DATA PLANE PROGRAMMING

MODULE 2 – DATACENTER NETWORKING AND LOADBALANCING

HHK3.KAU.SE/DPP

COMPUTER SCIENCE
DATAVETENSKAP

AGENDA FOR WEBINAR

- Introduction to Course Module
- Datacenter Traffic Characteristics and Workloads
- Introduction to Datacenter Networks

Please note: The webinar will be recorded. We intend to make available the video for course participants. When enabling your camera and microphone, you agree that your video and audio will be recorded and made available electronically. In case you do not want your video/audio to be recorded, switch off your video and mic. You can interact with us via Slack, too.

COURSE LAYOUT

- Loadbalancing for datacenter networks
  - DVAD42: Module 2

25.Jan -14.Mar
INTRODUCTION TO DATAPLANE PROGRAMMING (1.5 ECTS)
DVAD41

15. Mar – 25. April
LOAD BALANCING FOR DATA-CENTER NETWORKS (1.5 ECTS)
DVAD42

26. April – 6.June
NETWORK MONITORING WITH PROGRAMMABLE DATAPLANES (1.5 ECTS)
DVAD43

MODULE 2 – LOADBALANCING FOR DATACENTER NETWORKS

Prerequisite: DVAD41!

- Learning Goals:
  - give an account of basic principles and concepts of **Data Center networks**, → Today
  - give an account of alternative approaches regarding **load balancing** and routing for **Data Center networks**, → Webinar 2
  - explain domain-specific concepts related to **data plane programming** regarding **load balancing** for Data Center networks, → Webinar 3
  - implement **simple data-plane load balancing in P4**. → 2 Exercises

https://www.kau.se/en/education/programmes-and-courses/courses/DVAD42

ASSIGNMENTS IN MODULE 2

- Everyone:
  - Active Participation (Webinar and Slack)
  - P4 Tutorials, basic exercises, read papers, watch videos
  - Quizz questions
  - Discussion posts
- For the Credit bearing course the following is required:
  - Submit assignment (graded)
  - Quizz and discussion posts

NEXT ONLINE MEETINGS FOR MODULE 1

- Online Schedule
  - Webinar 1: Course Introduction and Intro to Datacenter Networking
    - Now☺
  - Webinar 2: Introduction to Loadbalancing
    - Monday, 29th March, 17:00 Stockholm Time
    - https://kau-se.zoom.us/j/66276262445
  - Webinar 3: P4 based Loadbalancing
    - Monday, 12th April, 17:00 Stockholm Time
    - https://kau-se.zoom.us/j/66276262445

NEXT STEPS

- Go to the course webpage https://hhk3.kau.se/dpp/
  - Make yourself familiar with the course homepage
  - Read syllabus
  - Start to read the papers, watch videos, etc.
  - Each module comes with a weekly plan for you.
  - Until the next webinar, see online schedule for week 1 and week 2
- Join Slack Channel
  - Join link: https://bit.ly/2Arkr0U
  - Can also download Slack app

AGENDA FOR WEBINAR

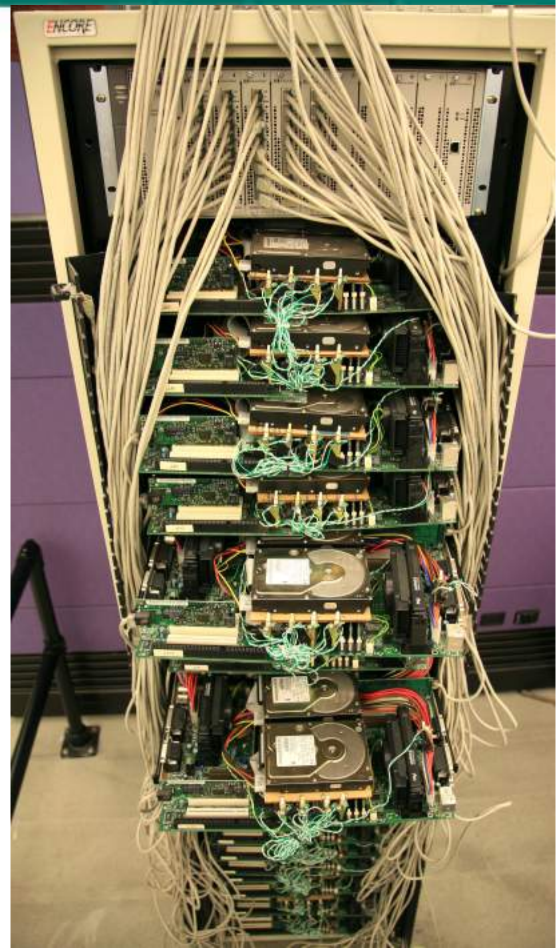
- Questions? → **In Slack**
- Wrapup and next steps
  - Go to **menti.com** and use the code **2400 4497**
  - Mentimeter

INTRODUCTION TO DATACENTER NETWORKING

COMPUTER SCIENCE
DATAVETENSKAP

WEBSEARCH – WHATS BEHIND THE SCENES?

- What happens when we search the Web?
- How does a search engine find results so fast?
- Do we crawl the whole Web in real time?
- Can we store the whole web on a single server?
- How many machines do we need for that? 10? 1.000?



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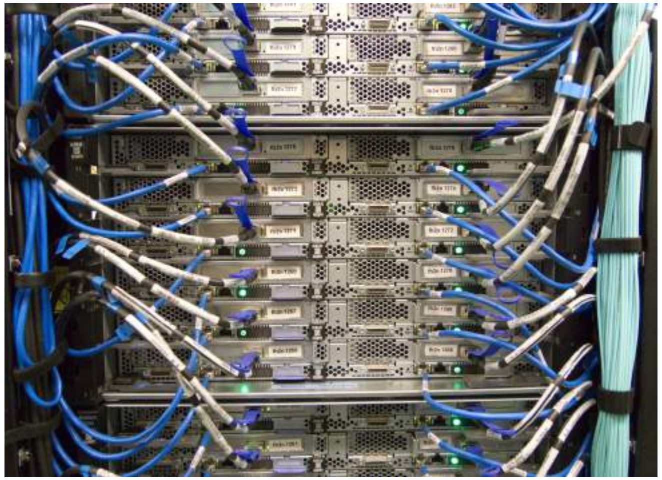
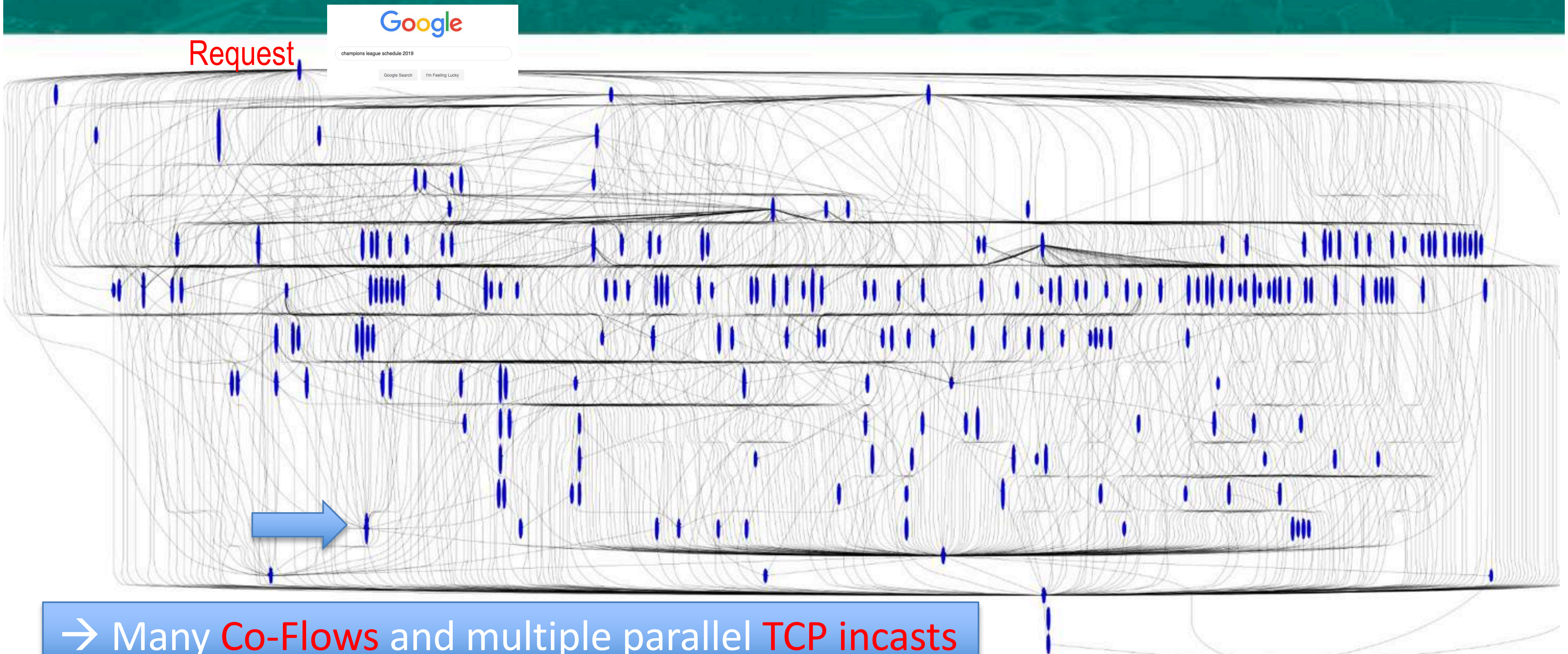
ANSWER: WE USE DATA CENTERS TO SEARCH THE WEB

- Warehouse computing on millions of commodity servers
- Have massive amount of CPU and disc
- Carry massive amount of traffic

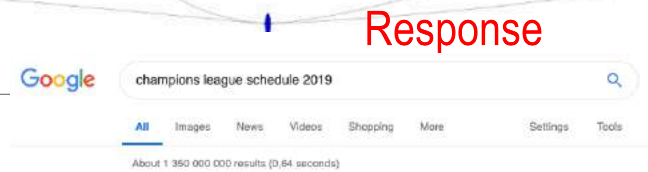


Tight Integration between Compute, Storage, Network

WEBSEARCH – WHATS BEHIND THE SCENES?

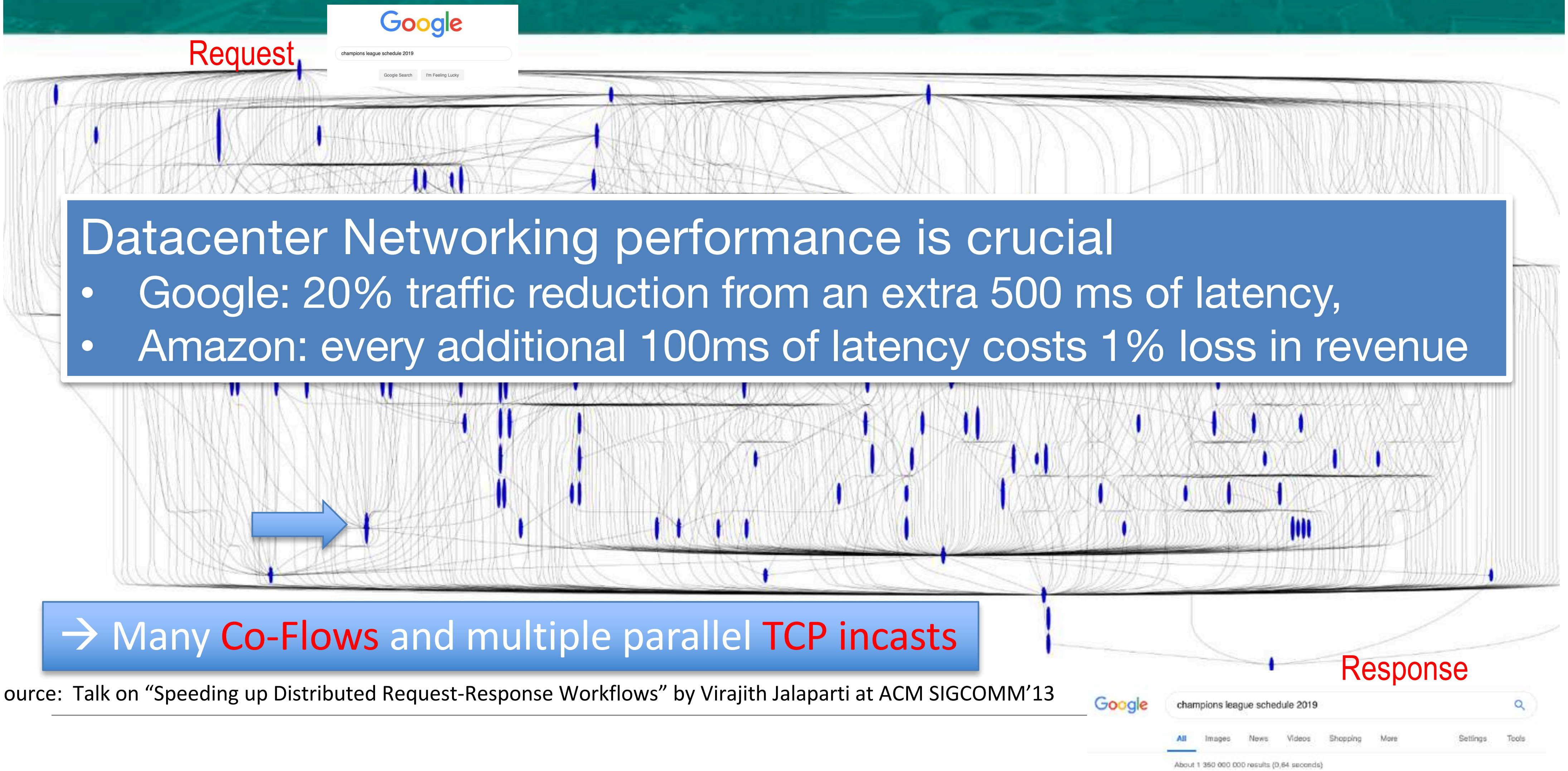


→ Many Co-Flows and multiple parallel TCP incasts



ource: Talk on “Speeding up Distributed Request-Response Workflows” by Virajith Jalaparti at ACM SIGCOMM’13

WEBSEARCH – WHATS BEHIND THE SCENES?



Datacenter Networking performance is crucial

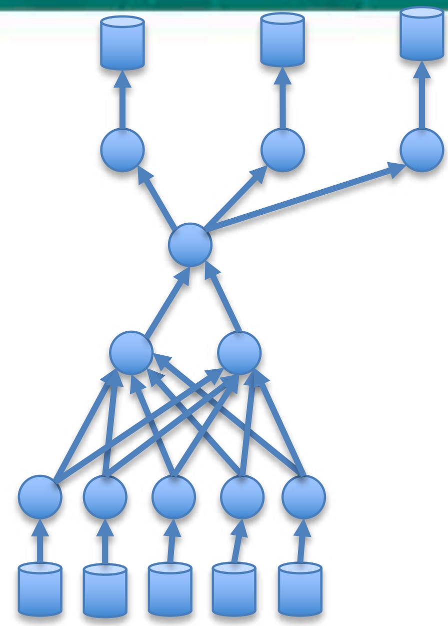
- Google: 20% traffic reduction from an extra 500 ms of latency,
- Amazon: every additional 100ms of latency costs 1% loss in revenue

→ Many **Co-Flows** and multiple parallel **TCP incasts**

ource: Talk on “Speeding up Distributed Request-Response Workflows” by Virajith Jalaparti at ACM SIGCOMM’13

IN DATA CENTER, COMMUNICATION IS CRUCIAL

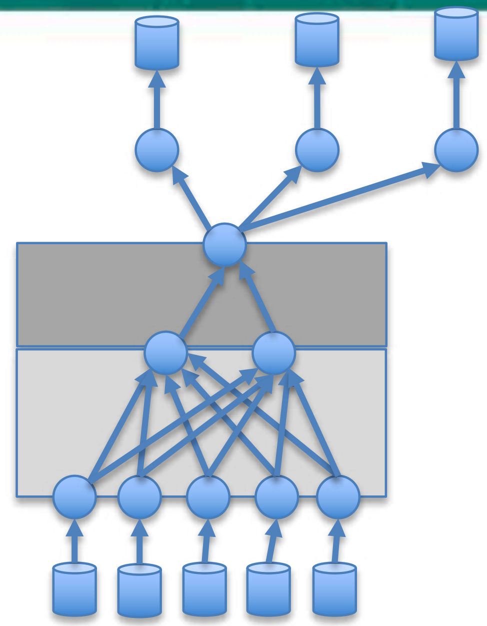
- Application Performance for Data Center Apps crucial for the service to be accepted
- Facebook analytics jobs spend **33%** of their runtime in communication
- *As in-memory systems proliferate, the network MUST scale for not become the bottleneck*
- *Appliction flow:*
  - A sequence of packets between two endpoints
  - Independent unit of allocation, sharing, load balancing, and prioritization



Framework	# peers
Spark	6
Hadoop	10
Yarn	20

COFLOW AND PERFRORMANCE

- Coflow Definition:
  – A collection of parallel flows with distibuted endpoints
  – Each flow within the CoFlow set is independent
- Performance Aspects
  – Job completion time depends on the last flow within a CoFlow set to complete!
  – Many Incoming flows lead to TCP Incast problem
    - Switch attached to server typically has small buffers
    - many incoming small requests may lead to buffer overflow
    → Switch drops packets → bursty retransmit and TCP RTO
    - May result in idle time and 90% throughput drop



Framework	# peers
Spark	> 6
Hadoop	> 10
Yarn	> 20

WHAT IS IMPORTANT TO A DATA CENTER?

- High availability
- High efficiency
- Smart agility
- Security

DATACENTER MAIN CHARACTERISTIC: ELASTICITY

- Manage the Workload!
  - Allows to rapidly install service capacity to scale with demands
  - Virtual Machines, docker containers, disk images → deploy, migrate
  - Re-assign Resources to match demands → horizontal and vertical scaling
- Manage the storage!
  - Allows a server access to persistent data
  - Highly distributed filesystems (e.g. HDFS) and key-value stores (e.g. Memcache)
- Manage the Network!
  - Allows a server to communicate with other servers, regardless of location
  - Vision: provide remote data access as fast as local, many techniques inside OS → RDMA, Infiniband Verbs, kernel bypass, DPDK, … → How about the network?

DATACENTER TRAFFIC CHARACTERISTICS

Inside the Social Network's (Datacenter) Network

ACM SIGCOMM 2015

Arjun Roy, Hongyi Zeng[†], Jasmeet Bagga[†], George Porter, and Alex C. Snoeren

Department of Computer Science and Engineering
University of California, San Diego

[†]Facebook, Inc.

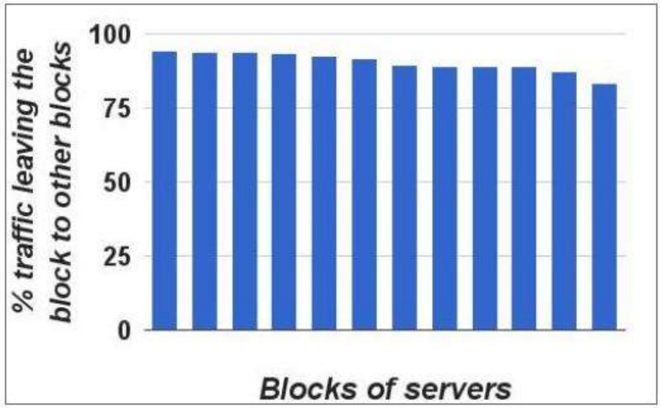
Locality	All	Hadoop	FE	Svc.	Cache	DB
Rack	12.9	13.3	2.7	12.1	0.2	0
Cluster	57.5	80.9	81.3	56.3	13.0	30.7
DC	11.9	3.3	7.3	15.7	40.7	34.5
Inter-DC	17.7	2.5	8.6	15.9	16.1	34.8
Percentage		23.7	21.5	18.0	10.2	5.2

Jupiter Rising: A Decade of Clos Topologies and Centralized Control in Google's Datacenter Network

ACM SIGCOMM 2015

Arjun Singh, Joon Ong, Amit Agarwal, Glen Anderson, Ashby Armistead, Roy Bannon, Seb Boving, Gaurav Desai, Bob Felderman, Paulie Germano, Anand Kanagala, Jeff Provost, Jason Simmons, Eiichi Tanda, Jim Wanderer, Urs Hölzle, Stephen Stuart, and Amin Vahdat
Google, Inc.
jupiter-sigcomm@google.com

Job Category	B/w (%)
Storage	49.3
Search Serving	26.2
Mail	7.4
Ad Stats	3.8
Rest of traffic	13.3



CONCURRENT FLOWS

Inside the Social Network's (Datacenter) Network

ACM SIGCOMM 2015

Arjun Roy, Hongyi Zeng[†], Jasmeet Bagga[†], George Porter, and Alex C. Snoeren

Department of Computer Science and Engineering
University of California, San Diego

[†]Facebook, Inc.

- *"Web servers and cache hosts have **100s to 1000s** of concurrent connections"*
- *"Hadoop nodes have approximately **25** concurrent connections on average."*
- *"median inter-arrival times of approximately 2ms"*

The Nature of Datacenter Traffic: Measurements & Analysis

ACM IMC 2009

Srikanth Kandula, Sudipta Sengupta, Albert Greenberg, Parveen Patel, Ronnie Chaiken
Microsoft Research

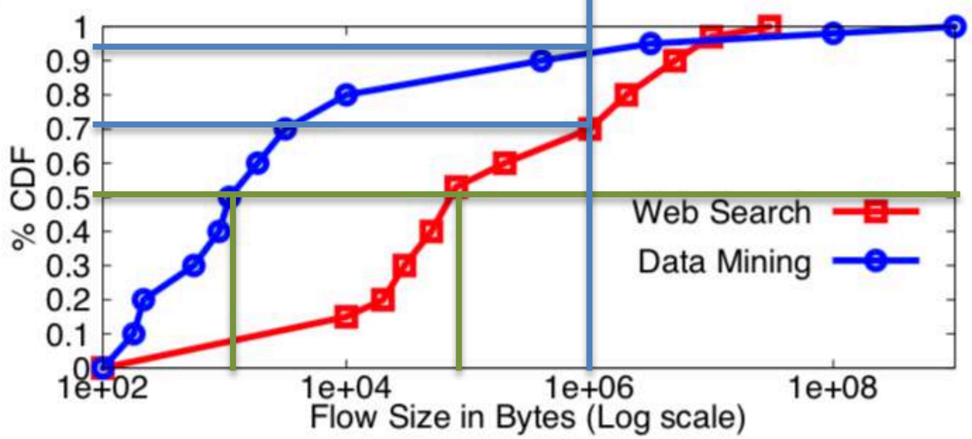
- *"median numbers of correspondents for a server are two (other) servers within its rack and four servers outside the rack"*

DATACENTER TRAFFIC CHARCTERISTICS

- Different application flow types
  - Large Flows (Elephant)
    - Few, carry most volume

  - Small Flows (Mice)
    - Many, small volume in total

- Traffic patterns
  - Highly volatile
    - Changing rapidly even during a day
  - Highly unpredictable
    - Weak correlation



HULA: Scalable Load Balancing Using Programmable Data Planes

SOSR'16, March 14–15, 2016, Santa Clara, CA, USA

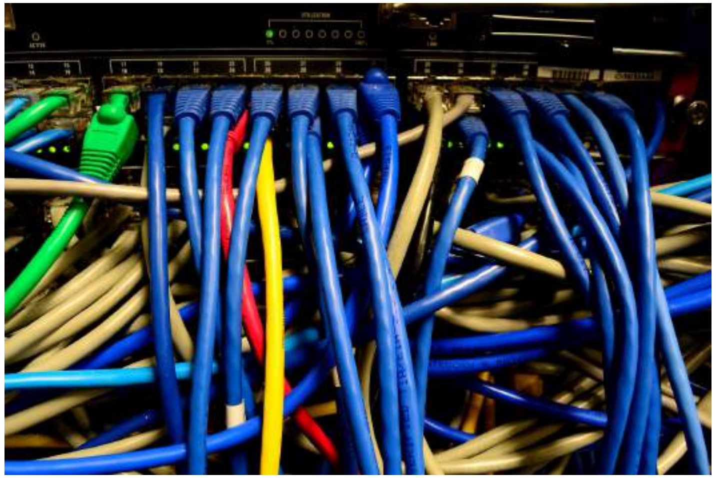
Naga Katta[*], Mukesh Hira[†], Changhoon Kim[‡], Anirudh Sivaraman[+], Jennifer Rexford[*]
[*]Princeton University, [†]VMware, [‡]Barefoot Networks, [+]MIT CSAIL
{nkatta, jrex}@cs.princeton.edu, mhira@vmware.com, chang@barefootnetworks.com, anirudh@csail.mit.edu

Traffic-aware optimization needs to be done frequently and rapidly

IMAGES FROM WIKIPEDIA

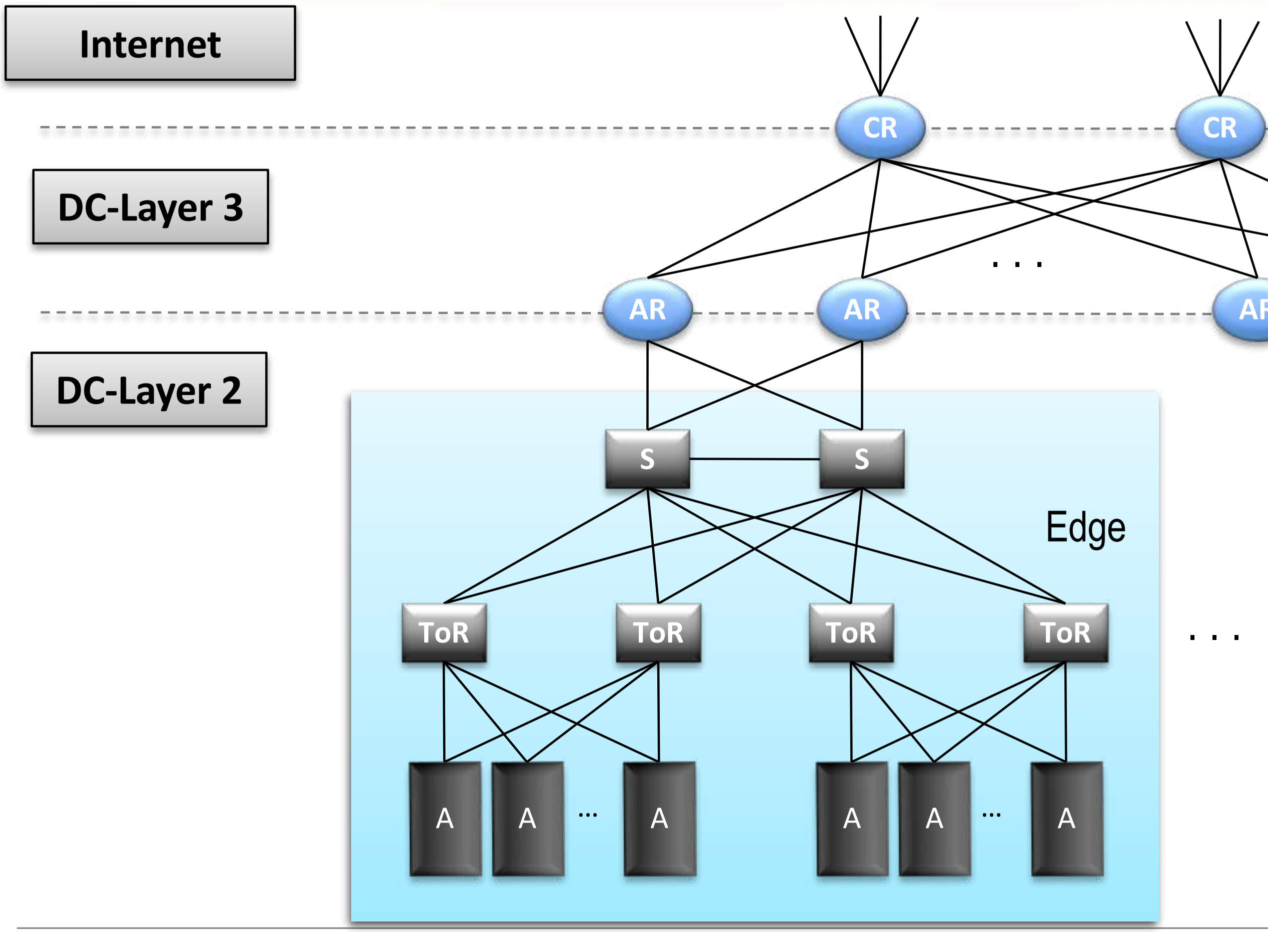
DATACENTER NETWORK

- Connects servers with each other and the outside world
- Built to optimize cost and performance
- Tiered Architecture
  - 3 layers; edge, aggregation, core
  - Cheap devices at edges and expensive devices at core
  - Devices typically proprietary and closed
- Over-subscription of links closer to the core
  - Fewer links towards core reduce cost
  - Trade loss/delay for fewer devices and links



Data Center Network must provide High Capacity at Ultra Low Latency

CONVENTIONAL DATACENTER NETWORK



Legend

- **CR** = Core Router (L3)
- **AR** = Access Router (L3)
- **S** = Ethernet Switch (L2)
- **ToR** = Top of Rack Switch (L2)
- **A** = Rack of application servers

~ 1,000 servers/pod == IP subnet

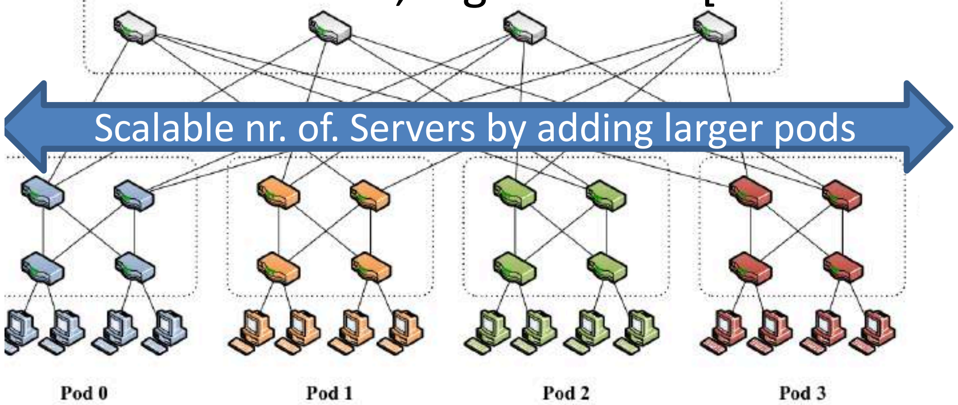
From: "Data Center: Load balancing Data Center Services", Cisco 2004

CONVENTIONAL DATACENTER NETWORK PROBLEMS

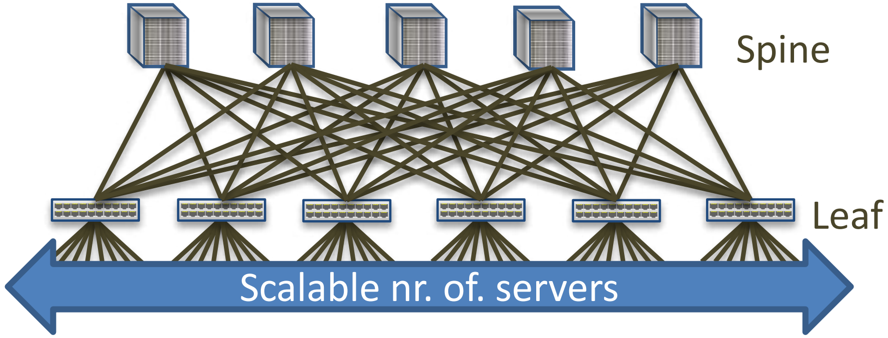
- Layer 2 Problems
  - Broadcast must be limited (ARP)
  - Spanning tree protocol does not scale well
- Layer 3 problems
  - Complex configuration
  - Cannot migrate containers and VMs easily without changing IP-@
- Limited server-to-server capacity due to oversubscription
  - High port number switches expensive → oversubscription
  - Oversubscription ratio: Ratio of ports facing downwards vs. ports facing upwards (with equal bandwidth ports)
    - E.g. Access to core layer: 4:1 oversubscribed, ToR to access 20:1 oversubscribed
    - Switch uplinks get heavily loaded → microbursts and congestion

EXAMPLE TOPOLOGY DESIGNS

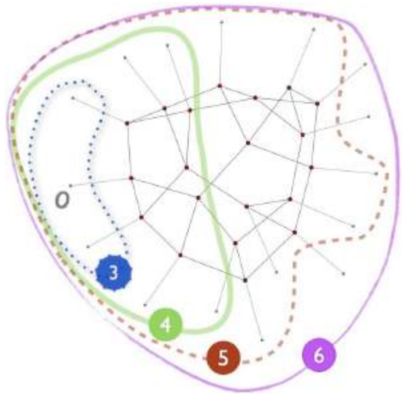
Multi-rooted trees, e.g. Fat-tree [SIGCOMM’08]



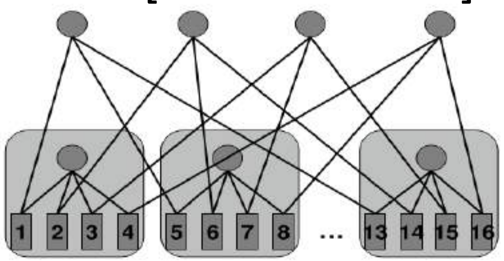
Leaf-Spine (2-Tier Clos Network)



Jellyfish (random) [NSDI’12]



Bcube [SIGCOMM’10]

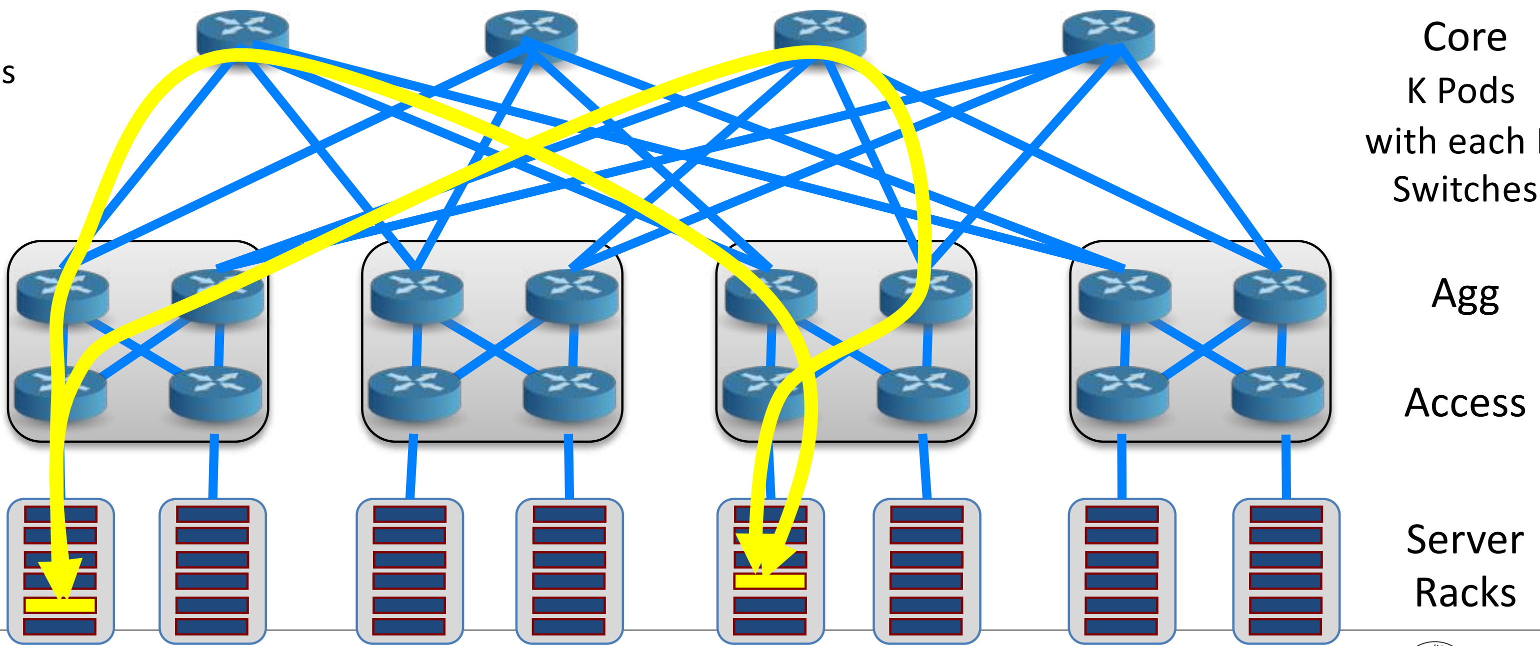


MULTIROOTED TREE PROPERTIES

Multi-rooted tree [Fat-tree, Leaf-Spine, …] achieve full bisection bandwidth assuming perfect multipathing

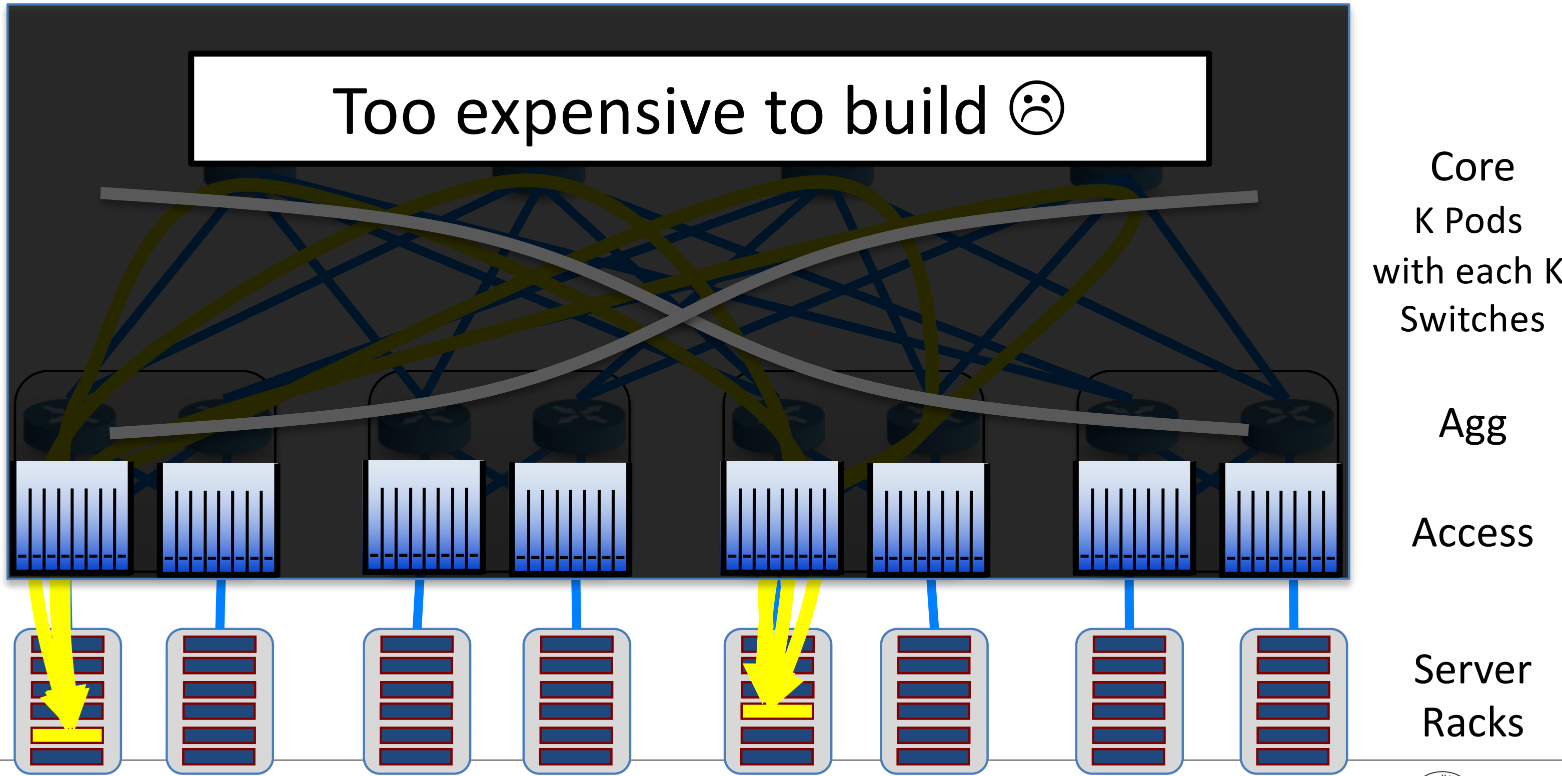
Charles E. Leiserson, Fat-trees: universal networks for hardware-efficient supercomputing, IEEE Transactions on Computers, Vol. 34, no. 10, Oct. 1985, pp. 892-901.

$(k/2)^2$ core switches
each connects to k pods
→ Supports $k^3/4$ hosts
→ Example: k=4



MULTIROOTED TREE TRIES TO APPROXIMATE BIG SWITCH

Multi-rooted tree [Fat-tree, Leaf-Spine, ...] try to approximate one big switch abstraction



ONE BIG SWITCH APPROXIMATION

- Google 2004: Cluster Routers (CR)
  - 512 ports → expensive
  - Special purpose
  - Oversubscription → bottleneck for intra-rack

Jupiter Rising: A Decade of Clos Topologies and Centralized Control in Google's Datacenter Network

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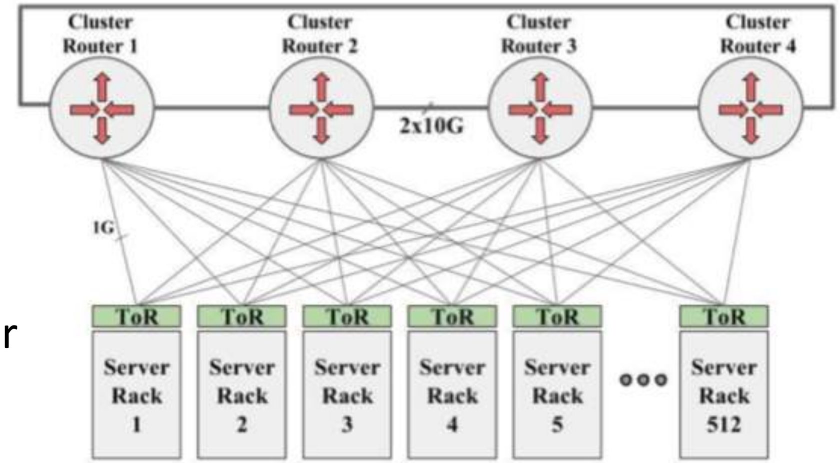
Google, Inc.
jupiter-sigcomm@google.com

Cluster Capacity: 20k servers

2 x 10 G to CR
512 x 1G to ToR

4 x 1G to CR
40x 1G to server



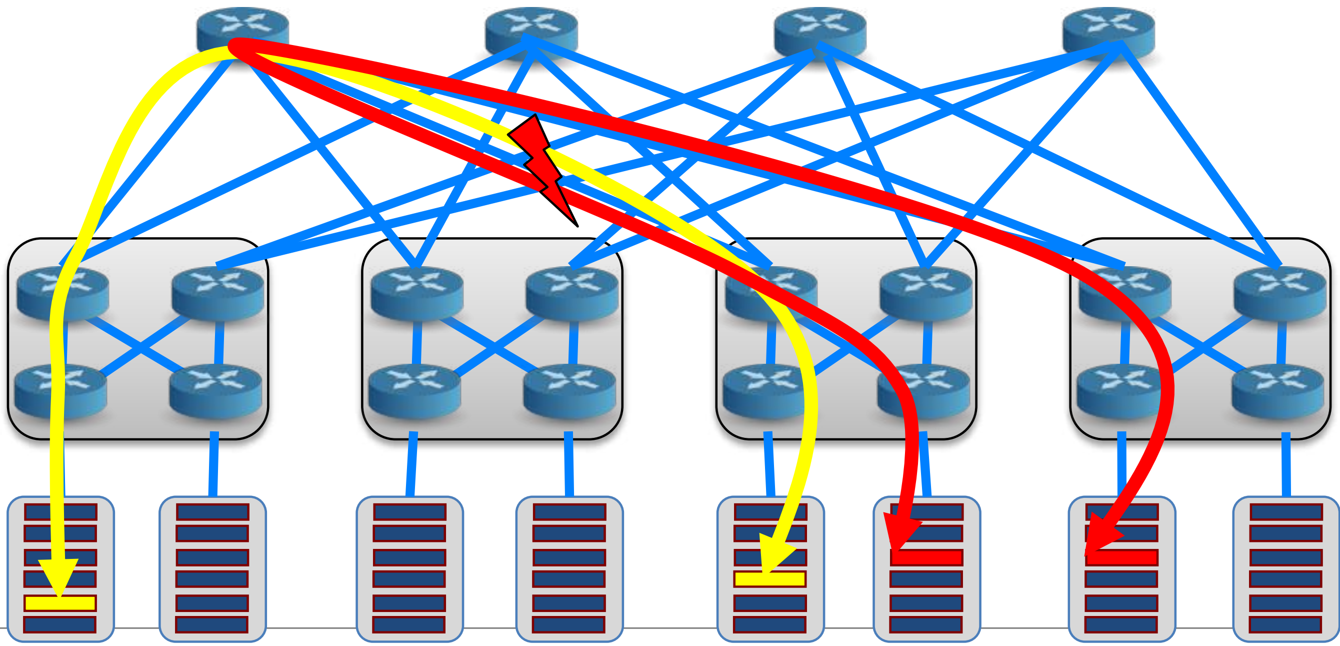
- Challenge
  - How can we increase capacity?
  - How can we approximate one big switch with cheap commodity switches using clever load-balancing?

MULTIROOTED TREE PROBLEMS

With standard routing, can only exploit a single path

Flow collisions result in suboptimal traffic distribution

Packet based load-balancing results in reordering (TCP!)



IMPLICATIONS FOR DATACENTER NETWORKING

- MASSIVE internal network traffic
- Complex network shared by many applications
- Tight deadlines for network I/O → business impact
- Congestion and TCP incast due to many Co-Flows
- Low latency and high capacity at same time
- Need highly adaptive localized capacity on demand → fine loadbalancing
- cheap, scalable, fault tolerance, ...

NEXT WEBINARS

- Data Center Load Balancing
  - Network layer
  - ECMP → you will implement in P4
  - Conga
- P4 based load balancing
  - Hula → you will (partly) implement in P4
  - MP-Hula Hula with support for Multipath transport protocols)