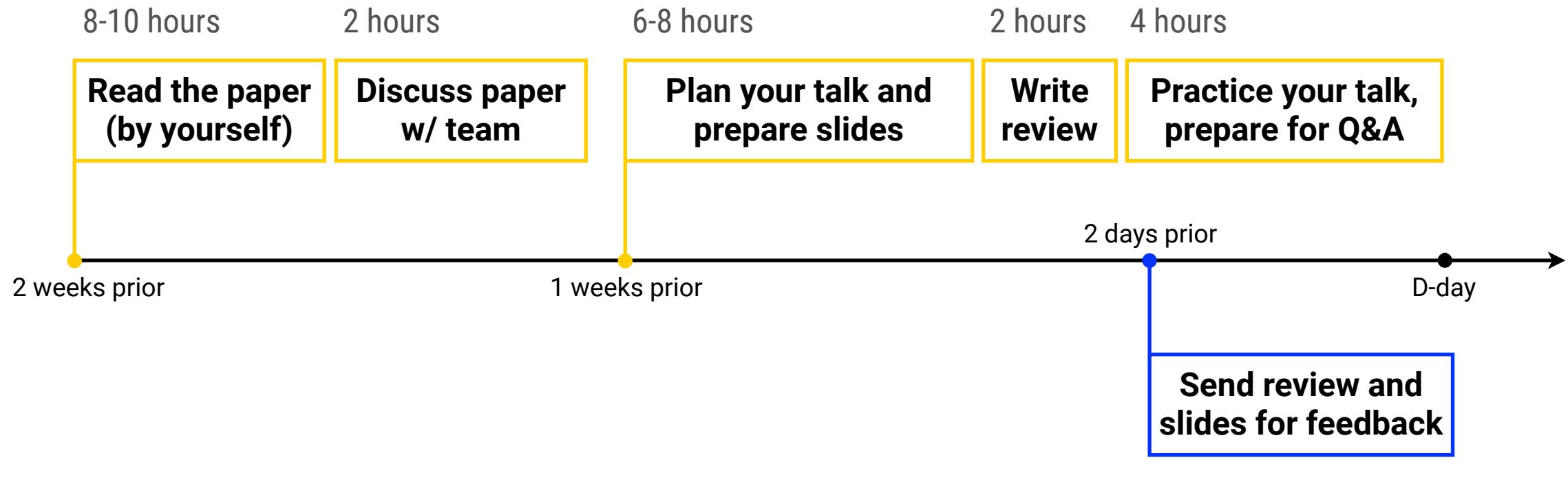


CS5630

Datacenters (1): Computing at Warehouse-Scale

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Preparing for Paper review and Presentations

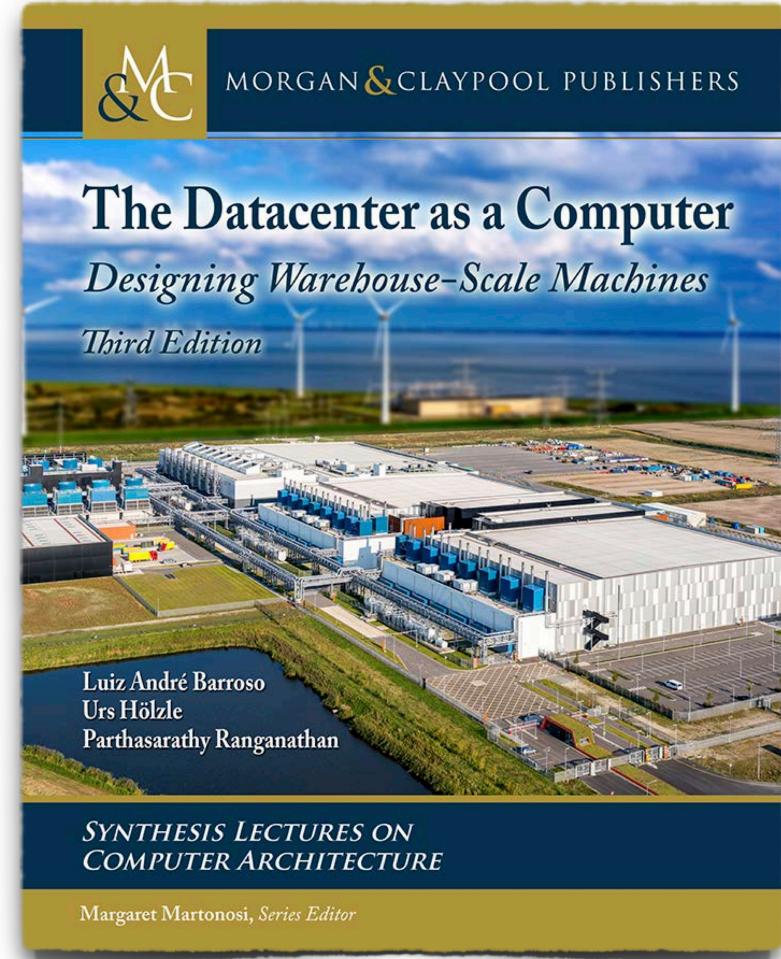


Expect to spend ~25 hours (YMMV)

Lecture goals

Technical introduction to datacenters and warehouse-scale computing

- Genesis and impact of WSC
- Hardware organization in datacenters
- Planning/building datacenters



Chapter 1

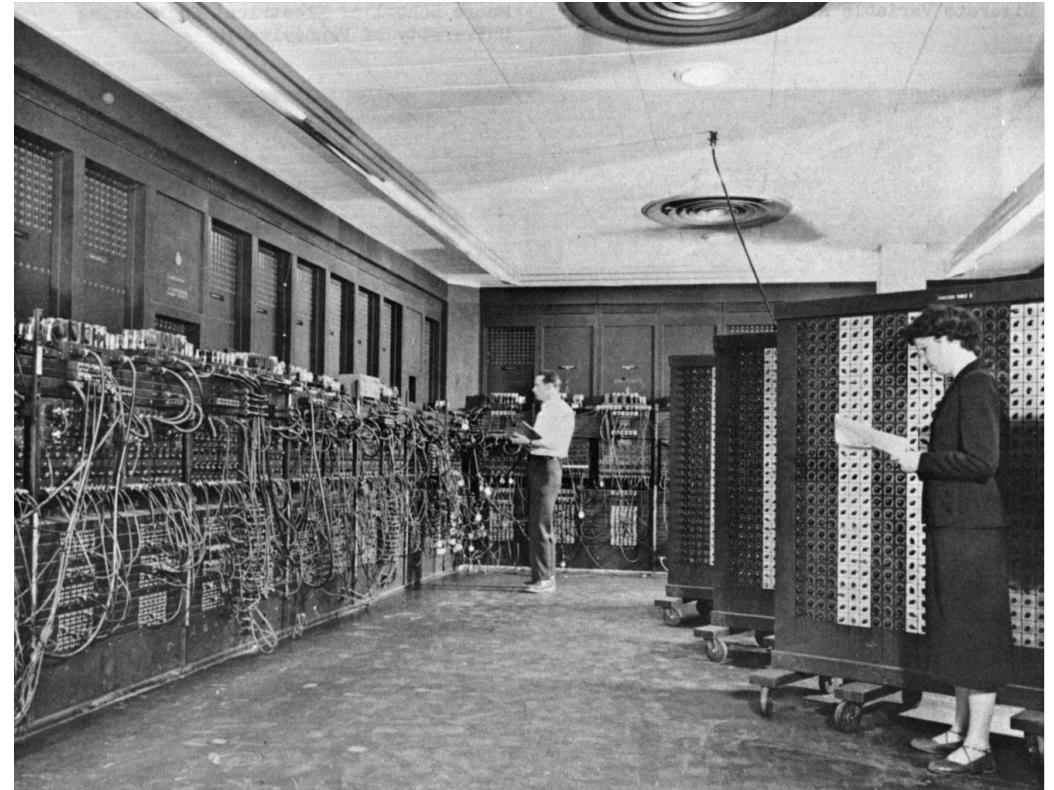
Datacenter

A building that houses computer systems, storage, and telecommunication equipment

Why a dedicated building?

- ▶ Complex, heavy, and elaborate machinery
- ▶ Component connectivity needed special accommodations
- ▶ Consumed significant amount of power and needed cooling
- ▶ Expensive; thus, needed security and isolation

Q: Is this a datacenter?



ENIAC (1946) at UPenn and Army Research Lab

Modern Datacenters

A building that houses computer systems, storage, and telecommunication equipment

- ➡ Built with commodity components
- ➡ O(10K - 100K) servers; O(100K) hard disks
- ➡ High-bandwidth commodity networking
(1–100Gbps Ethernet switches)
- ➡ Dedicated power generators
- ➡ Heavily secured and guarded



E.g., Google's datacenter in Amsterdam, Netherlands (CapEx: \$1.1B)

Warehouse-Scale Computing

A paradigm of computing where applications require infrastructure at a massive scale (of the order of entire datacenters) to meet their performance goals

Consider Google search

- ➡ it receives more than 5 billion queries per day (and has user base of a few billions)
- ➡ it takes over 200 factors into consideration before deciding on a search result
- ➡ and also...

The screenshot shows a news article from WIRED magazine. At the top, the WIRED logo is displayed next to a navigation bar with links for BACKCHANNEL, BUSINESS, CULTURE, GEAR, IDEAS, and MORE. A blue 'SUBSCRIBE' button is also visible. Below the header, the author 'CADE METZ' and the publication date '09.16.2015 10:00 AM' are shown. The main title of the article is 'Google Is 2 Billion Lines of Code—And It's All in One Place'. A subtitle below the main title reads 'By comparison, Microsoft Windows—one of the most complex software tools ever built for a single computer—is about 50 million lines.' A large yellow circle highlights the word 'Windows' in this subtitle.

Warehouse-Scale Computing: the genesis

In pioneer days they used oxen for heavy pulling, and when one ox couldn't budge a log, they didn't try to grow a larger ox. We shouldn't be trying for bigger computers, but for more systems of computers.

– Grace Hopper (1987)



Storage backend

No. of pages fetched: **24M**
WWW repository: **53.2GB**
Total system size: **108.7GB**

*Google infrastructure
(circa 1998)*

Warehouse-Scale Computer

is the abstraction of a datacenter—internally consisting of hundreds of thousands of commodity components, but—providing a unified and massively scaled up view of computing

Warehouse-Scale Computing: impact

WSC has had significant impact on all aspects of hardware and software, performance and security

Scale of computing and storage

- ➡ No longer bound by the bottlenecks in processor/memory/interconnect architecture/capacity
- ➡ *For e.g., Moore's law (i.e the number of transistors on microchips doubles every two years) ended ~2010*

Economy of computing and storage

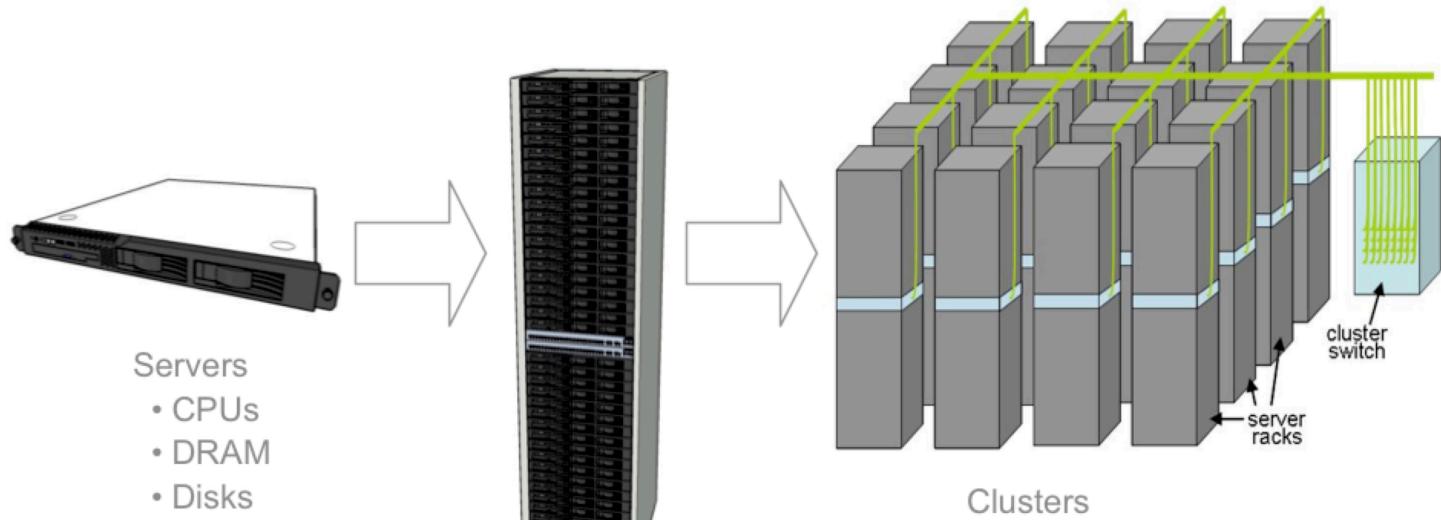
- ➡ Cost of computing/storage has fallen the fastest in the last decade (compared to any other time period)
- ➡ This has attracted more users and newer applications to cloud, further improving the economics

Reliability of computing and storage

- ➡ No longer limited by the electrical and physical laws of individual components
- ➡ *For e.g., AWS S3 offers eleven 9s of durability (there is no a storage system in the market with that feature)*
- ➡ New challenge: create warehouse-level fault-tolerance mechanisms/policies

Datacenters: A Technical Overview

Hardware Organization



Hierarchical structure

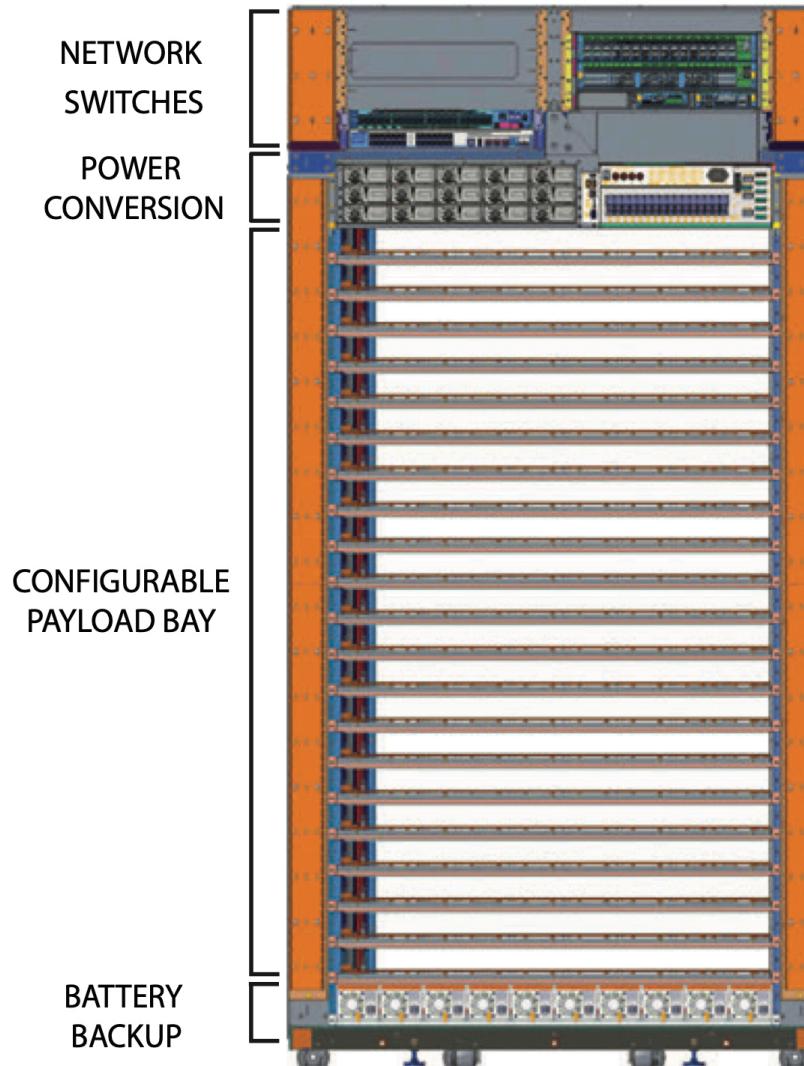
- ▶ low-end, commodity components
- ▶ Blade servers mounted within a rack
- ▶ Racks organized as clusters
- ▶ Ethernet switches (lower capacity at rack level, and denser interconnects at cluster level)

How do these schematics look in the real datacenters?

Hardware Organization

Racks up close!

- ▶ Network switches and power management on the top
- ▶ Compute and storage blades in the middle (10-40 Rack Units)
- ▶ Made of reinforced metal; open in the front and back; wheels for ease of movement



Hardware Organization

Compute + Networking

Server racks have 2-4 switches to which servers connect using different colored cables.

Fiber optic cables (running in yellow cable trays near the ceiling) provide connectivity to the Internet and other Google datacenters.

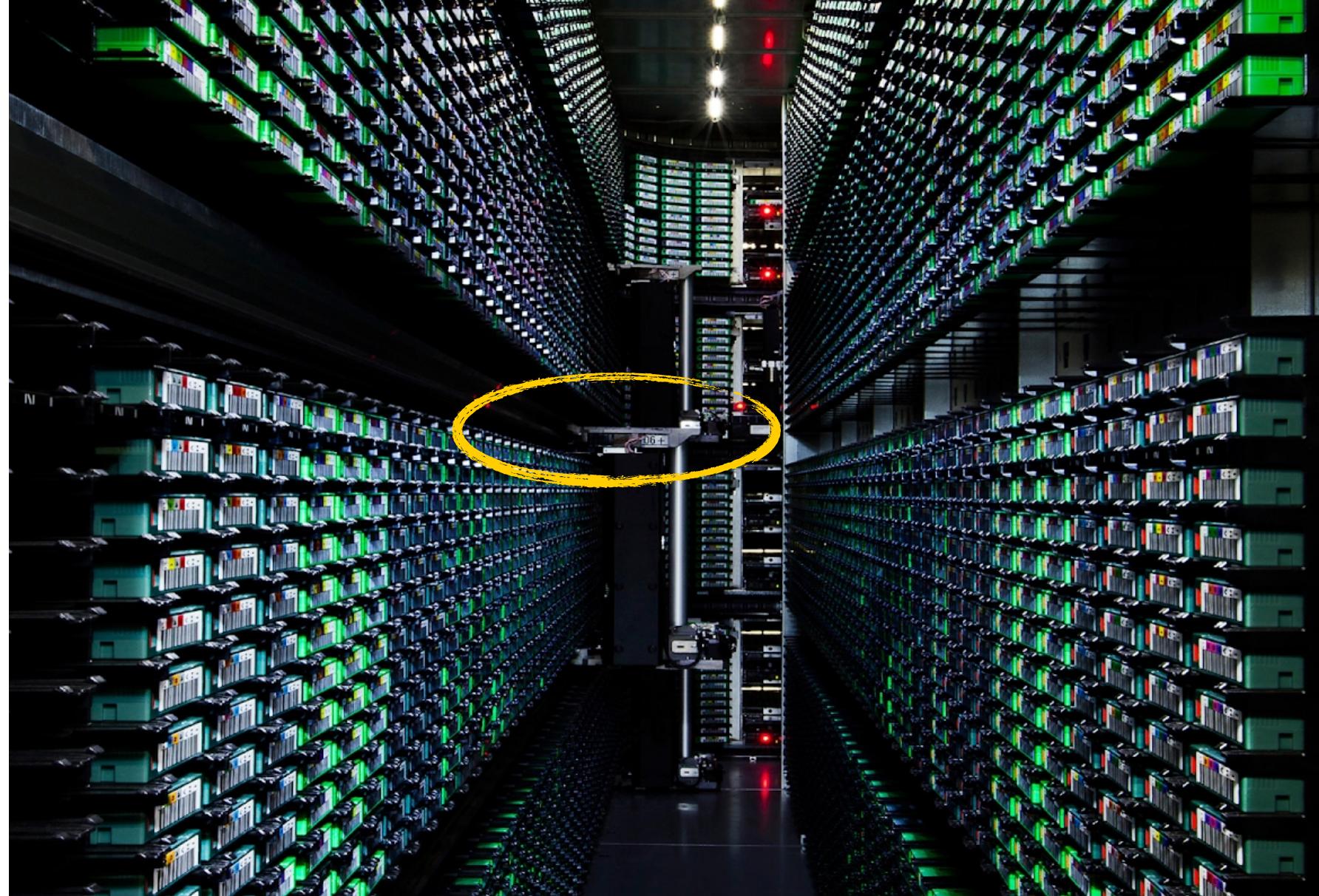


Hardware Organization

STORAGE

A tape library in a South Carolina data center.

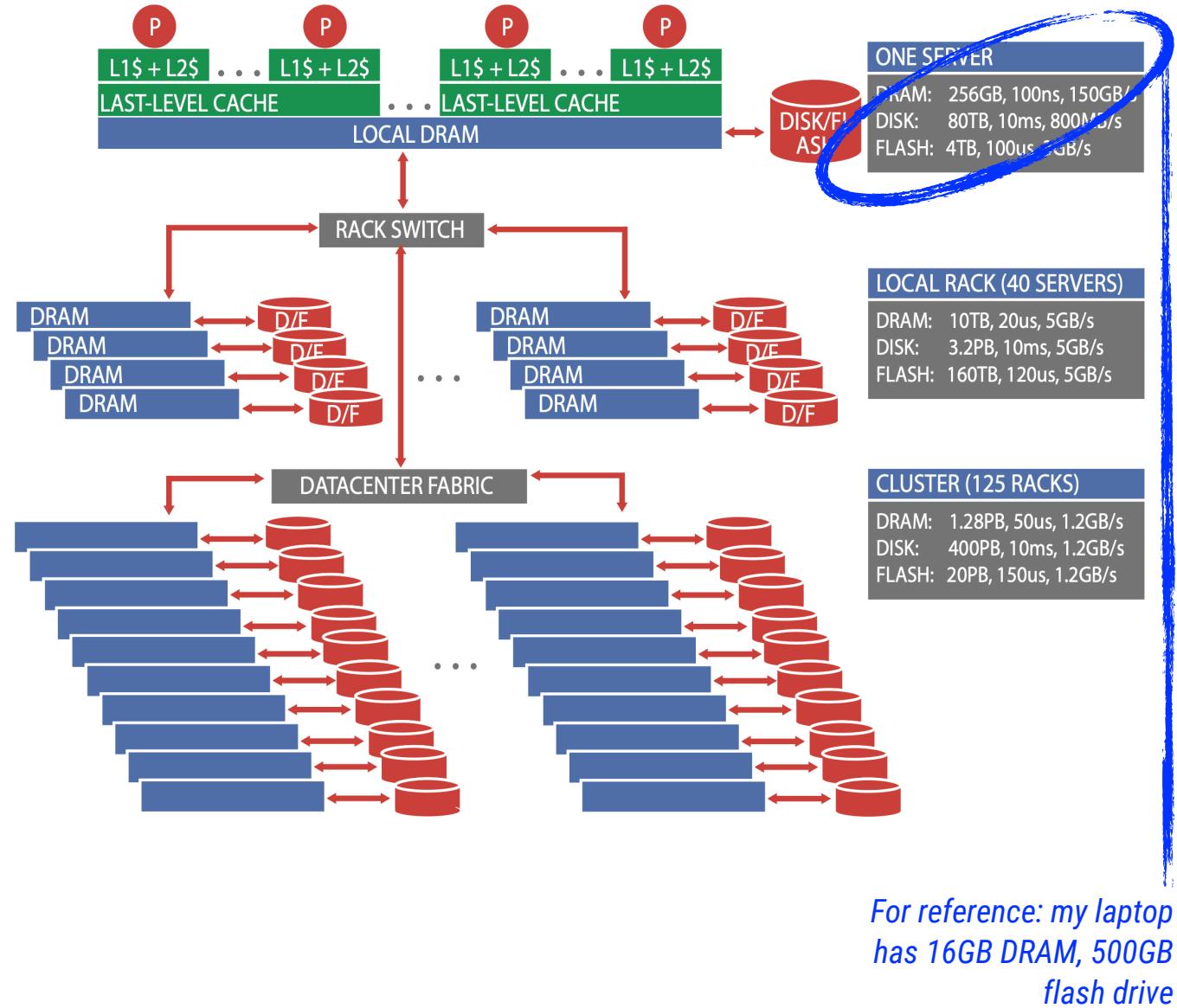
Robotic arms (visible at the end of the aisle) assist in loading and unloading of tapes when their data need to be accessed.



Hardware Organization

A Programmer's View of Storage Hierarchy

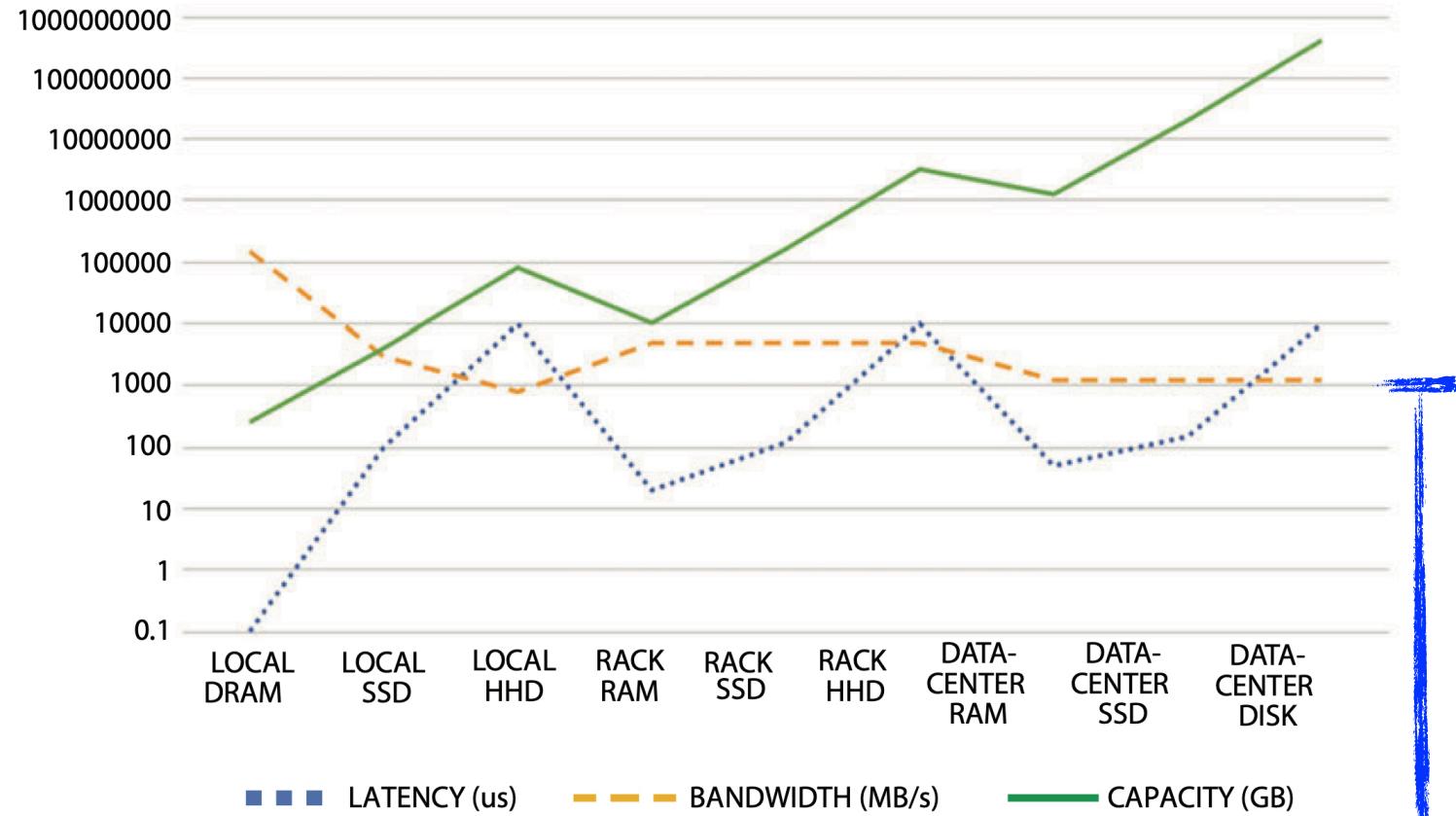
- Each server consists of its own cache, memory, and disk/flash drive
- Each server has access to the three storage media of other servers in the same rack via Ethernet
- Each server can also access the storage media at the cluster level using the datacenter fabric
- Remote procedure APIs make these device accesses seamless



Hardware Organization

A Programmer's View of Storage Hierarchy

- ▶ The choice of storage media should be governed by the needs of the application
- ▶ Local vs. remote phenomena is observable in latency, bandwidth, and capacity
- ▶ Network setup: 40Gbps rack-level switch supports 40 servers; cluster-level router provides a bandwidth of 10Gbps per rack (*oversubscribed*)



Storage bandwidth at rack/cluster level is largely governed by the network bandwidth (plateauing of the orange curve)

Hardware Organization

Putting it all together

Datacenter in Council Bluffs, Iowa provides 115,000 sq. feet of rack space.

It supports services including Search and YouTube



Hardware Organization

Zooming out

*85 datacenters in
28 locations
worldwide*

*No. of servers
estimated to be
2.5M (circa 2016)*



... there is more (a lot more) to learn about datacenters

https://www.google.com/about/datacenters/

The screenshot shows a web browser displaying the Google Data Centers page. The URL <https://www.google.com/about/datacenters/> is visible in the address bar. The page features a large banner image of a modern data center building with multiple cooling towers. Overlaid on the banner is a white rectangular box containing the heading "About Google Data Centers". Below this, there is a brief text summary and a link to "Learn more about innovation". A video player is positioned below the banner, with the title "Watch more about Google Data Centers" above it. Three video thumbnails are shown: "Inside a Google Data Center", "Data Center Security: Six Layers Deep", and "Google Data Center 360° Tour". Each thumbnail includes a play button and a brief description.

Google Data Centers

Clean Energy Gallery Life@ Podcast Discover FAQ

About Google Data Centers

Google owns and operates data centers all over the world, helping to keep the internet humming 24/7. Learn how our relentless focus on innovation has made our data centers some of the most high-performing, secure, reliable, and efficient data centers in the world.

Watch more about Google Data Centers

Inside a Google Data Center

Joe Kava, VP of Google Data Centers, gives a tour inside a data center, and shares details about the security, sustainability and the core architecture of Google's infrastructure.

Google Data Center Security: Six Layers Deep

Security is one of the most critical elements of our data centers' DNA. Journey to the core of a data center to see the six layers of physical security designed to thwart unauthorized access. Learn more about [data and security](#).

Google Data Center 360° Tour

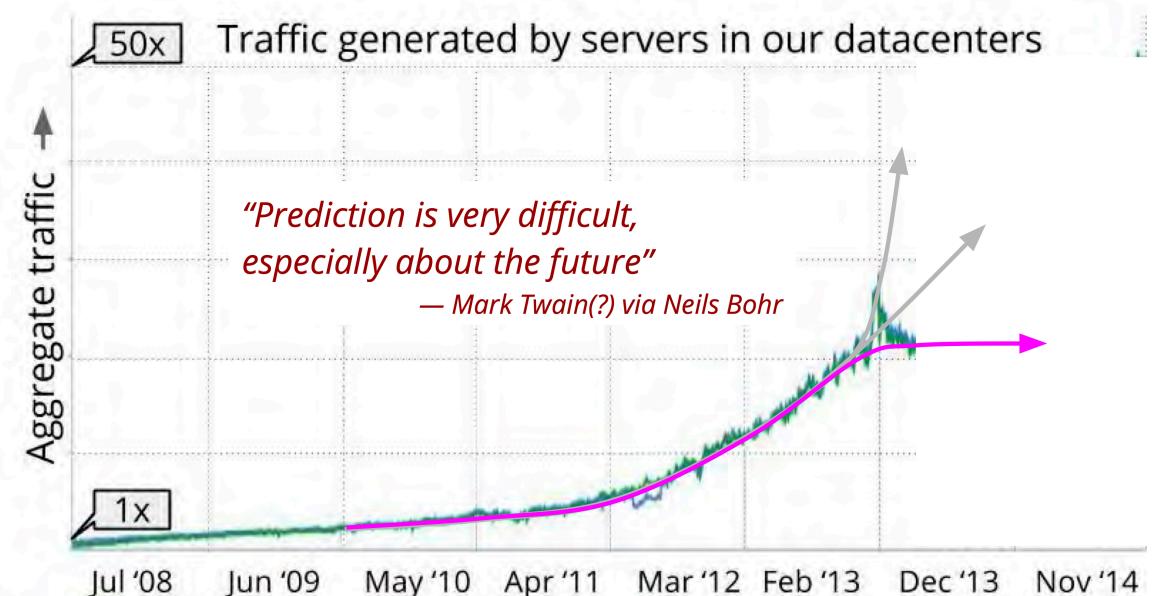
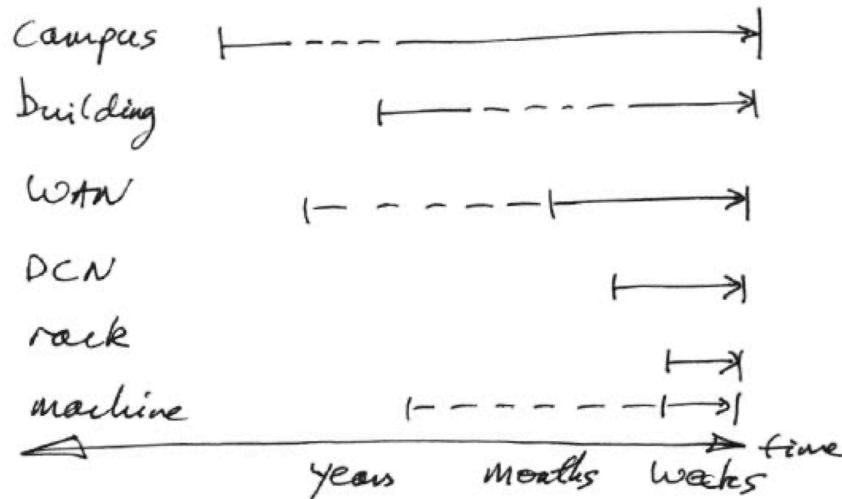
Learn about the massive scale, the incredible attention to security and privacy, and the amazing efforts to make the data center extremely efficient and green.

Building WSC in the Real-World

Reference: John Wilk's keynote at ACM SoCC 2018

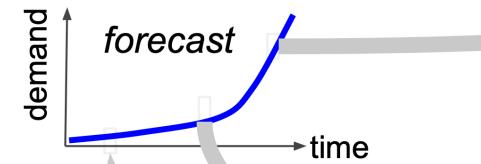
Unified Fulfillment Optimization (UFO) at Google

How long does it take to build capacity?

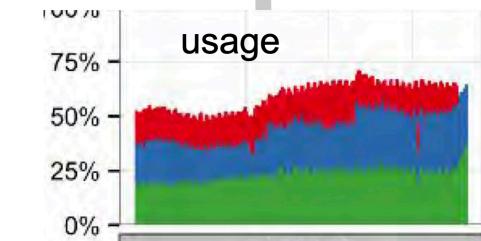


UFO at Google

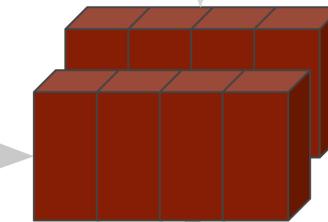
A simplified overview



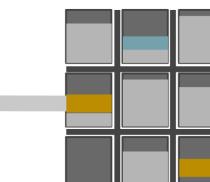
sites, data centers, power



network,
machines,
storage



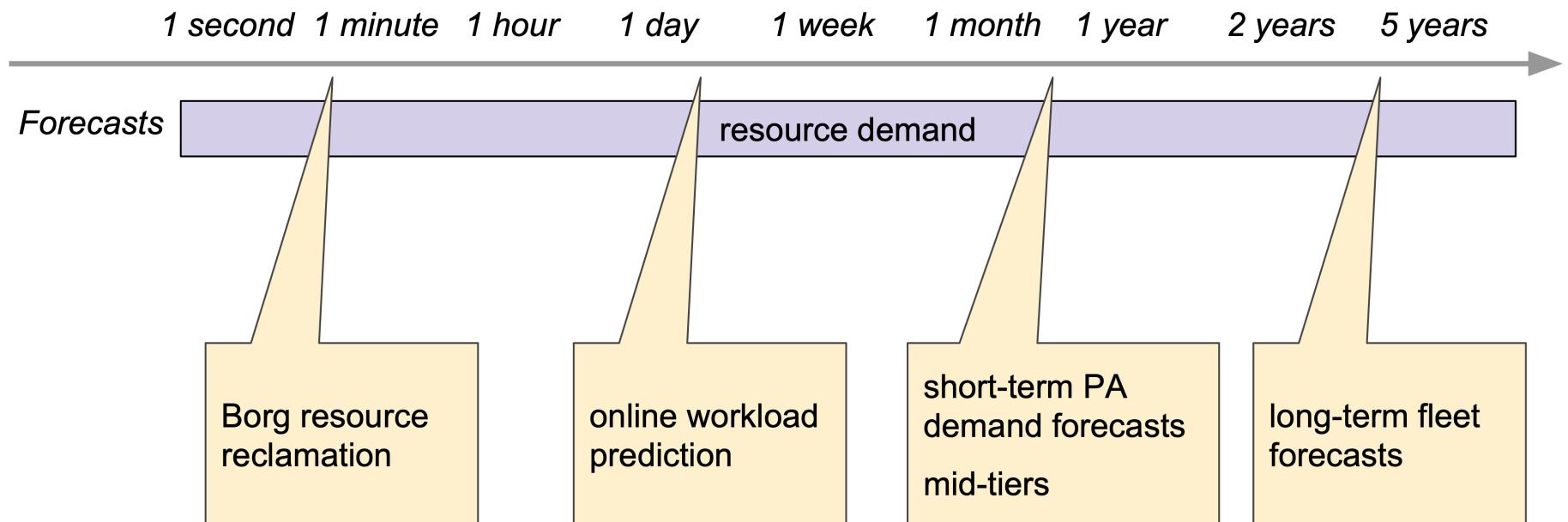
\$\$ prices



compute/storage

UFO at Google

Putting it all together



Spot Quiz (ICON)