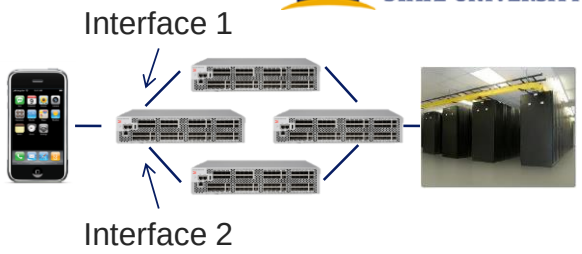
Virtual Circuit (VC) networks

- Virtual-circuit network provides network-layer connection service
  - Call setup, teardown for each call before data can flow
  - Every router on source-dest path maintains "state" for each passing connection
  - Bandwidth and buffers allocated to VC (dedicated resources = predictable service)
- Packets forwarded using VC identifiers:
  - VC ids embedded in cells (packets)
  - Router looks up outgoing interface for VC id



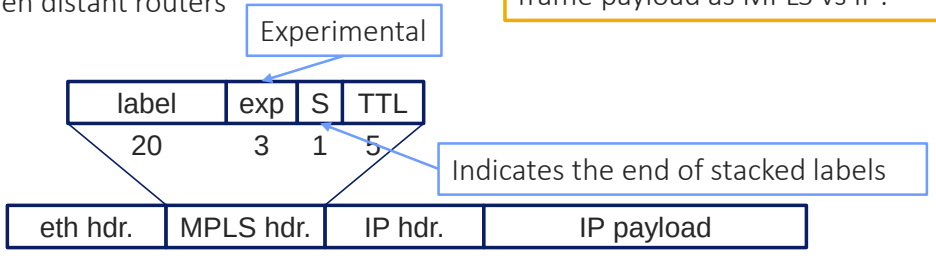
In interface	In VC id	Out VC id	Out interface
1	6	22	1
1	7	13	2
1	13	5	1

Multiprotocol label switching (MPLS)

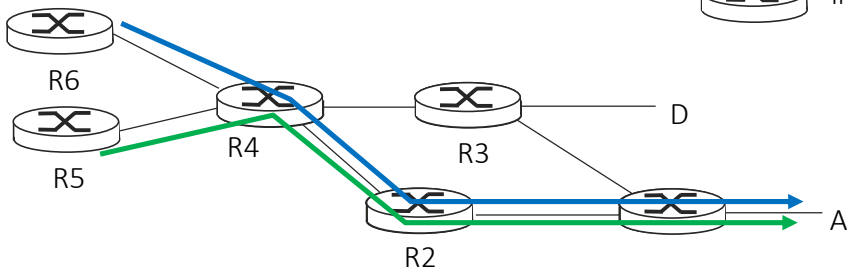
- Initial goal: high-speed IP forwarding using **fixed length label** (instead of IP address)
  - Fast lookup using fixed length identifier (rather than shortest prefix matching)
  - Borrowing ideas from ATM networks
  - IP datagram keeps its IP address!
- Considers forwarding paths as links between distant routers

- Label-switched routers
  - Forward packets to outgoing interface based only on label value (don't inspect IP address)
  - MPLS forwarding table distinct from IP forwarding tables

How does a router know to interpret frame payload as MPLS vs IP?

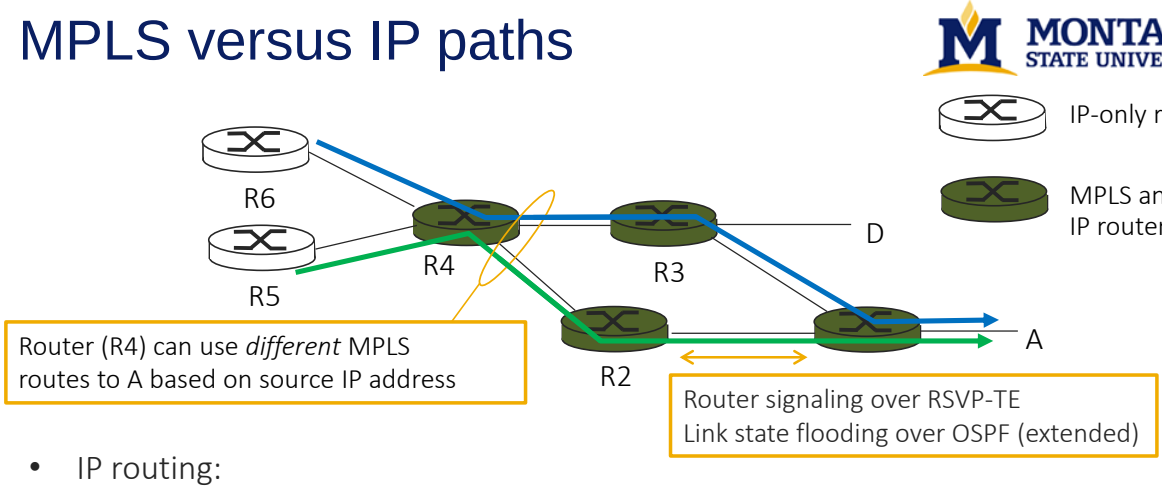


MPLS versus IP paths



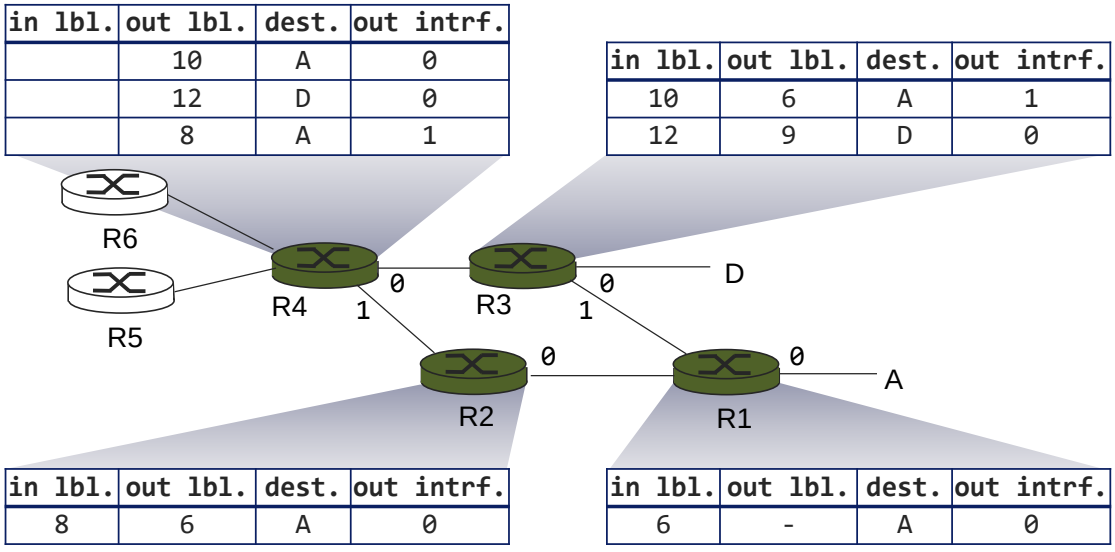
- IP routing:
  - Path to destination determined by destination address alone

MPLS versus IP paths

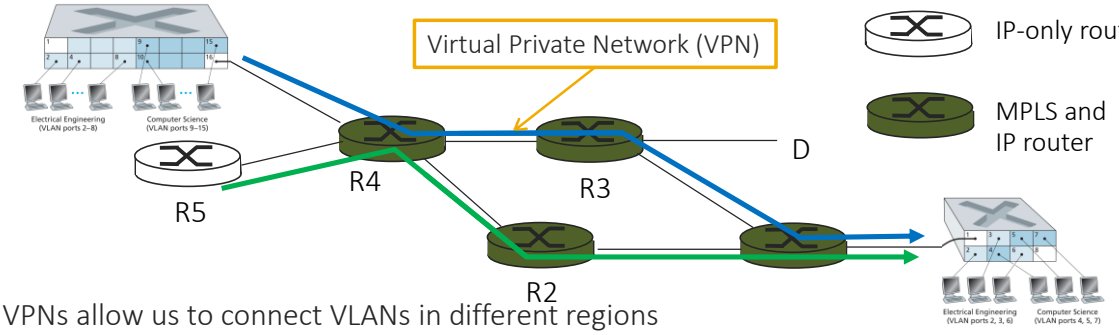


- IP routing:
  - Path to destination determined by destination address alone
- MPLS routing:
  - Path to destination can be based on source and dest. address
  - Fast reroute: precompute backup routes in case of link failure (useful for VoIP)

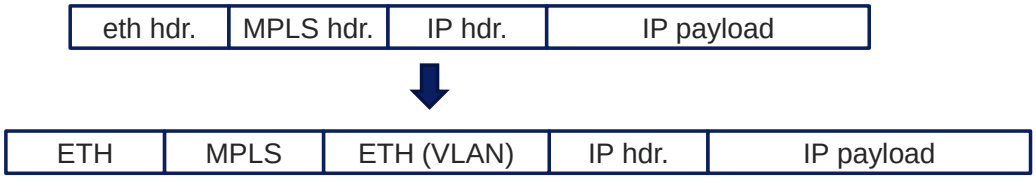
MPLS forwarding tables



MPLS and VLAN



- VPNs allow us to connect VLANs in different regions
- MPLS packets can encapsulate Ethernet packets



Data center networks

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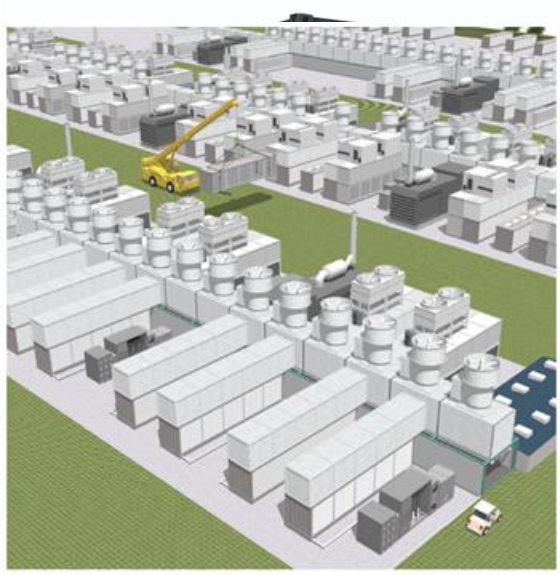
- 10's to 100's of thousands of hosts, often closely coupled, in close proximity:
  - Online services (e.g. Amazon)
  - Content-servers (e.g., YouTube, Akamai)
  - Search engines, data mining (e.g., Google)
- Challenges:
  - Multiple applications, each serving massive numbers of clients
  - Complex traffic patterns
  - Managing/balancing load to avoid processing, networking, data bottlenecks
- New trends
  - Outside data tonnage
  - AI arms race



Data center networks

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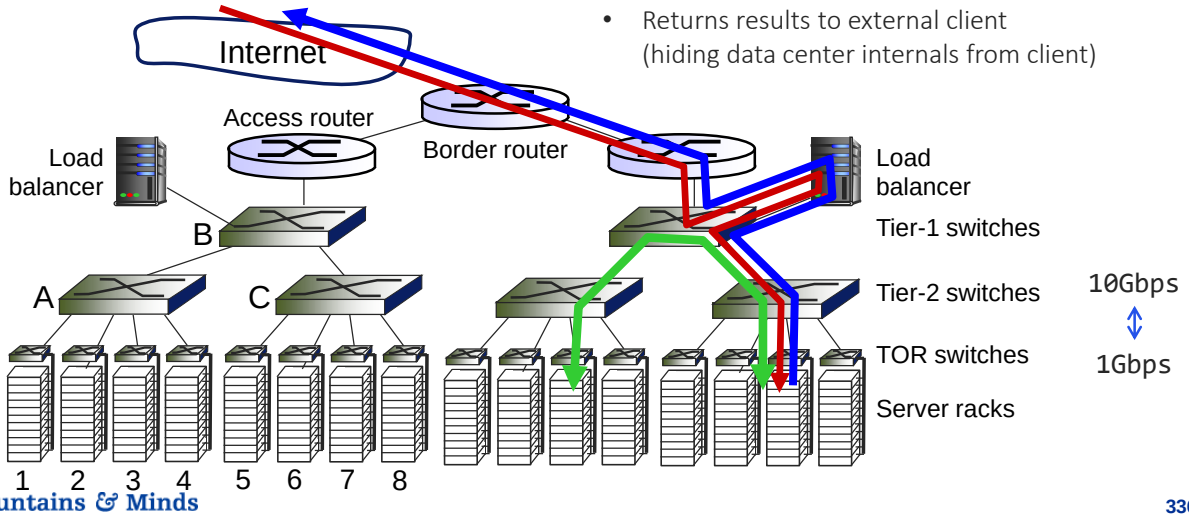
- Load balancer: application-layer routing
  - Receives external client requests
  - Directs workload within data center
  - Returns results to external client (hiding data center internals from client)



Data center networks

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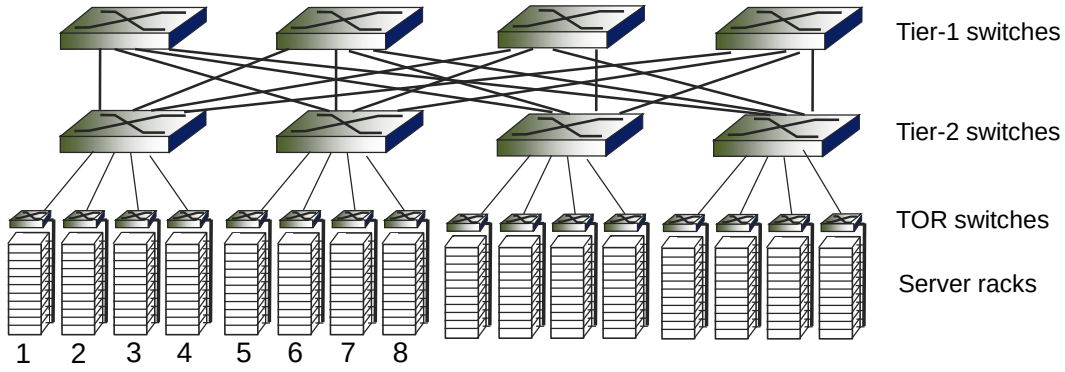
- Rich interconnection among switches, racks:
  - Increased throughput between racks (multiple routing paths possible)
  - Increased reliability via redundancy



Fat tree

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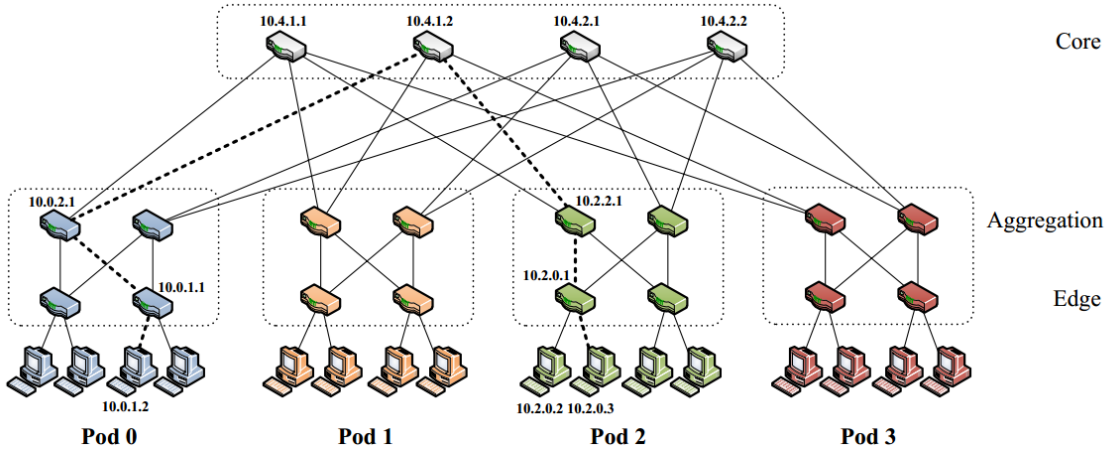
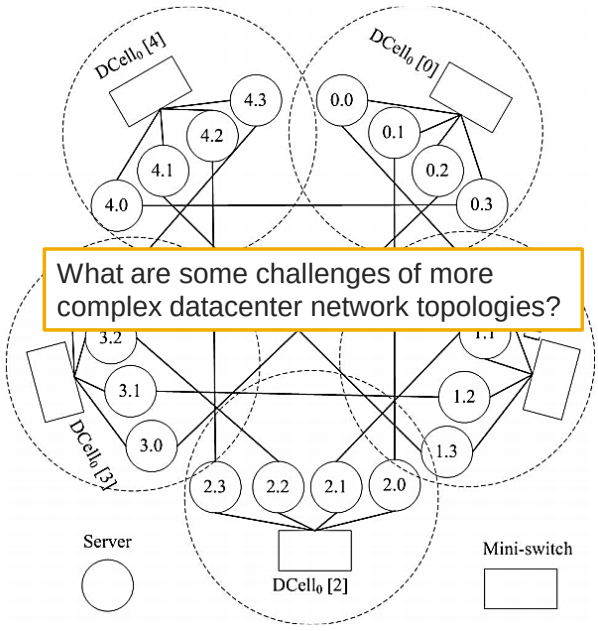


DCell


DCell0 [4]
DCell0 [0]
4.3
4.2
4.1
4.0
0.0
0.1
0.2
0.3
What are some challenges of more complex datacenter network topologies?
3.2
3.1
3.0
DCell0 [3]
1.2
1.3
2.3
2.2
2.1
2.0
Server
DCell0 [2]
Mini-switch