CSCI 5409 Cloud Computing – Fall, 2023
Week 3 – Lecture 2 (Sep 22, 2023)

Cloud-Enabling Technology – Data Center Hardware

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Housekeeping and Feedback

- Newly registered students please ask me to add you to the Teams channel and AWS Academy courses.
- Term assignment released on Brightspace
- Start learning Terraform by yourself. The K8s assignment will require this. I will release K8s assignment soon.

Objectives

- Understand the hardware and software that enables cloud computing
- Understand the potential constraints for making architectural decisions
- Understand the technologies that make cloud computing possible
  - Data center hardware
  - Broadband networks and Internet architecture
  - Virtualization
  - World Wide Web

Contents

Broadband Networks

1. Internet Architecture
2. Bandwidth
3. Hops between Sites
4. Bandwidth Cost

Internet Architecture

- One of cloud computing's characteristics - "**ubiquitous access**" indicates cloud is widely accessible by a range of devices, transport protocols, etc.
- The Internet is the miracle that makes this possible, it is one of humankind's greatest achievements
- The figure on the right demonstrates ubiquitous access: a cloud provider delivering services to a mobile device user as well as desktop users on-premise at a cloud consumer

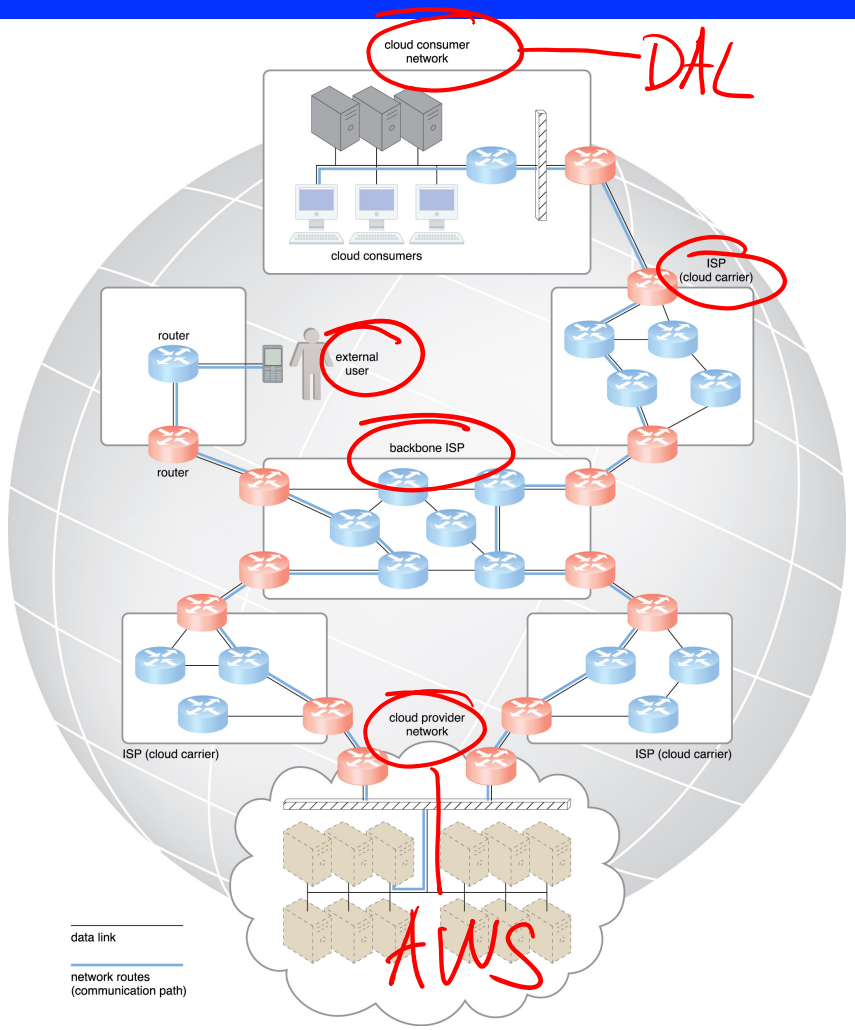
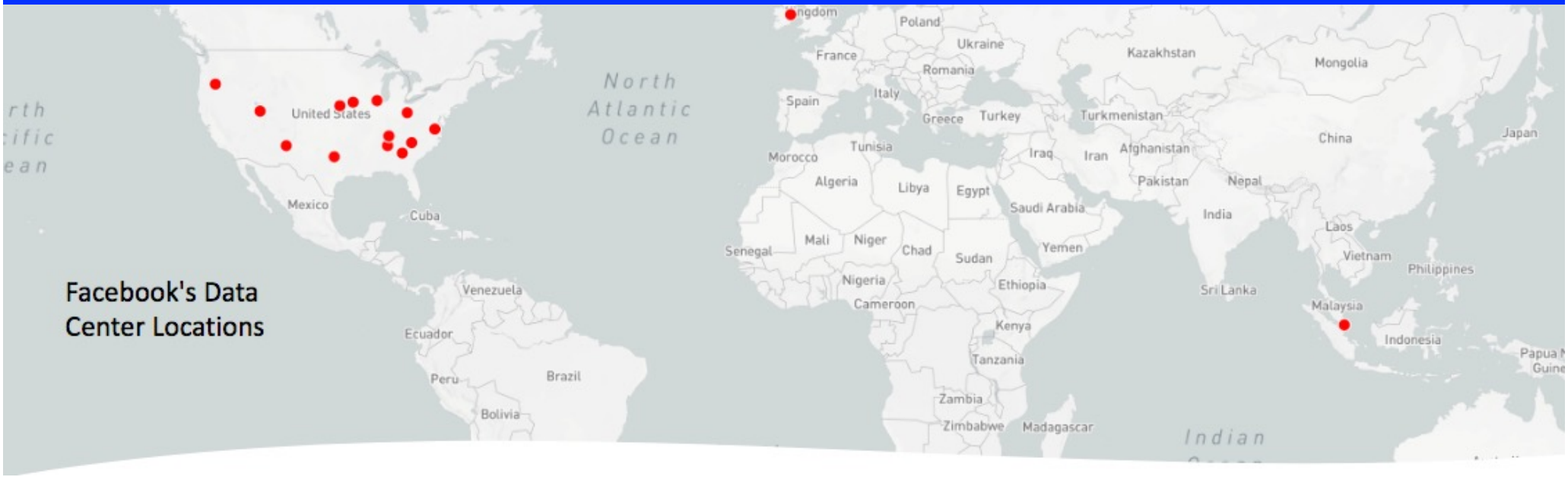


Figure from: Cloud Computing (T.Erl, Z. Mahmood, R. Puttini)

Bandwidth

- "They want to deliver vast amounts of information over the Internet. And again, the Internet is not something that you just dump something on. It's not a big truck. It's a series of tubes. And if you don't understand, those tubes can be filled and if they are filled, when you put your messages in, it gets in line and it's going to be delayed by anyone that puts into that tube enormous amounts of material, enormous amounts of material." – US Senator Ted Stevens
- If the Internet is a series of tubes, bandwidth is the diameter of the pipe, it is the data transfer limit of any one interconnect on the path from source to destination

Latency



- "Also referred to as time delay, latency is the amount of time it takes a packet to travel from one data node to another. Latency increases with every intermediary node on the data packet's path."[1]
- Latency, in addition to redundancy, is the reason cloud providers have data centers spread around the world
  - Organizations use this geographical diversity to replicate their infrastructure globally
  - In terms of ability to offer speed to your customers, most organizations cannot compete with the capacity of cloud providers.

1. Cloud Computing (T. Erl, Z. Mahmood, R.Puttini), page 36

Hops between Sites

My house

My ISP

Gateway into Google

Infrastructure setup on Google

```
Lus-MacBook-Pro:~ lyang$ traceroute google.com
traceroute to google.com (172.217.12.174), 64 hops max, 52 byte packets
 1  mynetwork (192.168.2.1)  5.972 ms  3.680 ms  2.850 ms
 2  hlfxns014qw-47-54-68-1.dhcp-dynamic.fibreop.ns.bellaliant.net (47.54.68.1)
 3  be22-181.cr01.hlfx.ns.aliant.net (142.176.208.85)  9.465 ms
    ae23-182.cr02.hlfx.ns.aliant.net (142.176.208.89)  4.033 ms
    be22-181.cr01.hlfx.ns.aliant.net (142.176.208.85)  5.464 ms
 4  be19.bx01.nycm.ny.aliant.net (207.231.227.110)  23.434 ms  22.422 ms  22.357
 5  72.14.220.96 (72.14.220.96)  23.625 ms  21.783 ms  22.070 ms
 6  72.14.220.96 (72.14.220.96)  21.153 ms  20.908 ms  23.051 ms
 7  108.170.248.1 (108.170.248.1)  26.490 ms
    172.253.70.5 (172.253.70.5)  24.381 ms
    108.170.248.65 (108.170.248.65)  21.456 ms
 8  lga25s62-in-f14.1e100.net (172.217.12.174)  24.576 ms  24.359 ms  21.607 ms
```

Bandwidth Costs

- Bandwidth isn't free for companies like it is at your house, not at the scale required to operate enterprise level websites
- In addition to the cost of actual network traffic, organizations must also maintain backup ISPs in case one ISP goes down (which it turns out happens a lot)
- Cloud providers buy in bulk, they can negotiate better prices with internet providers than smaller organizations, this is the major factor in their ability to provide low cost on-demand usage

2

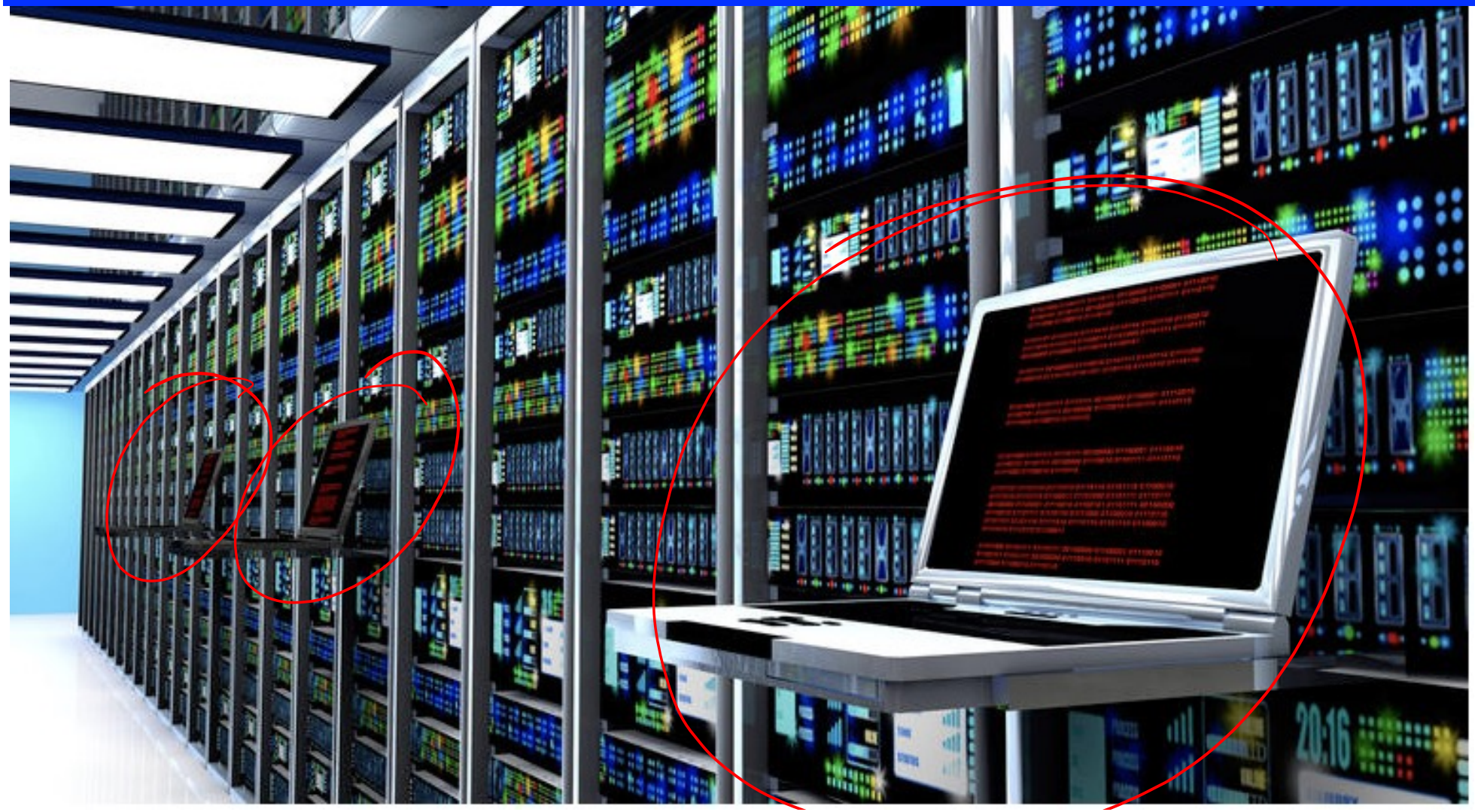
Data Center Hardware

1. What Does a Data Center Look Like?
2. Data Center Hardware

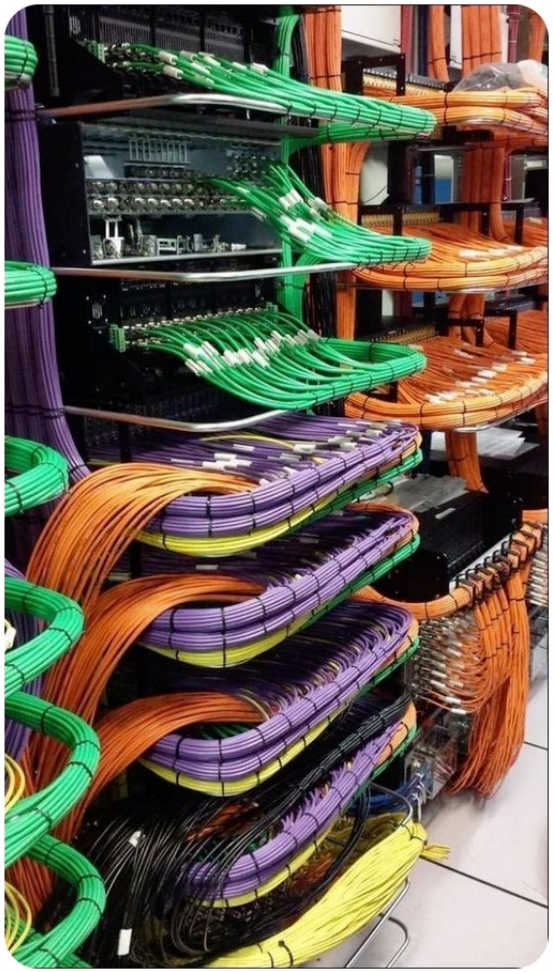
What Does a Data Center Look Like? (1/3)

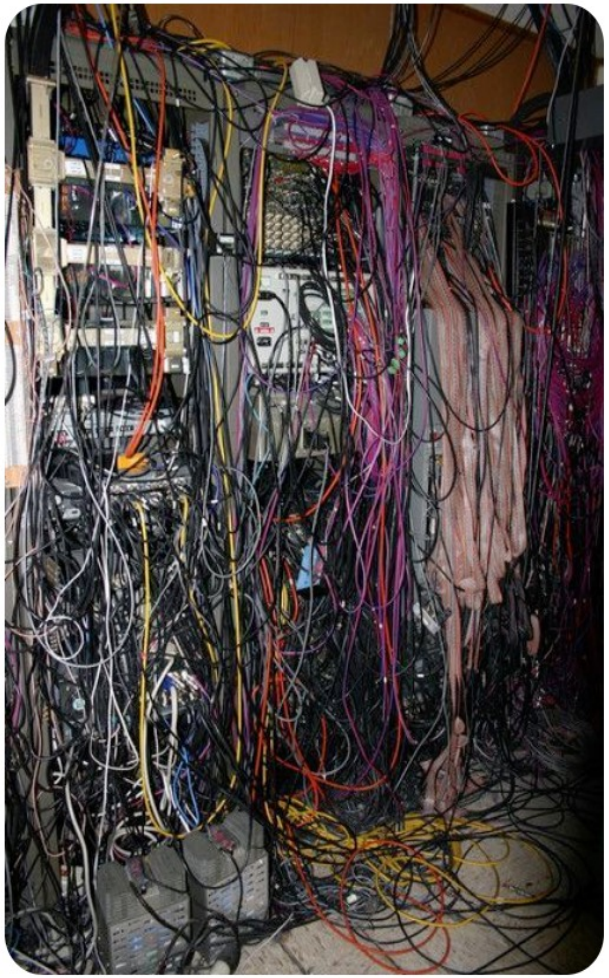
https://www.youtube.com/watch?v=9CL3pZfsHbs

What Does a Data Center Look Like? (2/3)



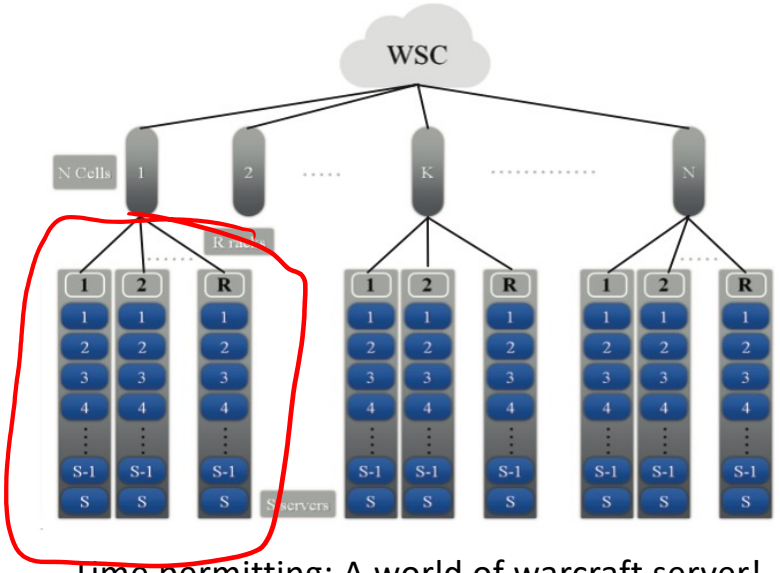
What Does a Data Center Look Like? (3/3)





Warehouse Scale Computer (WSC)[1]

- A **cluster** is a collection of desktop computers or servers connected together by a local area network to act as a single larger computer
- A **Warehouse Scale Computer** (WSC) is a cluster comprised of tens of thousands of servers
- WSCs form the backbone of cloud infrastructure
- Contains 50,000 – 100,000 processors
- A hierarchy of network connects, servers, racks and cells/arrays
- A "rack" consists of ~48 servers connected to an ethernet switch, the switch connects to a cell
- A cell/array consists of several racks, the racks in a cell are connected by an array switch
- As a general rule, it costs between $600 to $1,100 per gross square foot or $7 million to $12 million per megawatt of commissioned IT load to build a data center.



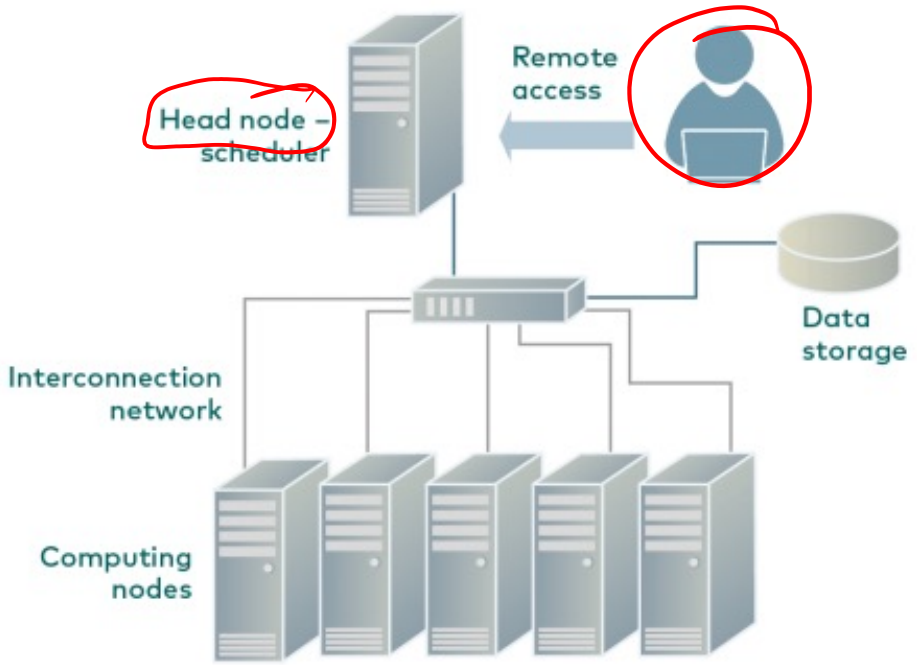
Time permitting: A world of warcraft server!
https://youtu.be/Qak6a9alQB8?t=120

[1] Cloud Computing Theory and Practice, 2nd Ed. Dan C. Marinescu

Automation & Remote Access

serial console

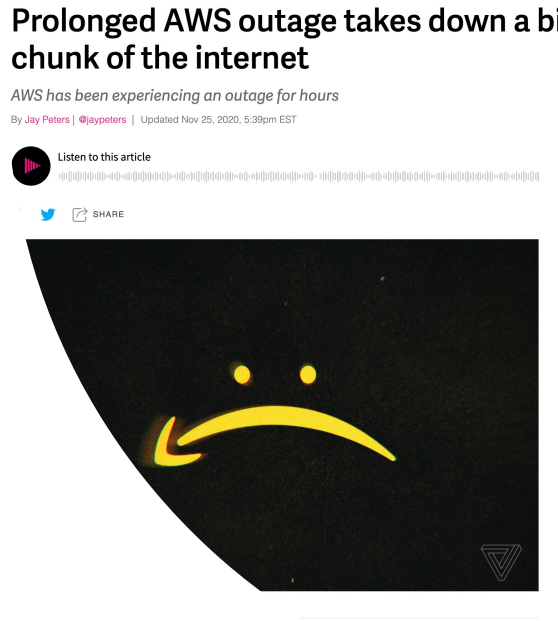
- Cloud providers invest heavily in software development to automate their data centers:
  - Provisioning (adding and removing hardware in the WSC)
  - Fault detection and recovery
  - Replication
- Data centers have extremely limited physical access, ensuring physical security, most monitoring and administrative tasks are performed remotely



High Availability

- Any form of data center outage impacts every business served by that data center, millions of dollars are at stake
- **Everything** about their hardware and software choices is focused on increasing the number of 9's of reliability they can provide, for example:
  - AWS regions can operate for 24 hours disconnected from the global AWS infrastructure, and recover and replicate outwards when reconnected
  - AWS: 99.9999999% ← Nice!
  - Azure: 99.995% ← Not bad
  - Google cloud platform: 99.95% ← Pfft lame

The term "five 9s" refers to a reliability level of 99.999%. This means that the system or process is operational 99.999% of the time. This is an incredibly high level of reliability, and is often used as a benchmark for mission-critical systems.



Availability and Reliability

What is availability in cloud computing?

High availability is the ultimate goal of moving to the cloud. The idea is to make your products, services, and tools available to your customers and employees at any time from anywhere using any device with an internet connection.

Cloud availability is related to cloud reliability.

What is reliability in cloud computing?

- When you access an app or service in the cloud, you can reasonably expect that:
  - The app or service is up and running.
  - You can access what you need from any device at any time from any location.
  - There will be no interruptions or downtime.
  - Your connection is secure.
  - You will be able to perform the tasks you need to get your job done.

Availability, or the amount of time a system is up and functioning properly, is another term associated with **reliability** in cloud computing. While **availability** is measured in terms of time loss, **reliability** is measured in terms of the number and impact of failures. Reliability may be seen as a measure of availability.

Security-Aware Design & Operations

- **Physical and software access controls:**
  - Motion sensers
  - Biometrics
  - 24-hour security
  - Sharks with laser beams
- **Principle of lease privilege**:
  - If you don't **need** it, you don't **get** it
  - Entry is logged, monitored and timed
  - Physical access only to what you **need** to access
- Hardware decommissioning policies/practices (e.g. hard drive woodchippers)

Photo: https://www.dublininquirer.com/2018/11/28/paul-on-dublin-amazon-and-the-secret-region

CPUs

- Server blades contain ~96 processor cores (this changes every day, see Moore's Law)
- This changes so quickly there's little point in specifying how many, how powerful, minimums or maximums
- This is an additional core benefit of the cloud, cloud providers are constantly swapping out old ones and replacing with new ones that push the boundaries of computing, by letting cloud providers worry about infrastructure we can ride that technological wave
- **Let's see what AWS will let us pick!**

Memory

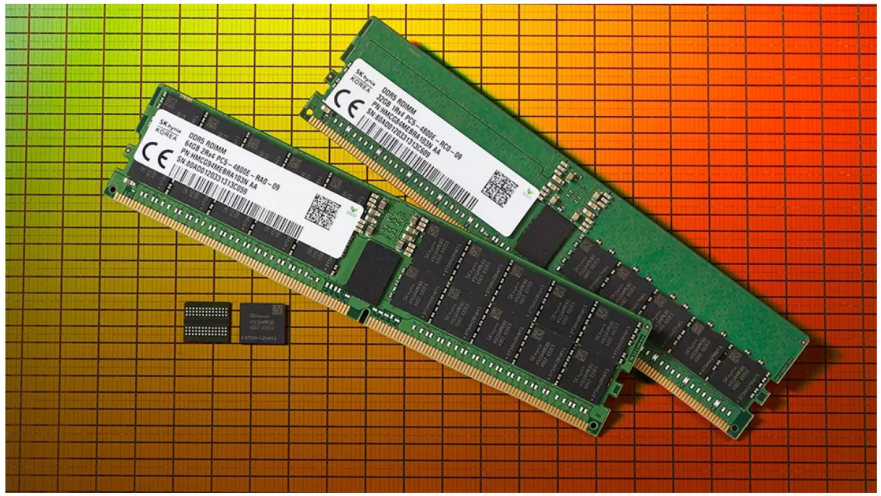
- The memory used in data centers has better fault detection:
  - "Unlike normal RAM, ECC RAM includes an additional ECC memory chip that uses complex algorithms to identify and remedy errors. ECC RAM constantly scans data as it is processed by the system, using a method known as parity checking. ECC RAM adds an additional bit to each byte, called a parity bit. The parity bit totals the 1s in the byte as either an even (0) or odd (1) binary digit. If the parity bit doesn't match what was previously recorded for a specific byte, the ECC RAM knows that an error has occurred. It can then use sophisticated code to restore the original, uncorrupted data and therefore correct the error."[1]
- When we're talking about massive data centers that process big data, hardware faults and even cosmic rays become reality. These faults must be prevented to achieve 99.9999999% reliability.

Linus Torvalds Blasts Intel For Strangling the ECC Memory Market

By Aaron Klotz 18 days ago

Says ECC can permanently fix memory instability in the consumer space

Comments (11)



(Image credit: SK Hynix)

[1]: https://www.fasthosts.co.uk/blog/ecc-ram-keeping-critical-data-error-free/

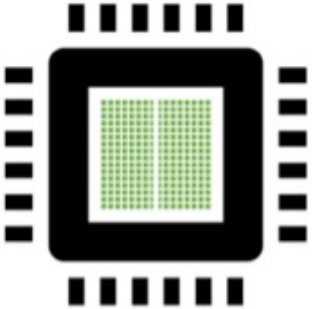
Storage

- Data centers have specialized storage systems… containers housing numerous hard disks that are organized into arrays.[1]
- These arrays include:
  - Redundant Arrays of Independent Disks (RAID) hard disk arrays
  - Controllers with massive cache
  - Hot-swappable hard disks, removeable without powering down
  - Software that virtualizes the physical drives
  - Fast data replication mechanisms: snapshotting, volume cloning
- **Network-Attached Storage (NAS)**:
  - We can connect arrays to a network device to provide storage to virtual machines through technologies like Network File System (NFS) and Server Message Block (SMB)
- Cloud providers further increase reliability by replicating data across geographical regions, everything you store is stored in many many places
- Robot controlled tape libraries provide cost-effective cold storage for big data / backup

[1]: Cloud Computing (T. Erl, Z. Mahmood, R. Puttini), pg. 93

GPU

- Some cloud systems require the accelerated computing power provided by GPUs:
  - Machine learning
  - Big Data processing
  - Image / video processing
- These are priced much higher than CPU only machines, yet the cost is offset by the quantity or speed of processing made possible by GPUs
- CPUs are optimized for **latency**, speed of computation[1]
- GPUs are optimized for **throughput**, operating on bulks of data at once[1]



CPU	GPU
Central Processing Unit	Graphics Processing Unit
4-8 Cores	100s or 1000s of Cores
Low Latency	High Throughput
Good for Serial Processing	Good for Parallel Processing
Quickly Process Tasks That Require Interactivity	Breaks Jobs Into Separate Tasks To Process Simultaneously
Traditional Programming Are Written For CPU Sequential Execution	Requires Additional Software To Convert CPU Functions to GPU Functions for Parallel Execution

[1]: https://towardsdatascience.com/the-ai-illustrated-guide-why-are-gpus-so-powerful-99f4ae85a5c3

Network

- Network hardware in data centers is obviously extremely complicated, it could probably be an entire engineering course
- Switches:
  - Routing devices that connect network nodes
  - These ain't your Asus router in your house →
- Role-specific network hardware:
  - Hardware-based firewalls
  - Hardware-based load balancers
  - Web accelerators (XML pre-processors, encryption/decryption appliances, layer 7 switching devices)

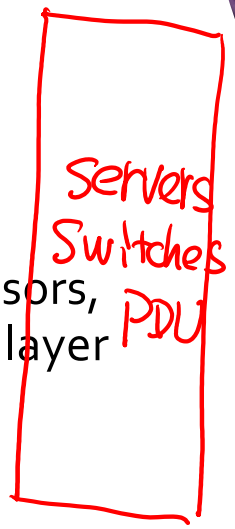


Photo: http://www.firewall.cx/cisco-technical-knowledgebase/cisco-switches/1171-cisco-nexus-7000-module-shutdown-replacement-removal.html


Kahoot!