UMD DATA605 - Big Data Systems

11.2: Technologies Enabling Cloud Computing

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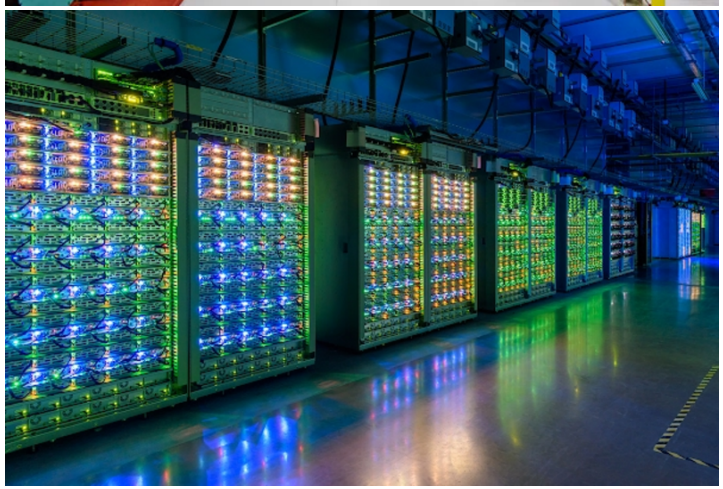
- ***Data centers***
- Virtualization
- Programming frameworks
- Challenges and opportunities

Data Centers: Capex

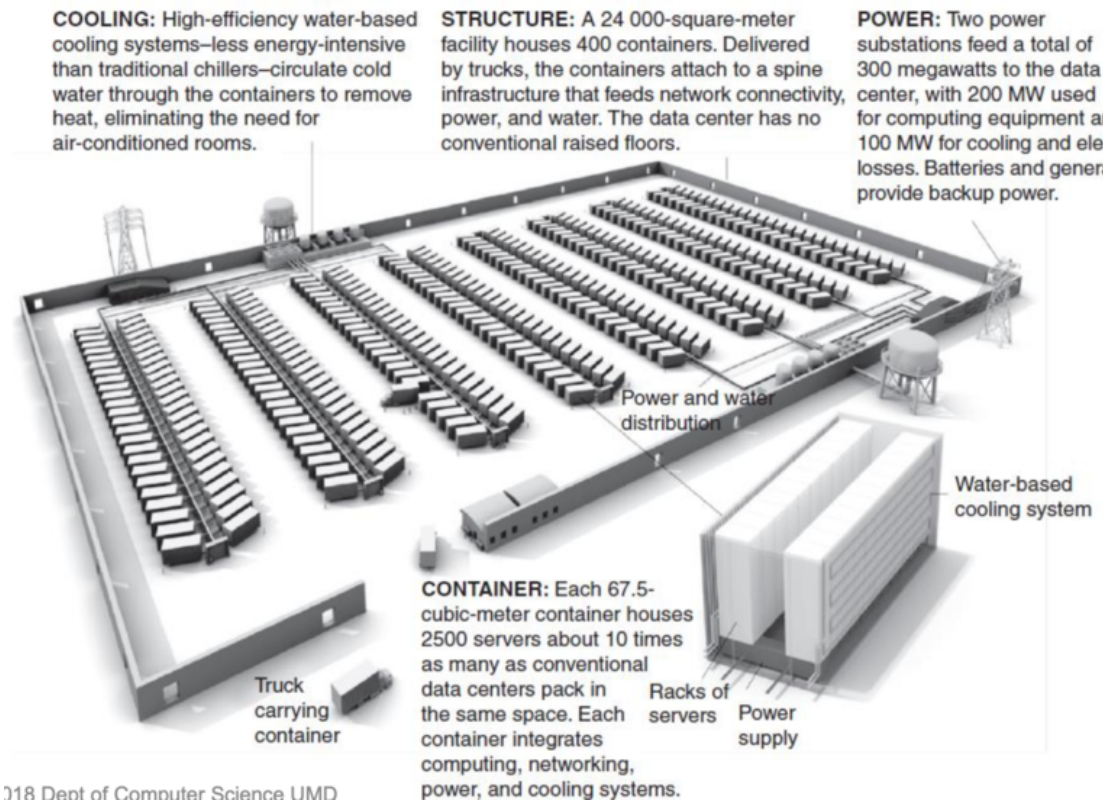
- Data centers enable cloud computing
- Large companies (e.g., AWS, Apple, Google, Facebook) build data centers globally
- Data center costs around 1B USD to build
  - Capex: Computing, memory, storage, networking
  - Prices dropping
  - Size is increasing



Data Centers: Opex

- **Powering equipment cost**
  - Focus on energy-efficient computing
- **High cooling cost**
  - Vent placement is key to manage thermal hotspots
  - PUE (Power Usage Effectiveness)
    - Some power converted into computation
    - Rest is overhead
  - Hard to optimize in small data centers
    - Ideal PUE is 1
    - Current is 1.07-1.22
    - May lead to large data centers soon
- **Research on energy-saving**
- **Data centers built**
  - Close to cheap energy sources
  - In cold climate

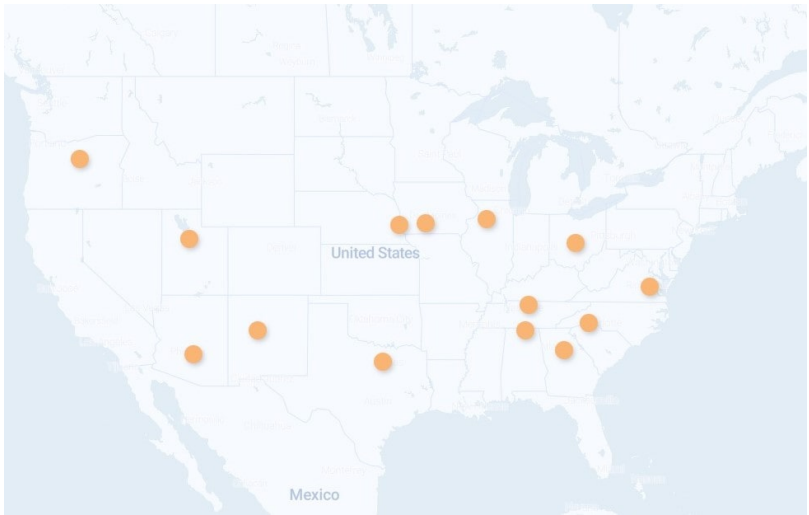
(Modular) Data Centers



Meta

- Global scale of data centers
  - 29 dedicated Meta data centers
  - Hyperscale and AI-optimized facilities
- Investment
  - $600 billion in U.S. infrastructure by 2028
  - El Paso data center: $1.5 billion
  - Louisiana campus: $10 billion for 9 buildings
  - Power infrastructure upgrades: over $3 billion

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**



Amazon Web Services

- AWS
  - 2022: 28 geographical regions
  - 2025: 38 regions

Amazon Web Services (EC2)

- Widely used solution for cloud computing
  - Many alternatives to suit your needs
  - Prices are low due to competition
  - 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

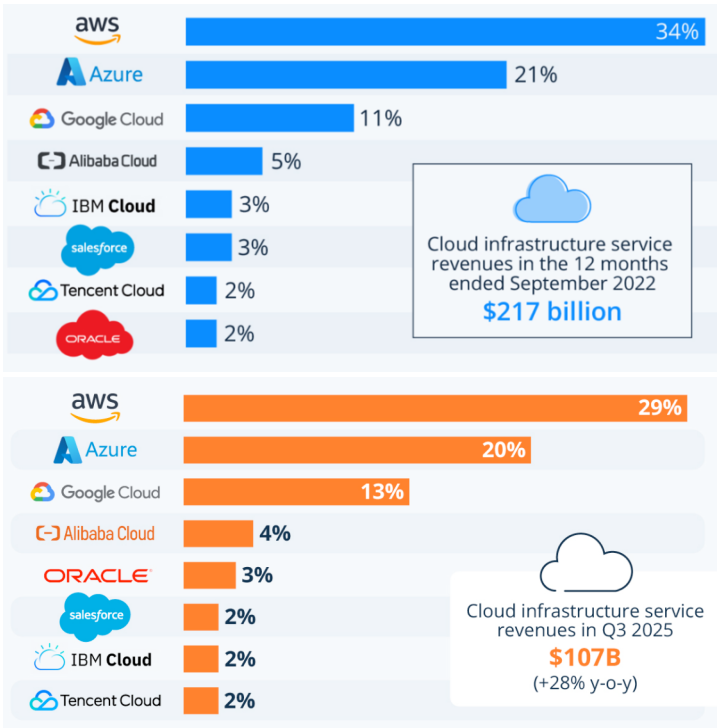
Amazon S3

- Amazon storage services (S3 = Simple Storage Solution)
  - Pay for storage you use
- Different tiers for reliability, cost, performance

	Default	**RRS**	**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)
  - Competes with AWS EC2
- **Google Infrastructure** (PaaS)
  - Run Docker containers on Google resources
  - Managed services (e.g., databases)
- **Google Docs** (SaaS)
  - Word processor, spreadsheet, presentations in the cloud
- Google Cloud's **compute market share**
  - Built software 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



SCIENCE ACADEMY

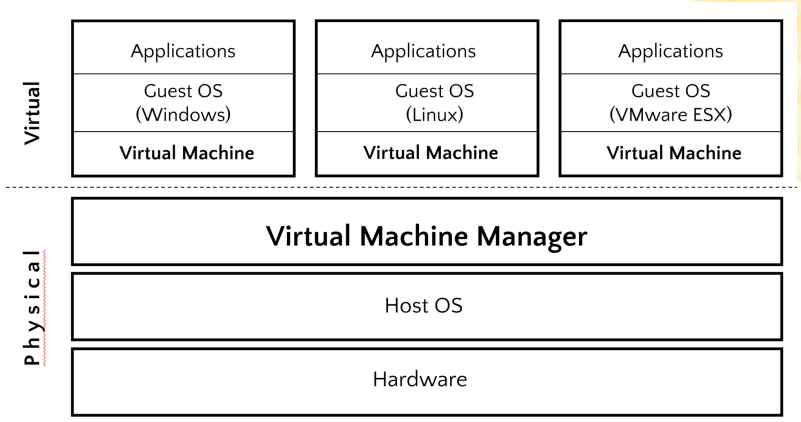
- Data centers
- ***Virtualization***
- Programming frameworks
- Challenges and opportunities

Virtualization

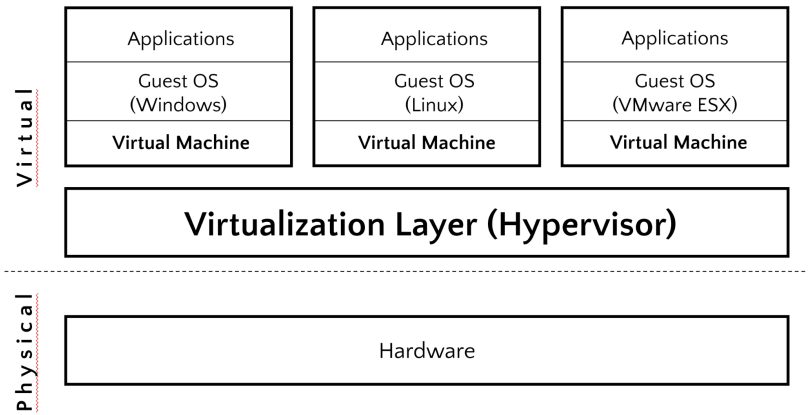
- **Virtual machines have been around for a long time**
  - Processors had support since 1980s
  - In 2000s efficient enough for cloud computing
- **Basic idea of cloud computing**
  - Run virtual machines on servers and sell time on them
  - E.g., AWS, Microsoft Azure, Google Cloud
- **Many advantages**
  - *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

Desktop vs Server Virtualization

- **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 it uses AWS Nitro
- **Performance are tricky**
  - Hard to reason about performance
  - Identical VMs may deliver different performance
  - Multi-tenancy, different hardware
  - "Bare-metal" compute to improve performance



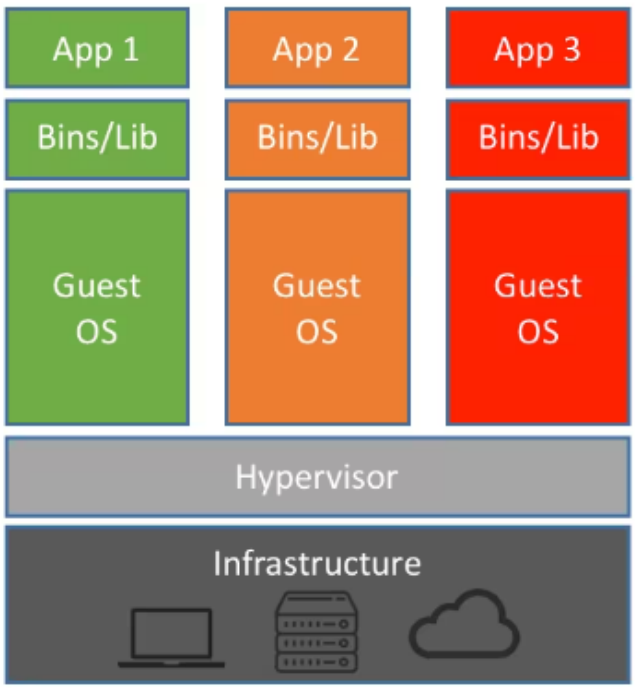
Consumer / desktop virtualization



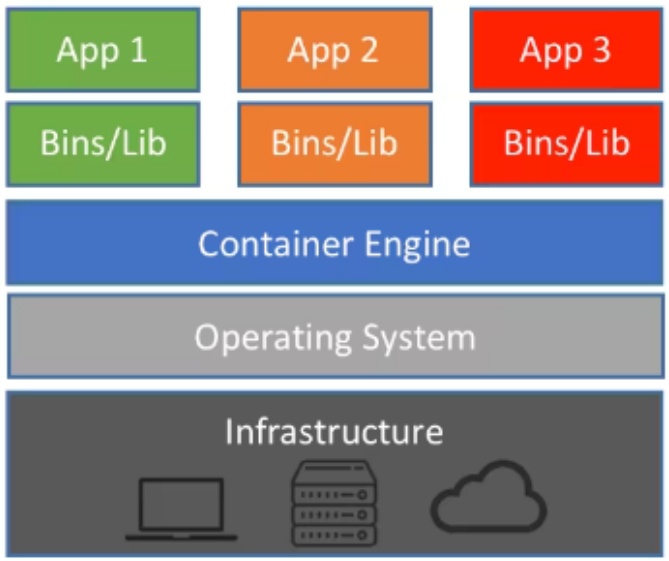
Server virtualization

Docker

- Package all dependencies in a single object
- **Advantages**
  - Containers are fast and portable
  - Reduce virtualization overhead
  - All containers run on a single host
  - Reduce OS licensing cost / maintenance overhead



Machine Virtualization



Containers

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

Programming Frameworks

- **Programming frameworks** emerged to:
  - "scale out" workloads
  - Distribute work over thousands of machines
- **Parallel approach** has existed for a long time to program clusters
  - Challenging for programmers
  - Track many things:
    - Parallelize application
    - Distribute data
    - Handle failures
    - Debugging
    - Race conditions/Heisenbugs
- **The difference is the user interface**
  - Google developed MapReduce 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

- Data centers
- Virtualization
- 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)