.ovirt.org/Home>
- ❑ <http://www.proxmox.com/proxmox-ve/features>
- ❑ <http://www.xenproject.org/developers/teams/xapi.html>

Related Web Sites

- ❑ Distributed Management Taskforce, <http://www.dmtf.org/> - -----Develops standards for cloud management
- ❑ Storage Networking Industry Association, <http://www.snia.org/> - Cloud Data Management Interface (CDMI) Standard
- ❑ Cloud Security Alliance, <https://cloudsecurityalliance.org/>
- ❑ OpenCloud, <http://www.opencloud.com/>
- ❑ Cloud Standards Customer Council (CSCC), <http://www.cloud-council.org/>
- ❑ Global Inter-Cloud Technology Forum (GICTF), http://www.gictf.jp/index_e.html
- ❑ Open Data Center Alliance (ODCS). <http://www.opendatacenteralliance.org/>
- ❑ The Open Group, <http://www.opengroup.org/>
- ❑ TeleManagement Forum (TMF), <http://www.tmforum.org/>
- ❑ NIST Cloud Computing, <http://www.nist.gov/itl/cloud/>

Standards

- ❑ DMTF, “Cloud Infrastructure Management Interface – Common Information Model (CIMI-CIM) Specification,” V1.0.0, Dec 14, 2012, 21 pp. http://dmtf.org/sites/default/files/standards/documents/DSP0264_1.0.0.pdf
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Wikipedia Links

Technology:

- ❑ https://en.wikipedia.org/wiki/Cloud_computing
- ❑ https://en.wikipedia.org/wiki/Cloud_computing_architecture
- ❑ https://en.wikipedia.org/wiki/Cloud_computing_security
- ❑ https://en.wikipedia.org/wiki/Cloud_broker
- ❑ https://en.wikipedia.org/wiki/Fog_computing
- ❑ https://en.wikipedia.org/wiki/Virtual_private_cloud
- ❑ https://en.wikipedia.org/wiki/Managed_private_cloud

Software:

- ❑ <https://en.wikipedia.org/wiki/OpenStack>
- ❑ https://en.wikipedia.org/wiki/Apache_CloudStack

Organizations:

- ❑ https://en.wikipedia.org/wiki/Cloud_Security_Alliance
- ❑ https://en.wikipedia.org/wiki/Open_Cloud_Computing_Interface
- ❑ https://en.wikipedia.org/wiki/Open_Data_Center_Alliance
- ❑ https://en.wikipedia.org/wiki/Open_Virtualization_Alliance

Abbreviations

- ❑ API Application Programming Interface
- ❑ ASP Application Service Provider
- ❑ AWS Amazon Web Services
- ❑ CapEx Capital Expenditure
- ❑ CDMI Cloud Data Management Interface
- ❑ CEO Chief Executive Officer
- ❑ CIM Common Information Model
- ❑ CIMI Cloud Infrastructure Management Interface
- ❑ CPU Central Processing Unit
- ❑ CSAIL Computer Science and Artificial Intelligence Lab at MIT
- ❑ CSCC Cloud Standards Customer Council
- ❑ CSP Cloud Service Provider
- ❑ DHCP Dynamic Host Control Protocol
- ❑ DMTF Distributed Management Task Force
- ❑ DNS Domain Name Service
- ❑ DOI Document Identifier

Abbreviations (Cont)

- ❑ EC2 Elastic Compute 2
- ❑ GB Giga Byte
- ❑ GICTF Global Inter-Cloud Technology Forum
- ❑ GIMPS Great Internat Marsenne Prime Search
- ❑ HIV Human Immunodeficiency Virus
- ❑ HTML Hypertext Mark Up Language
- ❑ IaaS Infrastructure as a Service
- ❑ IDS Intrusion Detection System
- ❑ IEC International Electrotechnical Commission
- ❑ IEEE Institution of Electrical and Electronics Engineers
- ❑ IP Internet Protocol
- ❑ ISBN International Standard Book Number
- ❑ ISO International Standards Organization
- ❑ ISSN International Standard Serial Number
- ❑ IT Information Technology
- ❑ KVM Kernel-based Virtual Machine

Abbreviations (Cont)

- ❑ LAN Local Area Network
- ❑ NASA National Aeronautics and Space Administration
- ❑ .NET Dot Networking
- ❑ NFV Network Function Virtualization
- ❑ NIST National Institute of Standards and Technology
- ❑ OCCI Open Cloud Computing Interface
- ❑ ODBC Open Database Connectivity
- ❑ ODCC Open Data Center Alliance
- ❑ openQRM Open Source Qlusters Resource Management
- ❑ OpenVZ Open Virtuozzo
- ❑ OS Operating System
- ❑ oVirt Open Virtualization
- ❑ PaaS Platform as a Service
- ❑ PUE Power Usage Efficiency
- ❑ QoE Quality of Experience
- ❑ SaaS Software as a Service
- ❑ SDI Software Defined Intelligence
- ❑ SDN Software Defined Networking

Abbreviations (Cont)

- ❑ SETI Search for Extraterrestrial Intelligence
- ❑ SNIA Storage Networking Industry Association
- ❑ SQL Structured Query Language
- ❑ TB Tera Byte
- ❑ TMF TeleManagement Forum
- ❑ TR Technical Report
- ❑ vCD Virtual Cloud Director
- ❑ VE Proxmox Virtual Environment
- ❑ VM Virtual Machine
- ❑ vNIC Virtual Network Interface Card
- ❑ VPN Virtual Private Networks
- ❑ WAN Wide Area Networks

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