CS349D Cloud Computing

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Spring 2023, MW 1.30– 2.50pm, Hewlett 101

cs349d.stanford.edu

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Student Intro

Class Topics in 2018

Storage
CAP theorem
Cloud economics
Databases
Analytics systems
Stream processing
Resource managers
Resource allocation
Serverless computing
Monitoring & debugging
Programming models
ML platforms
ML serving
Hardware
Security
Privacy
SRE / DevOps
Edge computing

Class Topics in 2023

Cloud basics

Tools for building infrastructure *[management, observability]*

Data infrastructure *[databases and lakehouses]*

Infrastructure for ML *[training, serving, MLops]*

Security infrastructure *[Nitro, data-driven security]*

Confidential computing *[private analytics and ML]*

Class Format

Half lectures will be a guest lecture

- No video, come in person
- <u>Participate in the discussion</u>

Half lectures will be paper discussions

- Read the papers ahead of time and submit summaries
- 2-3 students summarize papers & lead discussion
- <u>We all participate in the discussion</u>
- 1 student takes notes

What to Look for in a Paper

The challenge addressed by the paper

The key insights & original contributions

- Real or claimed, you have to check

Critique: the major strengths & weaknesses

- Look at the claims and assumptions, the methodology, the analysis/evaluation, and the presentation style

Future work: extensions & improvements

- Can we apply the methodology to other problems?
- What are the broader implications?

Tips for Reading Papers

Read the abstract, intro, & conclusion first

Read the rest of the paper twice

First a quick pass to get rough idea then a detailed reading

Underline/highlight the important parts of the paper

Keep notes on the margins about issues/questions

Key insights, questionable claims, relevance to other topics, etc.

Look up references that seem to important or missing

You may also want to check who references this paper and how

Tips for Leading Discussion

Keep paper summary to 5min

- Assume everyone has read it recently

Prepare a few questions to keep discussion going

- Questions on basics, dig further into techniques, alternative approaches, draw links to recent discussions, …
- Be open to questions from the rest of the class

Moderate discussion

Research Project

Groups of 2-3 students

Topic

- Address an open question in cloud computing
- Suggested by staff or your own idea

Timeline (TBD)

- Project proposal – around week 3
- Mid-term checkpoint – around week 6
- Presentation/paper – week 10

Grading

Project 65%

Participation 20%

Paper summaries/presentation: 15%

Reminders

Make sure you are registered on Axess and EdStem

- Contact instructors if you need help

Fill in form with interests for discussion topics

- We will assign topics for leads and note taking

Start talking about projects

- Form a group

Next Meeting: Cloud Basics

Goal: get us all on the same page

Read the two white papers from AWS

- AWS Overview, Well architected Framework
- No summaries needed
- Come prepared to discuss the state of cloud

Cloud Computing Overview

Christos Kozyrakis

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What is Cloud Computing?

Informal: computing with large datacenters

What is Cloud Computing?

~~Informal: computing with large datacenters~~

Our focus: computing as a utility

» Outsourced to a third party or internal org

Types of Cloud Services

Infrastructure as a Service (IaaS): VMs, disks

Platform as a Service (PaaS): K8S, MapReduce

Software as a Service (SaaS): Email, GitHub

Public vs private clouds:

Shared across arbitrary orgs/customers
vs internal to one organization

Example

AWS Lambda functions-as-a-service

- Runs functions in a Linux container on events
- Used for web apps, IoT apps, stream processing, highly parallel MapReduce and video encoding

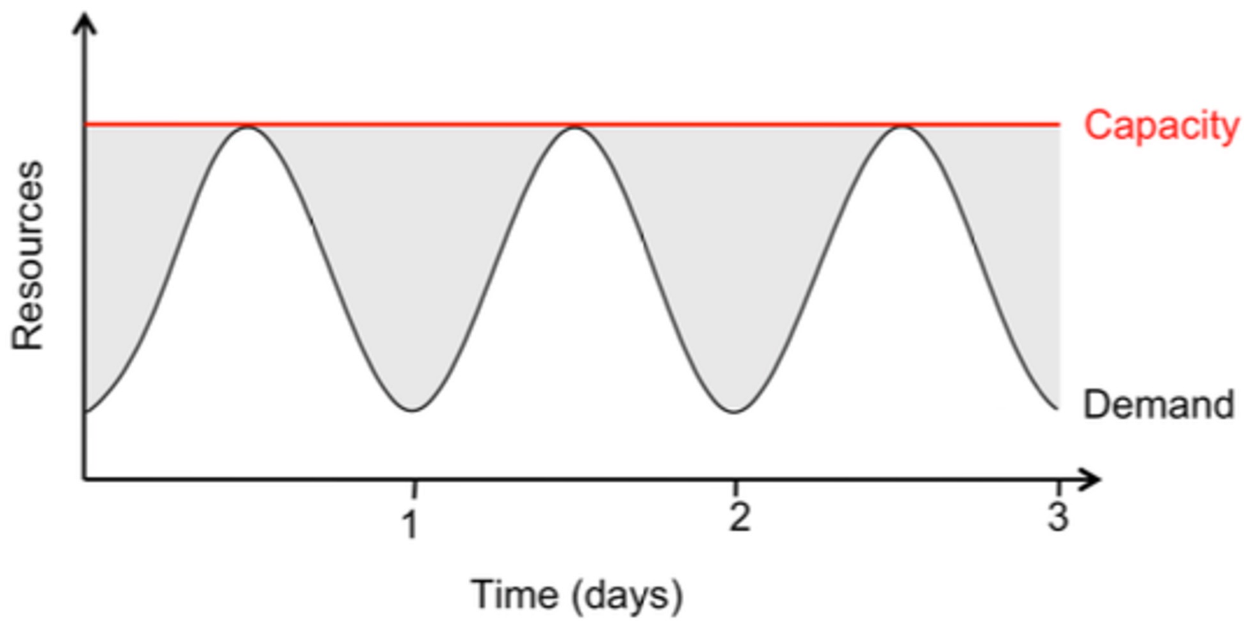
Cloud Economics: For Users

Pay-as-you-go (usage-based) pricing:

» Most services charge per minute, per byte, etc

» No minimum or up-front fee

» Helpful when apps have *variable utilization*

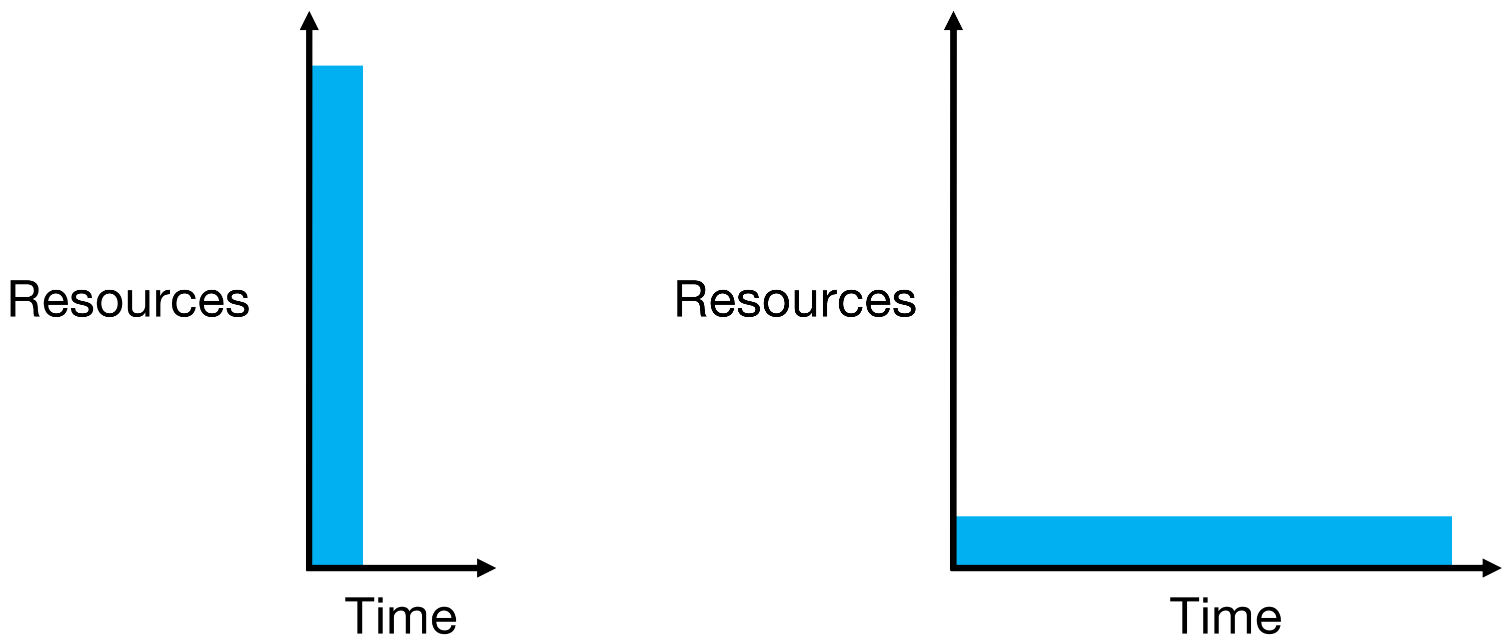


Cloud Economics: For Users

Elasticity:

» Using 1000 servers for 1 hour costs the same as 1 server for 1000 hours

» Same price to get a result faster!



Cloud Economics: For Providers

Economies of scale:

» Purchasing, powering & managing machines at scale gives lower per-unit costs than customers’

» Tradeoff: fast growth vs efficiency

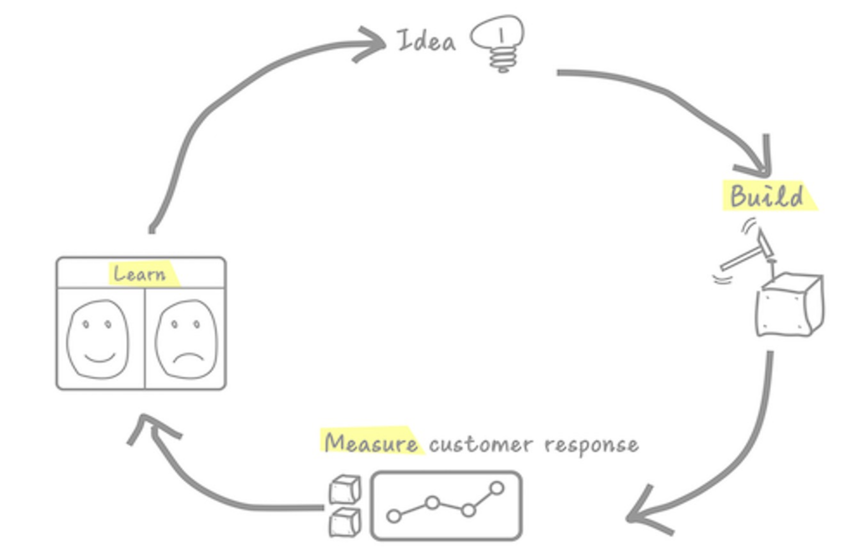
» Tradeoff: flexibility vs cost

Cloud Economics: For Providers

Speed of iteration:

» Software as a service means fast time-to-market, updates, and detailed monitoring/feedback

» Compare to speed of iteration with ordinary software distribution



Questions

- Assume you are a cloud provider

  How do you avoid having many your customers spike at the time time?

Other Interesting Features

Spot market for preemptible machines

Wide geographic access for disaster recovery and speed of access

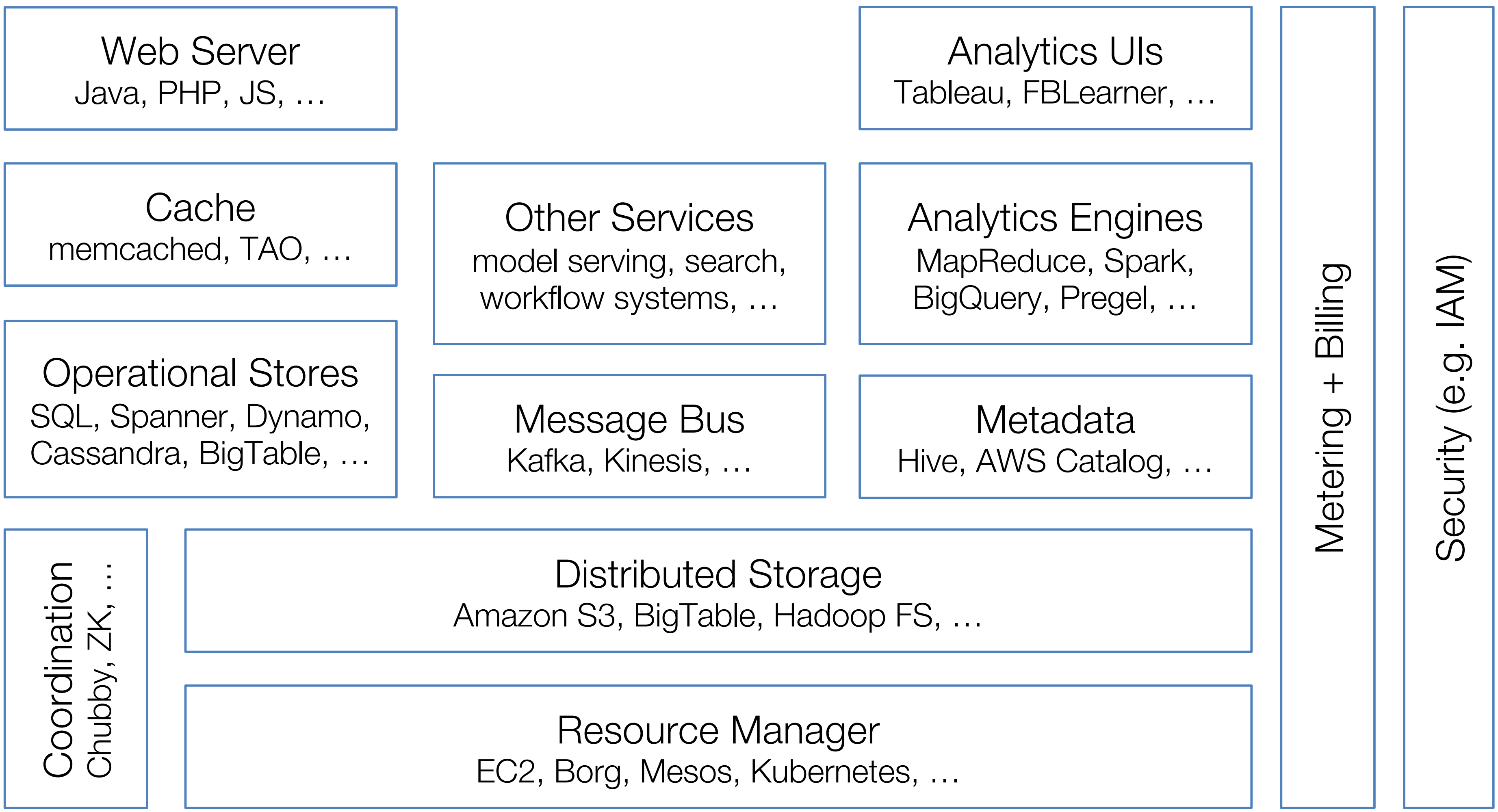
Ability to quickly try exotic hardware

Ability to A/B test anything

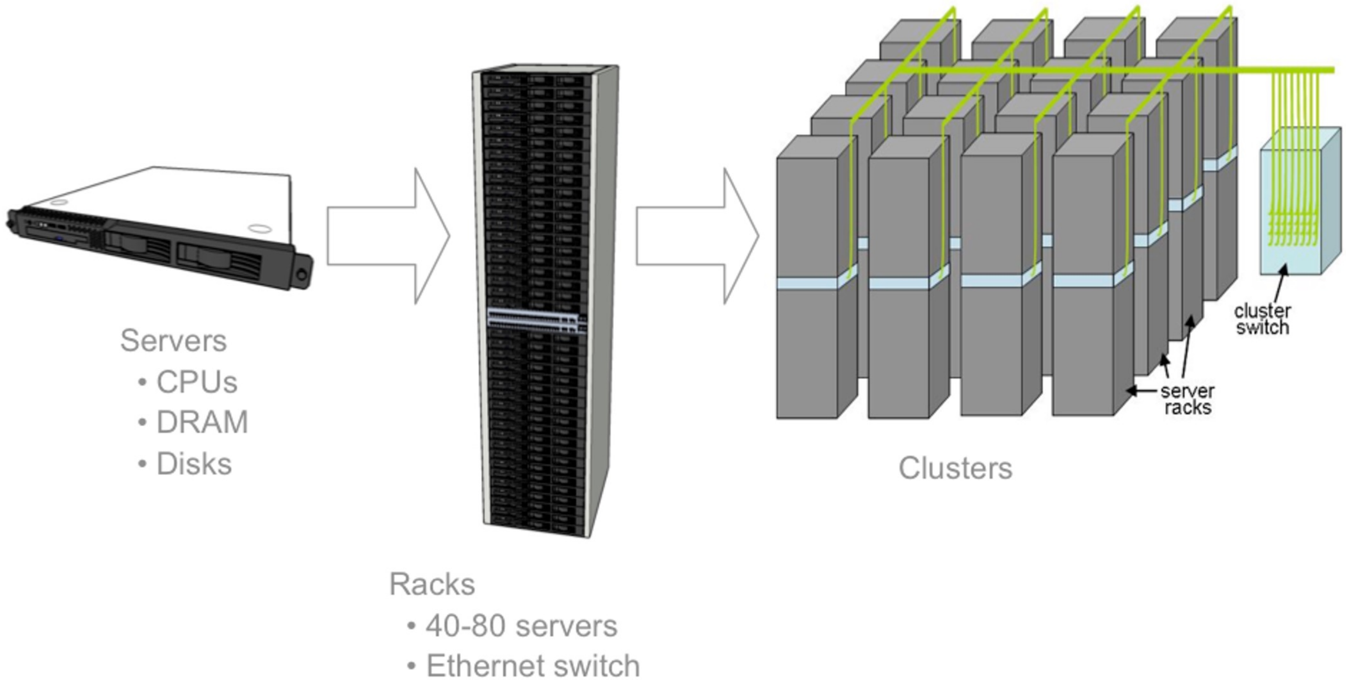
Common Cloud Applications

1. Web and mobile applications
2. Data analytics (MapReduce, SQL, ML, etc)
3. Stream processing
4. Batch computation (HPC, video, etc)

Cloud Software Stack



Datacenter Hardware



Rows of rack-mounted servers

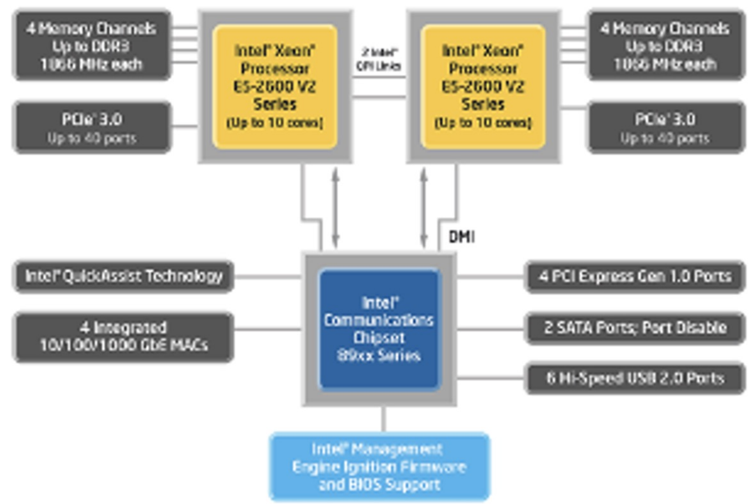
Datacenter: 50 – 200K of servers, 10 – 100MW

Often organized as few and mostly independent clusters

Datacenter Example

Datacenter HW: Compute

2-socket server



The basics

- Multi-core CPU servers
- 1 & 2 sockets

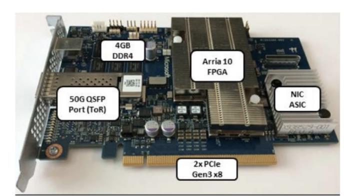
What's new

- GPUs
- Custom accelerators (AI)
- FPGAs

Google TPU2

Nvidia GPU

Microsoft Catapult

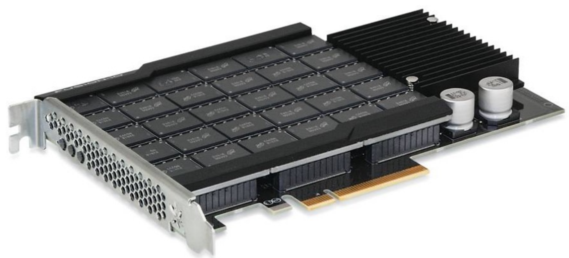


Datacenter HW: Storage

The basics

- Disk trays
- SSD & NVM Flash

NVMe Flash

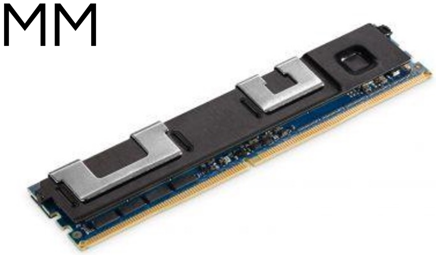


JBOD disk array

What's new

- Non-volatile memories
- New archival storage (e.g., glass)

NVM DIMM



Distributed with compute or NAS systems

- Remote storage access for many use cases (why?)

Datacenter HW: Networking

The basics

- 40, 100, 200 GbE NICs
- 100GbE to 200 GbE switches
- Clos topologies

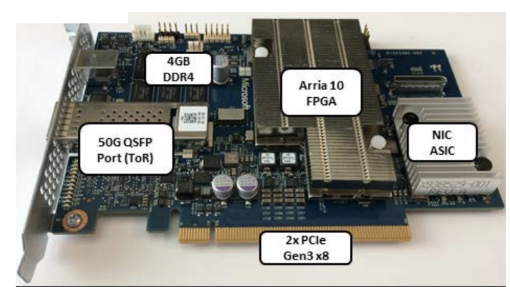
100GbE Switch

Smart NIC

What's new

- Software defined networking
- In network computation
- Smart NICs
- FPGAs

Microsoft Catapult



Performance Metrics

Throughput

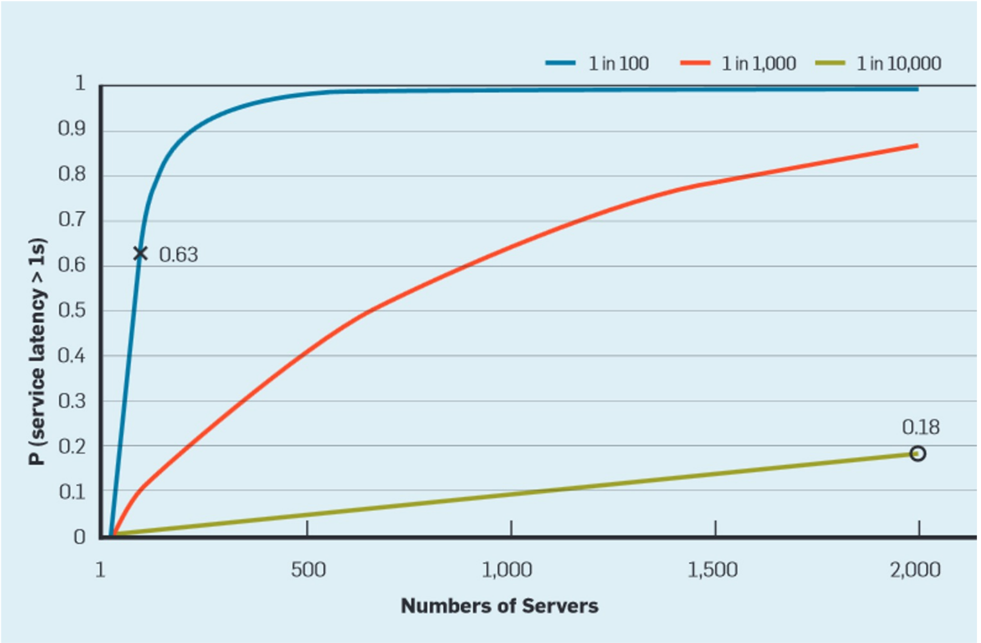
- Requests per second
- Concurrent users
- Gbytes/sec processed
- ...

Latency

- Execution time
- Per request latency

Tail Latency

[Dean & Barroso,'13]



The 95th or 99th percentile request latency

End-to-end with all tiers included

Larger scale → more prone to high tail latency

Total Cost of Ownership (TCO)

TCO = capital (CapEx) + operational (OpEx) expenses

Operators perspective

CapEx: building, generators, A/C, compute/storage/net HW

Including spares, amortized over 3 – 15 years

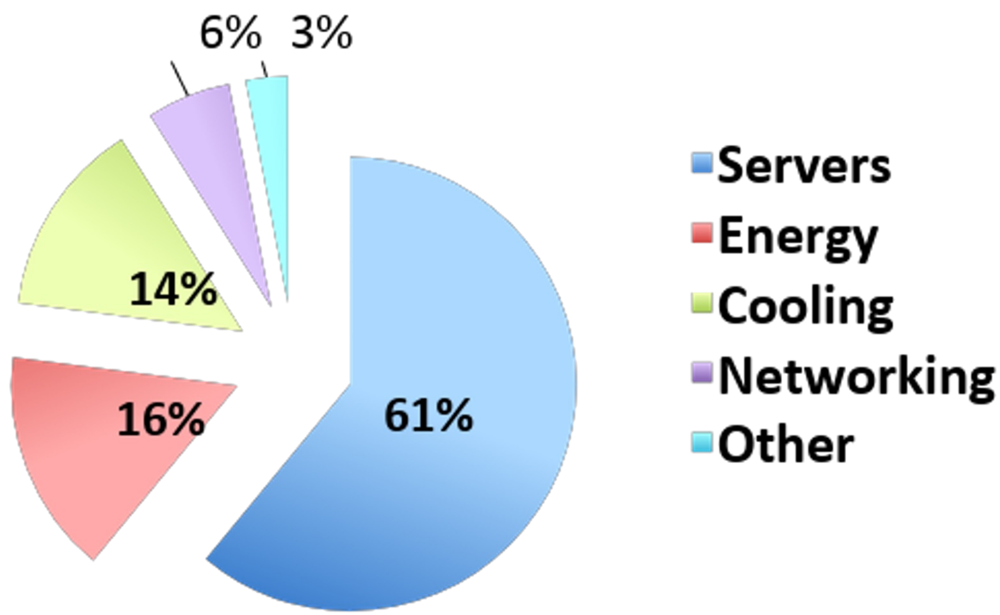
OpEx: electricity (5-7c/KWh), repairs, people, WAN, insurance, …

Users perspective

CapEx: cost of long term leases on HW and services

OpeEx: pay per use cost on HW and services, people

Operator's TCO Example



[Source: James Hamilton]

Hardware dominates TCO, make it cheap

Must utilize it as well as possible

Questions

How can both providers and users benefit financially from cloud computing

When should users consider hybrid or on-premise computing?

Reliability

Failure in time (FIT)

- Failures per billion hours of operation = 10^9/MTTF

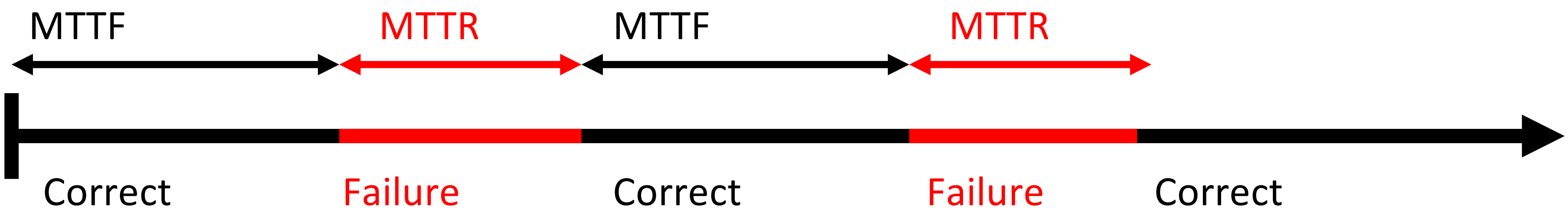
Mean time to failure (MTTF)

- Time to produce first incorrect output

Mean time to repair (MTTR)

- Time to detect and repair a failure

Availability



Steady state availability = MTTF / (MTTF + MTTR)

Key Availability Techniques

Technique	Performance	Availability
Replication	✓	✓
Partitioning (sharding)	✓	✓
Load-balancing	✓	
Watchdog timers		✓
Integrity checks		✓
Canaries		✓
Eventual consistency	✓	✓

- Make apps do something reasonable when not all is right
  - Better to give users limited functionality than an error page
- Aggressive load balancing or request dropping
  - Better to satisfy 80% of the users rather than none

The CAP Theorem

In distributed systems, choose 2 out of 3

Consistency

Every read returns data from most recent write

Availability

Every request executes & receives a (non-error) response

Partition-tolerance

The system continues to function when network partitions occur (messages dropped or delayed)

Useful Tips

Check for single points of failure

Keep it simple stupid (KISS)

- The reason many systems use centralized control

If it’s not tested, do no rely on it

Question: how do you test availability techniques with hundreds of loosely coupled services running on thousands of machines?

Questions

Other major advantages or disadvantages of cloud computing?