



# **ITCS443 Parallel and Distributed Systems**

# **Cloud Computing and**

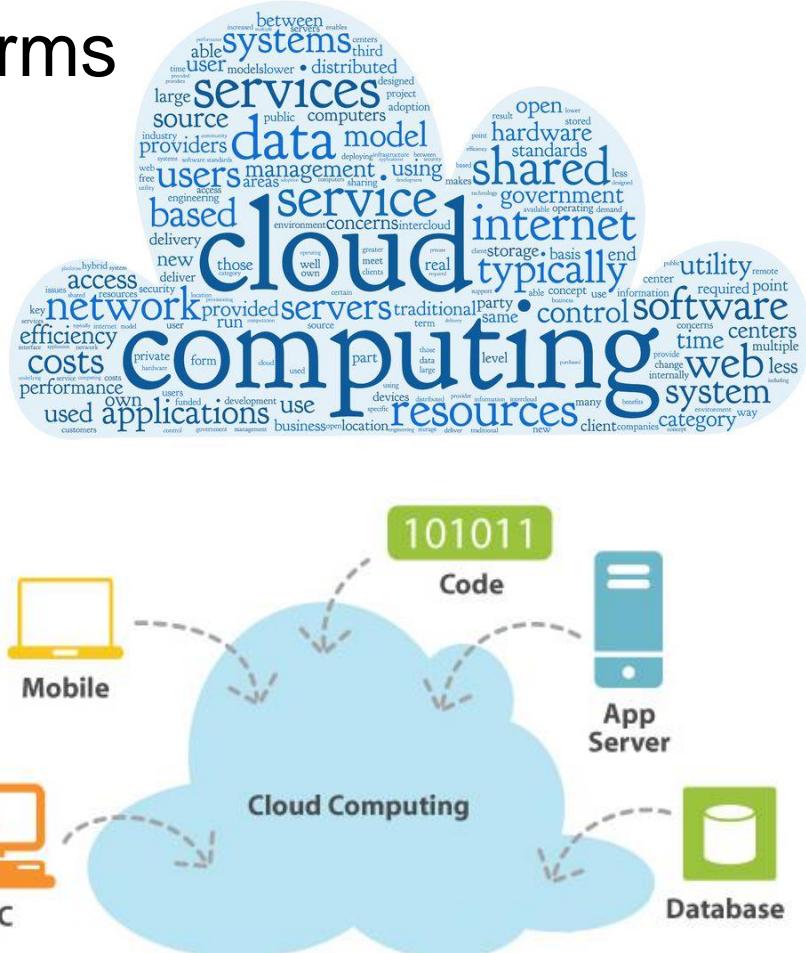
# **Virtualization**

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**Semester 1/2022**

# Outline

- Evolution of Computing Platforms
- NIST Cloud Framework
- Cloud Service Models
- Cloud Deployment Models
- Scaling
- Multitenant Technology
- Roles in Cloud
- Cloud Adoption Model
- Virtualization Concepts



# Evolution of Computing Platforms



**70's – 80's  
Mainframe Era**



**90's-2000's  
Client Server Era**



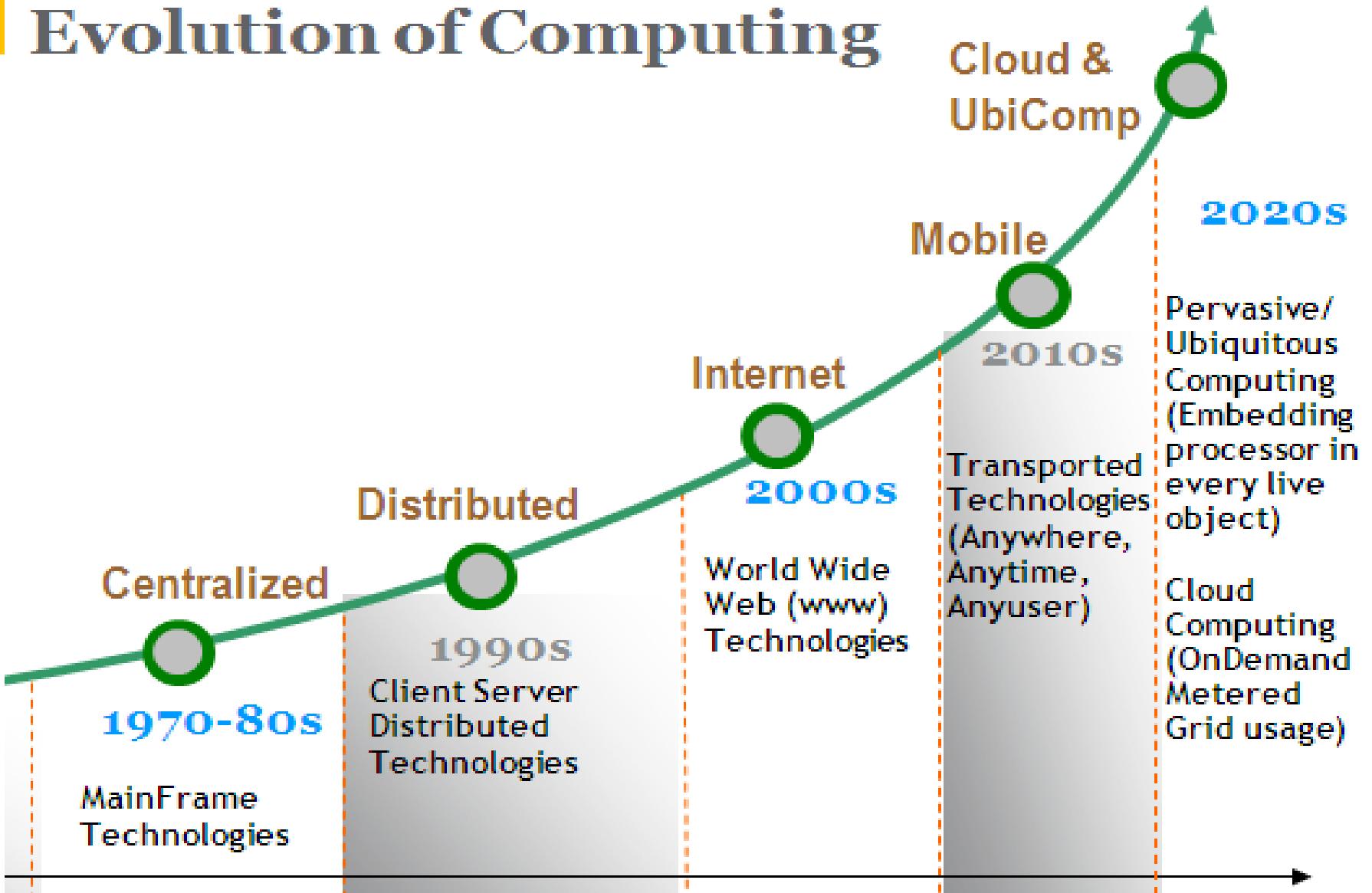
**2010-beyond  
Cloud Era**



# Evolution of Computing Platforms



## Evolution of Computing



# Latest Evolution

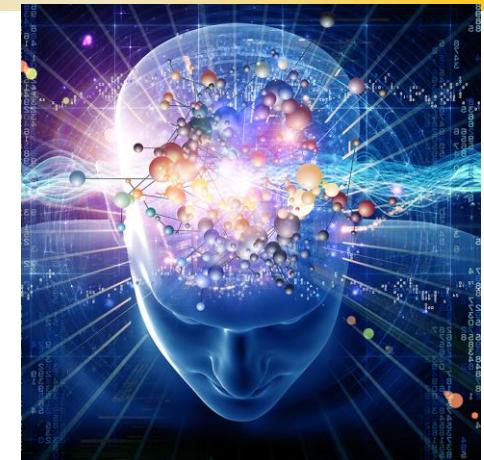
## Cloud Computing



## Big Data



## Machine Intelligence



## Internet of Things



## Mobile Computing



## Social Networks





# Internet of Things

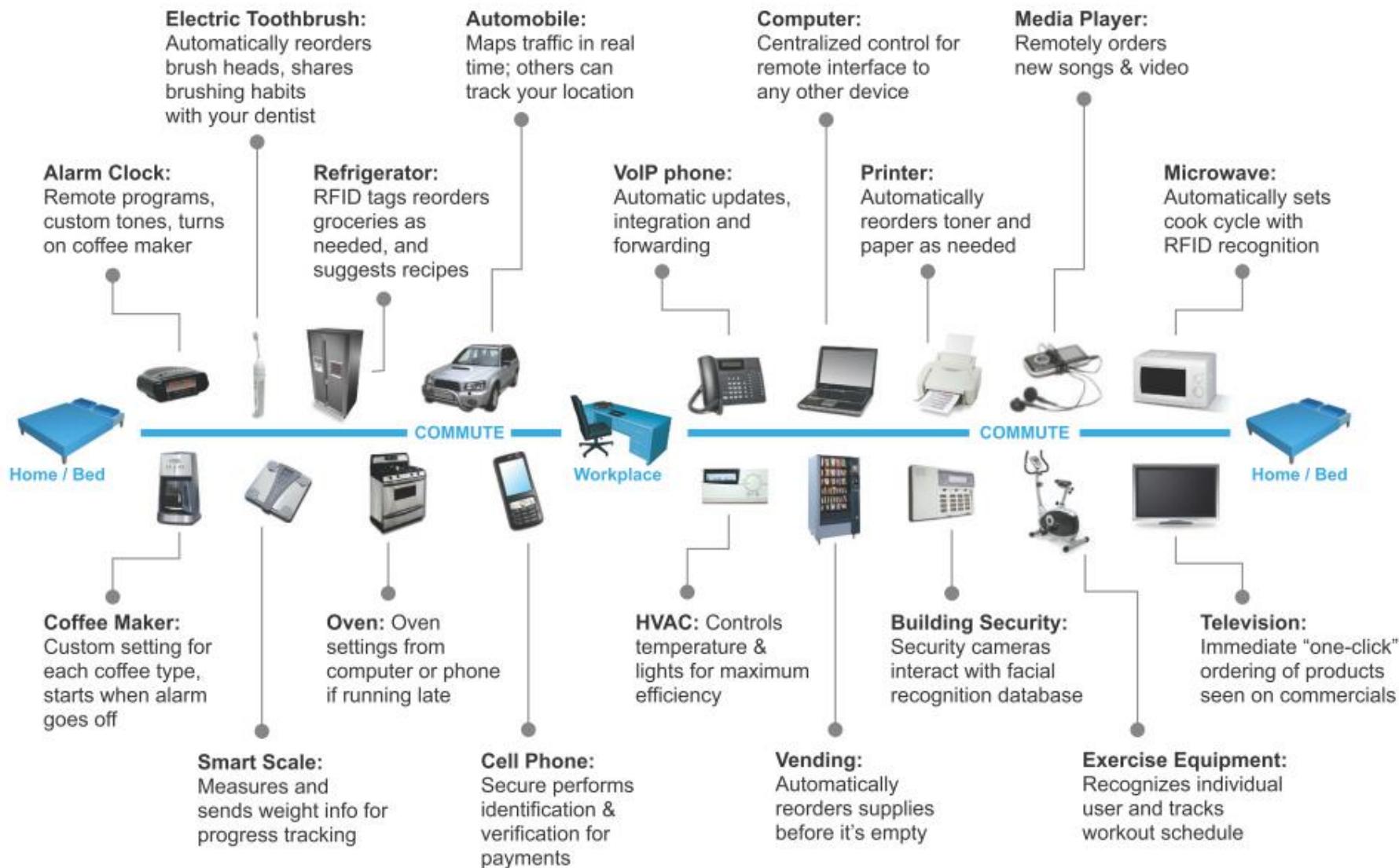


Figure 3. The Internet of Things

# Big Data: From Biology to Astronomy



Data are created every minute!

## 2021 This Is What Happens In An Internet Minute



# Top Technology Trends 2022

## Top Strategic Technology Trends for 2022

 Accelerating Growth	 Sculpting Change	 Engineering Trust
<ul style="list-style-type: none"> <li>• Generative AI</li> <li>• Autonomic Systems</li> <li>• Total Experience</li> <li>• Distributed Enterprise</li> </ul>	<ul style="list-style-type: none"> <li>• AI Engineering</li> <li>• Hyperautomation</li> <li>• Decision Intelligence</li> <li>• Composable Applications</li> </ul>	<ul style="list-style-type: none"> <li>• Cloud-Native Platforms</li> <li>• Privacy-Enhancing Computation</li> <li>• Cybersecurity Mesh</li> <li>• Data Fabric</li> </ul>

Source: Gartner

757234\_C

**Gartner**

<https://www.gartner.com/en/information-technology/insights/top-technology-trends>



# Corum Top Ten Disruptive Technology Trends



PEOPLE-CENTRIC  
PRODUCTIVITY



COMPOSITE  
COMMERCE



ACTIONABLE  
ANALYTICS



REMOTE  
TRUST



EDGE OF THE  
CLOUD

**CORUM**  
MERGERS & ACQUISITIONS

## Top 10 Disruptive Technology Trends

2022

[www.corumgroup.com](http://www.corumgroup.com)



LOW-CODE  
EVERYWHERE



FOCUSSED  
MANAGED SERVICES



HEALTHTECH  
CONTINUUM



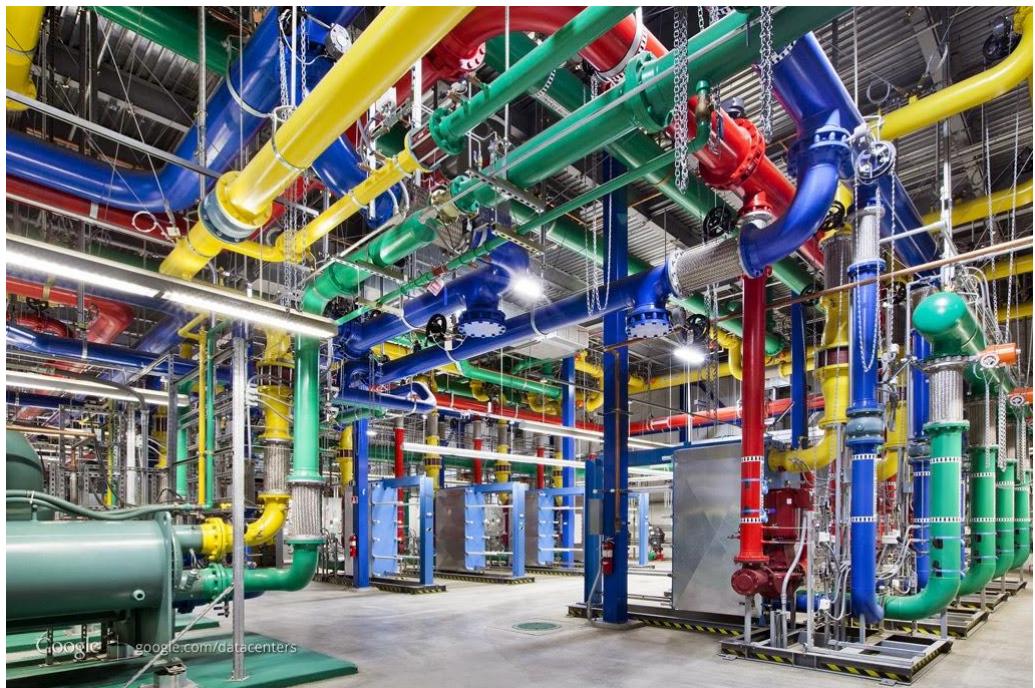
SMART  
LOGISTICS



BLUE COLLAR  
SOFTWARE



# Data Centers



C  
T

# Building a Data Center

## Sun's Modular Data Center: Project Blackbox

[HOW IT WORKS]

### KEEPING COMPUTERS COOL

Inside Project Blackbox, racks of up to 38 servers apiece generate tremendous heat. A panel of fans in front of each rack forces warm exhaust air through a heat exchanger, which cools the air for the next rack (*detail*), and so on in a continuous loop.

#### DESIGN SPECS

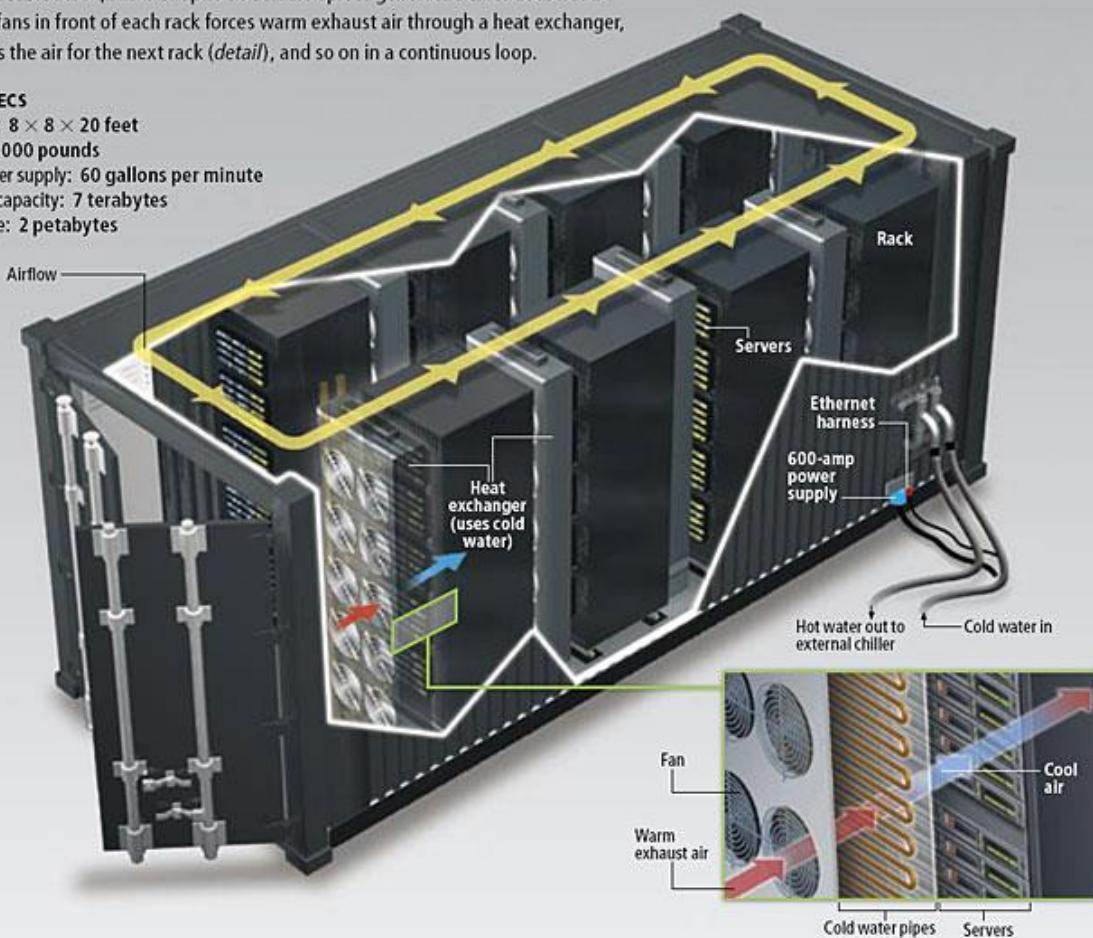
Dimensions: 8 × 8 × 20 feet

Weight: 20,000 pounds

Cooling water supply: 60 gallons per minute

Computing capacity: 7 terabytes

Data storage: 2 petabytes



# How Large of a Data Center?

## Facts and Stats of World's largest data centers

- **Google** 16 data centers: 9 in U.S., 1 in South America, 4 in Europe and 2 in Asia with about 2.5 million servers
- **Facebook:**
  - 1.13 billion daily active users (as of September 2016)
  - 60,000 servers (2010)
  - Own about \$3.63 billion in “network equipment” (end of 2015)
- **Amazon:**
  - Amazon has 11 cloud regions
  - **1.5 million servers** in 7 locations
- **Microsoft:**
  - 1 billion users and 1,000,000 servers
  - Microsoft has 17 regions.
- **Rackspace Hosting** has 100,000 servers across 6 data centers.

# Forces Driving Cloud Computing

## Data-Intensive Applications:

- Explosion of applications and user-generated content:
- Exabyte in 2006
- Zettabyte in 2010

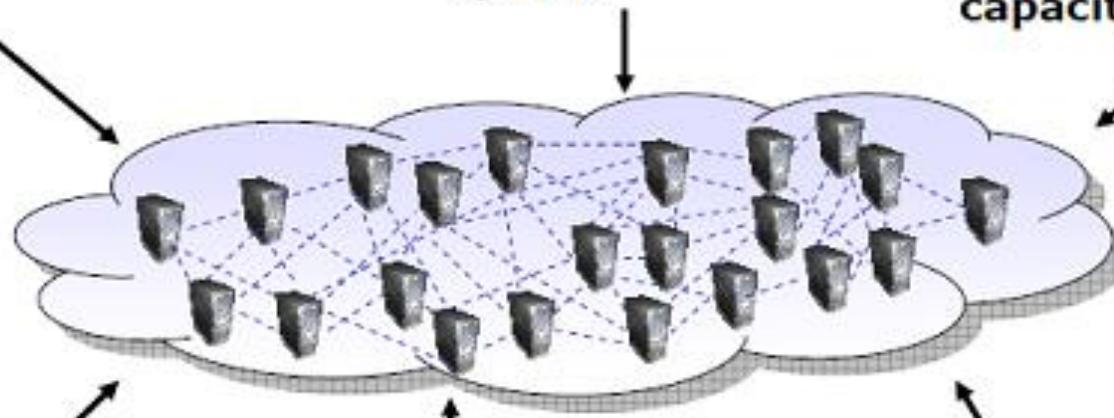


## Datacenter Pressures:

Growing operational complexity and cost from infrastructure and application sprawls



**Increased network capacity and availability**



## Innovation and Collaboration



## Rising Energy Cost & Green compliance



## Shared Services Across Lines of Business





# Cloud Services





# Cloud Services

## Service Catalogs



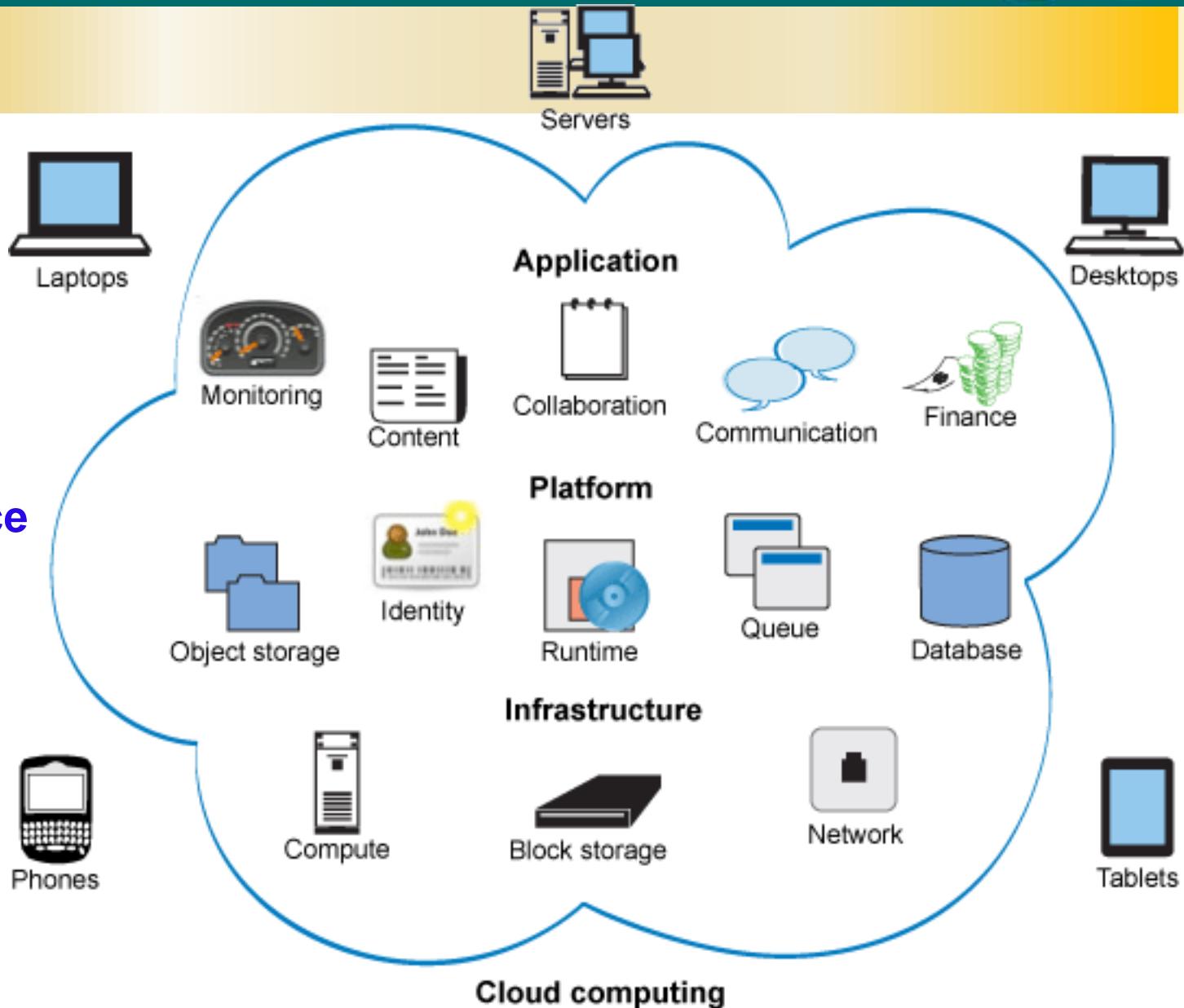
**Self-service provisioning**



# A Big Picture of Cloud

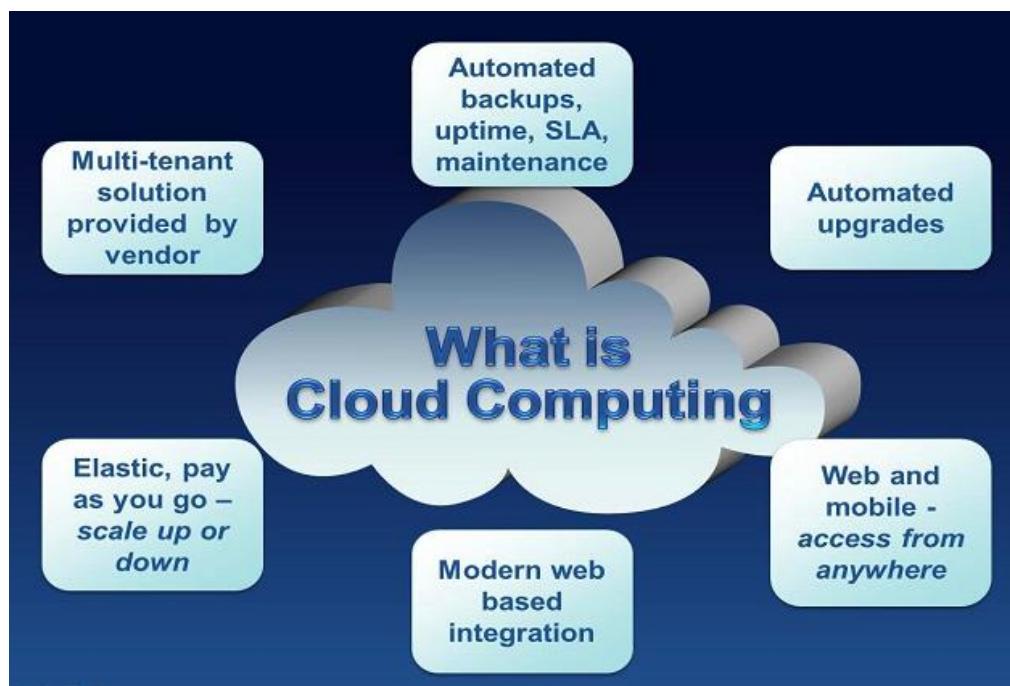
## Goals

- **Always online**
- **Anywhere, any time, any device**
- **Unlimited resources**



# NIST Cloud Definition

Cloud computing is a *pay-per-use* model for enabling *ubiquitous, convenient, on-demand access* to a shared pool of configurable computing resources that can be rapidly provisioned and released with *minimal management effort or service provider interaction*



**5 essential characteristics**

**3 service models**

**4 deployment models**

National Institute of Standards and Technology (NIST)

# NIST Cloud Framework



## Deployment Models



## Service Models



## Essential Characteristics



## Common Characteristics



# NIST Cloud Framework

On-Demand  
Self Service



Broad Network  
Access



Resource  
Pooling



Rapid  
Elasticity



Measured  
Service



## 5 Essential Cloud Characteristics

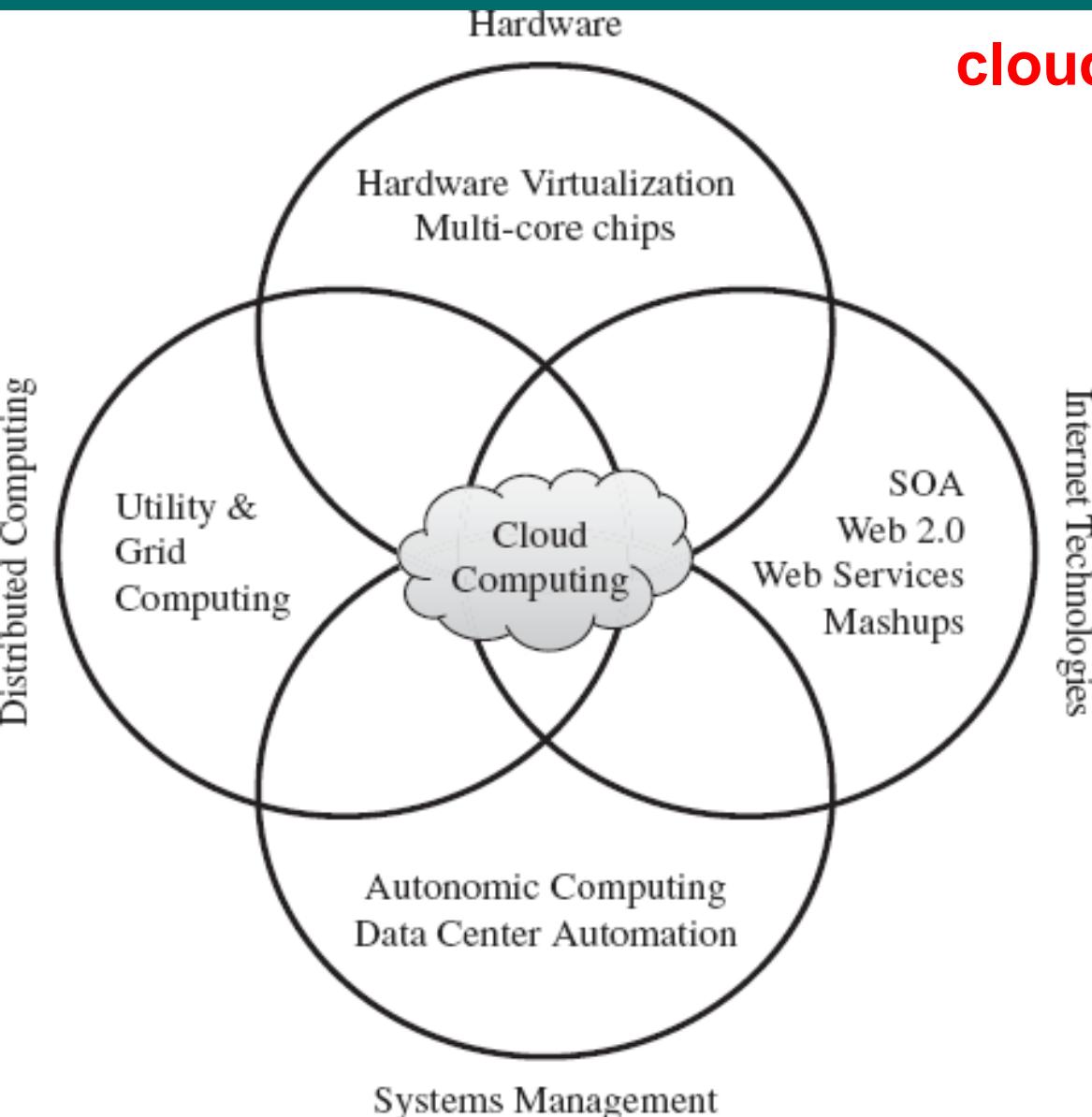
<b>On-demand self-services</b>	Users can provision servers and networks with little human intervention
<b>Broadband Network access</b>	Any computing capabilities are available over the network, and can be accessed thru many different devices
<b>Resource pooling</b>	Multiple users can access clouds that serve other consumers according to demand. Location independence.
<b>Elasticity</b>	Automated ability of a cloud to transparently scale IT resources. Provisioning is rapid and scales out or based on needs
<b>Measured services</b>	Ability to keep track of the usage of its IT resources Just like utilities paid by hours or transactions

## Additional Cloud Characteristics

<b>Multi-tenancy</b>	<ul style="list-style-type: none"><li>Enable an instance of the program to serve different consumers (<b>tenants</b>) whereby each is isolated from the others</li><li>Resource pooling allows cloud providers to pool large-scale IT resources to serve multiple cloud consumers</li></ul>
<b>Resiliency</b>	A form of failover that distributes redundant implementations of IT resources across physical locations

**Clouds optimize resource usage and control it according to SLA (Service Level Agreement)**

# What Technologies Leads to Clouds

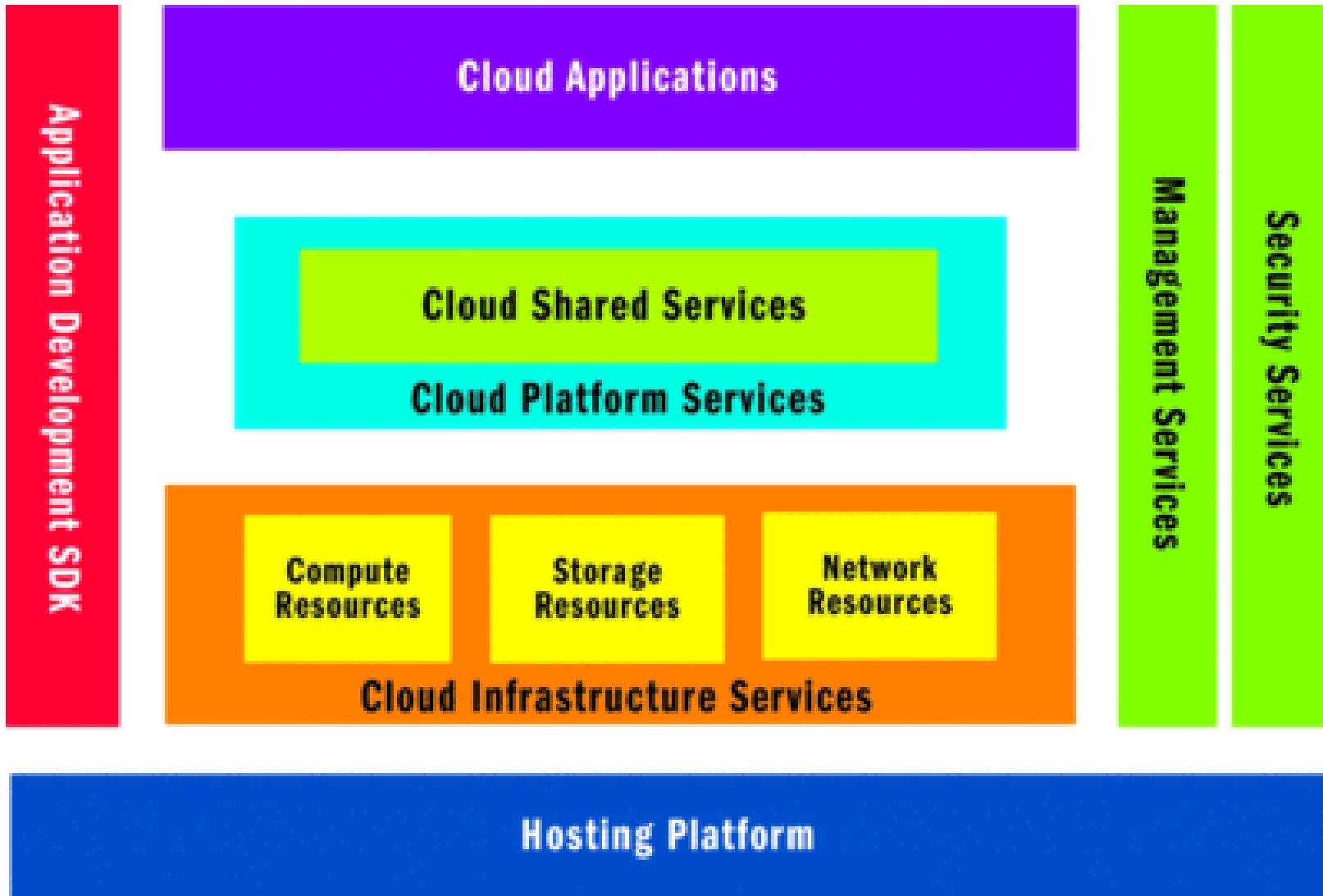


## cloud-enabling technologies

- **Broadband Networks**
- **Internet Architecture**
- **Data Center Technology**
- **Virtualization Technology**
- **Web Technology**
- **Multitenant Technology**
- **Service Technology**



# Cloud Computing Platform



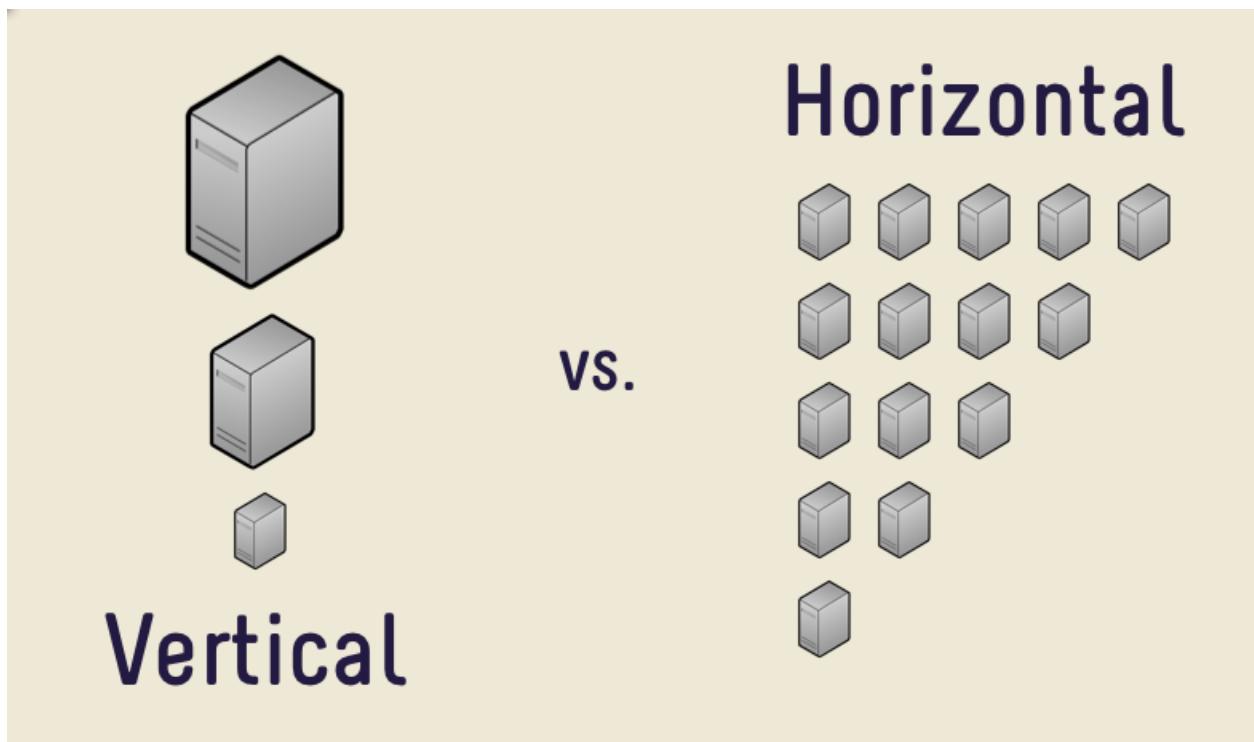
# Vertical vs. Horizontal Scaling

## Scale up/down vs. Scale out/in

**Ability of IT resources to handle increased / decreased demands**

**Horizontal Scaling:** allocating or releasing IT resources of the same type

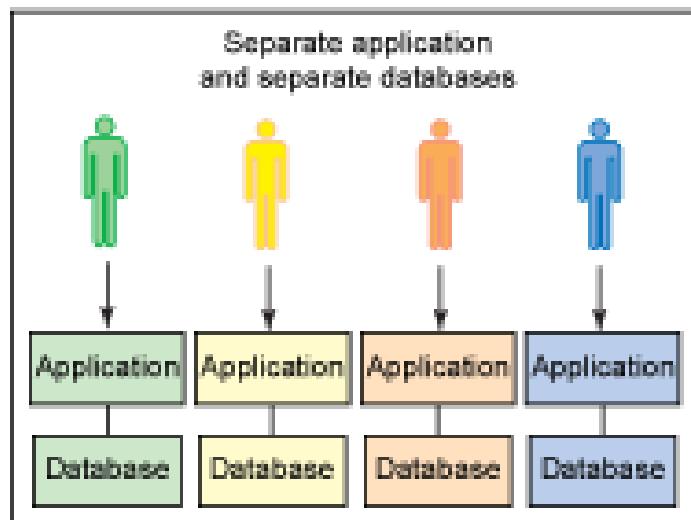
**Vertical Scaling:** replacing IT resources with higher or lower capacity



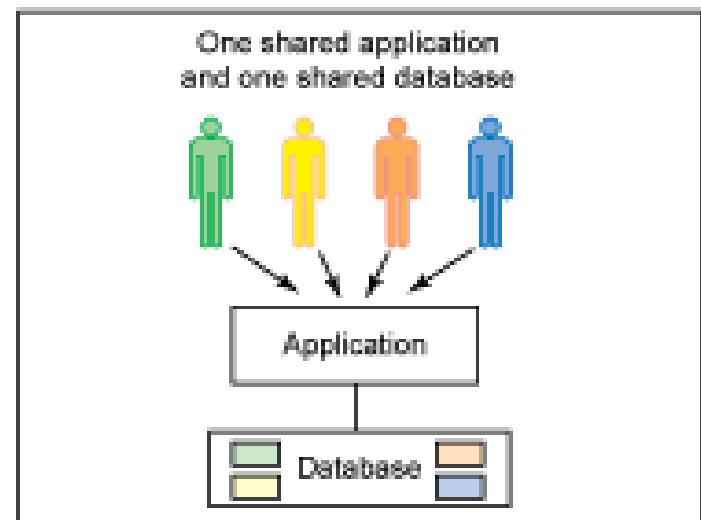
# Multitenant Technology

- **Single-tenancy:** each customer has their own software instance
- **Multi-tenancy:** multiple customers (tenants) share the **same application**, running on the same OS, same hardware, with same data-storage mechanism
- **Benefits: isolation, cost saving, improved security**

**single-tenant**



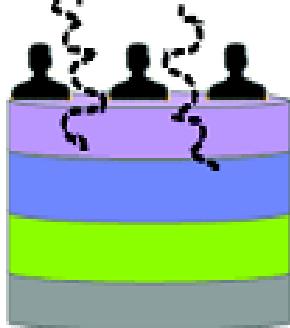
**multitenant**



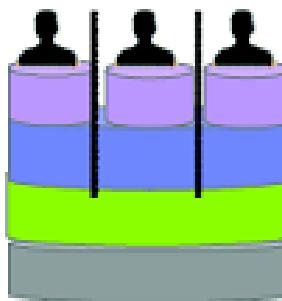
# Multitenant Technology

## Multi-tenancy at Different Levels

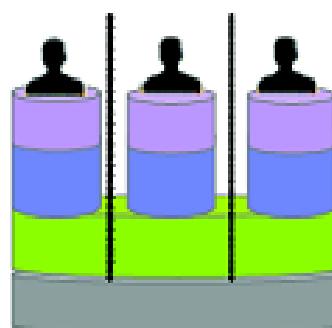
**Application Level MT**



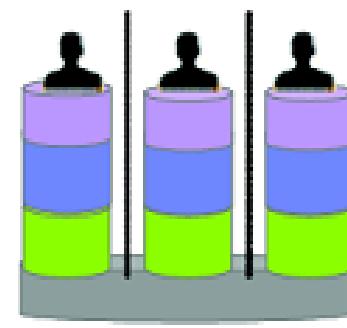
**Middleware Level MT**



**OS Level MT**

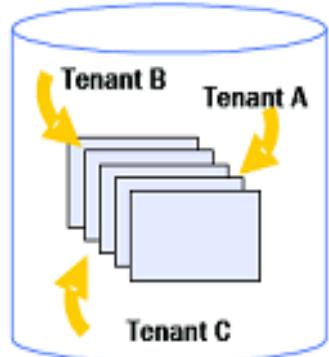


**VM Level MT**

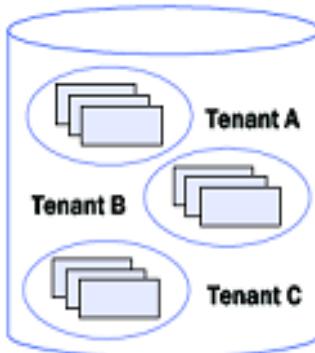


### Example: Database Multi-tenancy

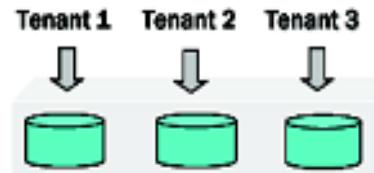
**Same Table, hidden tenant ID field**



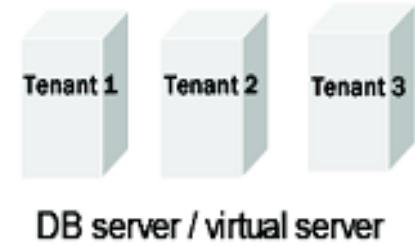
**Same DB, separate tables or schemas**



**Same server, separate DB**



**Separate DB servers (instances)**



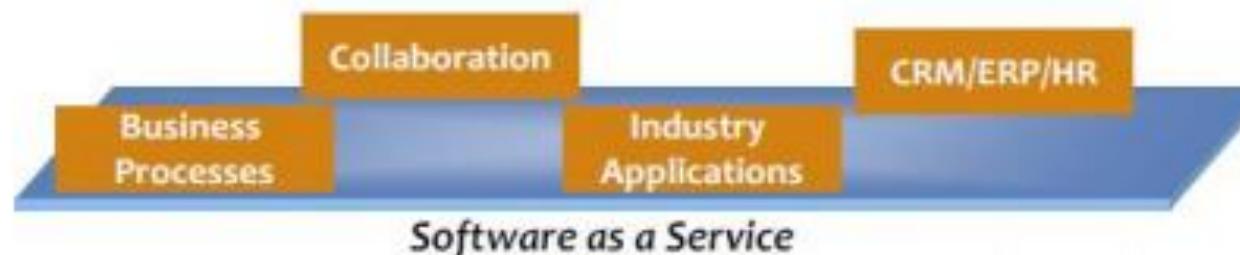
DB server / virtual server



# Cloud Service Models

## SaaS

Use provider's applications over a network



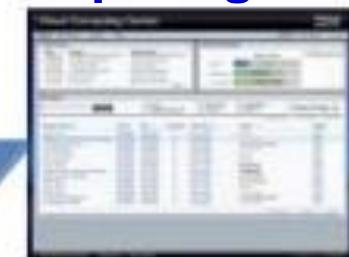
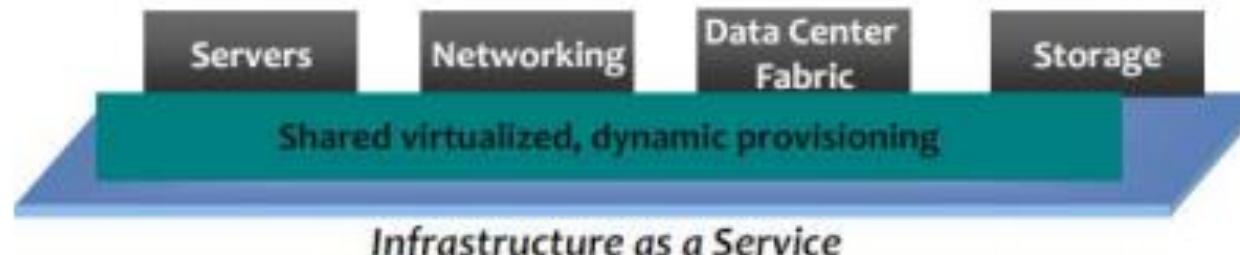
## PaaS

Deploy customer created applications to a cloud



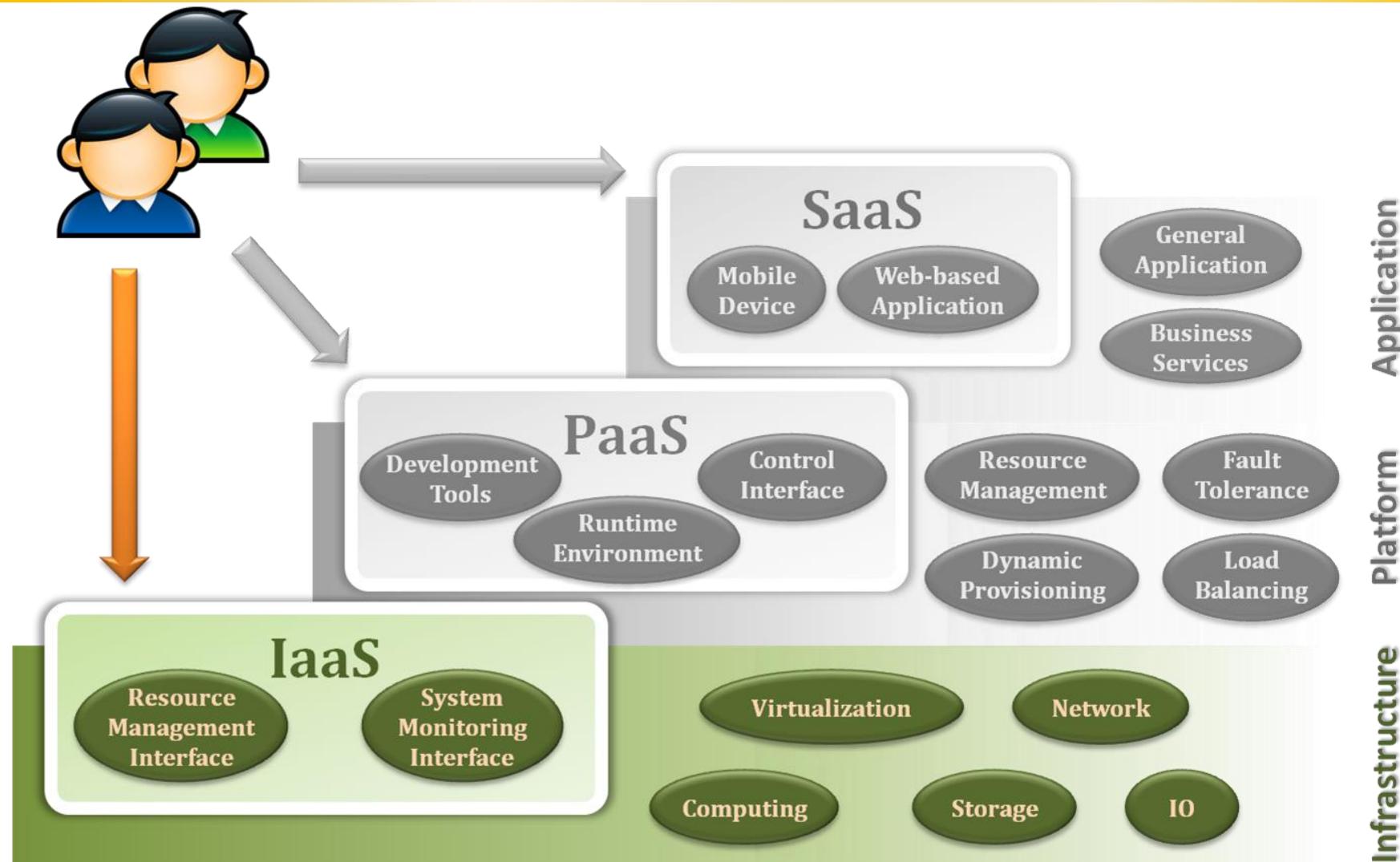
## IaaS

Rent processing, storage, network capacity, and other computing resources



# Cloud Service Models

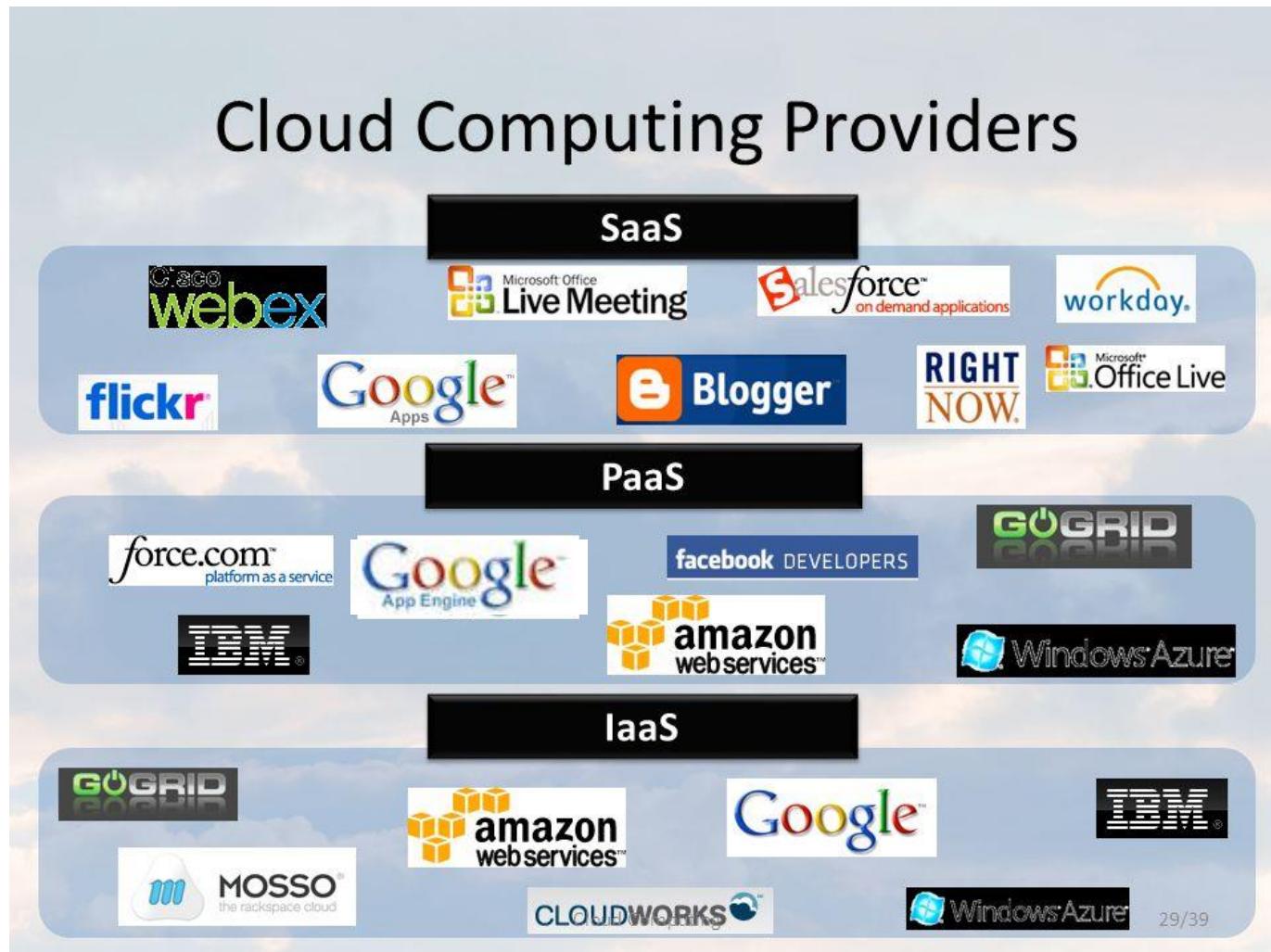
## Service Features





# Cloud Service Models

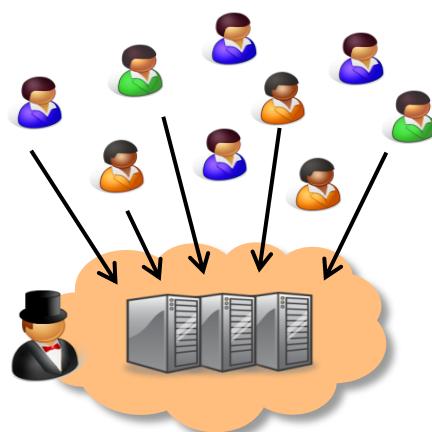
## Who are at which service?



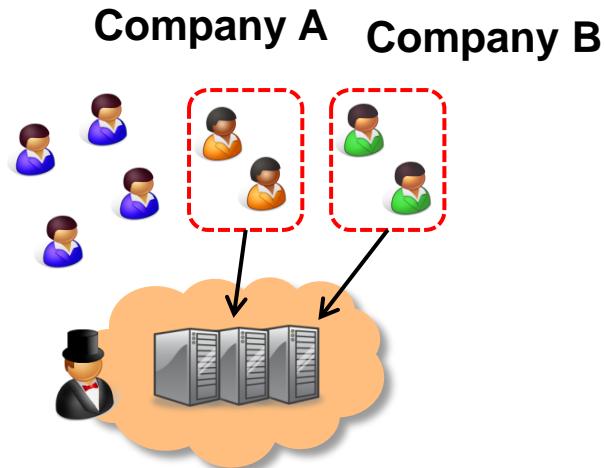
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# Cloud Deployment Models

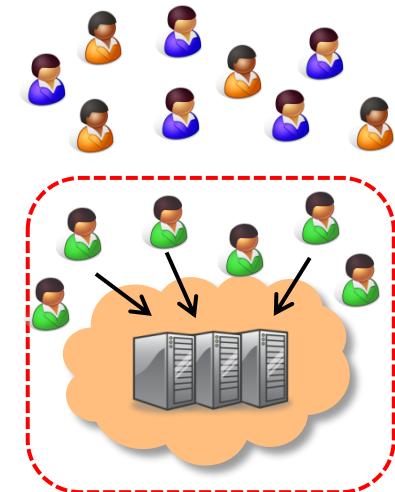
## Who is a customer of the cloud?



**Public**



**Community**



**Private**

**Public cloud:** Amazon, Microsoft, Google, IBM

**Community cloud:** Shared by several similar organizations

**Private cloud:** Shared within a single organization

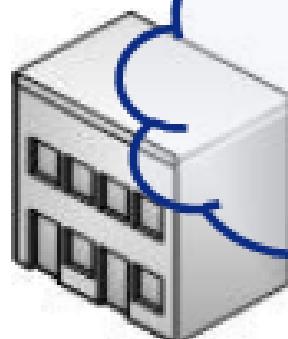
**Hybrid cloud:** Join between private and public cloud

# Cloud Deployment Models

## Deployment Model

Inside the Enterprise

Private  
(Internal)  
Cloud



Hybrid Cloud

Public Cloud



Private (External)  
Cloud

External, but owned  
by the enterprise

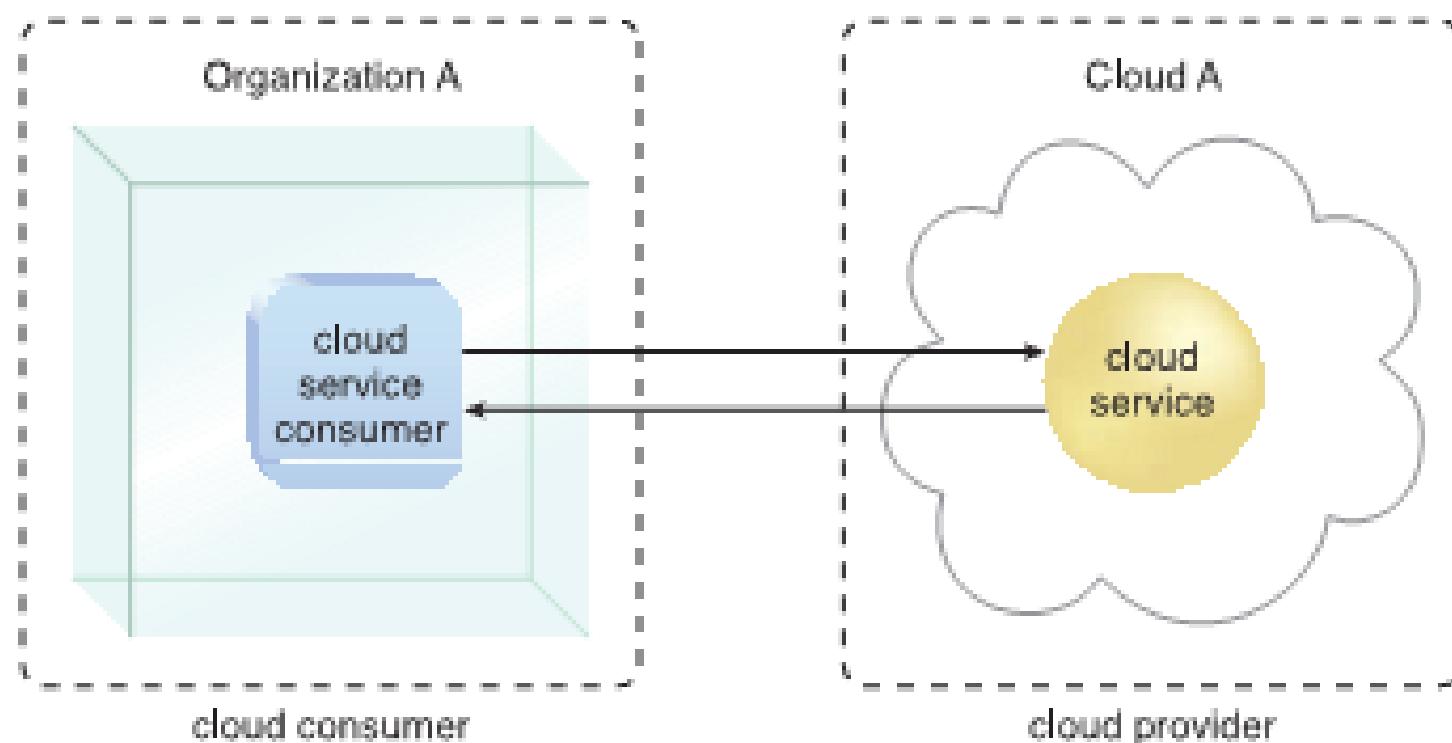


# Roles in Cloud

## Cloud Provider vs. Cloud Consumer

**Cloud provider** provides cloud-based IT resources

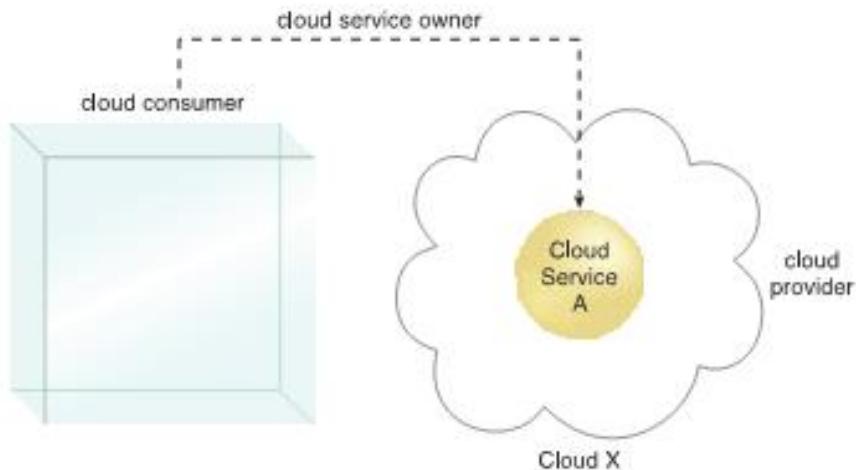
**Cloud consumer** uses IT resources made available by cloud providers



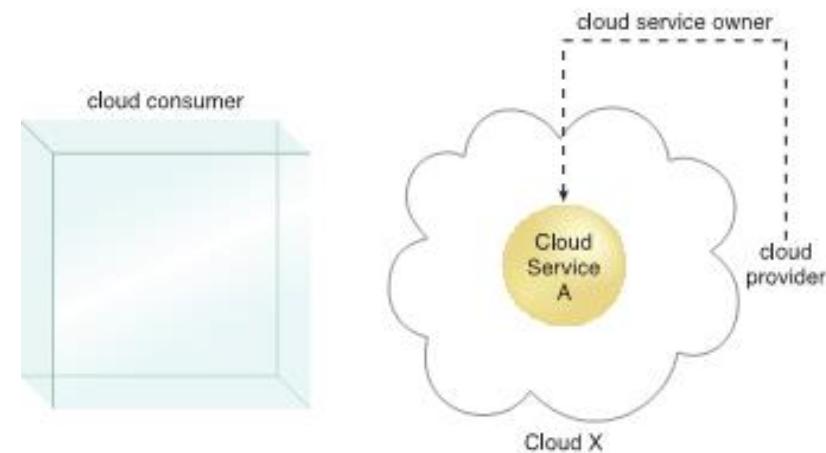
# Roles in Cloud

## Cloud Service Owner

A person/organization who **legally owns** a cloud service



**A cloud consumer can be a cloud service owner when it deploys its own service in a cloud**



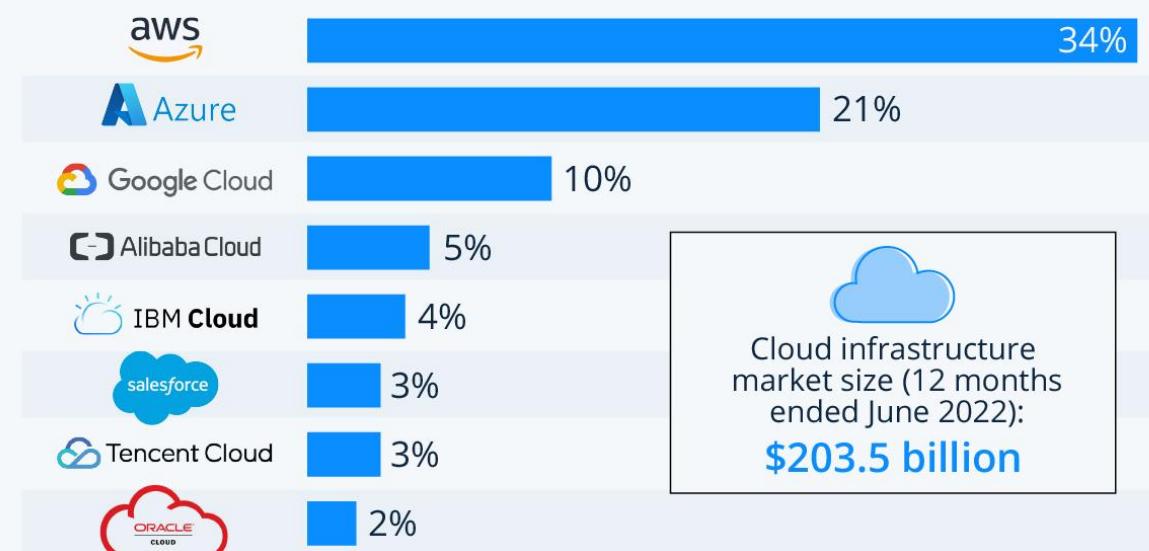
**A cloud provider becomes a cloud service owner if it deploys its own cloud service, typically for other cloud consumers to use**



# Cloud Market Share

## Amazon Leads \$200-Billion Cloud Market

Worldwide market share of leading cloud infrastructure service providers in Q2 2022\*



\* includes platform as a service (PaaS) and infrastructure as a service (IaaS) as well as hosted private cloud services

Source: Synergy Research Group



# Cloud Capacity and Utilization

## Motivation

Increase Margin  
(Make more money)

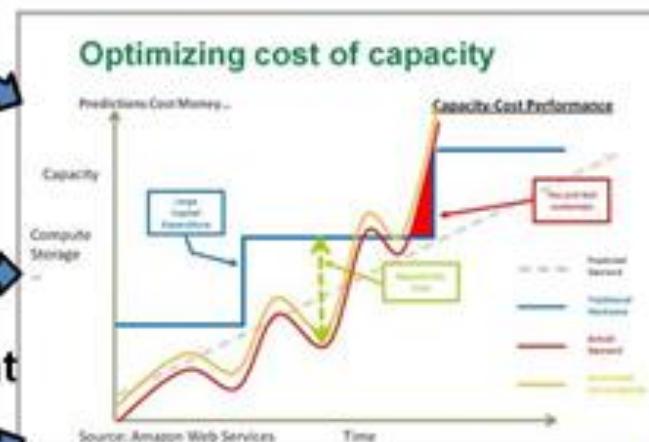
Speed of Cost reduction  
- Cost of adoption / de-adoption

Dynamic usage  
- Elastic provisioning & service management

Optimize Ownership use - faster access to new assets, capabilities

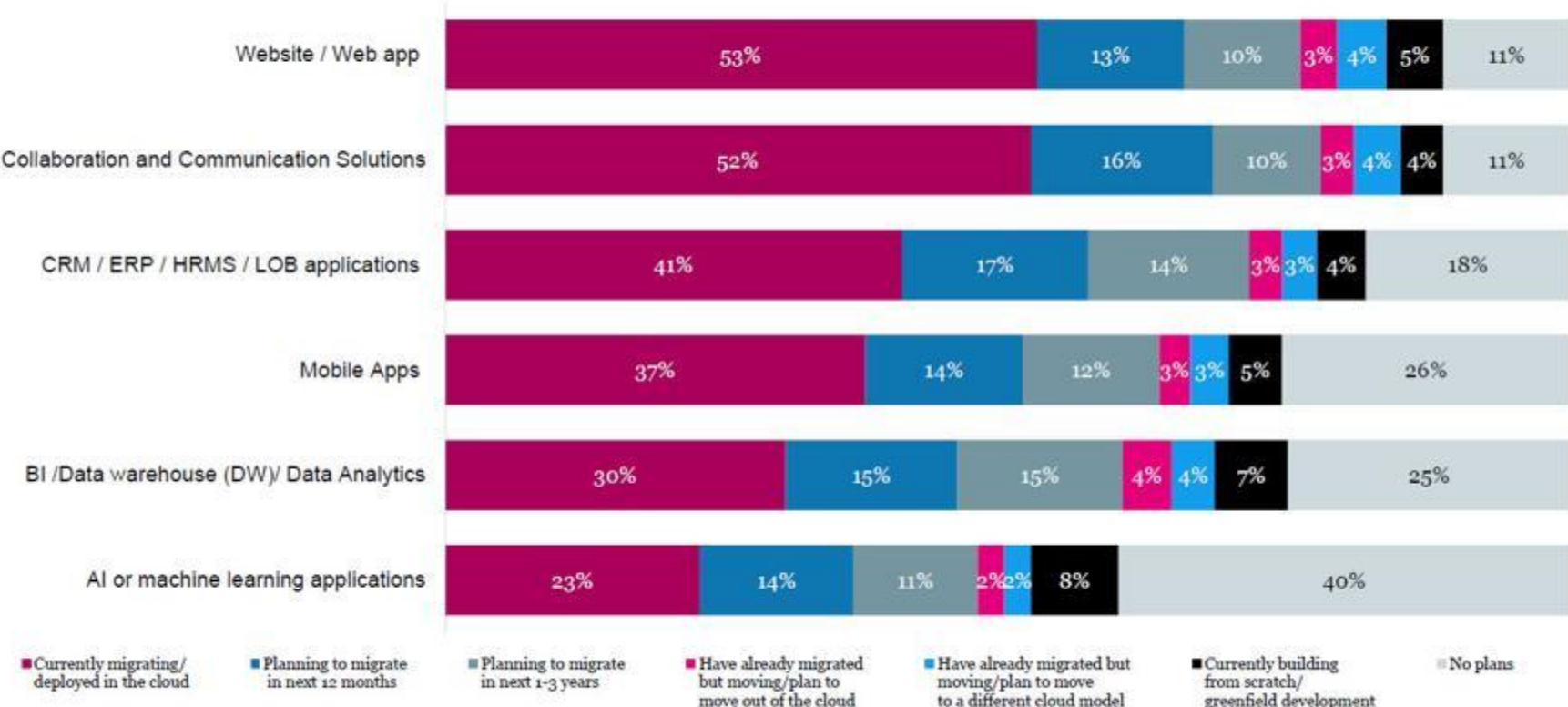
Risk and Compliance Improvement

Rapid Provisioning



# Top Cloud Applications

## Top Applications in the Cloud



Q. Please use the scale below to describe your organization's plans for building, employing, or migrating each of the following types of applications/workloads.



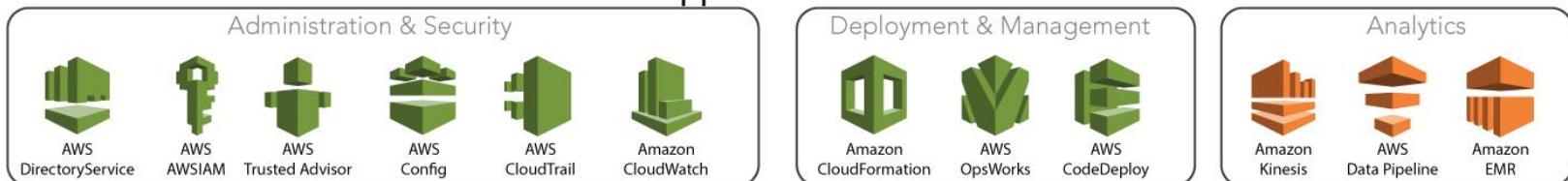
# Example of AWS Cloud Services

## AWS Services

### Deployment & Management



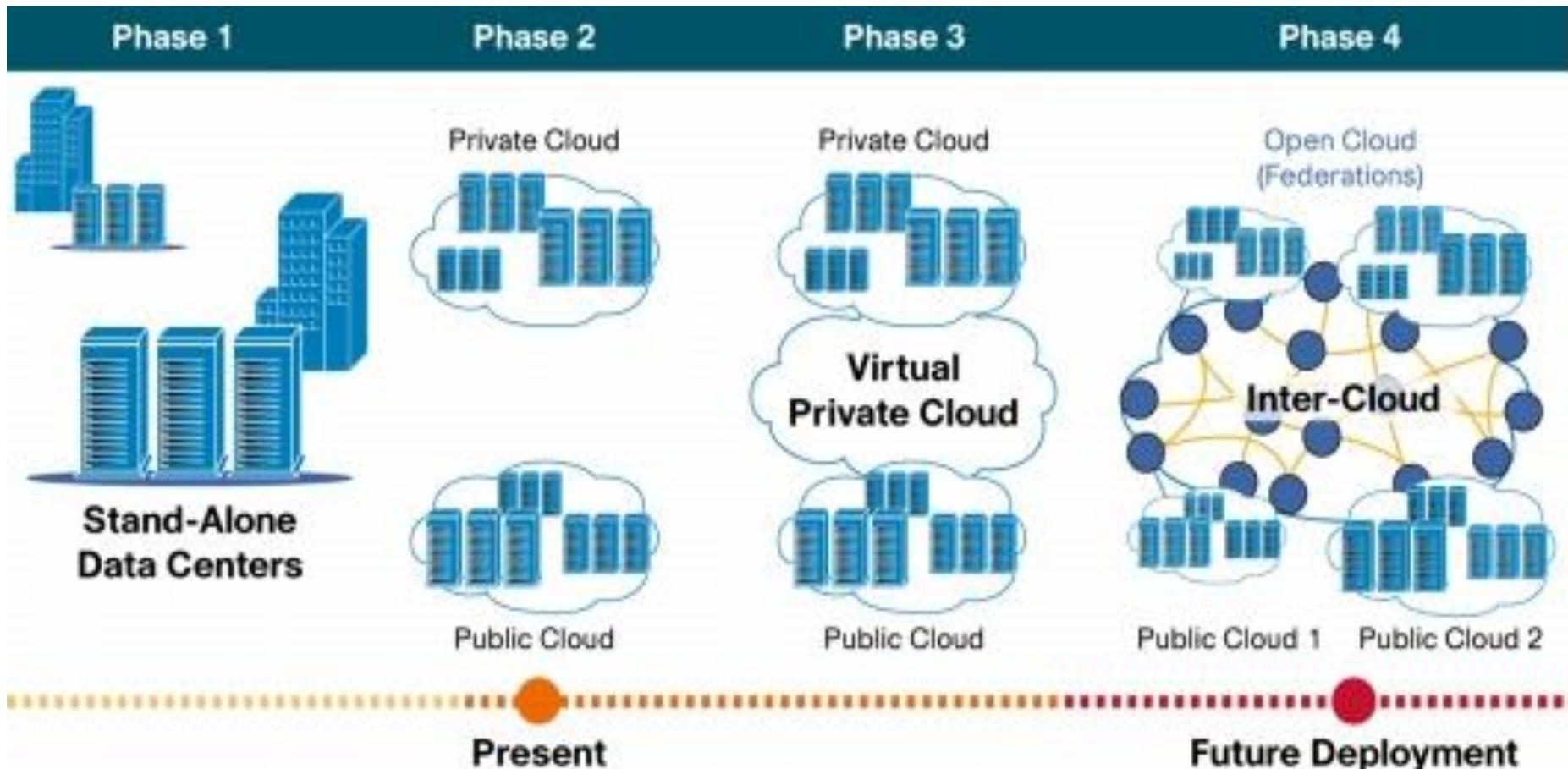
### Application Services



### Foundation Services

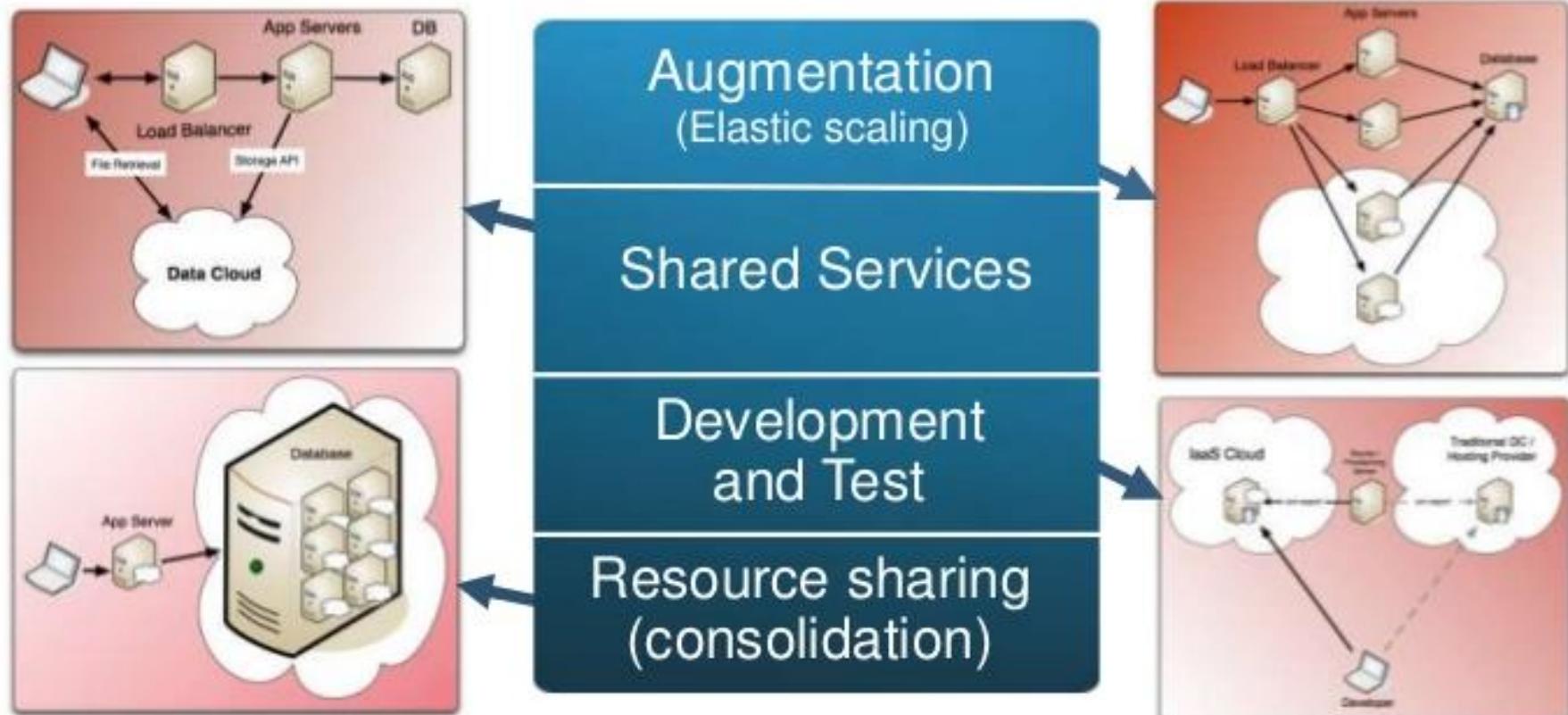


# Cloud Adoption Model



# Cloud Adoption Model

## Starting with Common Use Cases



**Most enterprises are trying**

- **Shared development and test environments**
- **Hardware & Services consolidation**



# Cloud: Pros and Cons

## Cloud Computing

### Advantages

- Storage and Scalability
- Backup and Recovery
- Mobility
- Cost Efficiency
- IT Innovation

### Disadvantages

- Control and Reliability
- Security and Compliance
- Compatibility
- Unpredicted Costs
- Contracts and Lock-Ins



# Cloud Downtime

1  
2  
3  
4  
5  
6  
7  
8  
9  
10

<b>Microsoft's Windows Azure</b>			A sub-component of the system failed worldwide
<b>Google</b>			Services went down, causing global Internet traffic volume to plunge by about 40%
<b>Amazon Web Services</b>			Connectivity issues affected a single availability zone, disrupting a notable portion of Internet activity
<b>NASDAQ</b>			Software bug, and inadequate built-in redundancy capabilities, triggered a massive trading halt in the U.S.
<b>OTC Markets Group Inc</b>			Network failure prompted a shutdown in over-the-counter stock trading in the U.S.
<b>HealthCare.gov</b>			Downtime caused by a service outage at Verizon Terremark data center
<b>Amazon.com</b>			1hr of interrupted service may have translated to \$5M in lost revenue
<b>Microsoft /Hotmail/Outlook.com</b>			Firmware update caused servers to overheat. Hotmail and Outlook.com suffered a service loss
<b>Google Drive</b>			Slow download times caused by a network control software glitch, resulted in latency and recovery problems
<b>Google's Gmail</b>			Slow download times triggered by dual network failure affected 29% of users

Top Ten  
Cloud  
Computing  
Outages in  
2013

# Sample SLAs

	<b>Rackspace</b>	<b>Amazon</b>
Uptime	100%	99.95%
Time-to-resolve	1 hour	Not specified
Timespan	Current period	“Service Year”
Credit back when failing to meet SLA	“Users receive 5% of the fees for each 30 minutes of network downtime, up to 100% of the fees”	“If the Annual Uptime Percentage for a customer drops below 99.95% for the <i>Service Year</i> , that customer is eligible to receive a Service Credit equal to 10% of their bill.”

I  
C  
T

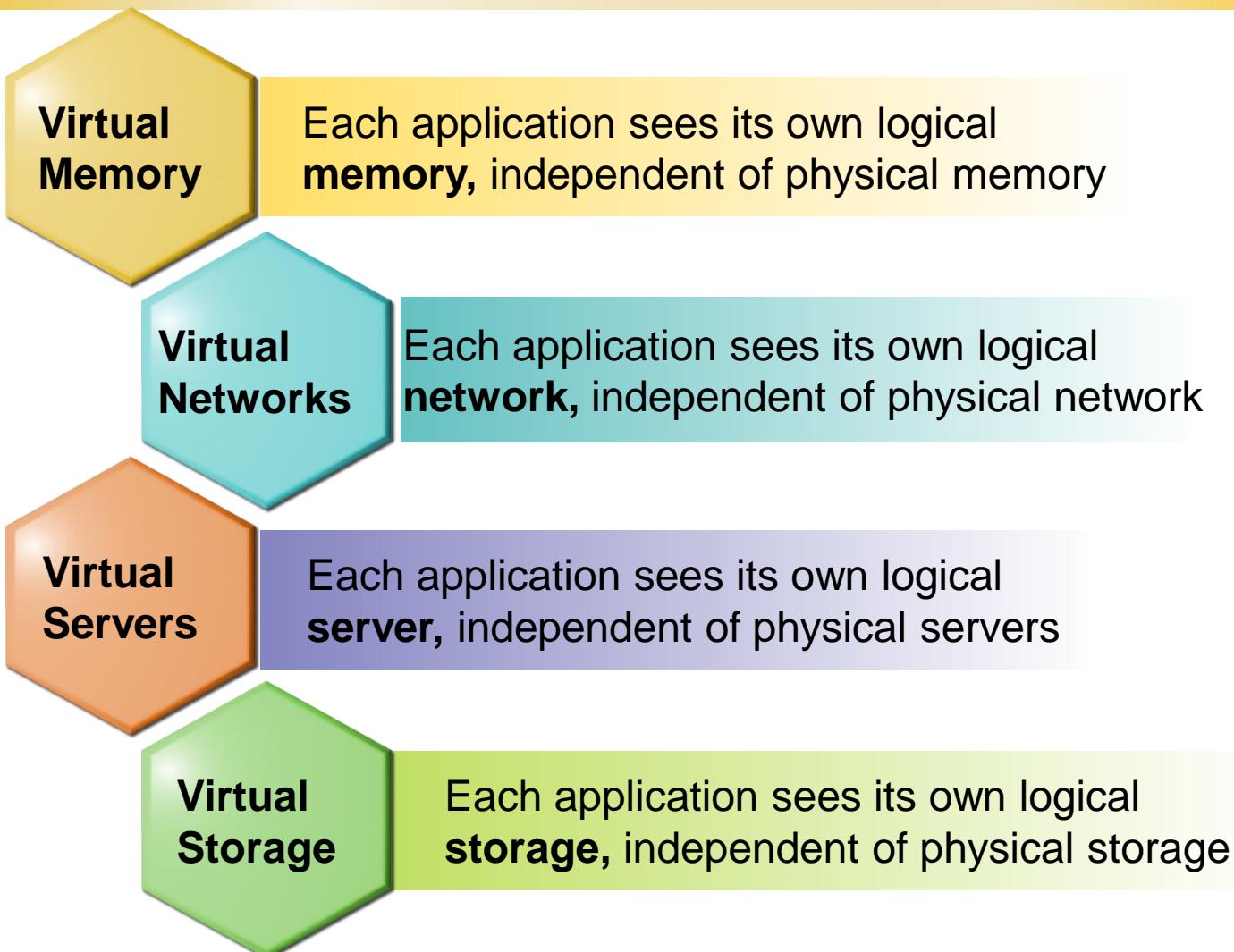
# 99.999% vs 99.9% uptime

## Five nine reliability

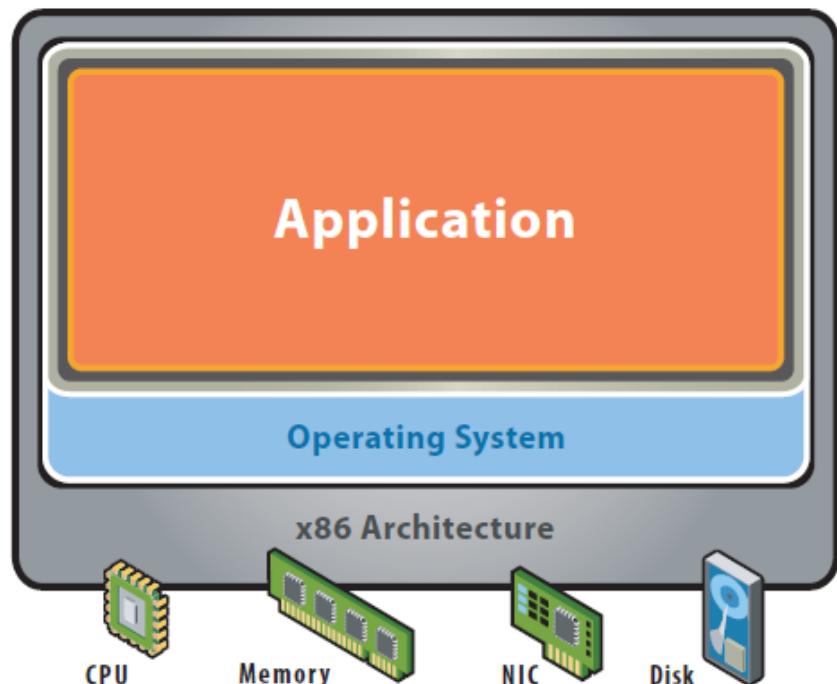
Availability	Downtime / Year	Downtime / Month	Downtime / Week	Downtime / Day
99.999%	5.256 Mins	0.438 Mins	0.101 Mins	0.014 Secs
99.995%	26.28 Mins	2.19 Mins	0.505 Mins	0.072 Secs
99.990%	52.56 Mins	4.38 Mins	1.011 Mins	0.144 Secs
99.950%	4.38 Hrs	21.9 Mins	5.054 Mins	0.72 Secs
99.900%	8.76 Hrs	43.8 Mins	10.108 Mins	1.44 Mins
99.500%	43.8 Hrs	3.65 Hrs	50.538 Mins	7.2 Mins
99.250%	65.7 Hrs	5.475 Hrs	75.808 Mins	10.8 Mins
99.000%	87.6 Hrs	7.3 Hrs	101.077 Mins	14.4 Mins



# Virtualization Concepts



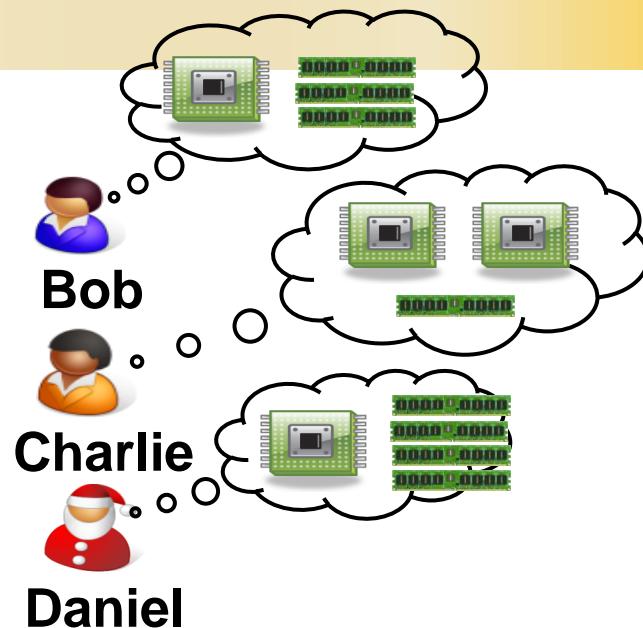
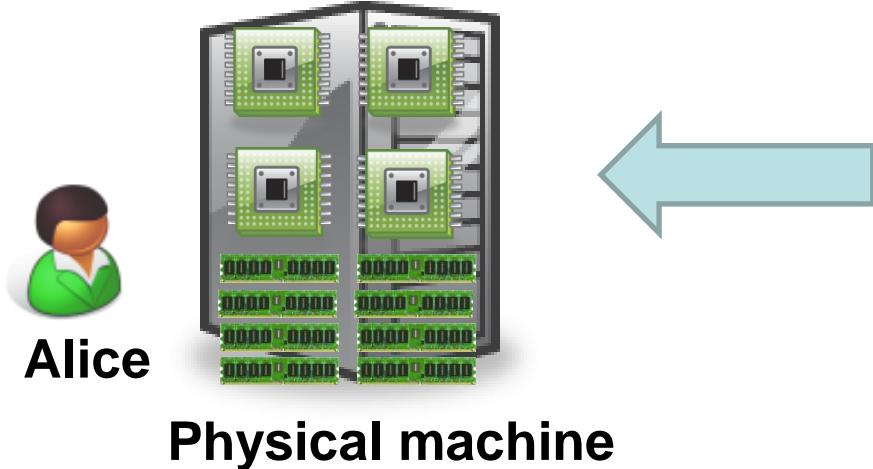
# No Virtualized Server



- Single OS per machine
- Software and hardware tightly coupled
- Running multiple applications on same machine often creates conflict
- Inflexible and costly infrastructure

# Server Virtualization

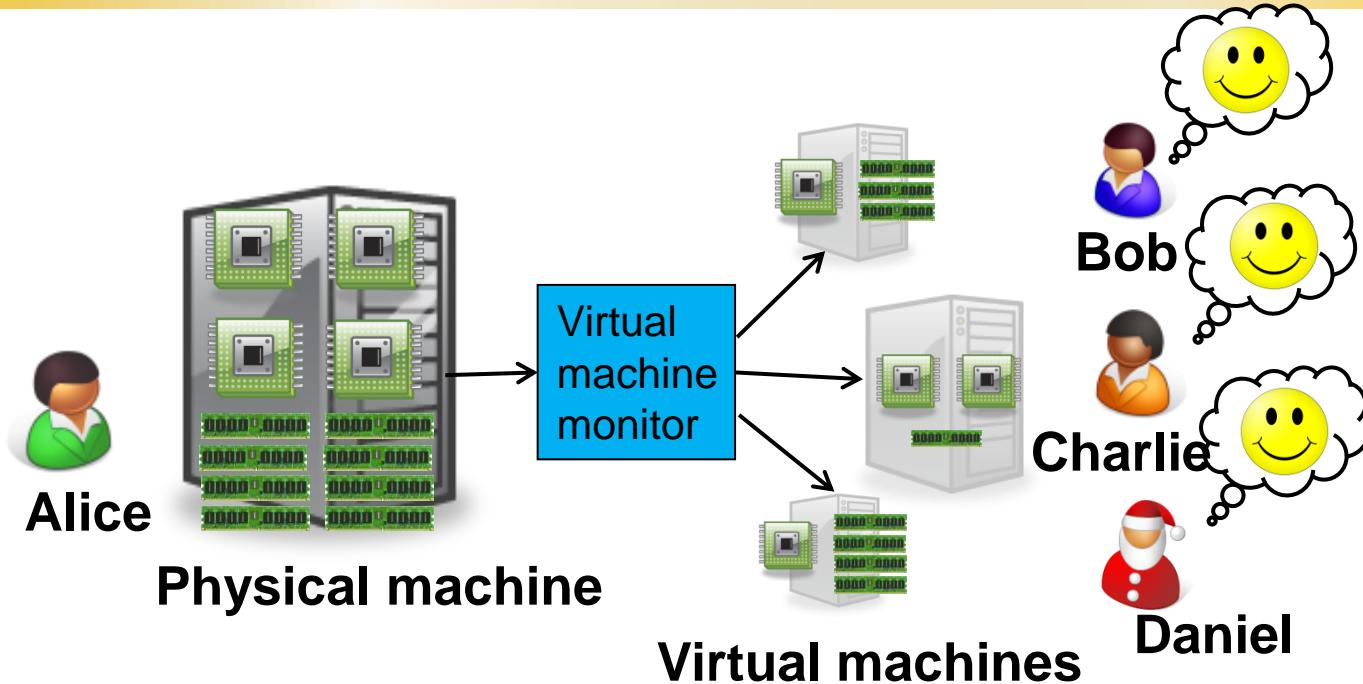
## Sample Scenario



- Suppose Alice has a machine with **4 CPUs and 8 GB of memory**, and three customers:
  - Bob wants a machine with **1 CPU and 3GB** of memory
  - Charlie wants **2 CPUs and 1GB** of memory
  - Daniel wants **1 CPU and 4GB** of memory
- What should Alice do?

# Server Virtualization

## Sample Scenario



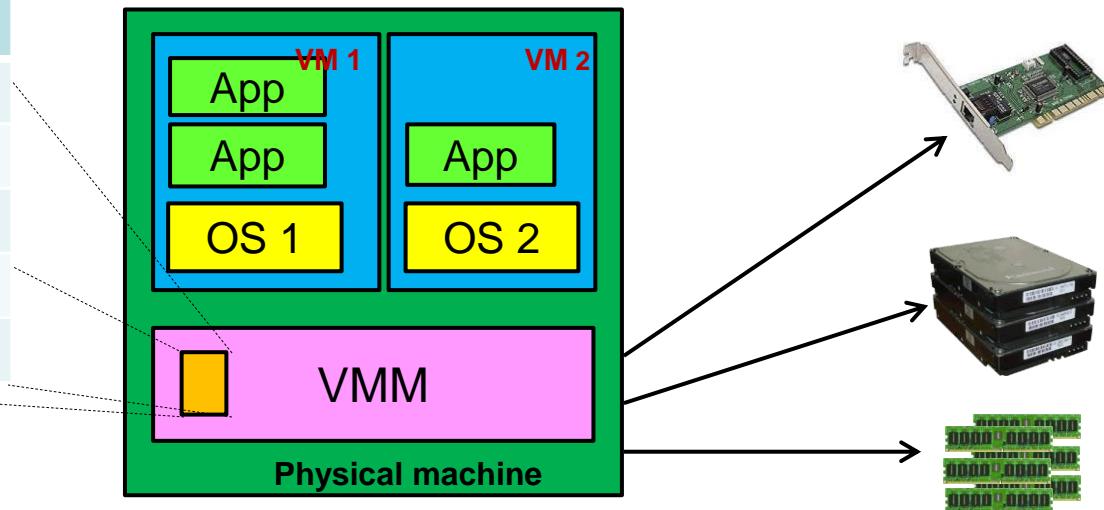
- Alice gives each customer a **virtual machine (VM)** with the requested resources
- From each customer's perspective, it appears **as if** they had a physical machine all by themselves (**isolation**)

# Server Virtualization

## Hypervisor (VMM)

VM	Virt	Phys
1	0-99	0-99
1	299-399	100-199
2	0-99	300-399
2	200-299	500-599
2	600-699	400-499

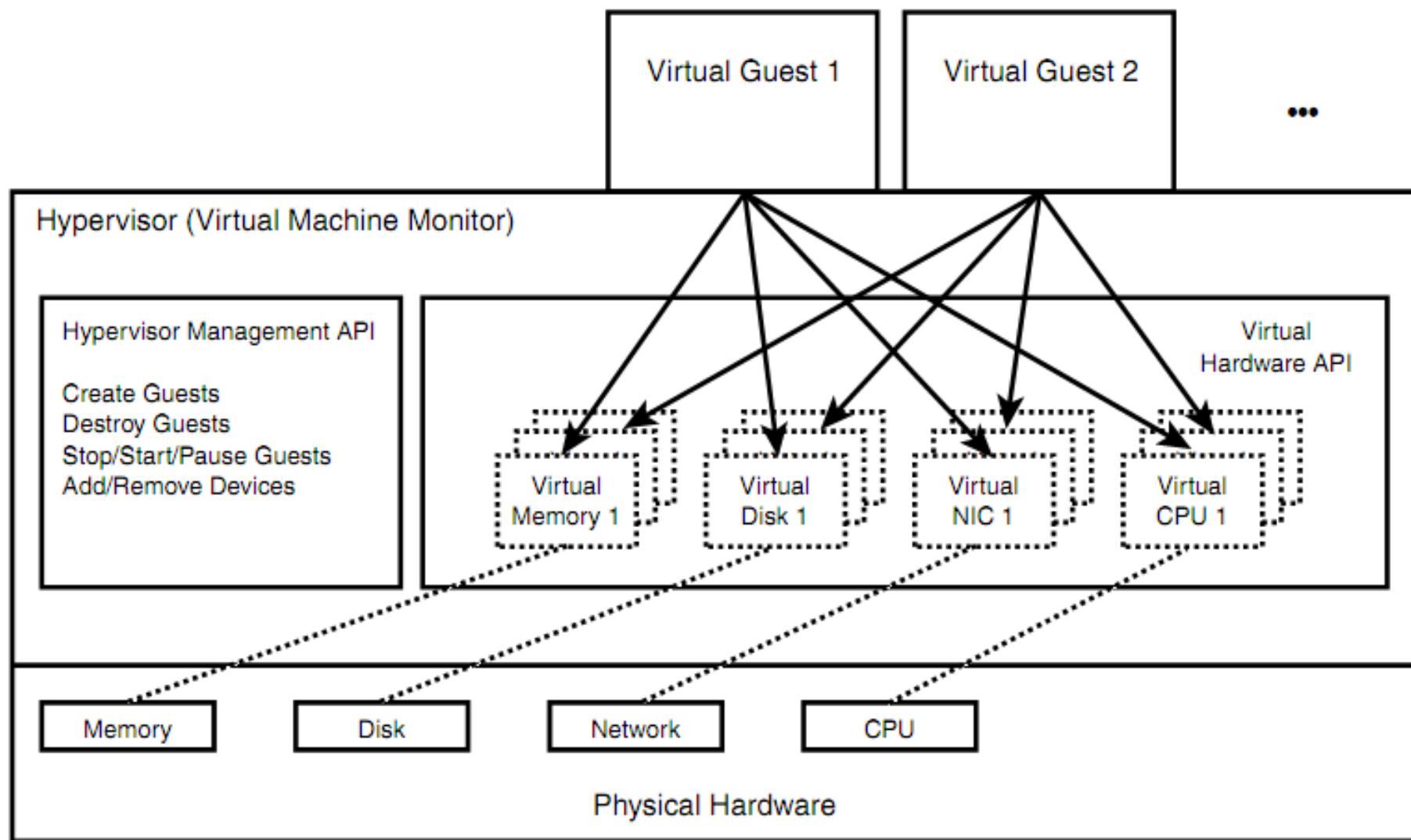
Translation table



- Resources (CPU, memory, ...) are virtualized
- VMM ("Hypervisor") has translation table that maps each VM request for virtual to physical resources

# Server Virtualization

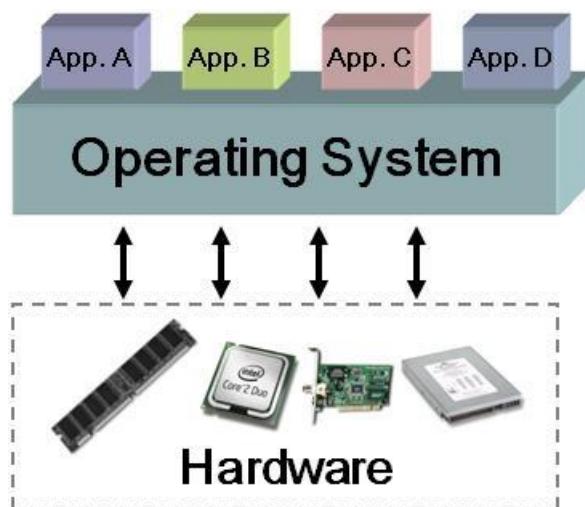
## Hardware, Hypervisor and VM



# Server Virtualization

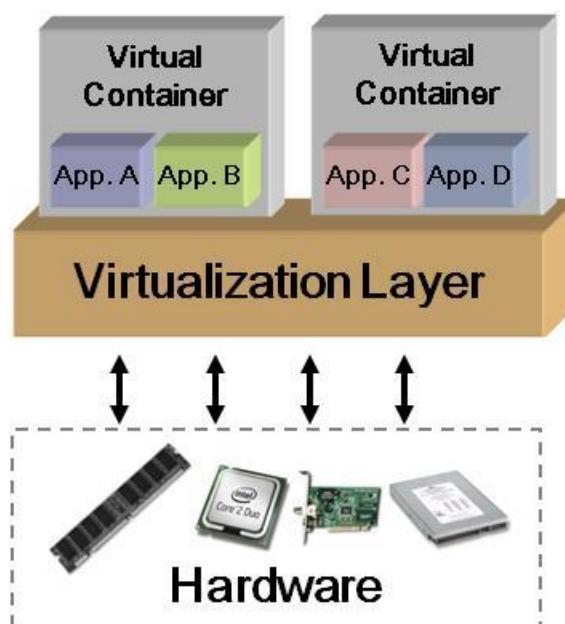
## Non-Virtualized system

A single OS controls all hardware platform resources



## Virtualized system

Multiple VMs on a single physical machine



## Isolated VM

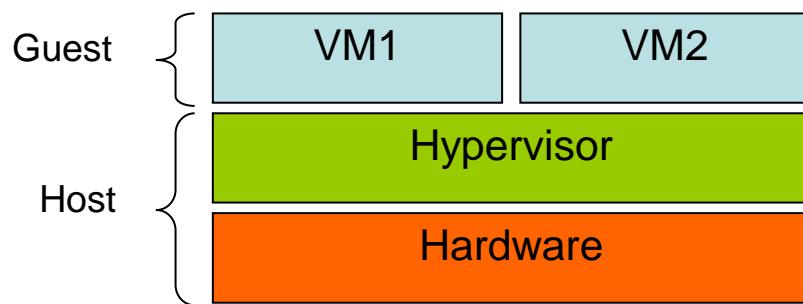
## Hypervisor/ virtualization manager

to manage and monitor VMs

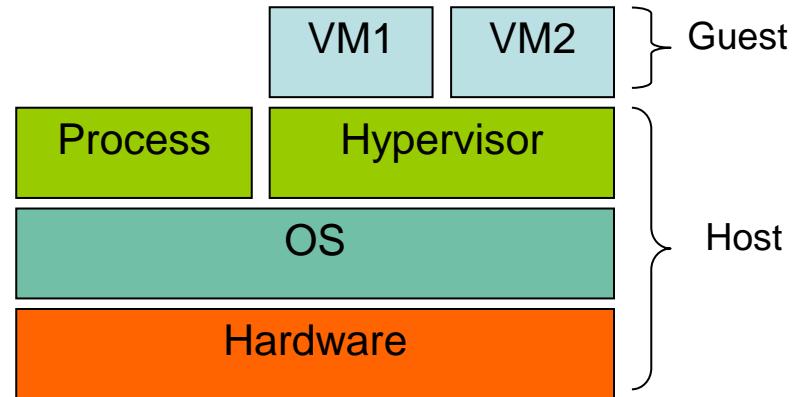
# Server Virtualization

## Two Hypervisor Types

### bare-metal hypervisor (type 1)



### hosted hypervisor (type 2)



VMware ESXi, Microsoft Hyper-V

***Hypervisors run directly on the system hardware***

- More efficient and more secure
- Less hardware support

VMware Workstation Player, Oracle VirtualBox, Linux KVM

***Hypervisors run on a host OS that provides I/O and memory management***

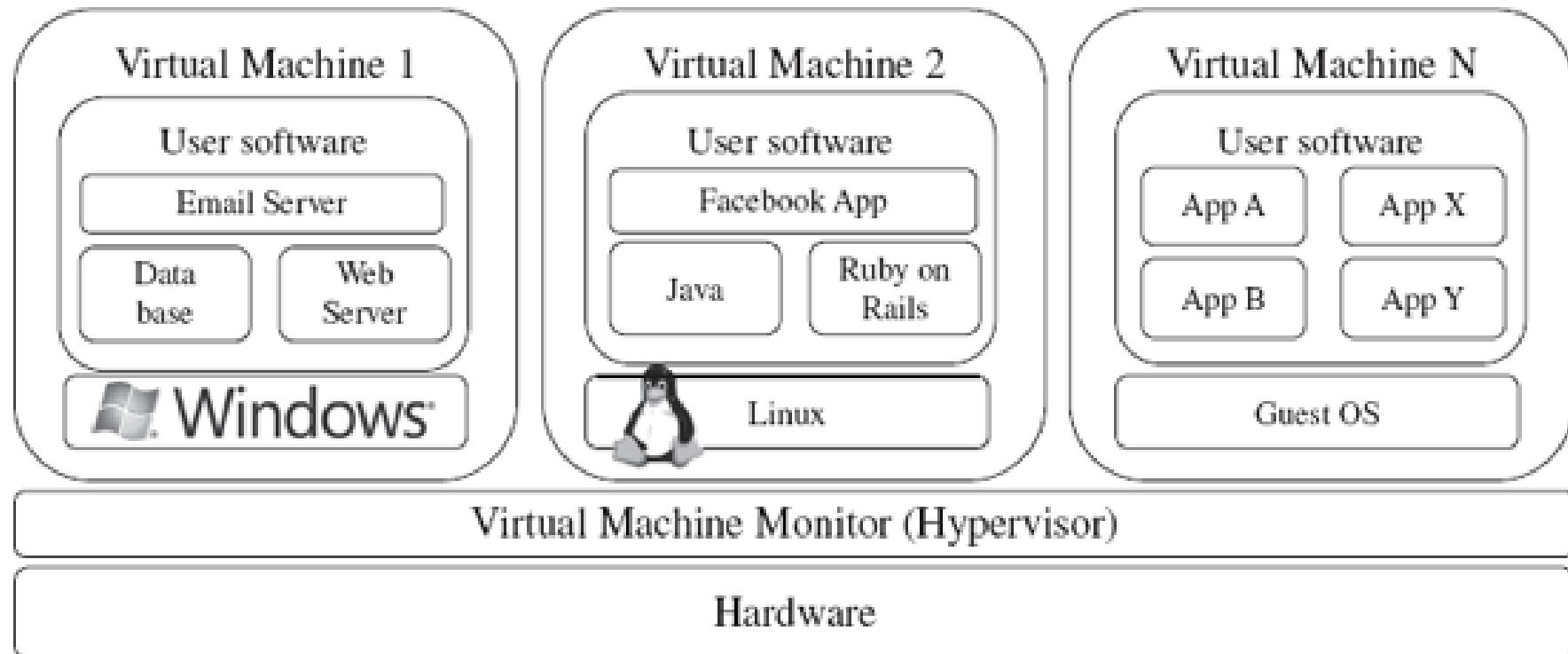
- Easy to install and manage
- more overhead, less secure

# Server Virtualization Techniques

- *Guest machine* is the virtual machine (VM)
- *Full virtualization*
  - Unmodified guest OS
  - Privileged instructions are translated into safe codes on the fly
  - Execution may slow
- *Para-virtualization* like *Xen*
  - Modified guest OS and co-work with hypervisor
  - Any privileged instructions are replaced by hypervisor calls
- *Hardware-assisted virtualization (VT)*
  - Unmodified guest OS
  - Require Intel VT-x or AMD-v support
  - Simplify VMM and give better performance
  - **Used by most hypervisors nowadays**

# Server Virtualization

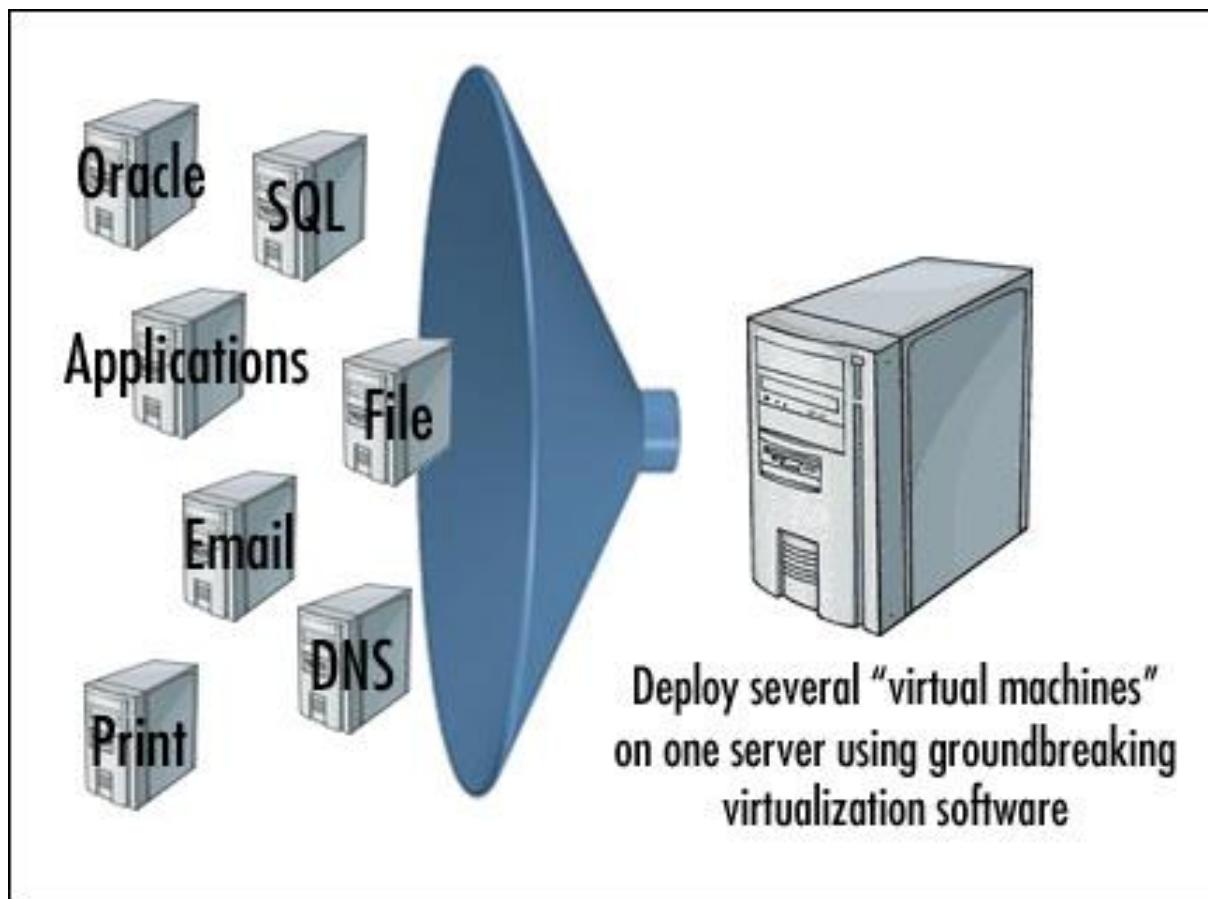
## Guest Virtual Machines



# Server Virtualization

## Resource Consolidation

Run many logical (virtual) machines on the same physical machine and divide system resources between virtual machines

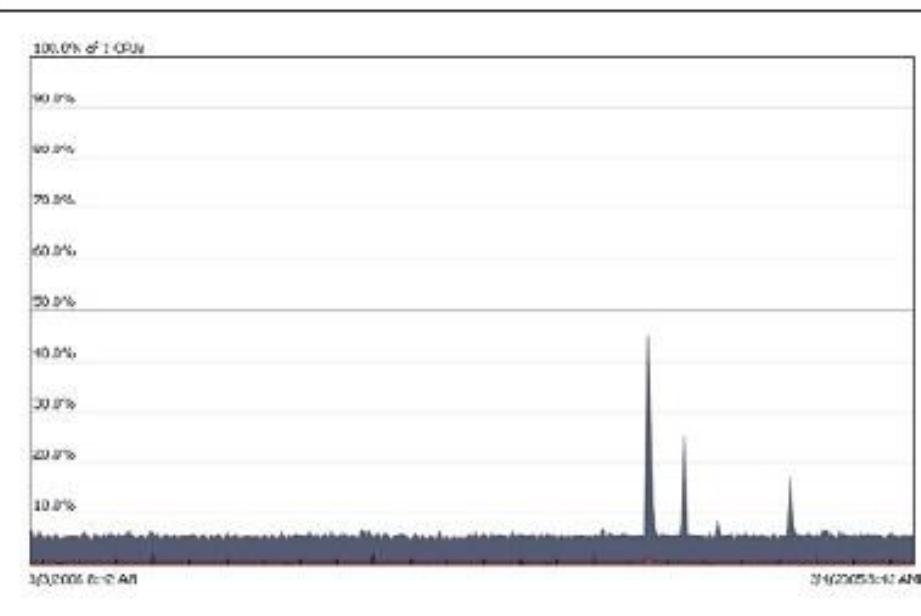


# Server Virtualization

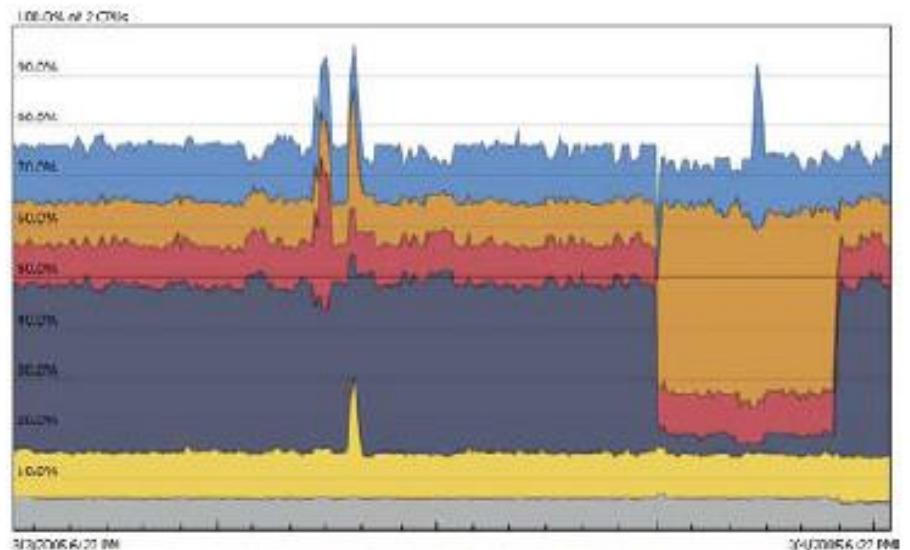
## Higher Utilization

**Consolidation of workloads from underutilized servers onto a single server to achieve higher utilization**

Dedicated Server

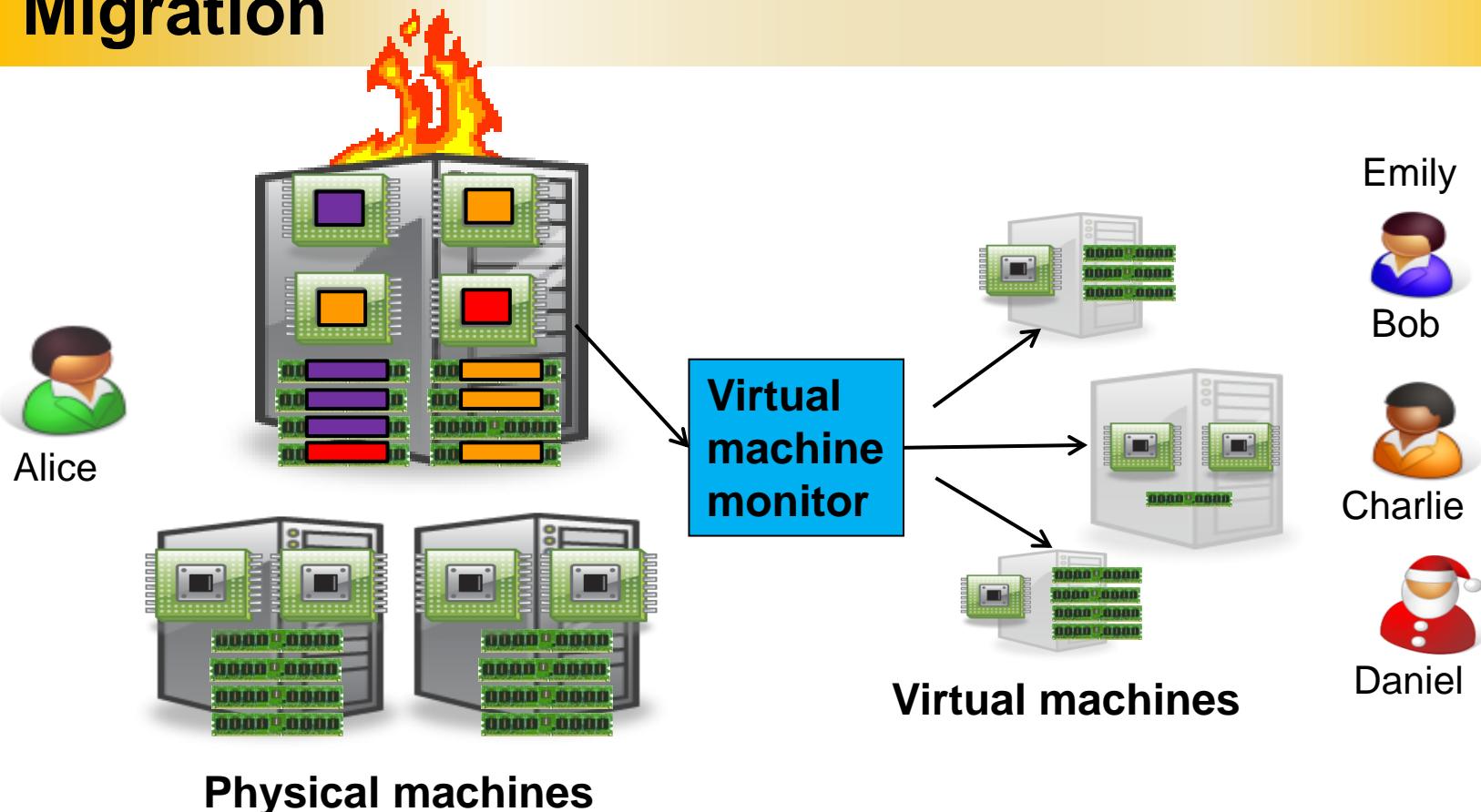


Virtualized Server



# Server Virtualization

## VM Migration

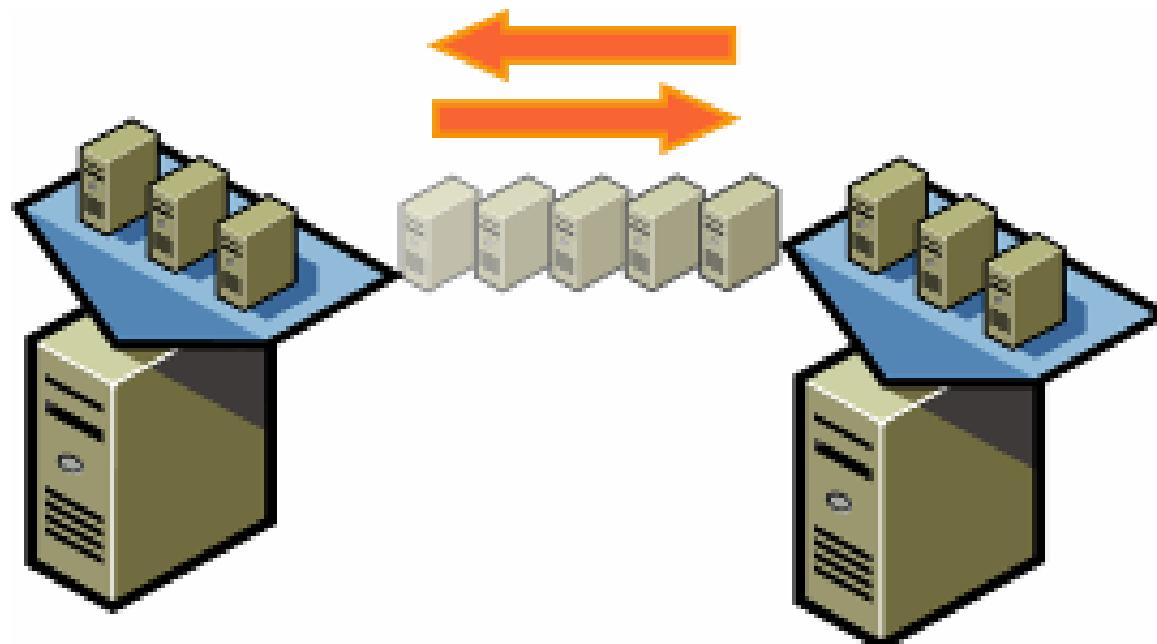


- What if the machine was **shut down**
- Alice can **migrate** a VM to another physical machine without any customer noticing

# Server Virtualization

## VM Migration

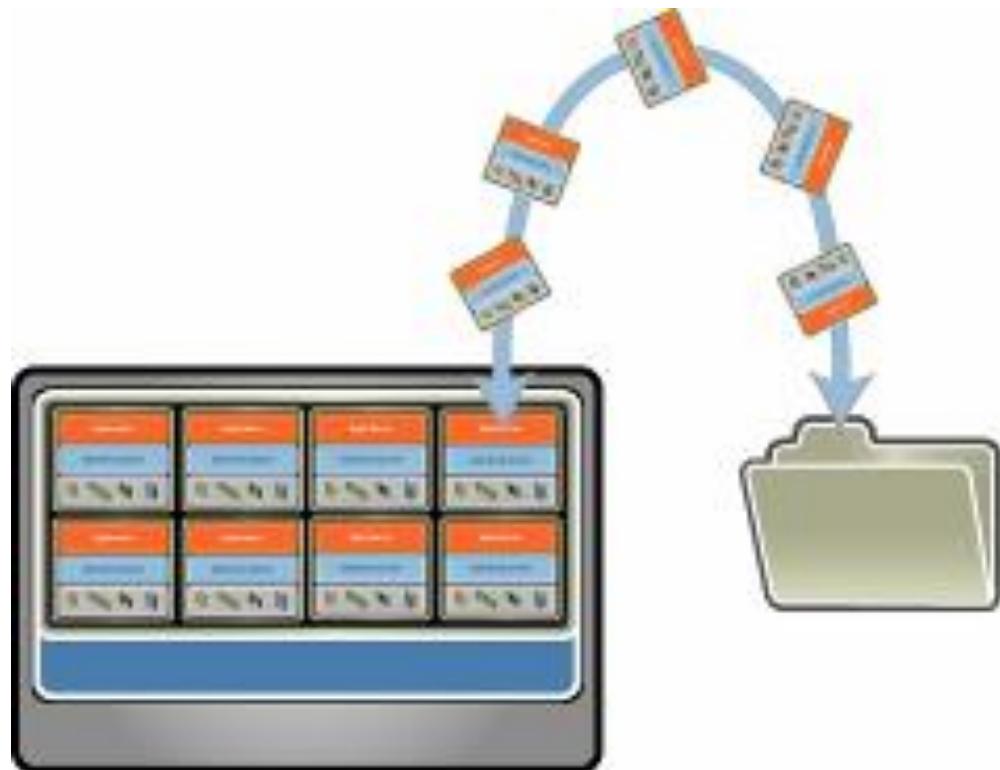
- Migrate a virtual machine to similar or different physical server
- **Live migration** of virtual machines with **(almost) zero downtime**



# Server Virtualization

## Snapshot as Backup

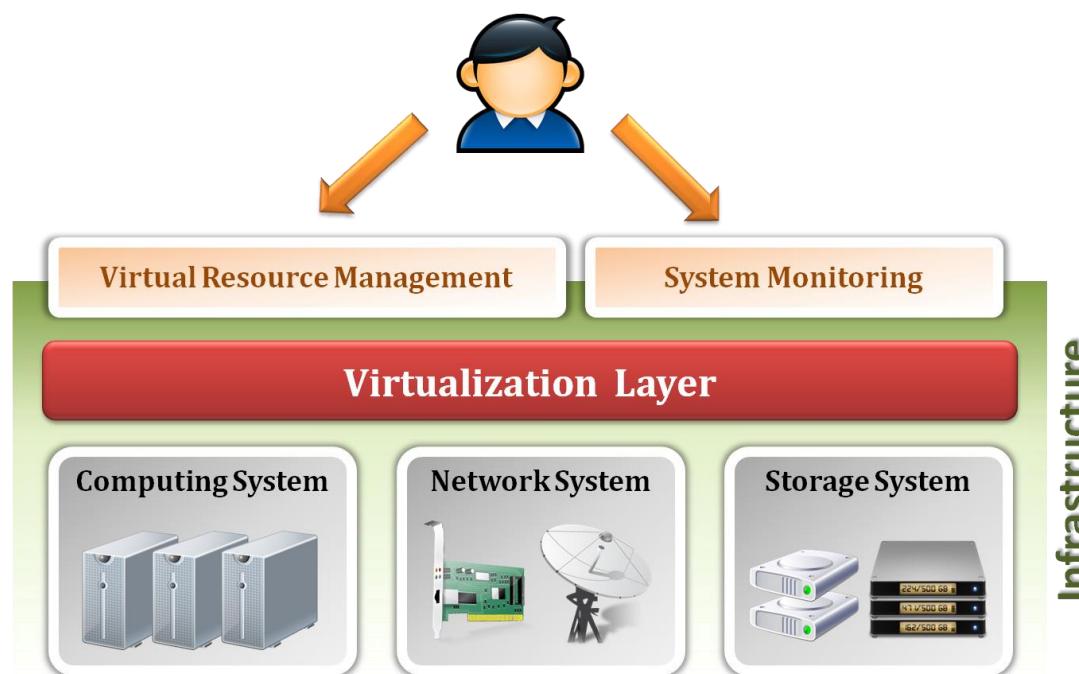
- Entire state of the virtual machine can be saved to files
- Move and copy virtual machines as easily as moving and copying files



# Server Virtualization

## Summary

- **Virtualization** is an **enabling technique** to provide mapping of **physical resources** to **multiple logical resources**
- Virtual instances of IT resources: **CPU, Memory, Network, Disk**
- **Isolate users from the underlying resources**
- **Isolate users from each other**
- **Isolate from fault and security**



# Forms of Virtualization

## Application Virtualization

- Application hosted in a datacenter and streamed to a desktop PC's
- Ex: Citrix XenApp, Microsoft App Virtualization

## Server Virtualization

- Hardware partitioning done on a server machines
- Ex: VMware Server, VMware ESX, SUN xVM, Citrix Xen Server, etc

## Desktop Virtualization

- Hardware partitioning performed on desktop machines
- Ex: VMware workstations, Microsoft Virtual PC

## Hosted Desktop Virtualization

- Desktop environment hosted in Datacenter & streamed to a thin client / PC.
- Ex: VMware virtual Desktop Infrastructure (VDI), Microsoft Terminal Services

## Operating System Virtualization

- The partitioning of system resources at the operating system level.
- Ex: Parallels Virtuozzo, SUN Solaris Containers

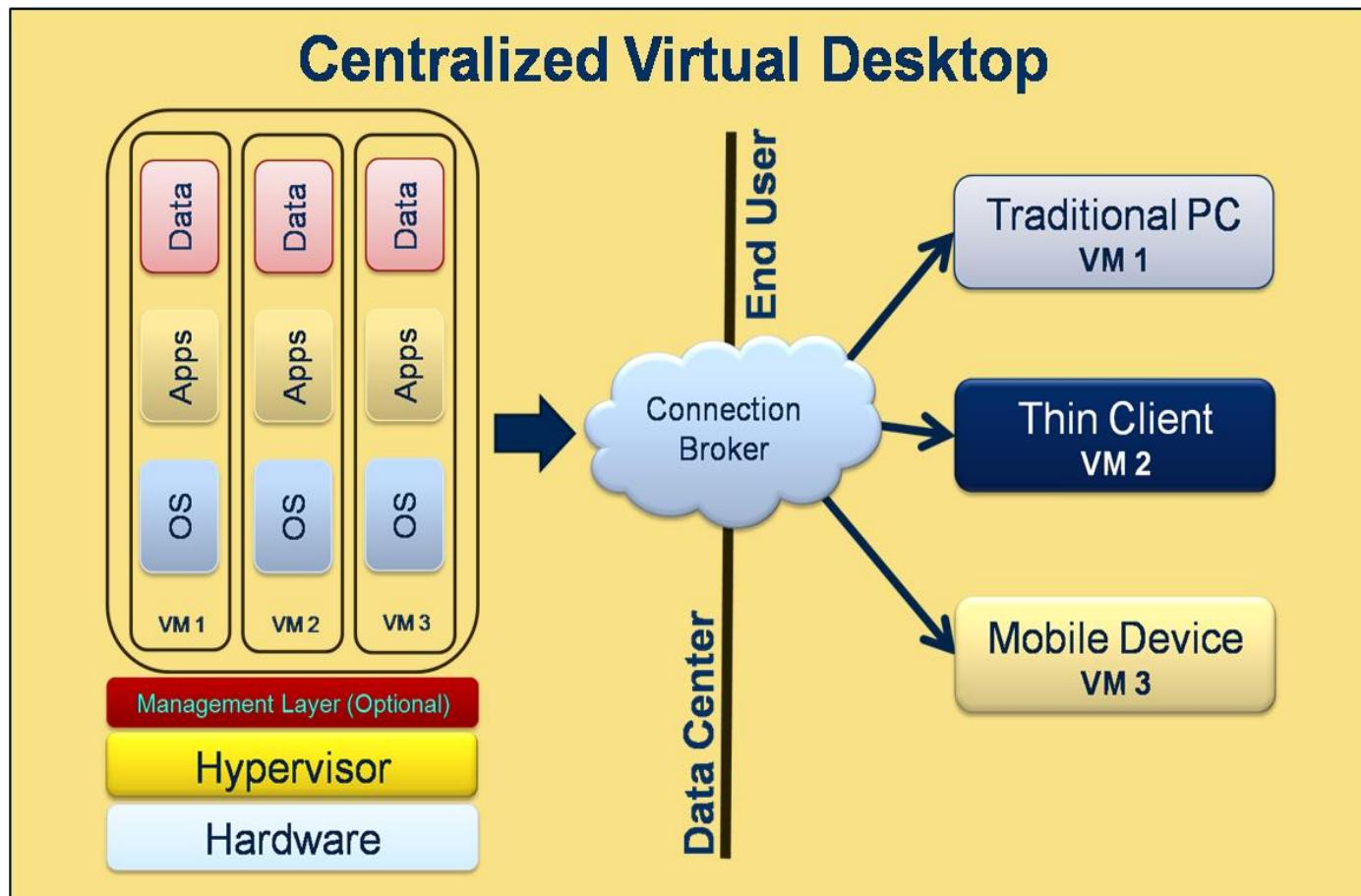
## Network Virtualization

- The logical segmentation of a physical network
- Ex: VPN, VLAN

## Storage Virtualization

- The pooling of multiple physical storage devices, often different types into a single logical device.
- Ex: NAS gateway

# Desktop Virtualization

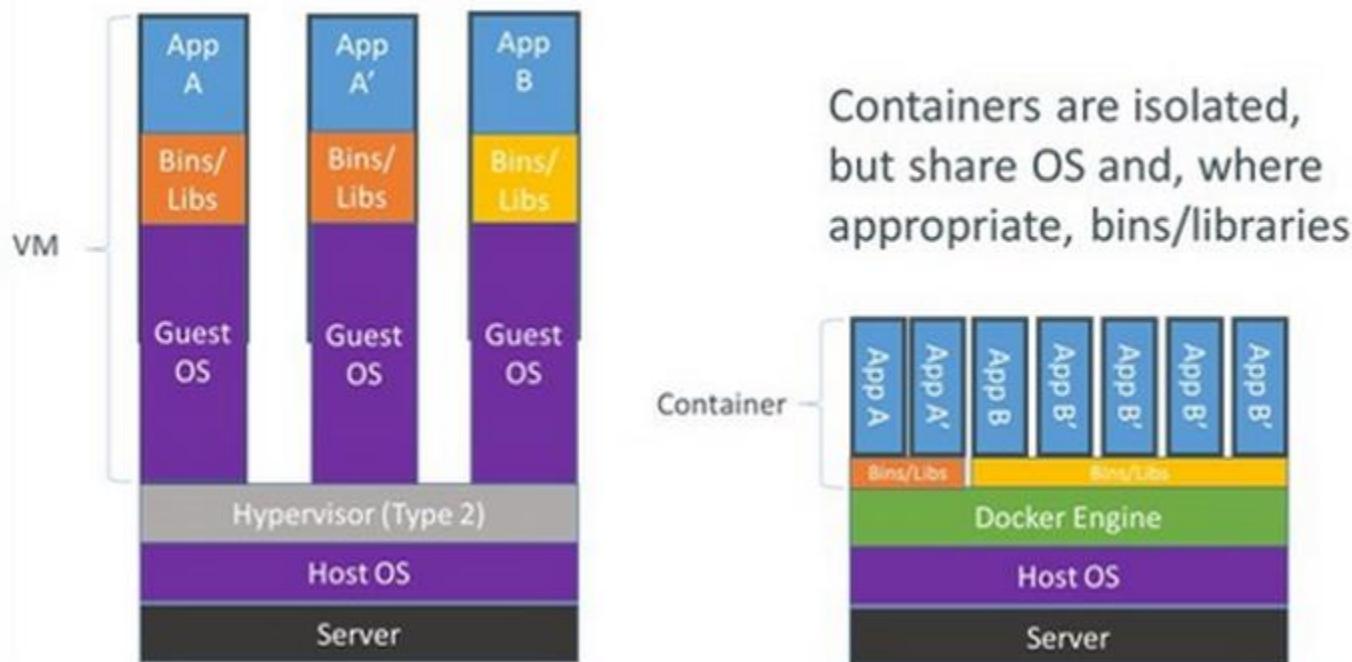


# OS Virtualization

## Container

- More light-weight than virtual machine
- Docker is popular

### Containers vs. VMs

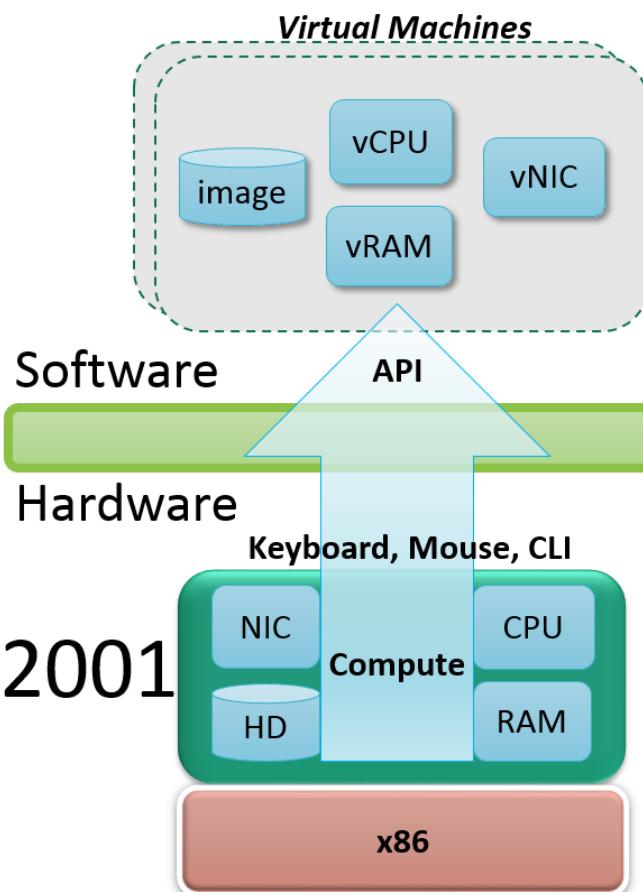




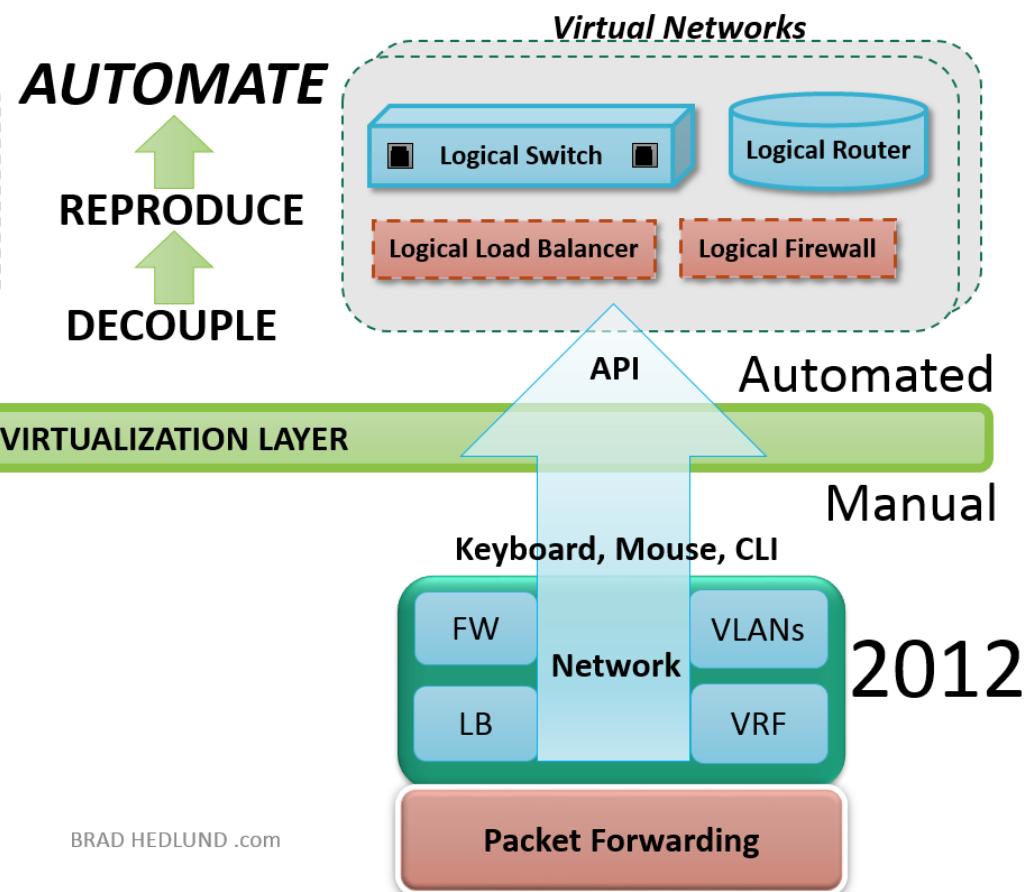
# Network Virtualization

Virtual networks are placed on top of physical network elements

## Server Virtualization

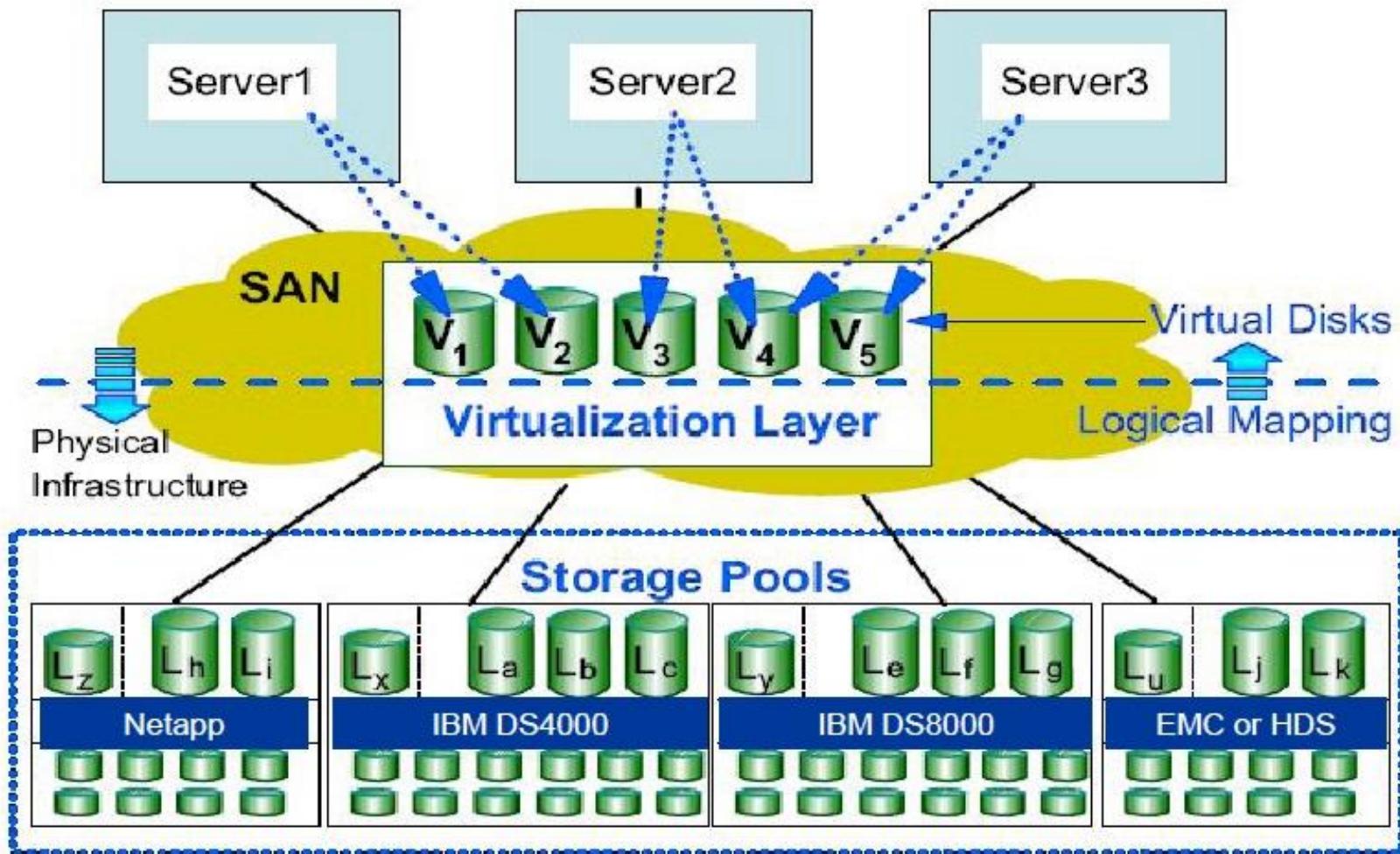


## Network Virtualization



# Storage Virtualization

Logical storage appears and behaves as physical storage directly connected to host, by combining multiple storage devices into a single storage pool



# Virtualization in Cloud

