Datacenters I:
Anatomy and Topologies

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cs168.io

Rob Shakir

Thanks to Ankit Singla and Murphy McCauley for some of the material!

Recall – where is the Internet?

- Carrier hotel locations.
- Generally for interconnection between networks.
- Some smaller application hosting.
- Where do large applications live?

A Datacenter

Google datacenter in Belgium - https://www.google.com/about/datacenters/gallery/

Inside a (Google) Datacenter

Server racks in a Google datacenter - https://www.google.com/about/datacenters/gallery/

Infrastructure in a Google Datacenter

Cooling infrastructure in a Google datacenter - https://www.google.com/about/datacenters/gallery/

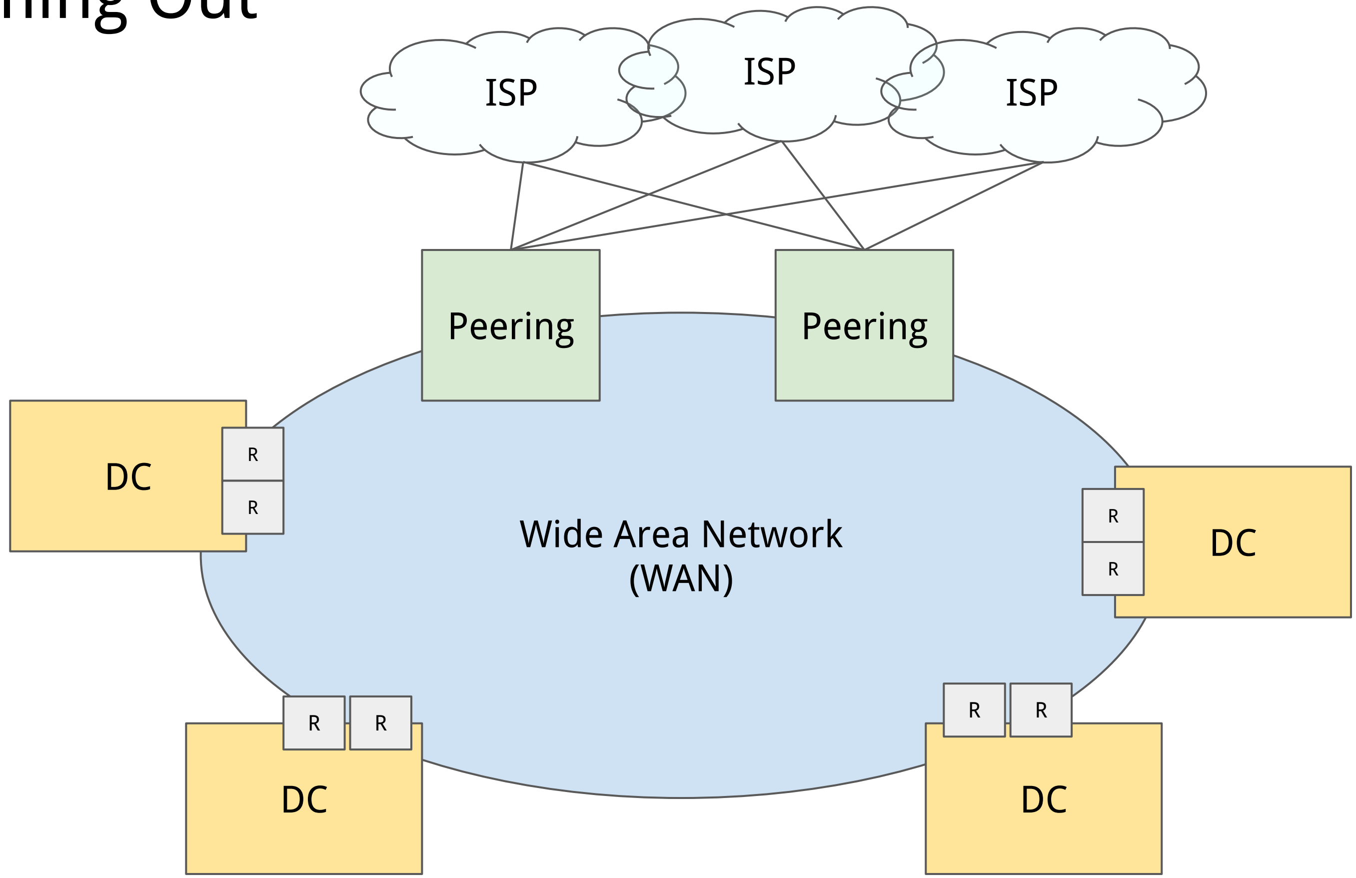
Datacenters

- Computing infrastructure, located in one physical location.

- Owned by one organisation.
- But used by multiple users and applications.

- Our focus: modern hyperscale datacenters.
  - Google, Facebook, Microsoft, Meta…
  - Concept scales down.

Zooming Out



ISP
ISP
ISP
Peering
Peering
DC
R
R
Wide Area Network
(WAN)
R
R
DC
R
R
DC
R
R
DC

Anatomy of an Application/Cloud Provider

- Data center locations – host servers and application infrastructure.
  - Often huge power requirements.
  - Does not need to be near other networks.

- Peering locations – host network interconnection infrastructure.
  - Typically mostly routers.
  - Needs to be near other networks.

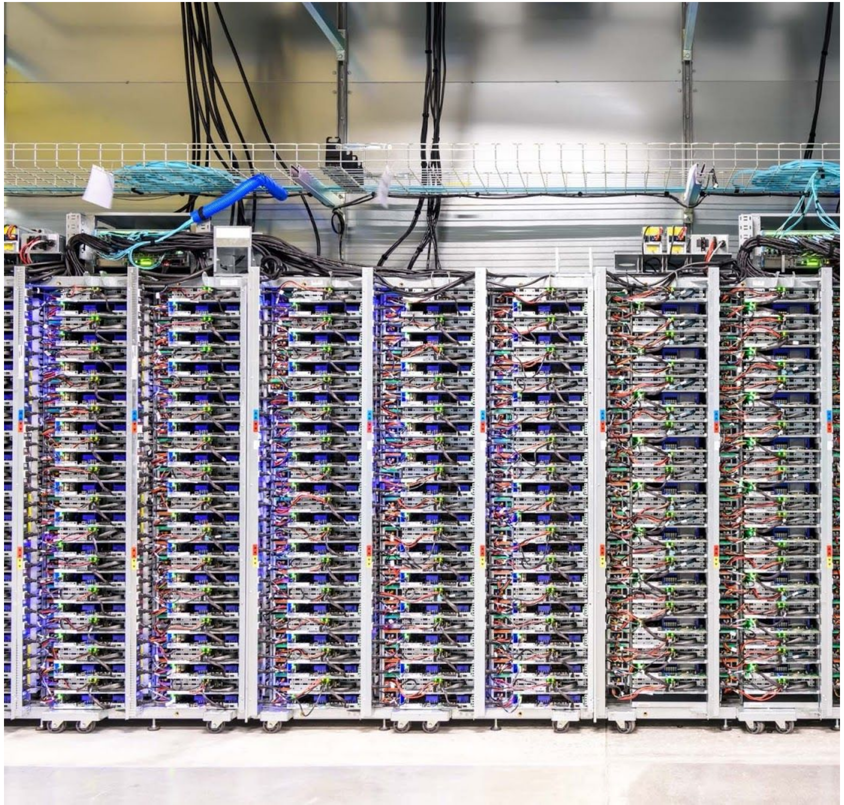
- **W**ide **A**rea **N**etwork - connects the different locations together.
- Datacenter network – within a particular DC facility.

Our focuses

- What does a datacenter network look like?
- What makes a datacenter different to the wide area networks we have discussed thus far?
- Components of a datacenter network.
- Specific solutions for datacenter networking [next time].
  - Routing in datacenters.

Questions?

Anatomy of a Datacenter



Anatomy of a Datacenter

1-2 servers per "U" [0]

Anatomy of a Datacenter

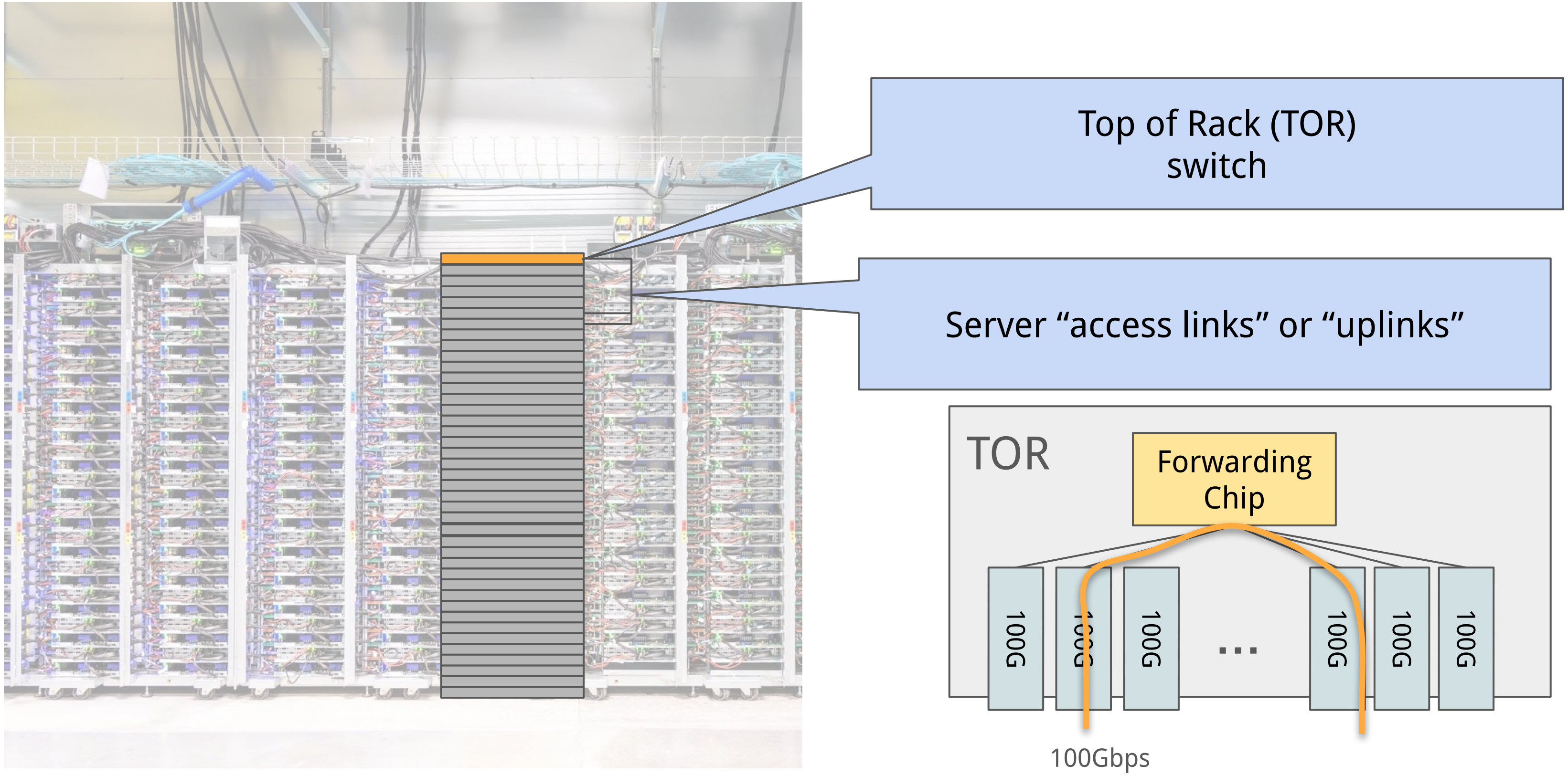
~40 “U” per rack.

Anatomy of a Datacenter

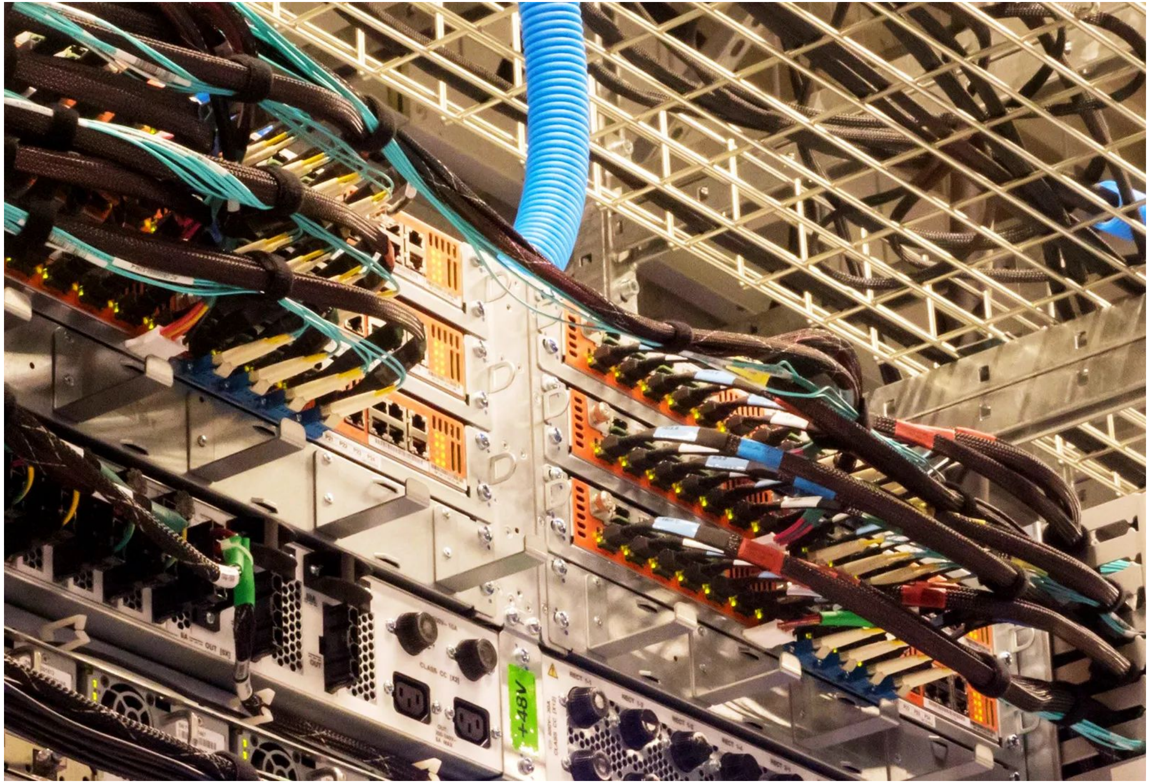
Top of Rack (TOR)
switch

Server “access links” or “uplinks”

Anatomy of a Datacenter

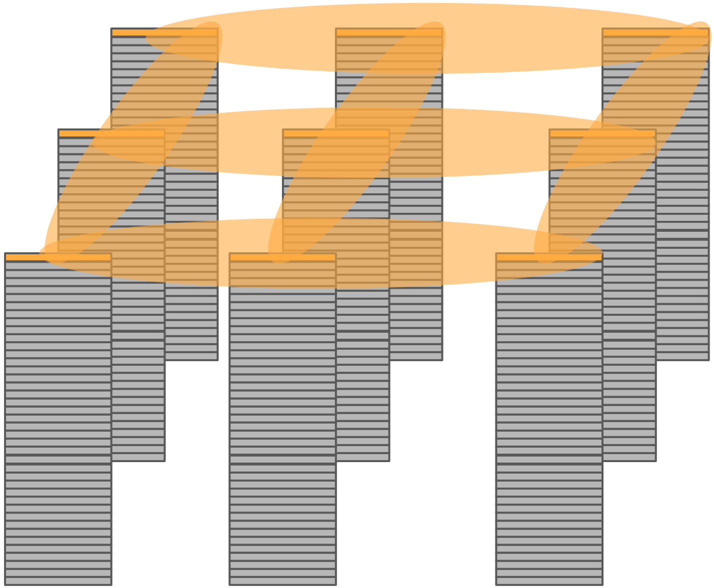


Top-of-Rack Switch



Google "pluto" TOR - - ~2015 – [Wired](#)

Anatomy of a Datacenter



- 40-80 servers per rack.
- 100Gbps per server.
- Many racks per datacenter!
- How do we connect racks together?

Why is the datacenter different?

- We have generally been thinking about Wide Area Networks.
- These WANs interconnect to make up the Internet.
- Why might datacenter networks be different?

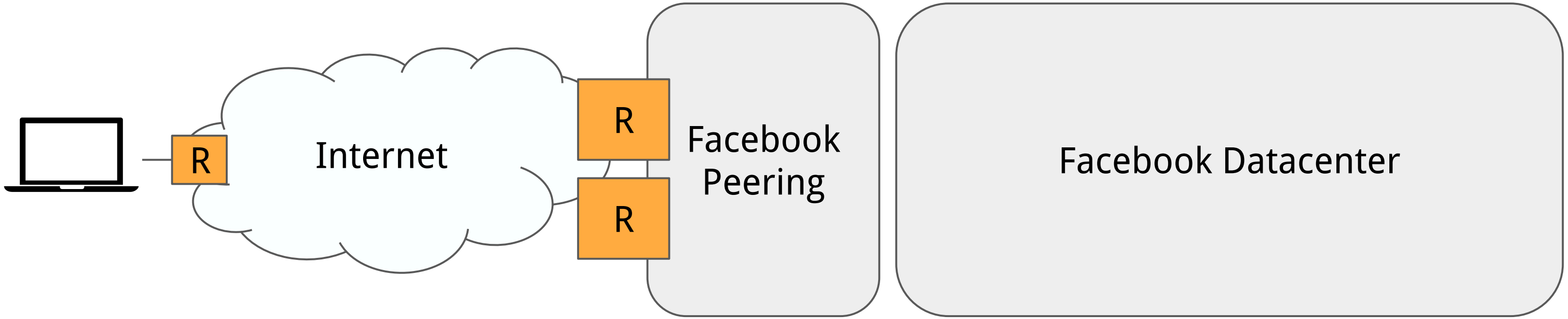
Why is the datacenter different?

- We have generally been thinking about Wide Area Networks.

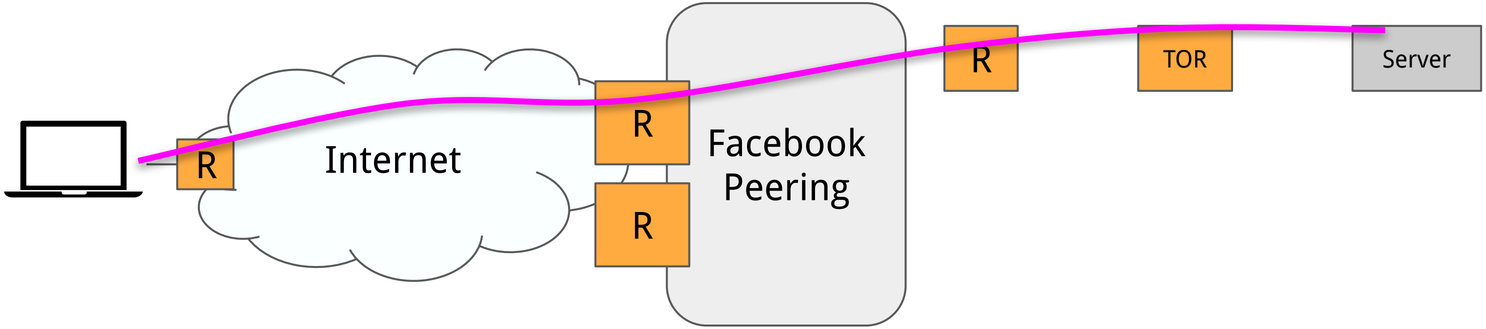
- These WANs interconnect to make up the Internet.

- Why might datacenter networks be different?
  - Run by a single organisation
  - Exist in a single physical location
  - High scale (in that single location!)
  - More control over network and hosts (to some degree)
  - Homogeneous
  - Performance, performance, performance!

Accessing an Application



Accessing an Application



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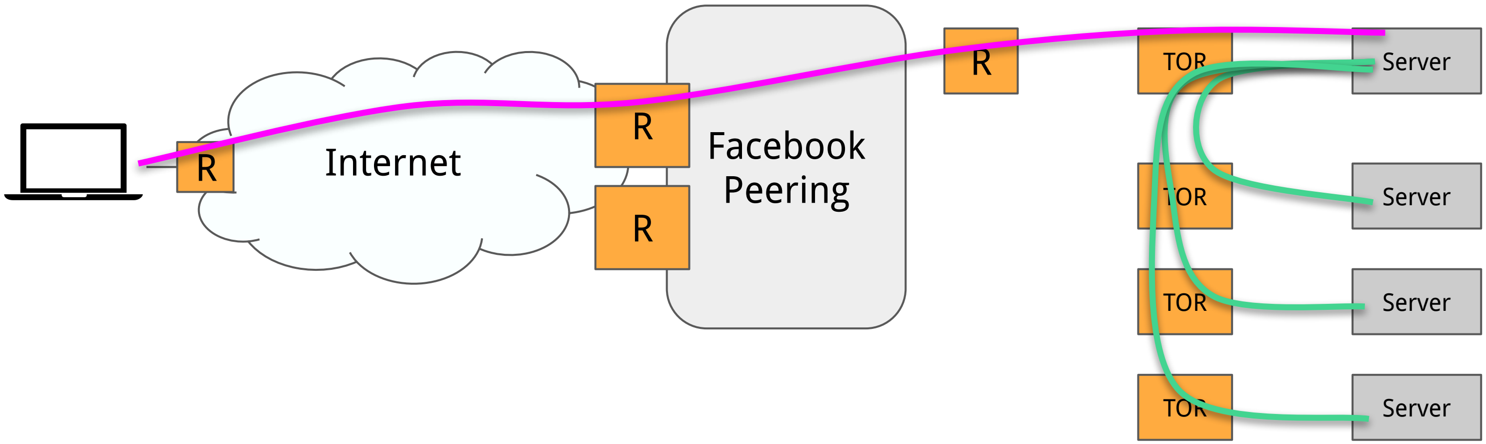


Accessing an Application

USENIX NSDI, 2013

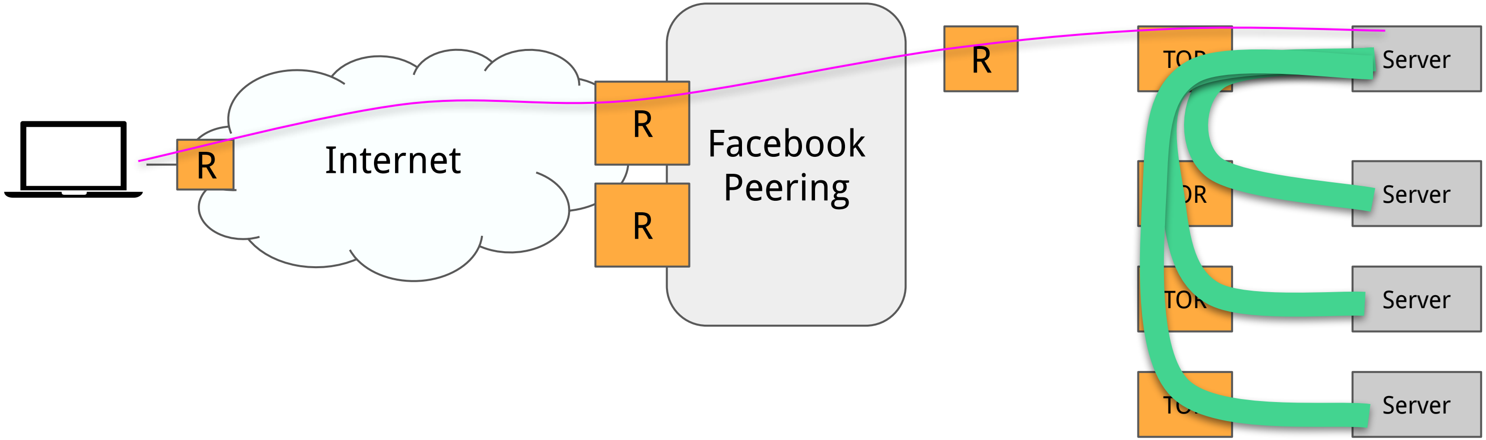
Scaling Memcache at Facebook

Rajesh Nishtala, Hans Fugal, Steven Grimm, Marc Kwiatkowski, Herman Lee, Harry C. Li,
Ryan McElroy, Mike Paleczny, Daniel Peek, Paul Saab, David Stafford, Tony Tung,
Venkateshwaran Venkataramani
{rajeshn,hans}@fb.com, {sgrimm, marc}@facebook.com, {herman, hcli, rm, mpal, dpeek, ps, dstaff, ttung, veeve}@fb.com
Facebook Inc.

1 popular page loaded = **521** distinct memcache loads

(95th percentile = 1740!)

Accessing an Application

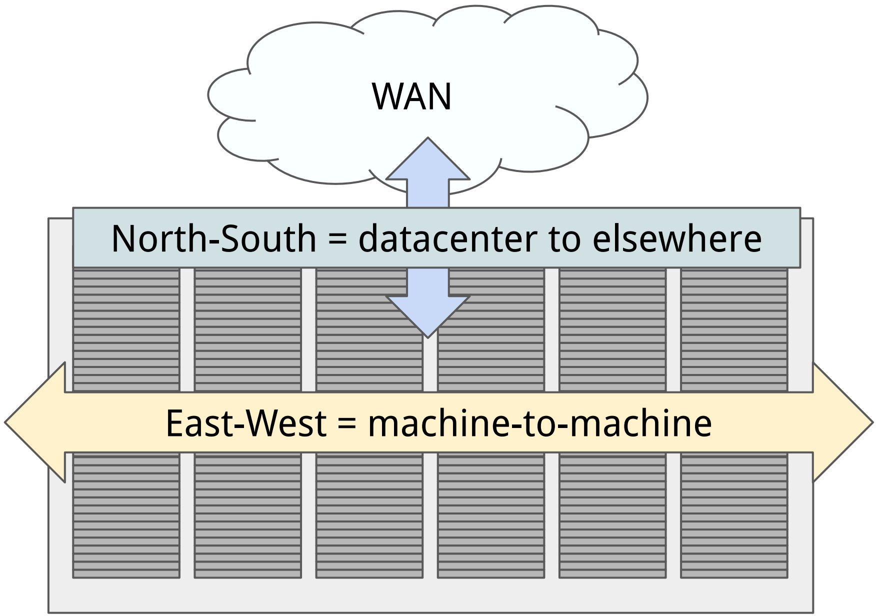


Significantly more inter-machine traffic than “user” to “machine”.

Other Applications

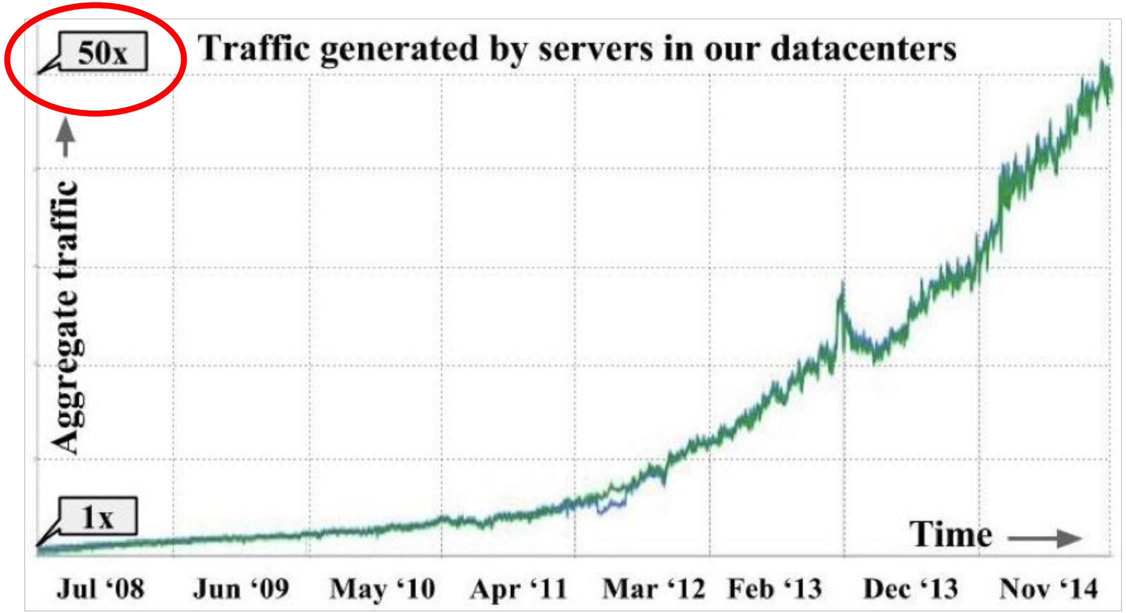
- Big data analytics
  - e.g., mapreduce
- Significantly more traffic between machines - maybe *no* user-facing traffic.
- We'll come back to some different application communication patterns.

Datacenter Traffic Patterns



East-West traffic is several orders of magnitude larger than North-South.

East-West Traffic Volume



"Jupiter Rising: A Decade of Clos Topologies and Centralized Control in Google's Datacenter Network", Arjun Singh et al. @ Google, ACM SIGCOMM'15

Questions?

How do we support East-West bandwidth?

- Ideally any server can talk to any server at line rate.

- We want a network with high **bisection bandwidth**.

Bisection Bandwidth

- Pick the number of links we must cut in order to partition a network into two halves.
- Bisection bandwidth is the sum of those bandwidths.

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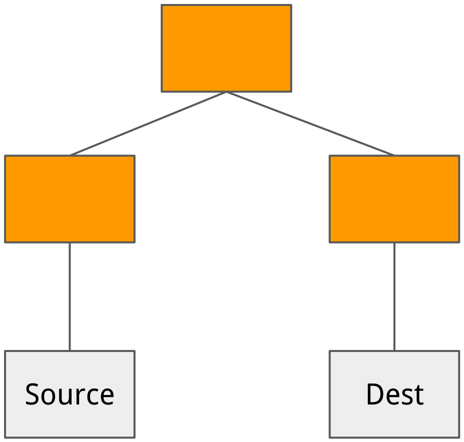

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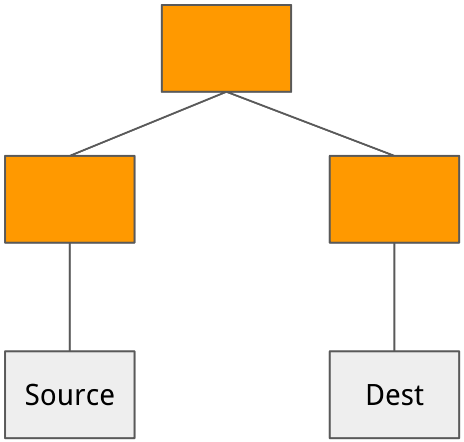

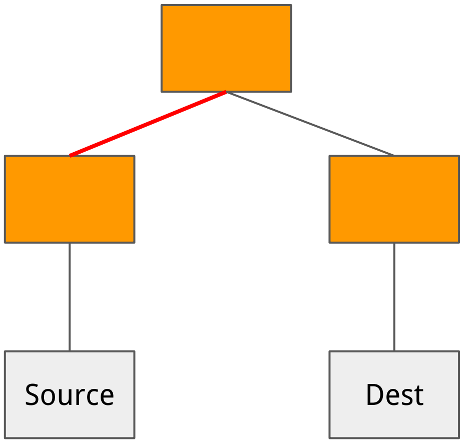

100G

Bisection Bandwidth

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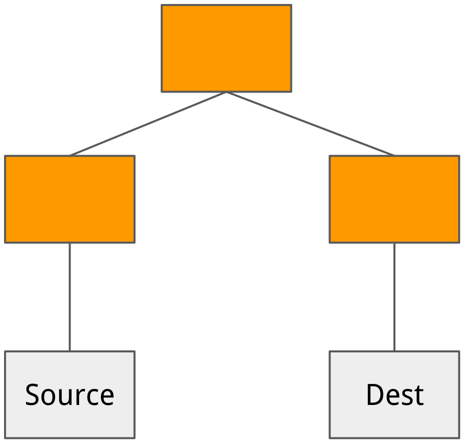
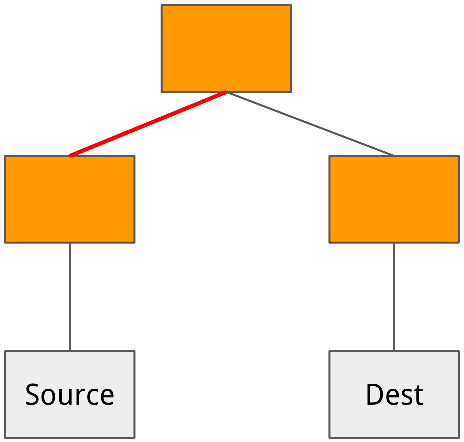
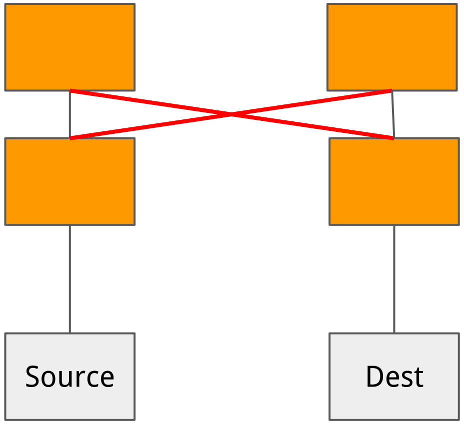




100G



200G

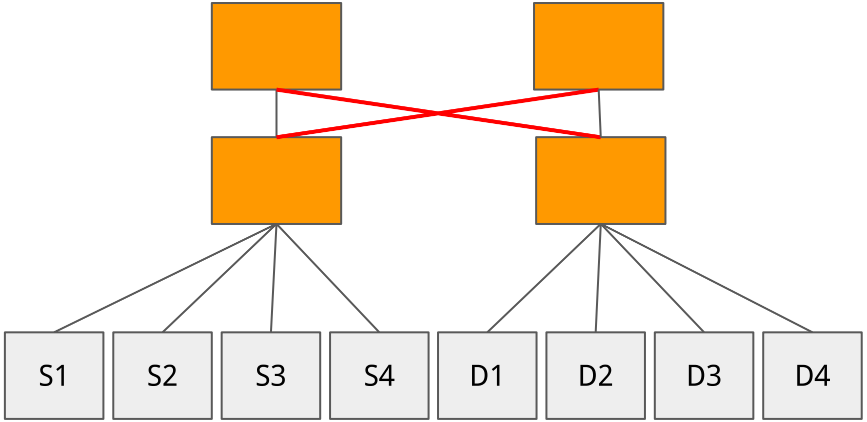
Bisection Bandwidth

- Pick the number of links we must cut in order to partition a network into two halves.
- Bisection bandwidth is the sum of those bandwidths.

- **Full** bisection bandwidth: Nodes in one partition can communicate simultaneously with nodes in the other partition at full rate.
  - Given N nodes, each with access link capacity R, bisection bandwidth = N/2 x R

- Oversubscription, informally, how far from the full bisection bandwidth we are.
  - Formally: ratio of worst-case achievable bandwidth to full bisection bandwidth.

Bisection Bandwidth



Bisection Bandwidth: 200G

Full Bisection Bandwidth: (8/2)*100G = 400G

Oversubscription: 200/400 = 0.5 (2x)

Questions?

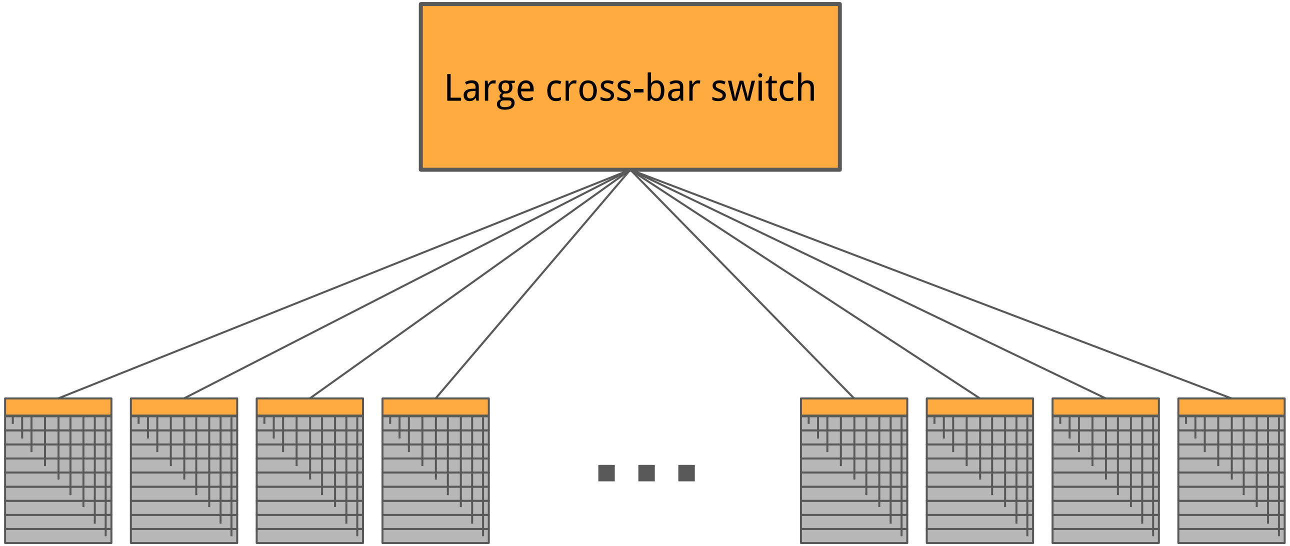
Maximising Bisection Bandwidth

- As we’ve seen, bisection bandwidth is a function of the topology of the network.

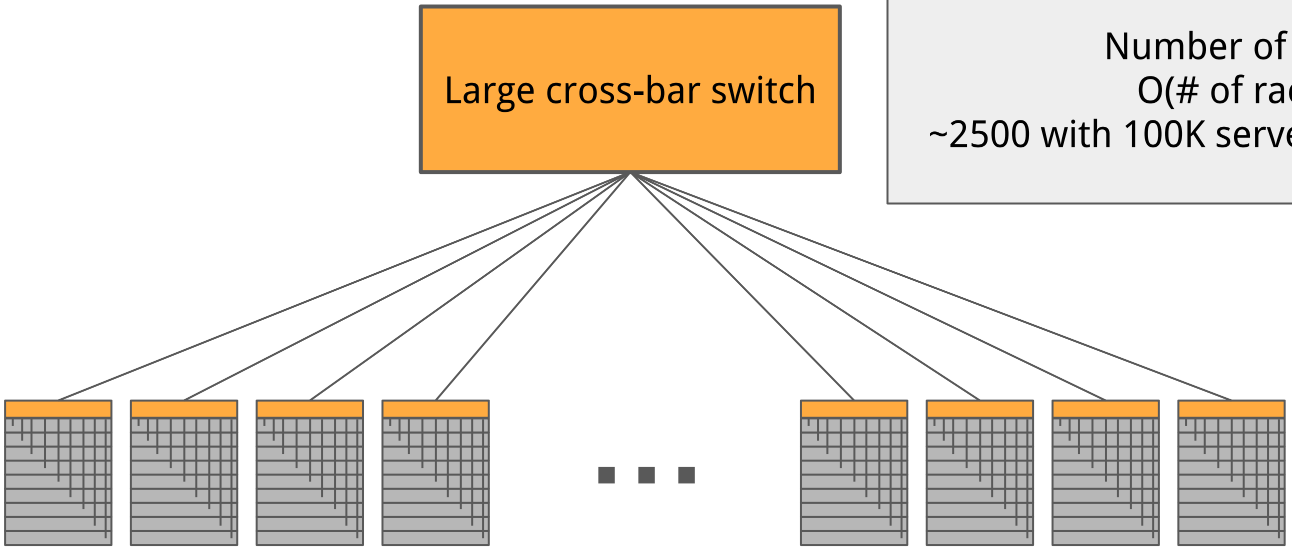
- In the datacenter we can choose our topology relatively easily.
    - Run more cables (fibre, electrical)

- What topology do we build?

“Big Switch” Approach for DC Networking



“Big Switch” Approach for DC Networking



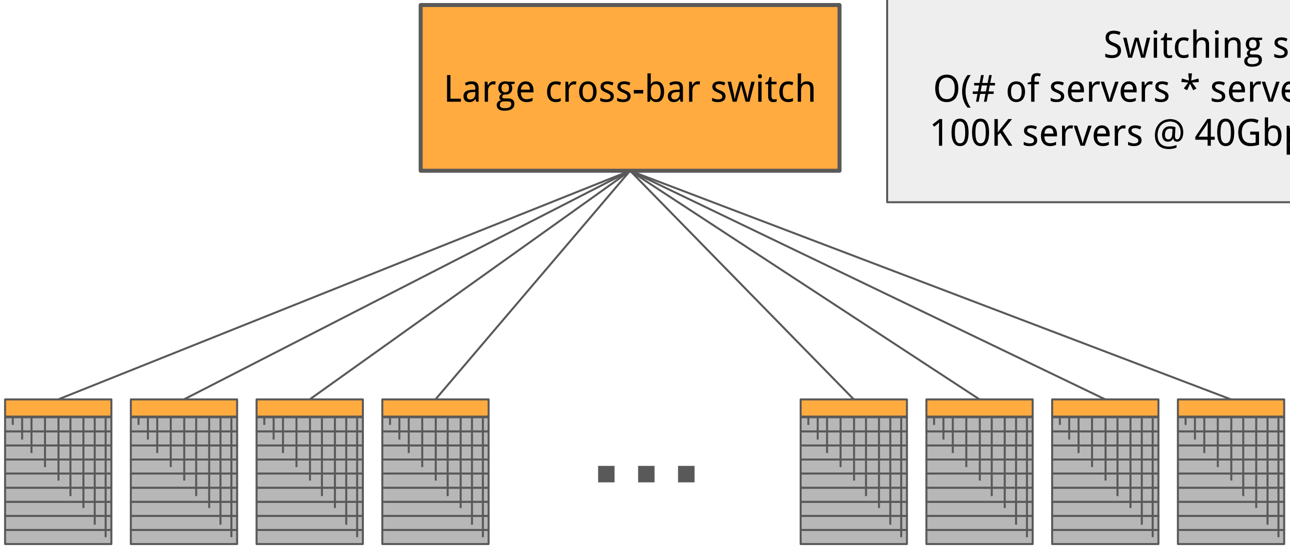
Number of ports
O(# of racks)
~2500 with 100K servers – large **radix**

Switch Radix

- Radix is used to describe the maximum degree a switch can have to other nodes in the network.
- Simply can be thought of as the number of ports the switch can have.

- Switches have constrained radix:
  - Number of line cards they can support.
  - Physical constraints of building fabric cards (remember router architecture).
  - Physical size!

“Big Switch” Approach for DC Networking



Switching speed:
O(# of servers * server access speed)
100K servers @ 40Gbps = O(Petabits)!

Does not scale (and if it did, would be $$$$)

We tried to do this!

10K Gig-E Switch

10K Gigabit Ethernet Switch

Request for Proposal

Google Part 900190
version 1.0

But what we needed was a 10,000-port switch that cost $100/port. So, almost exactly 20 years ago, we sent this five-page RFP to four different switch vendors (IIRC: Cisco, Force10, HP, and Quanta) and tried to interest them in building such a switch. They politely declined because “nobody is asking for such a product except for you”, and they anticipated margins to be low.

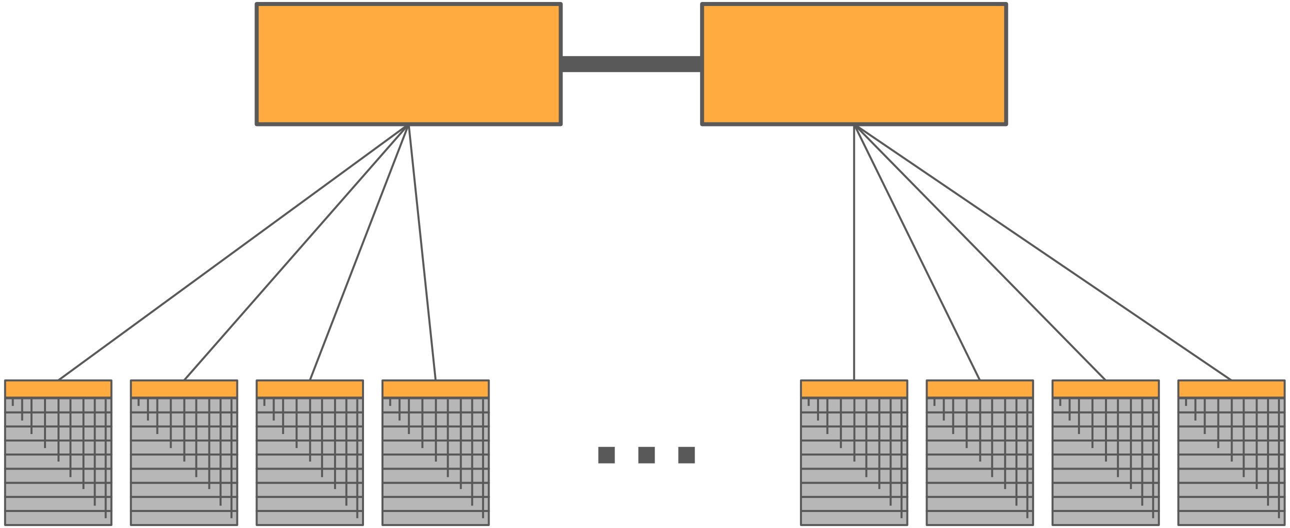
6 Implementation Ideas

This section attempts to explain why we believe it is possible to build a 10,000 port non-blocking switch for $100/port. This section does not imply any requirements for a specific design and should be thought of as one or more potential paths to a solution.

The Broadcom BCM5670 and BCM5671 provide what appear to be ideal solutions for our problem. The BCM5670 can be configured with 2 BCM5690 chips to create a 20 Gig-E port switch with 2 10G uplinks and 2 10G cross links to another box with 20 Gig-E ports. The BCM5670 can be configured with 4 BCM5690 chips to create a 40 Gig-E port switch with 4 10G uplinks. The total chip cost is $1338. Then we just need to aggregate the uplinks into a non-blocking mesh. We can build such a mesh by configuring 1125 BCM5670s into a CLOS network at a chip cost of $416250. This leads to a total chip cost of $75/port. This leaves $25/port for the phy layers, uplinks, circuit boards, power supplies, CPU or configuration system, etc.

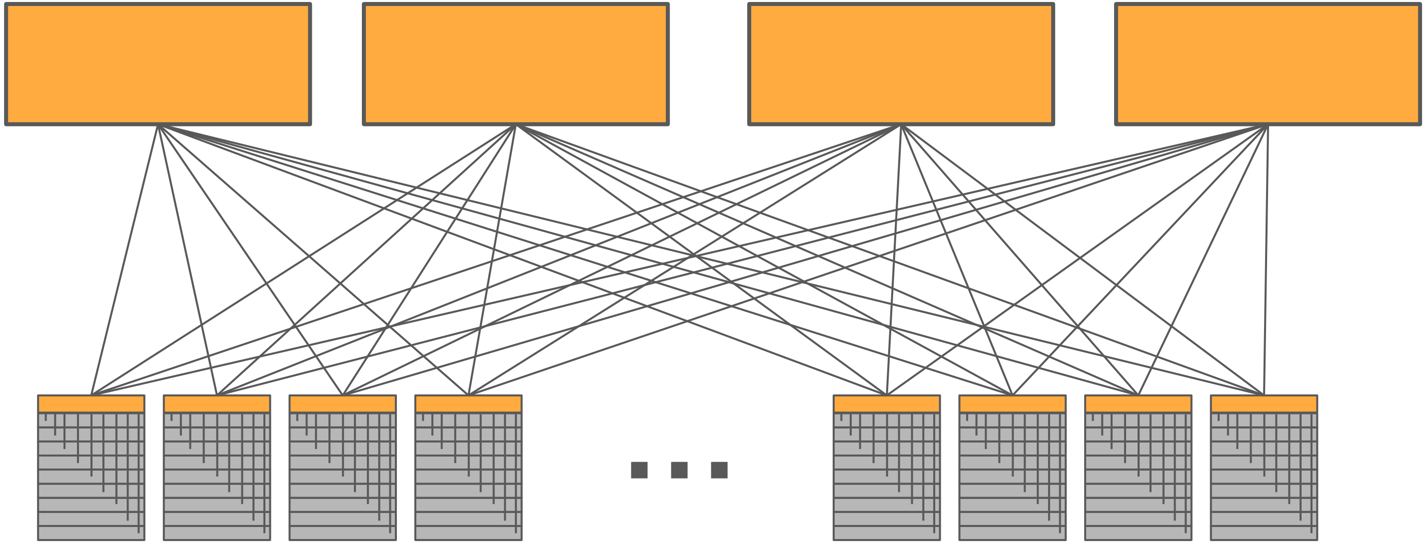
Urs Hözle (Google) on LinkedIn

Avoiding a “Big Switch”



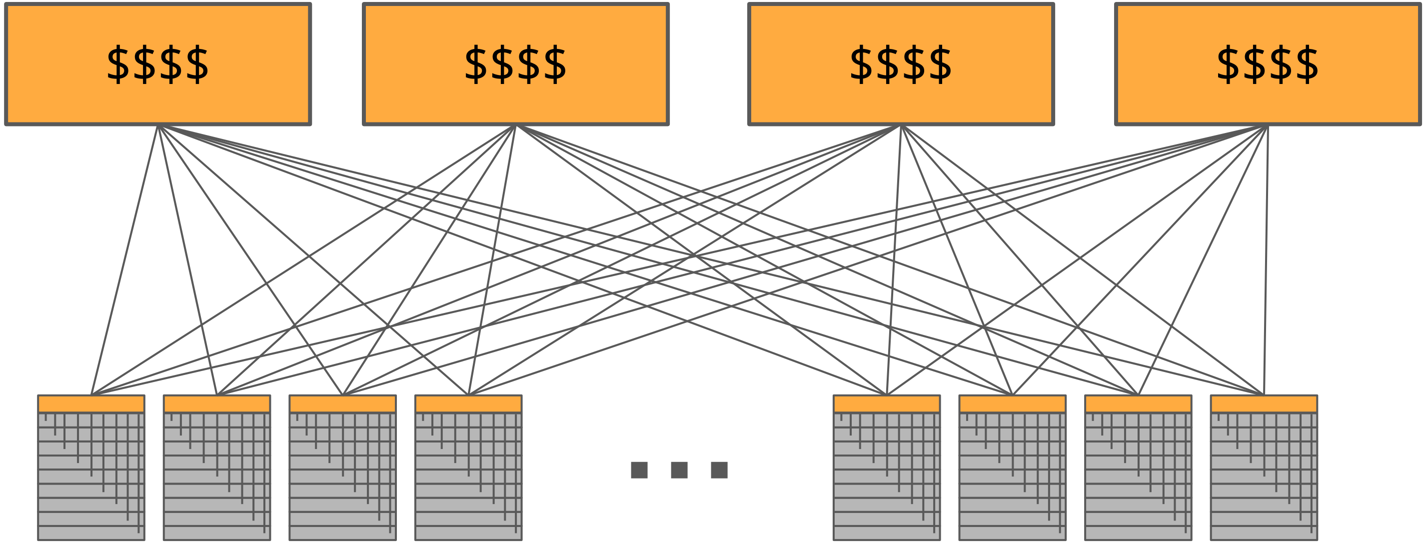
Reduced radix and bandwidth *if we don’t care about failures*

Avoiding a "Big Switch"



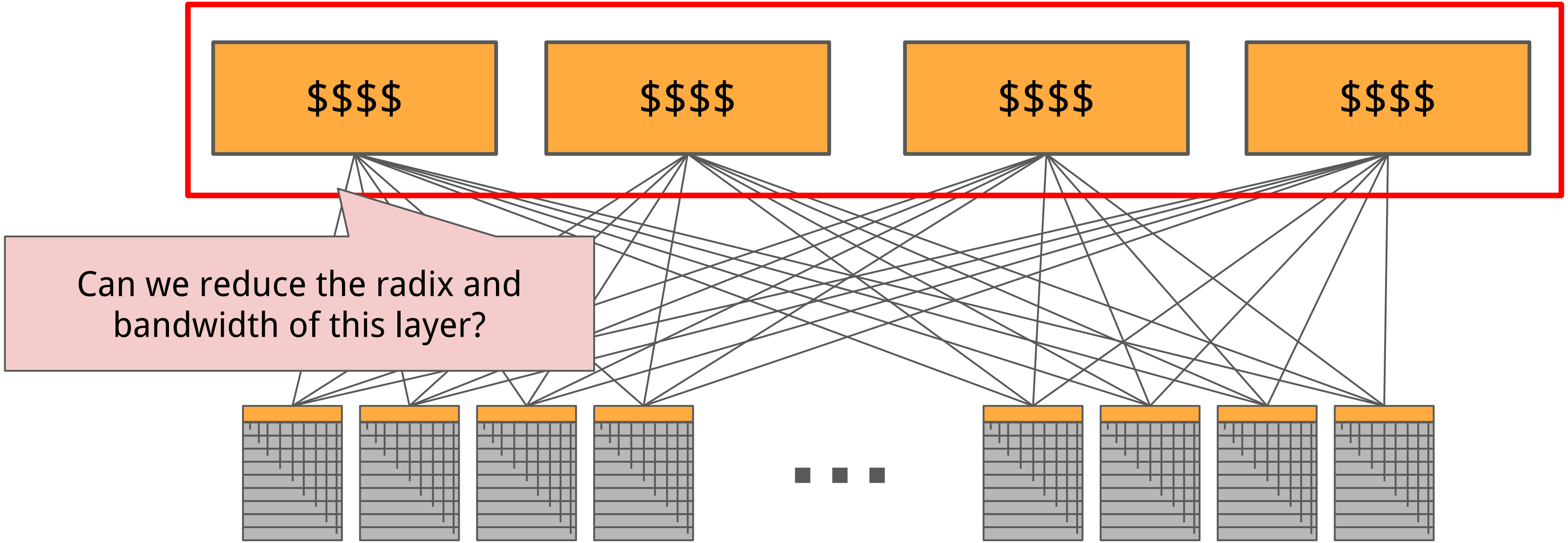
Reduced radix and bandwidth per switch - *if we can use multiple paths*

Building a DC network



This topology works (and has been used).

Building a DC network



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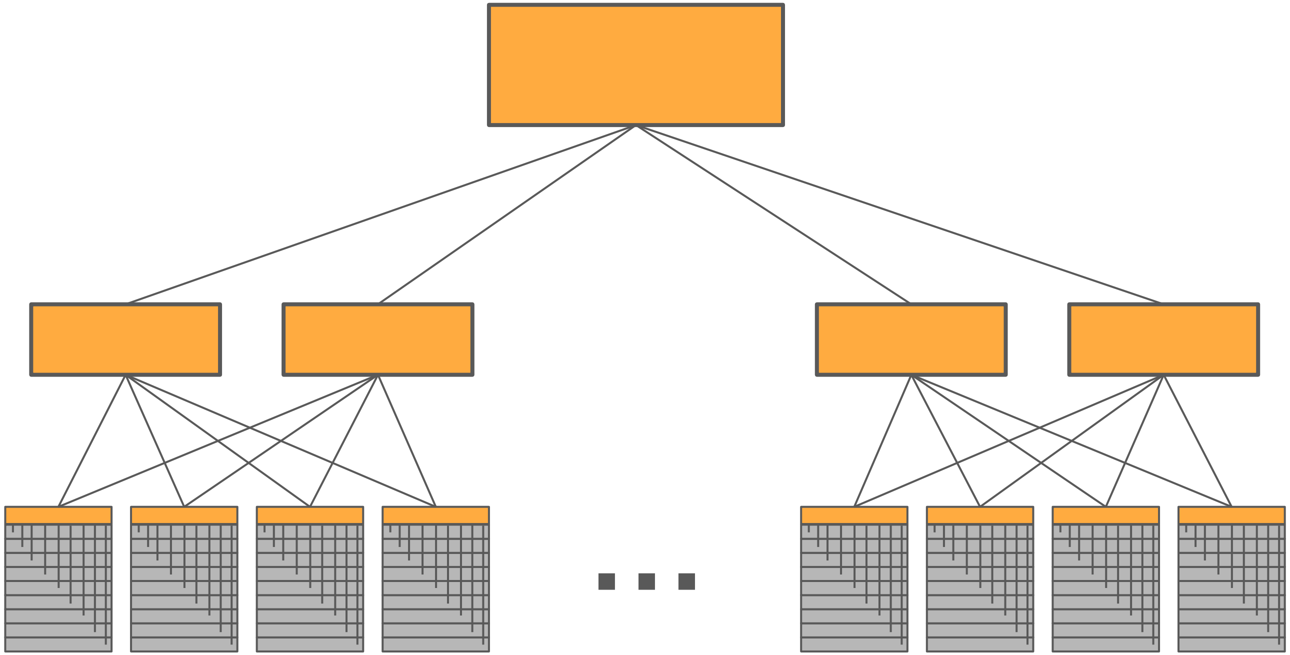
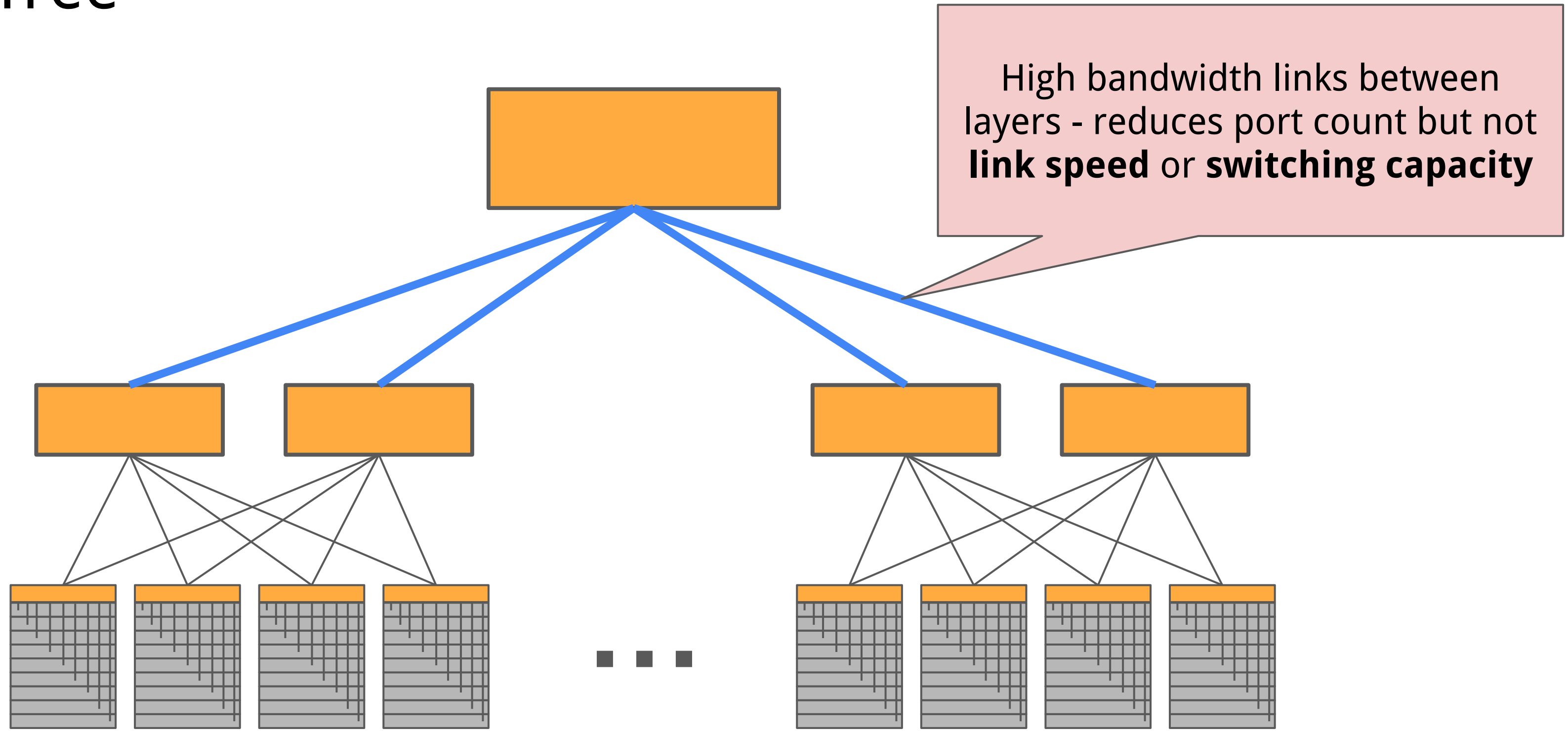
A **Tree**

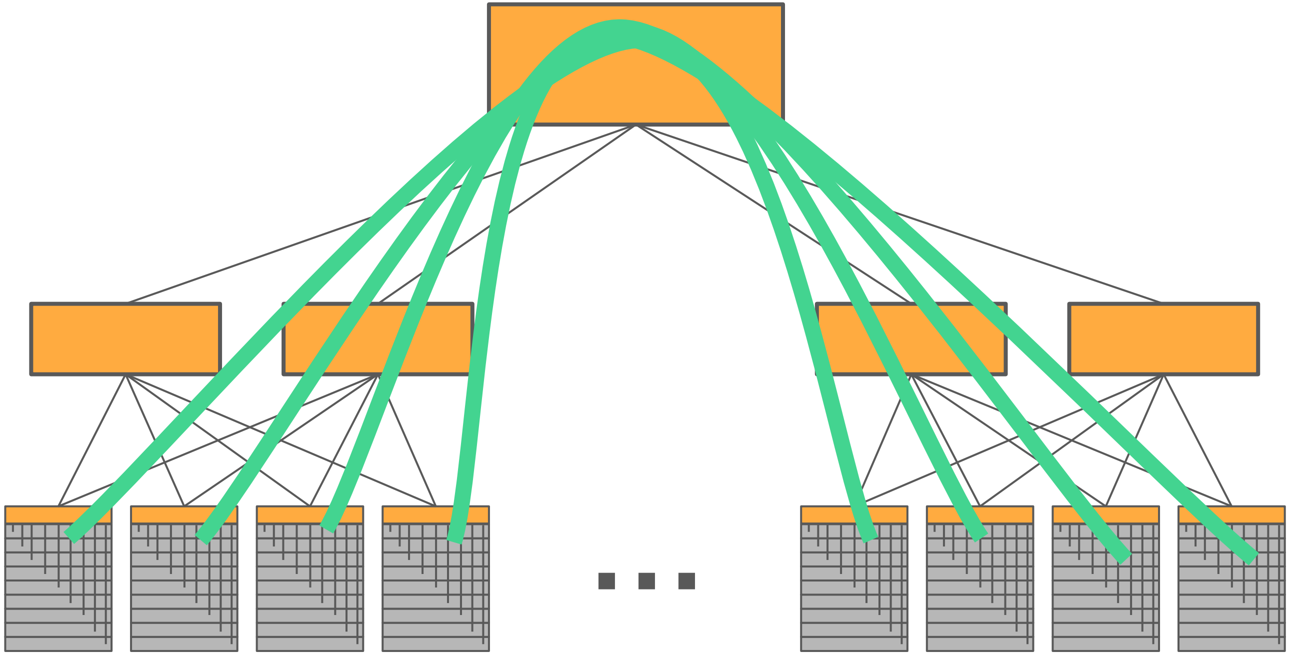


A **Fat** Tree



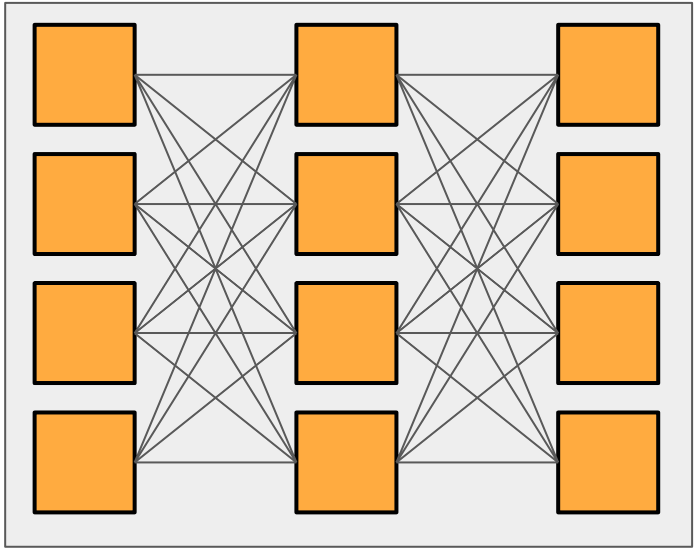
Still not scalable – or very expensive

A **Tree**



Problem: low bisection bandwidth → congestion

Clos Networks



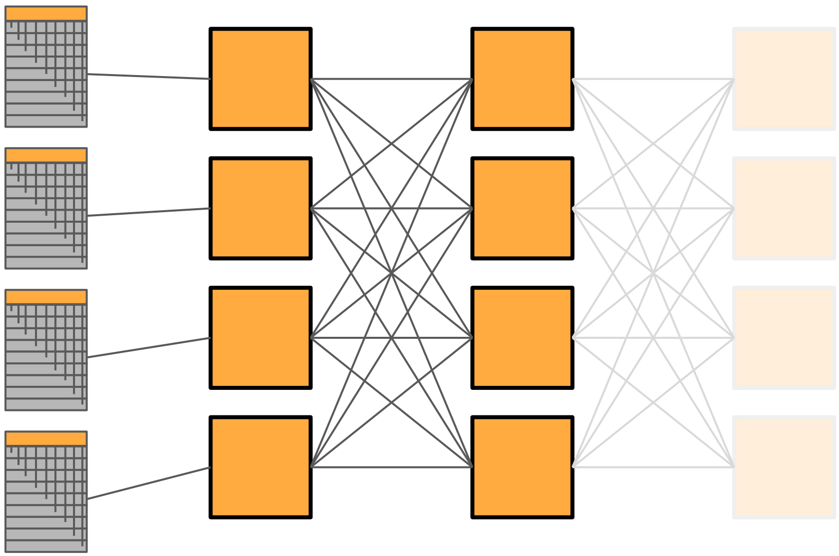
- All switches have same # of ports.
- # of ports per switch is low.
- All link speeds are the same.
- Highly multi-path.

Using small (commodity, cheap!) elements to build large capacity-rich networks.

Clos Networks

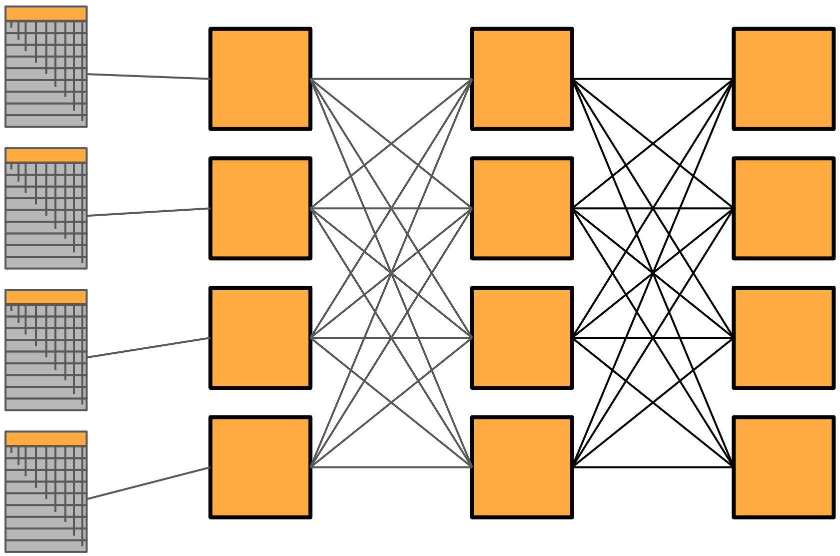
- Not a new idea!
- Formalised by Charles Clos in 1952.
- Networks can be scaled by adding *stages.*

Clos Networks



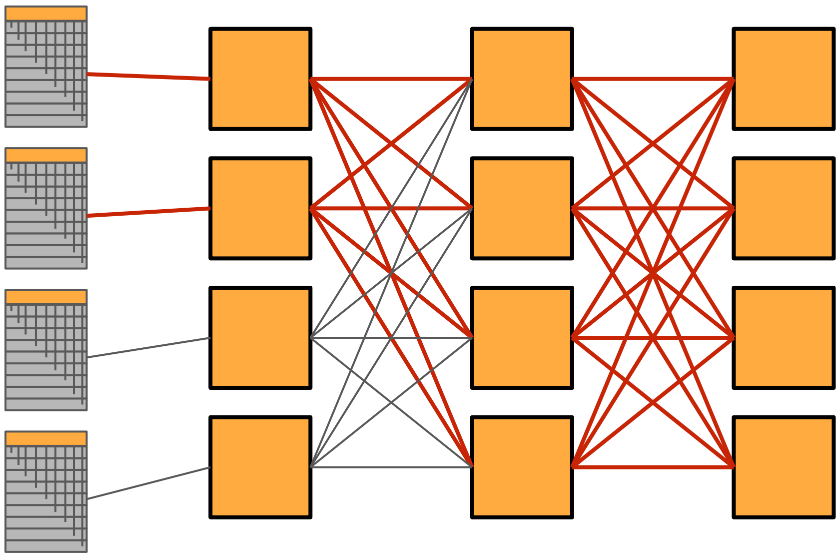
- DC networks tend to be *folded Clos*.
- Input and output switches are the same.
  - Network links are bidirectional

Clos Networks



- DC networks tend to be *multi-stage*.
- Allows scaling beyond the radix of the commodity switch platforms being used.

Clos Networks



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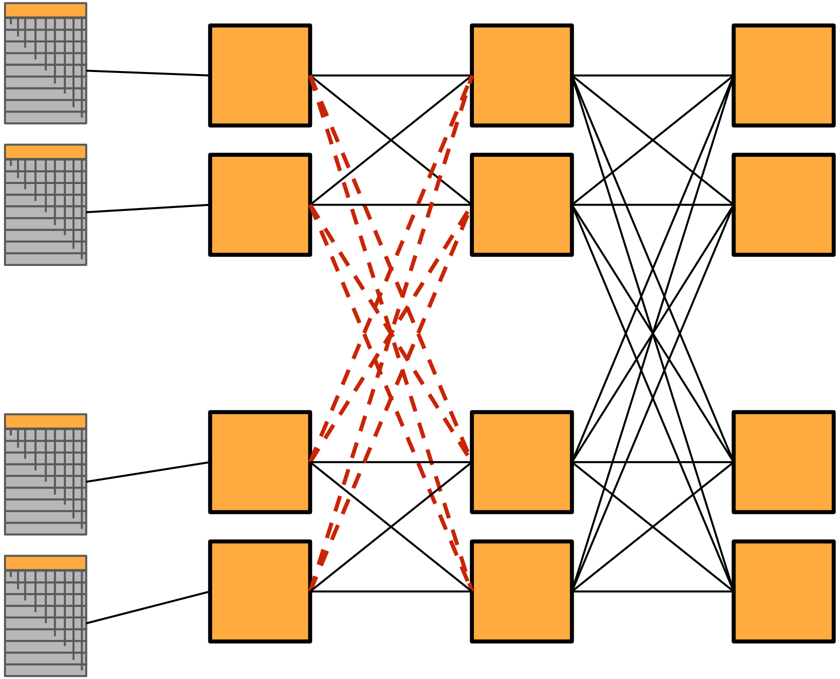
Clos Networks - Bisection Bandwidth



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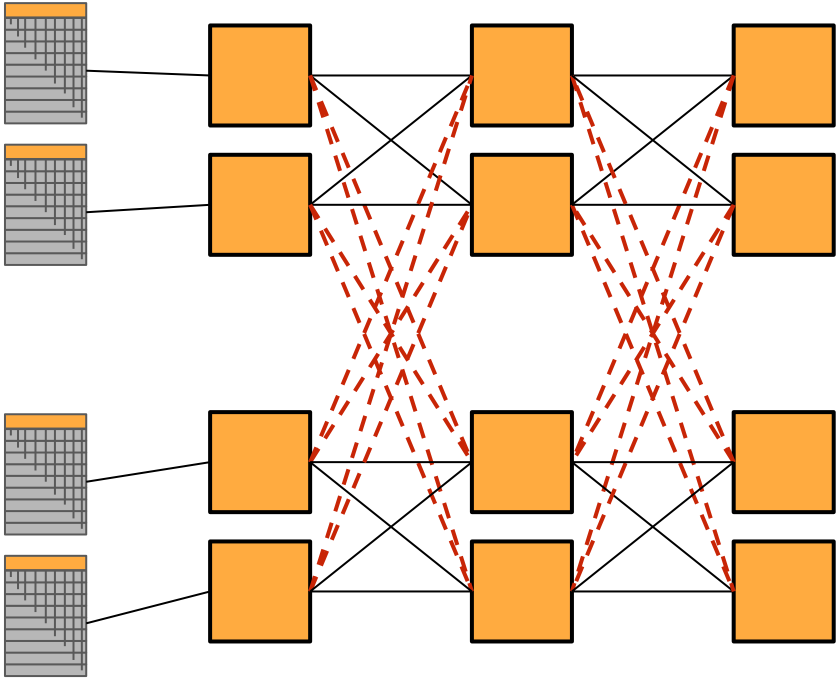

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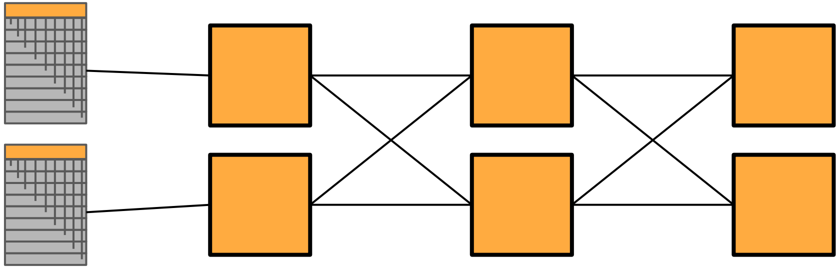
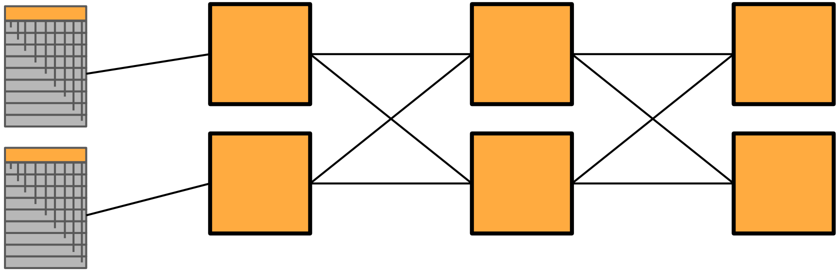
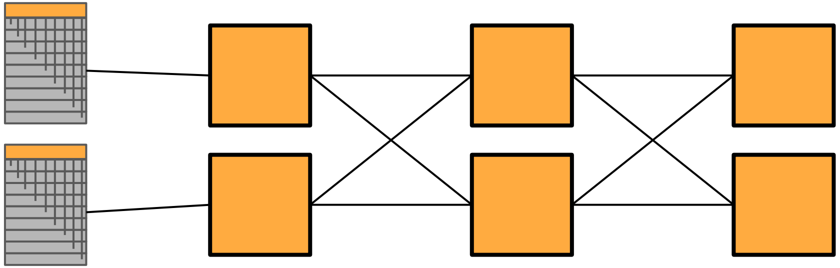


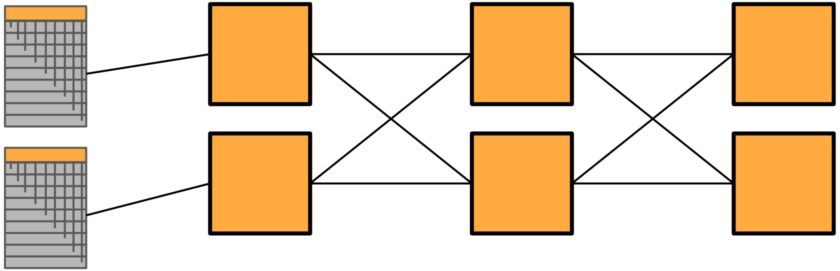
16*100G links failed to partition = 1600Gbps bisection bandwidth



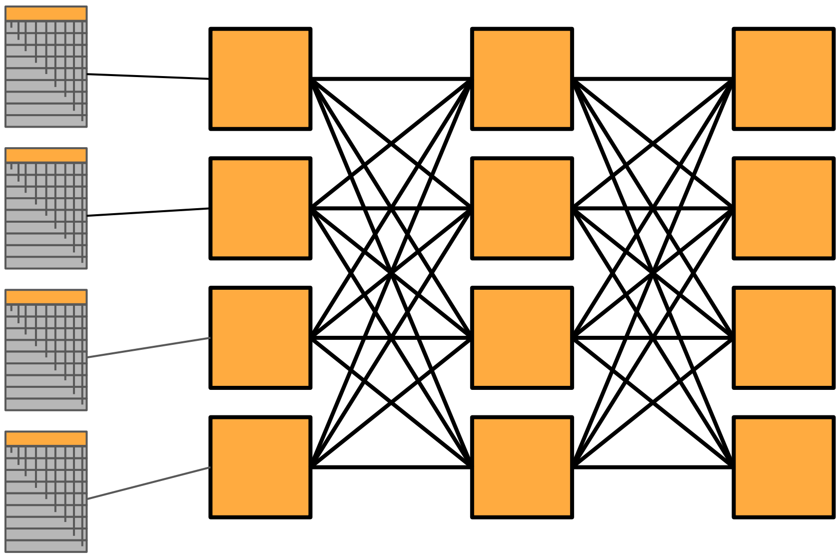
Clos Networks - Bisection Bandwidth



Full bisection bandwidth = (4*80)/2 * 100G = **1600G**

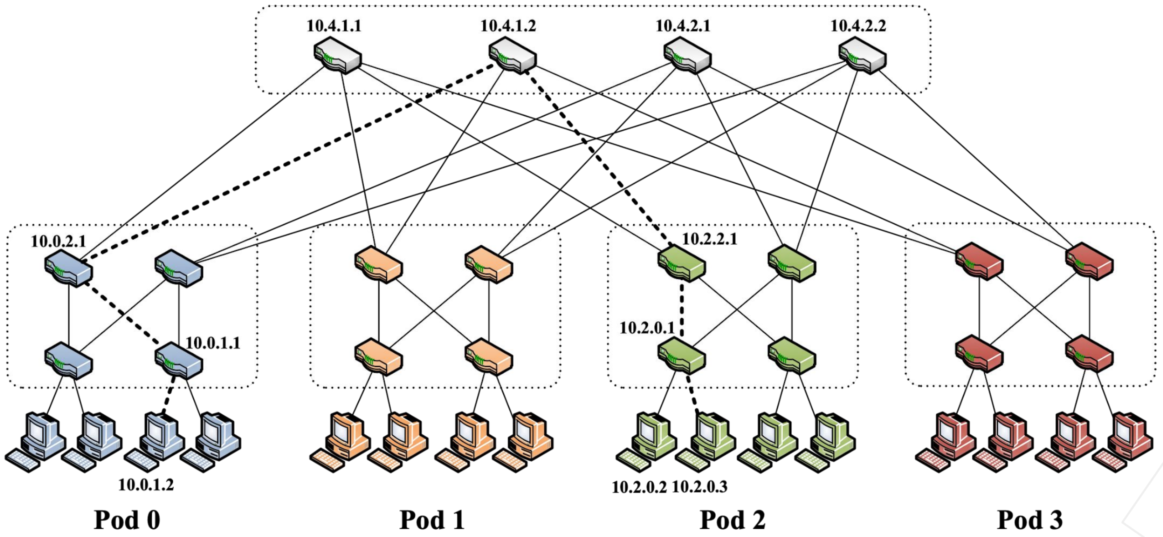


Mixing Link Speeds



- Need not have all the links be exactly the same capacity.
- Server uplinks/access links can be lower bandwidth than switch to switch links.
- Easy to accomplish where switch chips allow “breaking out” of individual ports.
- e.g., 200G server uplink, 400G switch-to-switch

Evolution of Clos Networks for DC

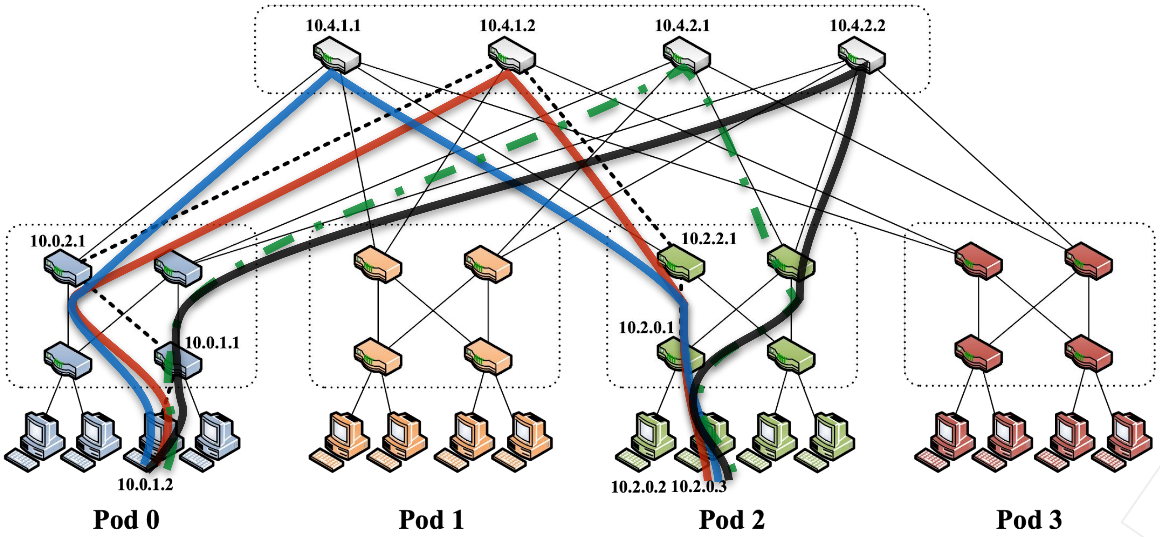


ACM SIGCOMM 2008

A Scalable, Commodity Data Center Network Architecture

Mohammad Al-Fares Alexander Loukissas Amin Vahdat

Evolution of Clos Networks for DC



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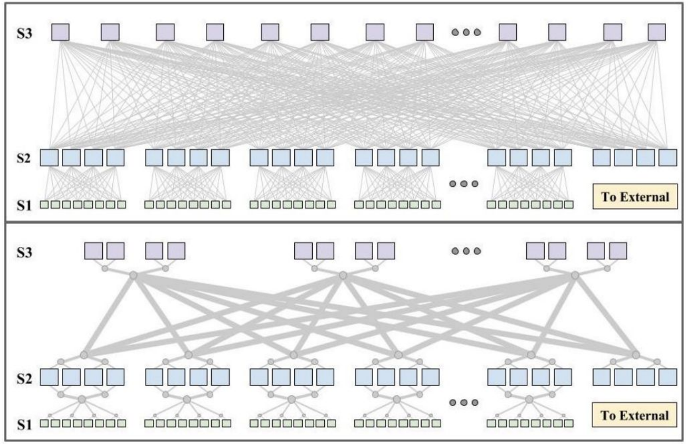
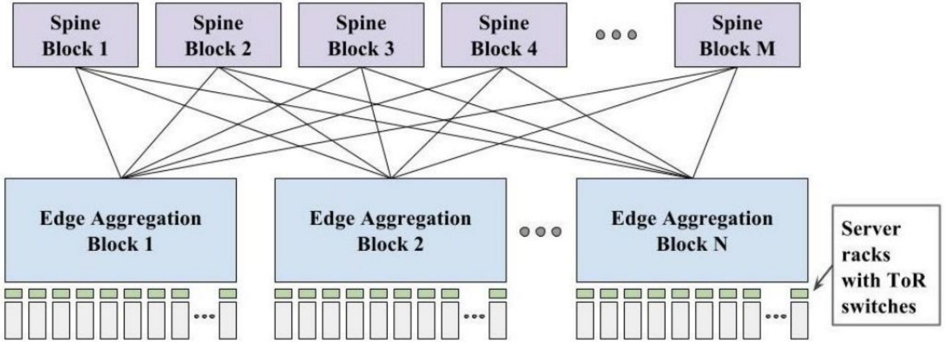


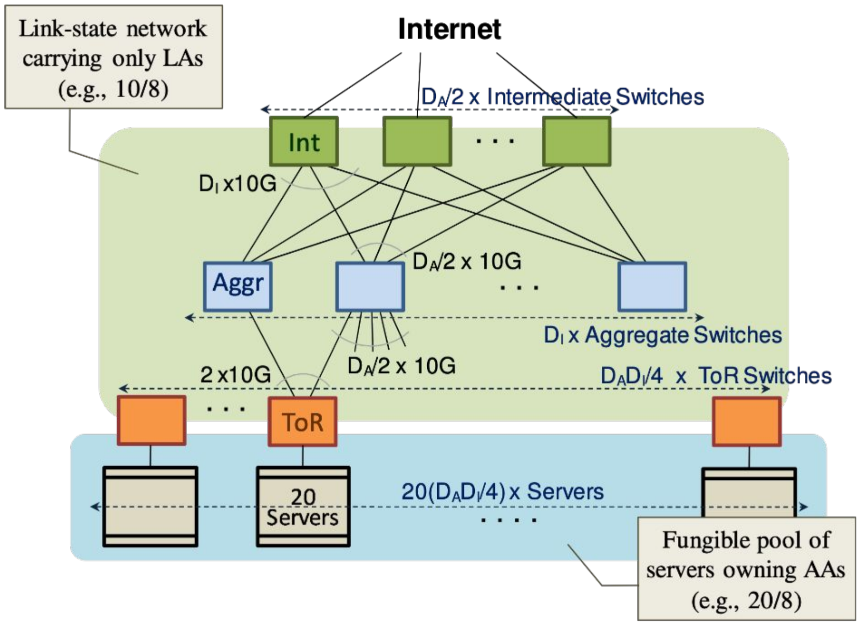


Jupiter Rising: A Decade of Clos Topologies and Centralized Control in Google's Datacenter Network

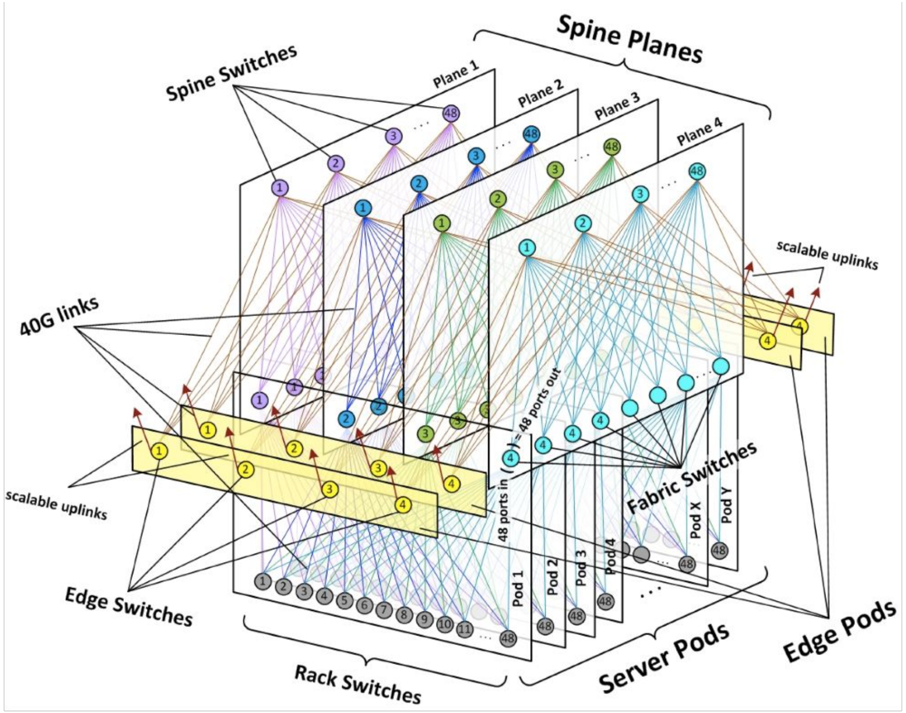
Arjun Singh, Joon Ong, Amit Agarwal, Glen Anderson, Ashby Armistead, Roy Bannon,
Seb Boving, Gaurav Desai, Bob Felderman, Paulie Germano, Anand Kanagala, Jeff Provost,
Jason Simmons, Eiichi Tanda, Jim Wanderer, Urs Hölzle, Stephen Stuart, and Amin Vahdat
Google, Inc.
jupiter-sigcomm@google.com

ACM SIGCOMM 2015

Design Variants are Common



VL2 @ **Microsoft**, ACM SIGCOMM'09
Greenburg, Hamilton, Jain, Kandula, Kim, Lahiri, Maltz, Patel, Sengupta



"Introducing data center fabric, the next-generation **Facebook** data center network", Alexey Andreyev, 2015

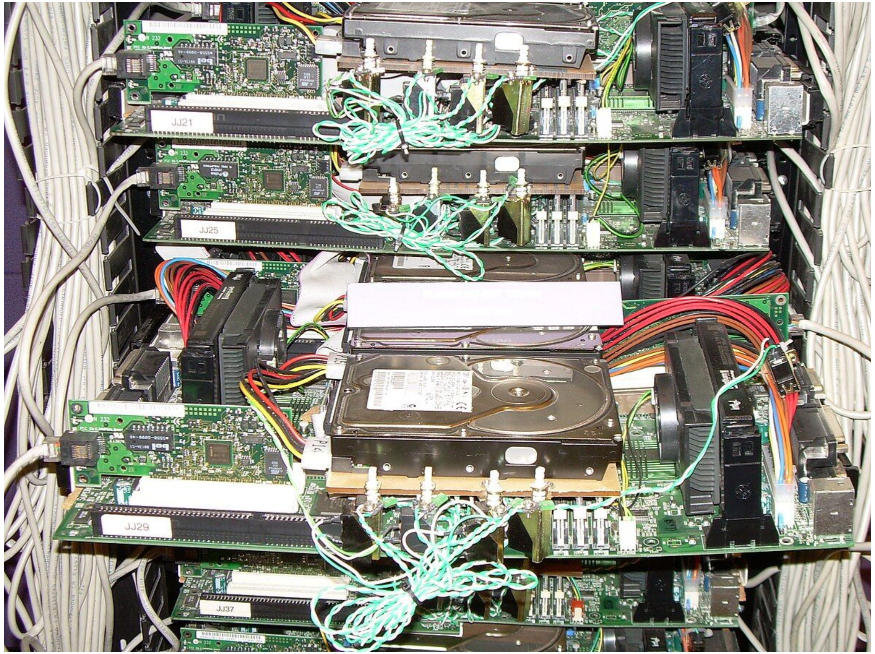
Questions?

Components of a Datacenter Network

End hosts are servers within the datacenter.

Components of a Datacenter Network

Server



Server

Historical Google servers within a rack.

Image: Wikipedia

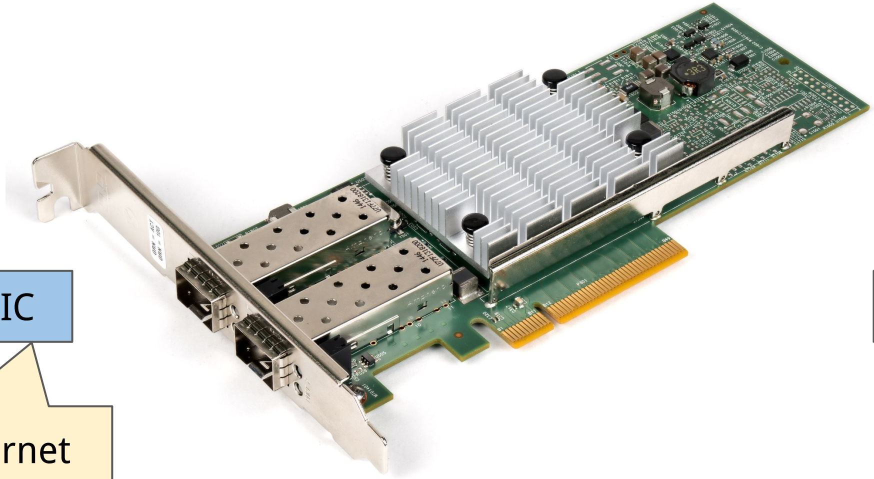
Components of a Datacenter Network

NIC = Network Interface Card.

Components of a Datacenter Network

Server | NIC

Provides Ethernet ports (L1+L2) functionality.

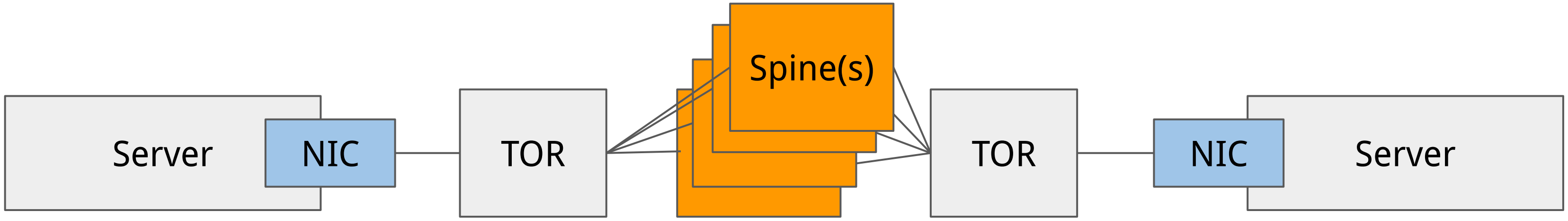


1…N cards per host server to provide bandwidth.

NIC | Server

NIC = Network Interface Card.

Components of a Datacenter Network



- Packets flow across multiple layers of switches according to the topology selected.
- All components (including servers, typically) are in the control of one organisation.

Thinking about *optimisation*

- We identified ways that the network topology can be designed to support the applications that are deployed within a datacenter.
- What other components of the end-to-end system could we think about optimising?
- Next time – can we think about optimising routing.
  - e.g.., how to choose paths to carry traffic according to performance requirements?
- Other questions:
  - How should *hosts* be designed to support datacenter applications?
  - How might congestion control be adapted to take advantage of datacenter characteristics?

Summary

- Datacenters are single organisation, multi-application environments.
- A key criteria is high any-to-any bandwidth.
  - We characterise this as bisection bandwidth.
- The topology of the datacenter must be designed to both be scalable, and cost efficient.

Next Time

- What else is different in datacenters?
  - Particularly, how does routing work in these topologies?
- How do we address the multi-tenant nature of a DC?