UMD DATA605 - Big Data Systems

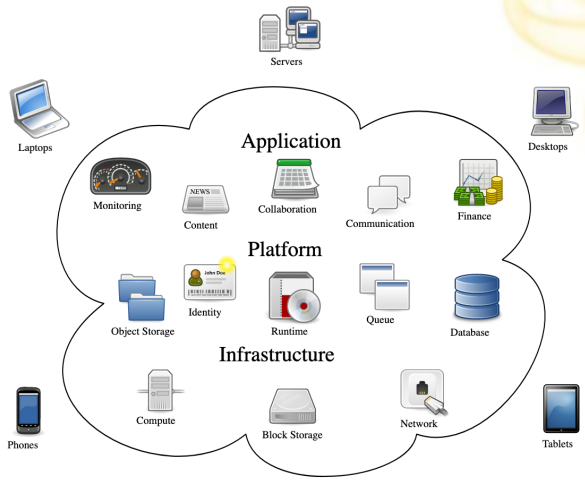
11.1: Cloud Computing

- **Instructor**: Dr. GP Saggese, gsaggese@umd.edu

- ***Cloud Computing***
- Technologies behind cloud computing

Cloud Computing

- Computing as **"service" rather than "product"**
  - Storage and computing in the cloud
  - Edge devices (e.g., phones, laptops, tablets) interact with the cloud



- **Advantages of cloud computing**
  - Device agnostic: seamless computation across devices
  - On demand
  - Efficiency / scalability
    - Programming frameworks (e.g., Hadoop, Spark, Dask) enable scalability
  - Reliability
  - Cost: "pay-as-you-go" for resources
    - Cheaper than building own systems
    - Computing as a commodity (like electricity)

Buying infrastructure

- **To buy or to rent?**
- **Building / buying infrastructure**
  - Require time and capital investments (Capex)
    - Especially at the beginning without revenues
    - Smooth cash flow (constant $/mo) is better than lumpy one (big one-time purchase)
  - Buy hardware (e.g., computers, storage, network)
    - Estimate current hardware size
    - Difficult to estimate future demands
  - Update obsolete hardware
  - Cost of owning hardware (Opex)
    - Data center, electricity, cooling, handling faults
  - Administering
    - Install, update, maintain software stack

Renting infrastructure

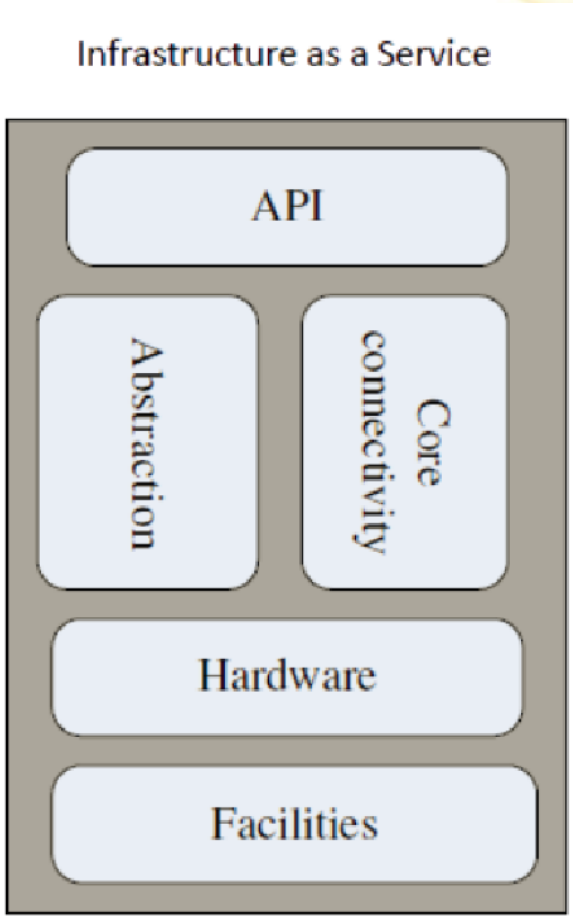
- **Renting infrastructure** (i.e., cloud computing)
  - Pay for what you use
    - Low initial capital investment
  - Ready systems with a click
  - No multi-year resource plan needed
  - Choose machines for your application and data needs

Cloud Computing

- **Ideas of cloud computing around for a long time**
  - Mainframes + thin clients (1960s)
  - Personal computers (1980s)
  - Grid computing for supercomputers (1990s)
  - Peer-to-peer architecture (early 2000s)
  - Client-server model (Web 1.0 and Web 2.0)
  - Cloud computing (2010s)
- **Now, it finally works**
- **Why now?**
  - A convergence of key technologies
    - OS virtualization
    - Large data centers
    - Decreasing hardware costs
    - Big data frameworks

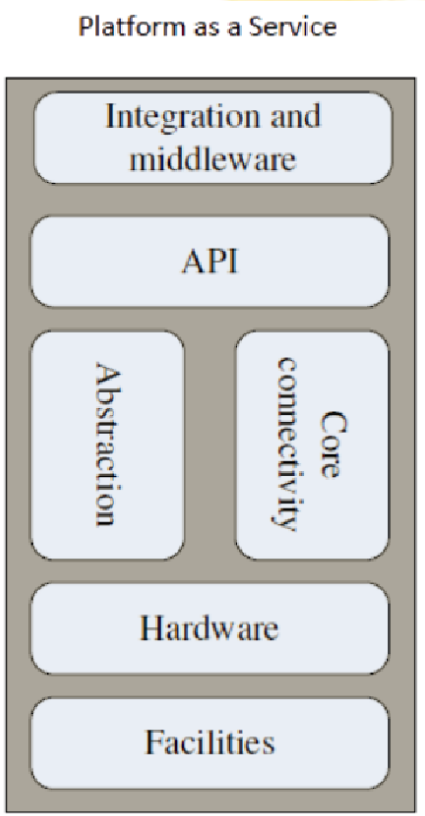
Infrastructure-as-a-Service

- Cloud provides low-level resources
- Install and maintain OS and applications
- E.g.,
  - AWS EC2
  - Google Compute Engine



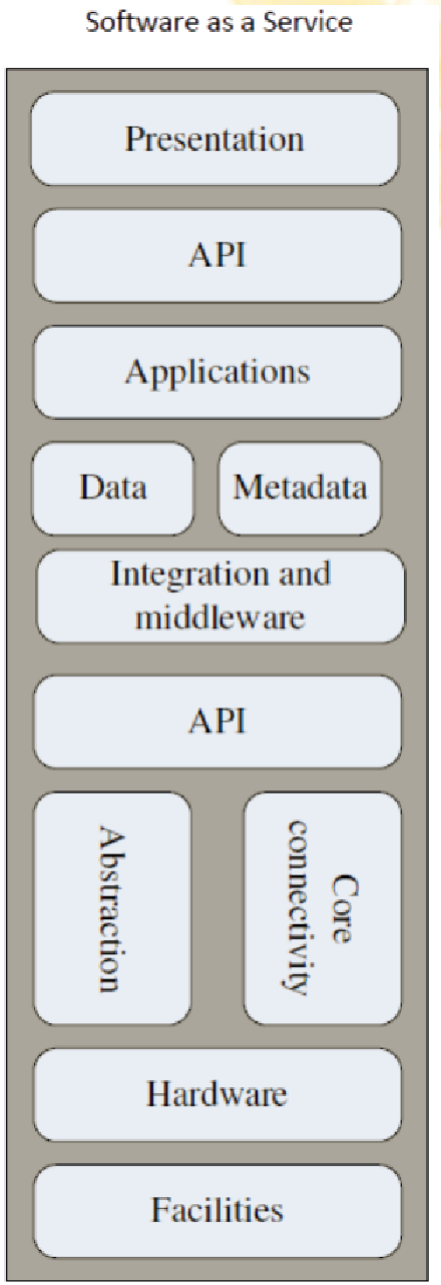
Platform-as-a-Service

- **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
    - Software stack as a large file with system image
    - **Business model built around this**
  - E.g., pre-built images for Hadoop
    - Hortonworks, Cloudera
  - E.g., pre-built distributions for Linux
    - RedHat, Gentoo, CentOS
- Cloud provides OS and programming languages
  - Build application on top of it
  - E.g.,
    - Google App Engine



Software-as-a-Service (SaaS)

- **Cloud provides the application**
  - No need to install on your machine
  - Use directly from the cloud
  - Examples include:
    - *Dropbox*: Access and share files without local storage
    - *Salesforce*: Manage customer relationships online
    - Any app running in a browser: Google Docs or Microsoft Office 365
- **Benefits**
  - Accessibility from any device with internet connectivity
  - Automatic updates and maintenance by the provider
  - Scalability for growing user needs
  - Cost-effectiveness by reducing physical hardware and software installations

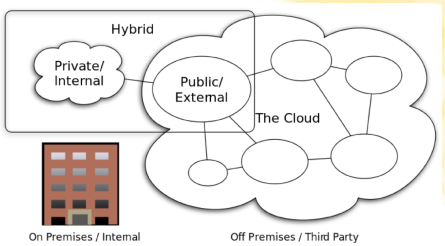


X-as-a-Service

- After 2010, business model of **X-as-a-service (XaaS)**
  - Mobility-as-a-service (e.g., Uber)
  - Games-as-a-service (e.g., Google Stadia)
  - Storage-as-a-service (e.g., S3, Google Drive)
  - Desktop-as-a-service (e.g., AWS app)
  - Marketing-as-a-service
  - Banking-as-a-service
  - ...

Cloud Deployment Models

- **Private**
  - Internal cloud hosted on organizational premises
  - E.g., company's data center running virtualized services
- **Public**
  - External cloud hosted by third-party providers
  - E.g., AWS, Azure, GCP offering compute and storage to clients
- Hybrid cloud
  - Combine private and public environments
  - Sensitive workloads stay internal
  - scalable tasks move to public cloud
- **On-premises resources**
  - E.g., corporate servers in a building
- **Off-premises resources**
  - Third-party cloud infrastructure
  - E.g., cloud provider's distributed data centers
- **Key idea**: Hybrid architectures optimize cost, security, scalability



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

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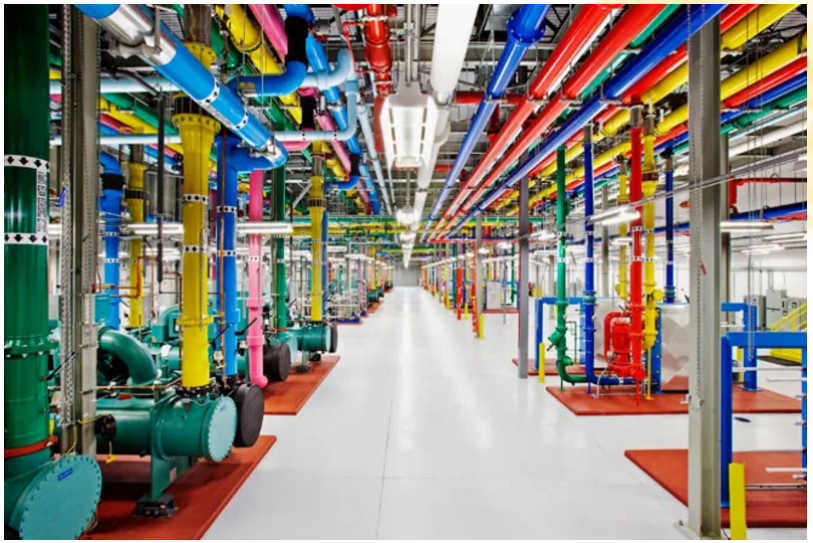
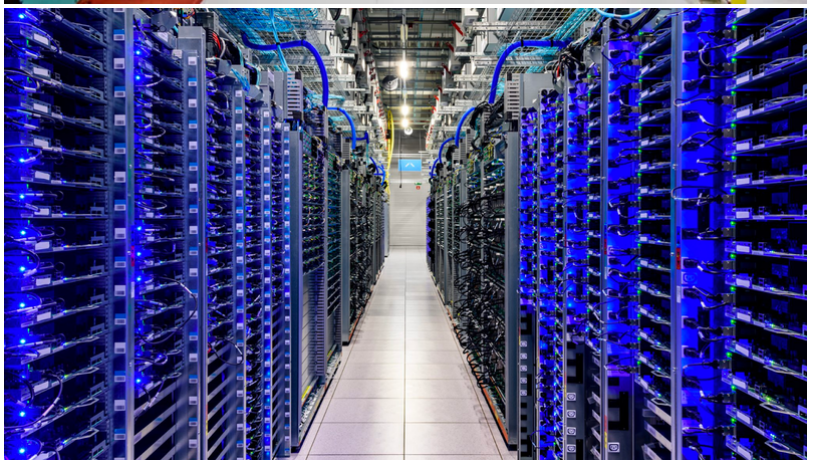
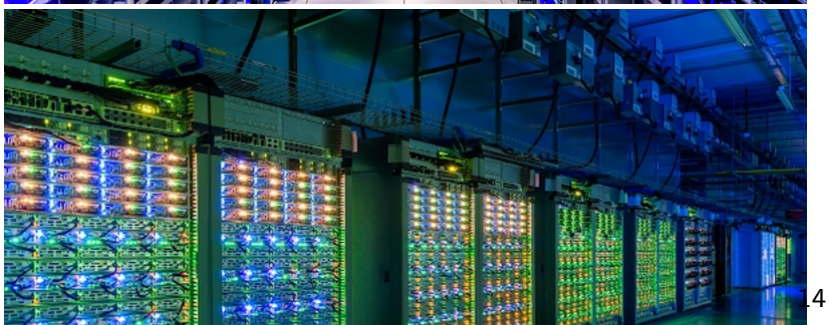
Data Centers

- Data centers enable cloud computing
  - Large companies (e.g., AWS, Apple, Google, Facebook) build data centers globally
- Design and construction decisions
- Research energy-saving for power and cooling





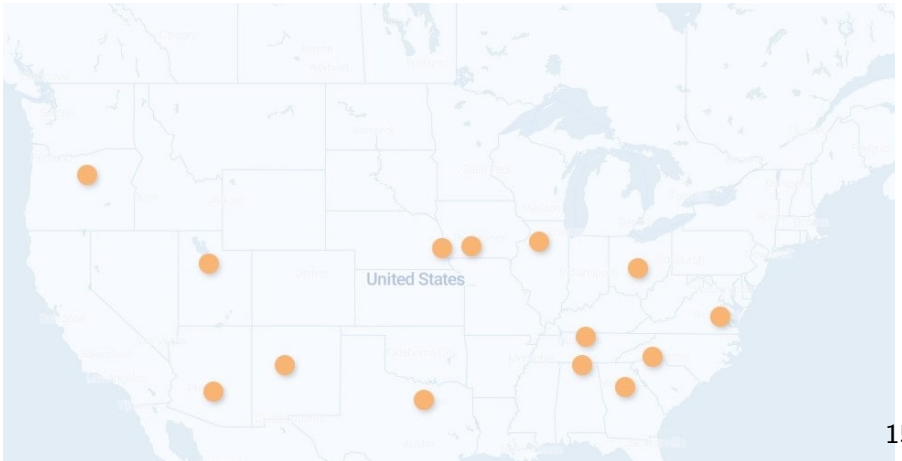


Data Centers

- **Equipment cost**
  - Computing, memory, storage, networking
  - Data center costs around 1B USD
  - Prices dropping
- **Powering / cooling cost**
  - Running equipment cost
  - High cooling cost
    - Focus on "energy-efficient computing"
  - Vent placement is key
    - Thermal hotspots need management
  - PUE (Power Usage Effectiveness)
    - Power converted to computation; rest is overhead
  - Hard to optimize in small data centers
    - Ideal PUE is 1; current

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**

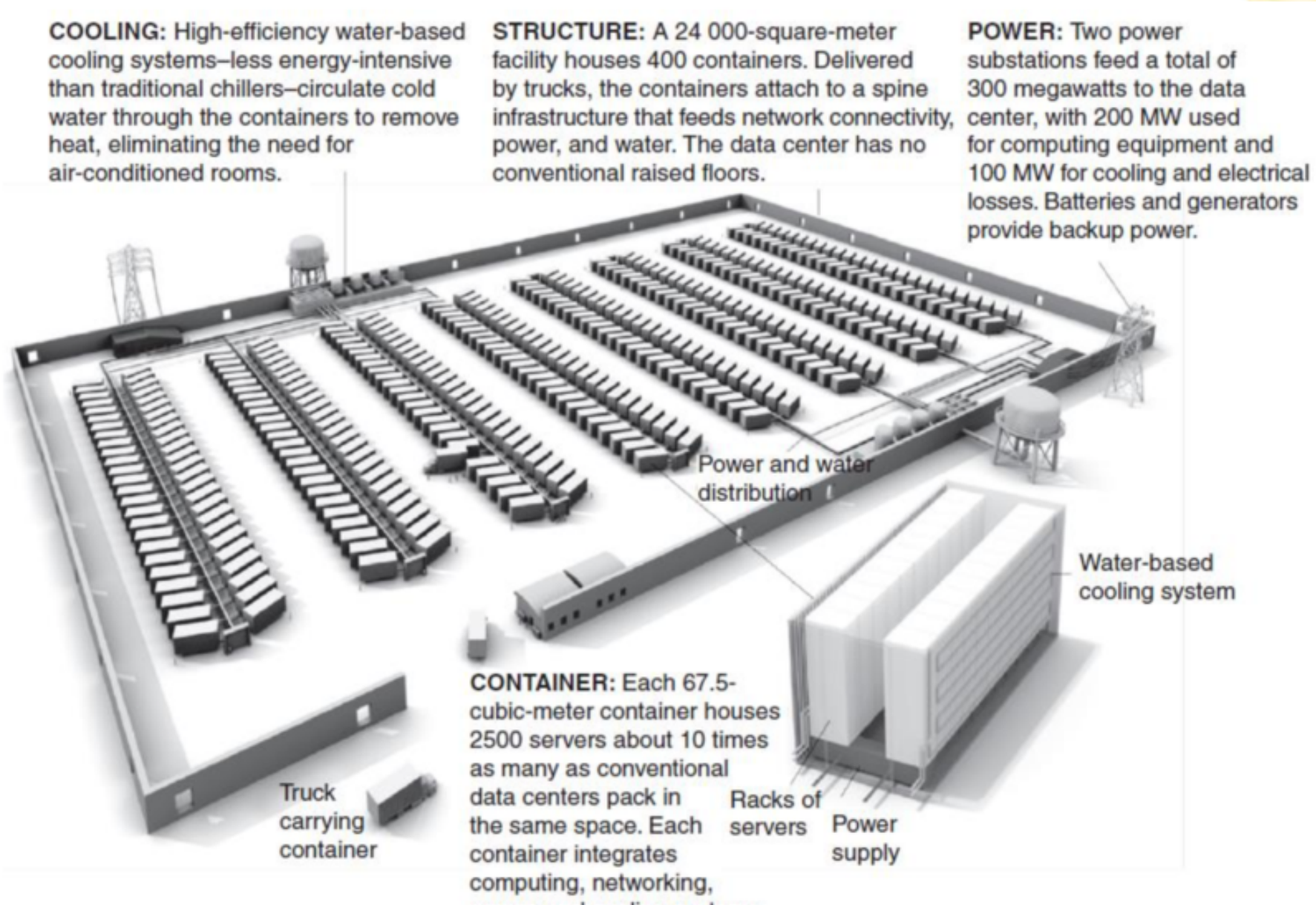
Meta investment in 18 data centers



Data Centers

(Modular) Data Centers

From James Hamilton Presentation



Amazon Web Services

As of 2022, 28 geographical regions

SCIENCE ACADEMY

Amazon Web Services (EC2)

- Widely used solution for cloud computing
  - Alternatives may suit your needs
  - Prices are low due to competition
  - See 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

1 2 3 4 5 6 7 ... 29

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

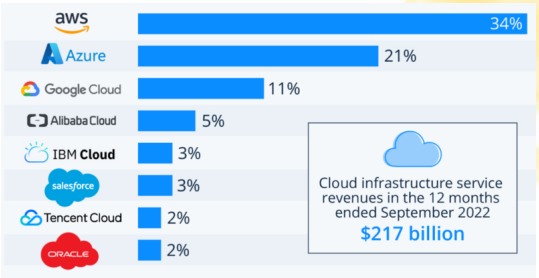
- Amazon storage services (Simple Storage Solution)
  - Pay for what you use

S3 Storage Types

	S3 Default	S3 RRS	S3 IA	Glacier
Durability	99.999999999%	99.99%	99.999999999%	99.999999
Availability	99.99%	99.99%	99.9%	99.99%
Extra Fees *	None	None	Retrieval	Retrieval
Real-Time Access?	Yes	Yes	Yes	No (mins/
Frequently Accessed?	Yes	Yes	No	No

Google App Engine

- Google Compute Engine (IaaS)
  - Competes with AWS EC2
- Google Infrastructure (PaaS)
  - Run Docker containers on Google resources
  - Managed services (e.g., SQL and NoSQL DBs)
- Google Docs (SaaS)
  - Share documents in the cloud
  - Includes word processor, spreadsheet, presentations
- Google Cloud Computing Market Share
  - Built software infrastructure/data centers before Amazon
  - Invented cloud technologies (e.g., Google File System, MapReduce, BigTable)
  - Market share 3x smaller than AWS
  - Issues:
    - Developer/customer unfriendliness
    - Lack of commitment (Killed by Google)
    - Poor customer service



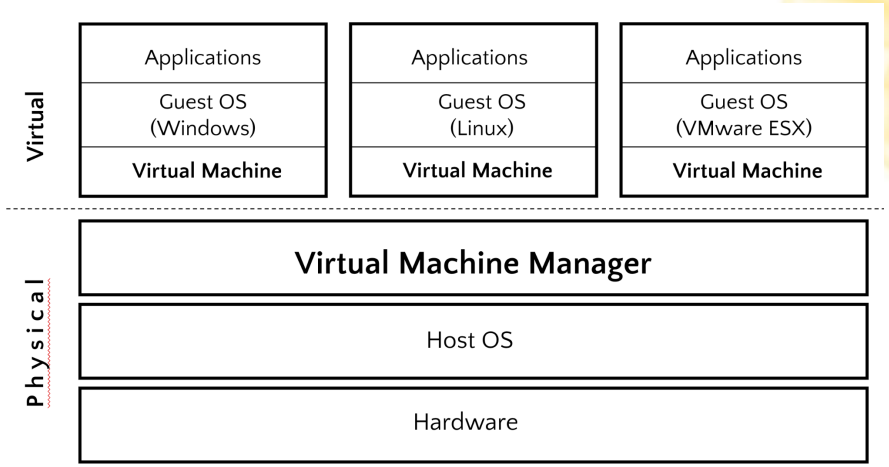
- Cloud Computing
- Technologies behind cloud computing
  - Data centers
  - ***Virtualization***
  - Programming frameworks
  - Challenges and opportunities

Virtualization

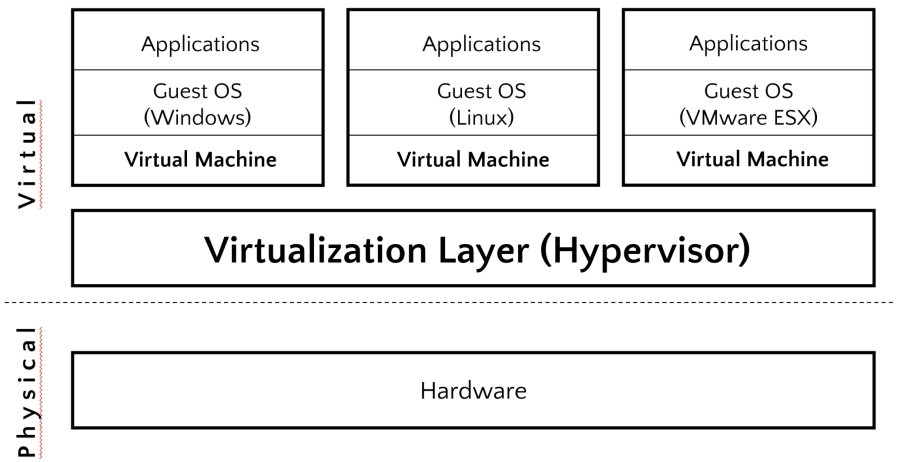
- **Virtual machines have been around for a long time**
  - E.g., running Windows inside a Mac
  - Used to be slow (e.g., QEMU)
- **Only recently (2000s) became efficient enough for cloud computing**
- **Basic idea of cloud computing**
  - Run virtual machines on servers and sell time on them
  - E.g.,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

Virtualization

- **Consumer / desktop virtualization**
  - VMWare, Xen, VirtualBox
  - Run on host OS
  - Hypervisor/VM supports guest OS
- **Server virtualization**
  - Run hypervisor on hardware
  - Ideal for server farms, cloud computing
  - Amazon used Xen on RedHat
  - Now uses AWS Nitro
  - Supports Windows and Linux VMs



Consumer / desktop virtualization



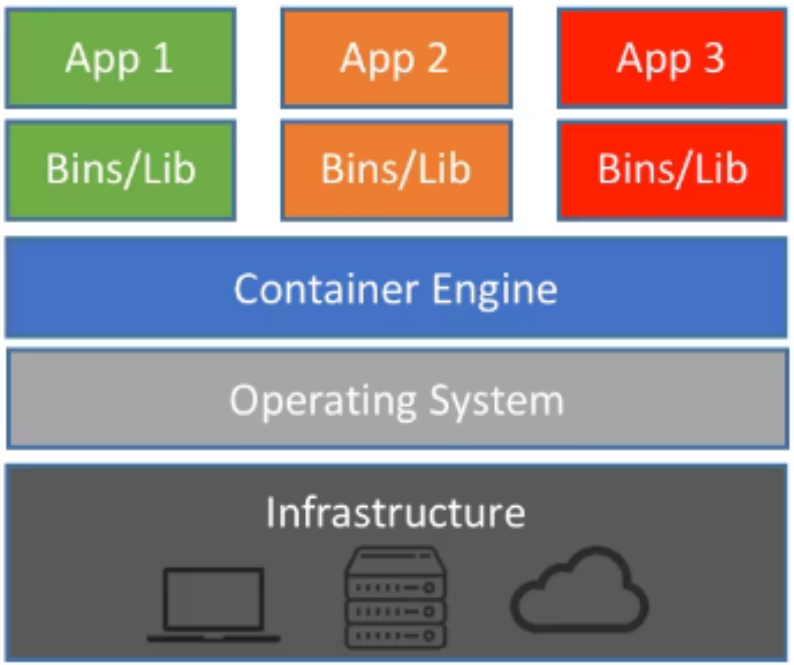
Server virtualization

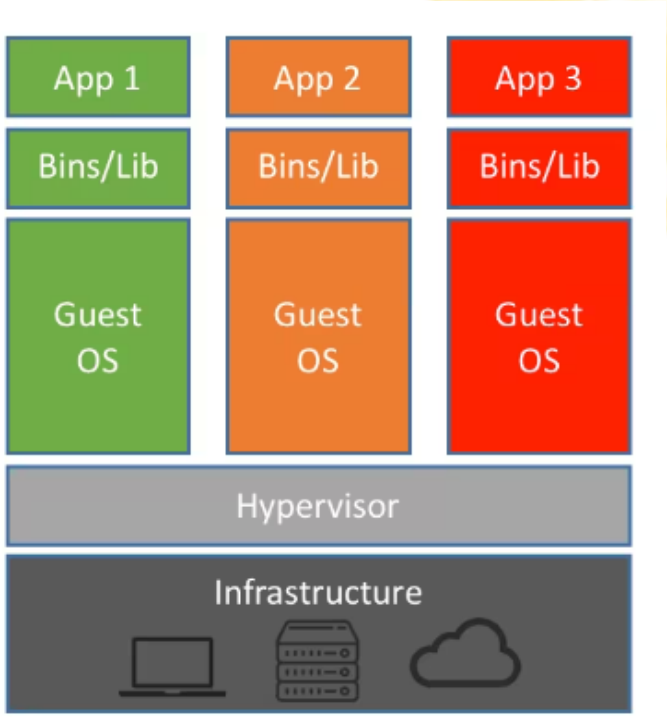
Virtualization

- Performance and tricky things to keep in mind
  - Hard to reason about performance
  - Identical VMs may deliver different performance
    - Multi-tenancy, different hardware
- "Bare-metal" compute to improve performance

Docker

- Enable true independence between application devs and IT ops
- Package all dependencies
- Advantages
  - Containers are fast and portable
  - Reduce virtualization overhead
  - Containers don't require full OS
  - All containers run on a single host
  - Reduce OS licensing cost
  - Reduce OS maintenance overhead





Machine Virtualization

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

Programming Frameworks

- **Programming frameworks emerged from efforts to "scale out" workloads**
  - Distribute work over thousands of machines
- Parallelism has been around for a long time
  - In a single machine and as a cluster of computers
- Parallelism is hard for programmers
  - Many things to track:
    - Parallelize application
    - Distribute data
    - Handle failures
    - Debugging
    - Race conditions/Heisenbugs
- **The difference is the user interface**
  - Google developed MapReduce and BigTable, starting a new era
    - Hadoop, Spark
  - AWS services

MapReduce Framework

- Provide a restricted, powerful abstraction for programming distributed workloads
- Programmers write functions: *map* and *reduce*
  - **map** programs
    - Input: list of "records" (e.g., images, genomes)
    - Output: set of **(key, value)** pairs for each record
  - **reduce** programs
    - Input: list of **(key, [values])** from mapper
    - Output: flexible
  - Perform arbitrary computations on input data within structure
- Framework handles task scheduling, fault tolerance
- **Batch processing of data**
  - MapReduce and analytics frameworks excel
- **Streaming data**
  - Large-scale applications need real-time access with low latency
  - Balance "consistency" and "performance"

Other Programming Frameworks

- Many programming frameworks for different applications
  - Address MapReduce limitations
- **High-performance Computing (HPC) Systems**
  - Cluster of supercomputers
  - E.g., GridRPC, MPI
  - More expressive, efficient
- **Spark**
  - Based on Resilient Distributed Data (RDD)
  - In-memory, efficient
  - Uses Scala, Python, Java
- **Apache Hive**
  - SQL-like interface on Hadoop/HDFS
- **Apache HBase**
  - NoSQL column-oriented DB
  - Random read/write large tables on Hadoop/HDFS
  - Modeled after Google BigTable
- **Apache Storm, Spark Streaming**
  - Handle real-time streaming data
- **Giraph, GraphLab, GraphX**
  - Graph processing systems

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

Advantages of Cloud Computing

- **Lower edge computer costs**
  - Applications run in the cloud, reducing desktop processing power/memory/disk needs
- **Improved performance of desktop**
  - Faster system boot due to less memory usage by large programs
- **Device independence**
  - Not tethered to a single computer
  - Applications/documents follow you through the cloud
  - Access applications/documents on any device
- **Reduced software costs**
  - Access most software for free(-ish)
    - Google Docs suite vs Microsoft
    - Most applications are cloud-based
  - Rent (monthly payments) instead of buying

Advantages of Cloud Computing

- **Instant software updates**
  - Avoid obsolete software and high upgrade costs
  - Web-based apps update automatically
    - Available next login
    - Access latest version without paying or downloading
  - Docker or VMs enable cross-platform software
- **Improved document format compatibility**
  - Ensure document compatibility across users
  - Eliminate format issues with shared cloud documents

Advantages of Cloud Computing

- **"Unlimited" storage capacity**
  - Cloud computing offers limitless storage
  - Your computer has ~1TB hard drive
  - Hundreds of PBs available in the cloud (elastic, on-demand)
- **Increased data reliability**
  - Hard disk can crash and destroy data
  - Few users regularly backup data
  - Cloud computer crash doesn't affect data storage
    - Data remains accessible in the cloud
    - Cloud computing is data-safe

Advantages of Cloud Computing

- **Universal document access**
  - Documents stay in the cloud
  - Instantly available wherever you are
  - Requires Internet connection
- **Latest version availability**
  - Edit at home, see changes at work
  - Cloud hosts latest version
  - Built-in revision control
- **Easier collaboration**
  - Sharing improves collaboration
  - Multiple users collaborate easily

Disadvantages of Cloud Computing

- **Using cloud computing means dependence on Big Tech**
  - AWS, Google, Microsoft monopolize the market
  - Limits flexibility and innovation
  - High barriers to enter the market
- **Security is an issue**
  - Unclear data safety
  - Unclear data ownership
- **Issues relating to policy and access**
  - Adhere to foreign policies if data stored abroad
    - Cloud providers store data within borders to comply with restrictions
    - E.g., TikTok saga
  - Remote server downtime affects file access
  - Users may be locked out and lose data access

Disadvantages of Cloud Computing

- **Requires a constant Internet connection**
  - Cannot access applications or documents without Internet
  - No Internet means no work
    - Some applications offer offline capabilities
- **Does not work well with low-speed/spotty connections**
  - Low-speed Internet makes cloud computing difficult
  - Web-based applications need high bandwidth
- **Web-interface can be slow**
  - Often slower than desktop even with fast connection
  - Interface sent between your computer and cloud
  - Latency is crucial

Disadvantages of Cloud Computing

- **Features might be limited**
  - Web-based apps often lack features compared to desktop apps
  - Microsoft PowerPoint offers more features than Google Slides
  - Situation is changing rapidly
- **Stored data might not be secure**
  - Cloud computing stores data on the cloud
  - Is the cloud secure?
    - Likely more secure than your laptop
  - Can unauthorized users access your data?
    - Data leaks are frequent
- **Stored data can be lost**
  - Cloud data is safe, replicated across machines
  - Local backups are still advisable

Disadvantages of Cloud Computing

- **HPC systems**
  - Run compute-intensive HPC applications using MPI or OpenMP
  - Require low-latency, high-bandwidth interconnect
  - Schedule applications effectively
  - Co-locate nodes to minimize communication latency
  - Evolving landscape (e.g., MapReduce, AWS EC2)
- **Interoperability**
  - Cloud systems use different protocols and APIs
  - Running applications across different cloud systems may be challenging
  - Solution: Use indirection layer (Terraform, Ansible)