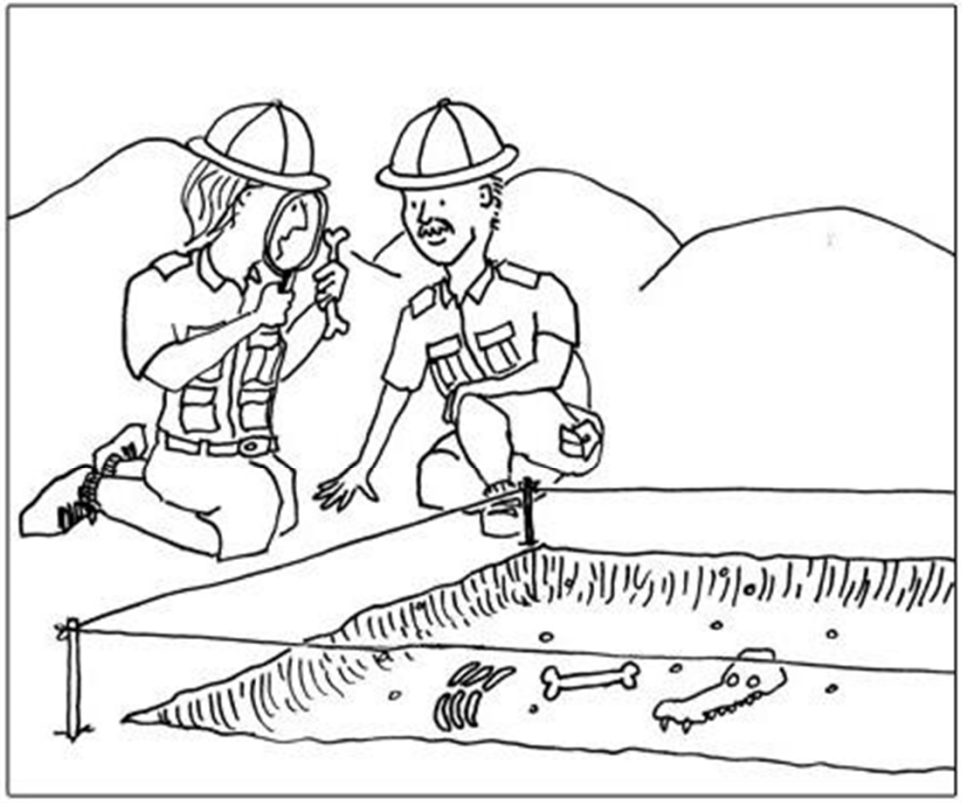
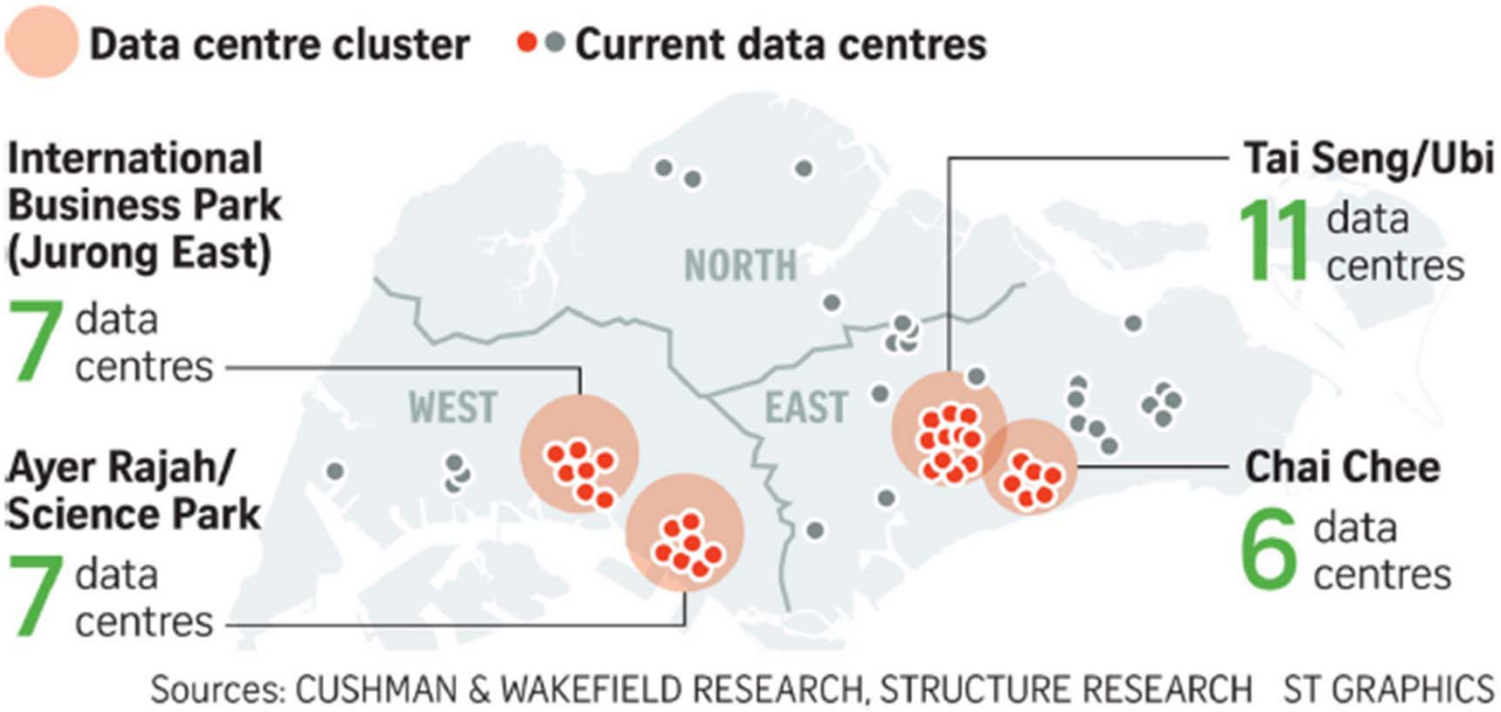
L03: Technologies behind Cloud Computing



At last, the fossil evidence to prove our theory! The dinosaurs died off – not because of a meteor or climate change – but because their cloud computing platform collapsed!

Singapore data centre distribution



Sources: CUSHMAN & WAKEFIELD RESEARCH, STRUCTURE RESEARCH ST GRAPHICS

Straits Times, Jan 12, 2016

Pipeline supply of data centre facilities

Operator	Location	Region	Ultimate IT load capacity (MW)	Completion date (this year)
Singtel	Yung Ho Road	West	36	Q4
Telin	Sunview Road	West	12	Q4
ST Telemedia /StarHub	Ayer Rajah	West	14	Q1
ST Telemedia	Defu Ave 1	East	12	Q2
DRT Loyang	Loyang Way (Brownfield)	East	13.2	Q1
Keppel T20	Tampines St 92	East	17	Q4
1-Net	Marsiling Road	North	12	Q1
ST Electronics	Ang Mo Kio	North	To be confirmed	To be confirmed
Global Switch	Gambas	North	To be confirmed	To be confirmed
TOTAL (9 facilities)			**At least 116.2**	

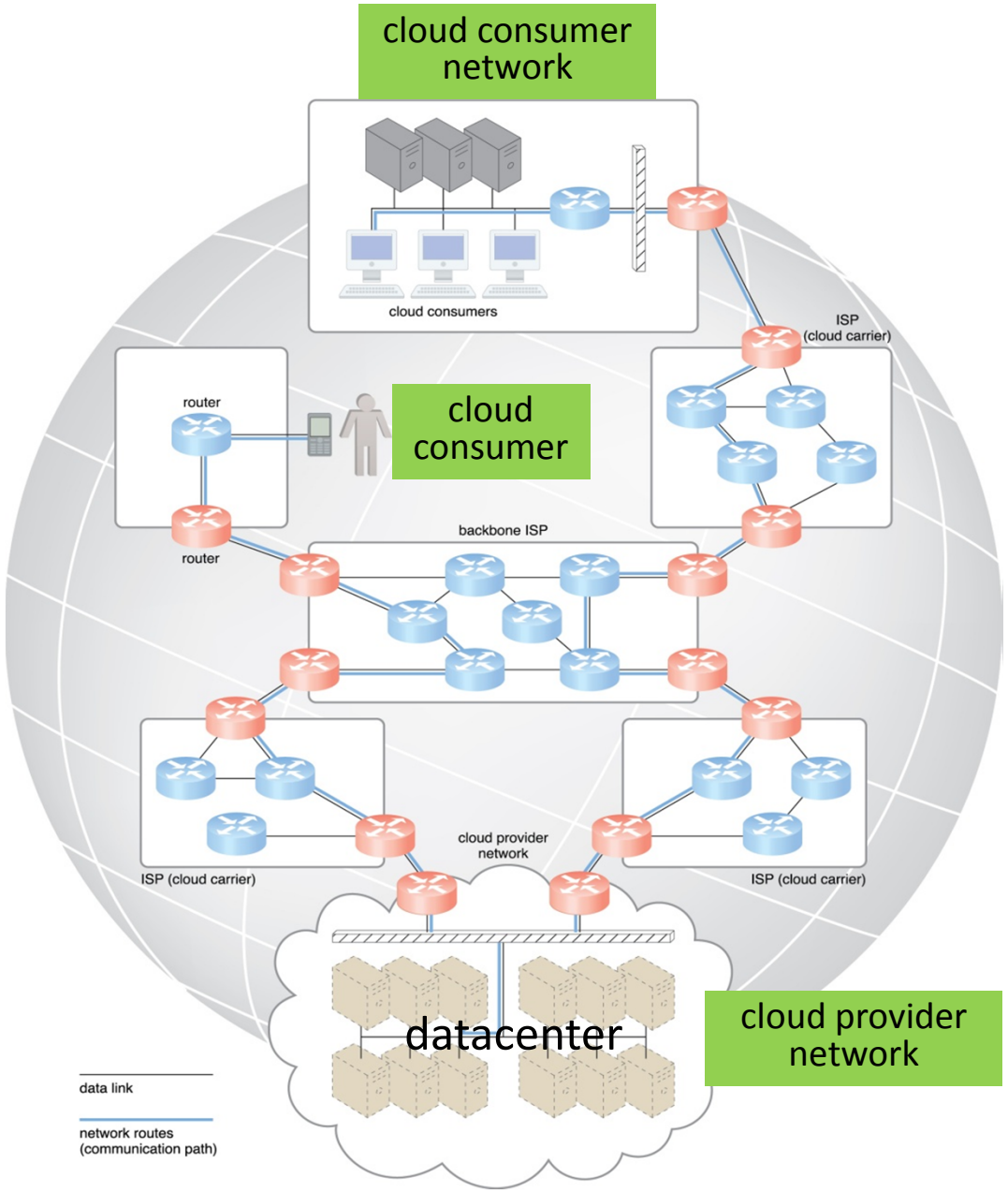
Outline

- Resource Hosting
- Main Components in a Datacenter
  - Server, storage and network
  - Cooling systems and energy
  - Fire protection
  - Security
- Datacenter Tiers
- Virtualization
- Multi-tenancy
- Summary

Key Terms

1. On-premise (cloud-based)
2. Datacenter tiers
3. PUE (Power Usage Efficiency)
4. Energy-proportional system
5. Virtualization
6. Multi-tenancy

Connectivity of a Cloud



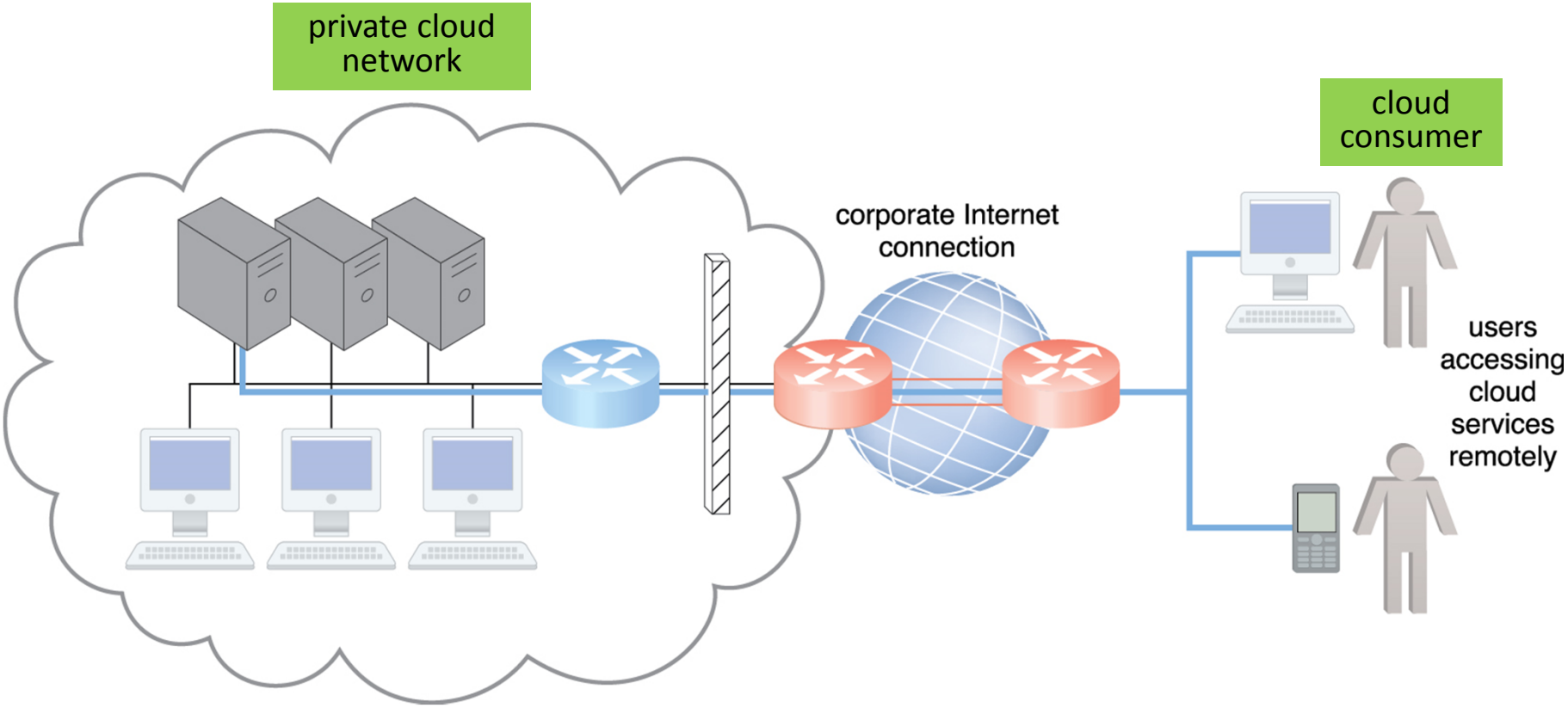
importance of cloud carriers or ISPs

RESOURCE HOSTING

- **on-premise**
  - organizations responsible for deploying, operating and maintaining Internet connectivity
  - have complete control on managing QoS (Quality of Service)
  - safeguard using firewalls and monitoring software

- **cloud-based**
  - use multiple ISPs: difficult QoS management
  - need multiple cloud carriers
    - Connectivity and reliability of cloud applications
  - easier to adopt for applications with relaxed bandwidth and latency
  - security concerns

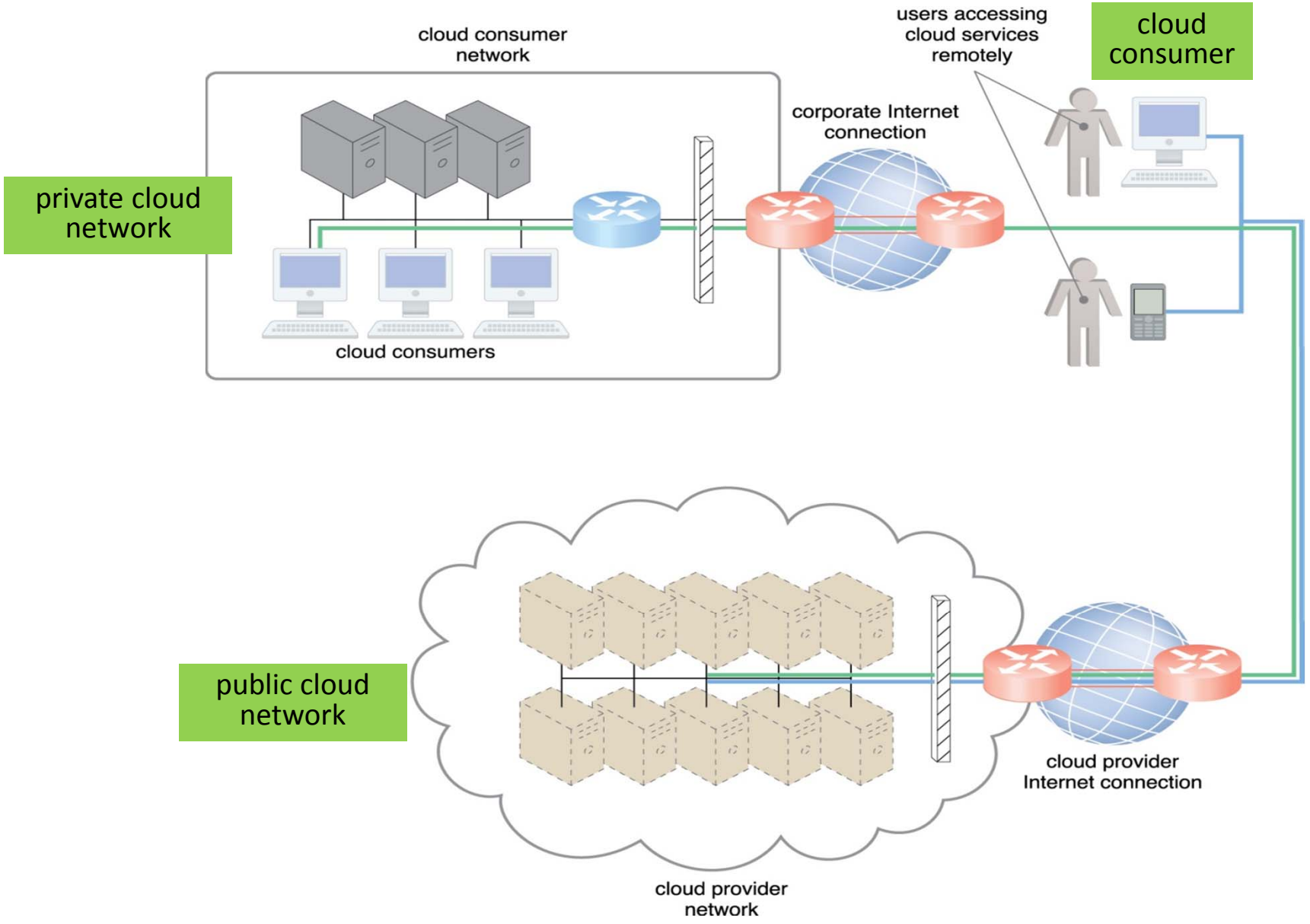
Private Cloud Internetworking



Latency – time it takes a packet to travel from one data node to another; highly variable latency with shared nodes; importance when application requires swift response time

Bandwidth – number of bits transferred per unit time; importance when applications require substantial amount of data transfer

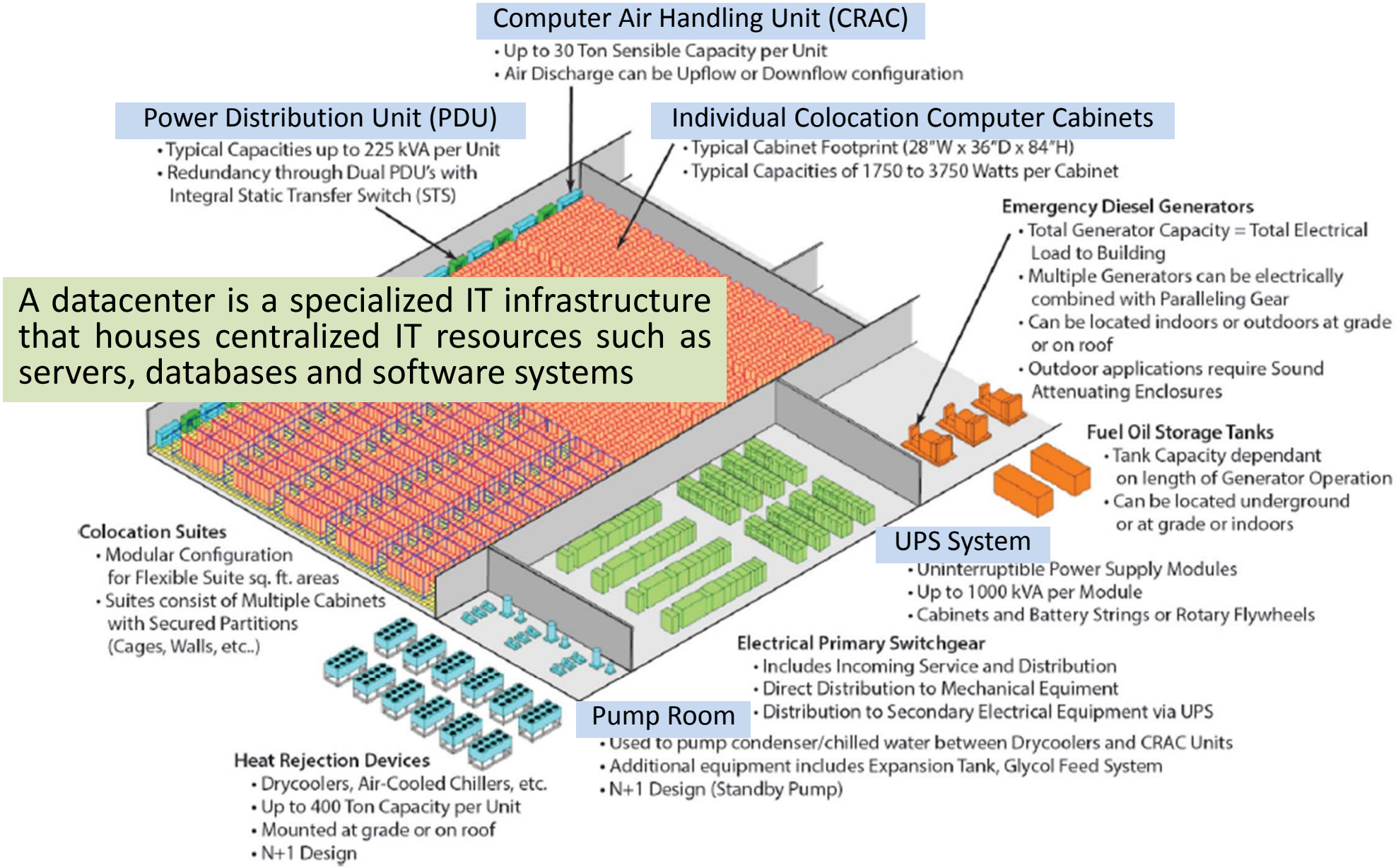
Public Cloud



On-premise vs Cloud-based

On-Premise IT Resources	Cloud-Based IT Resources
internal users access corporate IT services using **corporate** network	internal users access corporate IT services using **Internet** connection
while roaming in external networks, internal users access corporate IT services using **corporate Internet** connection	while roaming in external networks, internal users access corporate IT services using **cloud provider's Internet** connection
external users access corporate IT services using **corporate Internet** connection	external users access corporate IT services using **cloud provider's Internet** connection

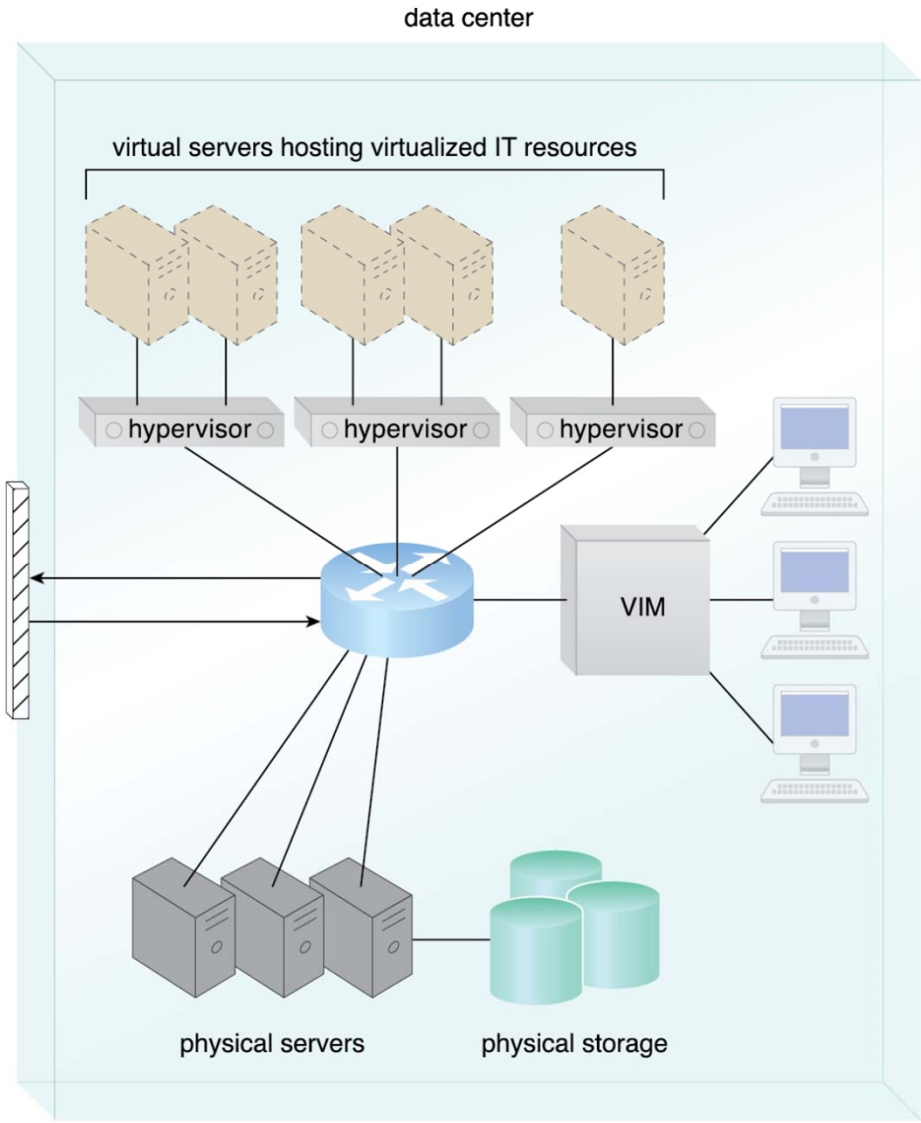
Main Components in a Datacenter



Main Components in a Datacenter

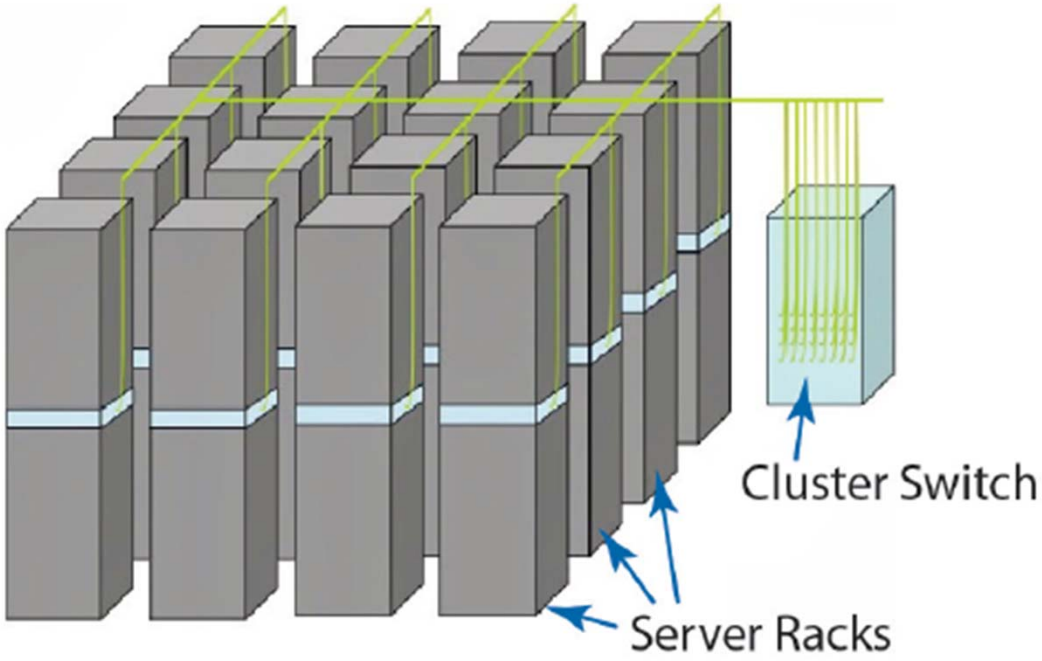
- Server
- Storage
- Interconnection network

- Cooling systems and energy
- Fire protection
- Security



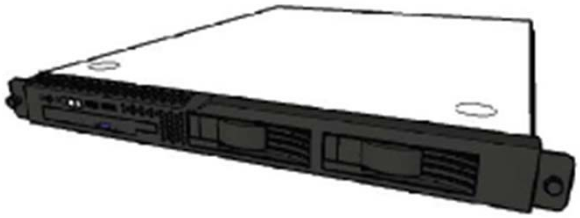
Standardized Commodity Hardware
Typical Modular Server Rack

Why?



42U Server Rack

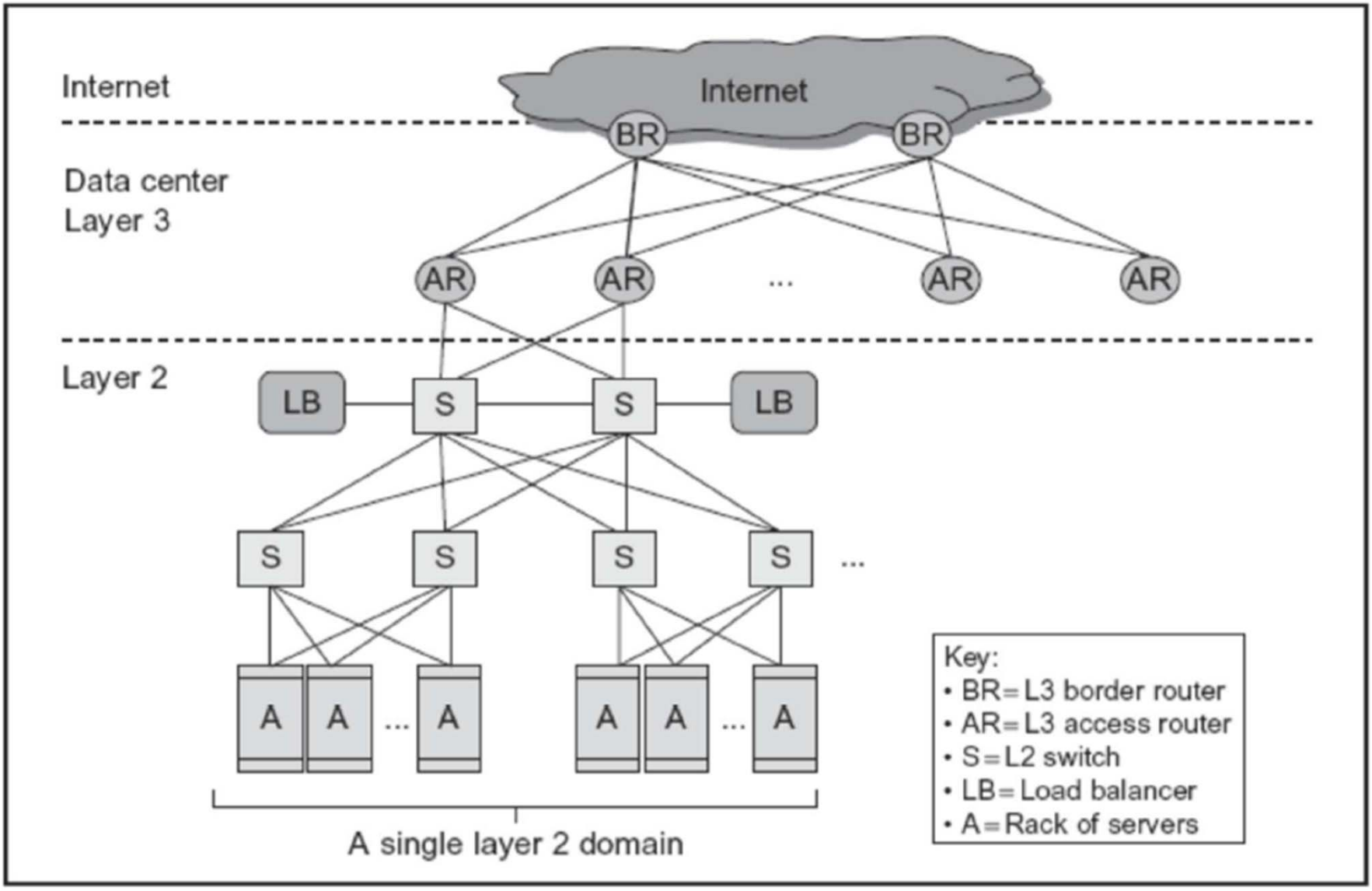
1U Server (1.75 inches or 44.45mm)



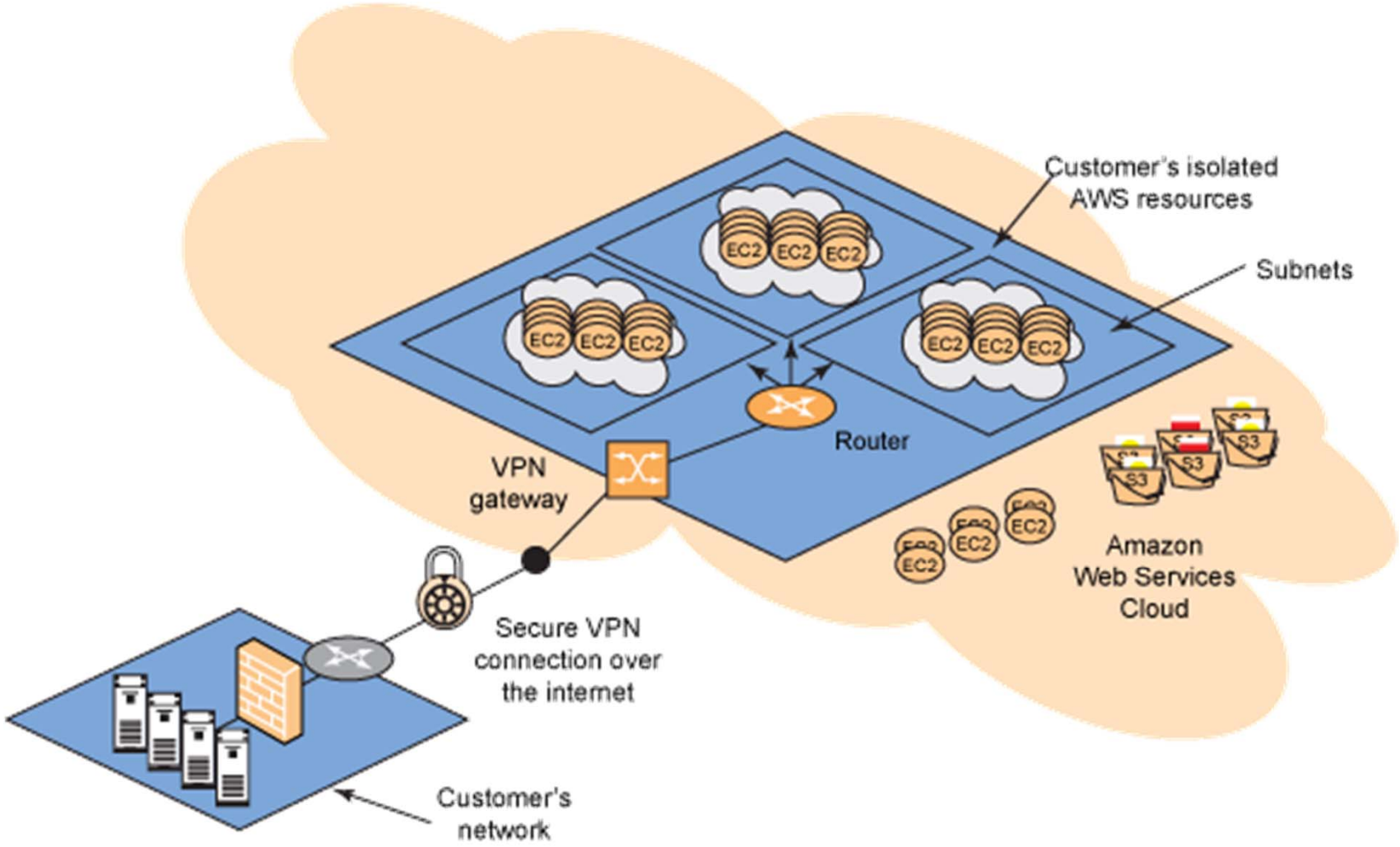
Interconnection Network

- carrier interconnection
  - between external WAN and datacenter LAN
- LAN fabric
  - high-performance (10Gbps)
  - redundant connectivity
- SAN fabric
  - between servers and storage systems (Fibre channel)

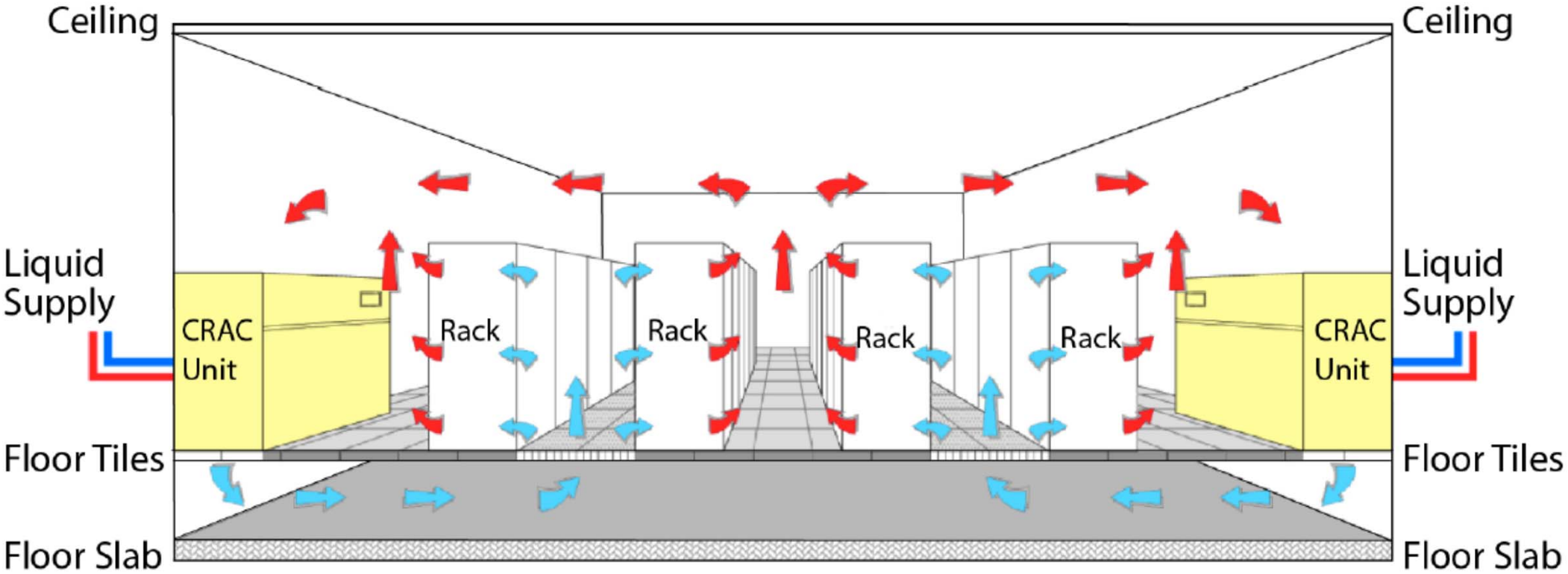
Networking in a Datacenter



Example: Amazon Virtual Private Cloud



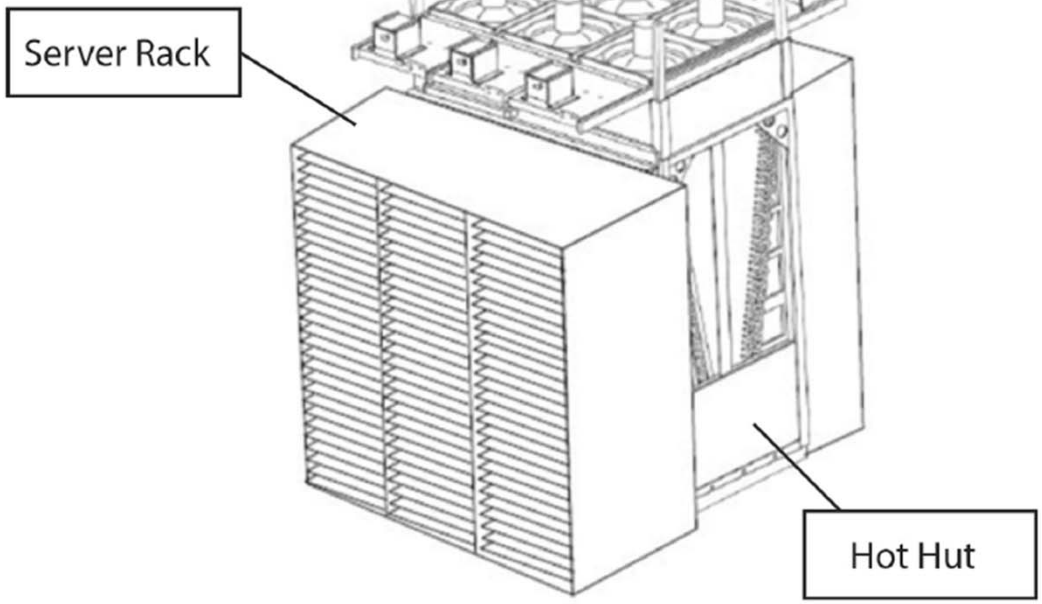
Cooling Systems

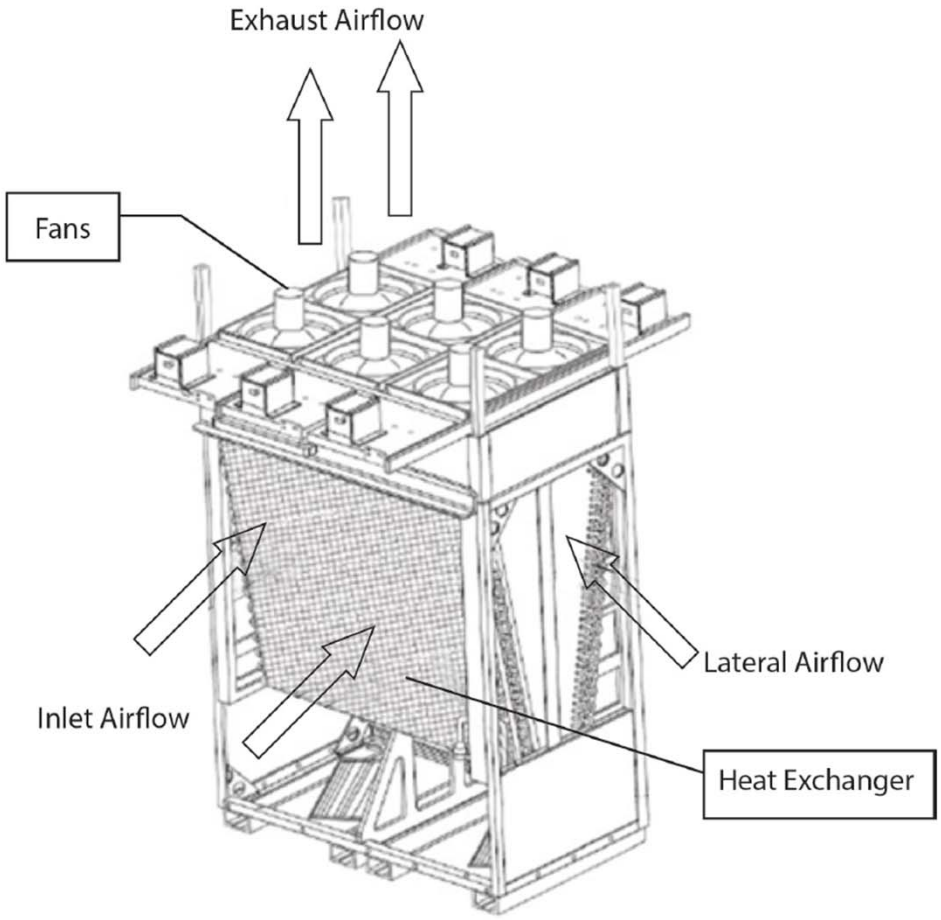


Cooling system in a raised-floor datacenter with hot-cold air circulation support water heat exchange facilities

CRAC (Computer Room Air Conditioning)

Example: Google's In-row Cooling



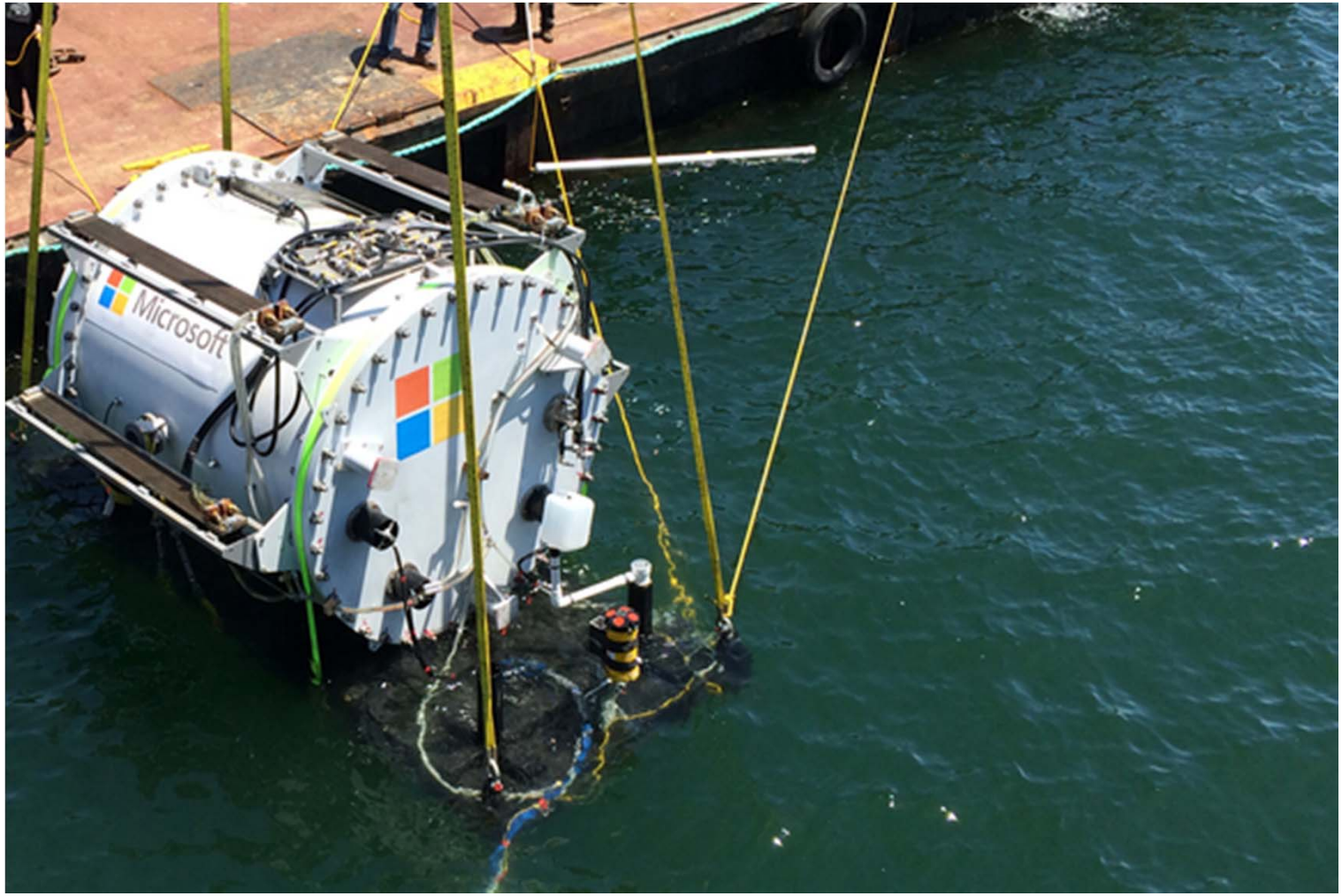


Google's Hot Hut
water-cooled fan unit

Google’s Container Based Datacenter

Microsoft Undersea Datacenter

natick.research.microsoft.com (Feb 1, 2016)



Power, UPS and Backup

Power Supply

UPS

Battery power backup

Fire Protection

FM200 Fire Suppression Tanks
Heptafluoropropane extinguishing agent HFC-227ea

Security & Monitoring

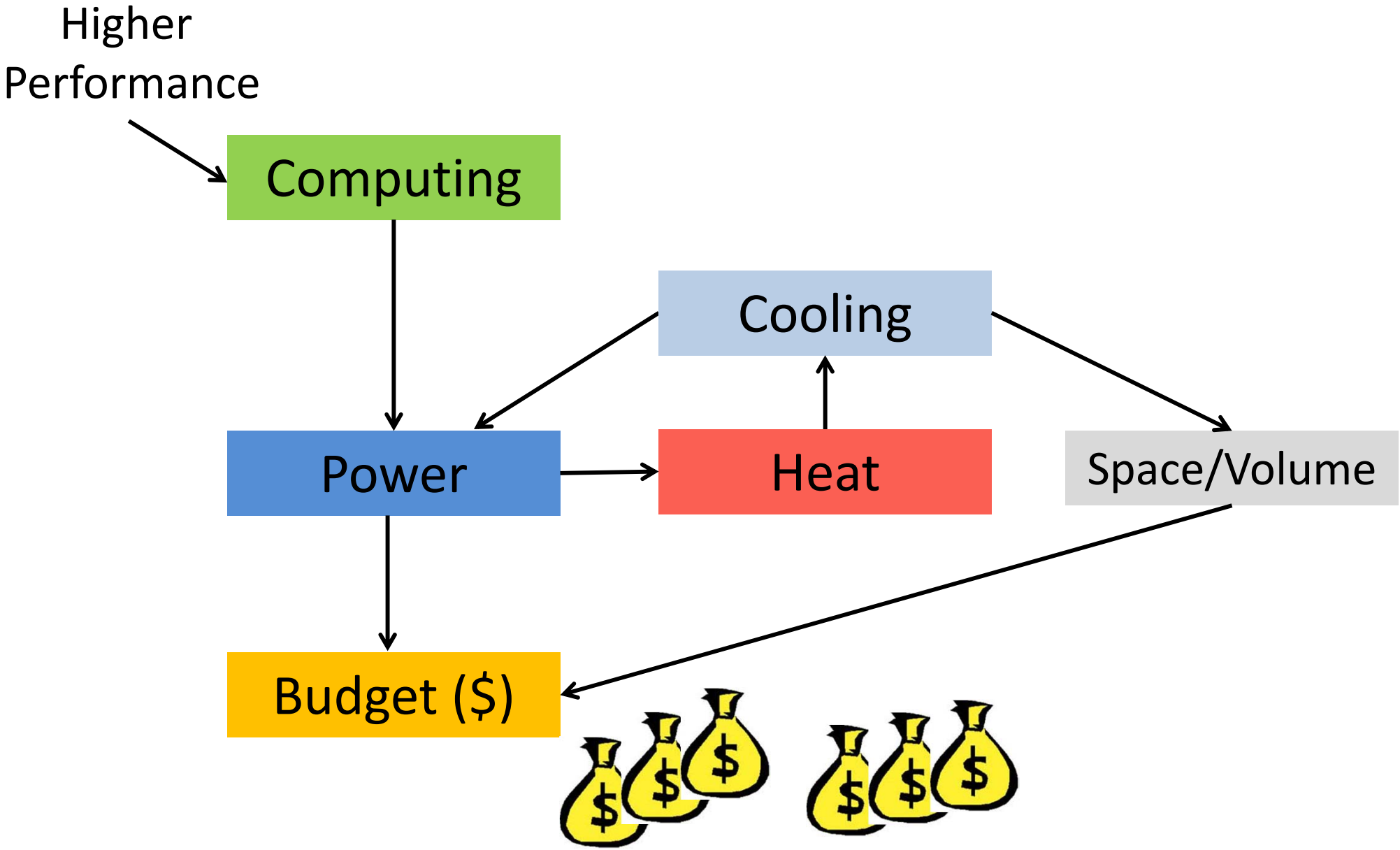
DATACENTER TIERS

- Tier I: a single path for power distribution, UPS, and cooling distribution, no redundant components
- Tier II: adds redundant components to this design (N + 1)
- Tier III: one active and one alternate distribution path for utilities
  - Each path with redundant components, concurrently maintainable
  - Redundancy even during maintenance
- Tier IV: two simultaneously active power and cooling distribution paths
  - Redundant components in each path
  - Tolerate any single equipment failure without impacting the load

increasing availability & cost

availability (downtime/yr)
99.671% (29hrs)
99.741% (23hrs)
99.982% (1.5hrs)
99.995% (0.5hrs)

Why Power Matters



Energy Use of Data Centers

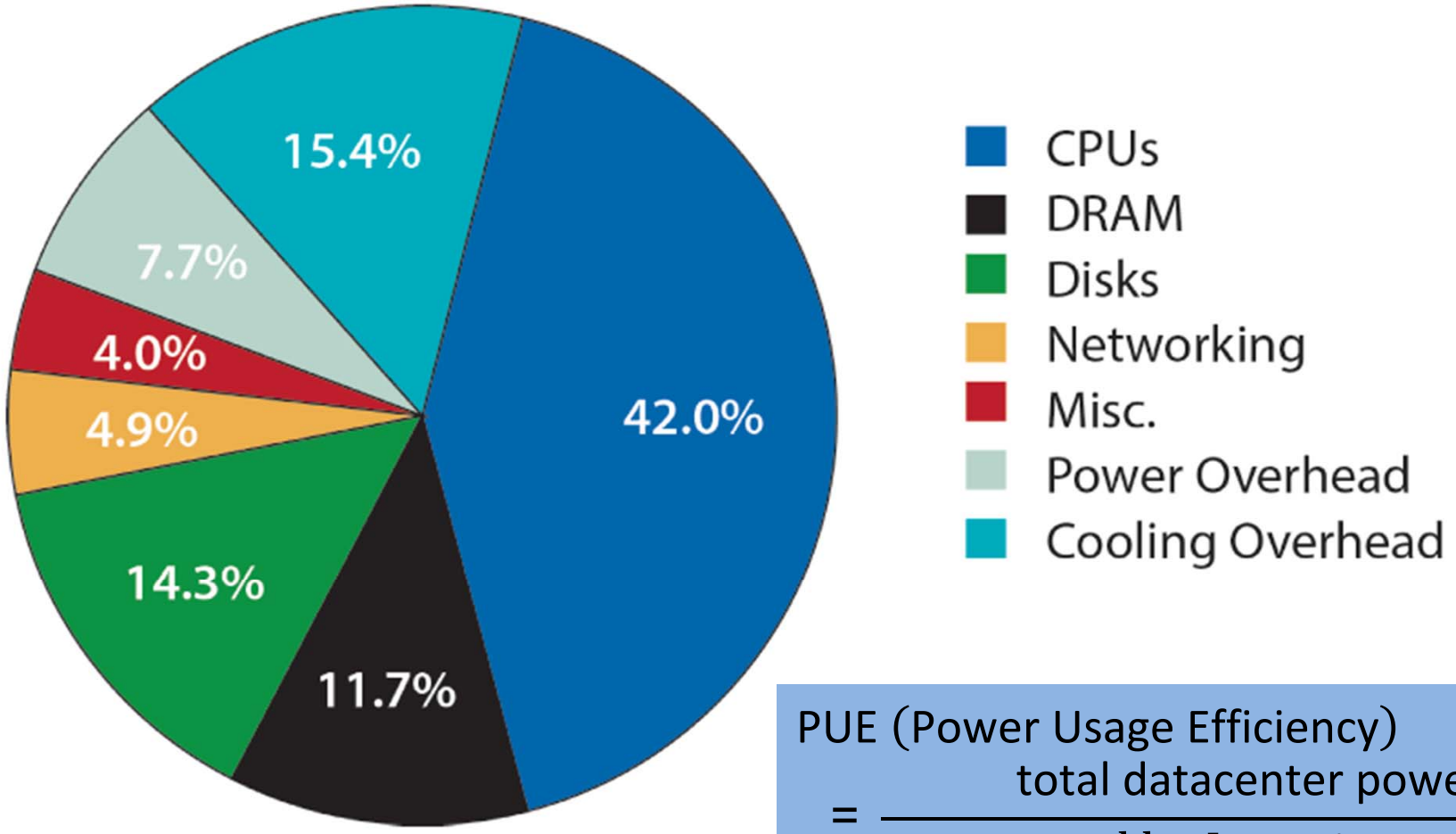
- Energy consumption of large-scale data centers and their costs for energy and for cooling are significant
  - 2006 - 6,000 data centers in US consumed 61×10^9 KWh of energy, 1.5% of all electricity consumption, at a cost of $4.5 billion
  - 2006-2011 - from 7 GW to 12 GW, 10 new power plants

- 1998-2007: performance of supercomputers (+7,000%) has increased 3.5 times faster than their operating efficiency (+2,000%)

- Operating efficiency of a system = *performance per Watt of power*

- Effort to reduce energy use is focused on computing, networking, and storage activities of a data center

Energy Usage and Power Efficiency

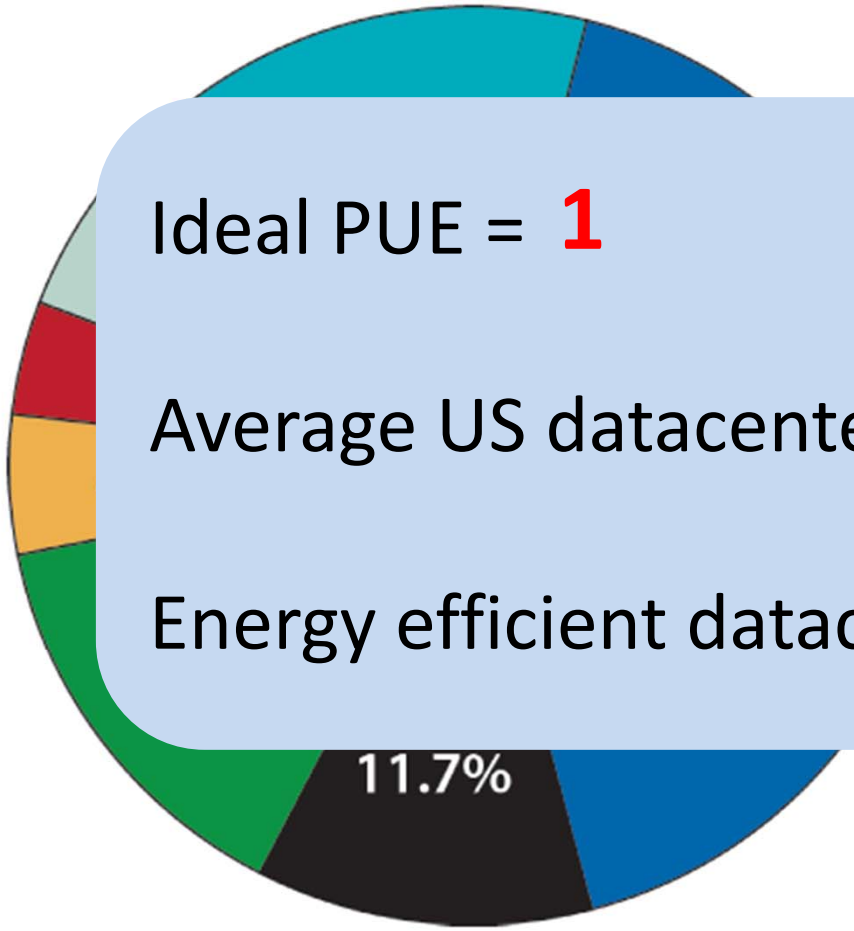


PUE (Power Usage Efficiency)

$$= \frac{\text{total datacenter power}}{\text{power used by IT equipment power}}$$

Barroso L.A., et al., The Datacenter as a Computer: An Introduction to the Design of Warehouse-Scale Machines, 2nd Edition, 2013 [2012 generation servers with facility energy overhead of 30%]

Energy Usage and Power Efficiency



Ideal PUE = **1**

Average US datacenter PUE = **2**

Energy efficient datacenter PUE = **1.2**

PUE (Power Usage Efficiency)

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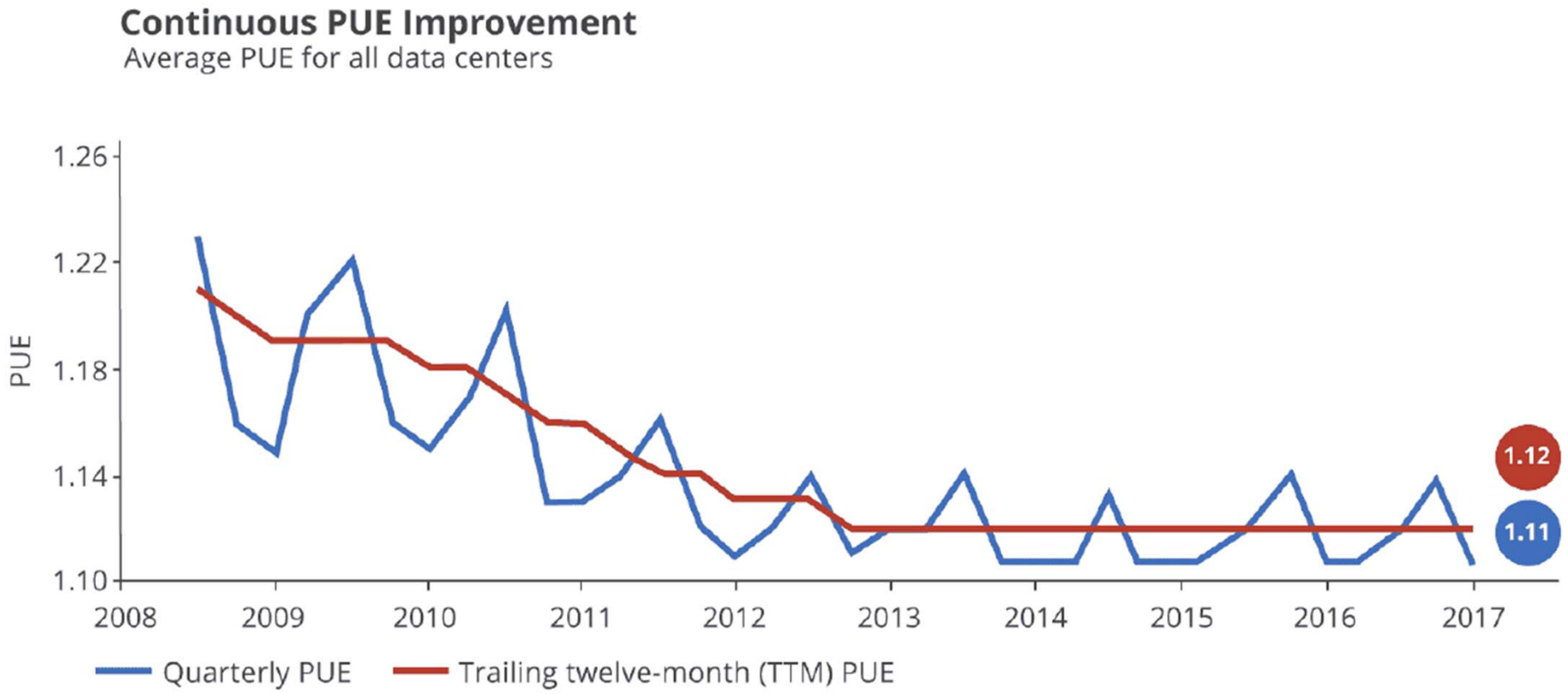
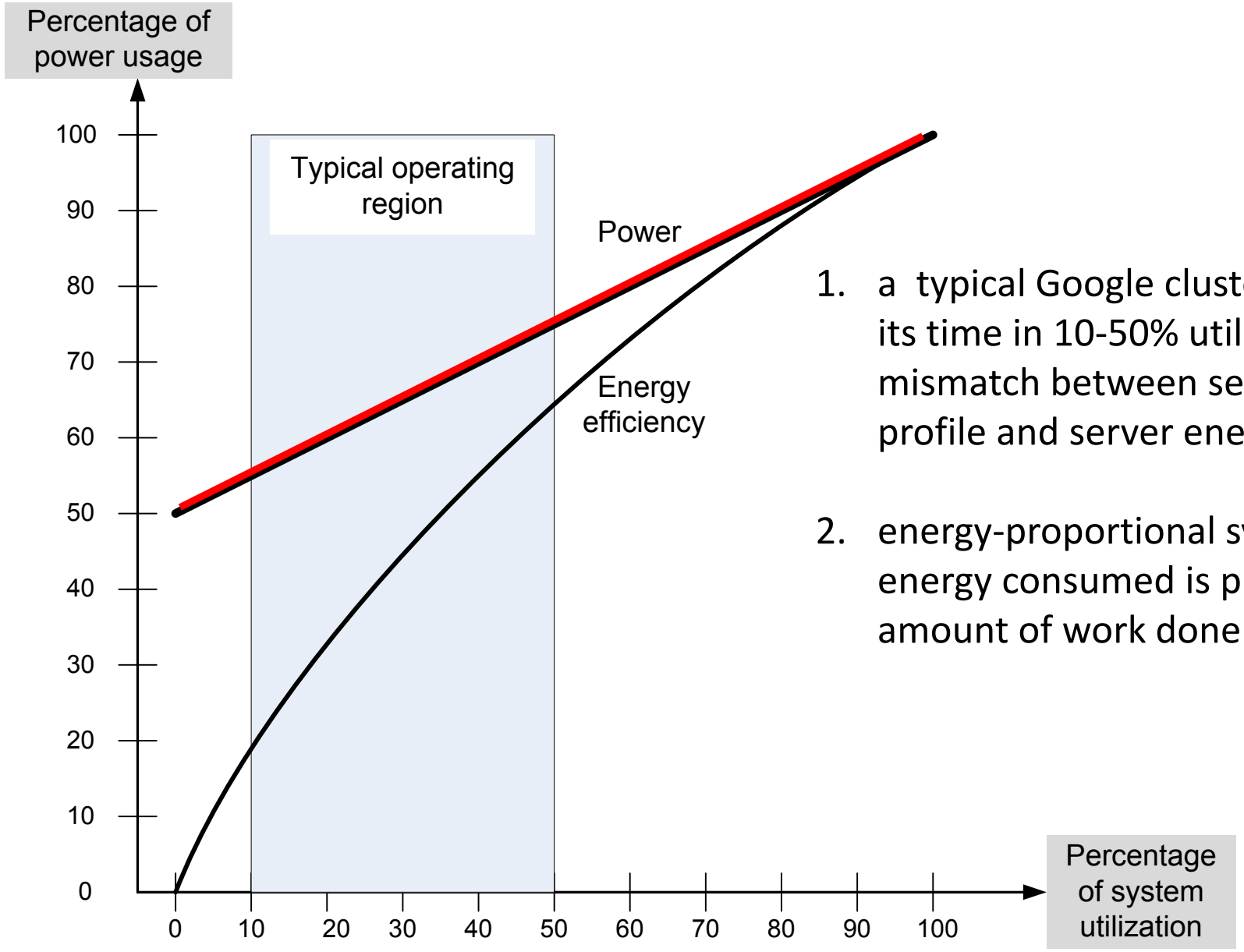
Google Datacenter PUE



System Utilization vs Percentage Power Usage



1. a typical Google cluster: spends most of its time in 10-50% utilization range - a mismatch between server workload profile and server energy efficiency

2. energy-proportional system (ideal): energy consumed is proportional to the amount of work done

Energy-proportional Systems

- Even when power requirements scale linearly with the load, energy efficiency is not a linear function of load; idle system use 50% power

- An energy-proportional system consumes no power when idle, very little power under a light load and, gradually, more power as the load increases

- **Dynamic power range**: low and upper range of the power consumption of a device
  - Processor (70%), DRAM (50%), disk drive (25%), network switches (15%), human(?%)
  - wide range is better

Human
- Idle (70W), average (120W), peak (1-2KW)
- Dynamic power range = 1 - 70/1000

VIRTUALIZATION

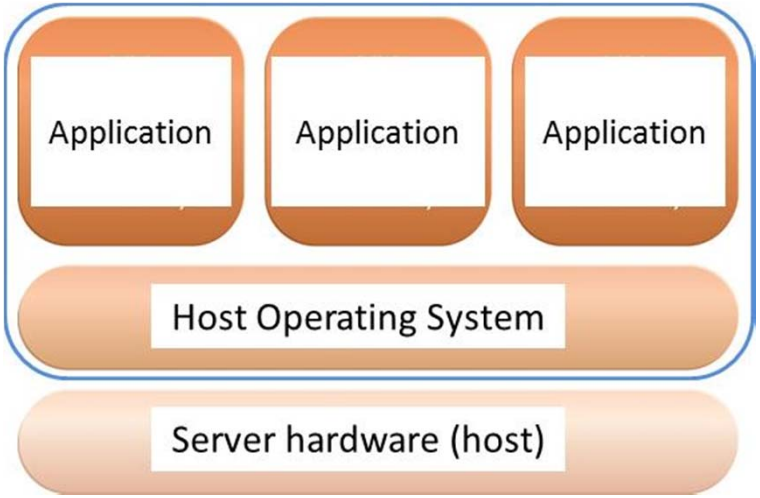
- converts *physical* IT resource into *virtual* IT resource
  - servers, storage, network
- E.g. virtual server, virtual machine (VM), Amazon instance
- Server virtualization – process of abstracting IT hardware into virtual servers using virtualization software
- virtualization software (for virtual machine management)
  - runs on physical server (also called *host* or *physical host*)
  - *Virtual Machine Manager (VMM)* or commonly as *Hypervisor*

Server Virtualization

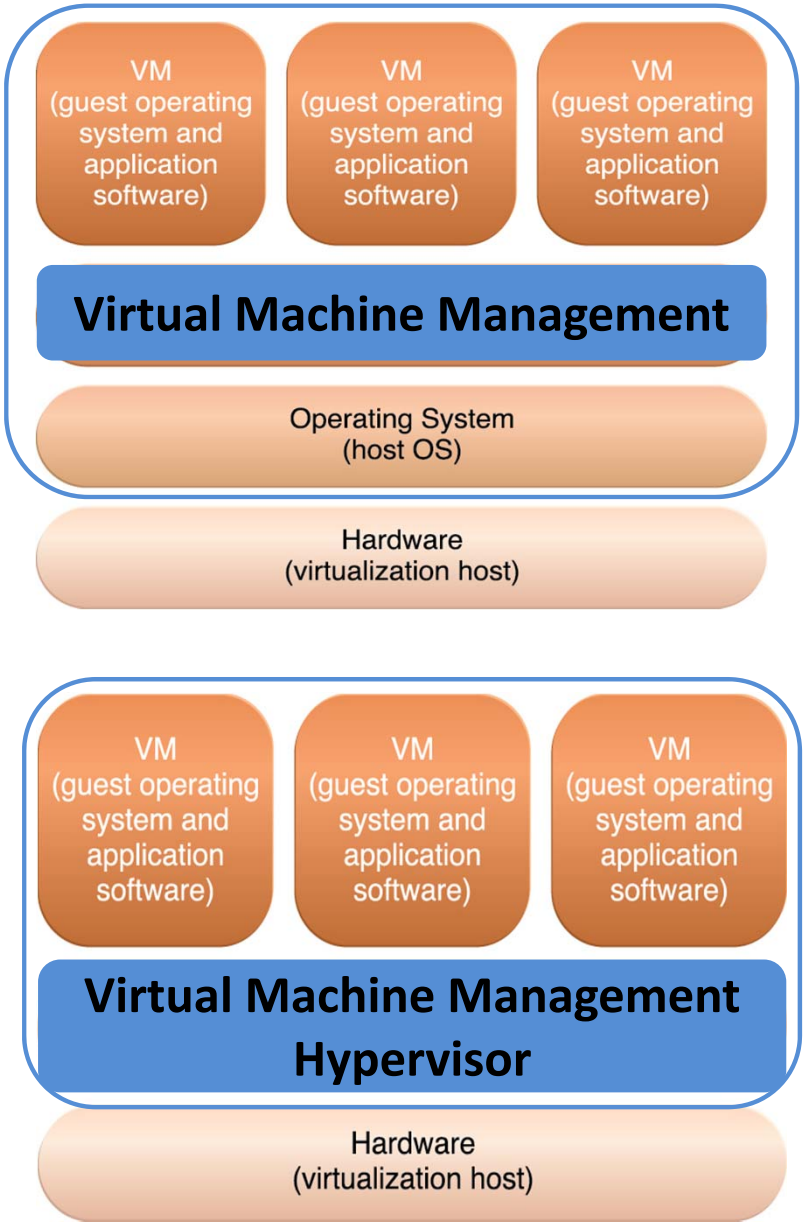
- advantages
  - **hardware independence**
    - traditional non-virtualized environment – software-hardware dependencies
    - virtualization - ease of movement to other hosts
  - **server consolidation**
    - different virtual servers share one physical server
    - increase hardware utilization, load balancing, …
    - flexibility to run different guest operating systems on the same physical server
  - **resource replication**
    - virtual servers are created as virtual disk images (with binary copies of hardware content)
    - virtual images are accessible to the host's operating system, agility in migration and to deploy new instances (rapid scaling)

- types of virtualization: operating system-based and hardware-based

Server Virtualization

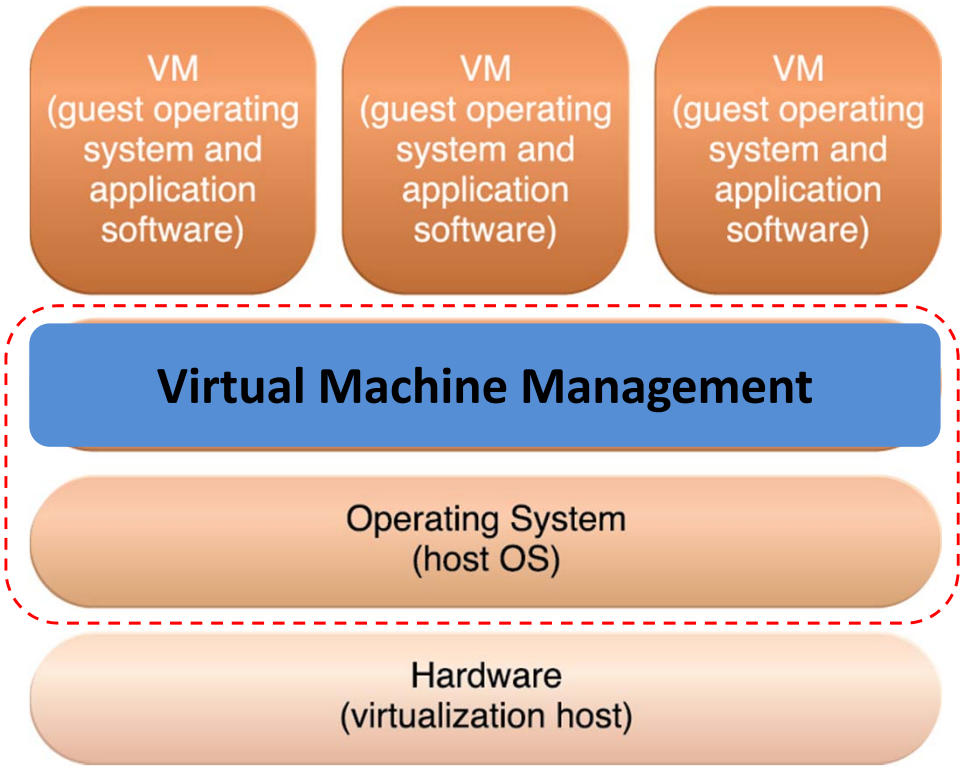


Before Virtualization



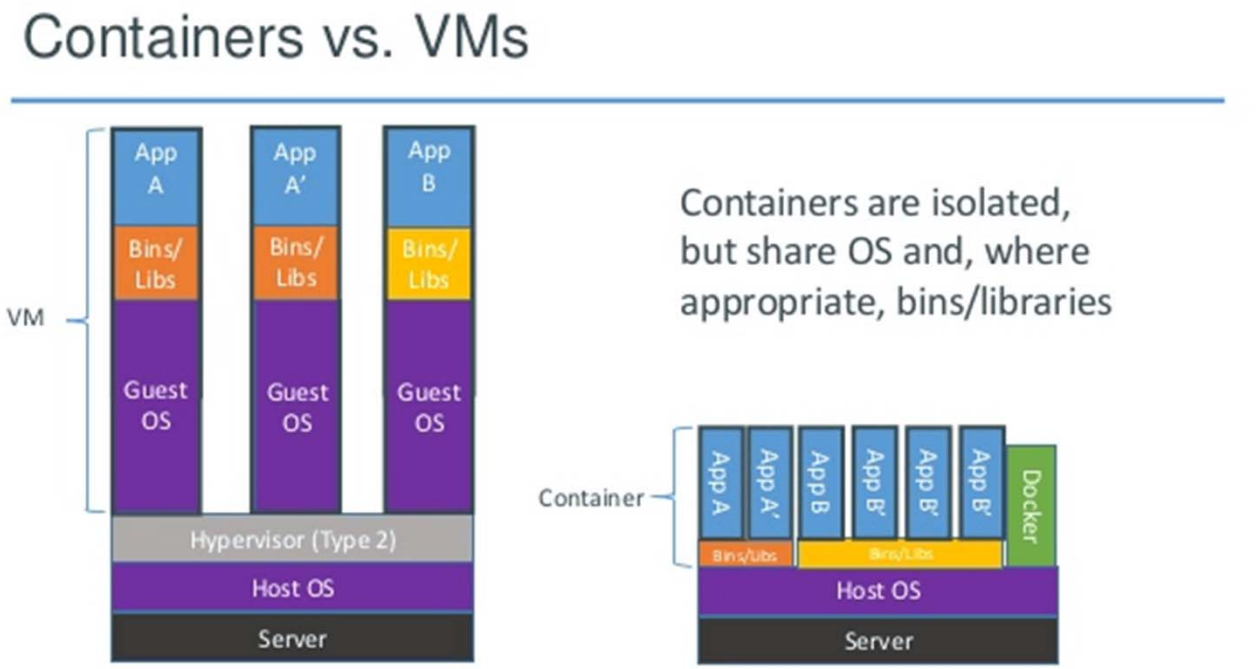
After Virtualization

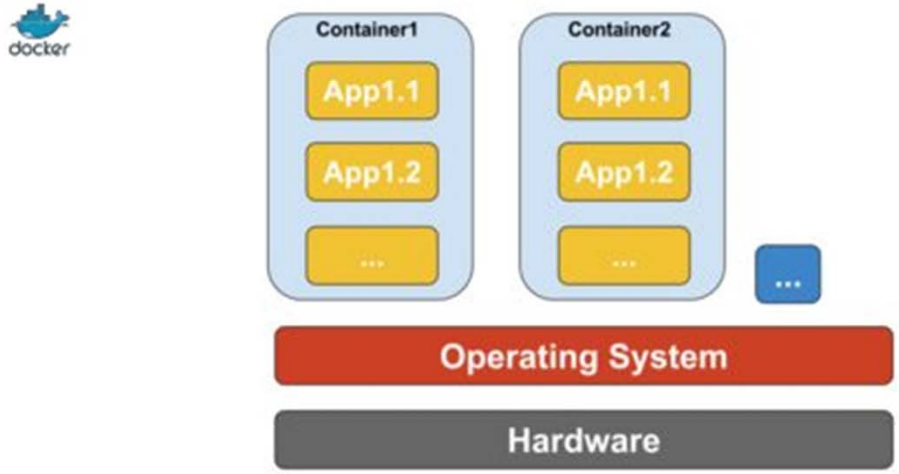
Operating System-based Virtualization



- virtualization software installed on a pre-existing OS (also called the host OS)
- Advantages
  - hardware resources can be used more flexibly
  - host OS enables backup & recovery, security management
- Disadvantages
  - host OS consumes resources
  - overhead in executing guest OS system calls
  - host OS license needed

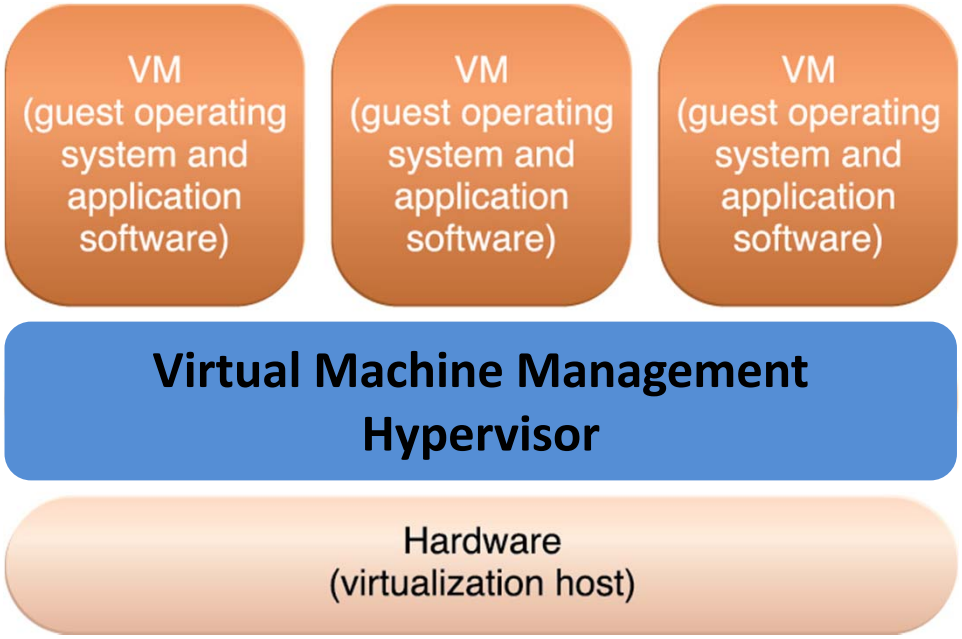
Operating-system based Virtualization





Containers or operating-system level virtualization

Hardware-Based Virtualization



- virtualization software directly installed on physical host hardware
- advantages
  - more efficient with VMs interact directly with hardware
  - Multiple (different) guest OS can interact with the same hardware
- disadvantages
  - compatibility with hardware devices – associated device drivers and support software need to be compatible with hypervisor

Virtualization in Clouds

- VMMs:
  - OS-based
    - VMware Workstation, Oracle VirtualBox, KVM (Kernel based Virtual Machine)
  - HW-based
    - Citrix: XenServer virtual infrastructure (XS-C) , Citrix Cloud Center (C3)
    - IBM: PowerVM and z/VM
    - Microsoft: Hyper-V
    - Symantec: Veritas Virtual Infrastructure (VxVI) Solution
    - Oracle: Open Solaris virtualization xVM
    - VMWare: VMware ESXi

- Virtualization Infrastructure Management (VIM) tools
  - Collectively manage virtual IT resources
  - Rely on centralized management module
    - Controller: runs on a dedicated computer

- Interoperability among clouds
  - Open Virtualization Format (OVF)

Types of Virtualization in Clouds

- Machine virtualization
  - VMMs
- Network virtualization
  - Combines hardware and software network resources and network functionality into a single, software-based administrative entity
- Storage virtualization
  - Enables storage management: administrators pool storage resources
  - Resources can be organized, allocated, and managed without regard for their physical location
  - Offers ease of deployment, though it typically relies on the availability of host servers or intelligent switches

Disadvantages of Virtualization

- Performance overhead
  - Not suitable for systems with high workload and little resource sharing and replication
- Special hardware compatibility
  - Hardware may not have drivers for virtualization software
  - Software not compatible with recent hardware
- Portability
  - Incompatibilities among virtualization solutions
- Security
  - Traditional intrusion detection may not work
  - Virtual-aware malware
  - Multiple users on the same physical hardware

MULTITENANCY

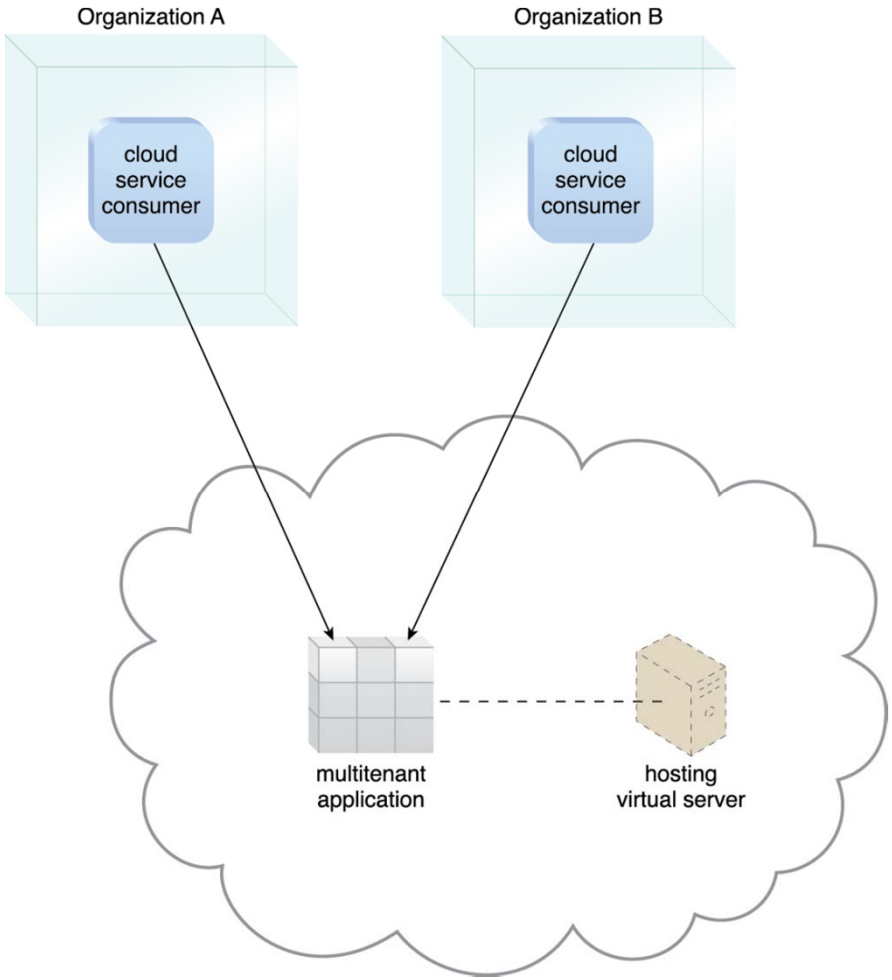
- enable multiple users (tenants) to access the same application
  - customized view and dedicated instance of software
  - tenants isolation ensures that tenants do not have access to data and configuration information that it do not own

- customization for each tenant
  - user interface: specific “look and feel”
  - business process: rules, logic, workflows
  - data model: extend add/remove/rename fields of data structures
  - access control: independent control of rights for users/groups

Characteristics of Multitenancy

- usage isolation – a tenant behavior does not affects other tenants
- data security – separate procedures for each tenant
- recovery - backup, restore
- scalability
  - increase in usage by existing tenants
  - increase in number of tenants
- metered usage – each tenant charged only for features being used
- data tier isolation – databases, tables, schemas can be isolated or allowed as shared resources among tenants

Multitenant Application in a Typical SaaS



- A multitenant application serves multiple cloud service consumers simultaneously
- Multitenancy vs virtualization? Multitenancy - dedicated consumer instance of software vs virtualization - abstraction of physical resources

Summary

- importance of Internet in resource hosting
- components of datacenters
  - hardware: computing, storage, network, cooling
- virtualization
  - abstracting physical resources into virtual resources
  - offers hardware independence, server consolidation, resource replication
- multitenant applications
  - allow per-user customization, data isolation and security

References

- Chapter 5 and Appendix D, Cloud Computing: Concepts, Technology and Architecture, Thomas Erl, Zaigham Mahmood and Ricardo Puttini, Prentice-Hall, 2013.

- Chapters 3 & 4, The Datacenter as a Computer: An Introduction to the Design of Warehouse-Scale Machines, Second Edition. Synthesis Lectures on Computer Architecture, Luiz André Barroso, Jimmy Clidaras, Urs Hölzle, Morgan & Claypool Publishers, 2013.

- Efficiency: How we do it, Google Datacenters, July 2017.

- Data Centres Shine Amid Property Gloom, Straits Times, Jan 12, 2016.

- Building Data Centres at Sea An Idea Worth Floating, Straits Times, May 2017.

- Supplementary slides L03S – organization of SoC datacenter

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