IOWA

CS5630

Datacenters (2): Software Infrastructure

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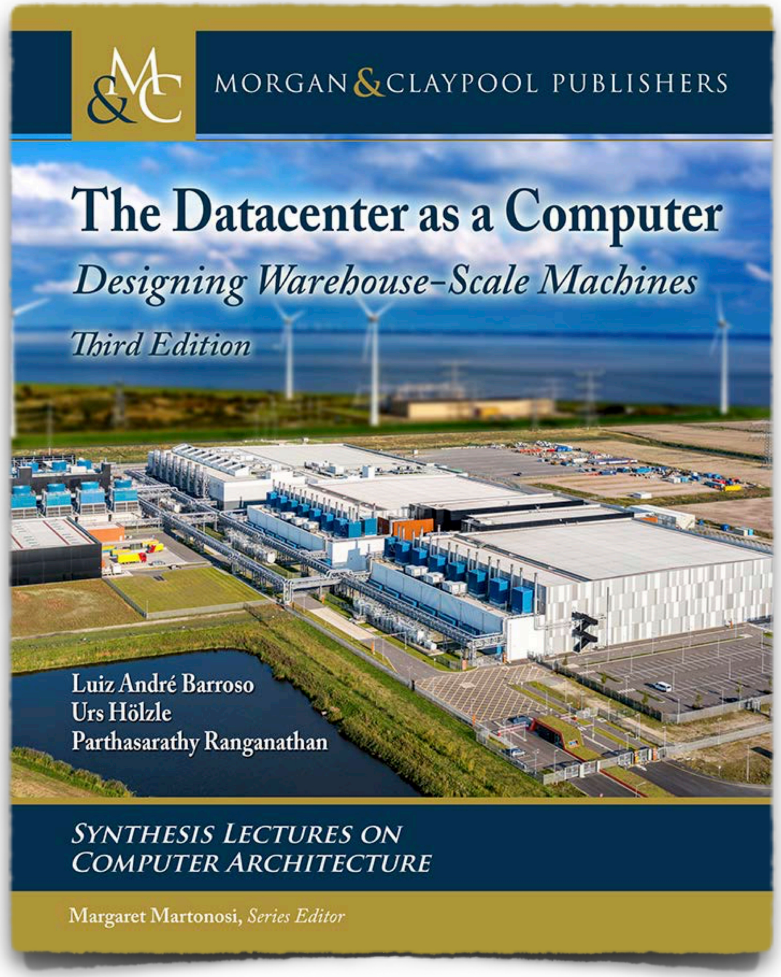
Lecture goals

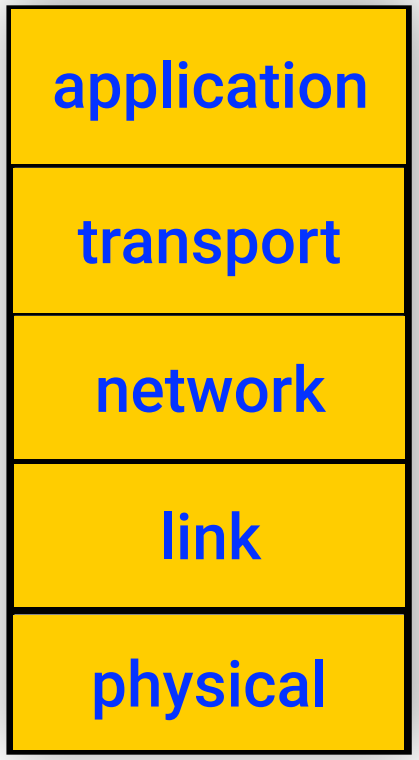
Deep dive into software systems that make WSC and datacenters work

- *Datacenter systems stack*
- *WSC applications*
- *WSC Software tradeoffs*



Chapter 2

Systems stack *(that we already know)*



What is **layering**?

An approach to **designing complex systems**

- *allows identifying system's components and explicitly defining their relationship*

Modularization eases maintenance and updating of system

- *change in layer's service implementation: transparent to rest of system*

Why is layering useful for **computer networks**?

Computer networks have multitude of components interacting with each other

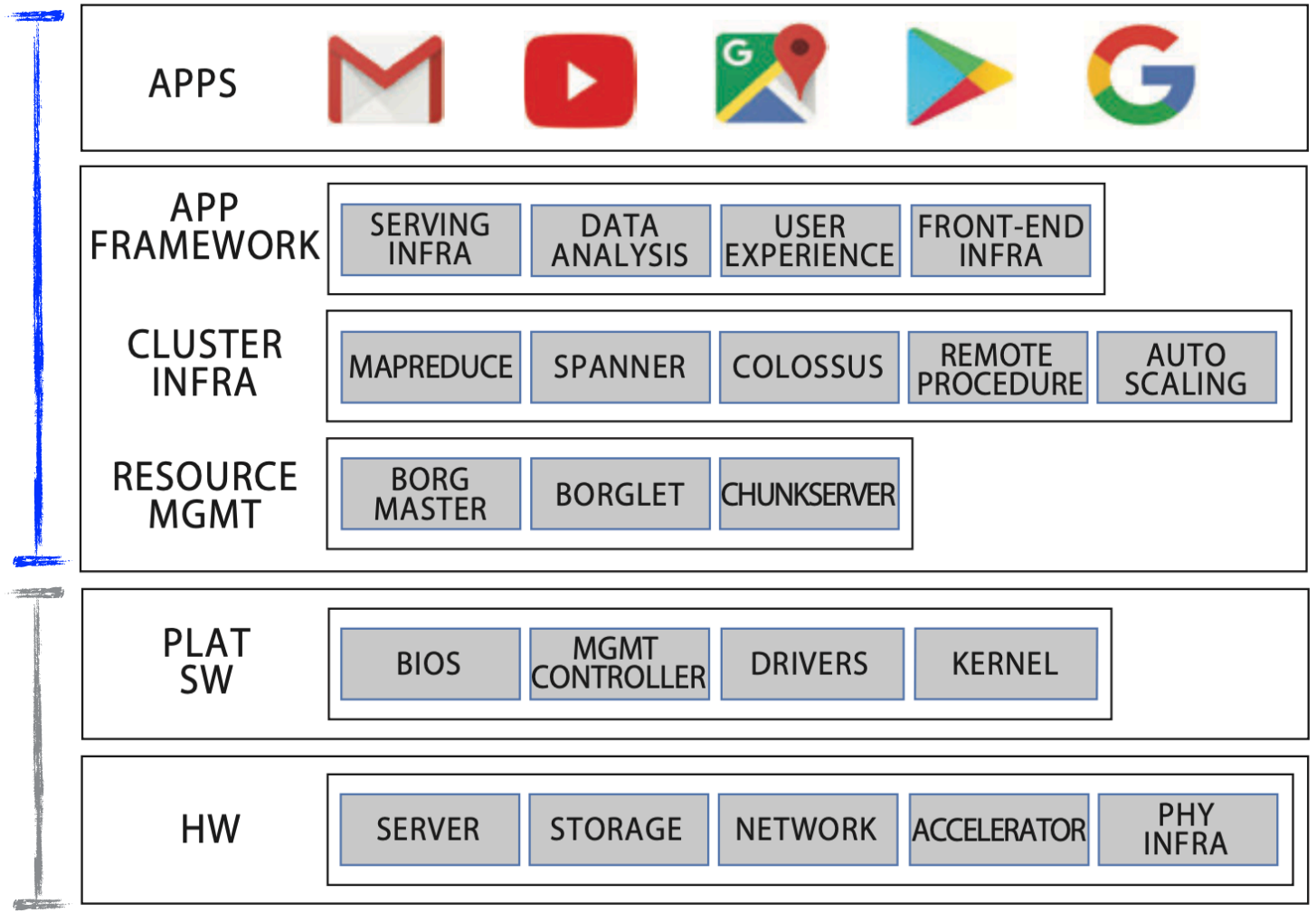
- *host devices, routers, links, protocols, applications, policies, and so on*

Internet is arguably the **largest engineered system** ever created by humans!

Datacenter systems stack

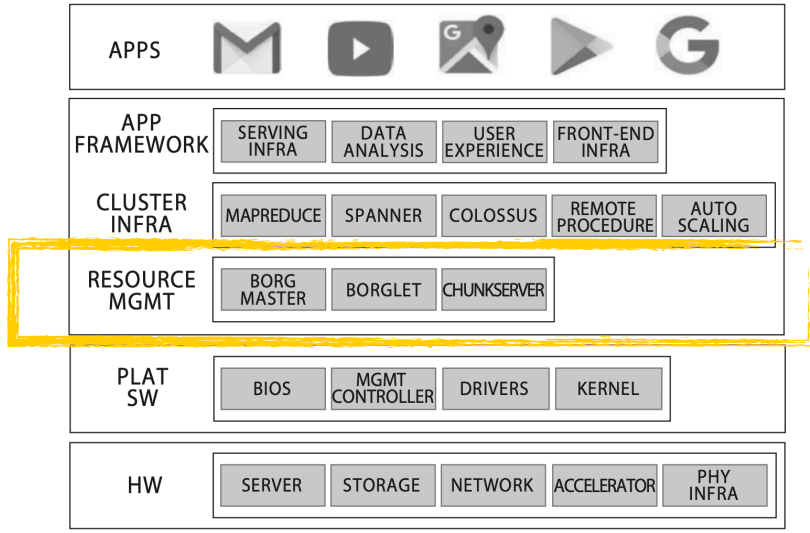
Focus of TODAY's lecture

Focus of NEXT lecture



Resource Management

The layer that maps user tasks to hardware resources



Key responsibilities

- Basic task management services
- Enforcing resource utilization quotas and priorities
- Efficient use of hardware resources
- Failure management (both for hardware/user jobs)

Service-levels

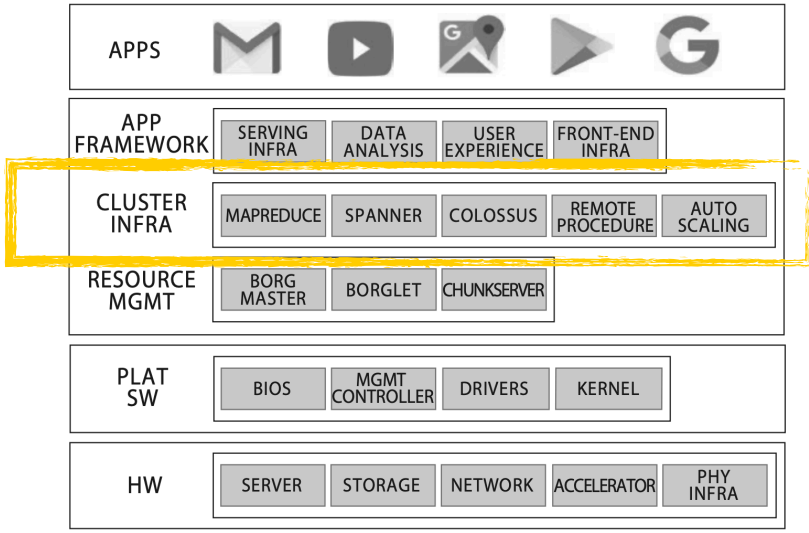
- In *simpler* forms, it would allow manual allocation of groups of machines to a given user or job
- In *advanced* forms, it would allow automate allocation and enable sharing at finer granularity

Real-world examples

- Google's Kubernetes, Borg
- Mesos, YARN, and Twine (all these three are in our set-2 research papers!)

Cluster Infrastructure

The layer that provides cluster-level functionalities



Key responsibilities

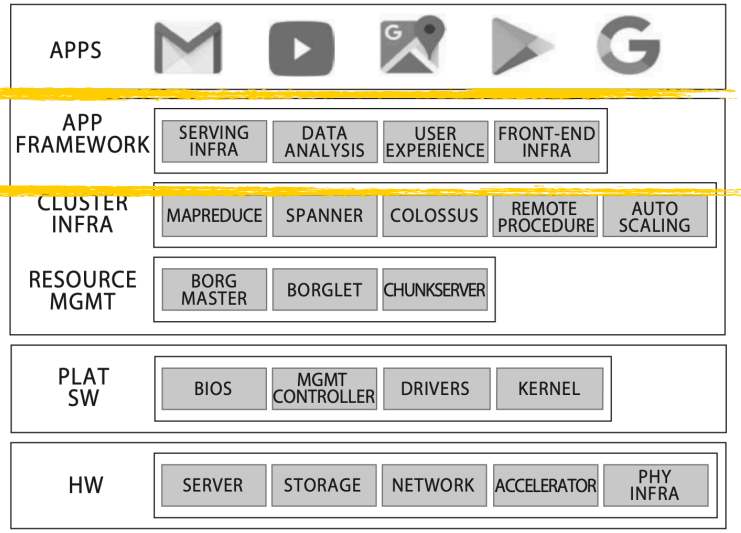
- Distributed computation and distributed storage
- Remote procedure calls (RPCs)
- Message passing and synchronization
- Cluster-level management (software images, tools for debugging/optimization)

Real-world examples

- *MapReduce, Hadoop, Spark* for distributed computing (included in set-2 research papers!)
- *Google File System* for distributed storage (included in set-2 research papers!)
- *X-Trace* for performance debugging

Application Framework

The layer that provides WSC abstraction for applications



Key responsibilities

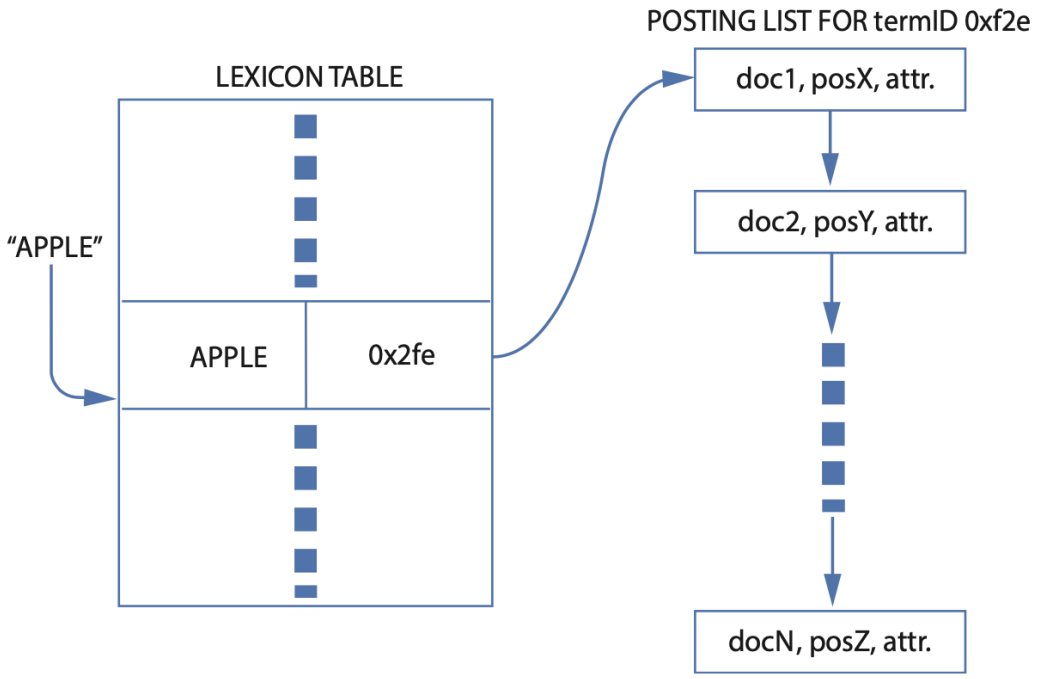
- Hide the inherent complexity of underlying WSC infrastructure
- Provide programming frameworks that ease of application development

Real-world examples

- *MapReduce, Hadoop, Spark* for distributed computing (included in set-2 research papers!)
- *Amazon RDS* for creating/operating SQL databases on the cloud
- *Google AppEngine* for developing scalable web apps

Applications on WSC

Web Search



Application design

- Search engines crawl and collect WWW documents into a repository
- Next, they build an index by inverting the documents into a lexicon table
- Each lexicon entry identifies a list of documents that contain that term + metadata (such as its position etc)

Scale *(only a ballpark since WWW is always growing)*

- WWW contains 100 billion documents (a conservative estimate)
- Average document size of 4KB (after compression)
- Crawl DB will be 400TB
- Inverted index will be on the same order of magnitude

Web Search

Runtime operation

- Receives a user query
- Looks up invested index to find all documents that contain all search terms
- Rank the resulting documents (e.g., PageRank)
- Return the highest ranked documents to the user

Key metrics

Latency (user's experience)
High throughput (volume of queries)
Scaling up/down (workload variation)

Mechanics under the hood

- *Index partitioning*: Given the massive scale of data, the index is split across a large number of machines
- *Replication*: For throughput and fault tolerance, multiple copies of index files are placed on different machines
- *Load-balancing*: A front-end server distributes the queries across multiple machines, combines the ranked lists, procures the actual documents identified in the top results, and returns a search-result view

Video Serving

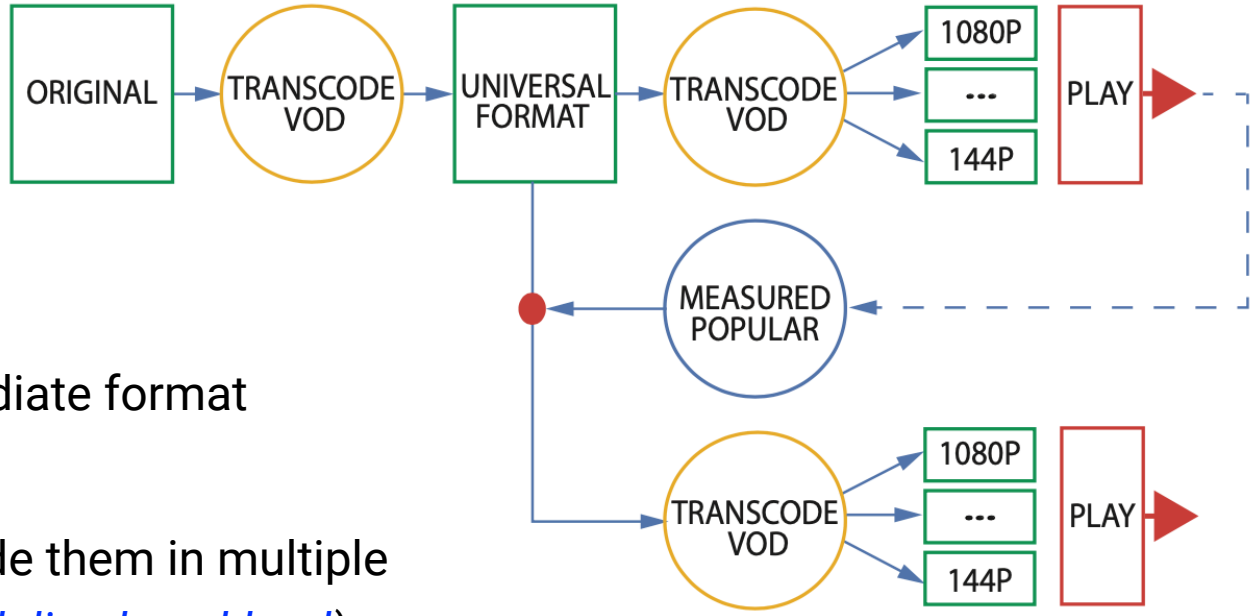
Key challenges

- *Data volume*: video traffic represents 73% of the global Internet traffic
- *Scale*: every minute, users upload 400 hours of video, and watch a million hours of video
- *Storage*: total estimated storage for YouTube videos = 10 million TB (circa 2020)
- *Heterogeneity*: user devices have wide range of capabilities and bandwidth (both of which may vary w/ time)

Key functionalities

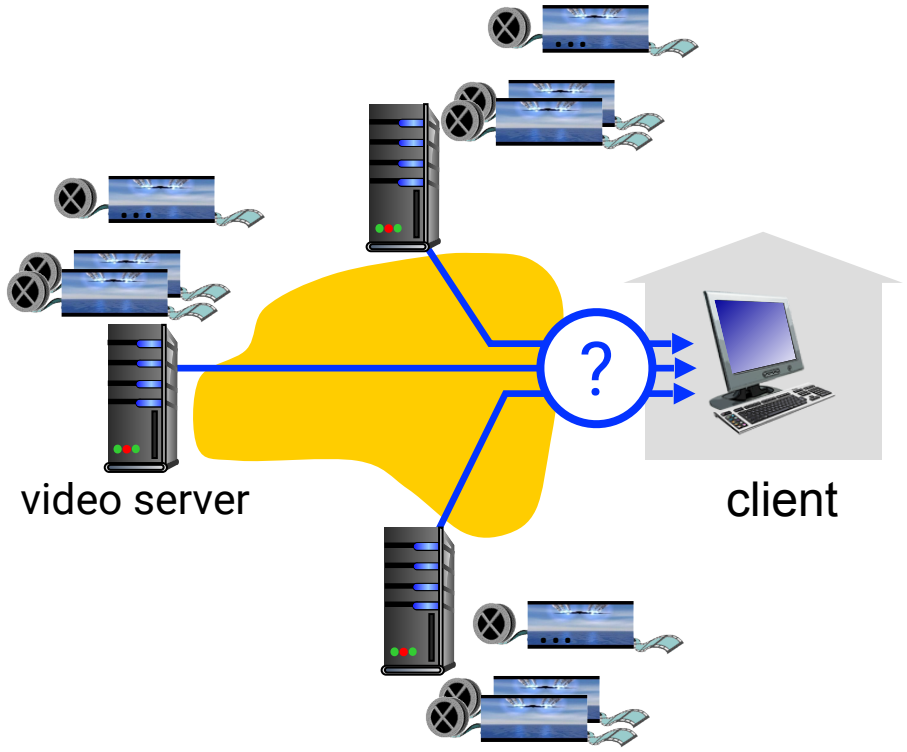
- *Transcoding* the video: convert the uploaded video into standard set of codecs, resolutions, formats, and frame rates
- *Storing* the video: both originals and transcoded versions are stored; compression is employed to save storage space
- *Transmitting* the video: identify the best choice of format, and serve using the closest CDN/edge network

Video Serving (provider perspective)



- Convert user video into a common intermediate format (*for ease of processing and storage*)
- Split all videos into small chunks and encode them in multiple output codecs and resolutions (*highly parallelized workload*)
- Transfer content to appropriate datacenters, CDNs, and edge locations (*for low latency streaming to users*)
- Identify popular videos and perform enhanced compression/ encoding (*to reduce network transmission costs*)

Video Serving (client perspective)



Dynamic Adaptive Streaming over HTTP:

client determines

- **when** to request chunk (to avoid both buffer starvation and buffer overflow)
- **what encoding rate** to request (to maximize video quality when bandwidth available)
- **where** to request chunk (to minimize latency to the destination CDN server)

Tradeoffs in WSC Software

Datacenter vs. Desktop

Ample Parallelism

WSC applications exhibit both data-level and request-level parallelism

- *E.g., crawling and processing of billions of web pages*
- *E.g., search requests are independent and are read-only operations*

Workload Churn

Users are shielded from Internet application's implementation (via well-defined APIs and protocols)

- *"Move fast and break things" i.e., applications are updated more frequently than desktop software*

Fault-free Operation

Failures are much more likely at WSC scale than individual machines (i.e. multiplicative effect)

- *E.g., WSC applications should expect faults every few hours (not months and years as in the case of desktop software)*

Buy vs. Build

In-house Software

WSC applications and cluster management software are mostly written in-house

- *E.g., Google has in-house software systems in all the layers of WSC stack*
- *Traditional IT relies heavily on third-party software like DBMS, OS, utility software etc*

Flexibility and efficiency

These metrics mean different things for WSC vs. traditional IT environments

- *Flexibility for Google might mean responding to market changes quickly*
- *For desktop users, flexibility (and economy) comes from the choice of DBMS/OS/utilities*

Lack of third-party software

This trend is largely driven by the fact that WSCs are closely guarded (as opposed to desktop platforms)

- *How does one design a network stack for Google without the operational knowledge of its WSCs?*

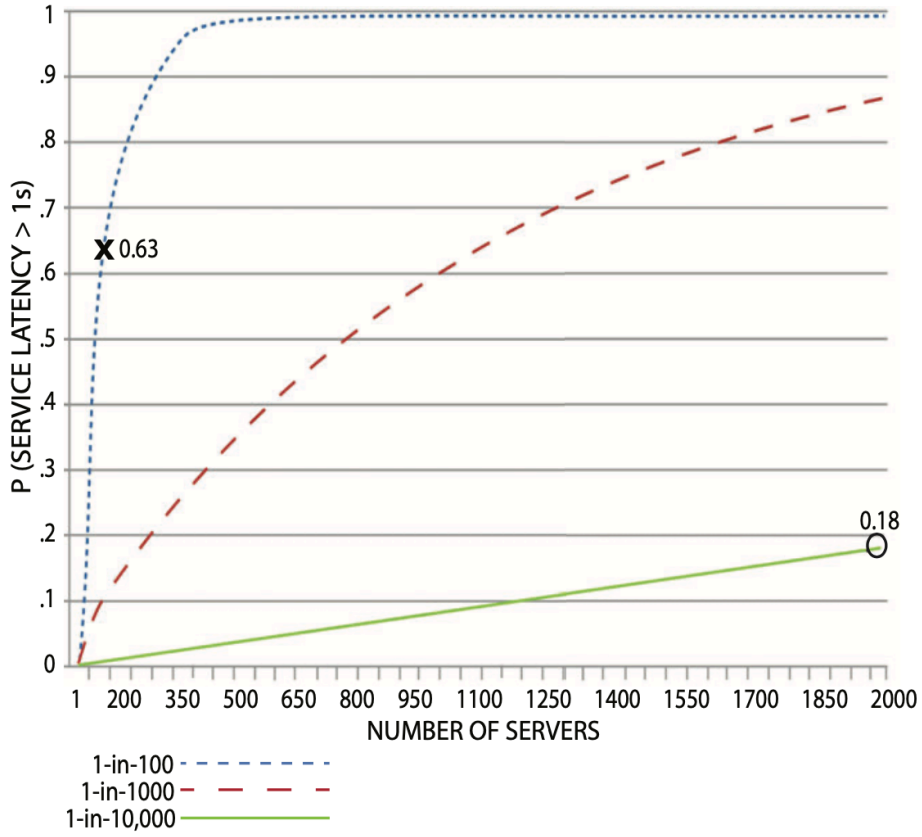
Tail Tolerance

Tail latency refers to the latency of the slowest responses

At WSC scale, variance cannot be fully eliminated

Consider a system where each server responds in 10ms but with a 99th percentile latency of 1s *(i.e., 1 out of 100 requests will experience 1s latency)*

- If a WSC application uses 100 servers for its work, then 63% of its requests will take 1s *(blue curve in CDF)*
- Let's change this to 1 in 10K requests experiencing 1s delay! Now, if your application uses 2000 such servers, you should expect 18% of requests to violate 1s mark (green curve in CDF)



Probability of >1s service level response time as the system scale varies

Performance vs. Availability

Technique	Advantage	Tradeoff
Replication	Throughput and Availability	Adds to complexity, decreases resource utilization
Sharding	Throughput and Availability	Adds to application complexity
Compression/encoding	Space savings	Adds to computation load, hurts runtime performance
Redundant execution	Performance guarantees	Degree of redundancy determines waste of resources
Load balancing	Lower latency	Application complexity, requires idempotency/ parallelizability
Eventual consistency	Performance	Stronger consistency guarantees increase complexity, and hurt performance