UMD DATA605 - Big Data Systems
Cloud Computing

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with thanks to Alan Sussman,
Amol Deshpande

Outline

- Cloud computing
- Technologies behind cloud computing
    - Data centers
    - Virtualization
    - Programming frameworks
- Challenges and opportunities

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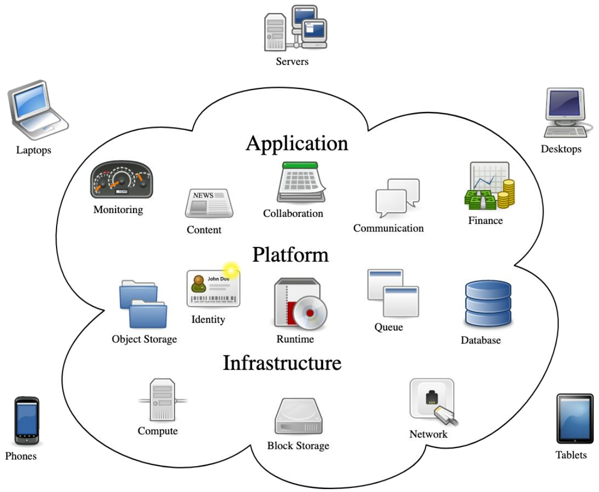
- **Cloud computing**
- Technologies behind cloud computing
  - Data centers
  - Virtualization
  - Programming frameworks
- Challenges and opportunities

Cloud Computing

- **Computing as "service" rather than "product"**
  - Everything happens in the cloud: both storage and computing
  - Edge devices (e.g., phones, laptops, tablets) simply interact with the cloud
- **Advantages of cloud computing**
  - Device agnostic: computation can seamlessly move from one device to other
  - On demand
  - Efficiency / scalability
    - Programming frameworks (e.g., Hadoop, Spark, Dask) allow "easy" scalability
    - Increasing need to handle Big Data
  - Reliability
  - Cost: "pay-as-you-go" allows renting computing resources as needed
    - Cheaper (?) than building your own systems
    - Computing becomes a commodity (like electricity or water)

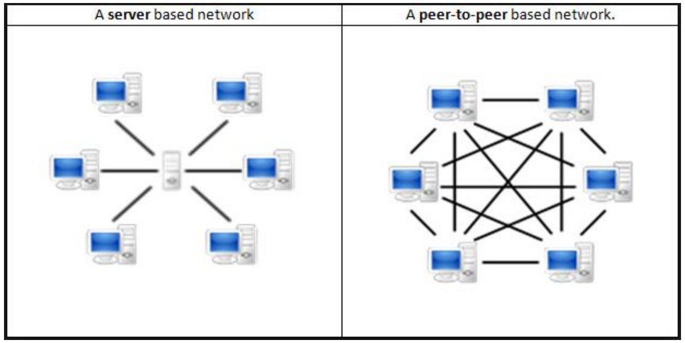


Building vs Renting

- **Building infrastructure**
  - Require time and capital investments (Capex)
    - Especially at the beginning when there aren't revenues
    - A smooth cash flow (constant $/mo) is better than lumpy one (big one-time purchase)
    - General finance phenomenon: credit cards, leasing cars, accounting
  - Buy hardware (e.g., computers, storage, network)
    - How do you estimate the size of your hardware for today?
    - Difficult to estimate future demands
  - Update hardware when it becomes obsolete
  - Cost of owning hardware (Opex)
    - E.g., data center, electricity, cooling, handling faulty
  - Administering
    - Installing, updating, maintaining software stack
- **Cloud computing**
  - Pay for what you use
    - Low initial capital investment
  - Get your systems with a click on a web-site
  - No need to estimate a multi-year resource plan
  - Pick machines that suit your application and data requirements

Cloud Computing

- **Basic ideas of cloud computing around for a long time (since 1960's)**
  - Mainframes + thin clients (more by necessity)
  - Grid computing for supercomputers (1990s)
  - Peer-to-peer architecture (early 2000s)
  - Client-server model (Web 1.0 and Web 2.0)
  - Cloud computing (2010s)
- **It finally works**
- **Why now? A convergence of several key technologies over the last few years**
  - OS virtualization
  - Large data centers
  - Decreasing hardware costs
  - Big data frameworks
- **Does it really work?**
  - Yes, but still growing pains and complexity



X-as-a-Service

Infrastructure-as-a-service (IaaS)

- Cloud provides low-level resources
- You install and maintain OS and applications
- E.g., AWS EC2

Platform-as-a-service (PaaS)

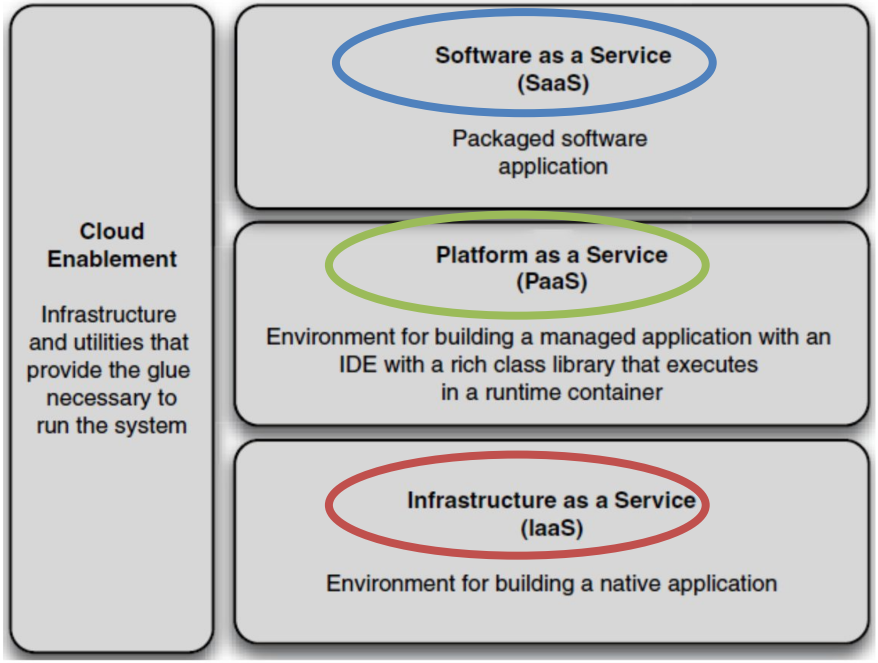
- Cloud provides OS and programming languages
- You build application on top of it
- E.g., Google App engine, managed Hadoop

Software-as-a-service (SaaS)

- Cloud provides the application
- You use it
- No need to install anything on your machine
- E.g., Dropbox, SalesForce, any app running in a browser

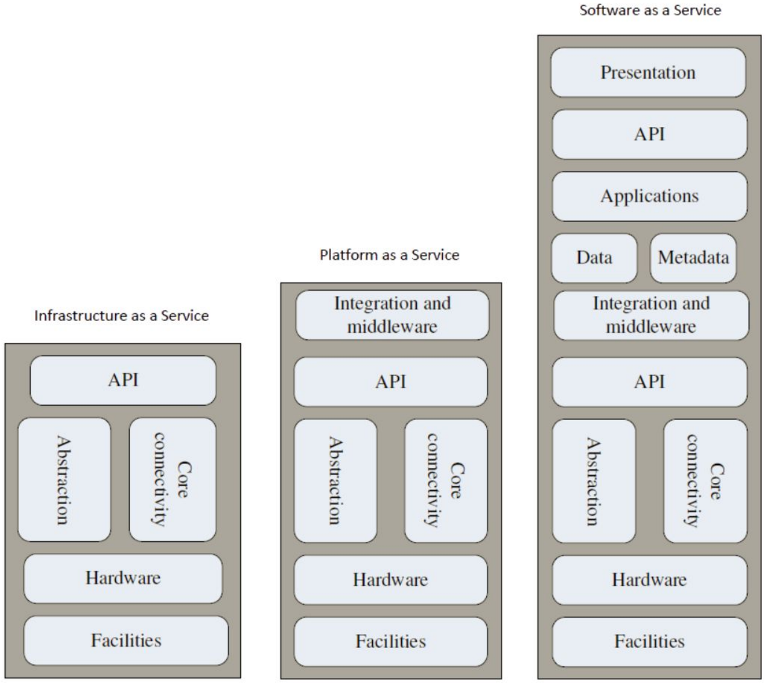
... XaaS

- Business model of “Anything-as-a-service”
- Desktop-as-a-service (e.g., AWS app)
- Mobility-as-a-service (e.g., Uber)
- Games-as-a-service (e.g., Google Stadia)
- Storage-as-a-service (e.g., S3, Google Drive)
- Marketing-as-a-service, Banking-as-a-service, ...


Cloud Enablement
Infrastructure and utilities that provide the glue necessary to run the system
Software as a Service (SaaS)
Packaged software application
Platform as a Service (PaaS)
Environment for building a managed application with an IDE with a rich class library that executes in a runtime container
Infrastructure as a Service (IaaS)
Environment for building a native application

Platform-as-a-Service

- **Problem: assembling your own software stack requires work**
  - Install
  - Configure
  - Manage dependencies
  - Incompatible versions
- **Solution: get a pre-built software stack**
  - Pre-installed OS
  - Libraries
  - Application software
  - As a virtualization solution
    - E.g., VMware or Docker
    - The software stack comes as a large file with the image of the system
- **Business model built around this**
  - E.g., pre-built images for Hadoop
    - E.g., Hortonworks, Cloudera
  - E.g., pre-built distributions for Linux
    - RedHat, Gentoo, CentOS

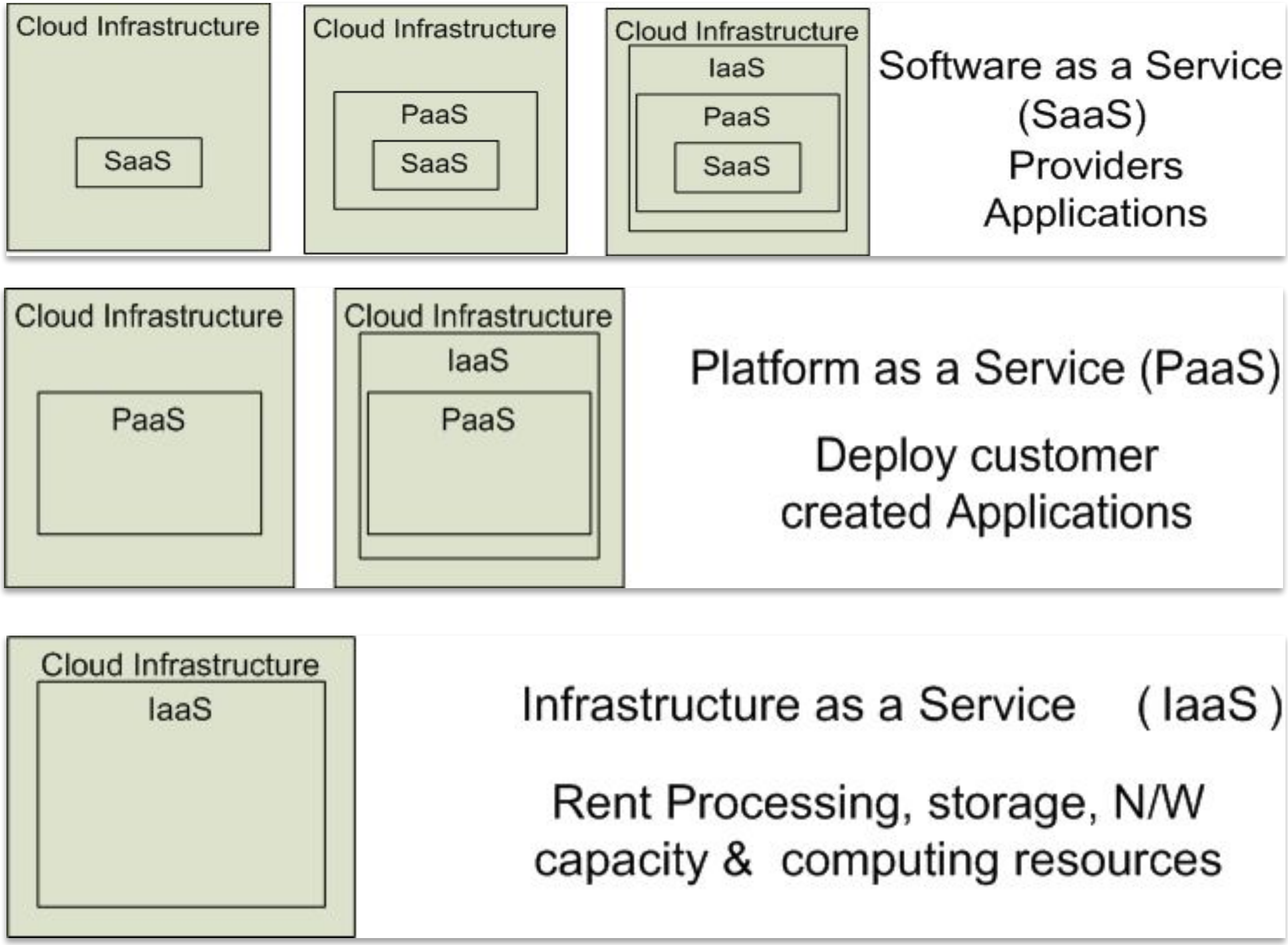


Cloud Service Models

Software-as-a-Service (SaaS)

Platform-as-a-Service (PaaS)

Infrastructure-as-a-Service (IaaS)



SalesForce CRM

LotusLive

Software as a Service (SaaS) Providers Applications

Google App Engine

Windows Azure
The Future Made Familiar

Platform as a Service (PaaS)

Deploy customer created Applications

amazon web services™

rackspace® HOSTING

Infrastructure as a Service (IaaS)

Rent Processing, storage, N/W capacity & computing resources

From Effectively and Securely Using the Cloud Computing Paradigm by Peter Mell & Tim Grance, NIST

Different Cloud Computing Layers

Application Service (SaaS)	Google Docs, Salesforce, Quicken Online, Zoho, ...*Pretty much everything on Internet*
Application Platform	Google App Engine, Heroku, AWS, Facebook
Server Platform	AWS EC2, Google Compute, Digital Ocean, Linode
Storage Platform	Amazon S3, Apple iCloud, Google Drive, DropBox, Box

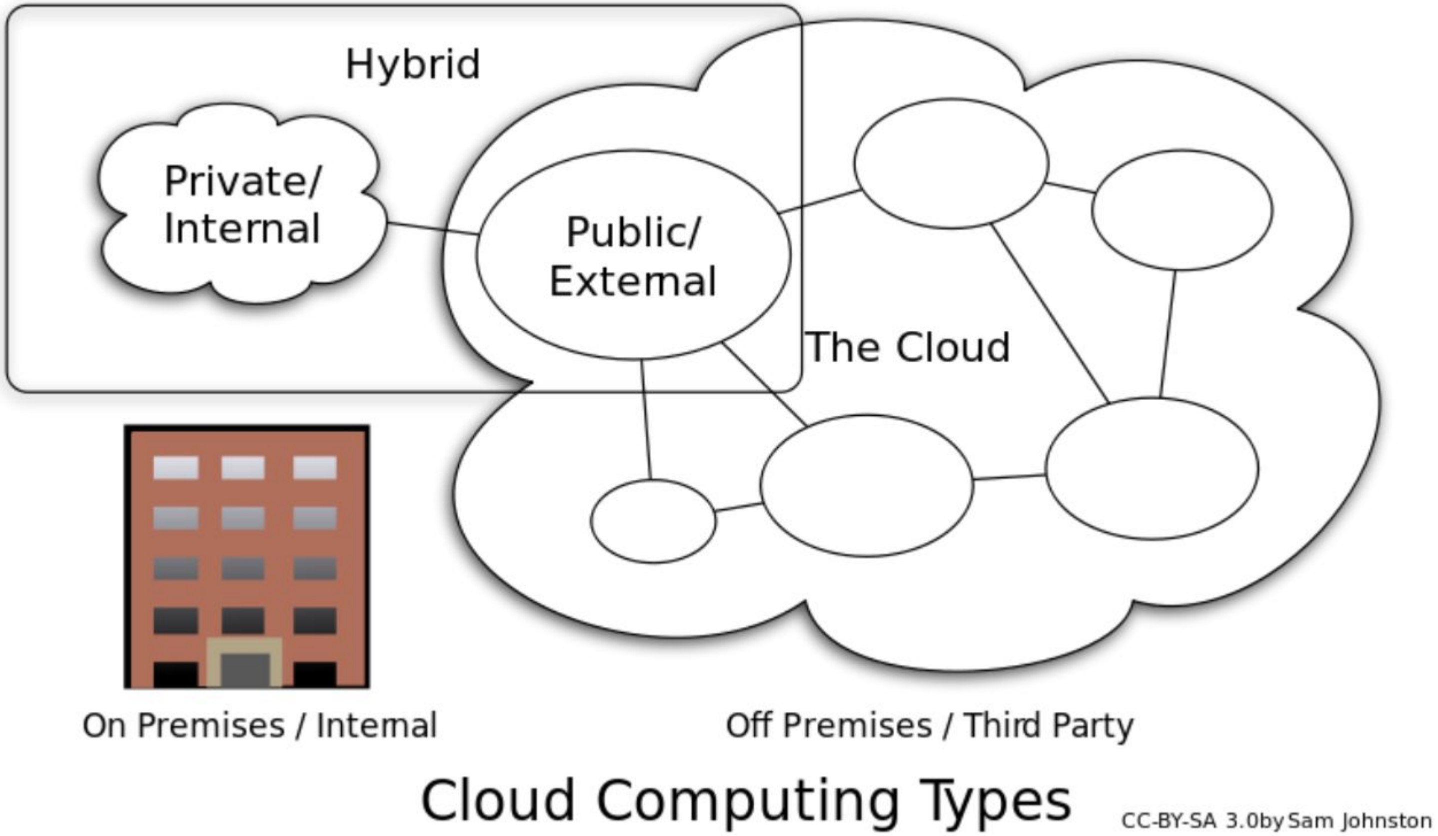
From Dr. Mehmet Gunes, U. Nevada Reno

Cloud Computing Service Layers

	Services	Description
Application Focused	Services	Services – Complete business services (e.g., PayPal, OpenID, OAuth, Google Maps, Alexa)
	Application	Application – Cloud based software that eliminates the need for local installation (e.g., Google Apps, Microsoft Office 365)
	Development	Development – Software development platforms used to build custom cloud based applications (PAAS & SAAS), e.g., SalesForce
Infrastructure Focused	Platform	Platform – Cloud based platforms, typically provided using virtualization (e.g., Amazon EC2, Google Compute)
	Storage	Storage – Data storage or cloud based NAS (e.g., AWS S3, Apple iCloud, CloudNAS, CTERA)
	Hosting	Hosting – Physical data centers (e.g., IBM, HP, DigitalOcean)

From Dr. Mehmet Gunes, U. Nevada Reno

Cloud Types

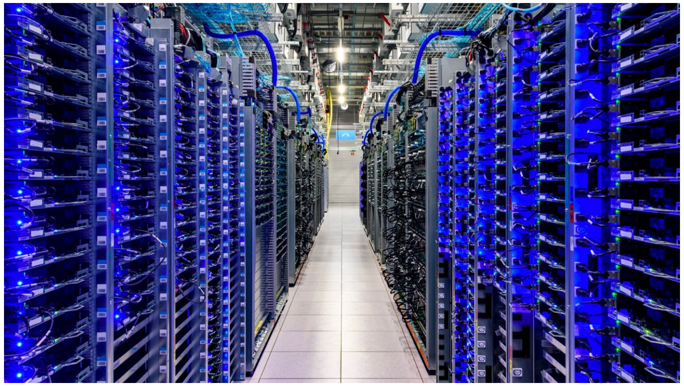
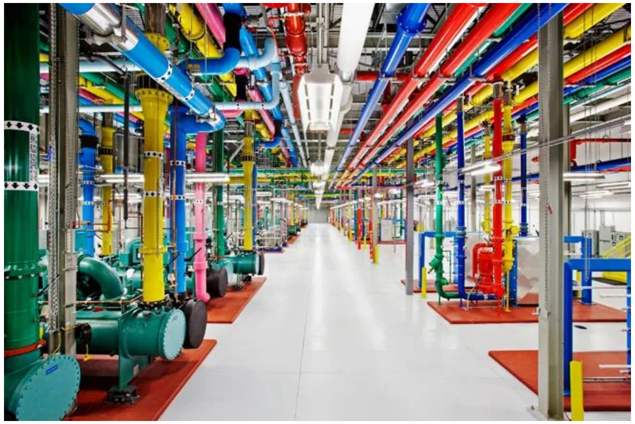

Hybrid
Private/ Internal
Public/ Extemal
The Cloud
On Premises / Intemal
Off Premises / Third Party
Cloud Computing Types
CC-BY-SA 3.0by Sam Johnston

Outline

- Cloud Computing
- Technologies behind cloud computing
  - **Data centers**
  - Virtualization
  - Programming Frameworks
- Challenges and opportunities

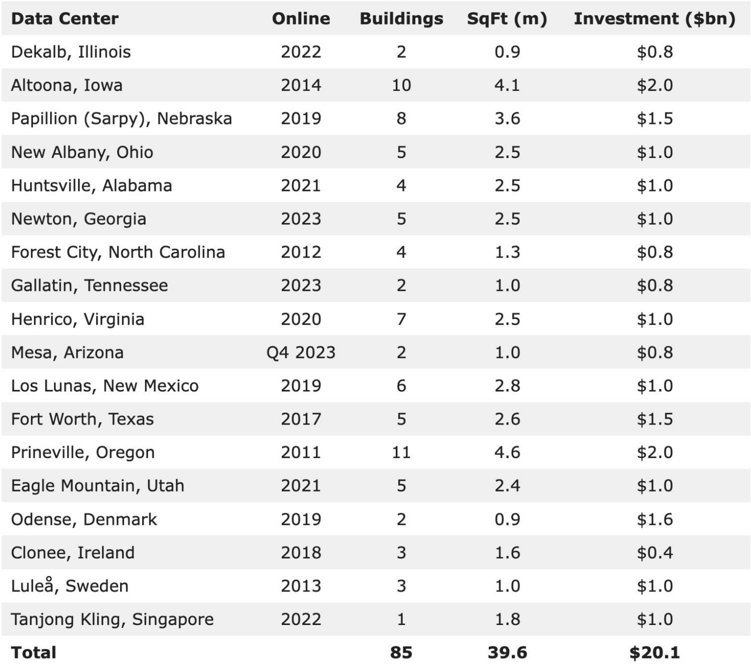
Data Centers

- Data centers are key infrastructure piece that enables cloud computing
  - Every large company (e.g., AWS, Apple, Google, Facebook) is building data centers around the world
- Huge amount of work on deciding how to build / design them
- Research on how to save energy to power and cool data centers

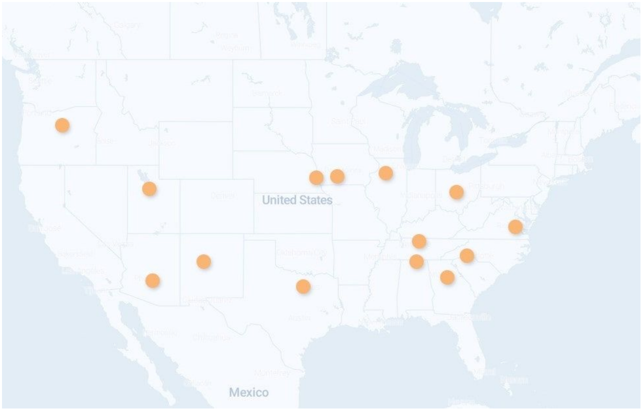
Data Centers

- **Equipment cost**
  - E.g., computing, memory, storage, networking
  - A data center costs around $1B
  - Very expensive, but prices keep dropping
- **Powering / cooling cost**
  - Cost of running the equipment
  - Cost of cooling is quite high
    - Both have led to focus on energy-efficient computing
  - Appropriate placement of vents is a key issue
    - Thermal hotspots often appear and need to worked around
  - PUE (Power Usage Effectiveness)
    - Measure of how much power is converted in computation, the rest is overhead
  - Hard to optimize in small data centers
    - Ideally PUE should be 1, currently numbers are around 1.07-1.22
    - May lead to very large data centers in near future (already happening)



Data Center	Online	Buildings	SqFt (m)	Investment ($bn)
Dekalb, Illinois	2022	2	0.9	$0.8
Altoona, Iowa	2014	10	4.1	$2.0
Papillion (Sarpy), Nebraska	2019	8	3.6	$1.5
New Albany, Ohio	2020	5	2.5	$1.0
Huntsville, Alabama	2021	4	2.5	$1.0
Newton, Georgia	2023	5	2.5	$1.0
Forest City, North Carolina	2012	4	1.3	$0.8
Gallatin, Tennessee	2023	2	1.0	$0.8
Henrico, Virginia	2020	7	2.5	$1.0
Mesa, Arizona	Q4 2023	2	1.0	$0.8
Los Lunas, New Mexico	2019	6	2.8	$1.0
Fort Worth, Texas	2017	5	2.6	$1.5
Prineville, Oregon	2011	11	4.6	$2.0
Eagle Mountain, Utah	2021	5	2.4	$1.0
Odense, Denmark	2019	2	0.9	$1.6
Clonee, Ireland	2018	3	1.6	$0.4
Luleå, Sweden	2013	3	1.0	$1.0
Tanjong Kling, Singapore	2022	1	1.8	$1.0
Total		**85**	**39.6**	**$20.1**

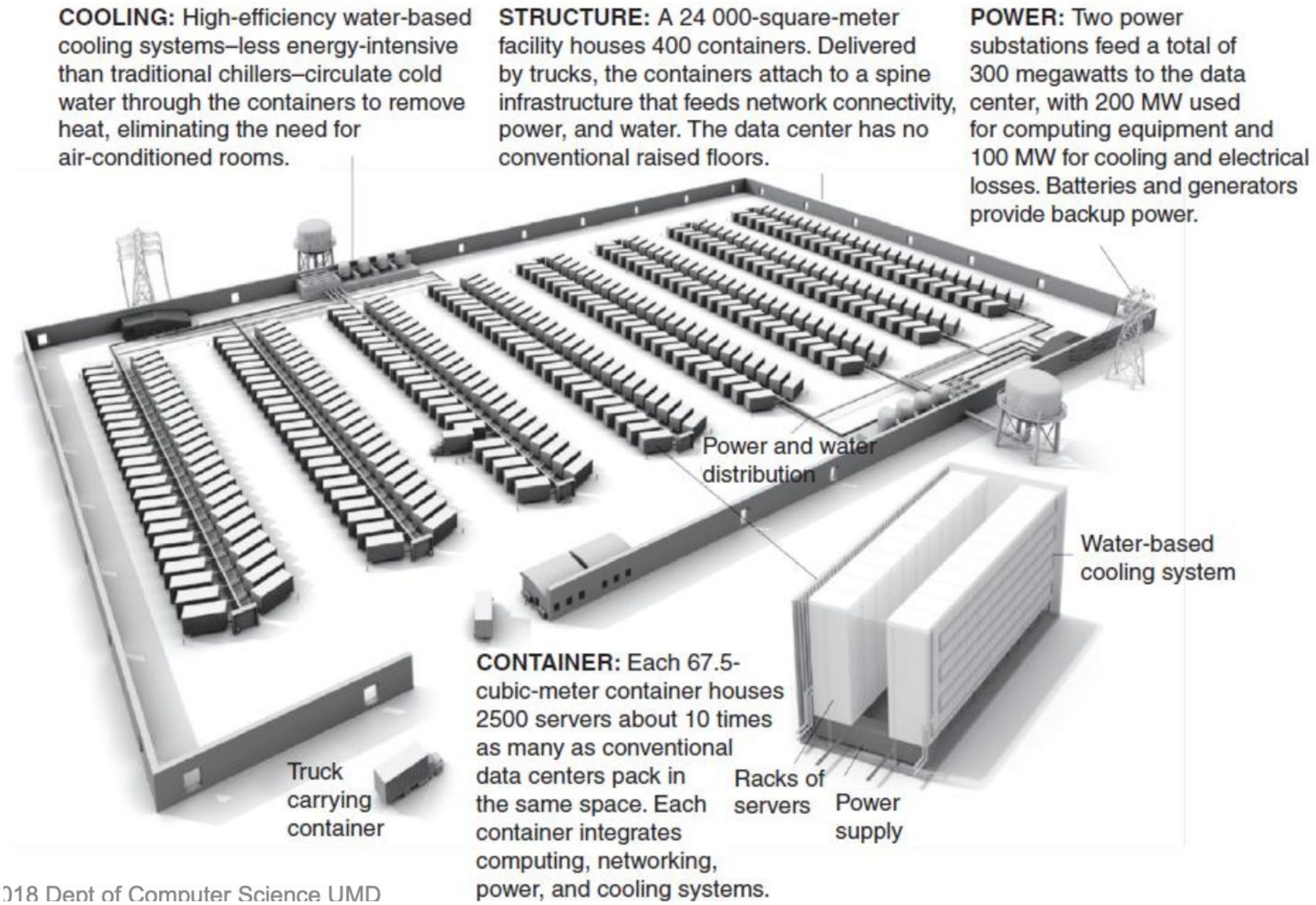
Meta investment in 18 data centers



From James Hamilton Presentation

Data Centers

(Modular) Data Centers



COOLING: High-efficiency water-based cooling systems–less energy-intensive than traditional chillers–circulate cold water through the containers to remove heat, eliminating the need for air-conditioned rooms.

STRUCTURE: A 24 000-square-meter facility houses 400 containers. Delivered by trucks, the containers attach to a spine infrastructure that feeds network connectivity, power, and water. The data center has no conventional raised floors.

POWER: Two power substations feed a total of 300 megawatts to the data center, with 200 MW used for computing equipment and 100 MW for cooling and electrical losses. Batteries and generators provide backup power.

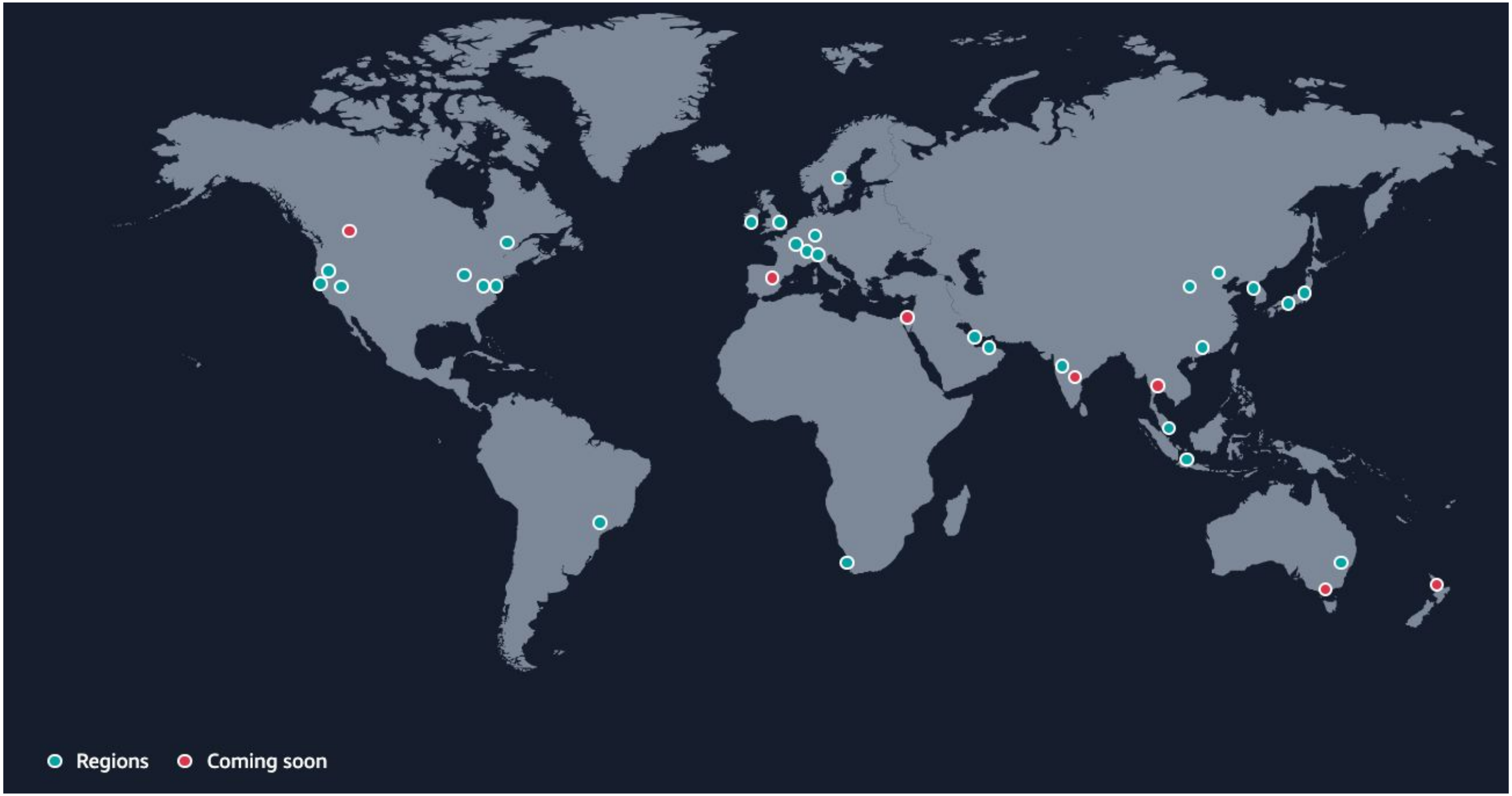
CONTAINER: Each 67.5-cubic-meter container houses 2500 servers about 10 times as many as conventional data centers pack in the same space. Each container integrates computing, networking, power, and cooling systems.

)18 Dept of Computer Science UMD

From James Hamilton Presentation

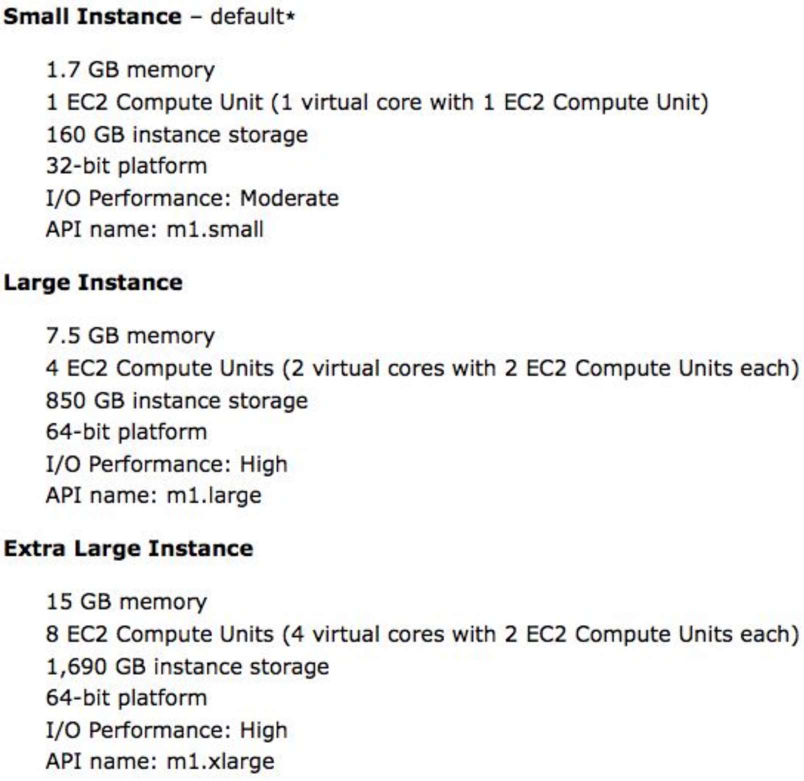
Amazon Web Services

As of 2022, 28 geographical regions



Amazon Web Services (EC2)

- The most widely used current solution to cloud computing
  - However alternatives are attractive depending on your needs
  - Current prices are very “low” and likely to remain that way
  - See https://aws.amazon.com/ec2/pricing/on-demand/ for current on-demand pricing



Small Instance – default*

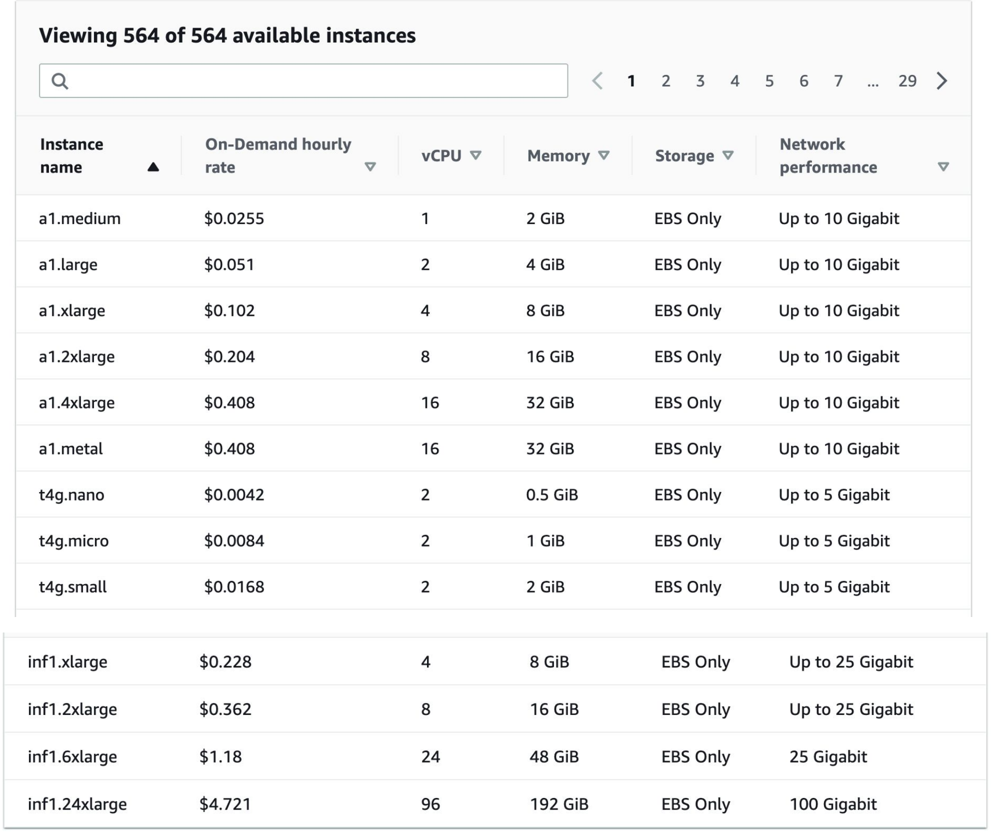
1.7 GB memory
1 EC2 Compute Unit (1 virtual core with 1 EC2 Compute Unit)
160 GB instance storage
32-bit platform
I/O Performance: Moderate
API name: m1.small

Large Instance

7.5 GB memory
4 EC2 Compute Units (2 virtual cores with 2 EC2 Compute Units each)
850 GB instance storage
64-bit platform
I/O Performance: High
API name: m1.large

Extra Large Instance

15 GB memory
8 EC2 Compute Units (4 virtual cores with 2 EC2 Compute Units each)
1,690 GB instance storage
64-bit platform
I/O Performance: High
API name: m1.xlarge



Viewing 564 of 564 available instances

Instance name ▲	On-Demand hourly rate ▽	vCPU ▽	Memory ▽	Storage ▽	Network performance ▽
a1.medium	$0.0255	1	2 GiB	EBS Only	Up to 10 Gigabit
a1.large	$0.051	2	4 GiB	EBS Only	Up to 10 Gigabit
a1.xlarge	$0.102	4	8 GiB	EBS Only	Up to 10 Gigabit
a1.2xlarge	$0.204	8	16 GiB	EBS Only	Up to 10 Gigabit
a1.4xlarge	$0.408	16	32 GiB	EBS Only	Up to 10 Gigabit
a1.metal	$0.408	16	32 GiB	EBS Only	Up to 10 Gigabit
t4g.nano	$0.0042	2	0.5 GiB	EBS Only	Up to 5 Gigabit
t4g.micro	$0.0084	2	1 GiB	EBS Only	Up to 5 Gigabit
t4g.small	$0.0168	2	2 GiB	EBS Only	Up to 5 Gigabit
inf1.xlarge	$0.228	4	8 GiB	EBS Only	Up to 25 Gigabit
inf1.2xlarge	$0.362	8	16 GiB	EBS Only	Up to 25 Gigabit
inf1.6xlarge	$1.18	24	48 GiB	EBS Only	25 Gigabit
inf1.24xlarge	$4.721	96	192 GiB	EBS Only	100 Gigabit

Amazon S3

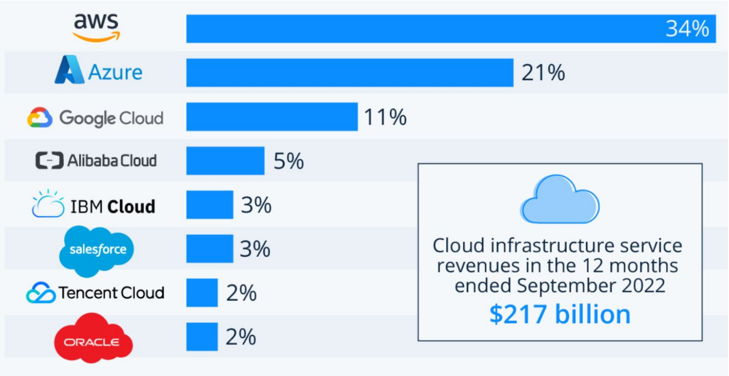
- Amazon storage services (Simple Storage Solution)
  - Pay for what you use

S3 Storage Types

	S3 Default	S3 RRS	S3 IA	Glacier
Durability	99.999999999%	**99.99%**	99.999999999%	99.999999999%
Availability	99.99%	99.99%	**99.9%**	99.99%
Extra Fees *	None	None	**Retrieval**	**Retrieval**
Real-Time Access?	Yes	Yes	Yes	**No (mins/hours)**
Frequently Accessed?	Yes	Yes	**No**	**No**

Google App Engine

- Google Compute Engine (IaaS)
  - Directly compete with AWS EC2
- Build websites on Google infrastructure (PaaS)
  - Run Docker container on Google resources
  - Managed services (e.g., SQL and NoSQL DBs)
- Google Docs (SaaS)
  - Share documents in the cloud
  - E.g., word processor, spreadsheet, presentations
- Google cloud computing market share
  - Built software infrastructure / data centers before Amazon
  - Invented many cloud technologies (e.g., Google File System, MapReduce, BigTable)
  - 3x smaller than AWS
  - Issues:
    - Developer / customer unfriendliness
    - (Often) lack of commitment (Killed by google)
    - No (or horrible) customer service



Cloud infrastructure service revenues in the 12 months ended September 2022
$217 billion

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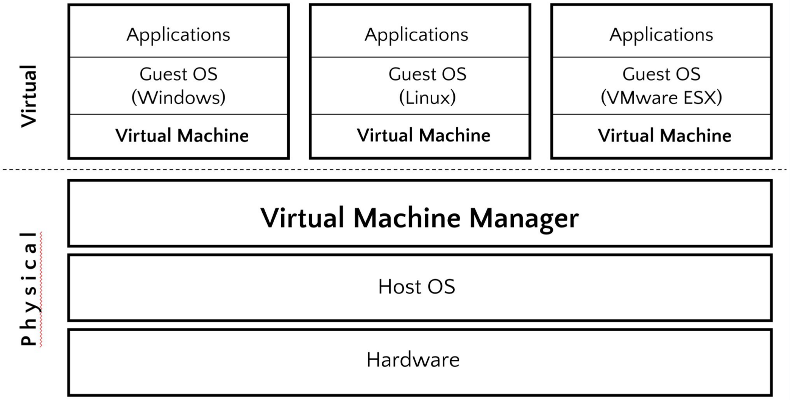
  - **Virtualization**
  - Programming frameworks
- Challenges and opportunities

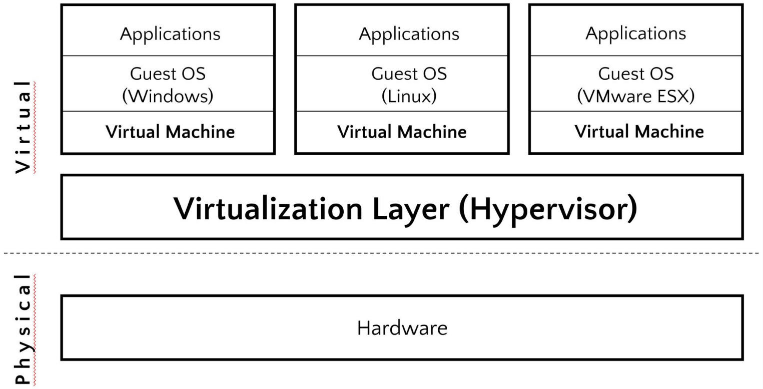
Virtualization

- **Virtual machines have been around for a long time**
  - E.g., running Windows inside a Mac
  - Used to be very slow (e.g., QEMU)
- **Only recently (~2000s) became efficient enough for cloud computing**
- **Basic idea: run virtual machines on your servers and sell time on them**
  - E.g., Amazon EC2, Microsoft Azure, Google Cloud
- **Many advantages**
  - Security: virtual machines have almost impenetrable boundary
  - Multi-tenancy: can have multiple VMs on the same server
  - Efficiency: replace many underpowered machines with fewer high-powered machines

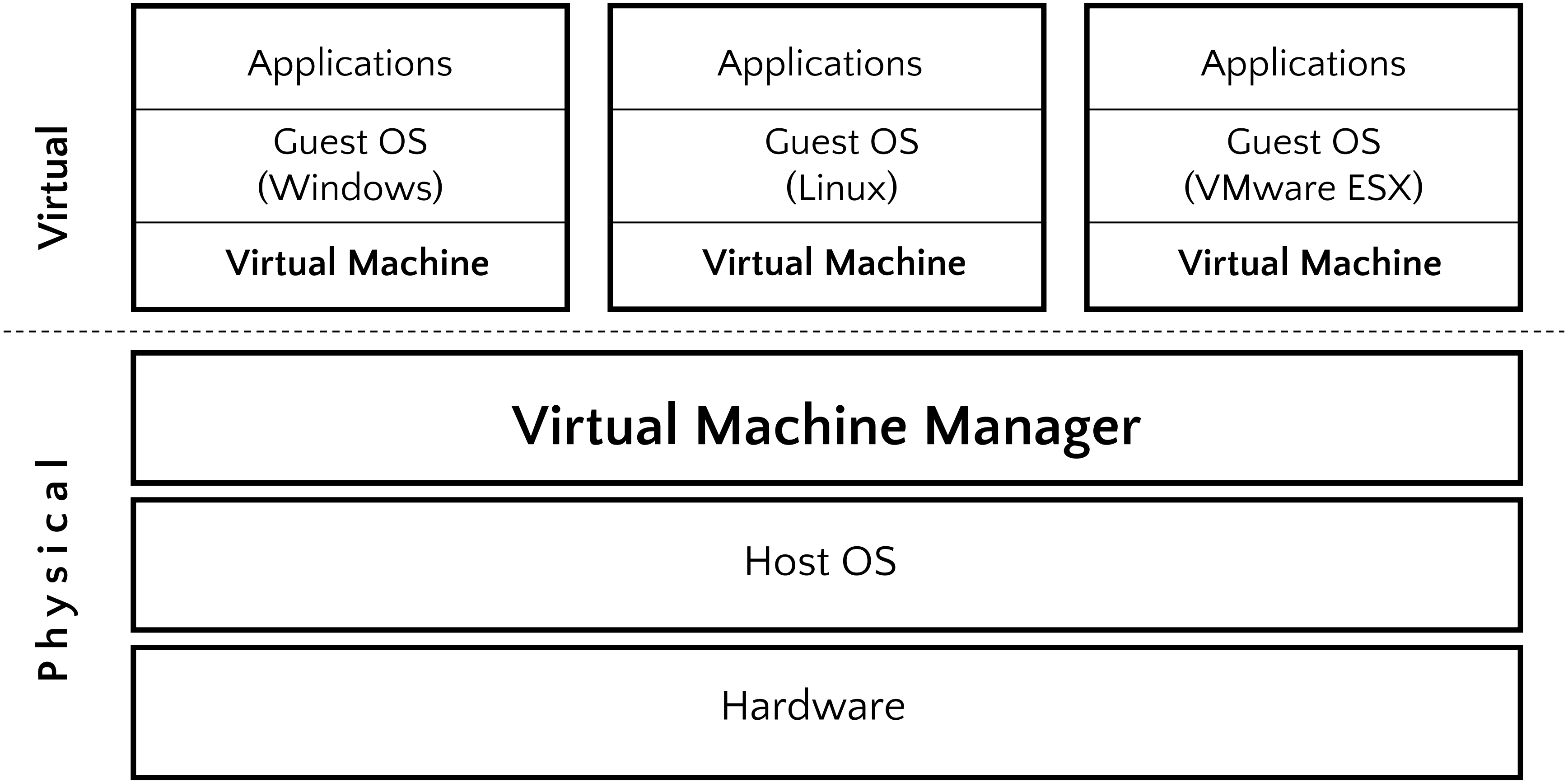
Virtualization

- **Consumer / desktop virtualization**
  - VM products include VMWare, Xen, VirtualBox
  - Run on top of host OS
  - Hypervisor / VM supports guest OS in virtual environment
- **Server virtualization**
  - Amazon used Xen running on RedHat machines
  - Now own custom hardware AWS Nitro
  - Support Windows and Linux Virtual Machines
- Continuing work on the virtualization technology itself
- "Bare-metal" versions to improve performance
  - Run hypervisor directly on top of hardware
  - Good for server farms, like in cloud computing
- Some tricky things to keep in mind
  - Hard to reason about performance (if you care)
  - Identical VMs may deliver somewhat different performance (multi-tenancy, different hardware)

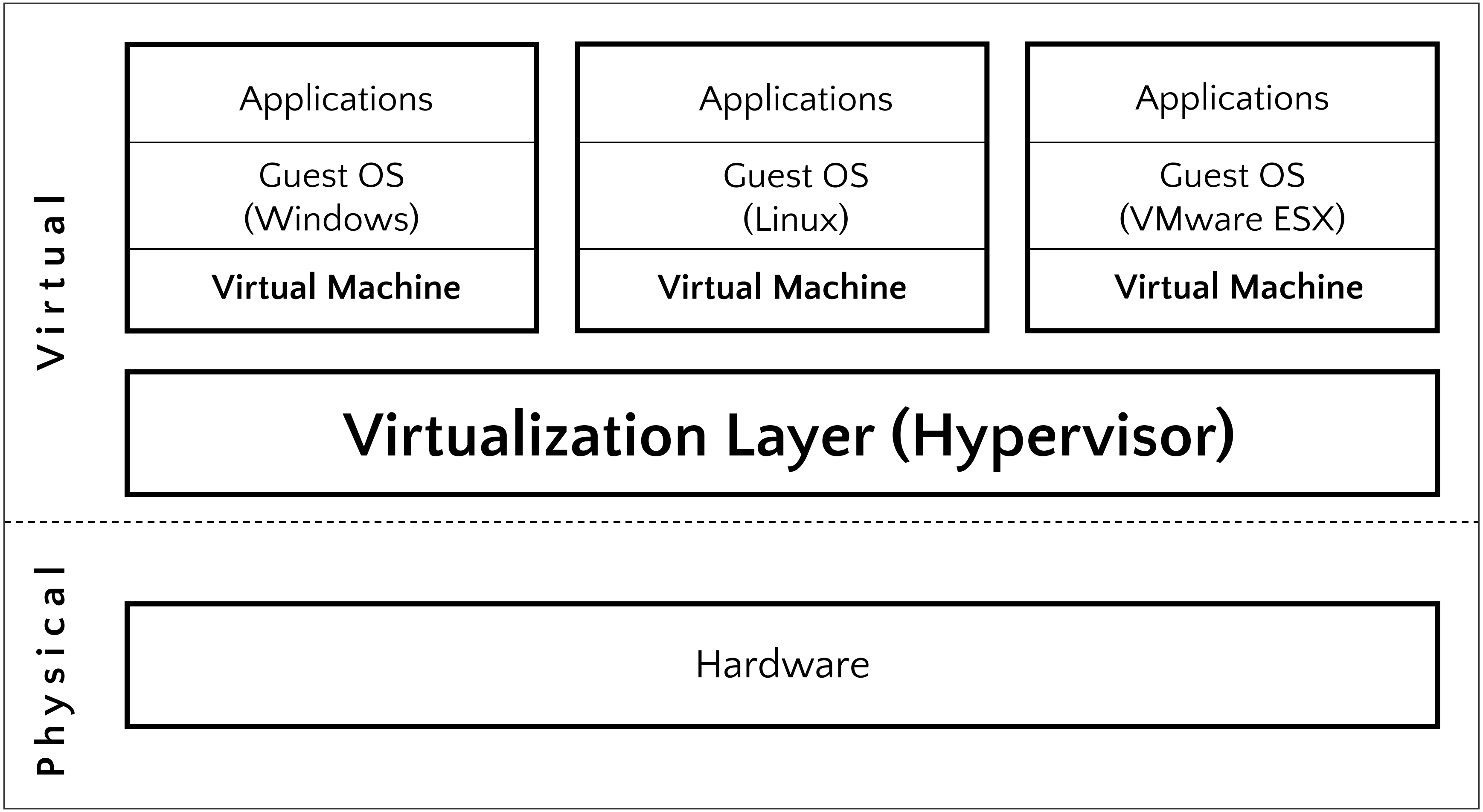




Desktop Virtualization Architecture

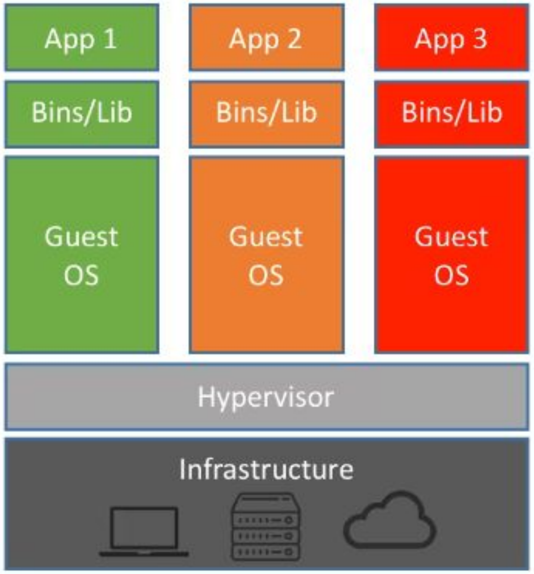


Server Virtualization Architecture

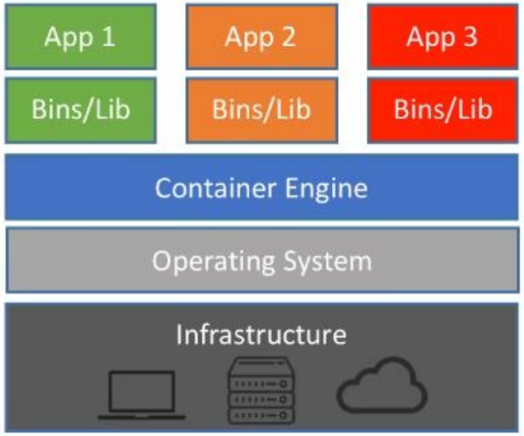


Docker

- Enable true independence between application devs and IT ops
- Unit of deployment
- Package all the dependencies
- Containers are fast and portable
- Reduce overhead of virtualization with containers
- Containers don’t require full-blown OS
- All containers run on a single host
- Reduce OS licencing cost
- Reduce overhead of OS patching and maintenance



Machine Virtualization



Containers

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Programming Frameworks

- **Programming frameworks emerged from efforts to “scale out” workloads**
  - Distribute work over large numbers of machines (thousands of machines)
- Parallelism has been around for a long time
  - Both in a single machine and as a cluster of computers
- Distributed parallelism very hard to program
  - Many things to keep track of:
    - How to parallelize application
    - How to distribute the data
    - How to handle failures
    - ...
- **The difference is the user interface**
  - Google developed MapReduce and BigTable frameworks and started a new era
    - Hadoop
    - Spark
  - AWS services

MapReduce Framework

- Provide a fairly restricted, but still powerful abstraction for programming distributed workloads
- Programmers only write functions called *map* and *reduce*
  - `map` programs
    - inputs: a list of “records” (e.g., images, genomes)
    - output: for each record, produce a set of `(key, value)` pairs
  - `reduce` programs
    - input: a list of `(key, {values})` grouped together from the mapper
    - output: whatever
  - Both can do arbitrary computations on the input data as long as the basic structure is followed
- Everything else (e.g., task scheduling, fault tolerance) is taken care of by the framework

- MapReduce and other analytics frameworks are great for batch processing of data
- Different use case: streaming
  - Very large-scale applications that need real-time access with few ms latencies
  - Trade-off between “consistency” and “performance”

Other Programming Frameworks

- Many different programming frameworks suitable for different applications
  - Address limitations of vanilla Hadoop or other MapReduce-based platforms
- **High-performance Computing (HPC) Systems**
  - Cluster of supercomputers (instead of cheap computers)
  - E.g., GridRPC, MPI
  - More expressive and complex, but a lot more efficient
- **Spark**
  - Based on Resilient Distributed Data (RDD)
  - All in-memory, much more efficient
  - Uses Scala, Python, Java for programming
- **Apache Hive**
  - SQL-like interface on top of Hadoop / HDFS, originally from Facebook
- **Apache HBase**
  - NoSQL column oriented DB
  - Random read/write very large tables (like SQL) on top of Hadoop / HDFS
  - Modeled after Google BigTable
- **Apache Storm, Spark Streaming**
  - Focused on handling real-time streaming data
- **Giraph, GraphLab, GraphX**
  - Graph processing systems

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Advantages of Cloud Computing

- **Lower edge computer costs**
  - Since applications run in the cloud, desktop does not need processing power or hard disk space demanded by traditional desktop software
- **Improved performance of desktop**
  - With few large programs hogging your computer's memory, better performance / faster system boot for your desktop
- **Device independence**
  - You are no longer tethered to a single computer
  - Changes to computers, applications and documents follow you through the cloud
  - Move to another (maybe portable) device, and your applications and documents are still available
- **Reduced software costs**
  - Instead of purchasing expensive software applications, you can get most of what you need for free(-ish)
    - Google Docs suite vs Microsoft
    - Most applications are cloud based today
  - Rent (monthly payments) instead of buying

Advantages of Cloud Computing

- **Instant software updates**
  - No longer faced with choosing between obsolete software and high upgrade costs
  - When the application is web-based, updates happen automatically
    - Available the next time you log into the cloud
    - You get the latest version without needing to pay for or download an upgrade
  - Docker or VMs can package software to run on any platform that supports virtualization
- **Improved document format compatibility**
  - Do not have to worry about the documents you create on your machine being compatible with other users' applications or OSes
  - Potentially no format incompatibilities when everyone is sharing documents and applications in the cloud

Advantages of Cloud Computing

- **"Unlimited" storage capacity**
  - Cloud computing offers virtually limitless storage
  - Your computer's current 1TB hard drive is small compared to the hundreds of PBs available in the cloud
- **Increased data reliability**
  - Unlike desktop computing, in which a hard disk can crash and destroy all your valuable data, a computer crashing in the cloud should not affect the storage of your data
    - If your personal computer crashes, all your data is still out there in the cloud, still accessible
  - Few individual users back up their data on a regular basis
    - Cloud computing is a data-safe computing platform

Advantages of Cloud Computing

- **Universal document access**
  - Documents stay in the cloud
  - You can access them whenever you have a computer and an Internet connection
  - Documents are instantly available from wherever you are
- **Latest version availability**
  - The cloud always hosts the latest version of your documents
    - As long as you are connected you are not in danger of having an outdated version
  - Built-in revision control system
  - When you edit a document at home, that edited version is what you see when you access the document at work.
- **Easier collaboration**
  - Sharing documents leads directly to better collaboration
  - Multiple users can collaborate easily on documents and projects

Disadvantages of Cloud Computing

- **Using cloud computing means dependence on Big Tech**
  - Big Internet companies like AWS, Google, and Microsoft monopolise the market
  - Can possibly limit flexibility and innovation
  - Lots of competition in cloud computing
  - High barriers to break into the cloud computing market
- **Security is an issue**
  - Unclear how safe outsourced data is
  - Ownership of data is not always clear, when using these services
- **Issues relating to policy and access**
  - If your data is stored abroad whose policy do you adhere to?
    - To deal with government restrictions (e.g., export restrictions), cloud providers ensure your data is stored within your country's borders
    - E.g., TikTok saga
  - What happens if the remote server goes down?
    - How will you then access files?
  - Cases of users being locked out of accounts and losing access to data

From Dr. Mehmet Gunes, U. Nevada Reno

Disadvantages of Cloud Computing

- **Requires a constant Internet connection**
  - If you do not have an Internet connection you cannot access anything, applications or your own documents
    - Many applications offer off-line capabilities
  - No Internet means no work: this could be a deal-breaker
- **Does not work well with low-speed / spotty connections**
  - Low-speed Internet connection makes cloud computing painful or impossible
  - Web-based applications require a lot of bandwidth to download
- **Web-interface can be slow**
  - Even with a fast connection, web-based applications are often slower than running similar software program on your desktop
  - Interface and data has to be sent back and forth from your computer to the computers in the cloud
  - Latency (more than throughput) matters

Disadvantages of Cloud Computing

- **Features might be limited**
  - Many web-based applications simply are not as full-featured as their desktop-based applications
  - For example, you can still do a lot more with Microsoft PowerPoint than with Google Slides
  - This situation has been changing
- **Stored data might not be secure**
  - With cloud computing, all your data is stored on the cloud
  - How secure is the cloud? (Probably more secure than your laptop)
  - Can unauthorized users gain access to your confidential data?
    - News are data leaks are constant
- **Stored data can be lost**
  - Theoretically, data stored in the cloud is safe, replicated across multiple machines
  - Doing local backups might still be a good idea

Disadvantages of Cloud Computing

- **HPC systems**
  - Unclear if you can run compute-intensive HPC applications that use MPI or OpenMP
  - Need low-latency, high-bandwidth interconnect
  - Scheduling is important with this type of application
  - All nodes should be co-located to minimize communication latency
  - This has changed (e.g., MapReduce, AWS EC2) and may be changing in the future
- **General Concerns**
  - Interoperability
  - Each cloud systems uses different protocols and different APIs
  - May not be possible to run applications across different cloud-based systems
  - Solution: indirection layer (Terraform, Ansible)