Network Virtualization

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What is “virtualization”?

- Creating a virtual version of a common resource
  - **Virtual memory** - process has its own address space
  - **RAID storage** - process thinks its writing to one disk, but many underneath
  - **Virtual machine** - the OS doesn’t know it is running on top of another OS (and not hardware)

- A way to share a common resource

Progress toward “network virtualization”

- Many different steps/techniques over the years
- Generally, doing something a little different from the typical layer-defined behavior

Ex 1: Network Address Translation (NAT)

Ex 1: an Internet debate from the late 80s/early 90s

At Stanford! Steve Deering (PhD 1991, inventor of IPv6)

- “We’re going to run out of IPv4 address space - we need IPv6”
- “But it might take a while to roll out IPv6...”

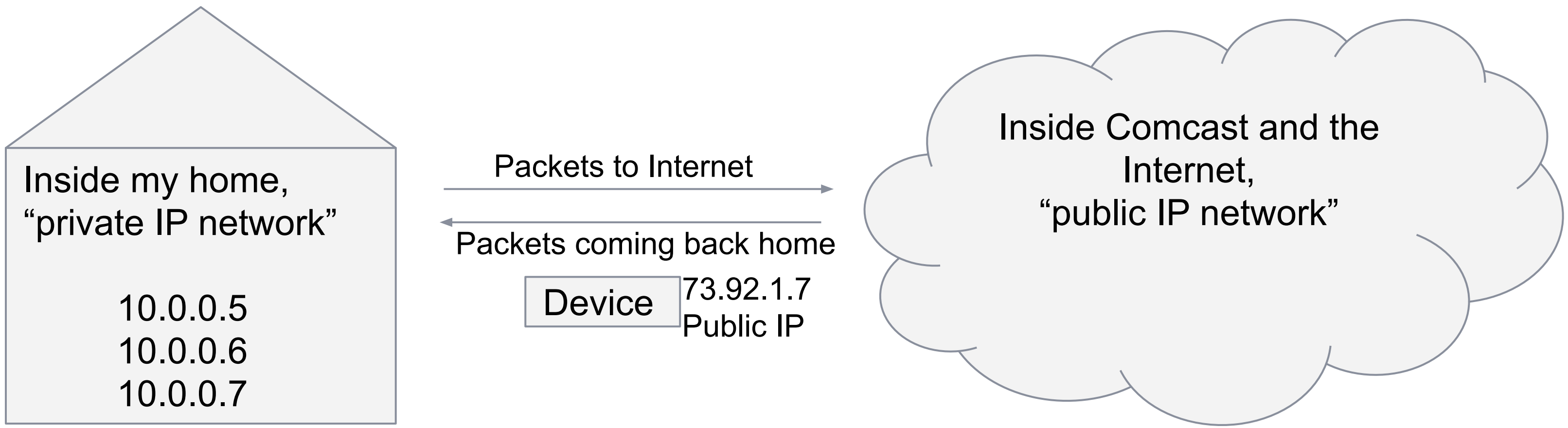
And thus, network address translation (NAT) was born - from RFC 1918:

```
3. Private Address Space

   The Internet Assigned Numbers Authority (IANA) has reserved the
   following three blocks of the IP address space for private internets:

     10.0.0.0        -   10.255.255.255  (10/8 prefix)
     172.16.0.0      -   172.31.255.255  (172.16/12 prefix)
     192.168.0.0     -   192.168.255.255 (192.168/16 prefix)
```

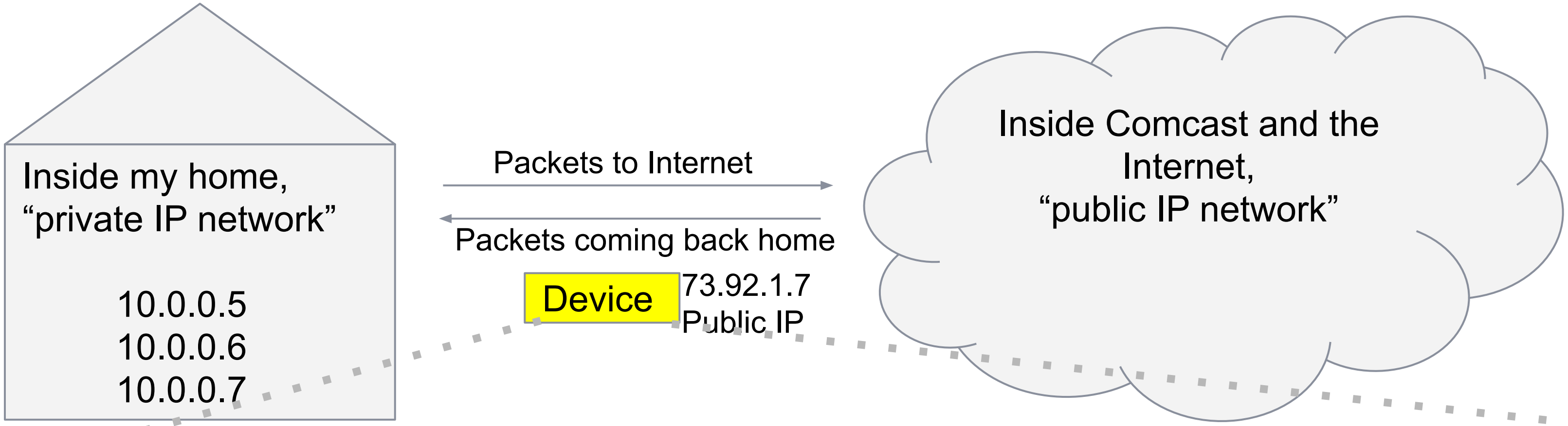
ifconfig on my laptop at home

```
ocb-mbp:~ ocb$ ifconfig
lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST> mtu 16384
     options=1203<RXCSUM,TXCSUM,TXSTATUS,SW_TIMESTAMP>
     inet 127.0.0.1 netmask 0xff000000
     inet6 ::1 prefixlen 128
     inet6 fe80::1%lo0 prefixlen 64 scopeid 0x1
     nd6 options=201<PERFORMNUD,DAD>

….

en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
     ether 8c:85:90:95:15:4a
     inet6 fe80::14b2:9162:5553:8b72%en0 prefixlen 64 secured scopeid 0x8
     inet 10.0.0.7 netmask 0xffffff00 broadcast 10.0.0.255
     inet6 2601:647:5a00:6510:c0f:3811:351b:5c4d prefixlen 64 autoconf secured
     nd6 options=201<PERFORMNUD,DAD>
     media: autoselect
     status: active
```

Private in home, public in Internet



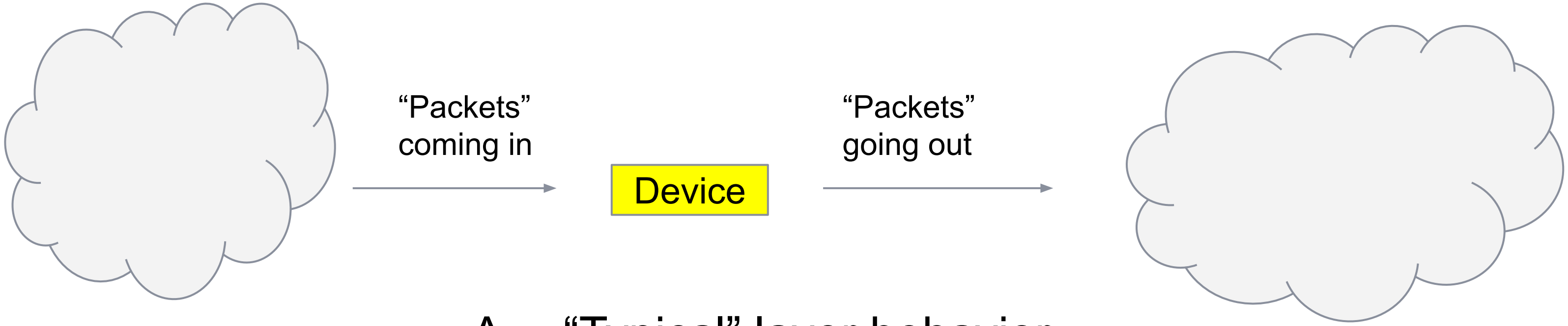
Translation table between private and public



Address & port **translation** table

Original Source IP	**Original Source Port**	**New Source IP**	**New Source Port**	**Protocol**	**Destination IP**	**Destination Port**
10.0.0.5	53323	73.92.1.7	45584	TCP	157.240.22.35	80
10.0.0.5	43023	73.92.1.7	9489	TCP	157.240.22.174	80
10.0.0.7	35803	73.92.1.7	49348	TCP	69.171.250.54	80

Changing the packet



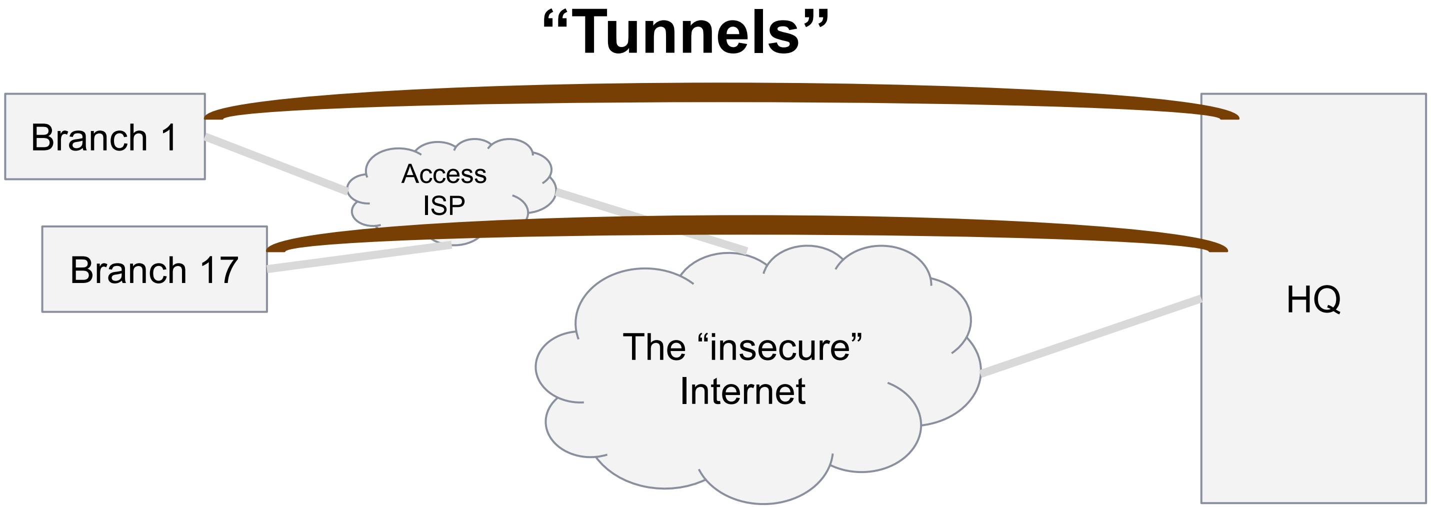
A. "Typical" layer behavior
B. Translation

Ex 2: Virtual Private Network (VPN)

Ex 2: Virtual Private Networks (VPNs) in mid 90s

Use case:

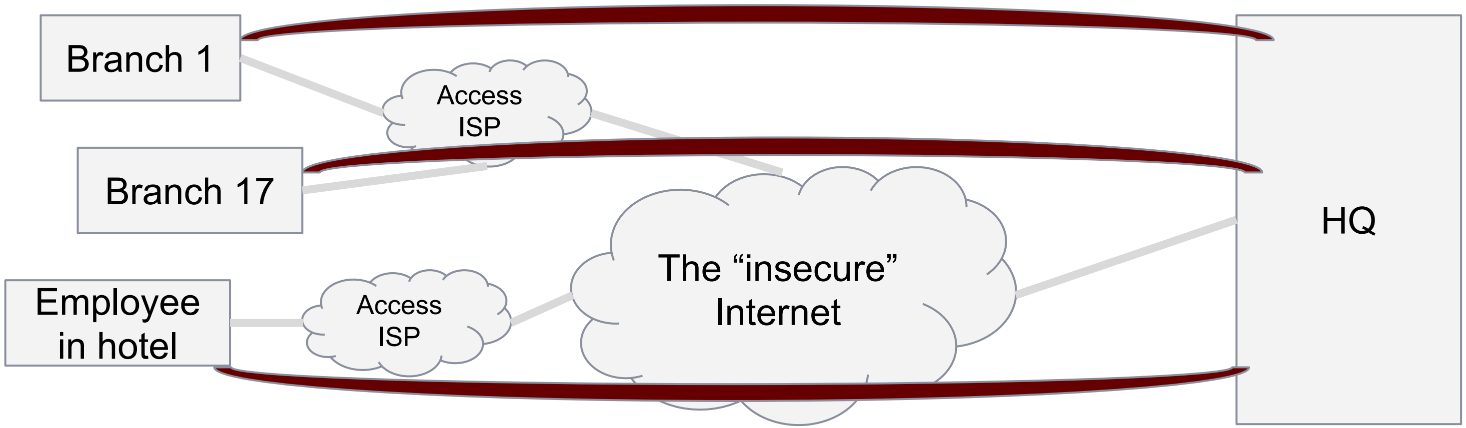
- Companies have “branches” (banks, sales offices) that want to connect to headquarters over Internet



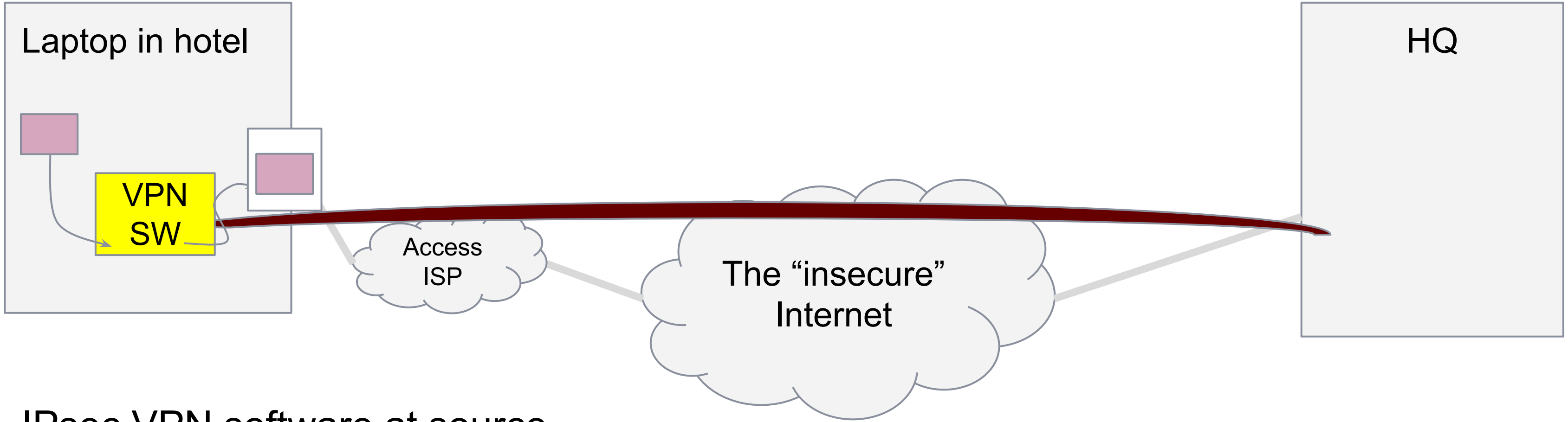
Ex 2: Virtual Private Networks (VPNs) in mid 90s

Use case:

- Companies have "branches" (banks, sales offices) that want to connect to headquarters over Internet
- Connect from public network (like a hotel)



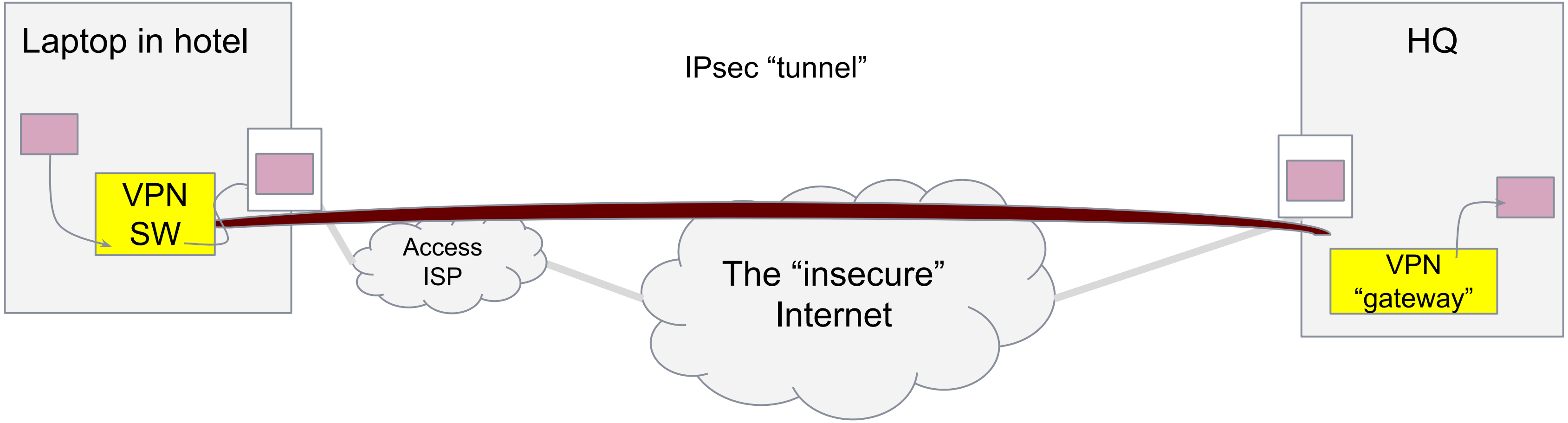
How a “tunnel” works - encapsulation



IPsec VPN software at source

- Creates new packet with “tunnel” IPs
- **Encapsulates** encrypted original IP packet as payload in new packet
- Sends it out to destination IP tunnel endpoint

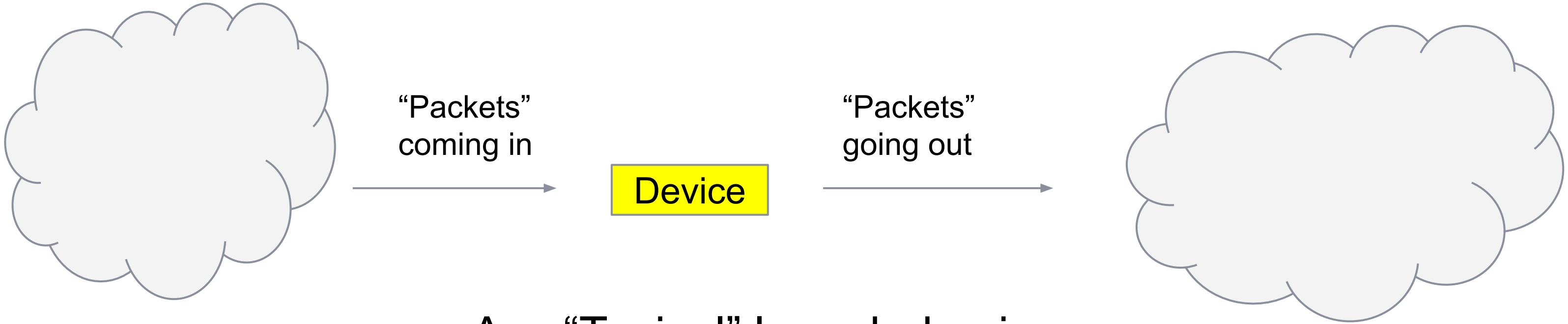
How a “tunnel” works - de-encapsulation



IPsec VPN gateway at destination

- Receives encapsulated packet
- **Deencapsulates** - removes outer IP header
- Unpacks the payload and decrypts
- Sends it along into HQ

Changing the packet

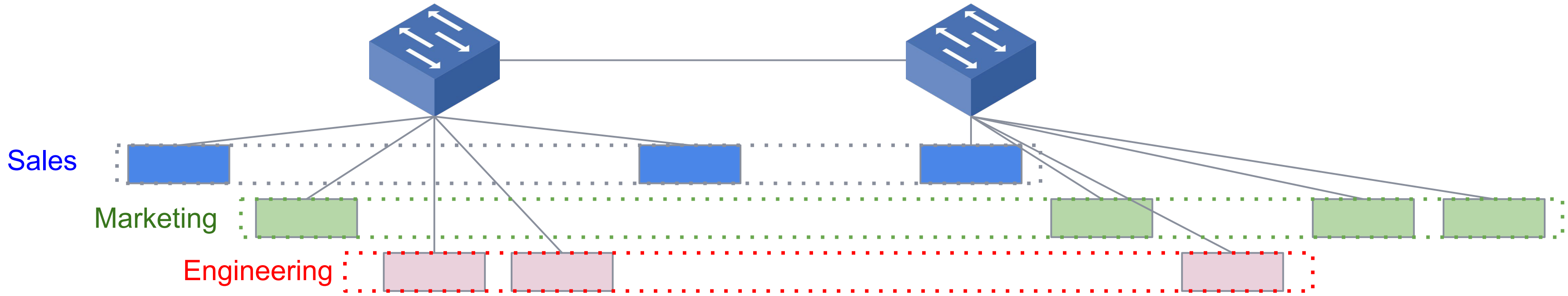


A. "Typical" layer behavior
B. Translation
C. Tunnels

Ex 3: Virtual LANs (VLANs)

Ex 3: from late 90s/early 00s

- “Ethernets have a lot of traffic now - wasn’t so bad with just email...”
  - Recall CSMA/CD class
- Too much broadcast in a big IP subnet
  - But without one big IP subnet, how to span multiple devices?
- Introduced a “tag” in header to create a virtual LAN (layer 2)

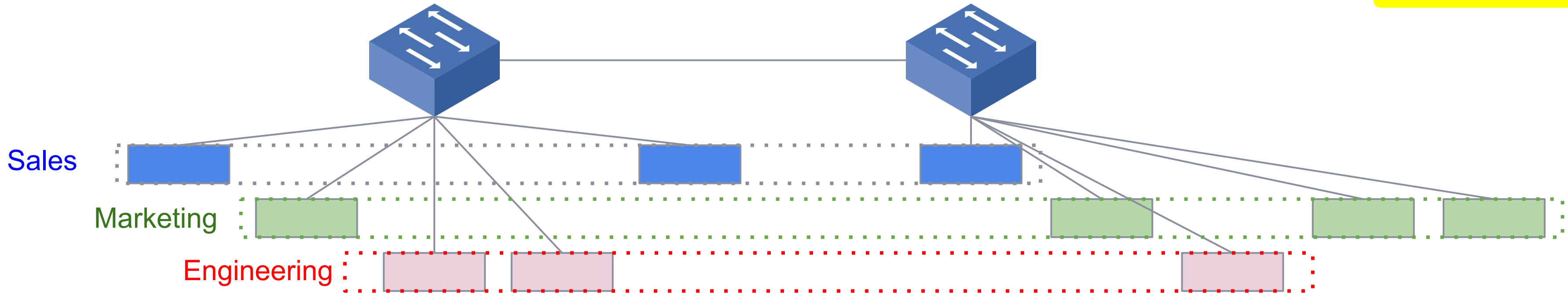


Pros and cons

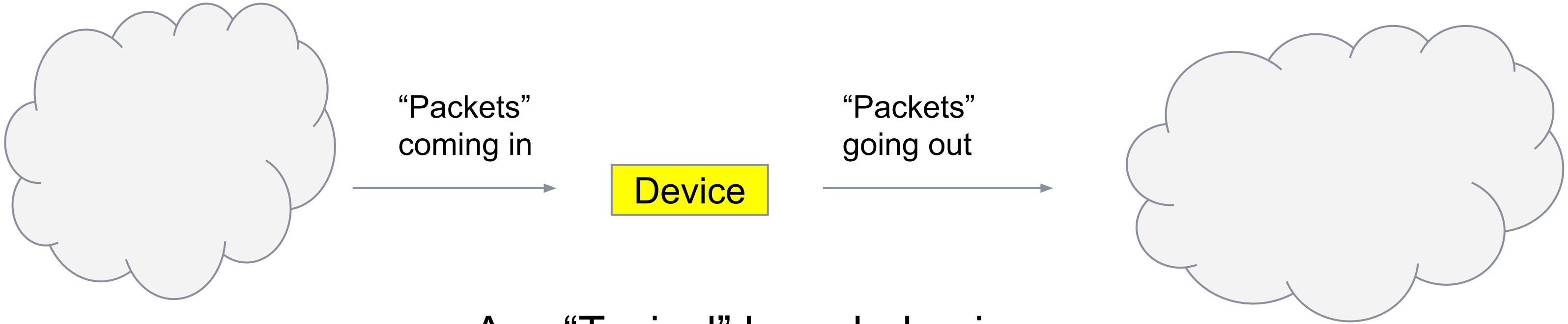
- Pros: super-easy to configure (don’t worry about subnets, routing, …)
    - Lots of people want L2 data centers
- Cons: 12 bits ~ 4K networks

802.1Q tag format

16 bits	3 bits	1 bit	12 bits
TPID	TCI		
	PCP	DEI	VID



Networking device - ins and outs



A. "Typical" layer behavior
B. Translation
C. Tunnels
D. Tagging

Lessons (from mid 2000s)

- Disparate tools in a toolbox
- Hard to implement compatible standards and technologies
- Hard to build “networks” with thousands of endpoints, and hundreds of thousands of tunnels

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You are in a maze of little twisty
passages, all different.
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Setting the stage - some trends

- Data centers @scale
- Efficient use of resources, even inside a company
- Rise of hosting/cloud providers mid-late 2000s
- Server virtualization (VMware, ...) - orders of magnitude more VMs, containers to address
- SDN - centralized control/mgmt software

State-of-the-art network virtualization

Allow complete virtual networks (“overlays”)
on top of a shared physical network (“underlay”)

Seen in clouds (AMZN, MSFT, GOOG, BABA, ORCL, …)
and enterprise-solutions from VMware, Citrix, ...

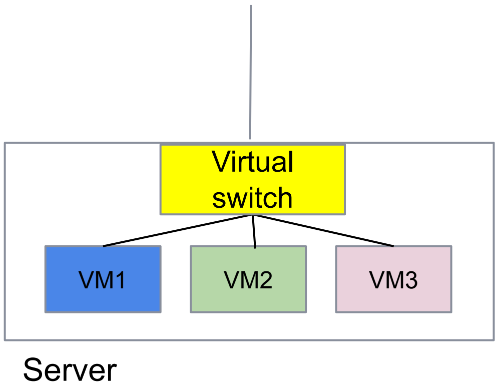
Network virtualization - basic requirements

- Multi-tenancy - customer’s VMs can connect only to their VMs *and no one else’s* (isolation)

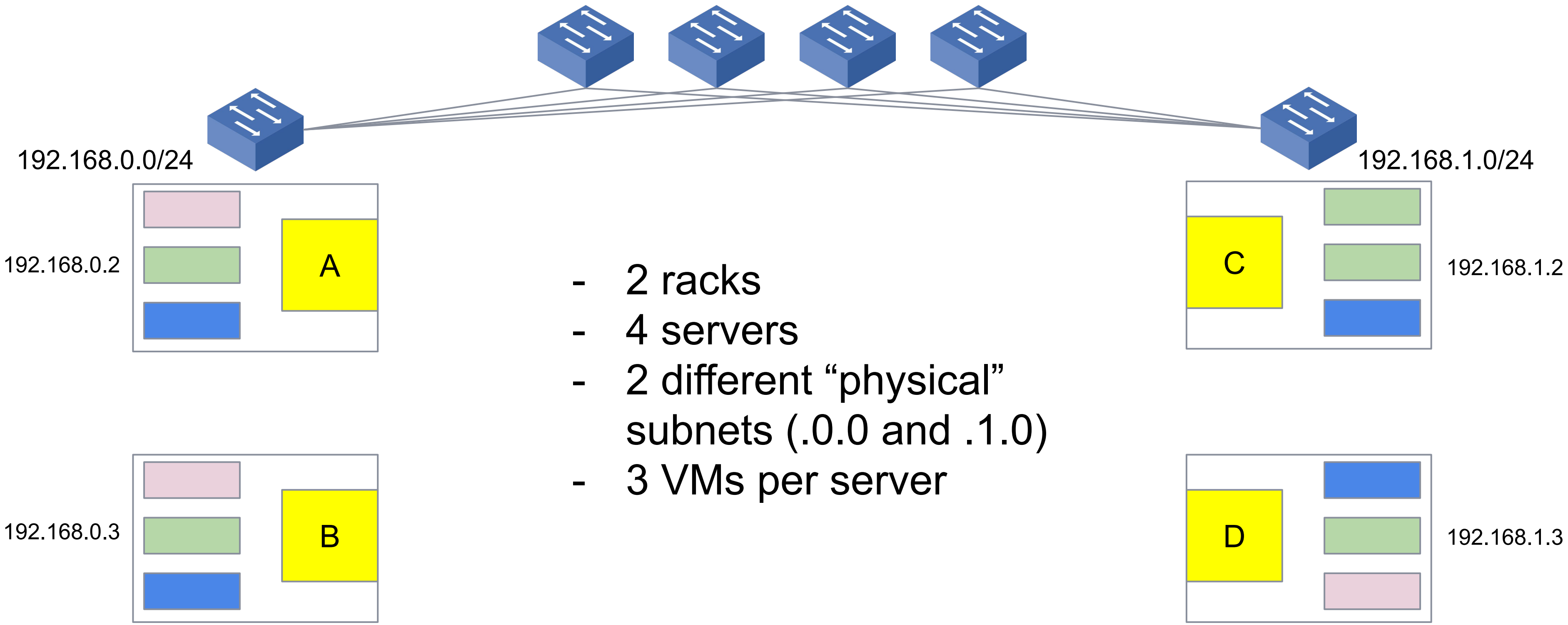
- Both virtual addressing and virtual topologies, independent of physical location/topology

- Operate @scale - easy to turn up, extend, operate, turn down networks of VMs

Building block: virtual switch on a host

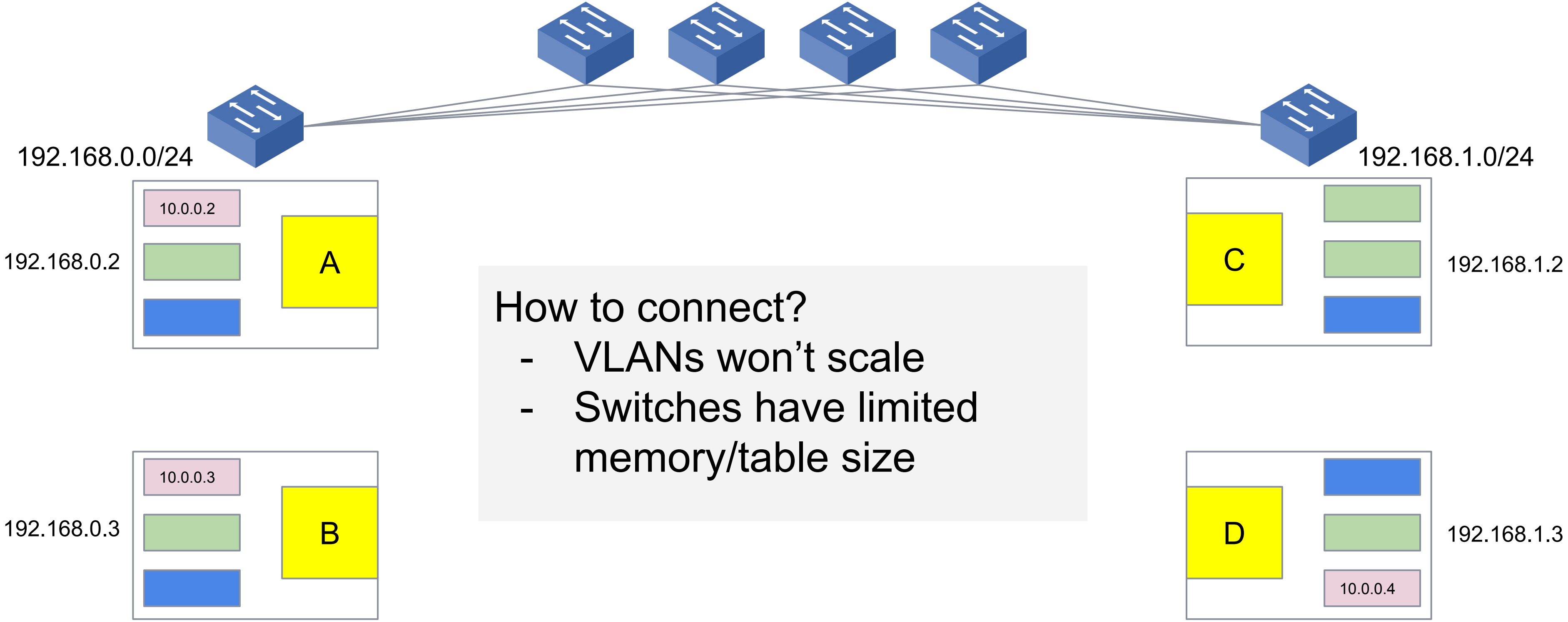


Physical "underlay" + VMs



- 2 racks
- 4 servers
- 2 different "physical" subnets (.0.0 and .1.0)
- 3 VMs per server

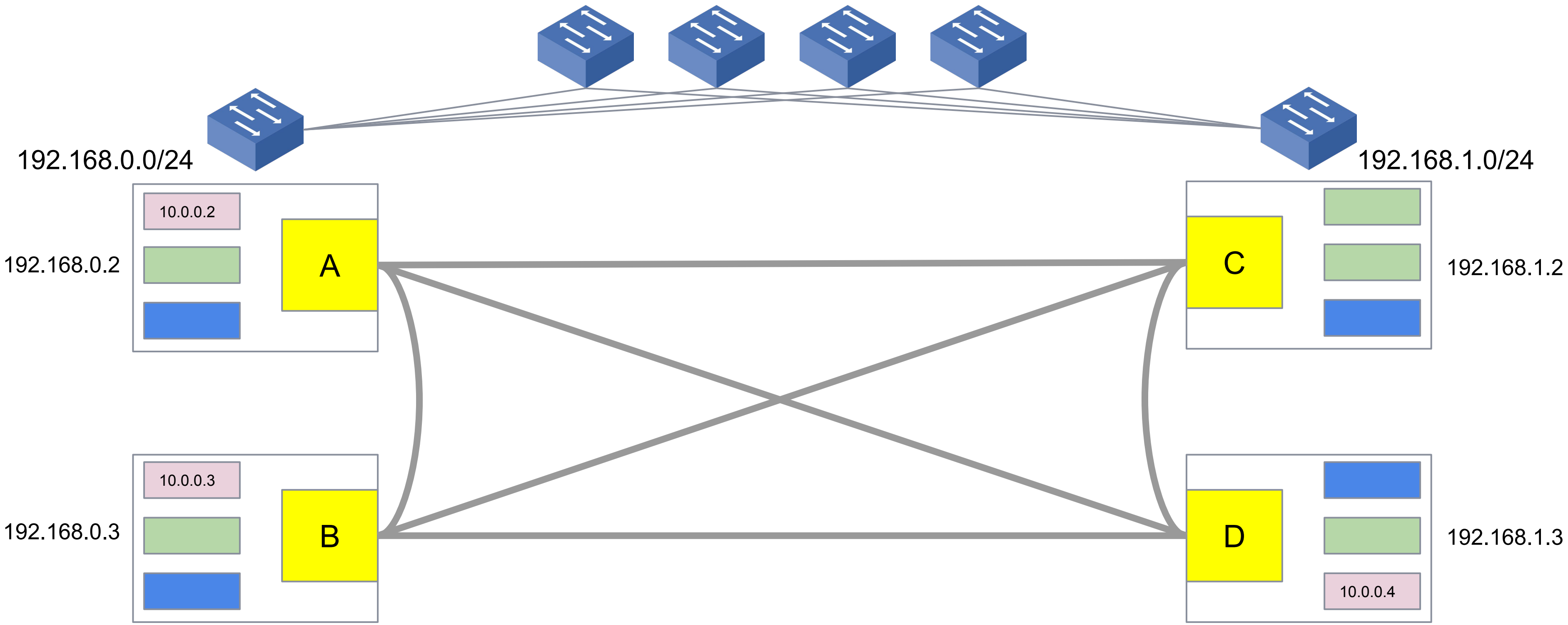
Ex 1: Red VMs in same subnet



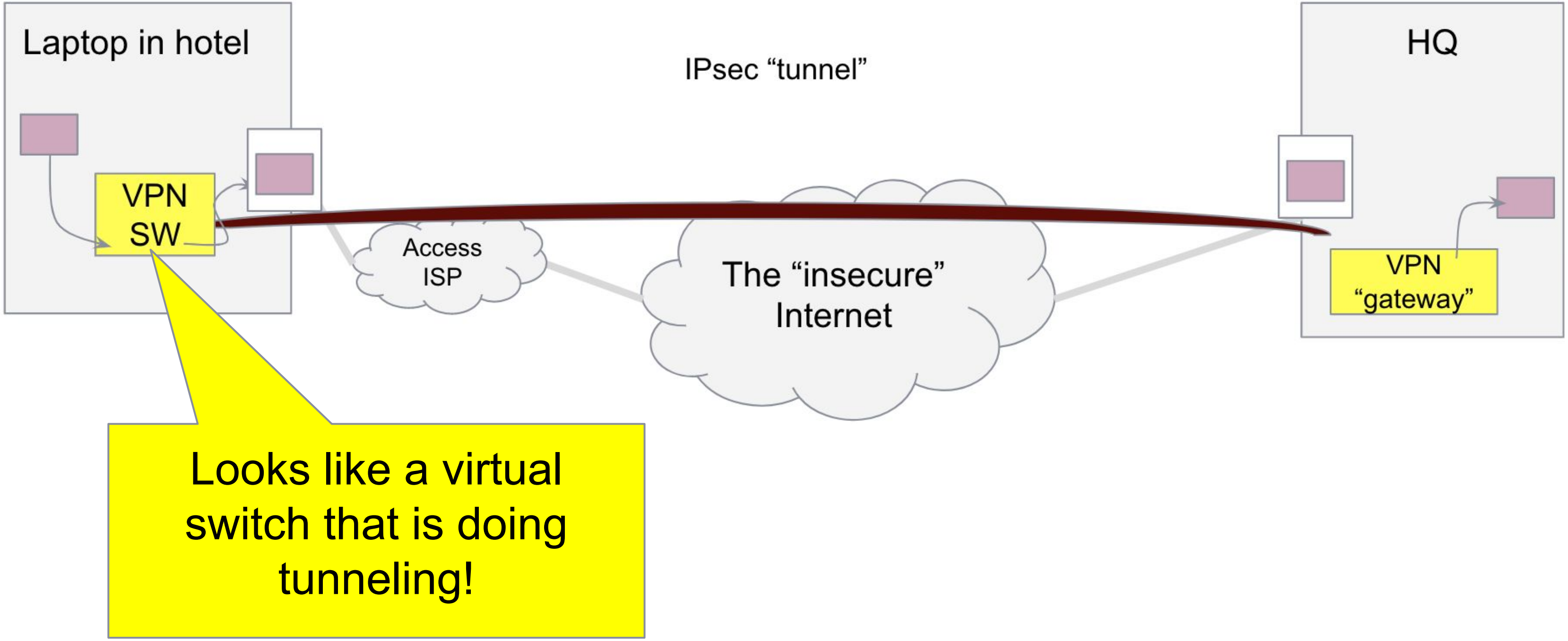
How to connect?

- VLANs won't scale
- Switches have limited memory/table size

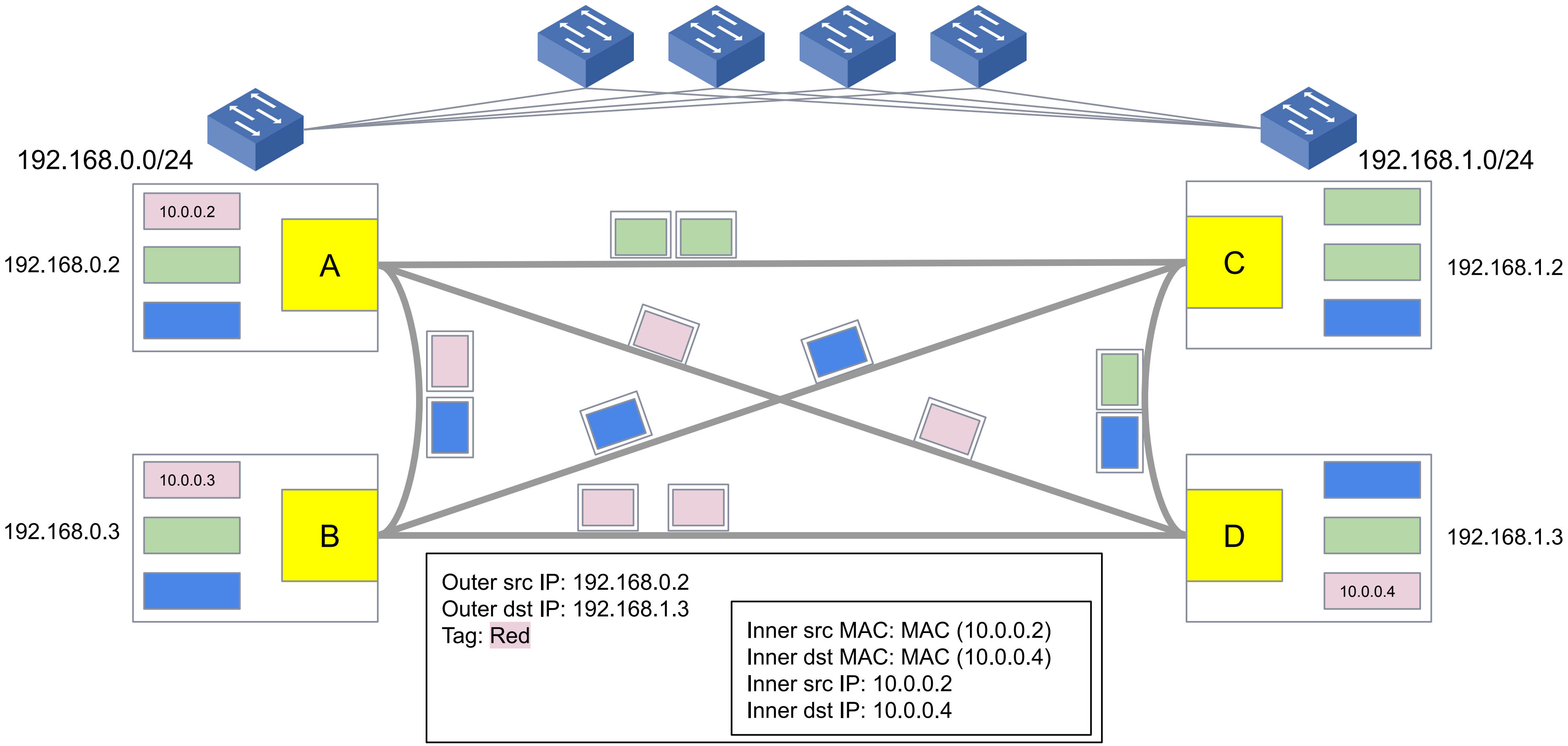
Tunnels & tags to rescue!



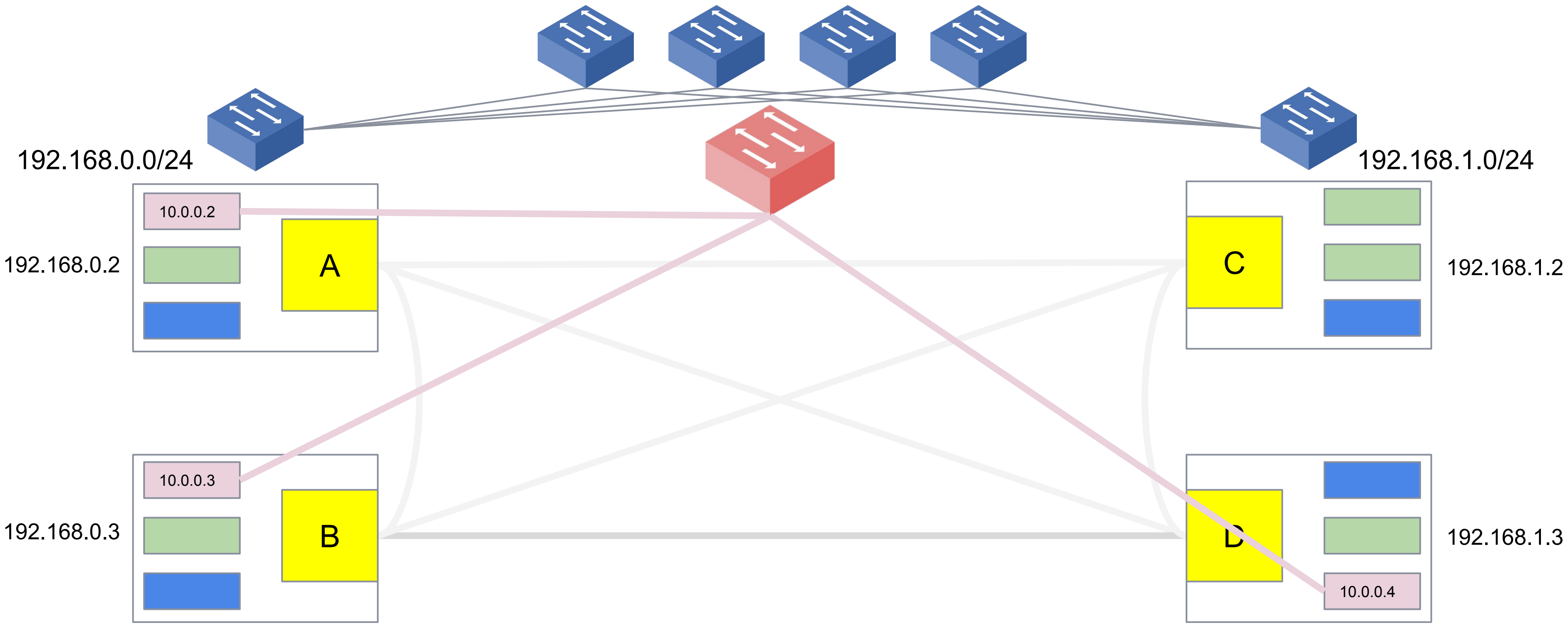
Remember this picture?



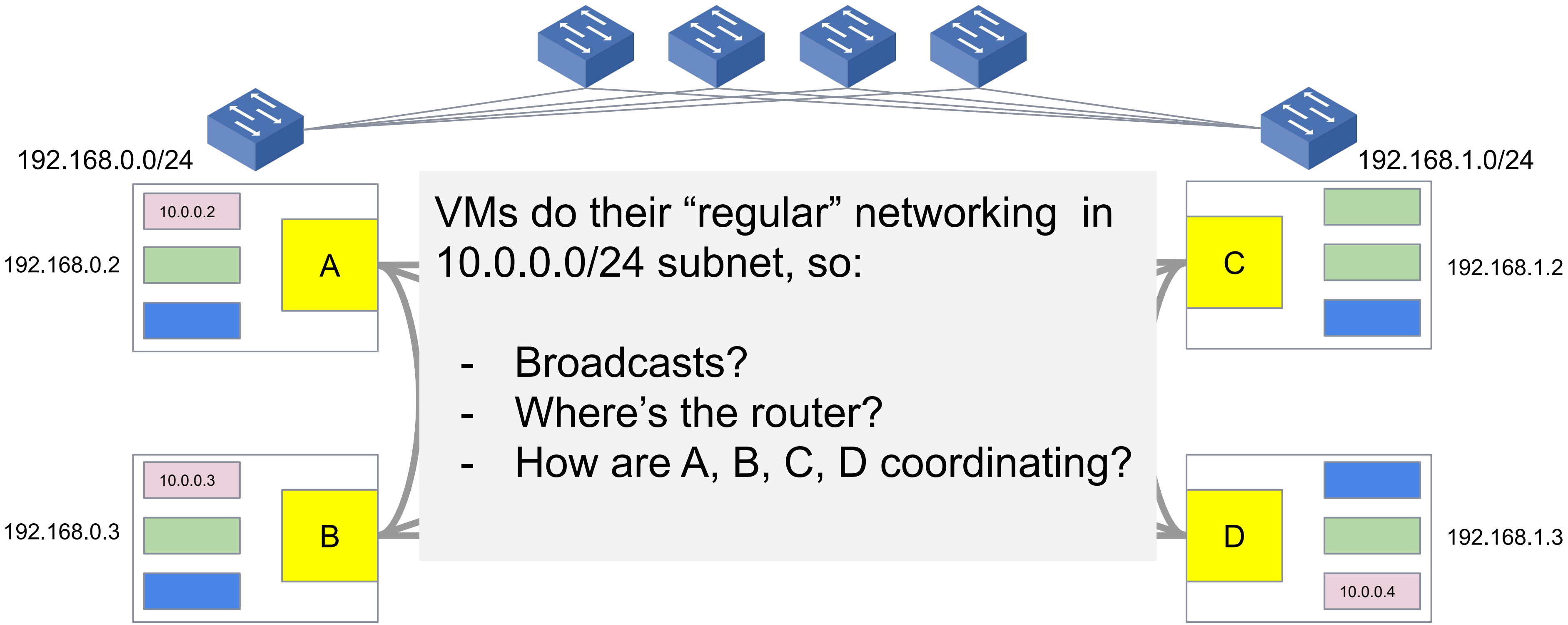
Tunnels & tags to rescue!



Red VMs connected to a "logical" switch



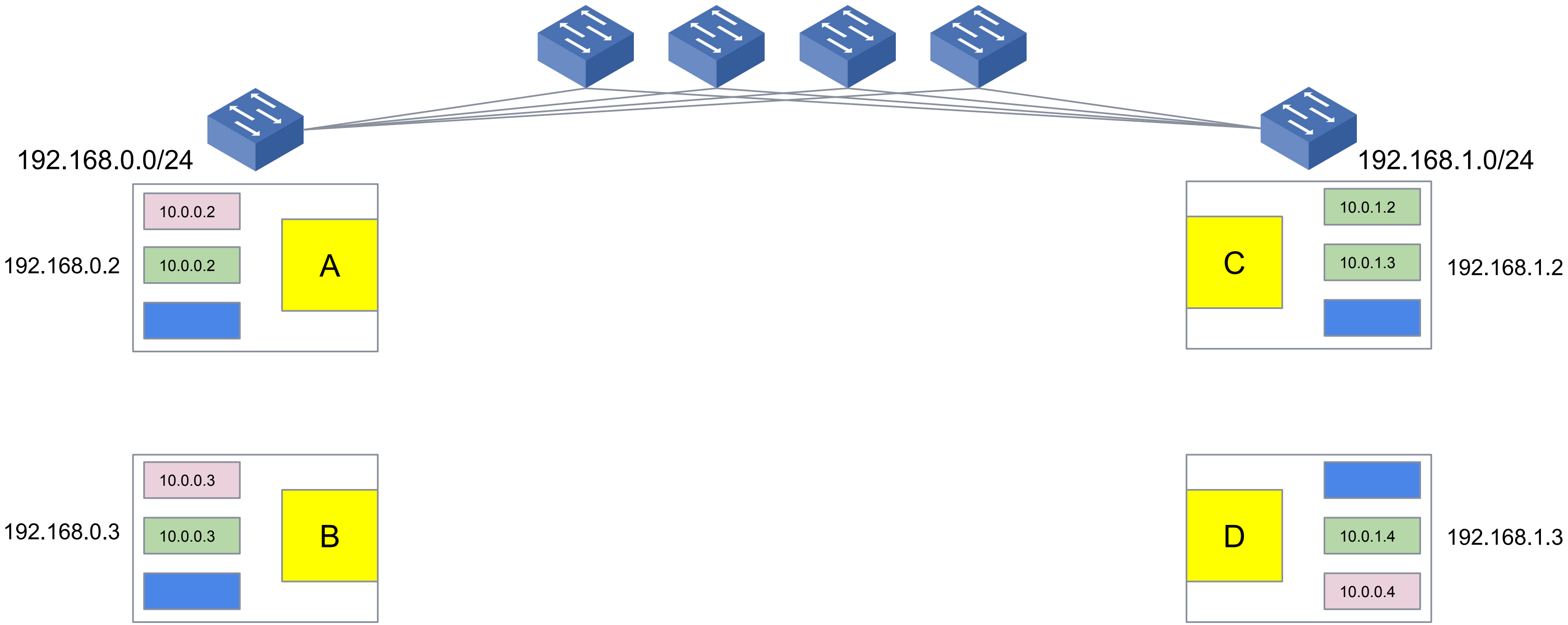
But some questions...



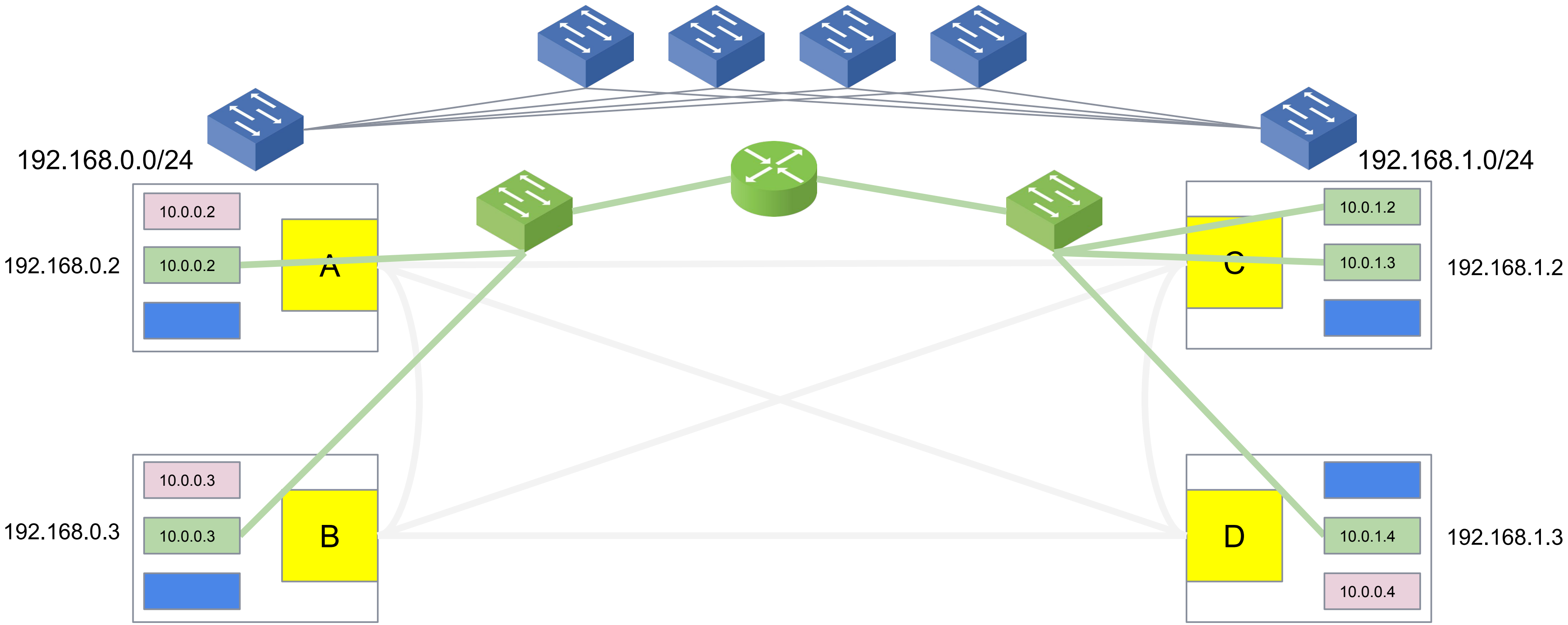
VMs do their “regular” networking in 10.0.0.0/24 subnet, so:

- Broadcasts?
- Where’s the router?
- How are A, B, C, D coordinating?

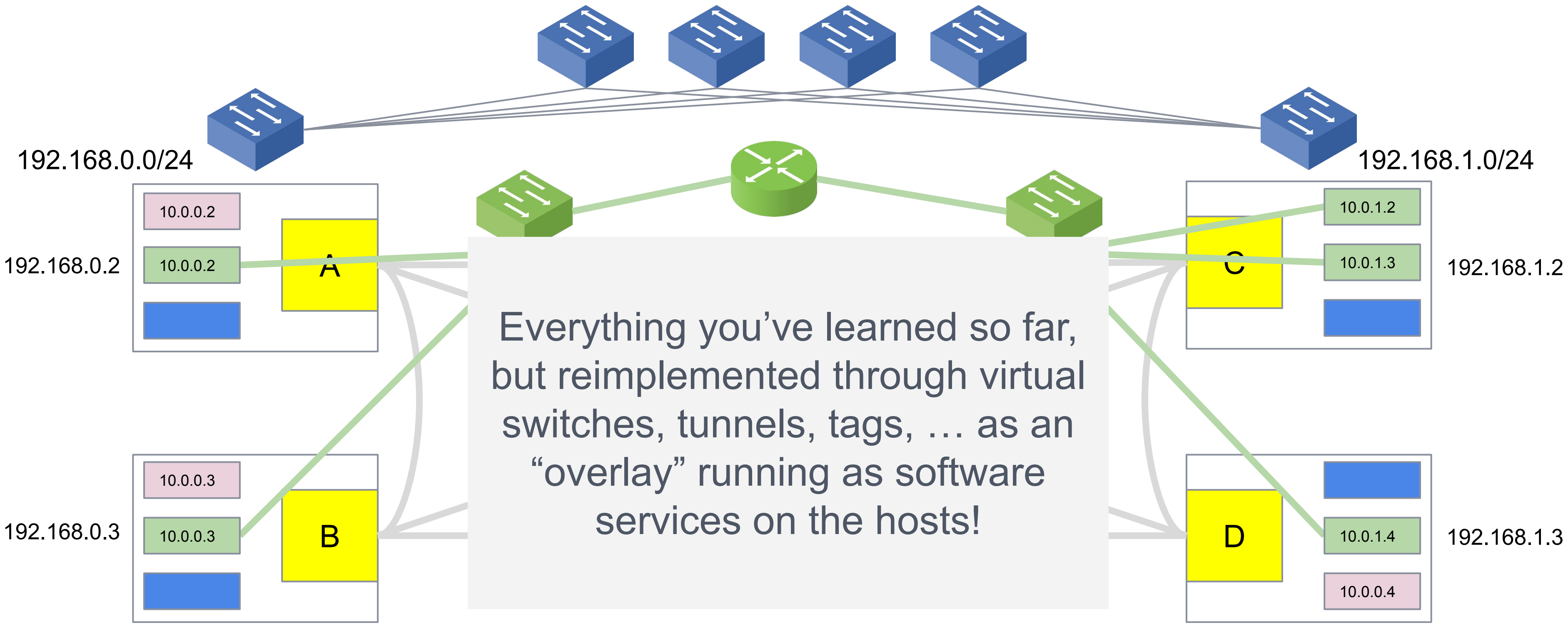
Ex 2: Green VMs in different subnets



Ex 2: logically, green switches and green router

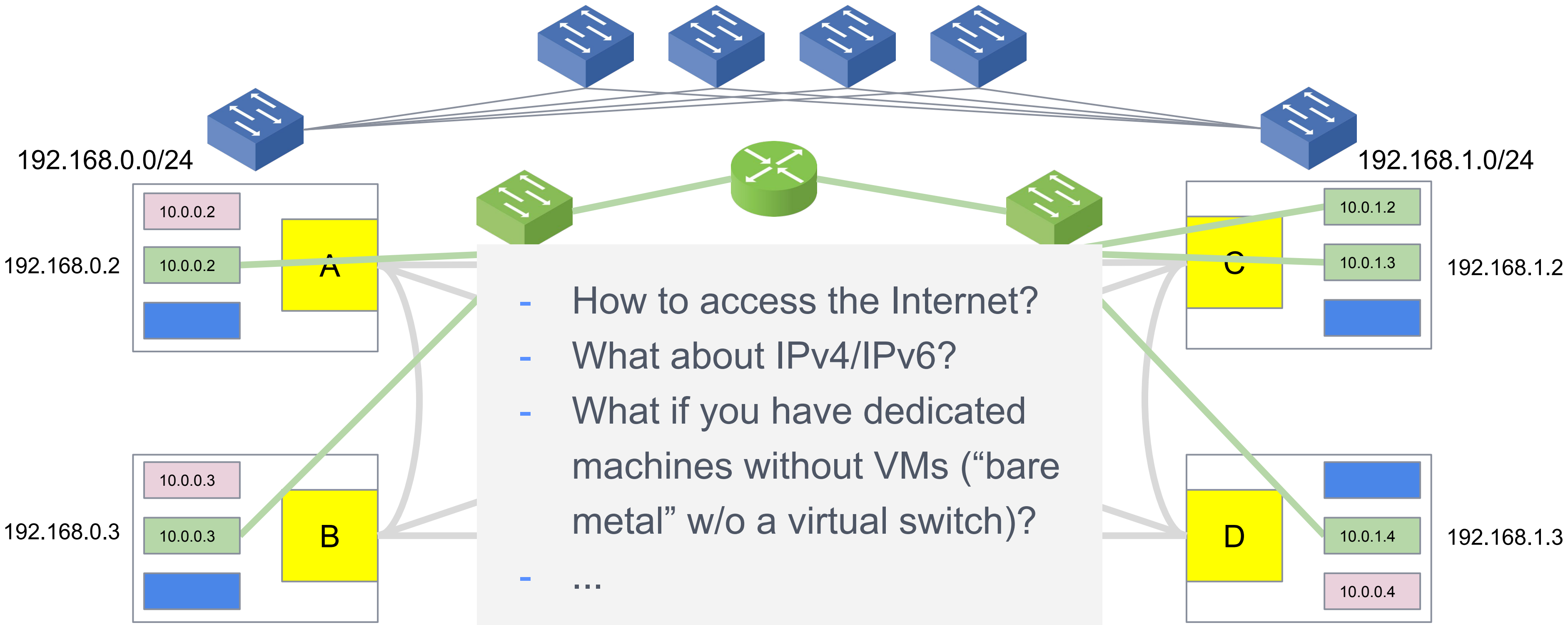


Ex 2: logically, green switches and green router



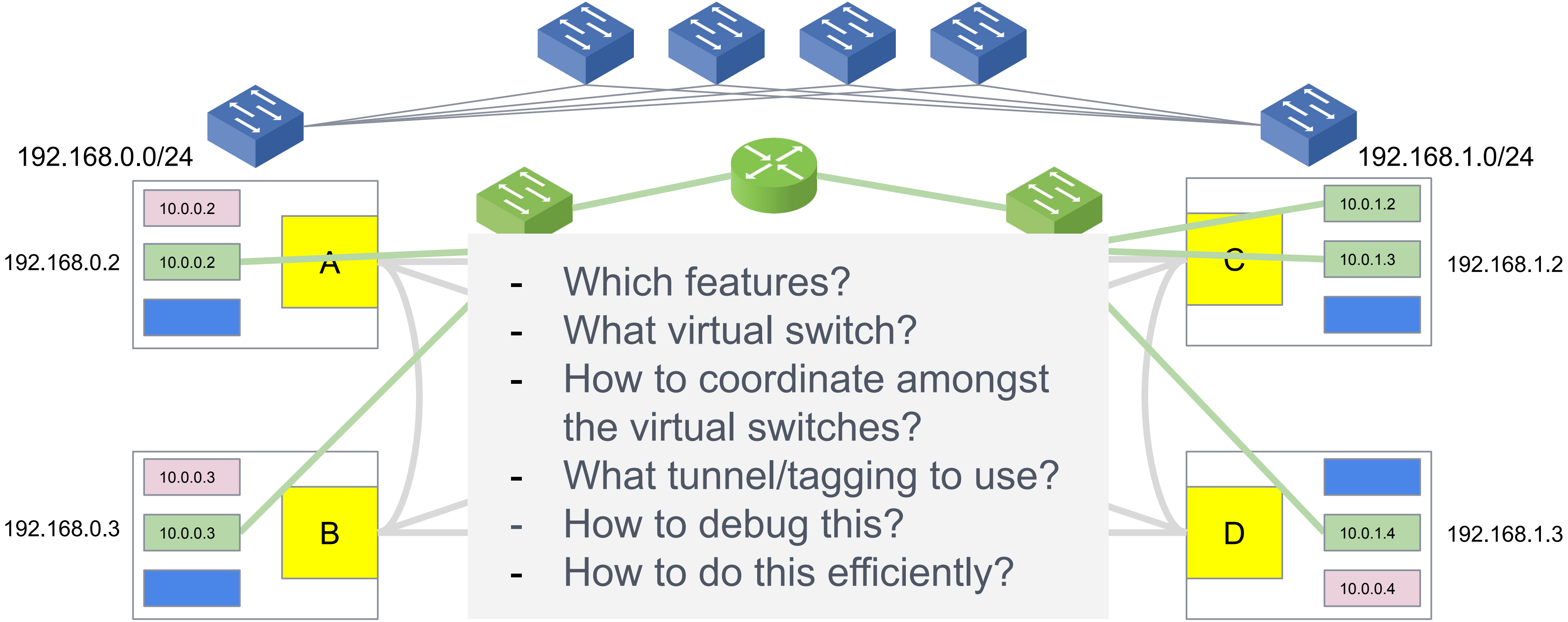
Everything you've learned so far, but reimplemented through virtual switches, tunnels, tags, … as an "overlay" running as software services on the hosts!

More features left to provide...



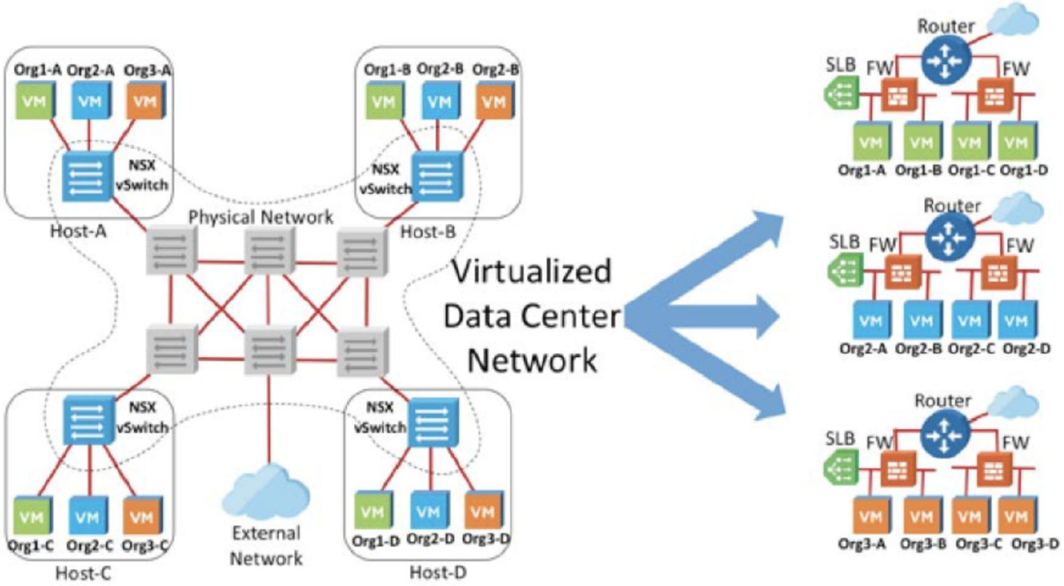
- How to access the Internet?
- What about IPv4/IPv6?
- What if you have dedicated machines without VMs (“bare metal” w/o a virtual switch)?
- ...

Every cloud has similar design choices



- Which features?
- What virtual switch?
- How to coordinate amongst the virtual switches?
- What tunnel/tagging to use?
- How to debug this?
- How to do this efficiently?

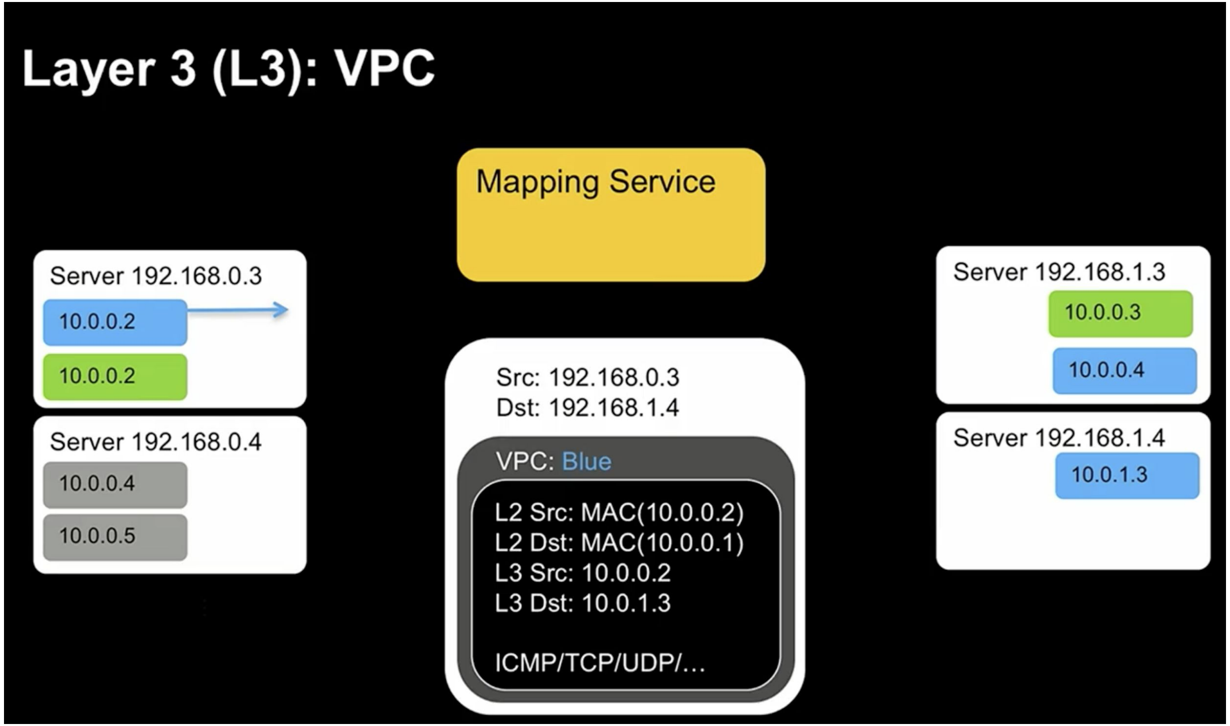
Ex: VMware/Nicira NSX



Source: VMware NSX Network Virtualization Fundamentals,

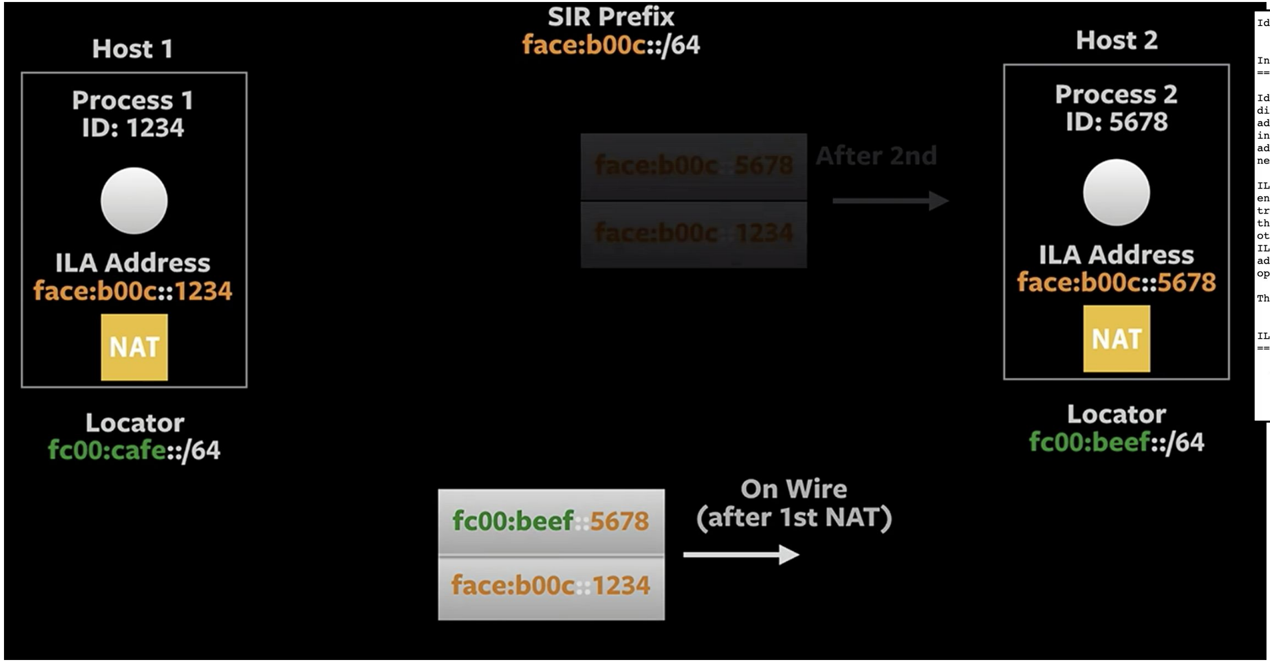
https://www.vmware.com/content/dam/digitalmarketing/vmware/en/pdf/products/nsx/vmware-network-virtualization-fundamentals-guide.pdf

Ex: Amazon Virtual Private Cloud (VPC)



Source: Networking @Scale 2017 video from Amazon,
https://engineering.fb.com/networking-traffic/networking-scale-2017-recap/

Ex: Facebook & Identifier Locator Addressing (ILA) - containers + translation (instead of VMs & tunnels)

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Identifier Locator Addressing (ILA)


Introduction
============

Identifier-locator addressing (ILA) is a technique used with IPv6 that
differentiates between location and identity of a network node. Part of an
address expresses the immutable identity of the node, and another part
indicates the location of the node which can be dynamic. Identifier-locator
addressing can be used to efficiently implement overlay networks for
network virtualization as well as solutions for use cases in mobility.

ILA can be thought of as means to implement an overlay network without
encapsulation. This is accomplished by performing network address
translation on destination addresses as a packet traverses a network. To
the network, an ILA translated packet appears to be no different than any
other IPv6 packet. For instance, if the transport protocol is TCP then an
ILA translated packet looks like just another TCP/IPv6 packet. The
advantage of this is that ILA is transparent to the network so that
optimizations in the network, such as ECMP, RSS, GRO, GSO, etc., just work.

The ILA protocol is described in Internet-Draft draft-herbert-intarea-ila.


ILA terminology
===============

  - Identifier  A number that identifies an addressable node in the network
                independent of its location. ILA identifiers are sixty-four
                bit values.
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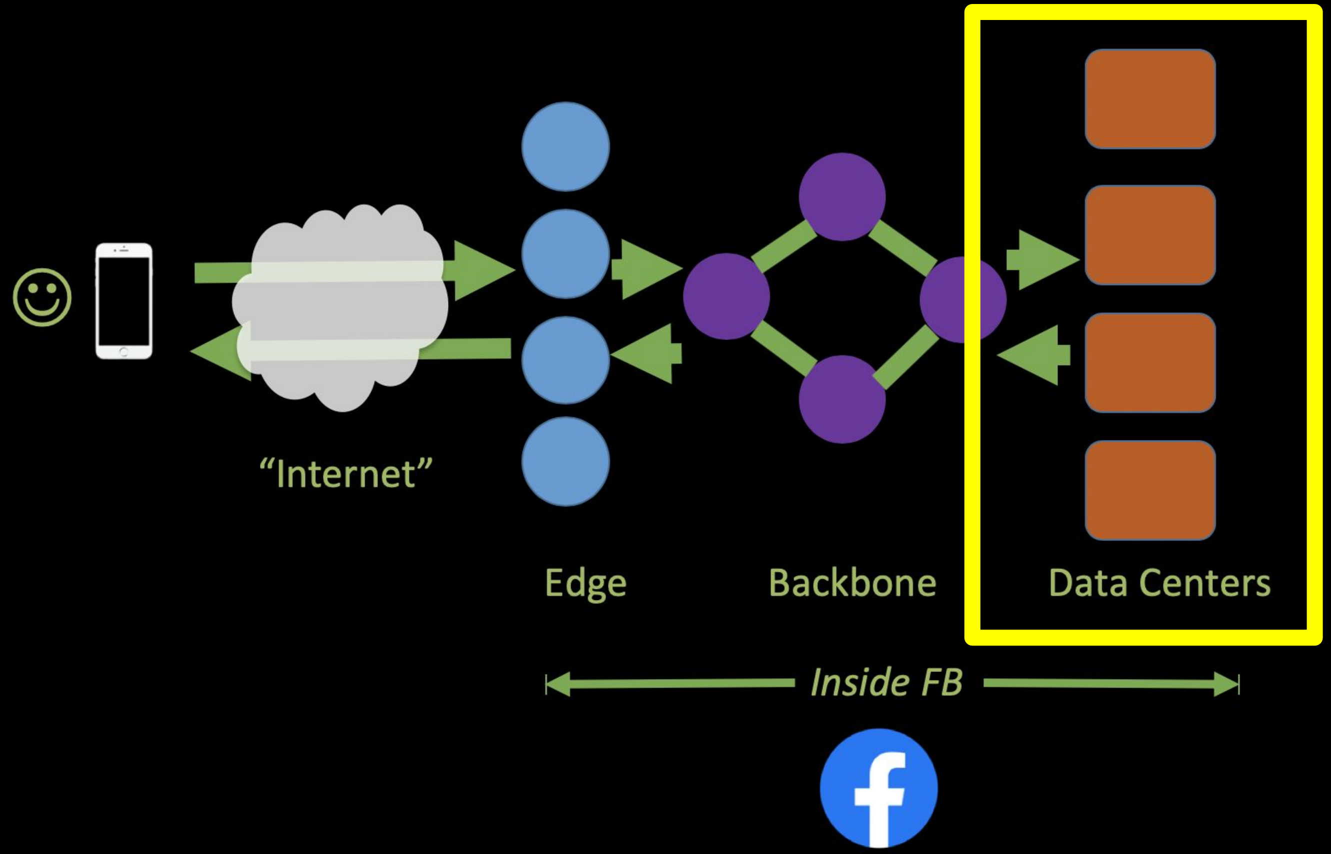
Source: Networking @Scale 2017 video from Facebook,
https://engineering.fb.com/networking-traffic/networking-scale-2017-recap/

Questions?

Networking at Facebook

NETWORK INFRA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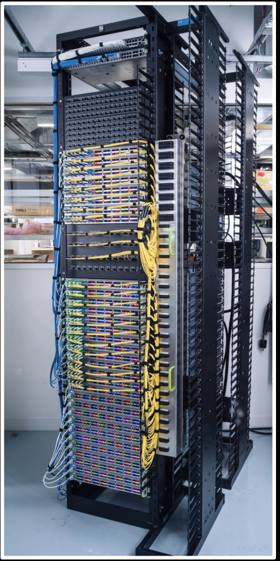

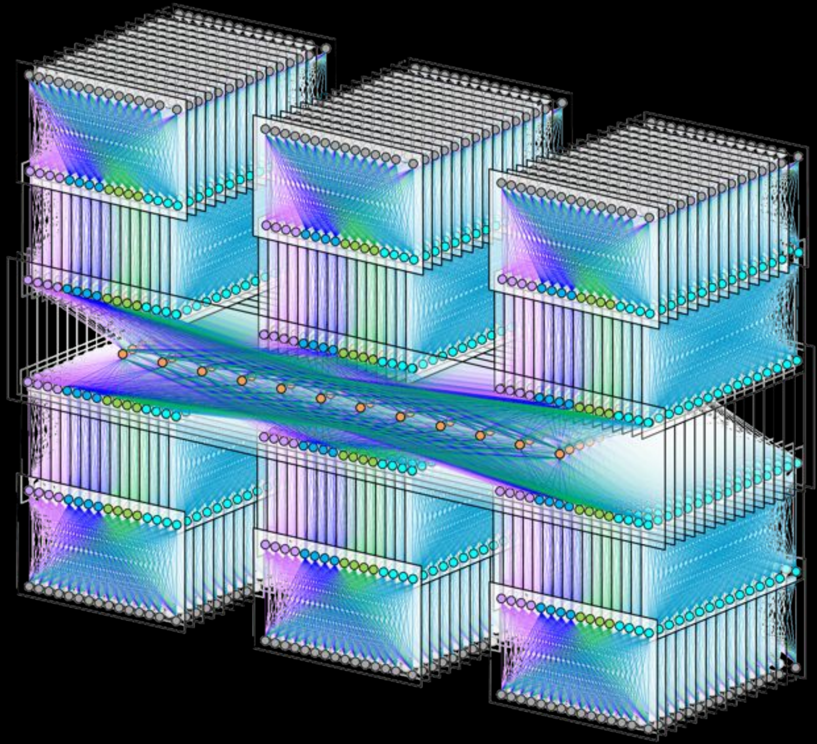

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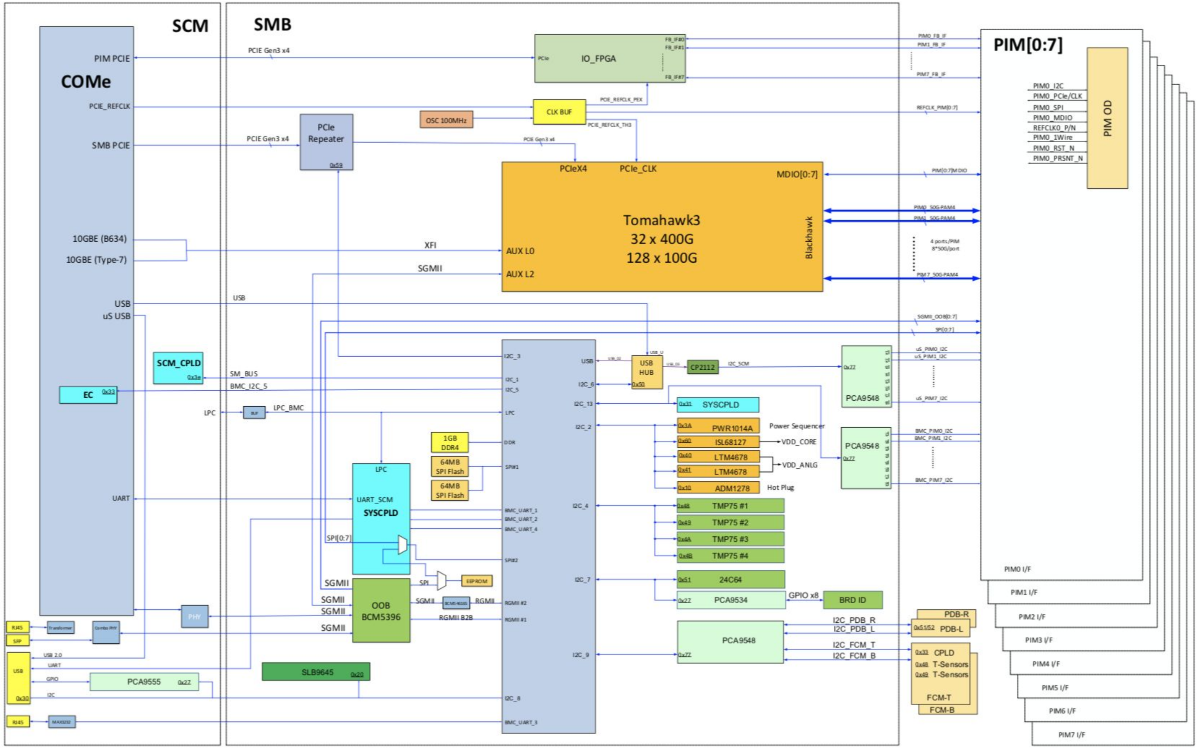
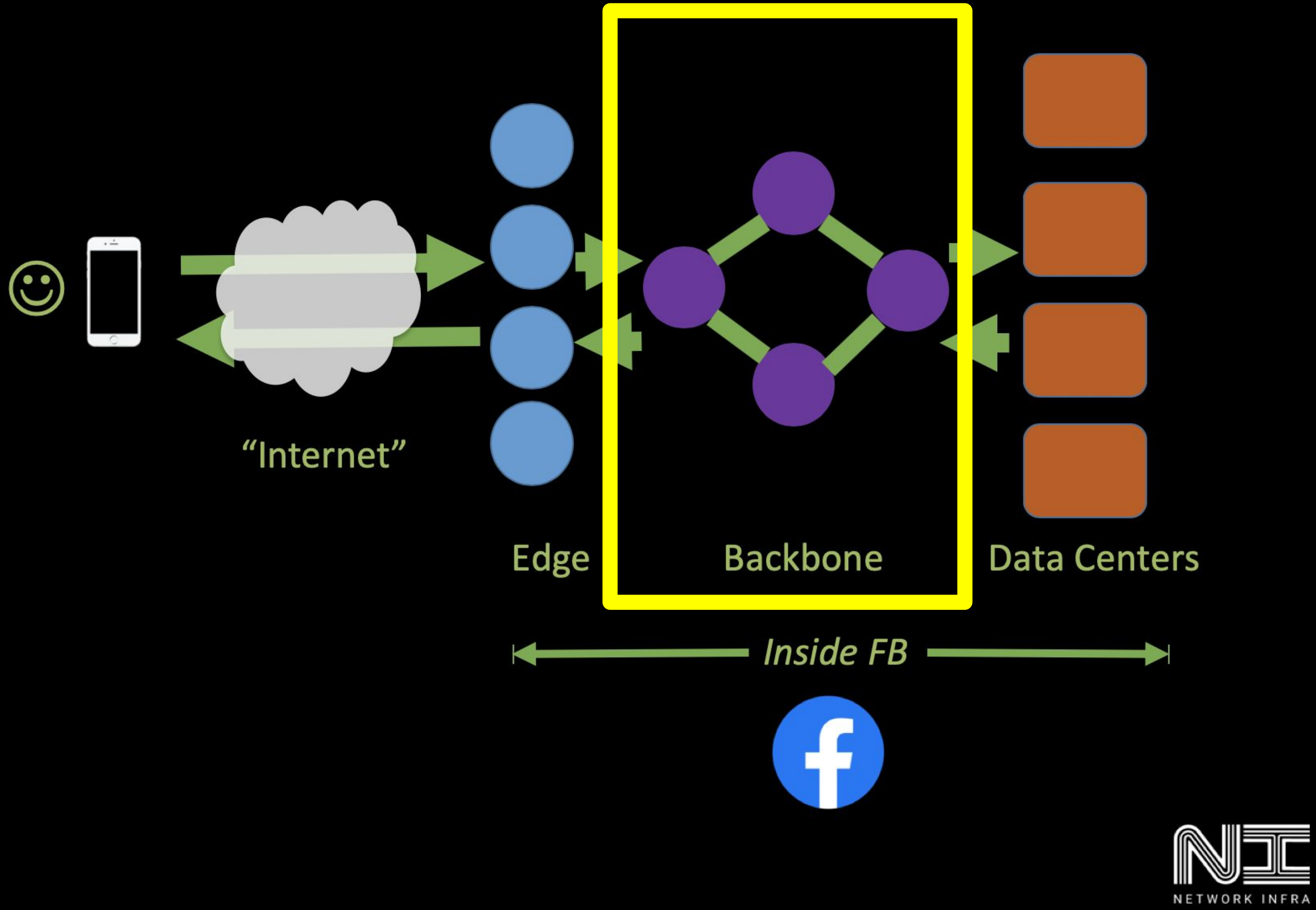


Figure 8-2: Switch Main Board Architecture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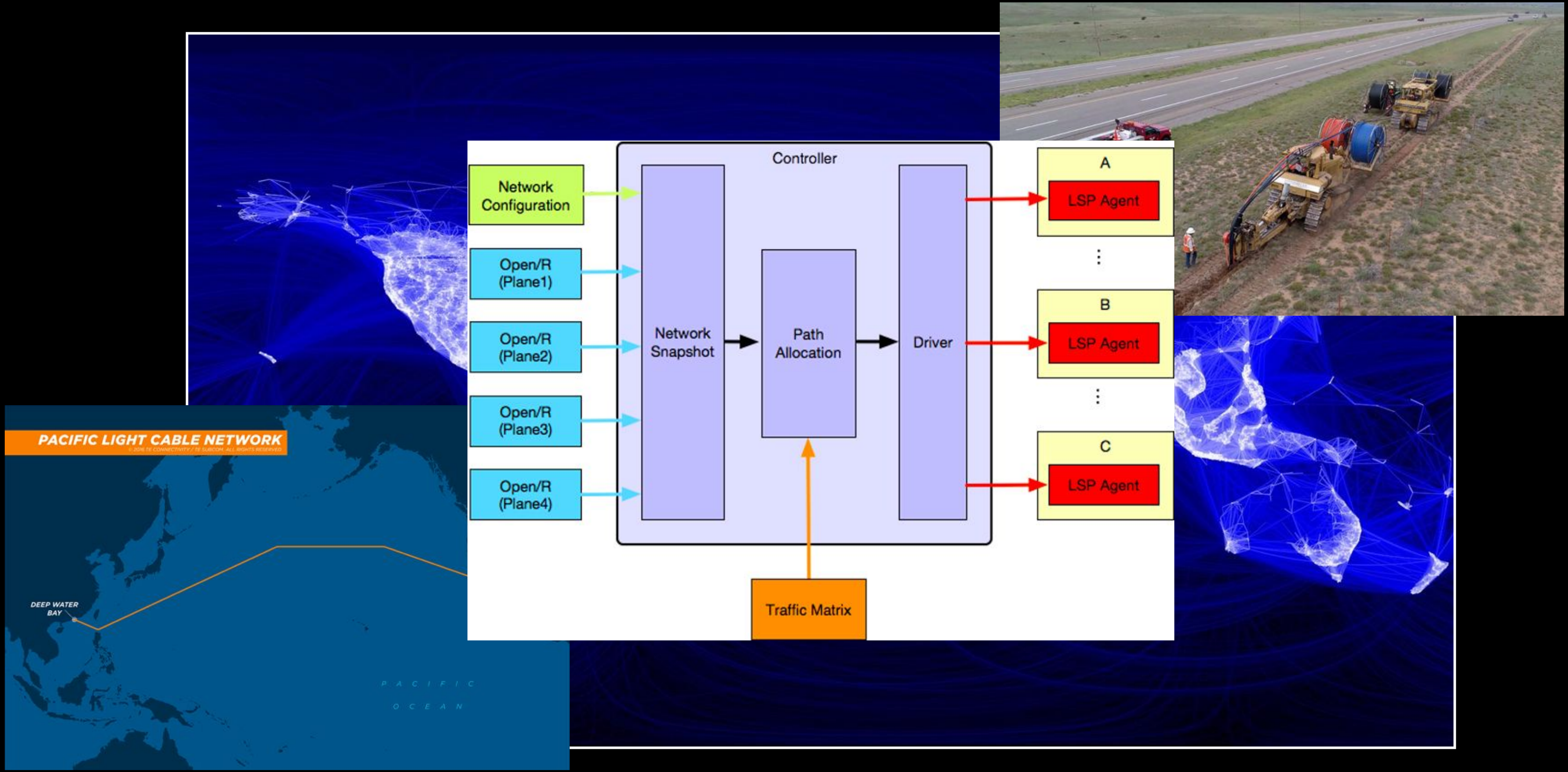

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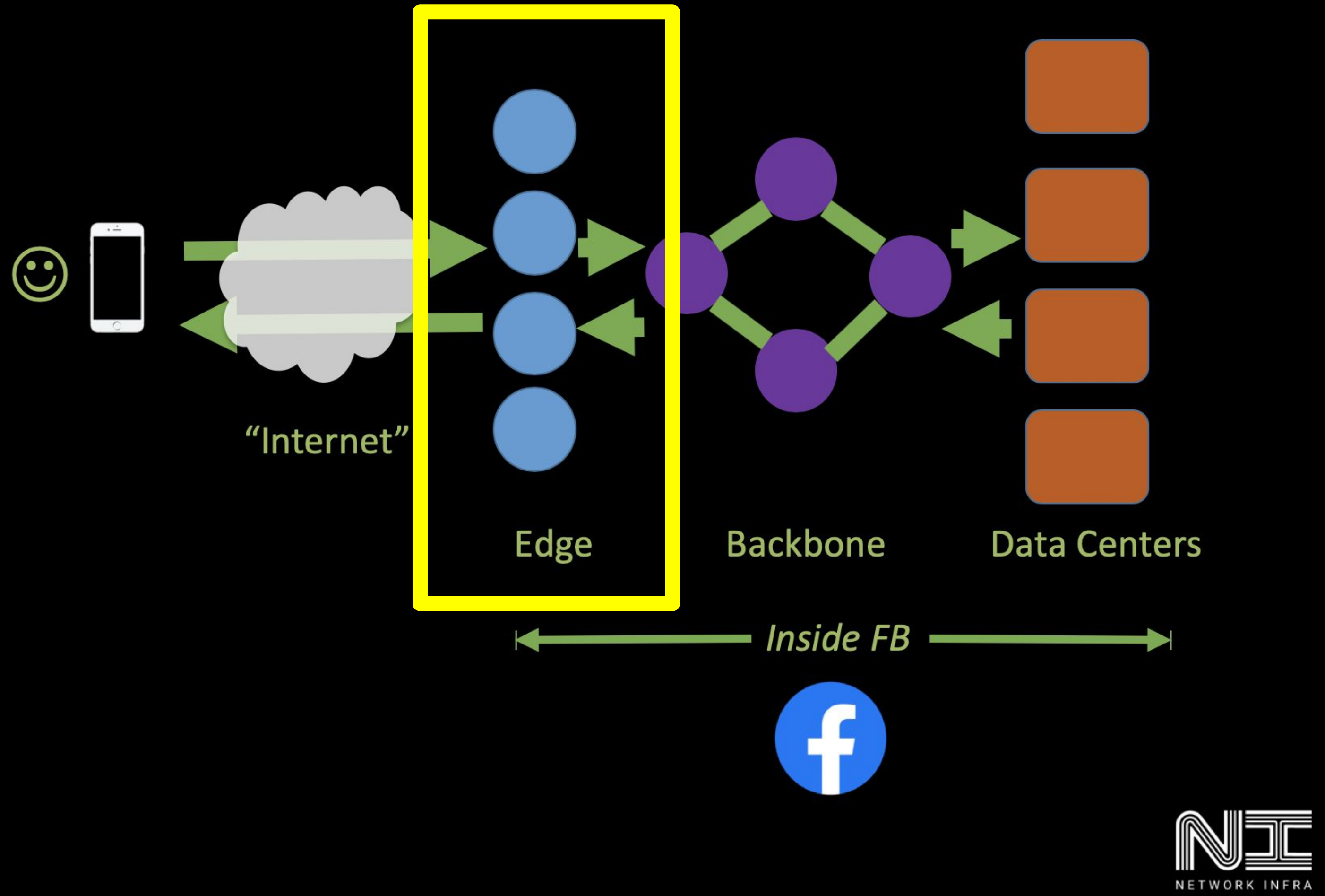

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NETWORK INFRA

facebook research

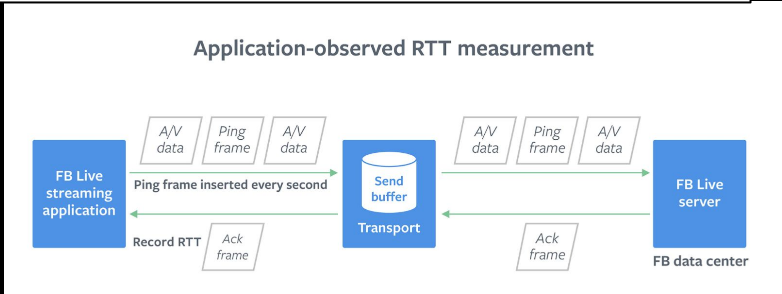
Internet Performance from Facebook's Edge*

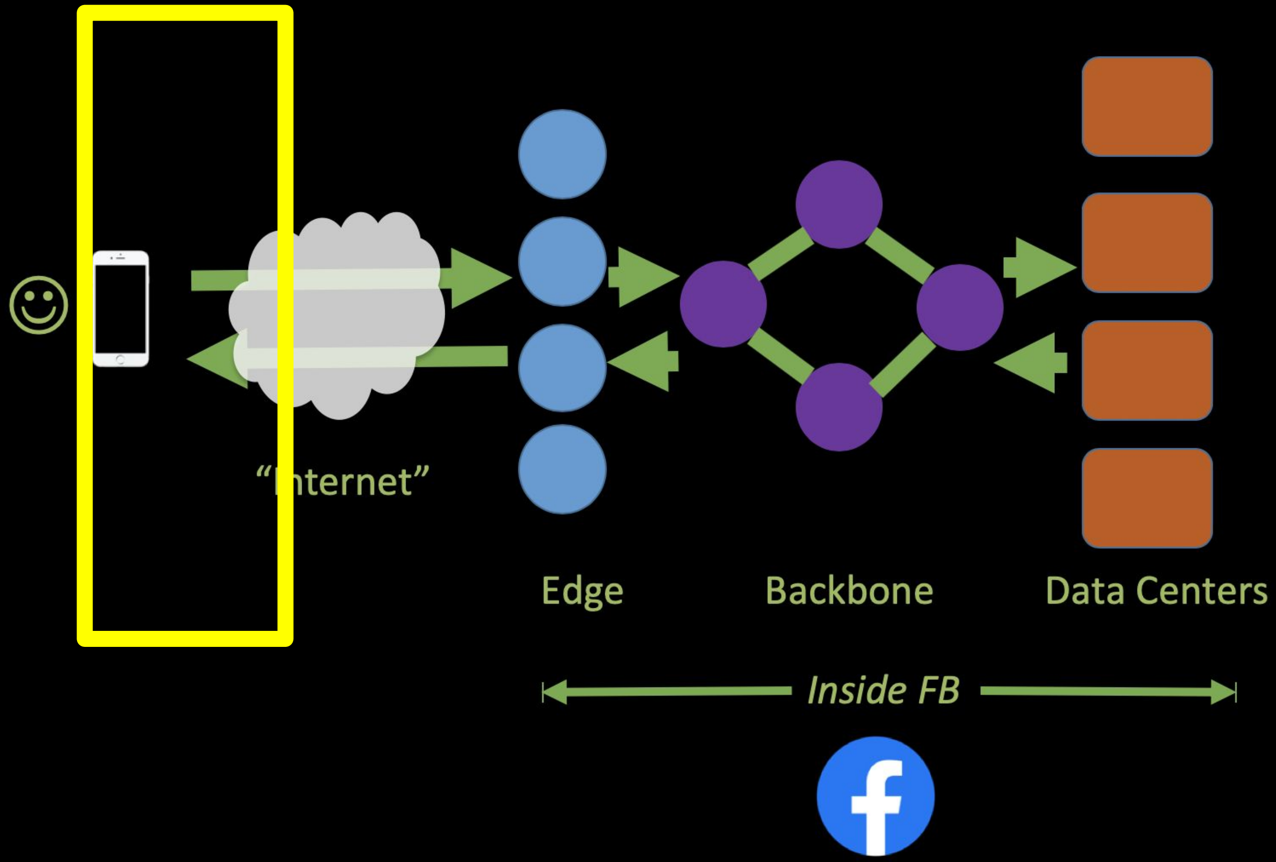
Brandon Schlinker[†♯] Italo Cunha[‡♮] Yi-Ching Chiu[†] Srikanth Sundaresan[♯] Ethan Katz-Bassett[♮]

[†] University of Southern California [♯] Facebook [‡] Universidade Federal de Minas Gerais [♮] Columbia University

POSTED ON NOV 17, 2019 TO NETWORKING & TRAFFIC, VIDEO ENGINEERING

Evaluating COPA congestion control for improved video performance

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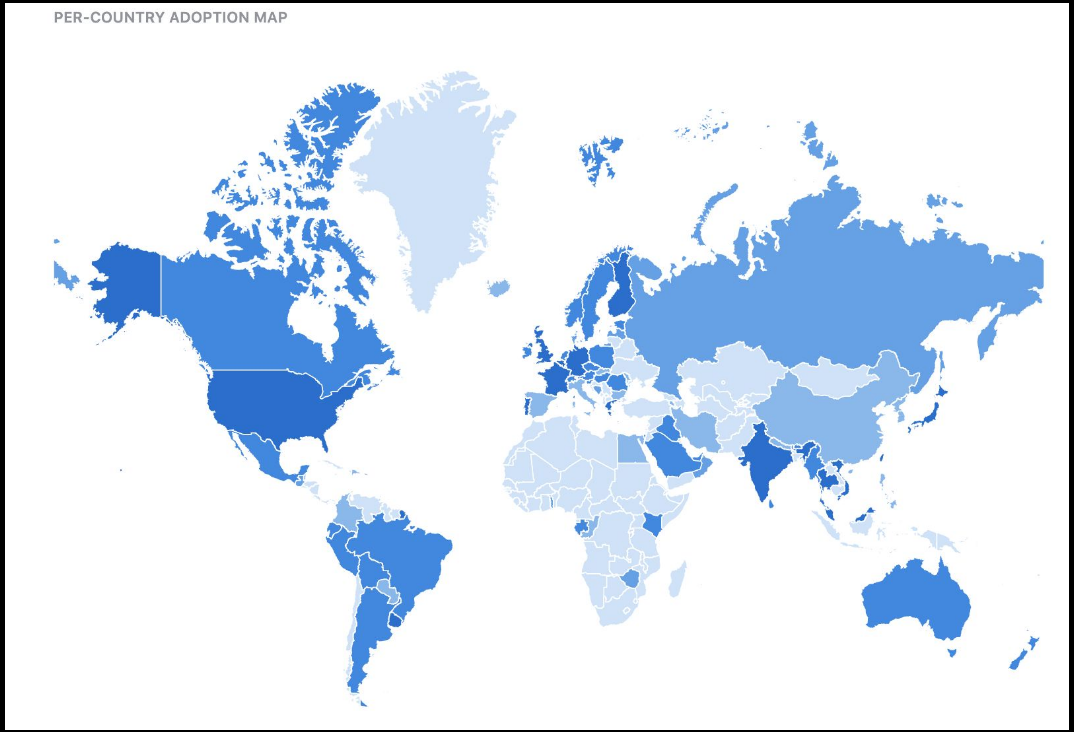

facebook.com/ipv6

Ranking *	Country / Region	IPv6 Adoption	Weekly Growth
2	India	61.18%	↗0.07%
1	United States	56.26%	↗0.09%
18	Belgium	51.62%	↘0.3%
7	Germany	49.42%	↗0.89%
21	Greece	45.85%	↘0.12%
11	Taiwan	44.49%	↘0.03%
4	Vietnam	41.46%	↗0.32%
8	Malaysia	41.43%	↗0.69%
38	Finland	38.87%	↗0.19%
10	France	37.82%	↘0.19%

Ranking *	Country / Region	IPv6 Adoption
34	Philippines	2.12%
164	Antarctica	1.94%
95	Iran	1.91%
121	St-Martin	1.89%
109	Gibraltar	1.73%
64	Dominican Rep.	1.38%
70	Bulgaria	1.31%
67	Paraguay	1.31%
50	Colombia	1.18%
181	Dem. Rep. Korea	1.17%

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Thanks!