Middleboxes and NFV

15-441 Fall 2017

Profs Peter Steenkiste & **Justine Sherry**

Thanks to Scott Shenker, Sylvia Ratnasamay, Peter Steenkiste, and Srini Seshan for slides.

Carnegie Mellon University

sli.do time…

Today

- Thanks for talking to the folks from the Eberly Center!
- CANDY POLL
- Quick midterm and mid-semester grade comments and
    - You’ll get your tests back on Thursday
- Where we’re at in the course
- The lecture: Middleboxes and NFV

Midterm

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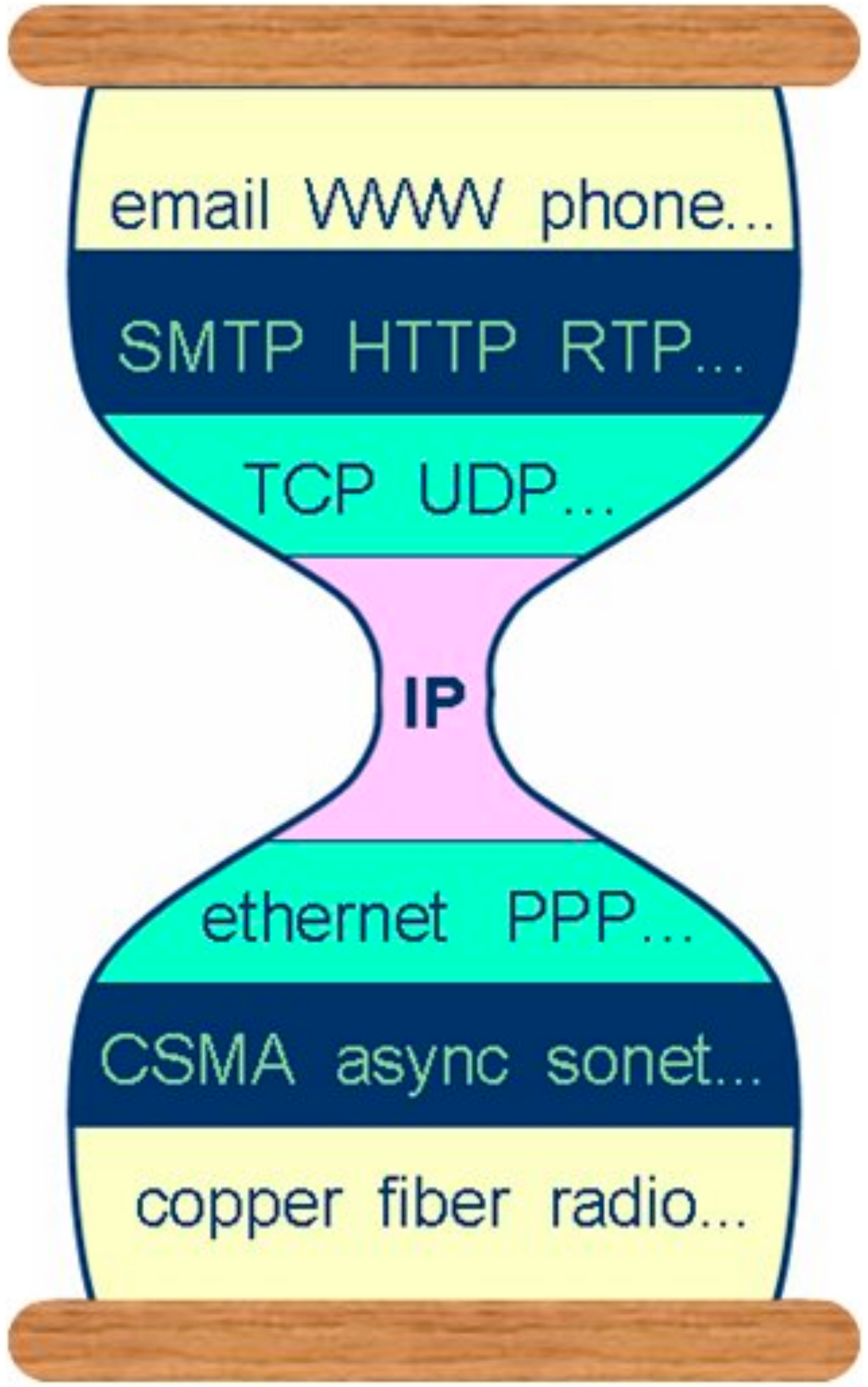
  - Therefore the test scores were calculated out of 74 points.
- Median and Average were both 57 (77%)
- You all are very good at BGP and IP Forwarding!
- Will hand back tests on **Thursday in class**.

Mid-semester grades

- Calculated over HW1, P1, and Midterm
  - Do not include HW2 or P1 Final Design Doc
- Includes 35% of the total points for the semester
  - i.e.: lots of opportunities to improve your grade
- Grades were curved **up** but not down (no one was hurt by curving)

You are here.



Application Layer

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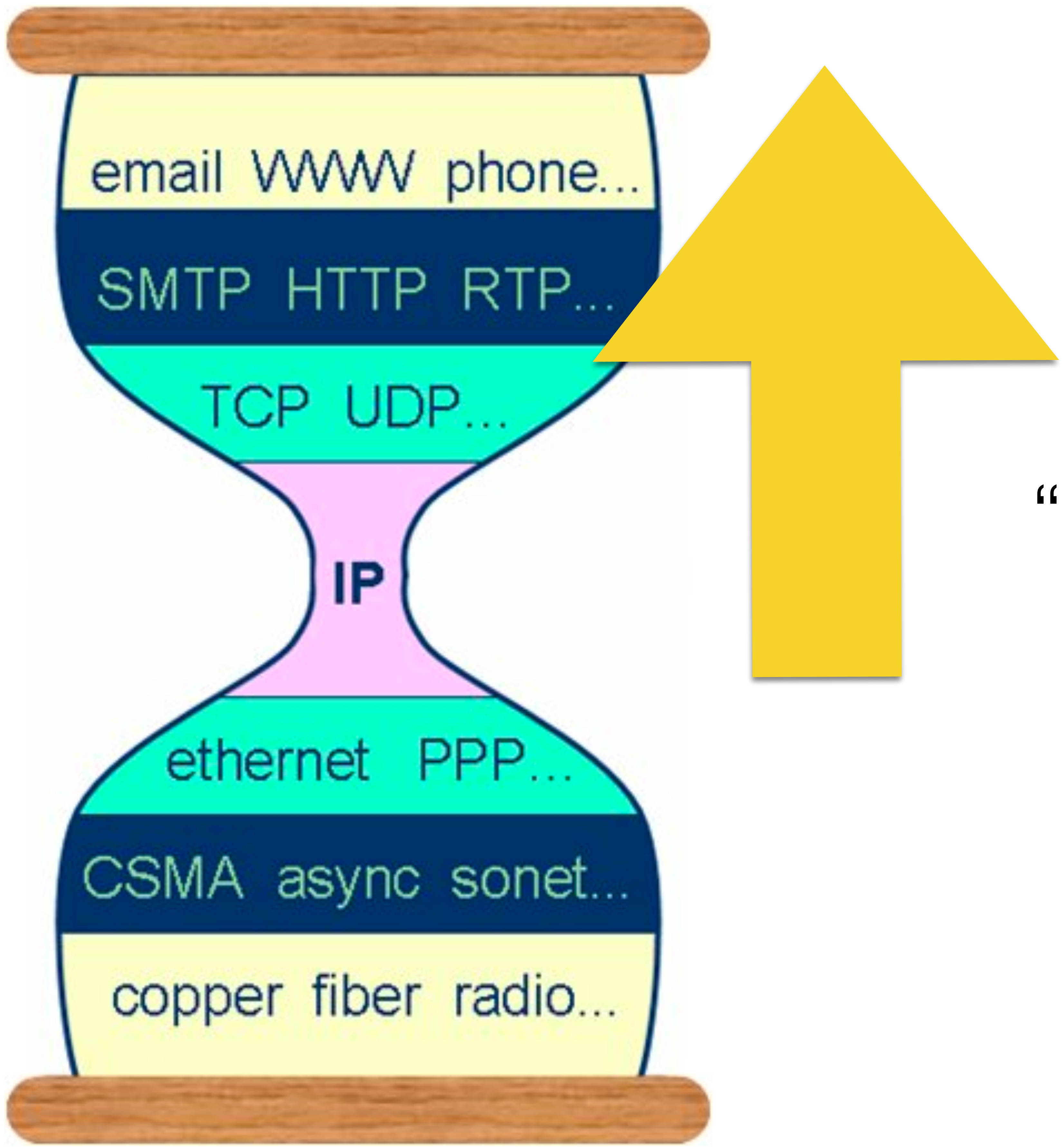
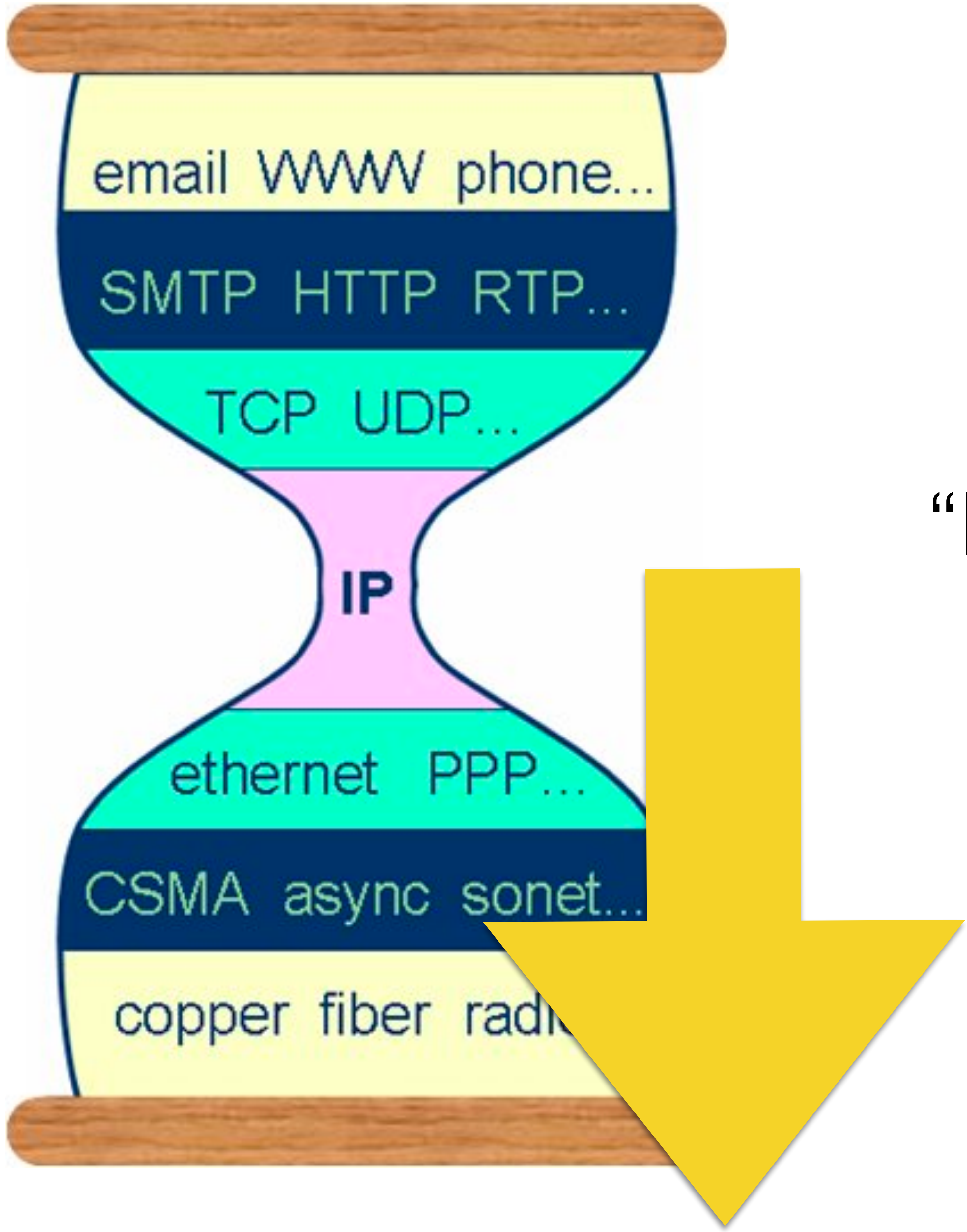


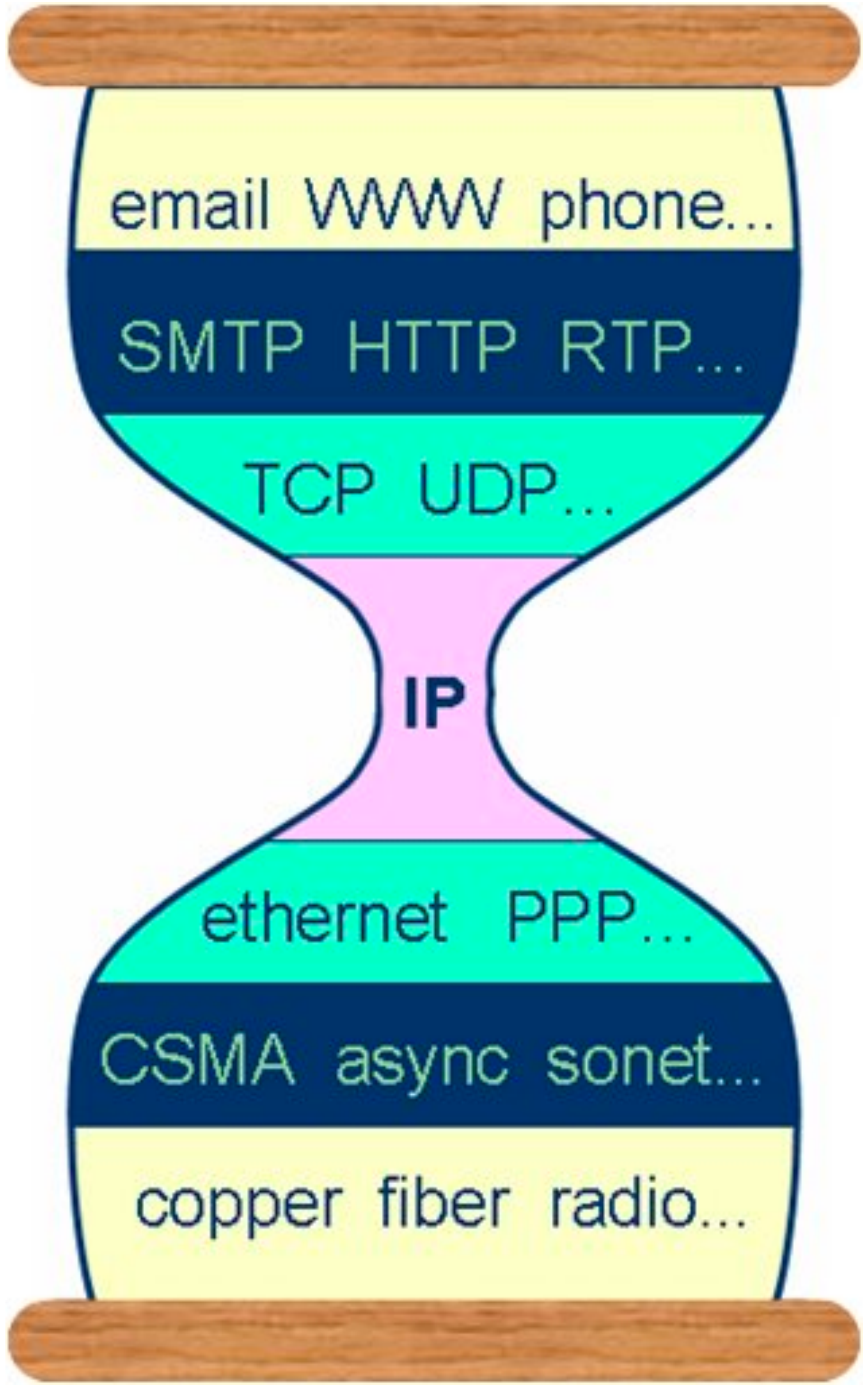
“From packets up to applications”

Next week++



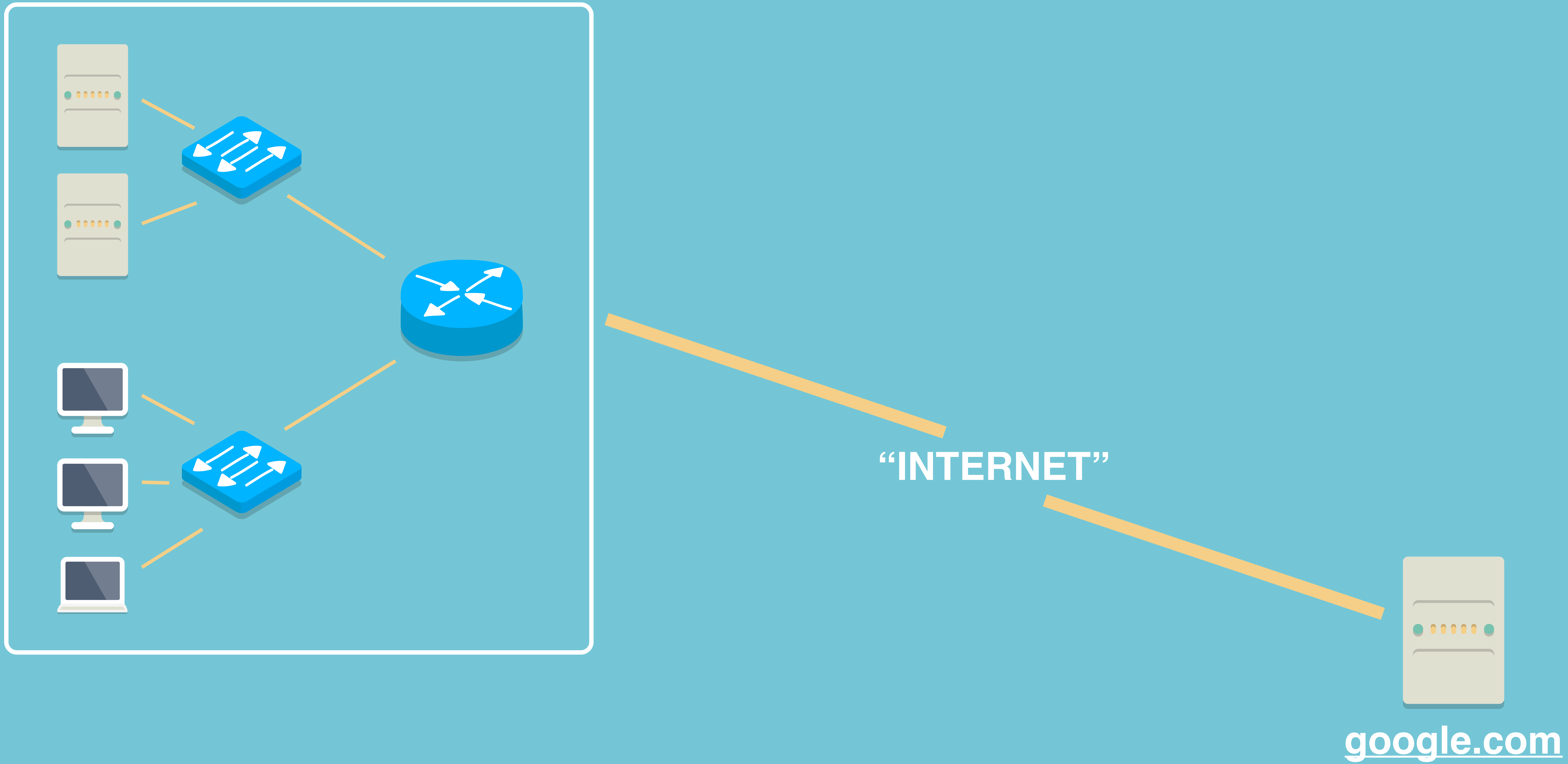
"From packets down to bits and signals"

This week…

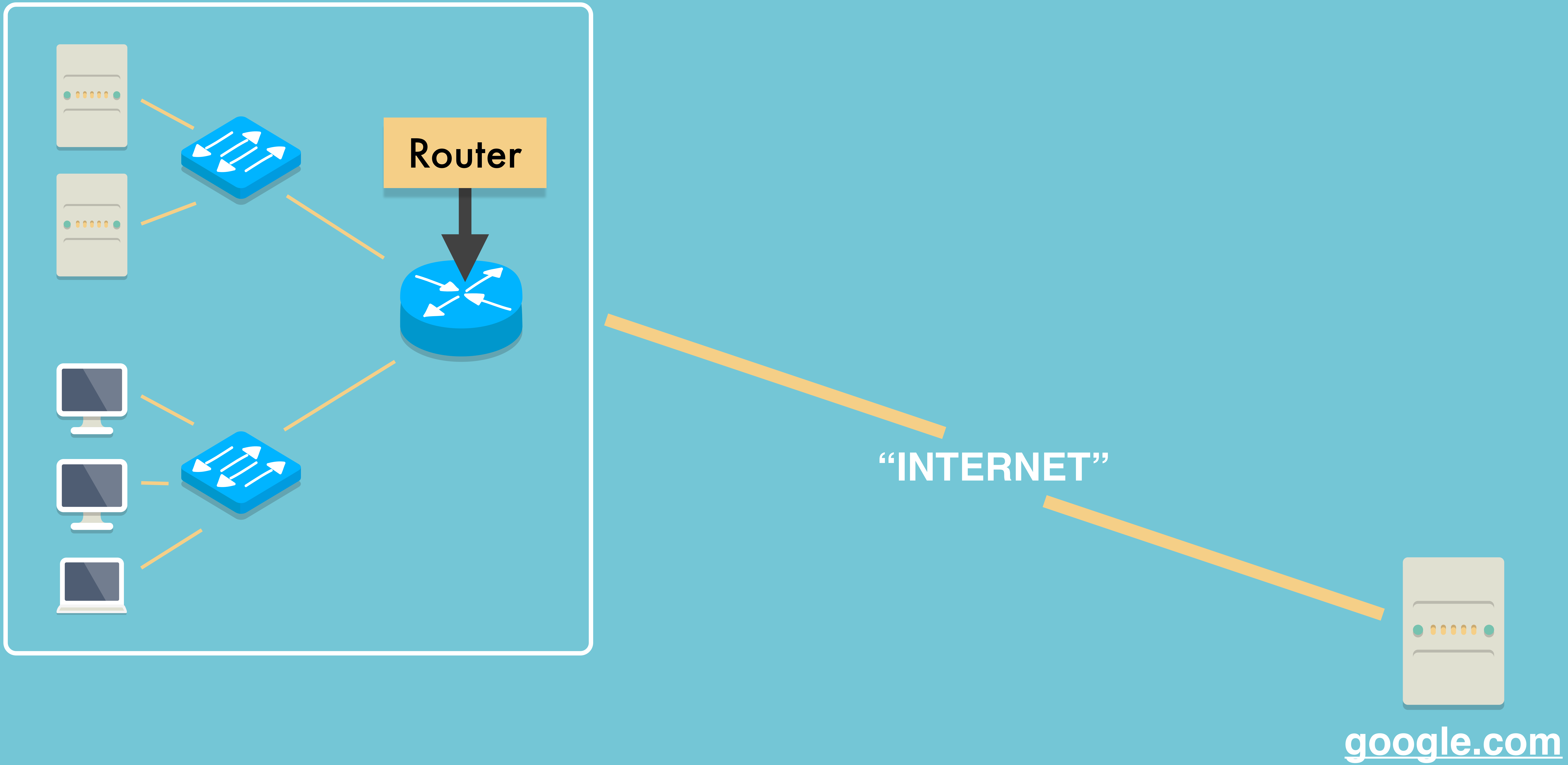


Breaking the model a little bit…

Enterprise Networks



Enterprise Networks



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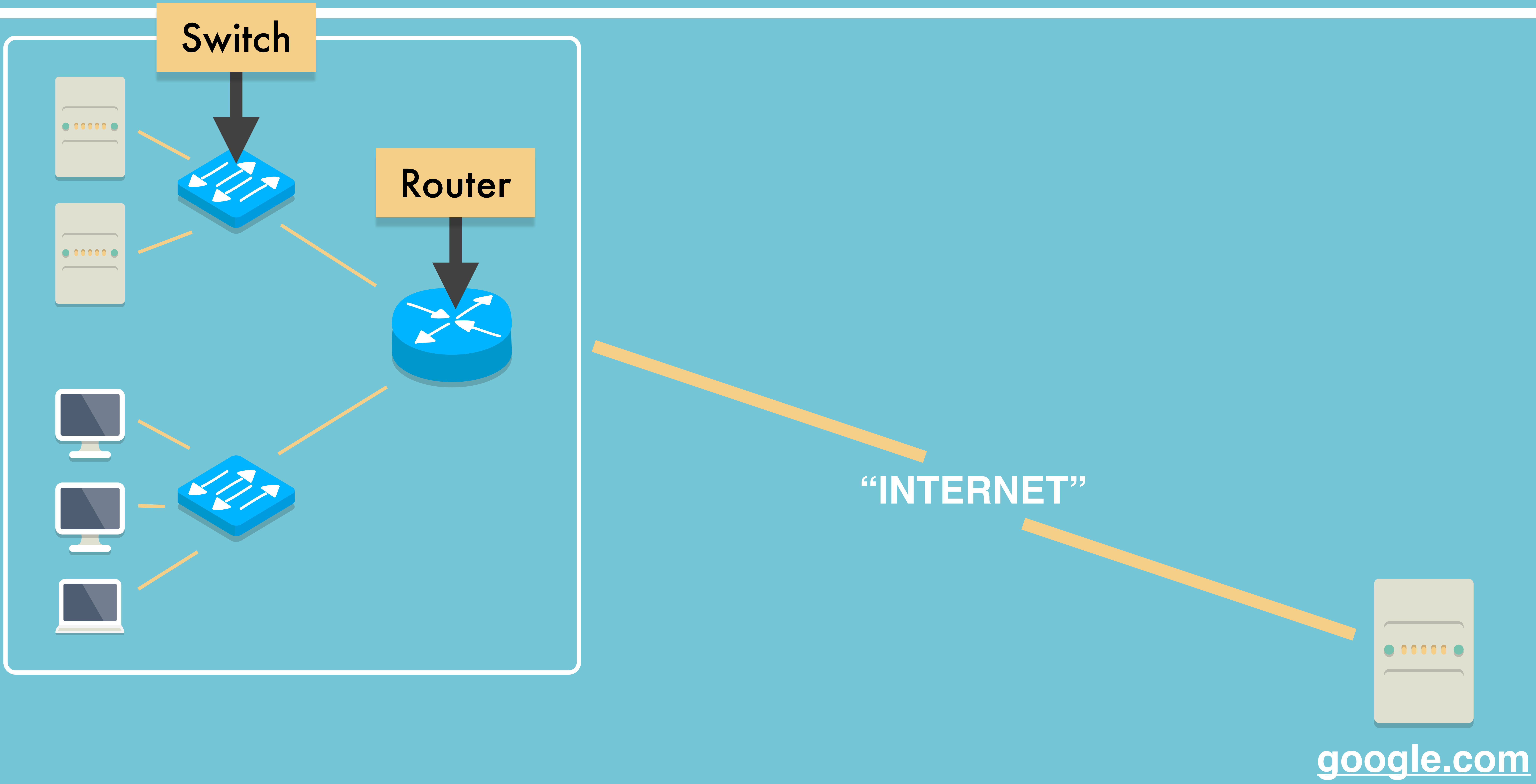

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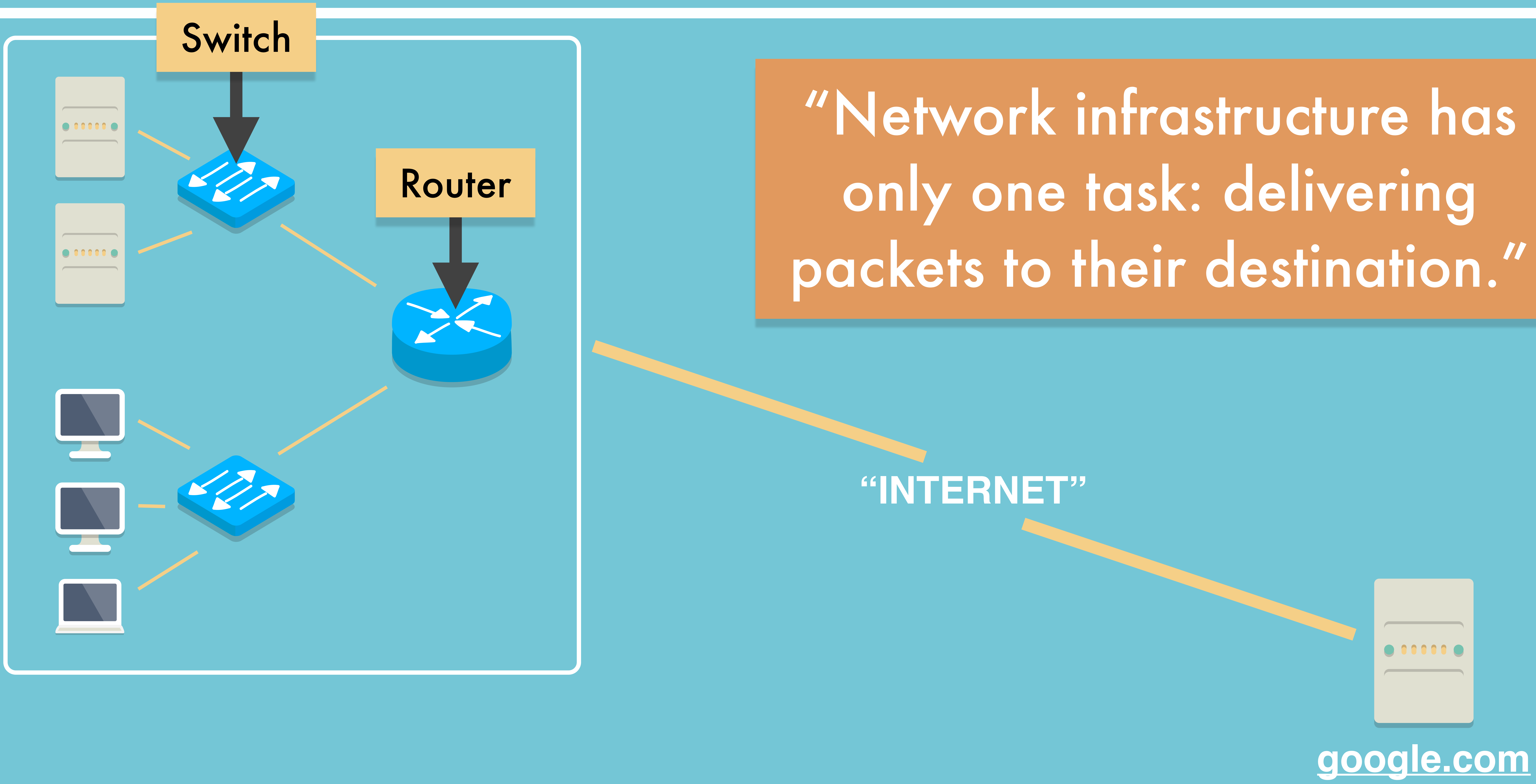
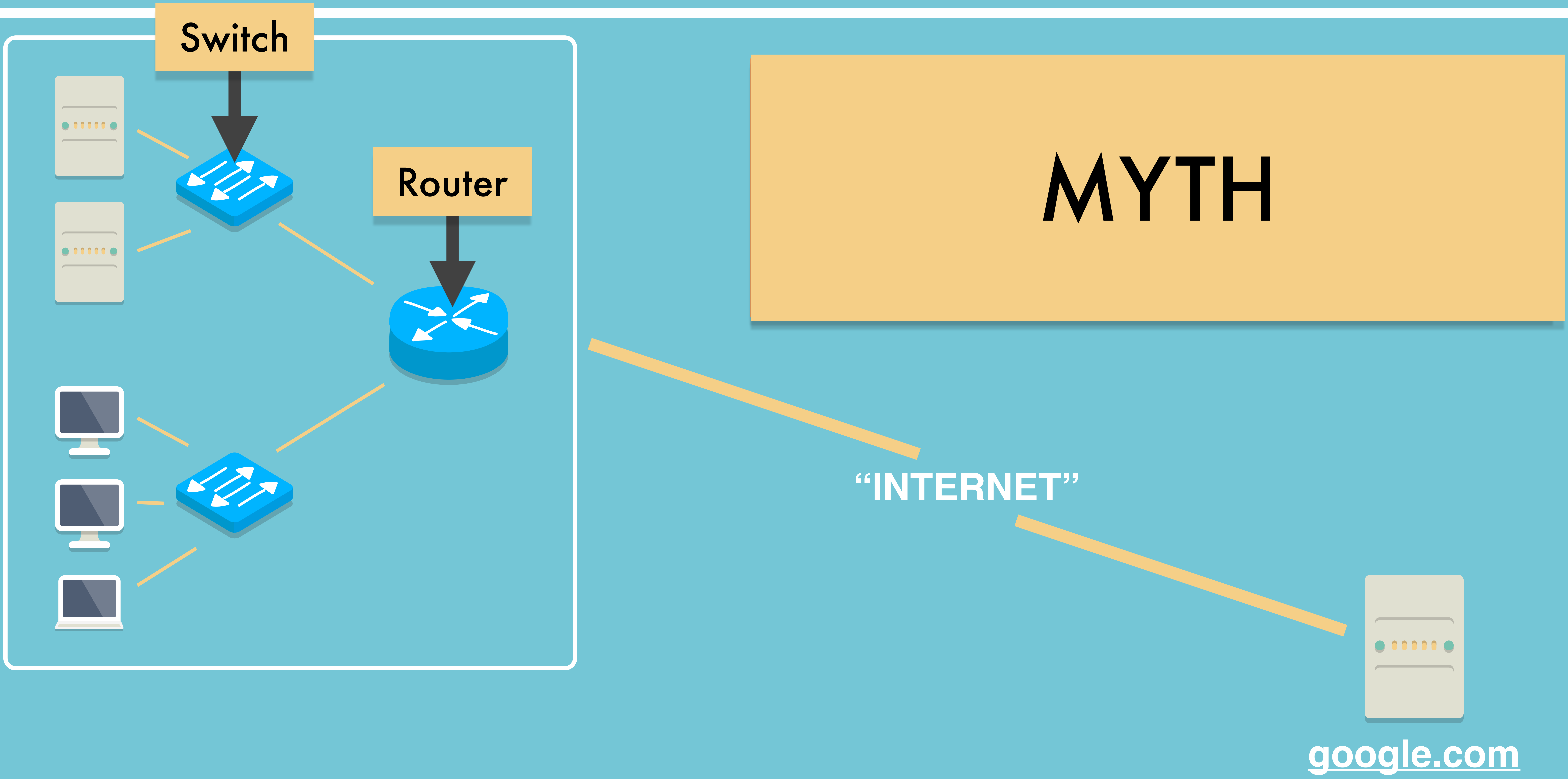


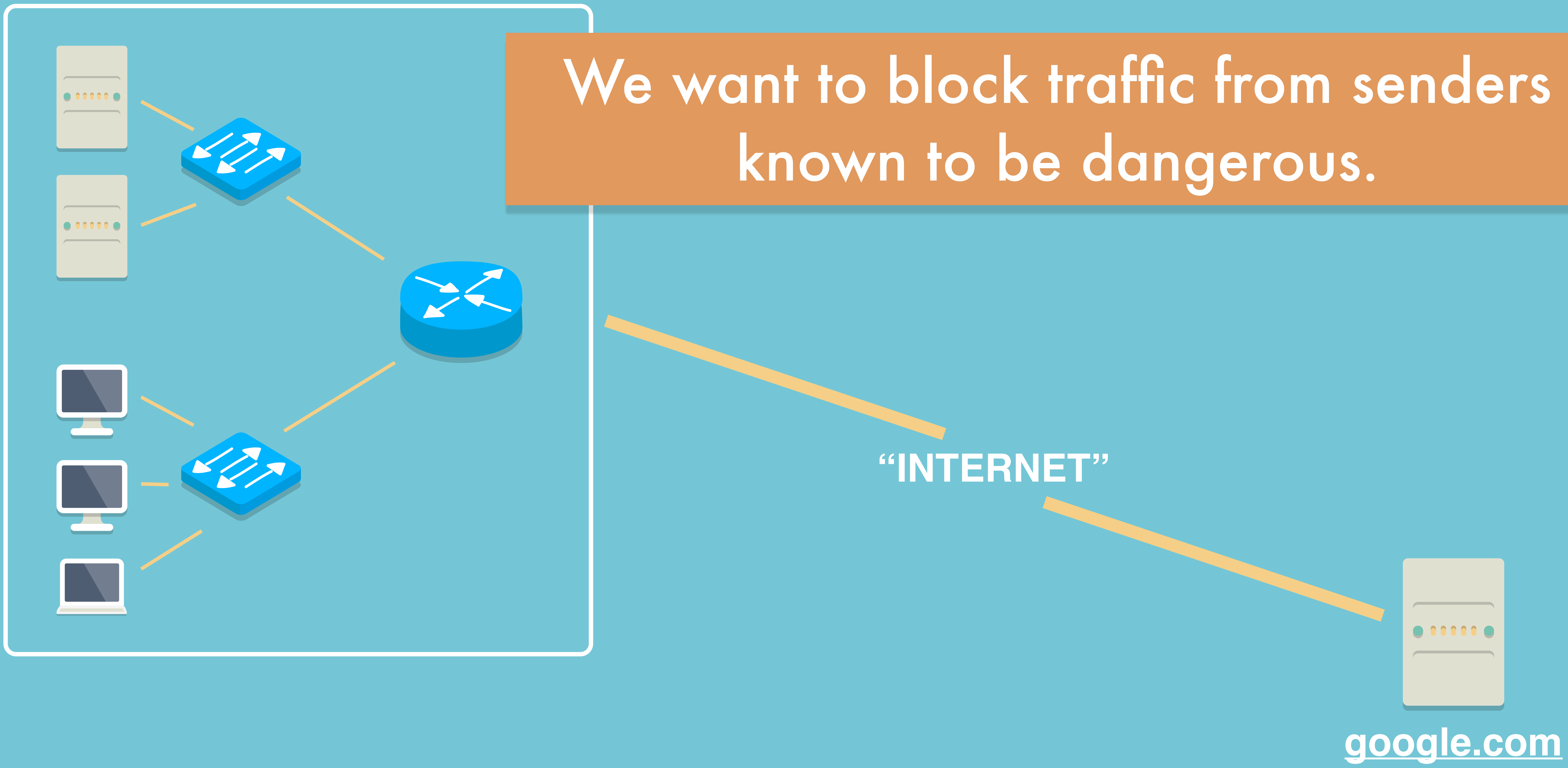
"Network infrastructure has only one task: delivering packets to their destination."

Enterprise Networks



Enterprise Networks

We want to block traffic from senders known to be dangerous.



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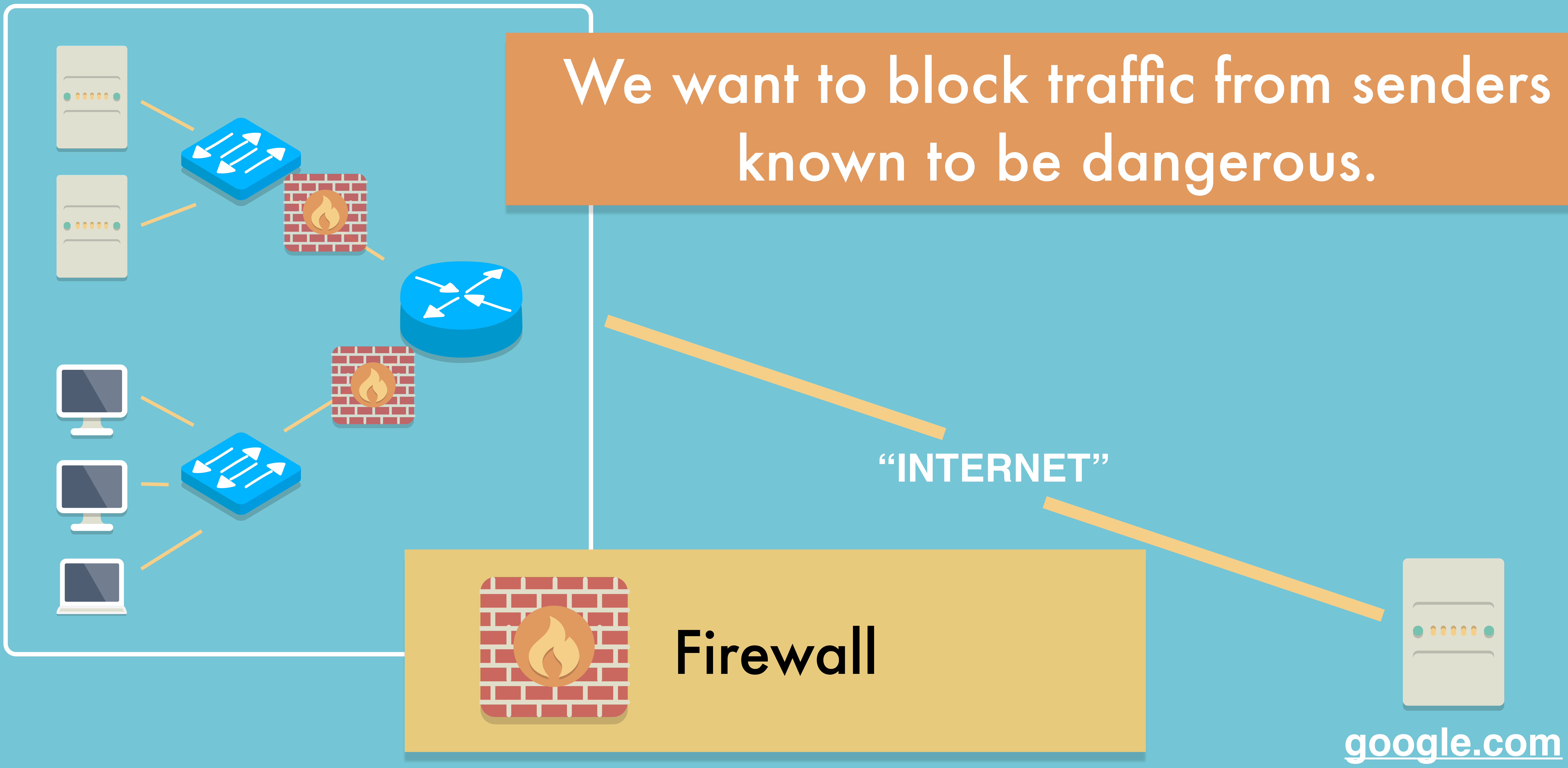
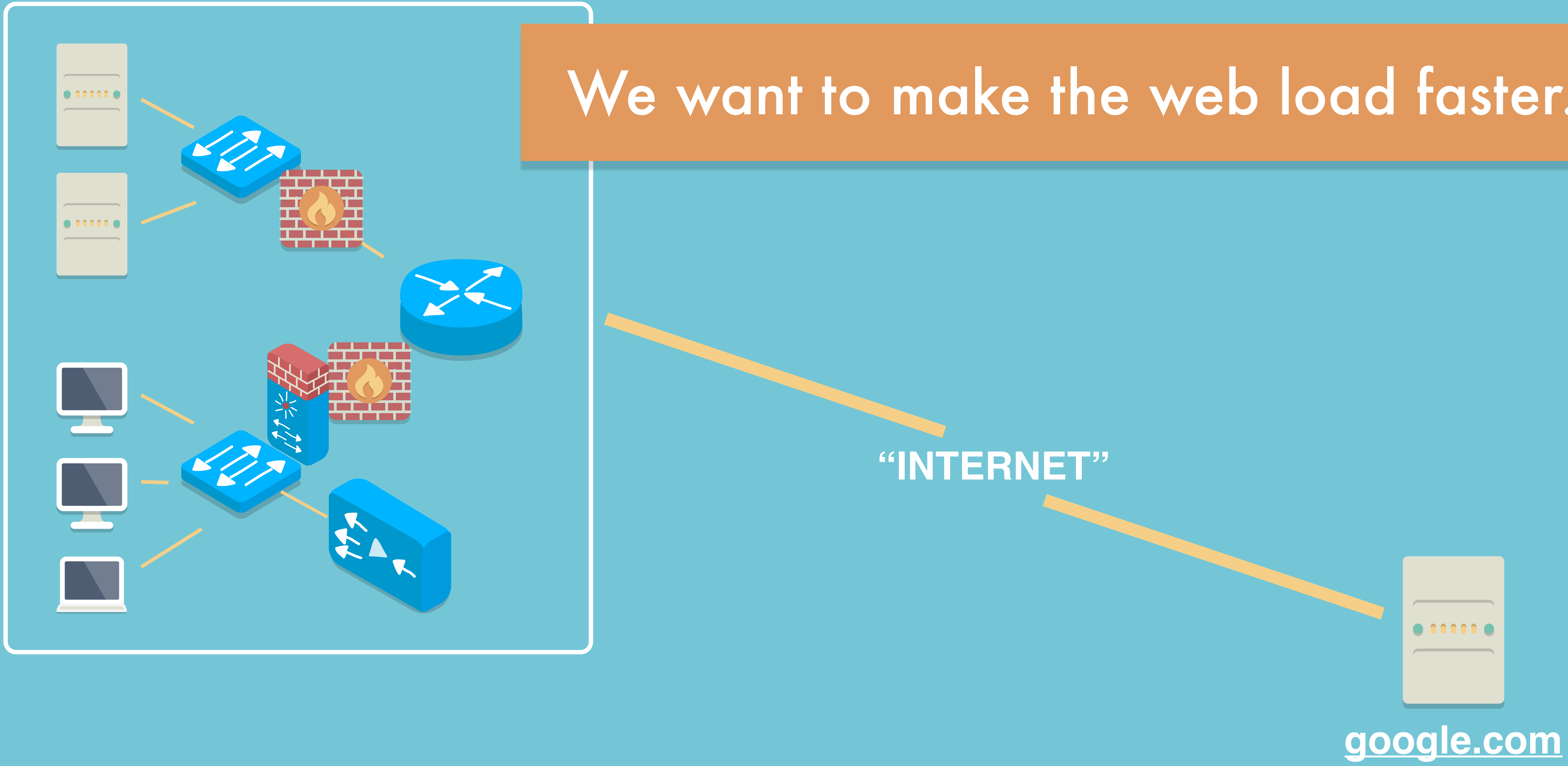
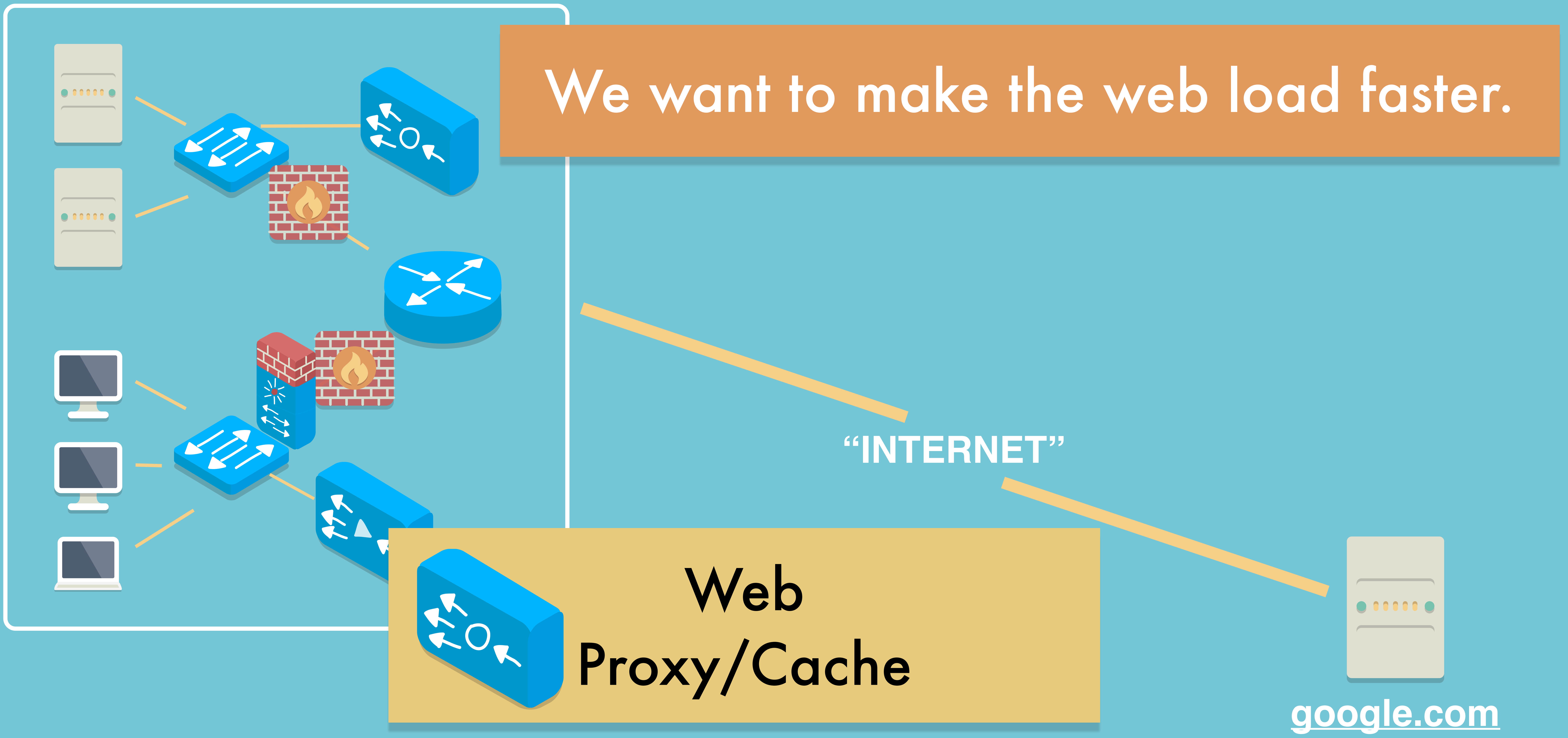


Enterprise Networks

We want to make the web load faster.



Enterprise Networks



Example: Web Proxy

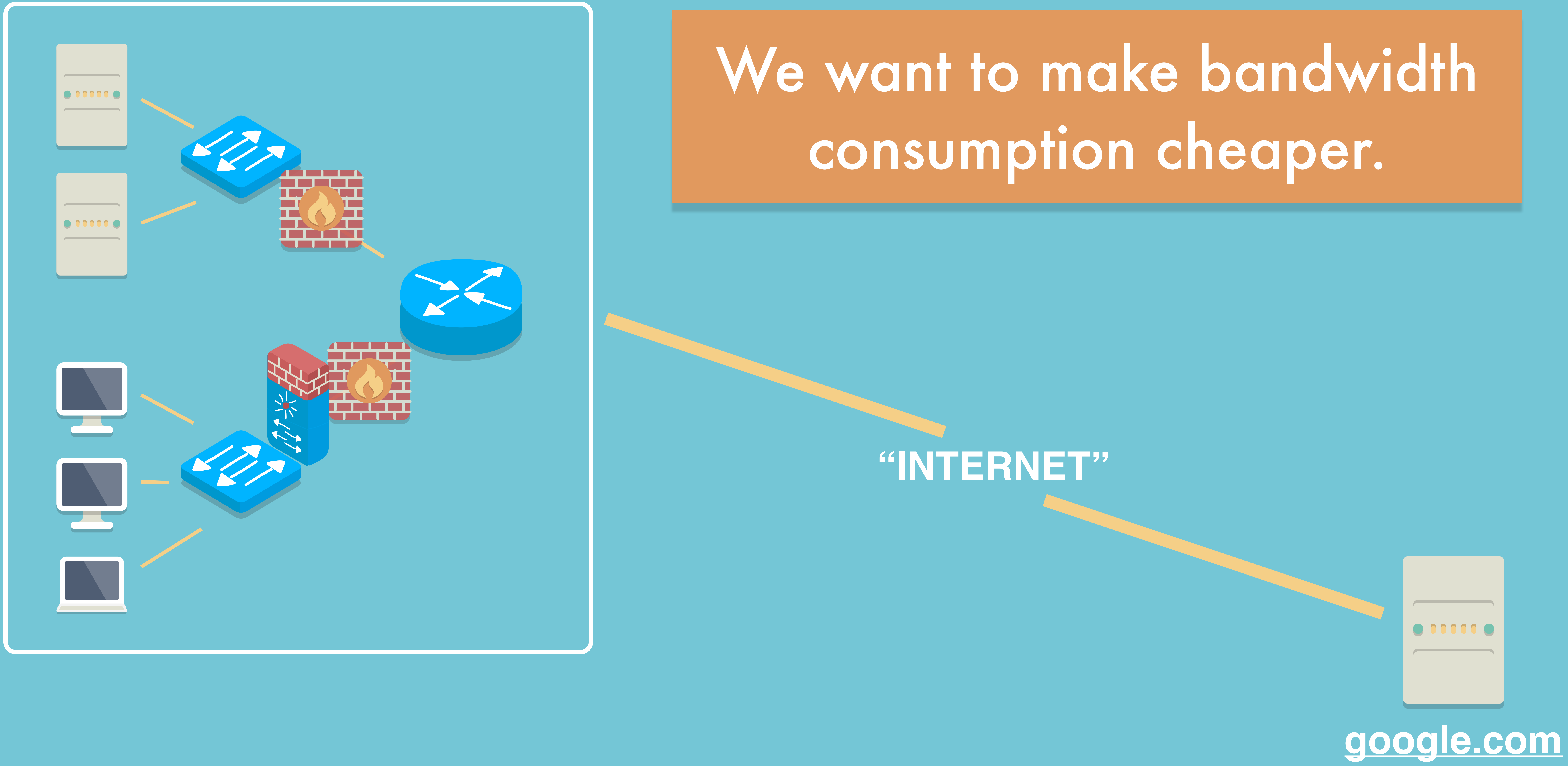
Intercepts HTTP connections and **caches** frequently accessed content.

Maintains dual connections — one to client, one to server!

- If client requests content in cache, serve locally rather than sending request to server.
- If client requests blocked content, deny the request.
- Recall: **forward** and **reverse** proxies (Lecture two weeks ago).

Enterprise Networks

We want to make bandwidth consumption cheaper.



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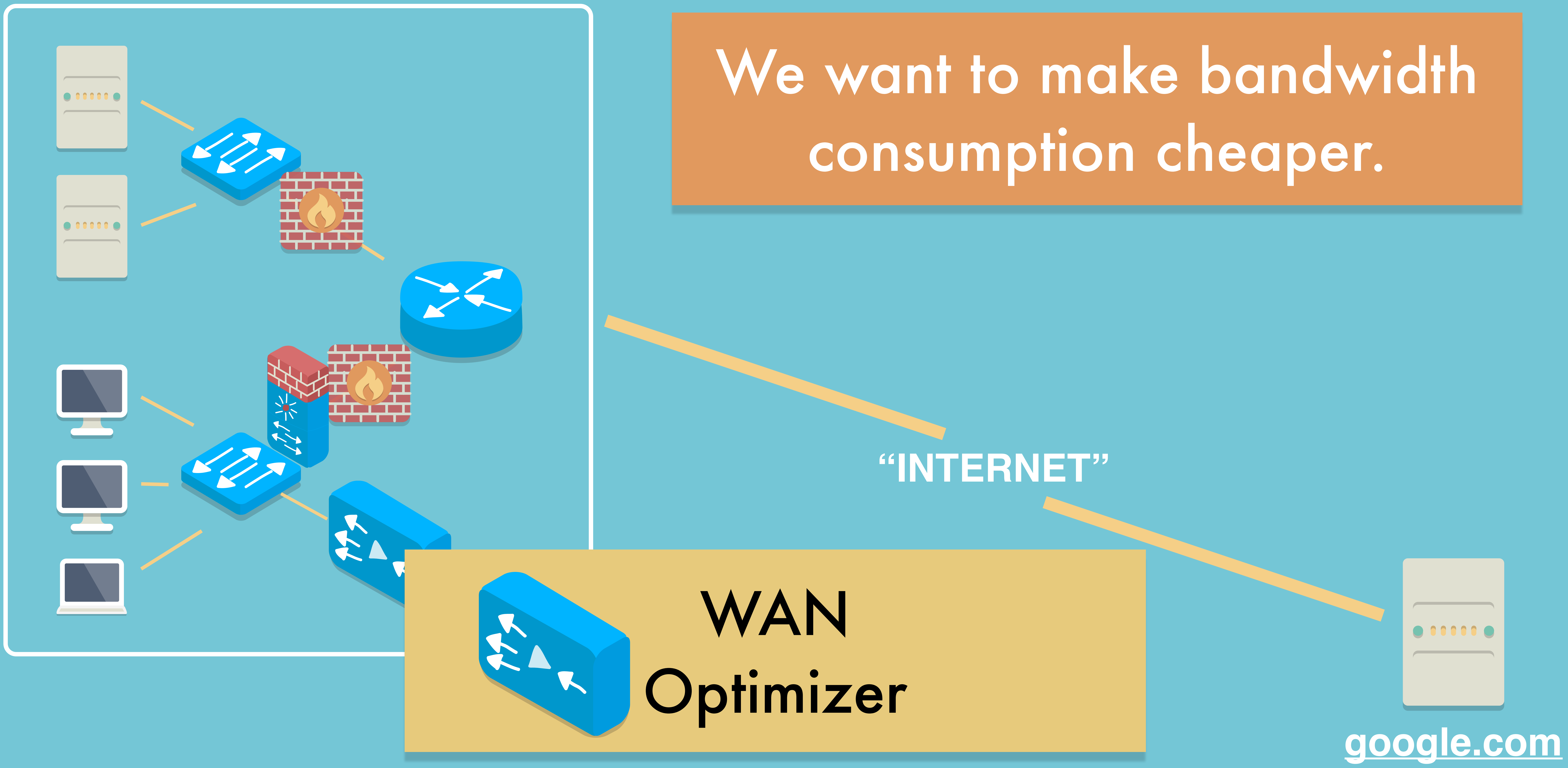


Example: WAN Optimizer

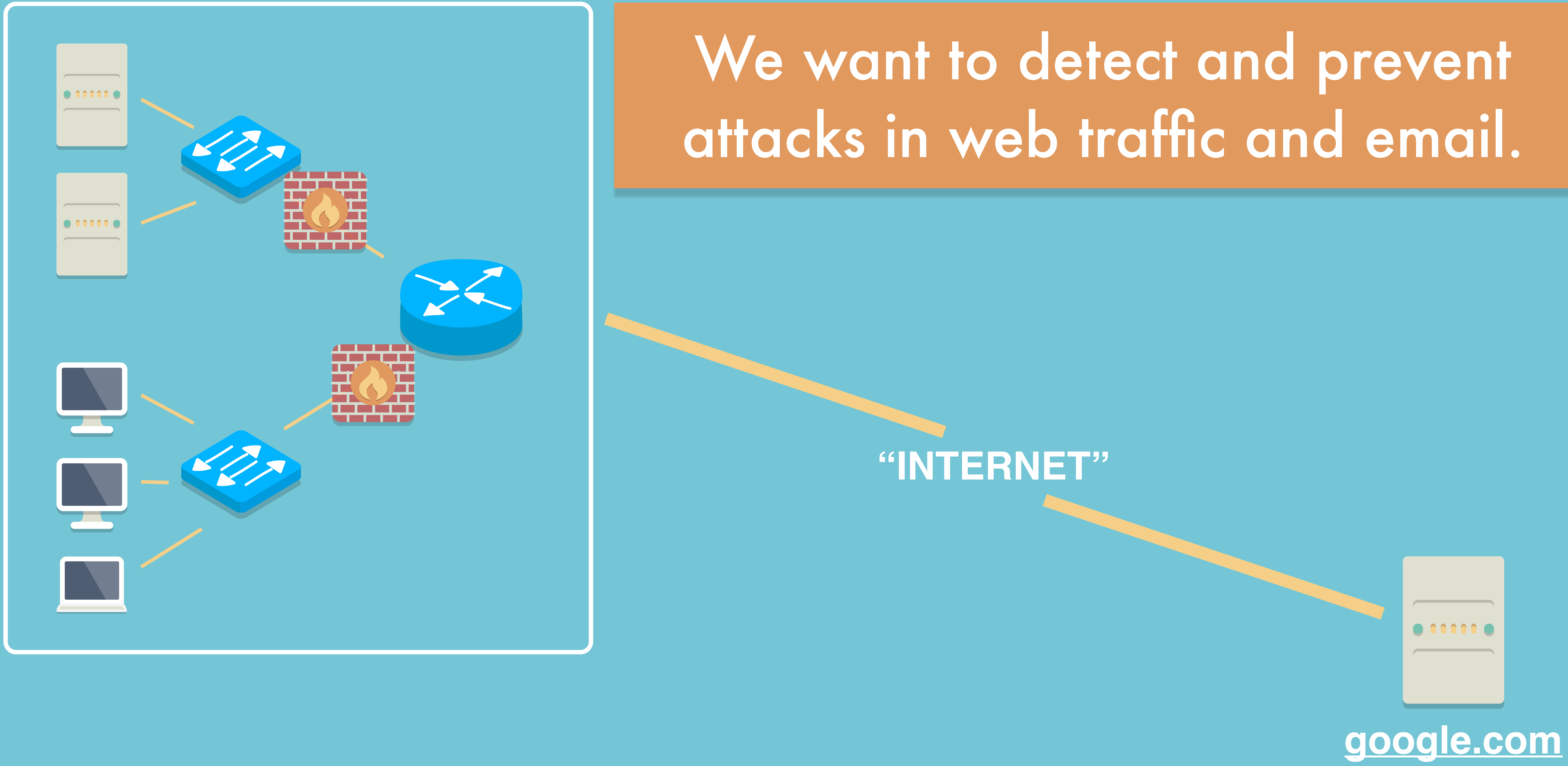
Compresses data so that it uses less bandwidth.

Sits at gateway between enterprise and Internet.

- Outgoing traffic to other sites of the same company is compressed.
- Incoming traffic is uncompressed.
- (Think gzip!)

Enterprise Networks

We want to detect and prevent attacks in web traffic and email.



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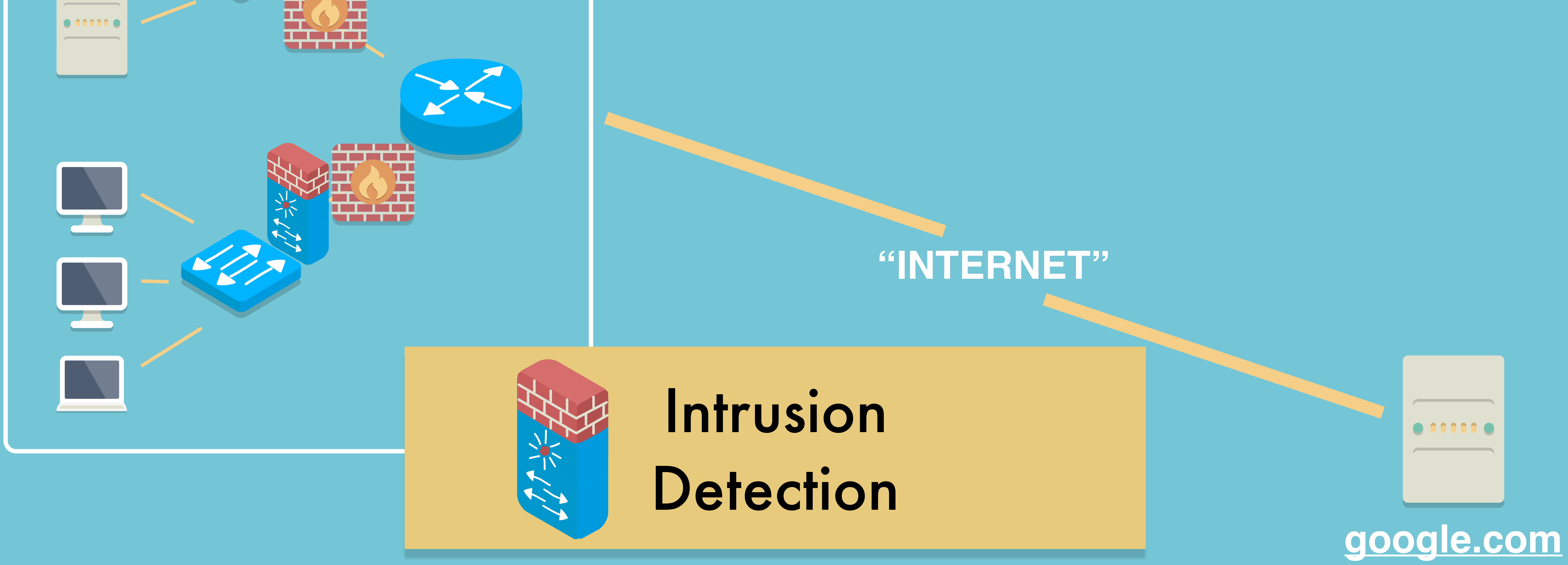

Example: Intrusion Prevention System

Detects anomalous or known-dangerous traffic and **blocks those connections.**

For each connection:

- Looks at port numbers, IP addresses and compares against blacklists.
- Reconstructs connection by stream and scans for malicious terms.
- Logs protocol, IP addresses, time of connection, etc.

…there are a lot of them!

- Network Address Translator
- Evolved Packet Gateway (EPC) Gateways
- Exfiltration Detection
- Forward and Reverse Proxies
- Firewalls
- Transcoders
- Intrusion Detection
- WAN Optimization
- Protocol Accelerators
- IPv4/IPv6 translators…

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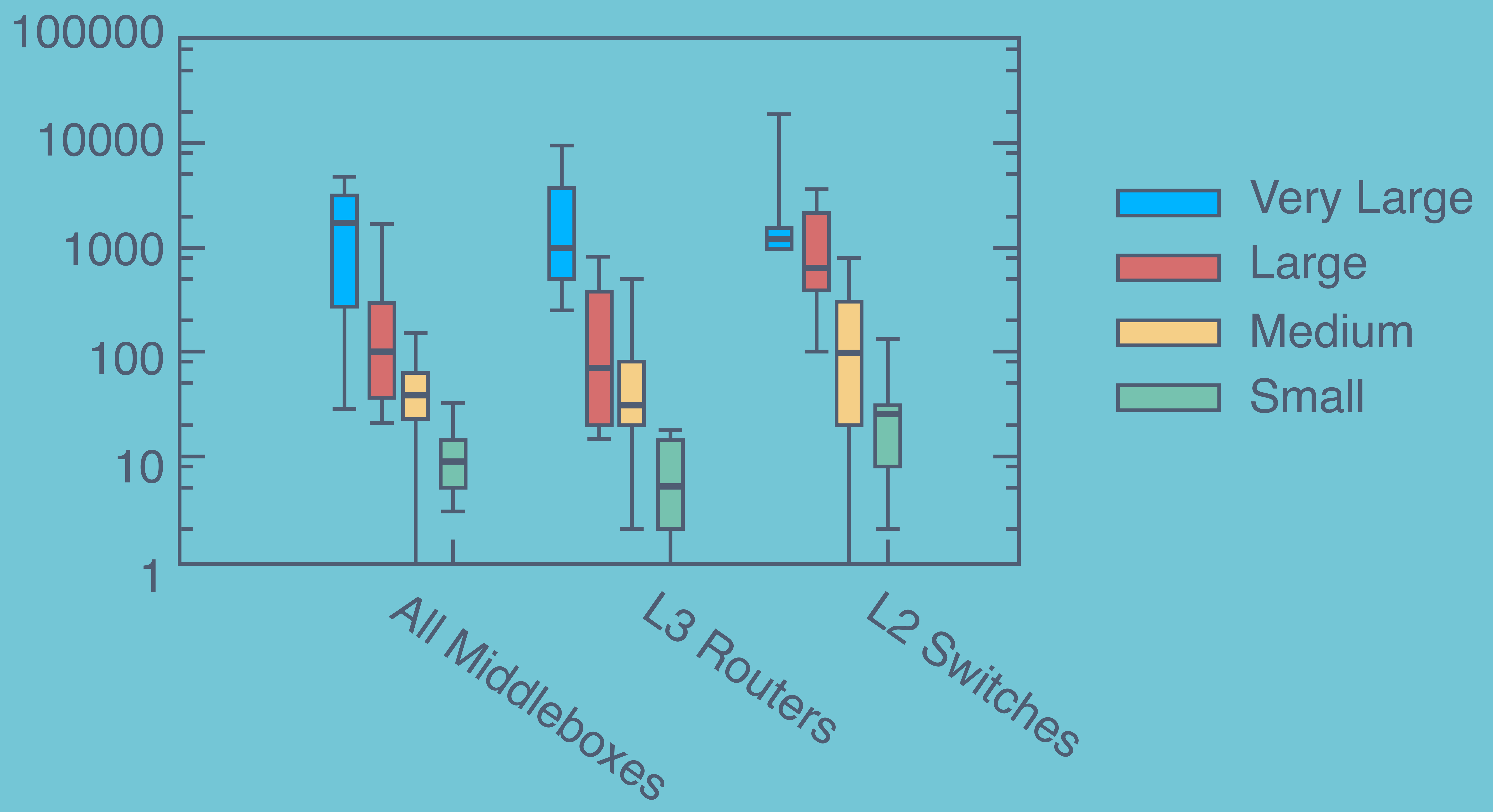
Don’t even try to memorize all of these, just learn the ones from the previous slides ;-)

Very widely deployed…



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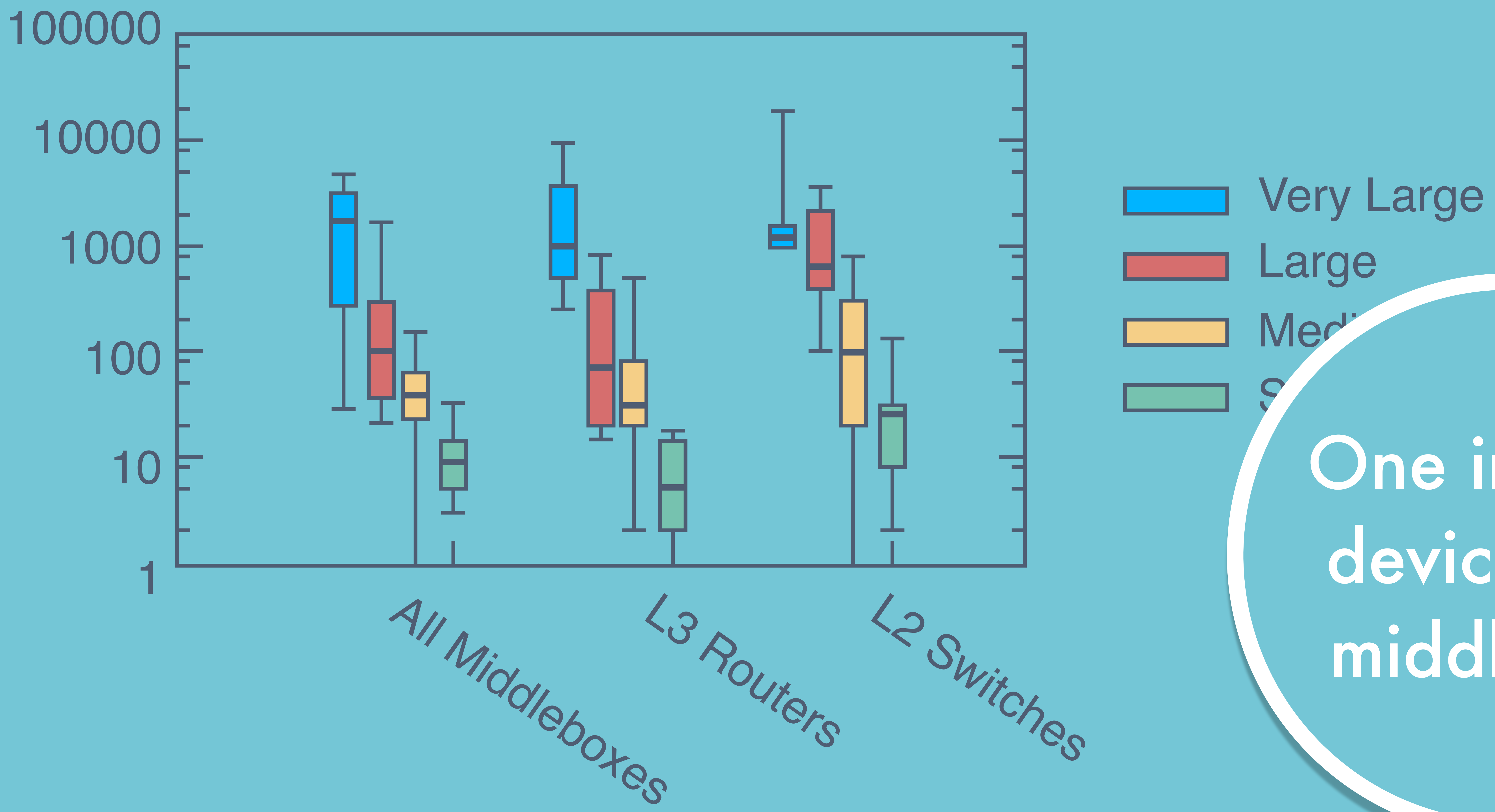
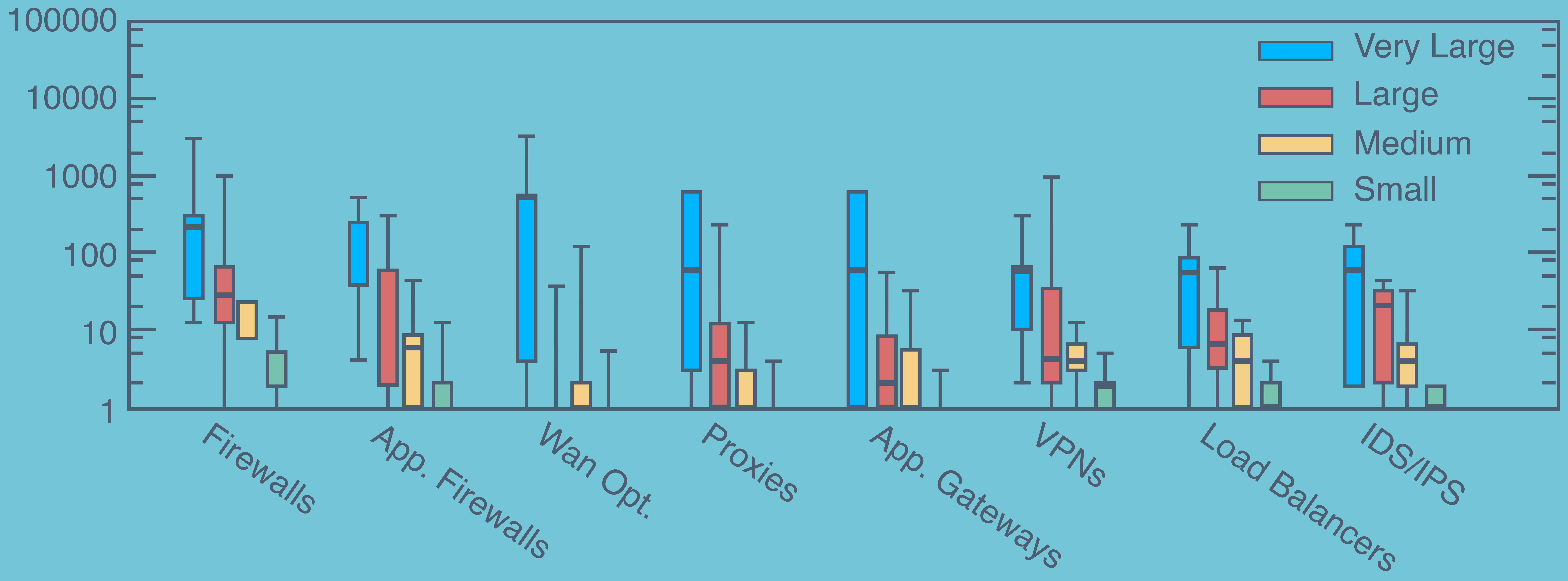


One in three devices is a middlebox!

…in great heterogeneity!



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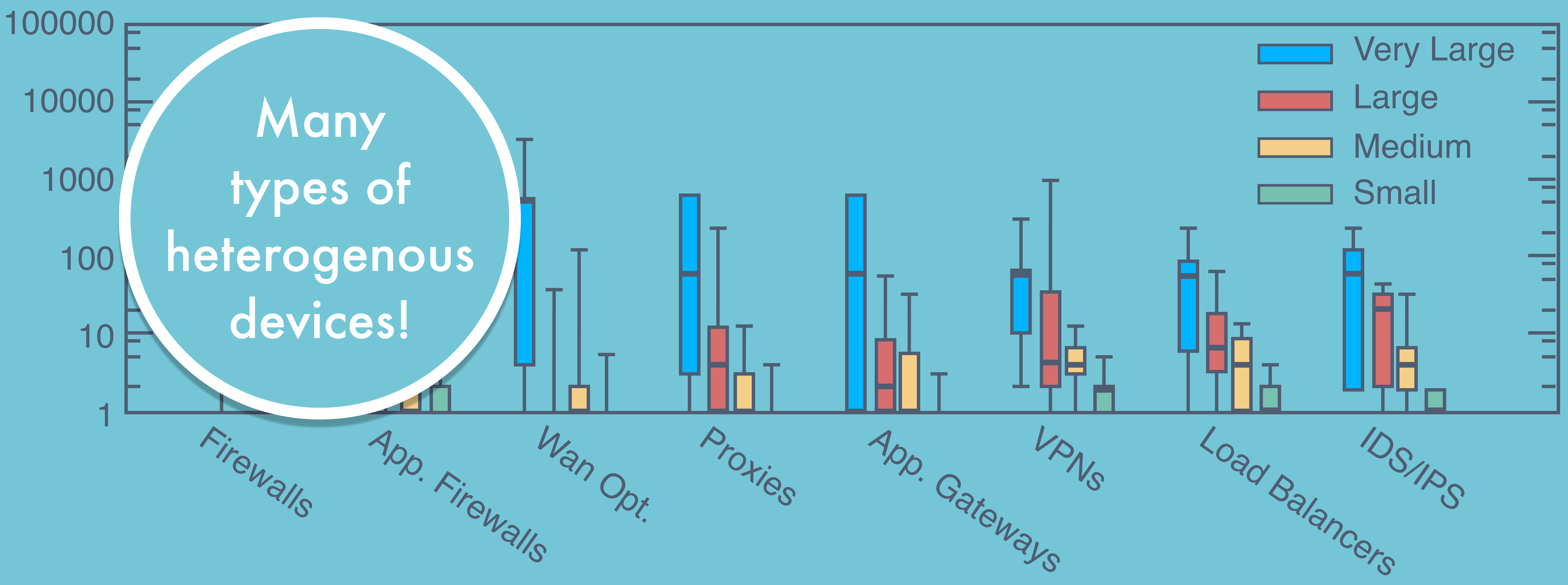
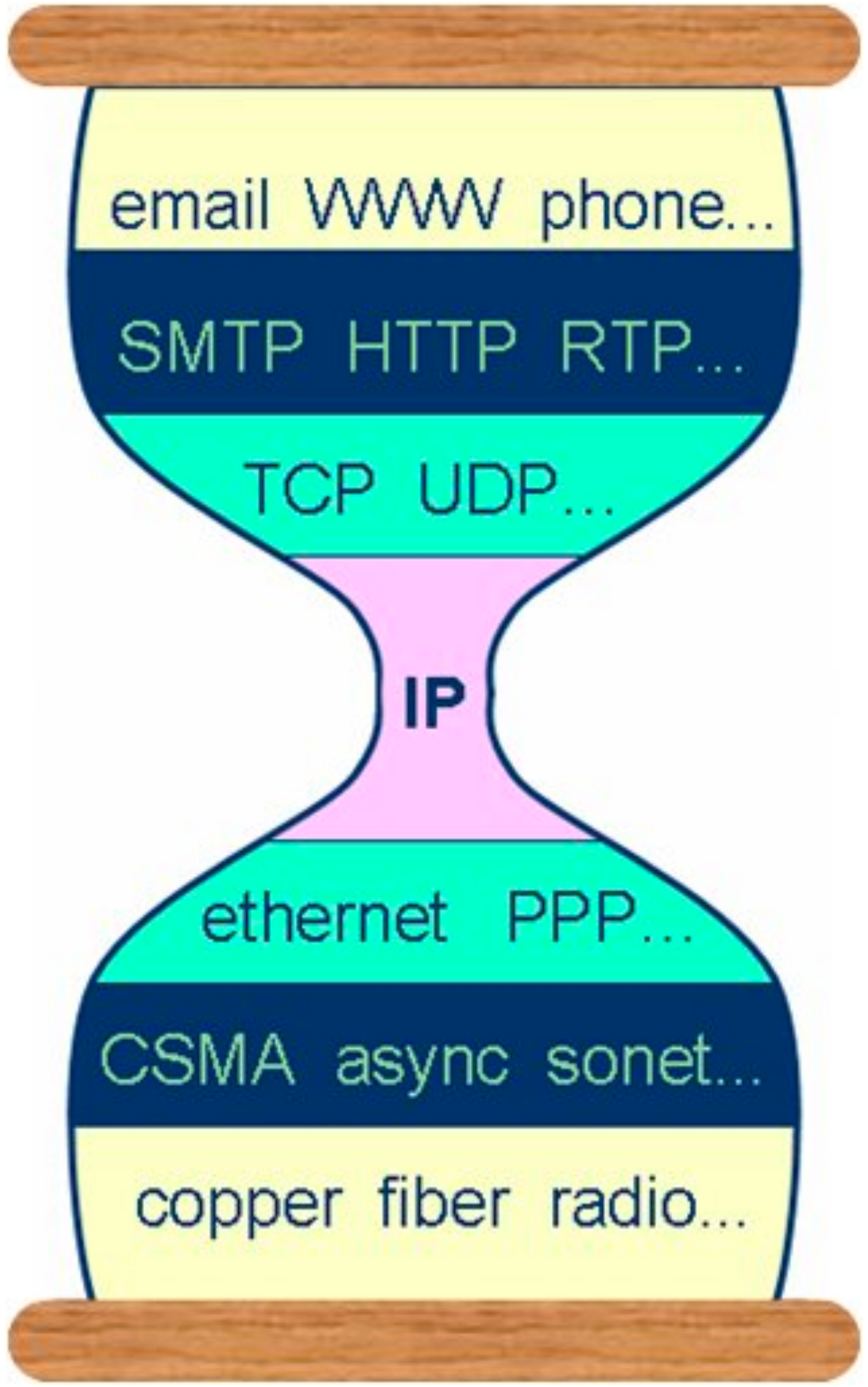


Where do middleboxes fit in the model?



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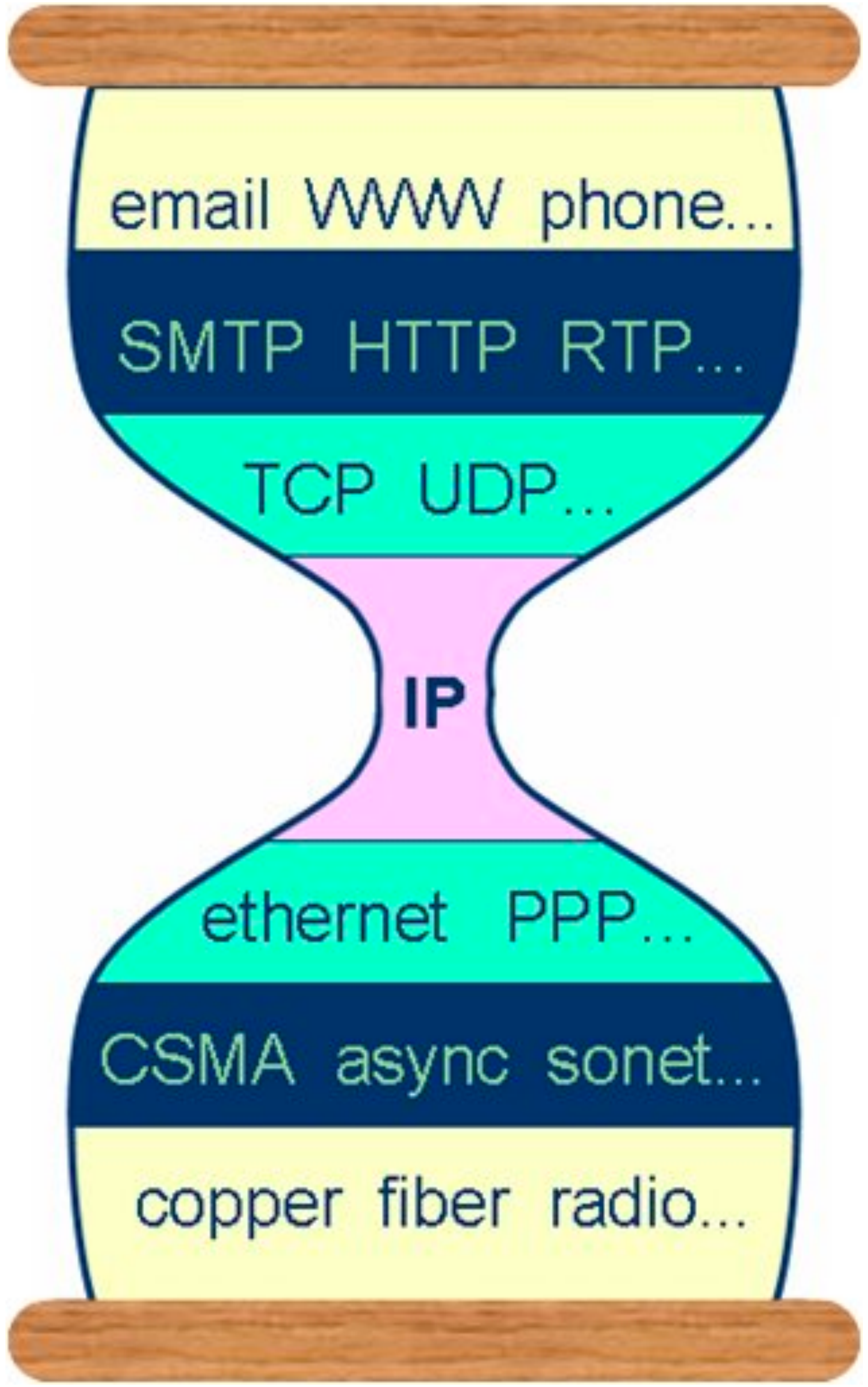

In what ways are middleboxes at the application layer?

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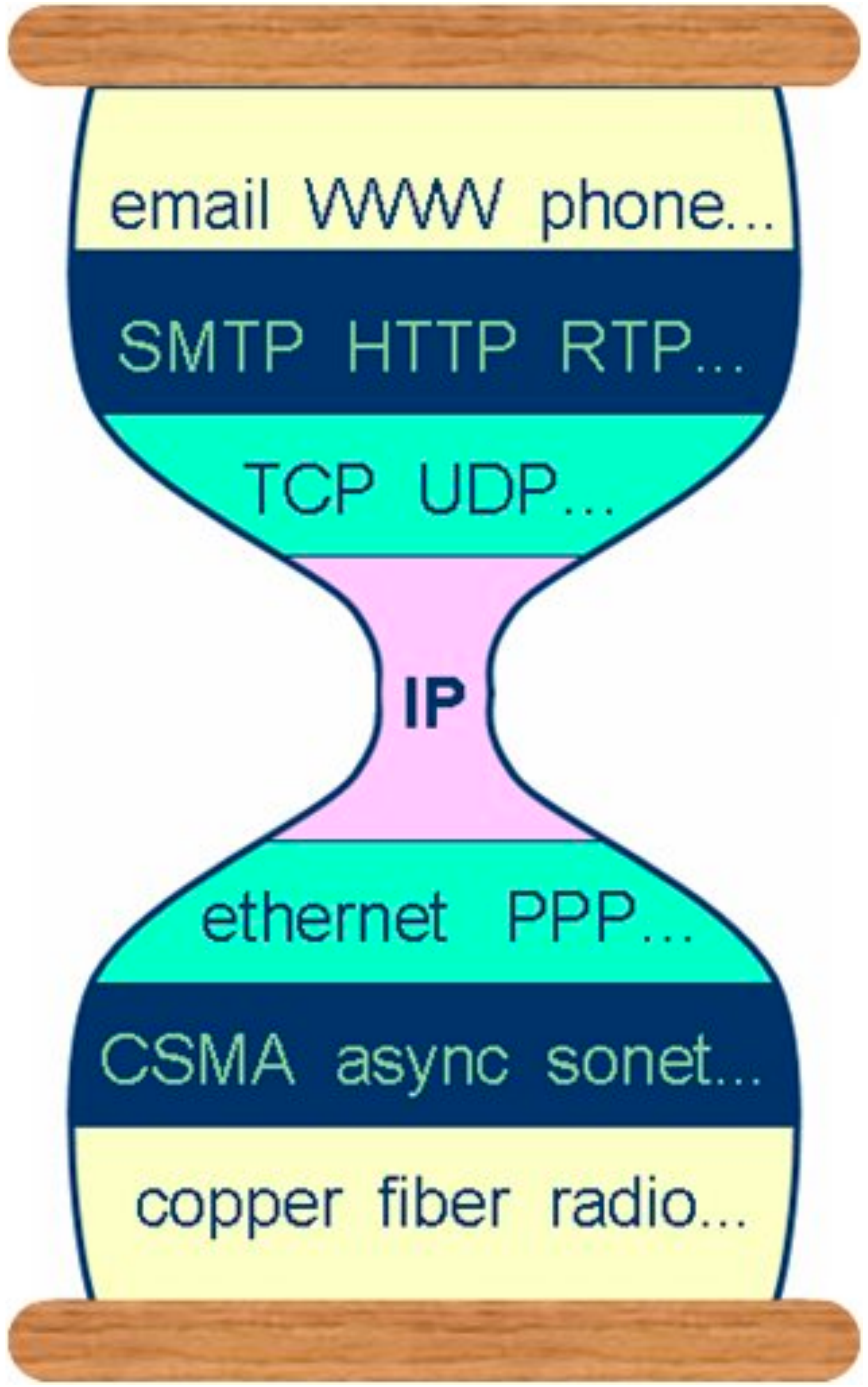

In what ways are middleboxes at the application layer?

In what ways are middleboxes at the network layer?

MIDDLEBOXES ARE CONTROVERSIAL

The rest of this lecture

- The End to End Argument (aka, why middleboxes are controversial)
- Why we deploy middleboxes anyway
- Some challenges they leave us with
- A new movement called Network Functions Virtualization

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- **The End to End Argument**
- Why we deploy middleboxes anyway
- Some challenges they leave us with
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"Careful File Transfer"

At host A the file transfer program calls upon the file system to read the file from the disk, where it resides on several tracks, and the file system passes it to the file transfer program in fixed-size blocks chosen to be disk-format independent.

A

File System

Program

Network

B

File System

Program

Network

“Careful File Transfer”

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A

B

Alternate ACM SIG Proceedings Paper in LaTeX Format

A	B
File System	File System
Program	Program
Network	Network

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Also at host A the file transfer program asks the data communication system to transmit the file using some communication protocol that involves splitting the data into packets. The packet size is typically different from the file block size and the disk track size.

A

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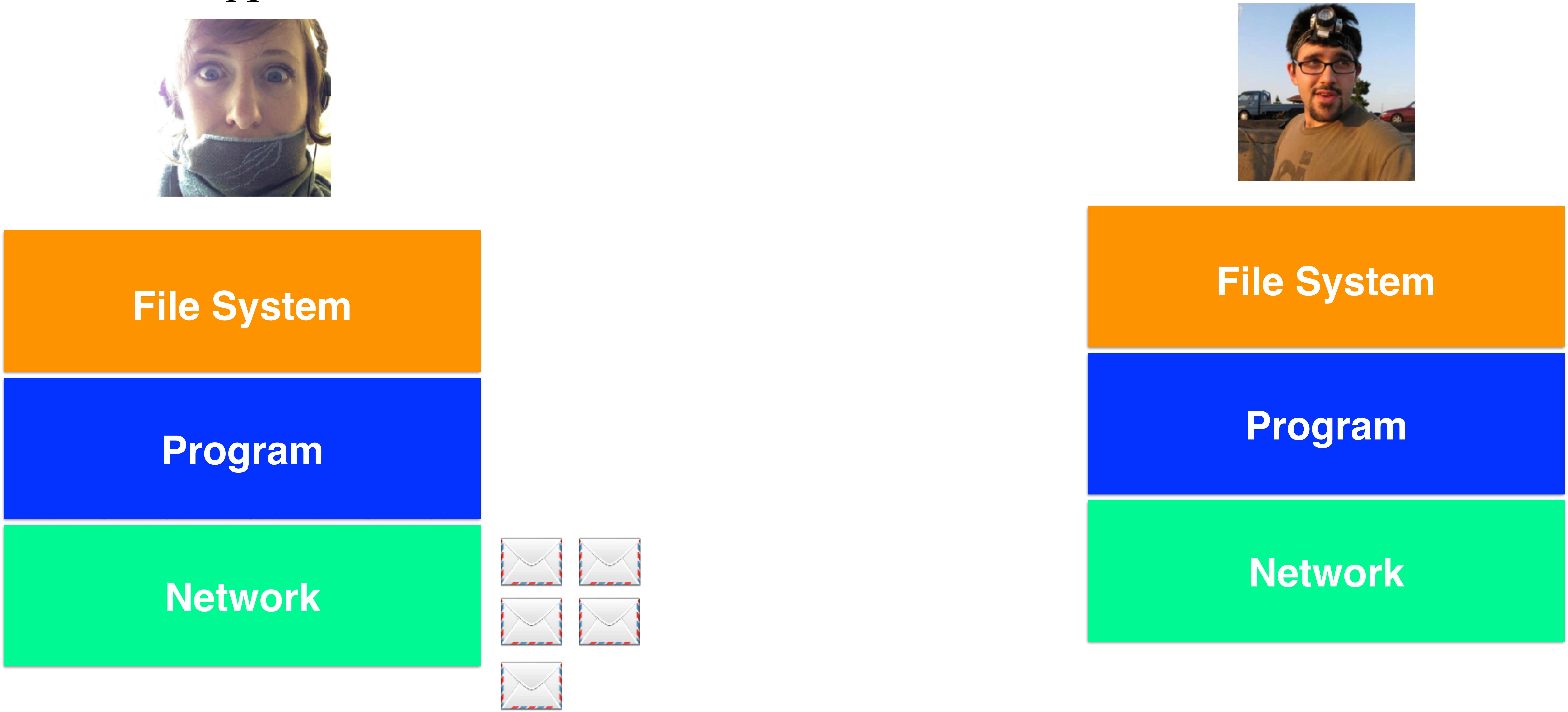

“Careful File Transfer”

The data communication network moves the packets from computer A to computer B.

A

File System

Program

Network

B

File System

Program

Network

“Careful File Transfer”

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A

File System

Program

Network

B

File System

Program

Network

“Careful File Transfer”

At host B a data communication program removes the packets from the data communication protocol and hands the contained data on to a second part of the file transfer application, the part that operates within host B.

A

B

File System

Program

Network

File System

Program

Network

“Careful File Transfer”

At host B, the file transfer program asks the file system to write the received data on the disk of host B.

A

File System

Program

Network

B

File System

Program

Network

What if Zeeshan later reads the file and find it is corrupted? What could have gone wrong?

The file, though originally written correctly onto the disk at host A, if read now may contain incorrect data, perhaps because of hardware faults in the disk storage system.

The software of the file system, the file transfer program, or the data communication system might make a mistake in buffering and copying the data of the file, either at host A or host B.

The hardware processor or its local memory might have a transient error while doing the buffering and copying, either at host A or host B.

The communication system might drop or change the bits in a packet, or lose a packet or deliver a packet more than once.

Either of the hosts may crash part way through the transaction after performing an unknown amount (perhaps all) of the transaction.

How do we re-design our system to make sure the file doesn’t get corrupted?

B

File System

Program

Network

B

File System

Program

Network

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File System

Program

Network

The End-to-End Argument

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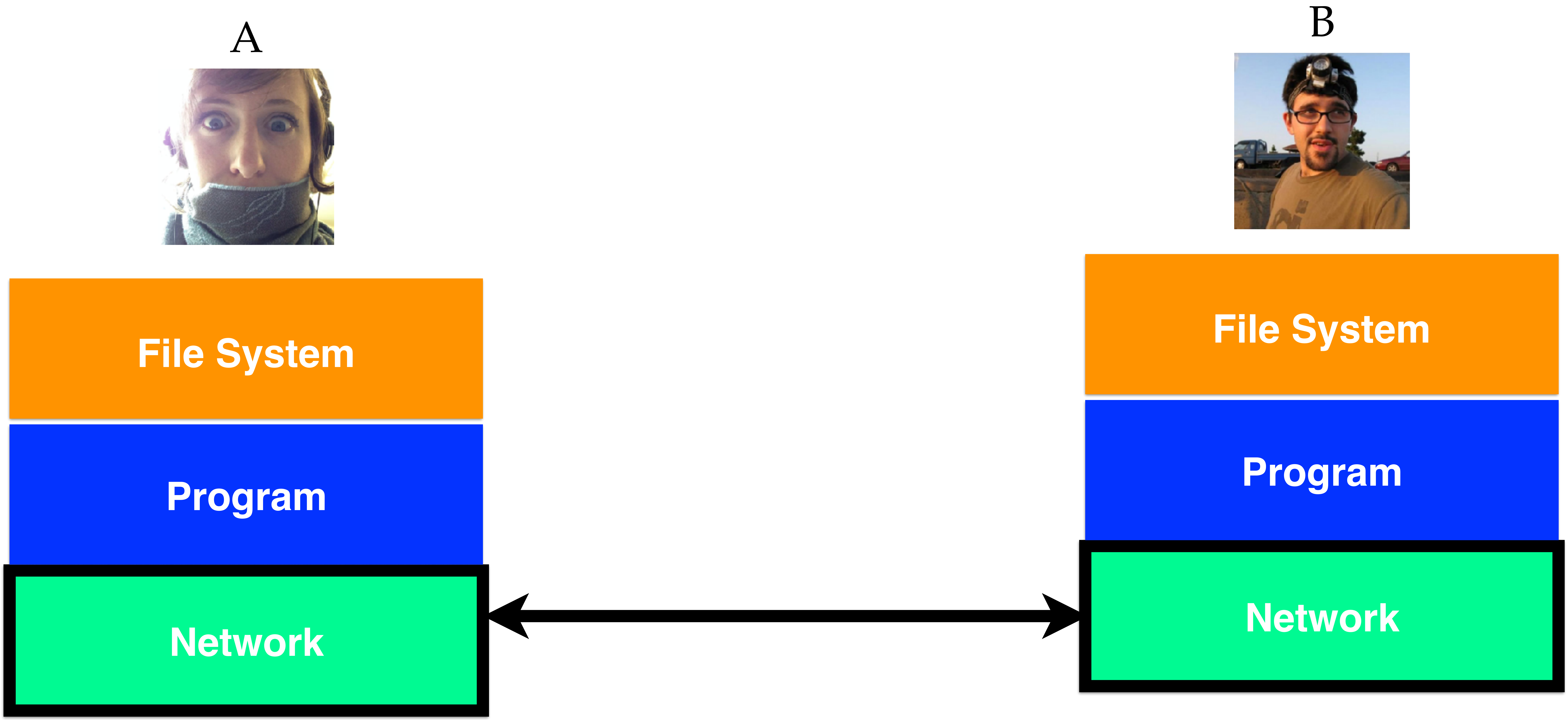
[However], sometimes an incomplete version of the function provided by the communication system may be useful as a performance enhancement.

Let’s say we had a perfectly reliable network



Would that solve our reliability problem?

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Well, that wasn’t very helpful…

"End to End Check and Retry"

A

File System

Program

Network

B

File System

Program

Network

“End to End Check and Retry”

Read file and its checksum from disk.
Verify file + checksum.
Send File AND Checksum.

A

File System

Program

Network

B

File System

Program

Network

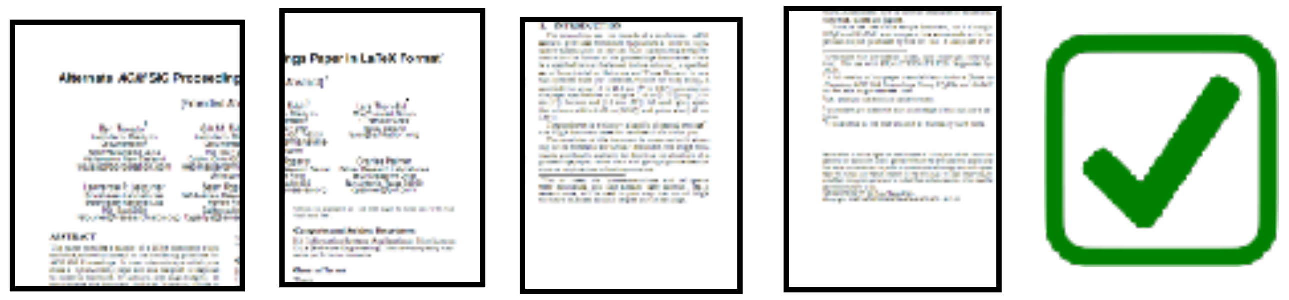
“End to End Check and Retry”

A

File System

Program

Network



B

File System

Program

Network

“End to End Check and Retry”

A

File System

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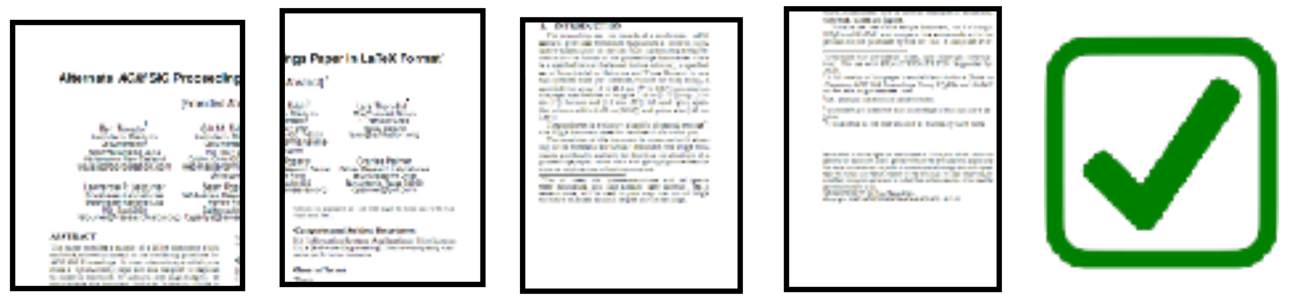

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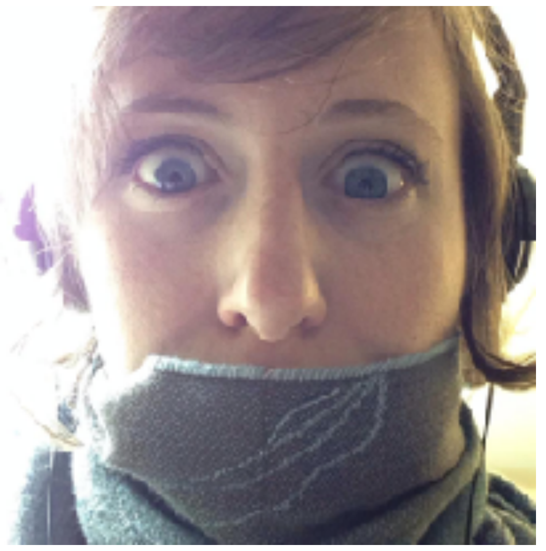

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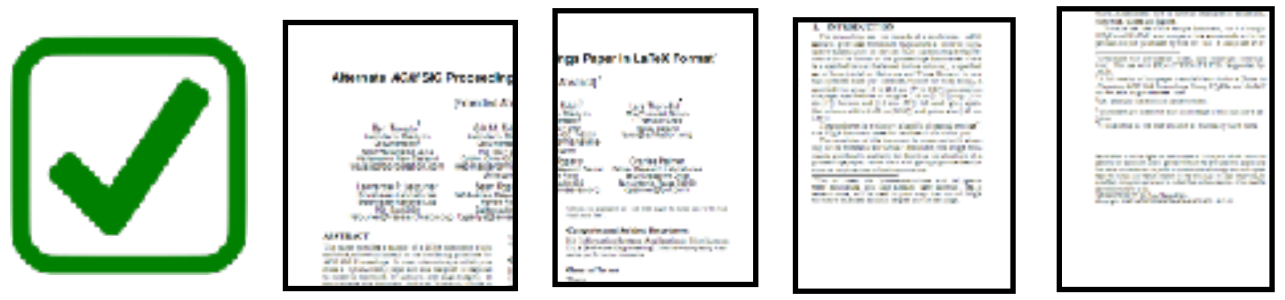

B

File System

Program

Network

“End to End Check and Retry”

A

Write file and checksum to disk.
Then read back and double-check that checksum + file verify.

B

A
File System
Program
Network

B
File System
Program
Network

"End to End Check and Retry"

A

File System

Program

Network

If Checksum doesn't match?
Just ask Justine to re-send.
(ie, try all over again!)

B

File System

Program

Network

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Lesson: If you can do it at the "higher" layer, don't bother implementing it at a lower layer.

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Don't waste your time!

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Don't waste your time!

Avoid causing confusion.

We’ve already seen some examples in this class.

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TCP Congestion Control?

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TCP Congestion Control?

Circuit Switched Networking?

We’ve already seen some examples in this class.

TCP Congestion Control?

Circuit Switched Networking?

Packet fragment reassembly?

The End-to-End Argument

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One Exception!

[Then] providi… …stio…ed function as a feature of the communica…n syste… [or …er layer] is not possible.

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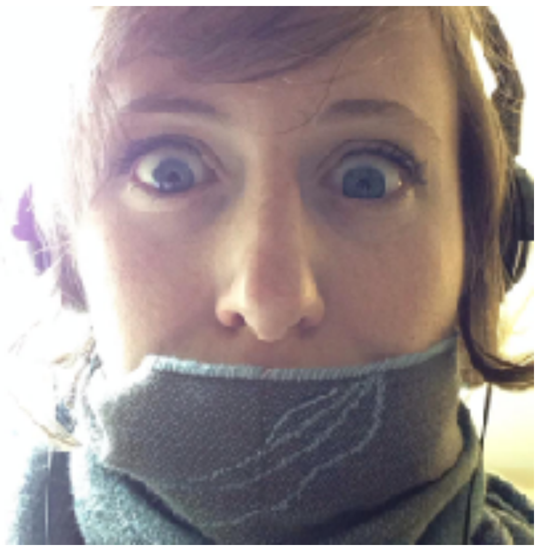
What if 90% of my loss really was happening at the network layer?

A



File System

Program

Network

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What if 90% of my loss really was happening at the network layer?

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File System

Program

Network

What if 90% of my loss really was happening at the network layer?

A

File System

Program

Network

As a performance optimization, you might want to implement it in the lower layer anyway (redundantly).

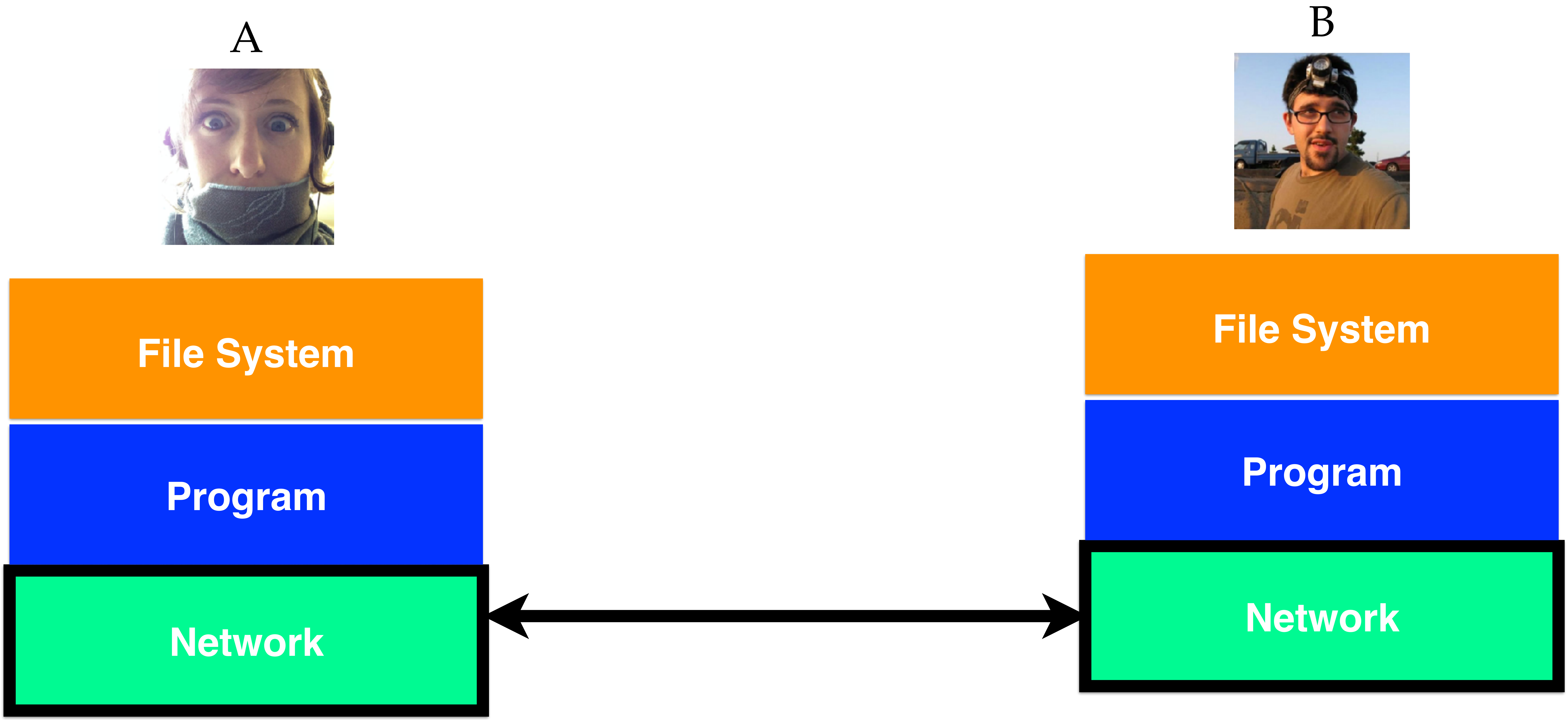
B

File System

Program

Network

“End to End Check and Retry” + A Reliable Network



The “Strong” End-to-End Argument

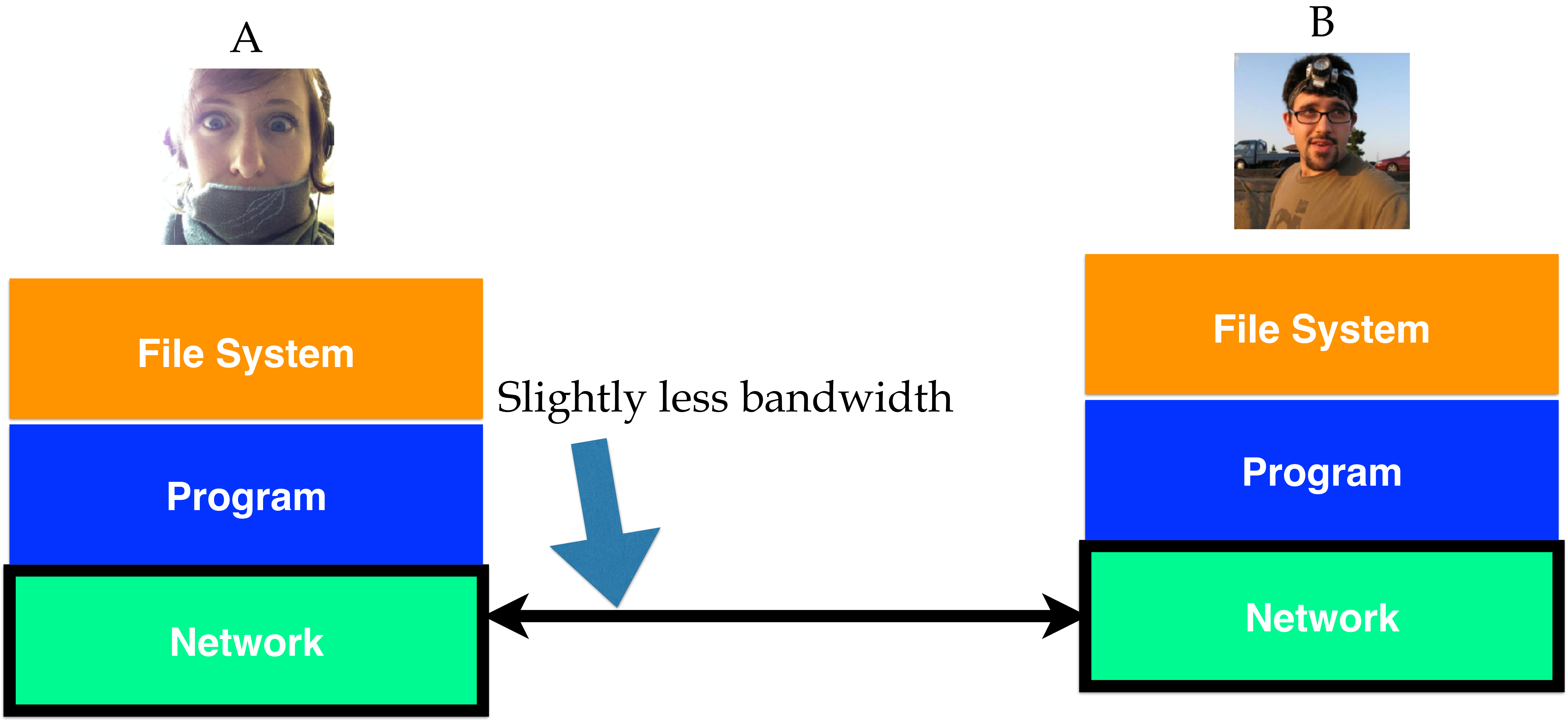
It’s not just a waste of time to put non-essential functionality at lower layers: *it’s actually harmful*.

“End to End Check and Retry” + A Reliable Network

A

B

“End to End Check and Retry” + A Reliable Network



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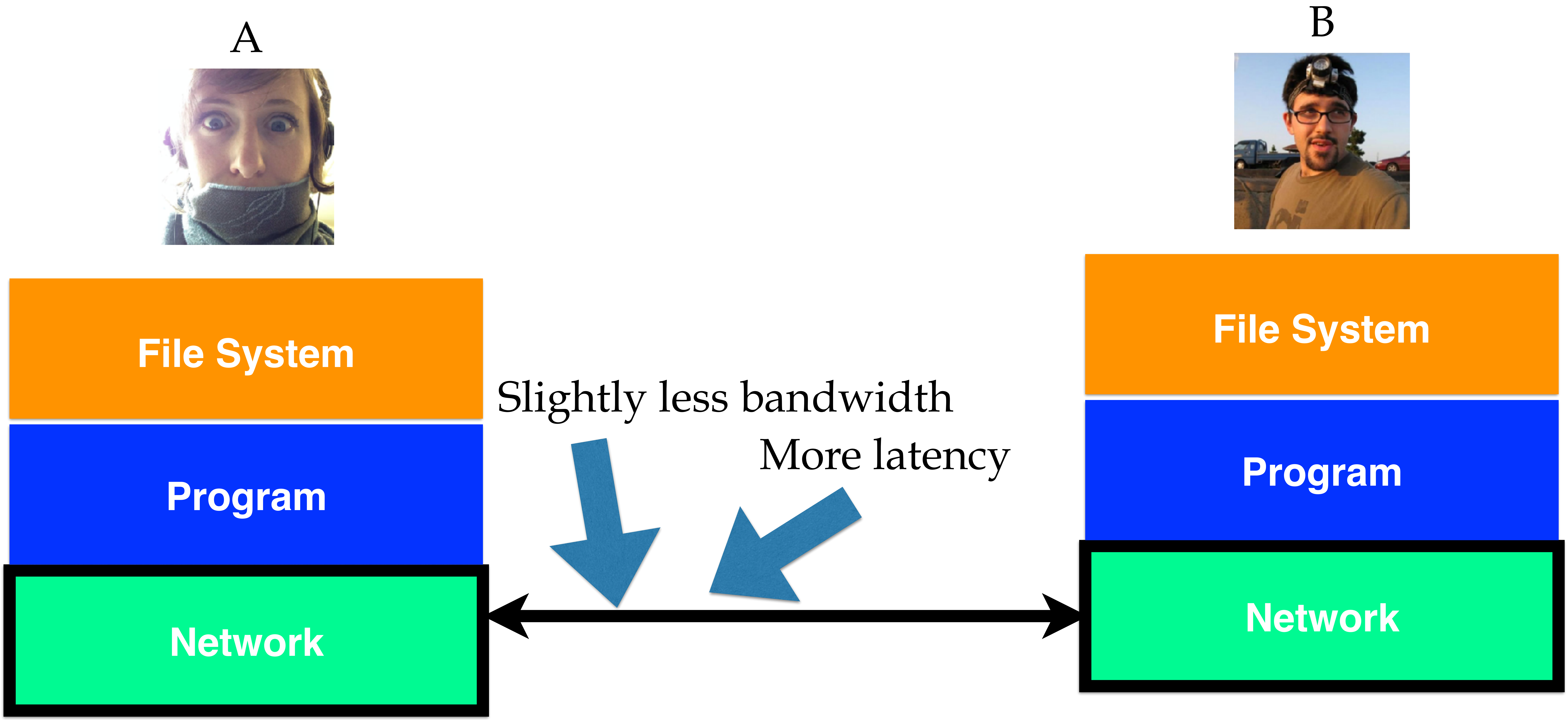

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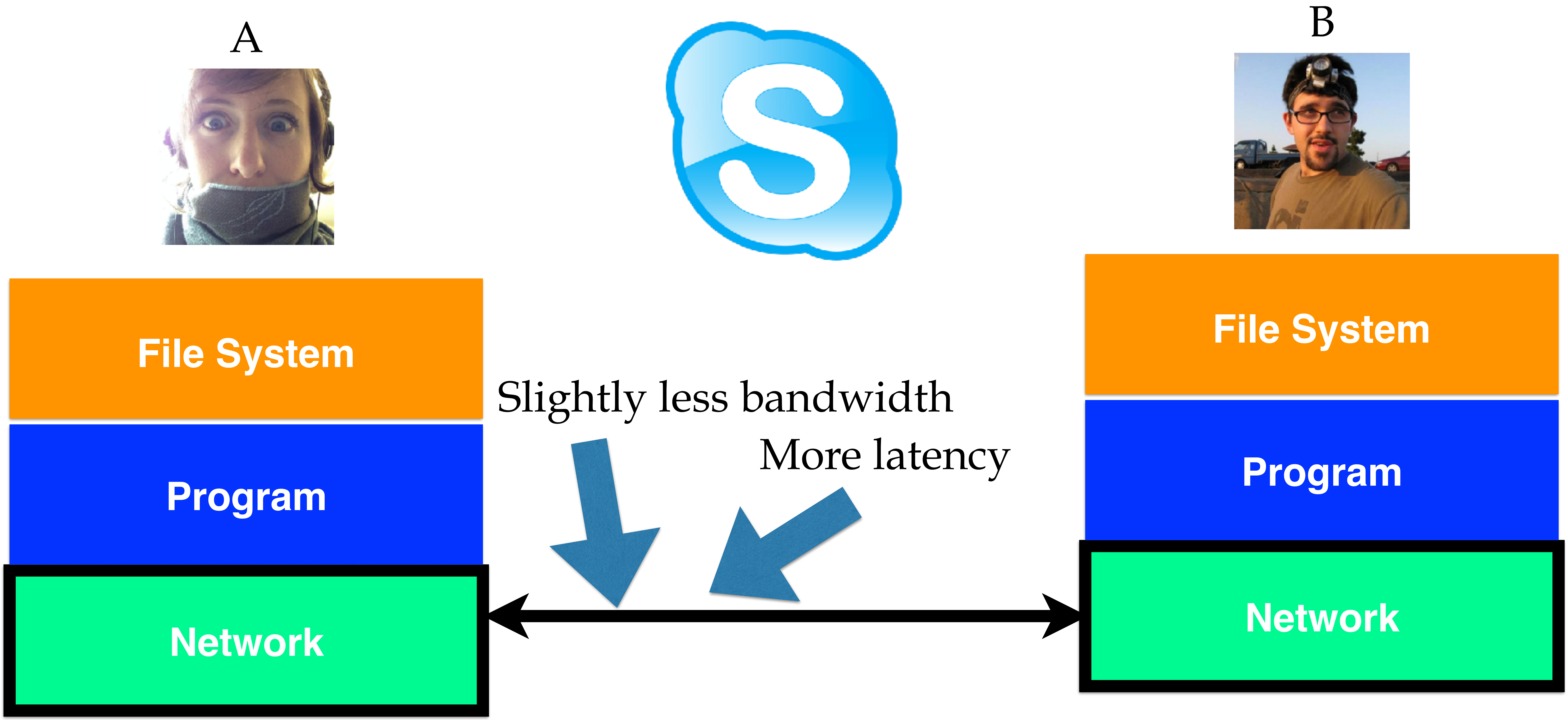
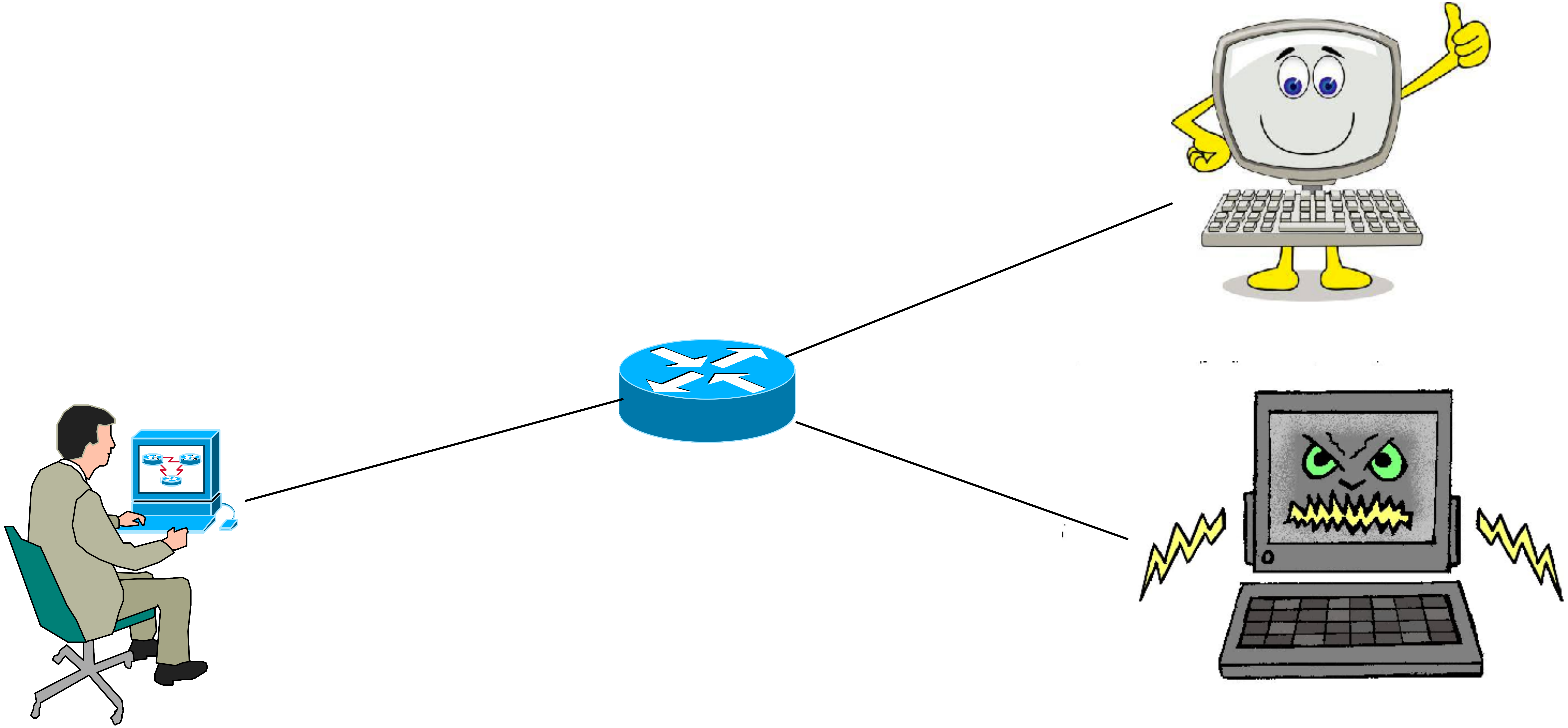
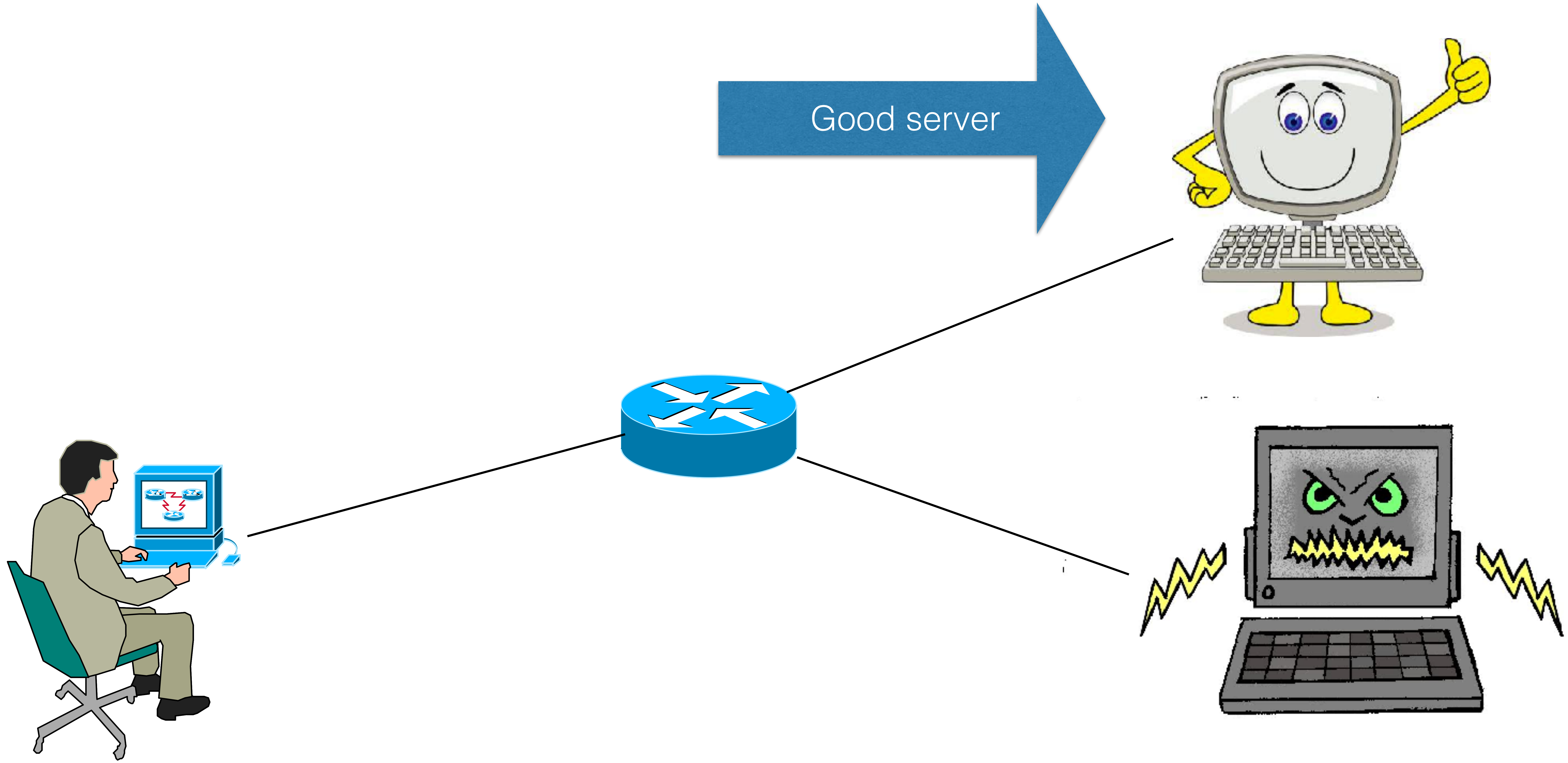


Some applications may be *constrained* by the new functionality.

Firewalls and Intrusion Detection



Firewalls and Intrusion Detection



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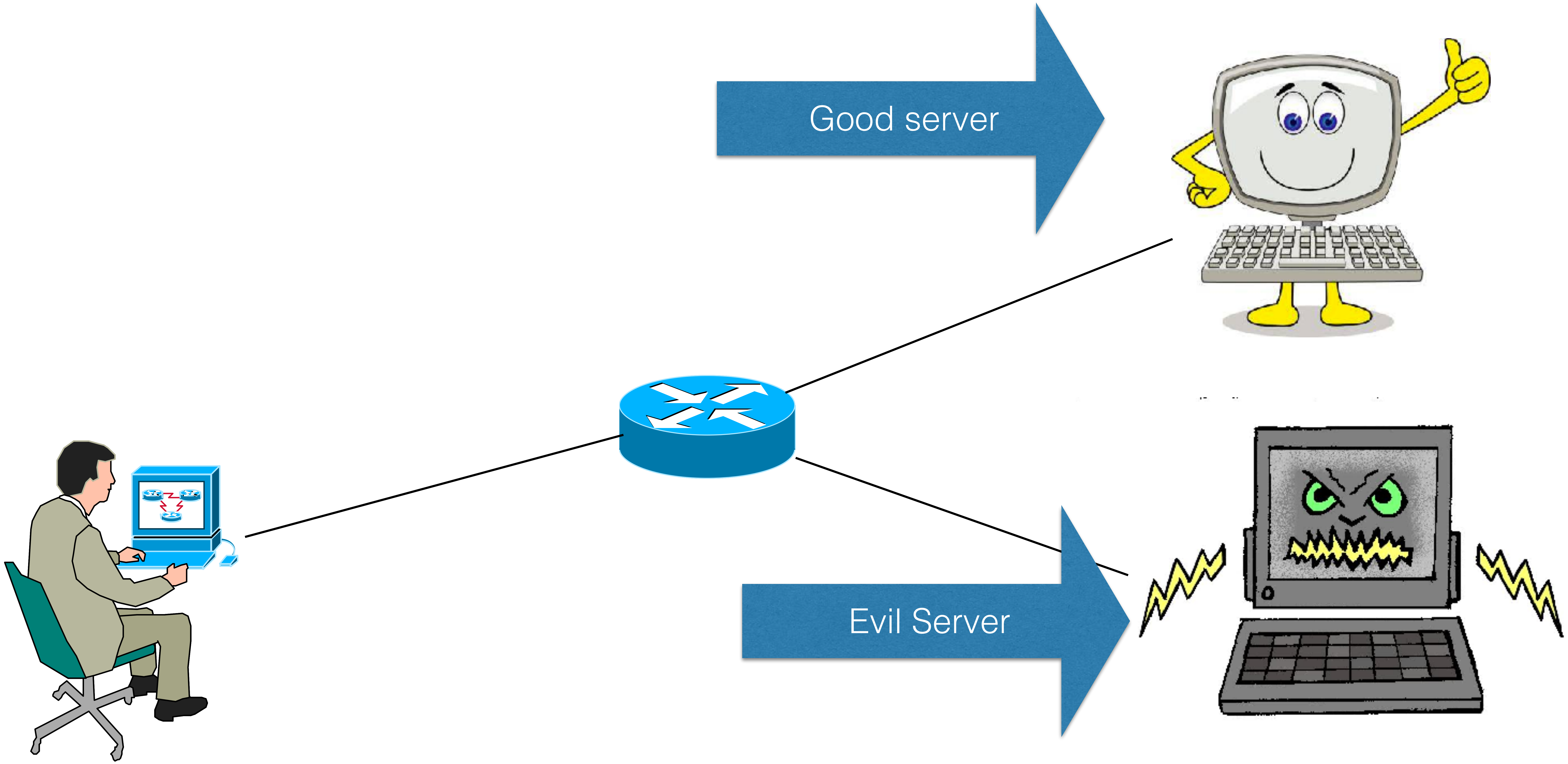

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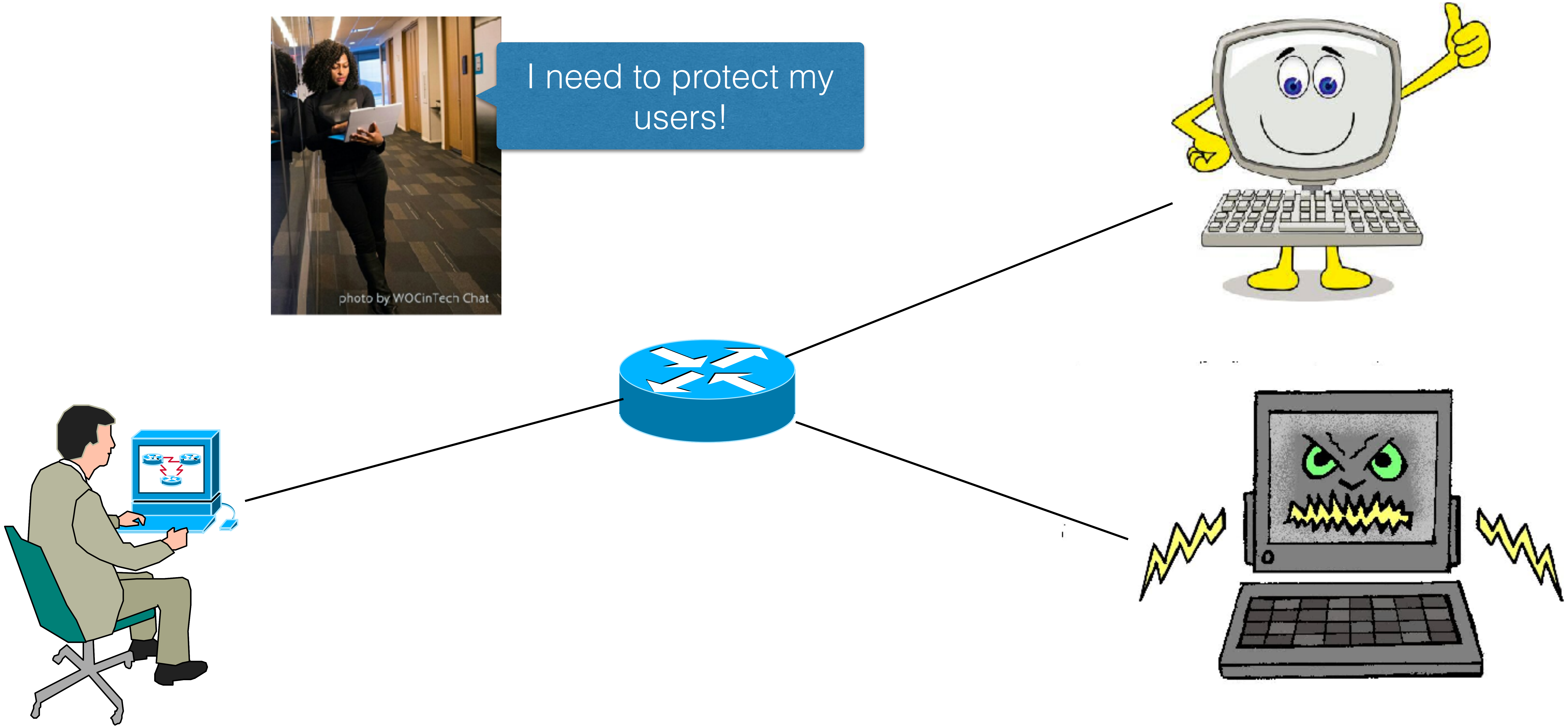

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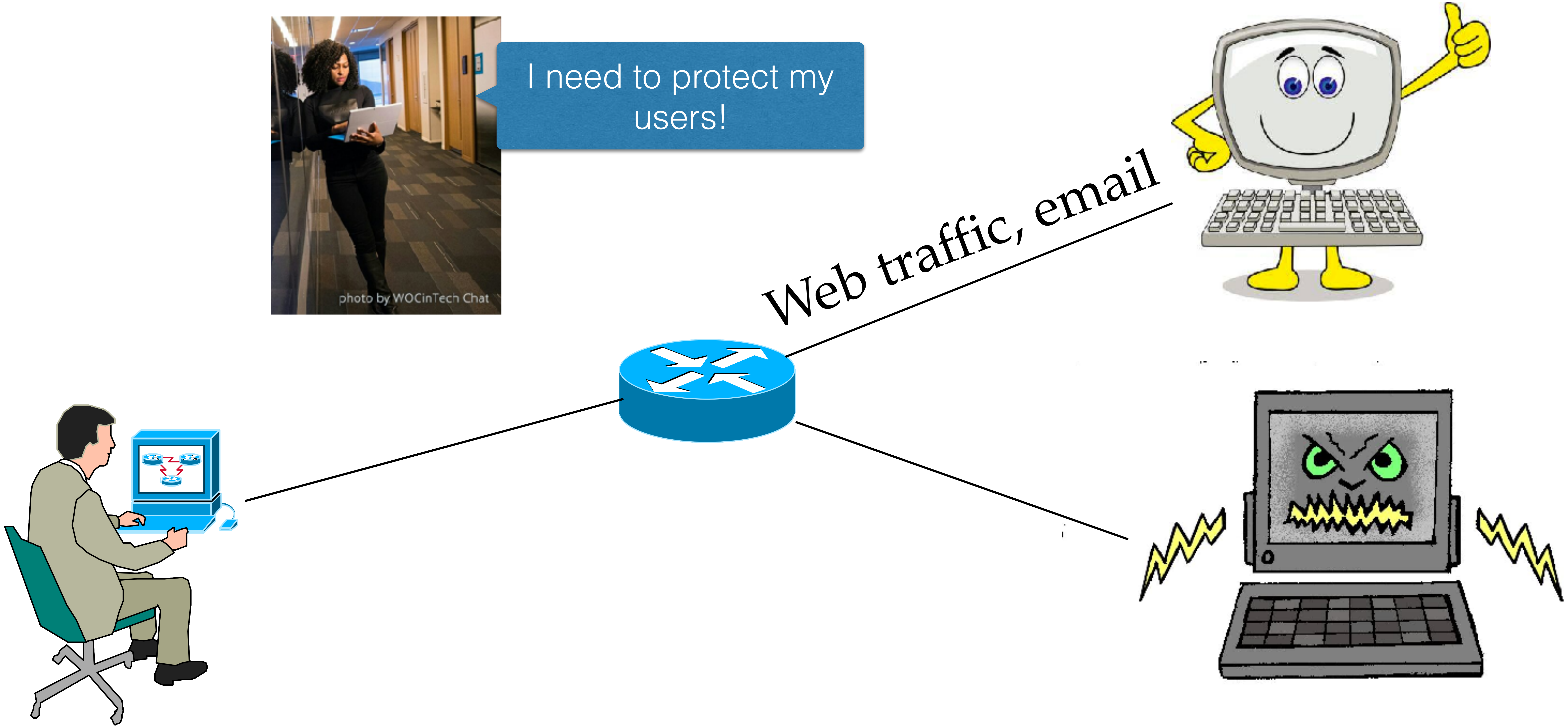

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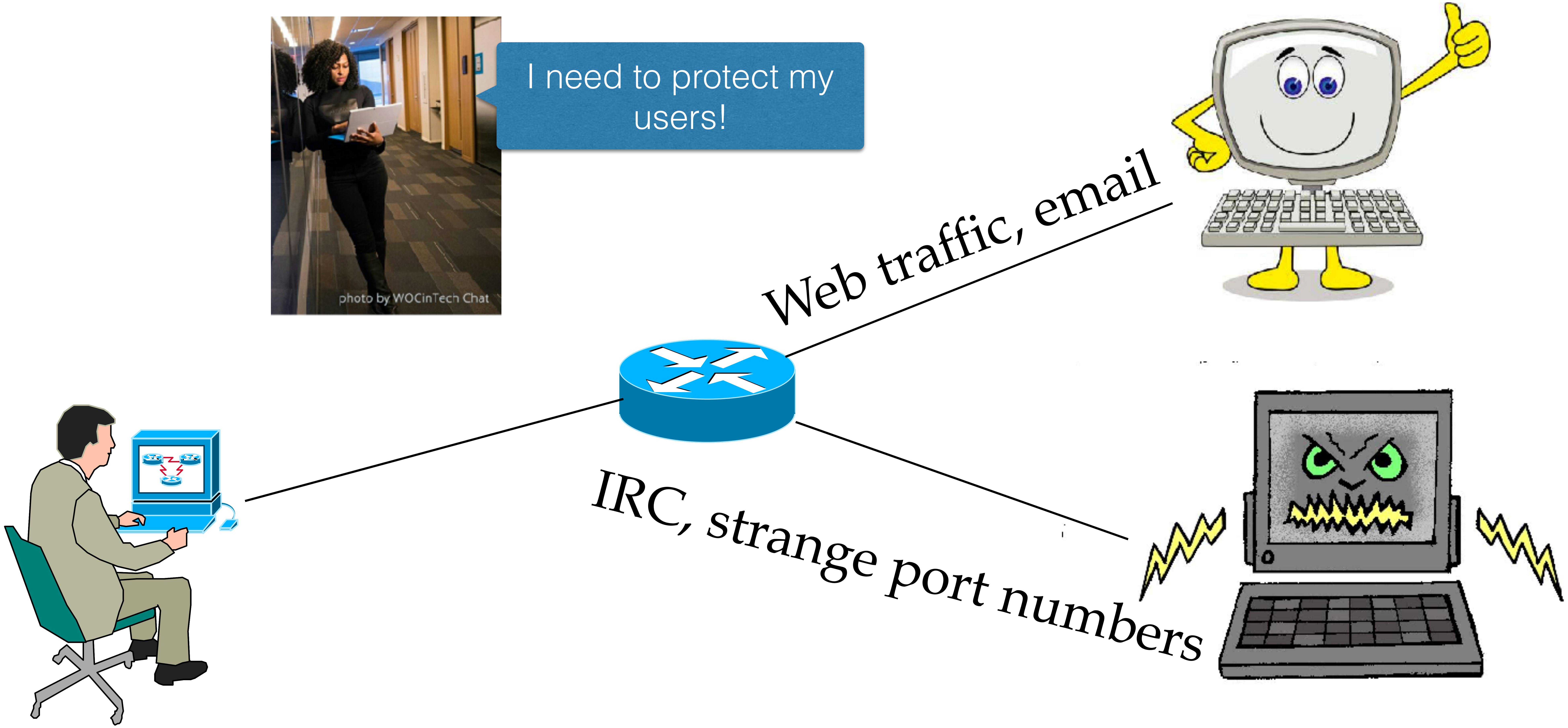

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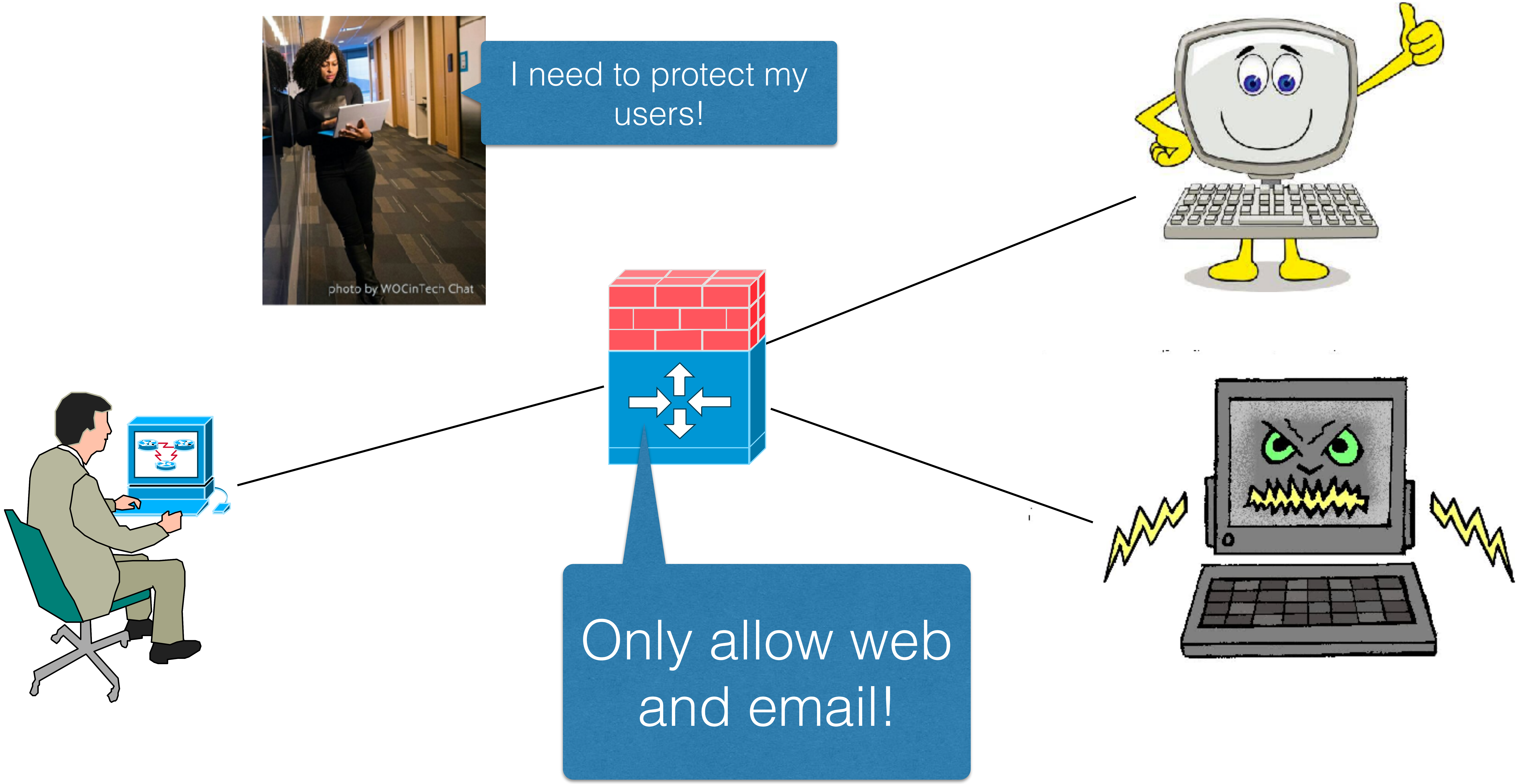

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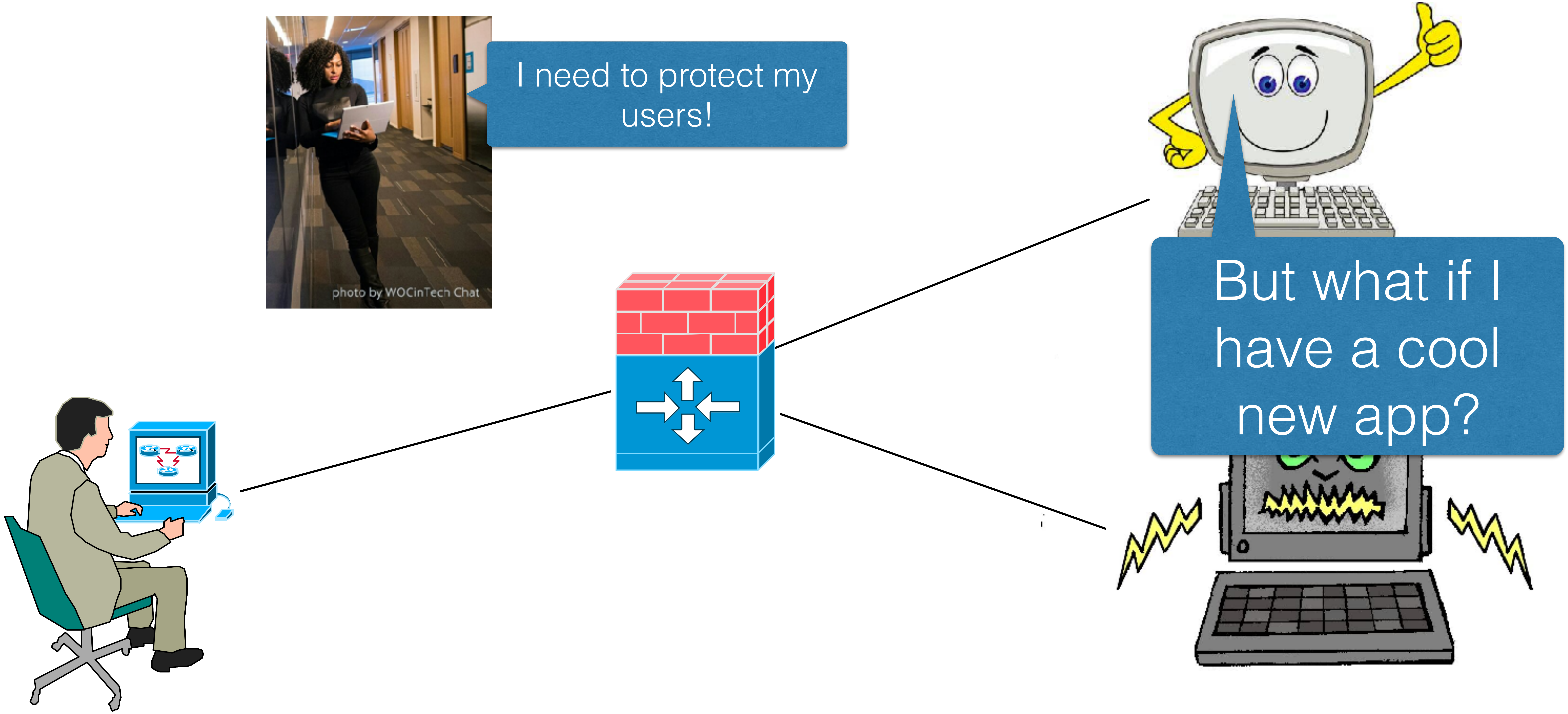

The rest of this lecture

- **The End to End Argument**
- Why we deploy middleboxes anyway
- Some challenges they leave us with
- A new movement called Network Functions Virtualization

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Two Reasons We Deploy Middleboxes

- (1) It's a fast, drop in way to upgrade network features.
- (2) It's a centralized point of control.

(1) A fast way to upgrade your network

- Remember address-space exhaustion?
  - IPv6 is the clean solution, but it takes a long time to upgrade because *everyone must update* their infrastructure and code.
  - The fast solution: Network Address Translators. Drop-in, no one needs to make any changes (for the most part) except network administrator.

(1) A fast way to upgrade your network

- Remember DDoS and attack traffic?
  - Many proposals exist to upgrade routers so that *receivers tell routers to start blocking certain traffic sources.* Once again… this requires upgrades to routers and hosts — lots of changes.
    - *See "IP pushback" work if you're curious*
  - The fast solution: Firewalls. Drop-in, no one needs to make any changes (for the most part) except network administrator.

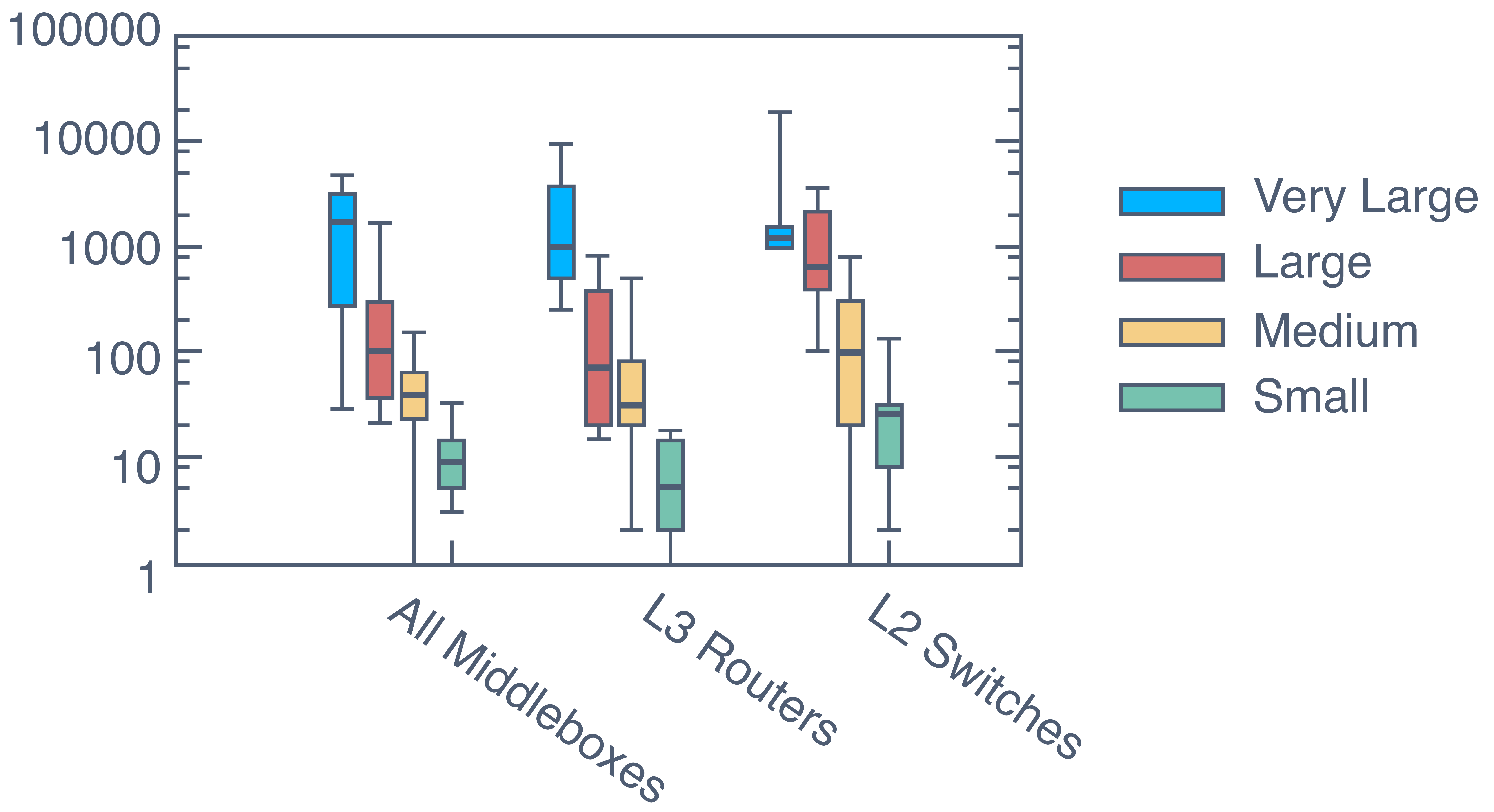
(2) A centralized point of control

- Network administrators want to *enforce policies* over how their networks are used.
  - “No one can host a botnet from within my network”: deploy and IDS
  - “All traffic is cached and compressed to save company $$ on bandwidth.”: deploy a WAN Optimizer

(2) A centralized point of control

- Network administrators want to *enforce policies* over how their networks are used, continued.
  - Note that some of these features *could be implemented by end users!* E2E would say to implement at the edge!
  - But network administrators cannot enforce what happens on end hosts: only what happens in the network.
    - Hence, middleboxes.

So, in practice, we’re here:



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Three practical challenges

- (1) Tussle
- (2) Compatibility
- (3) Complexity, Cost, and Management

Tussle

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  - Users install VPNs or use tunnels to route through filters
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      - Users make VPNs look like benign traffic…
        - The back and forth between users and providers is called “Tussle”

Tussle

Tussle

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    - Users run servers over a port other than port 80
  - ISPs rate-limit BitTorrent traffic
    - BitTorrent uses “camouflaged” port numbers to make it harder to detect/classify.

Compatibility

- Middleboxes make assumptions about how protocols work. What happens when protocols change or new protocols are deployed?
    - Need to upgrade the middlebox. But many don't.

Compatibility

- Cool story from a colleague at Google:
  - Google was testing the new QUIC protocol
  - They changed how they were using some header fields in QUIC
  - Deployed the new version of QUIC to Chrome
  - Large fractions of the Internet stopped being able to use QUIC!
  - The problem? A major middlebox vendor saw the changed ports, determined the traffic was non-standard and maybe dangerous. Blocked the traffic.

Manageability, Cost, and Complexity

- Middleboxes are custom, hardware-based devices.
  - Slow to upgrade, and expensive — $10ks
- Have to be physically wired together and configured one-by-one
  - Time consuming and confusing
- Every device has its own management interface and toolchain!

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Imagine cloud computing if it were deployed like middleboxes.

So you want to deploy a web service.

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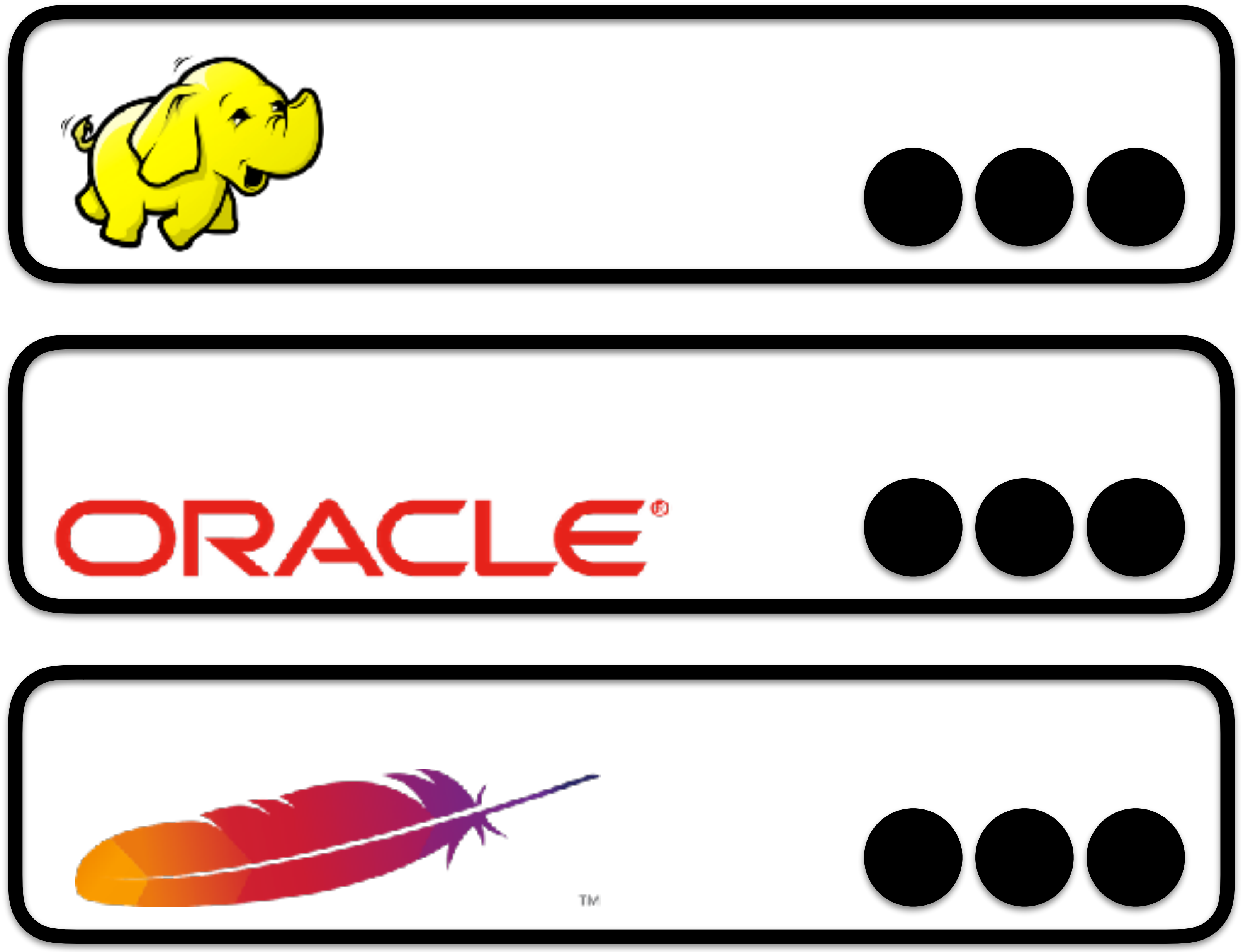

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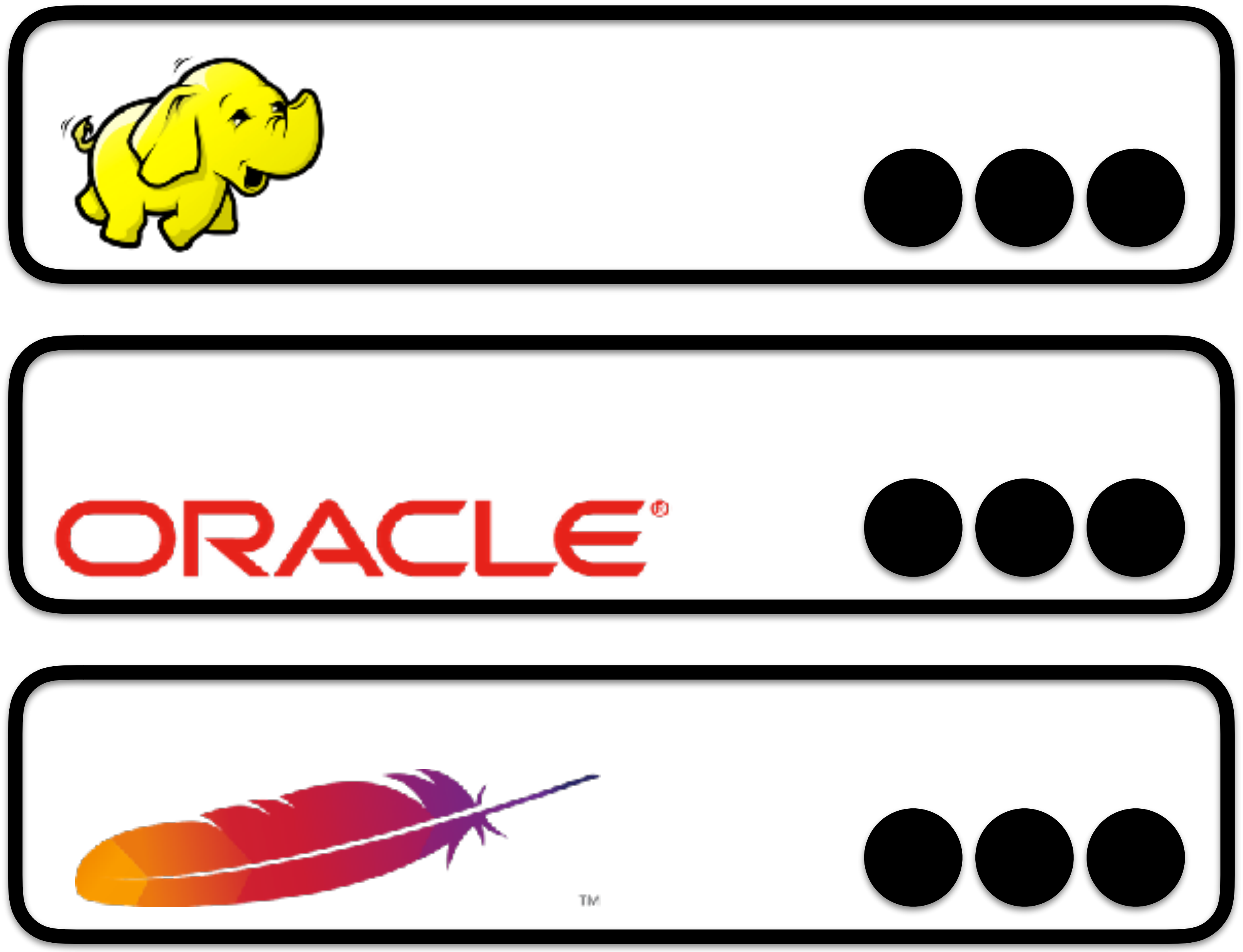

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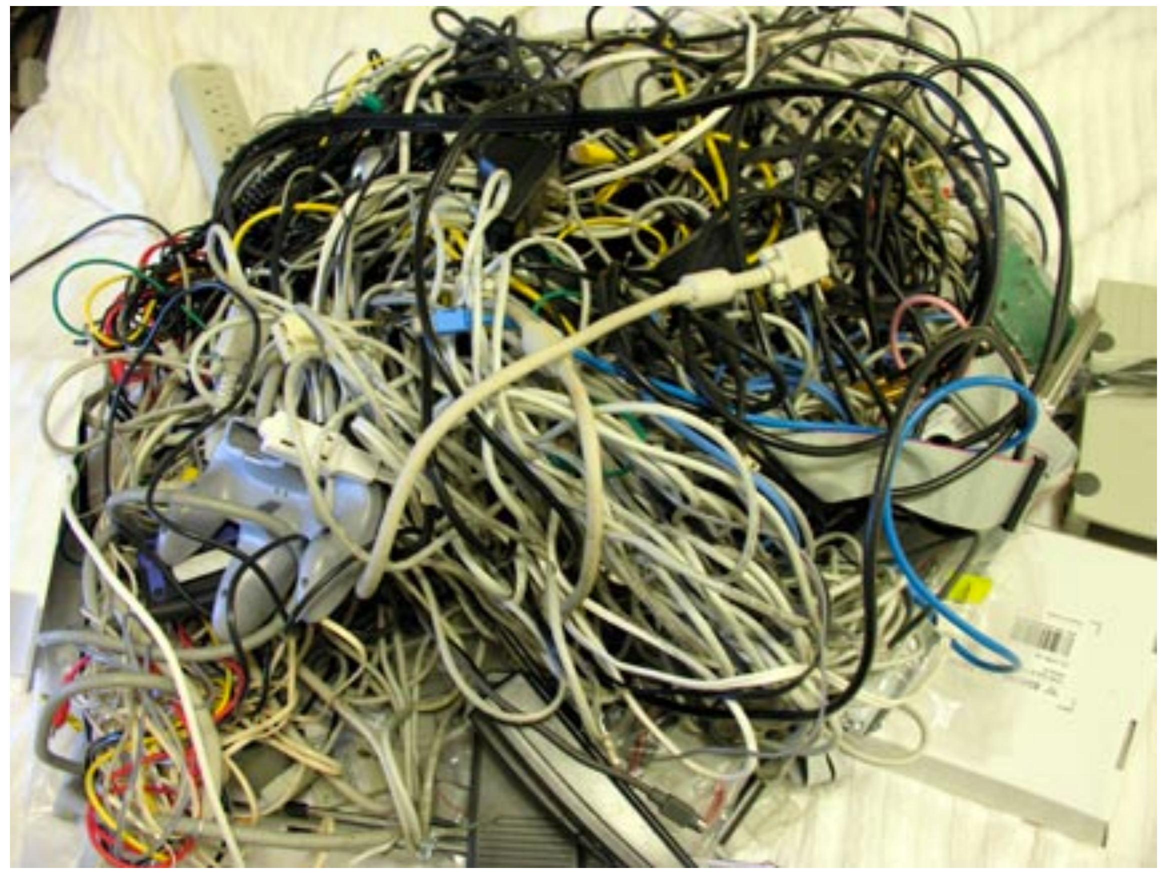

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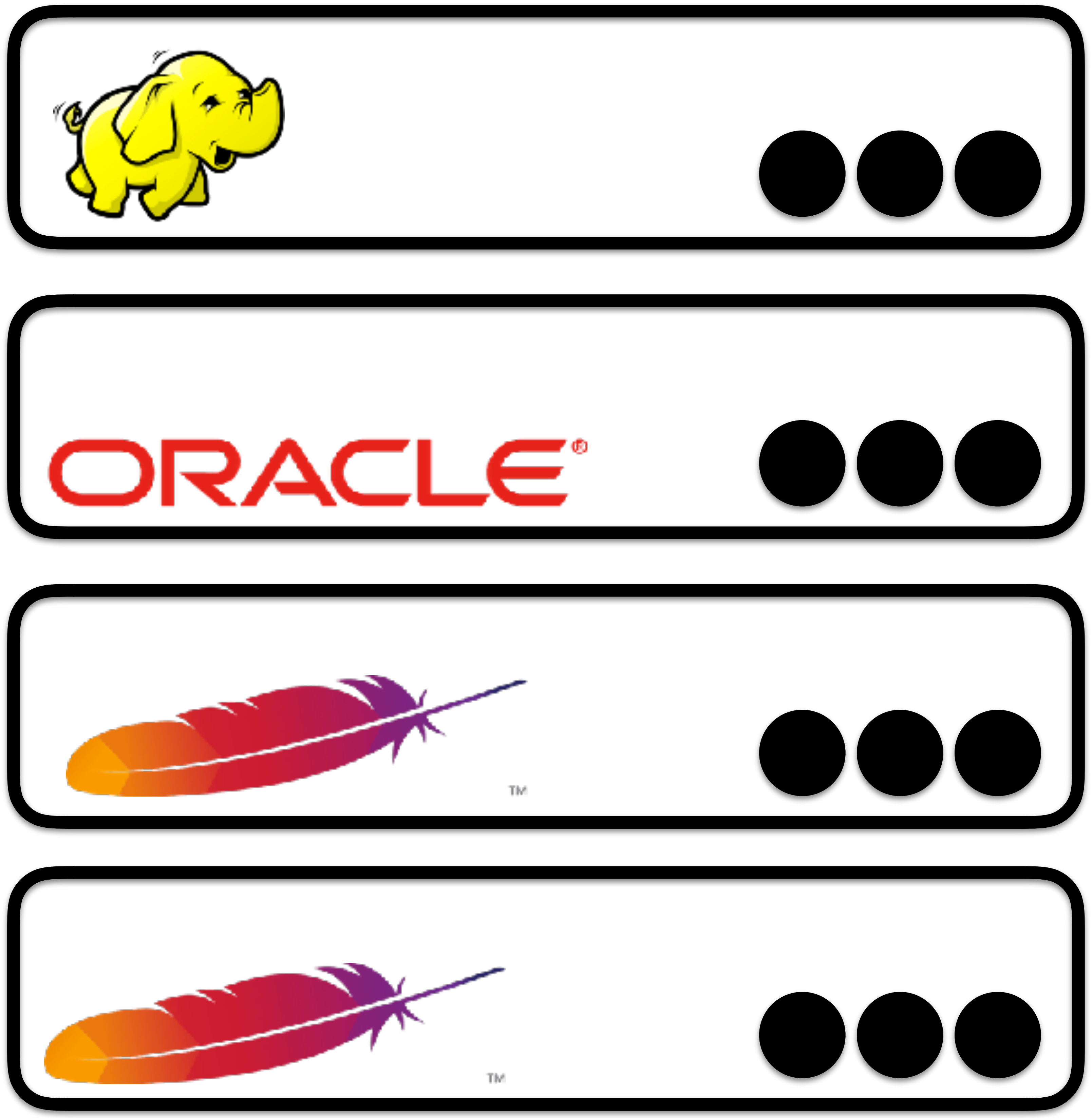
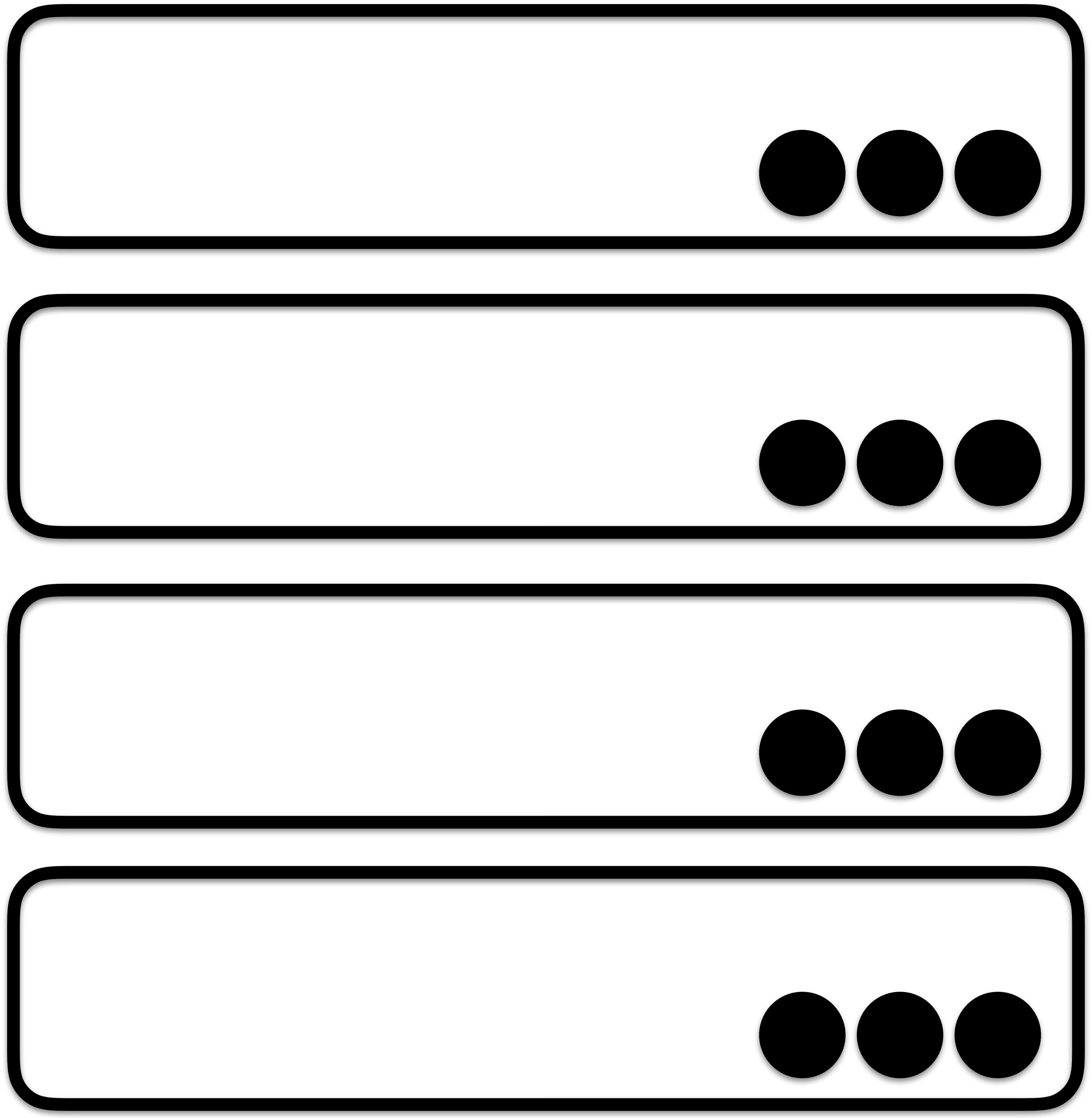


This is ridiculous and not what anybody does for cloud services. But it’s what we were doing with middleboxes!

What we actually do in cloud computing.



General-purpose hardware.

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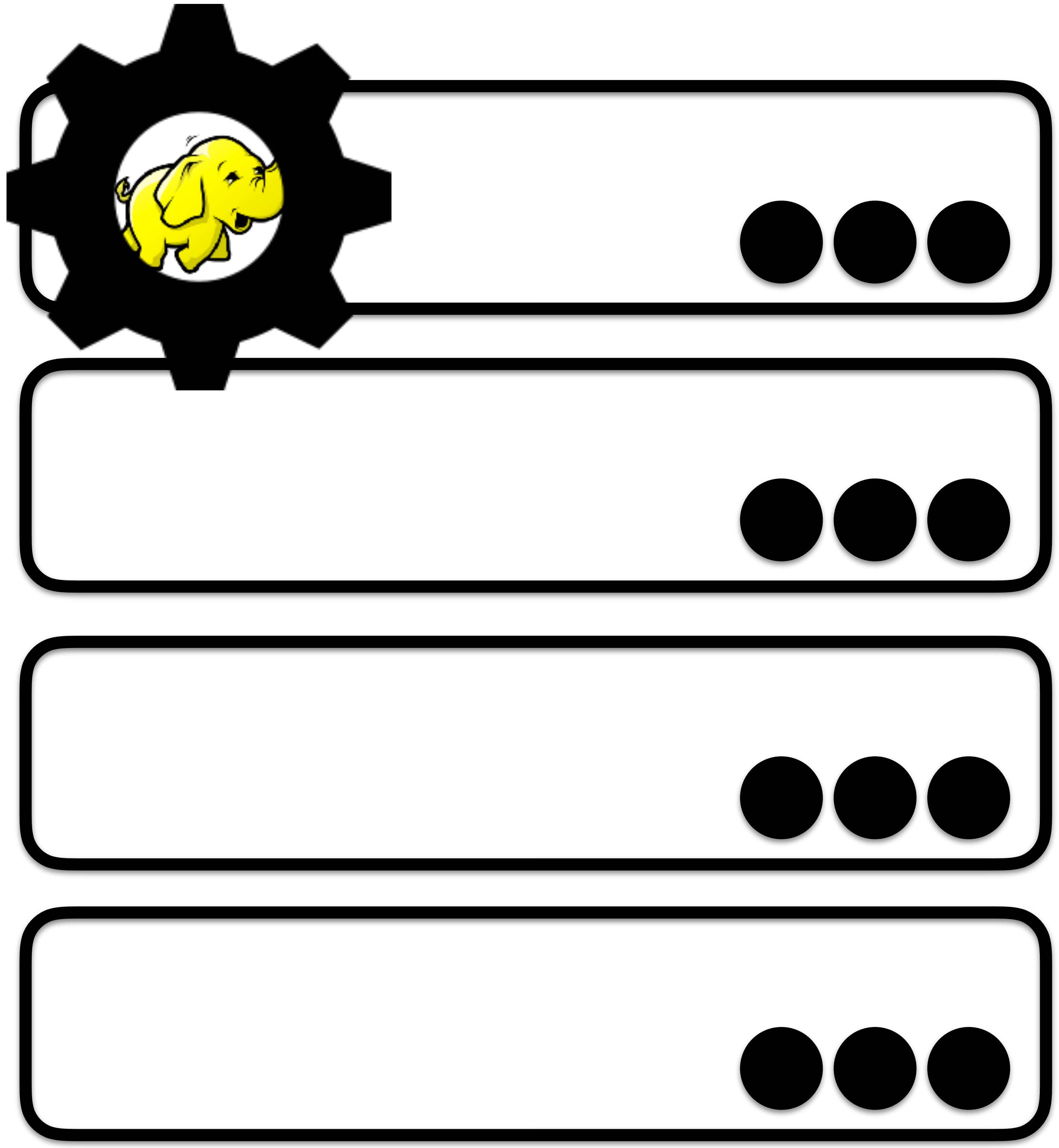

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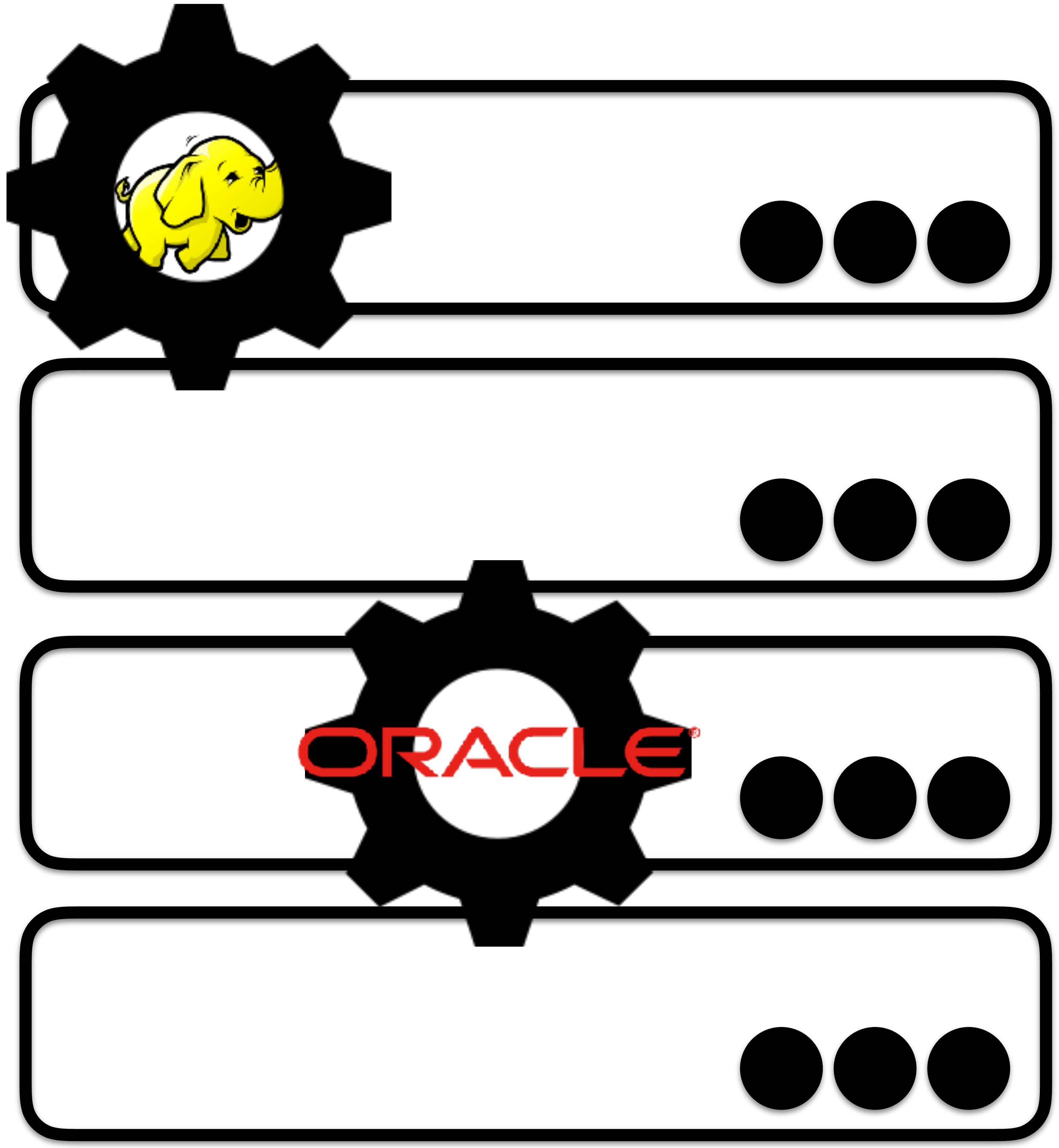

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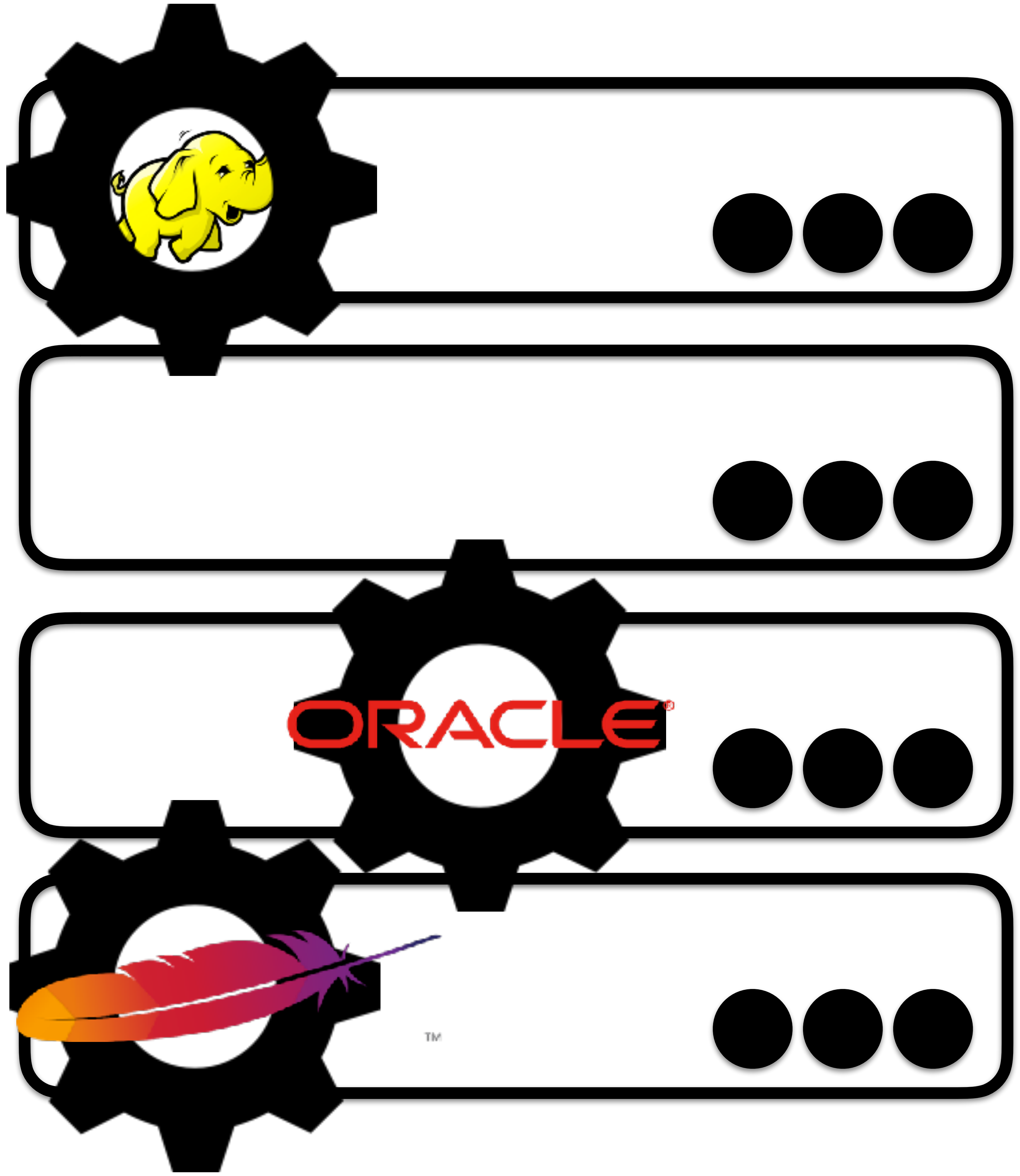

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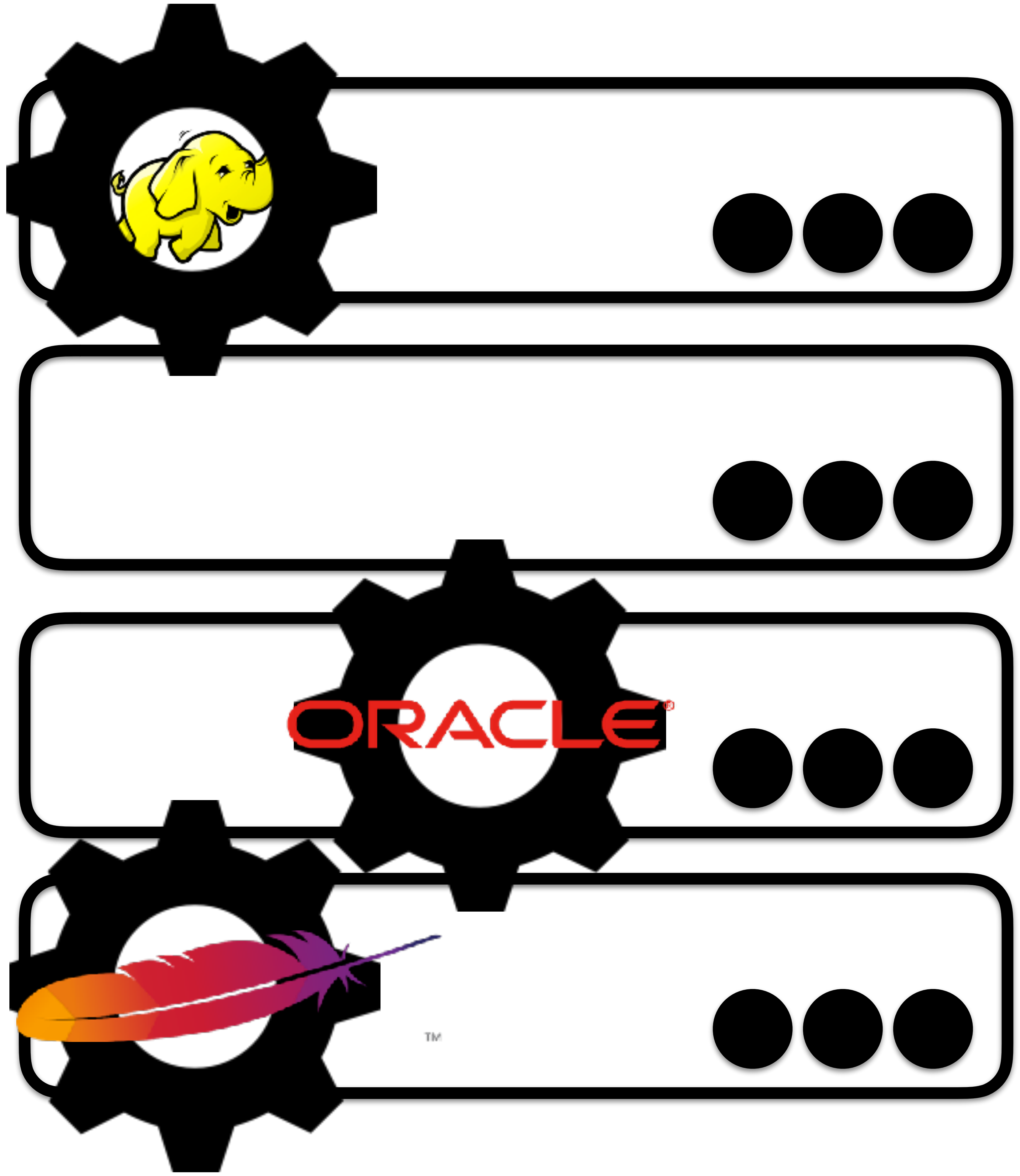


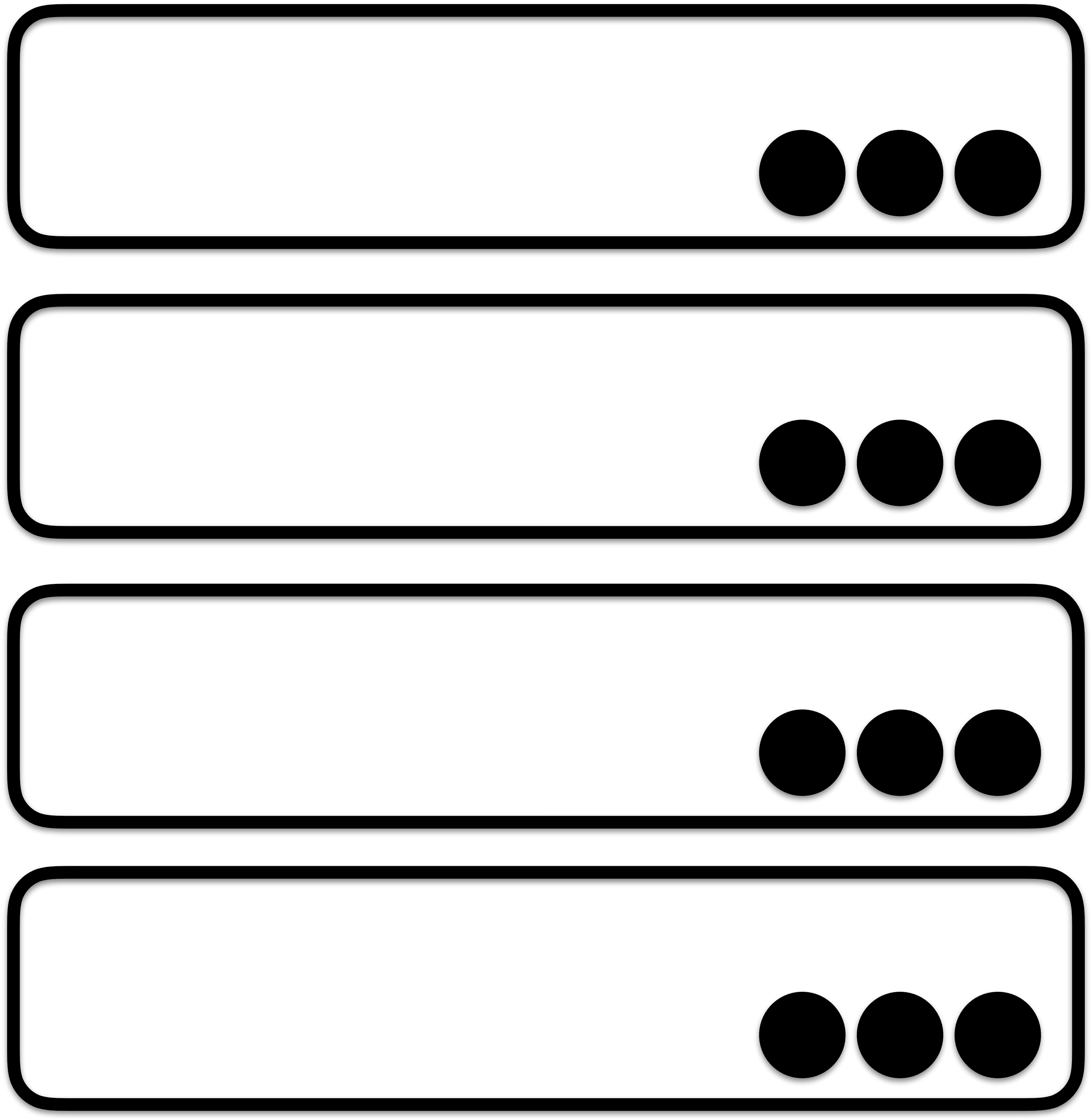
General-purpose hardware.

Services run in software.

Installation is a “click” — no cabling required.

Can re-use infrastructure for different tasks.

2012: ETSI Network Functions Virtualization



Network traffic routed through general-purpose hardware.

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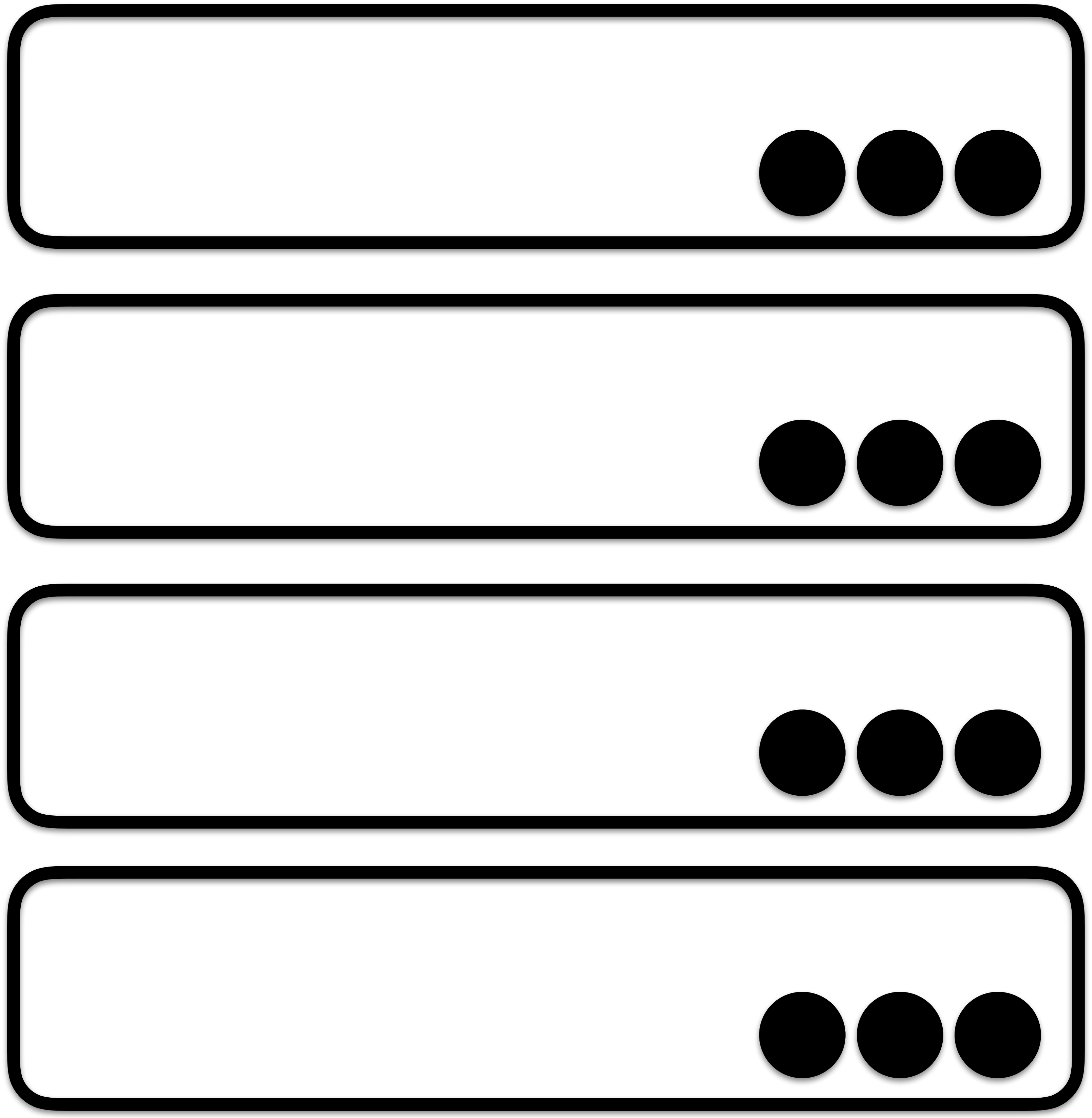

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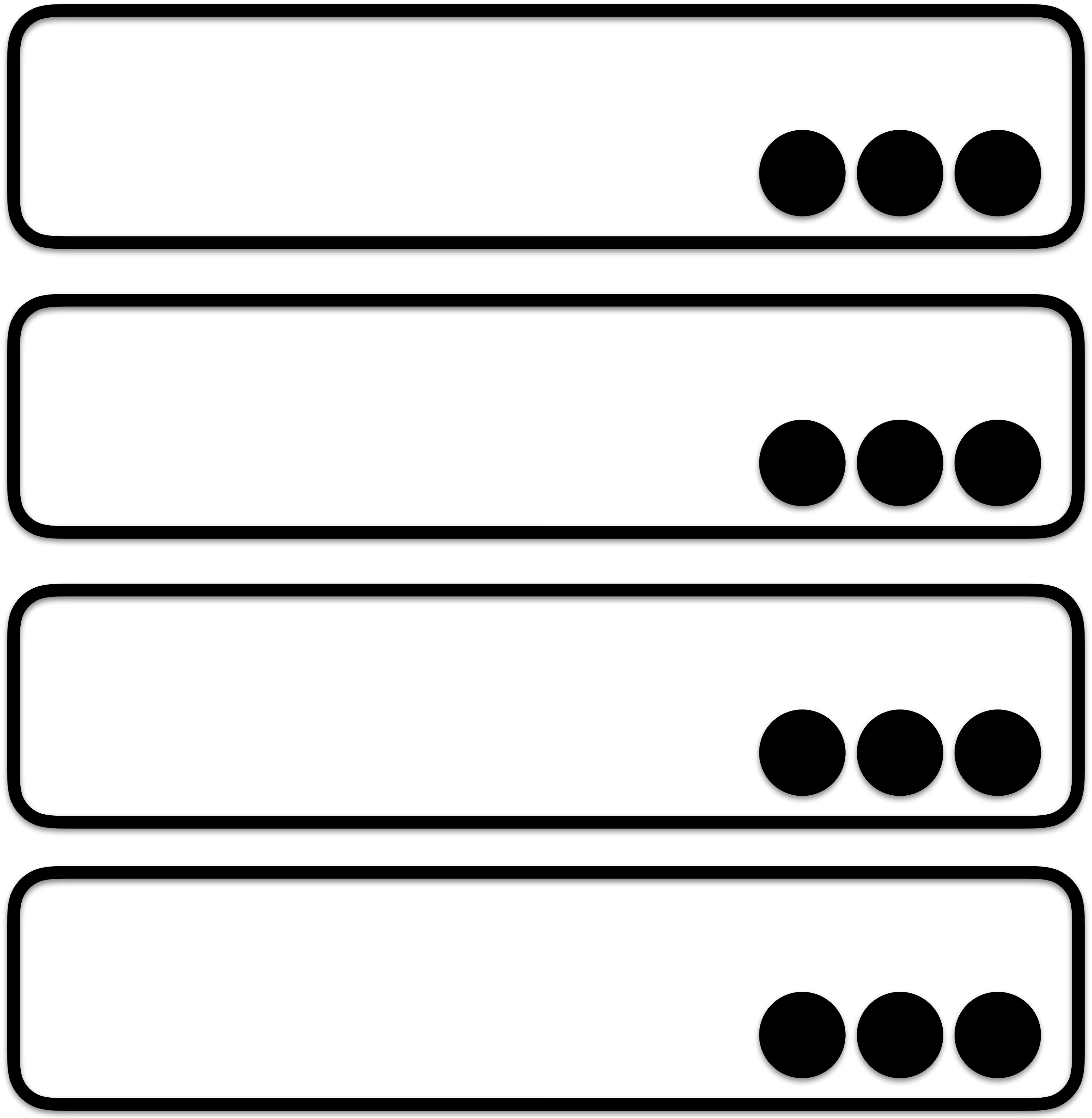

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"Network Functions"

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- Easier and more generic management tools
- Fast to upgrade and change software deployments
- Generic hardware usually -> cheaper, too!

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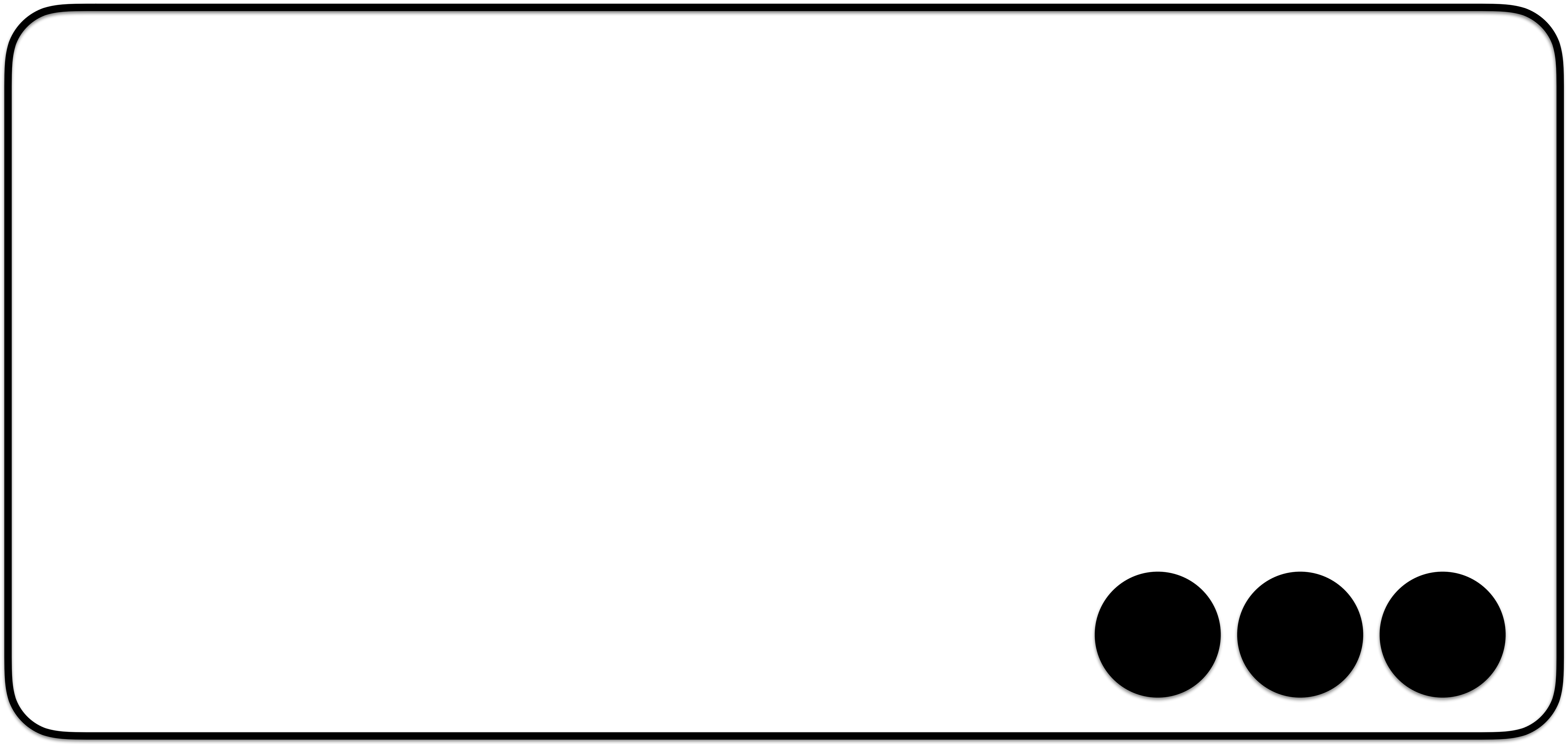

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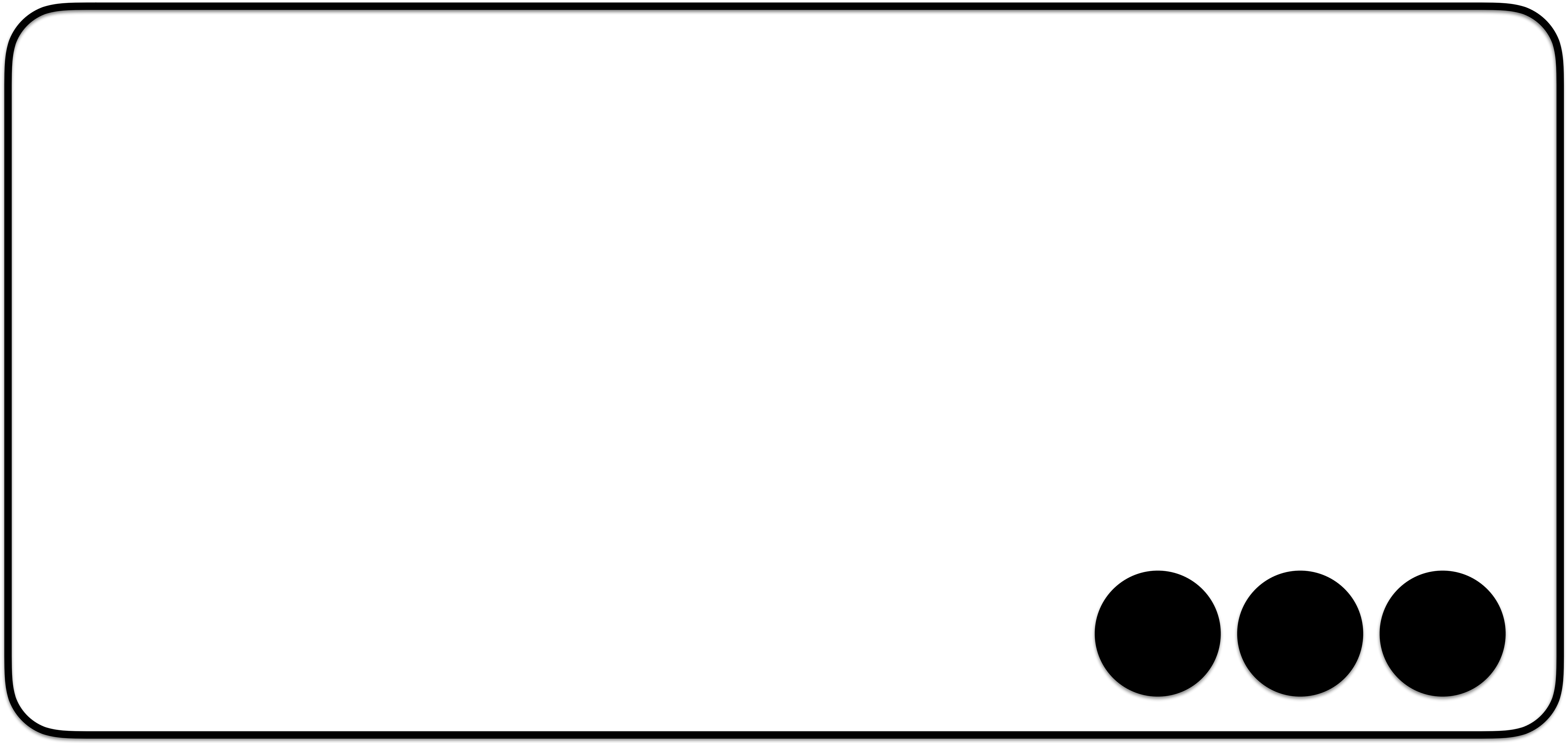

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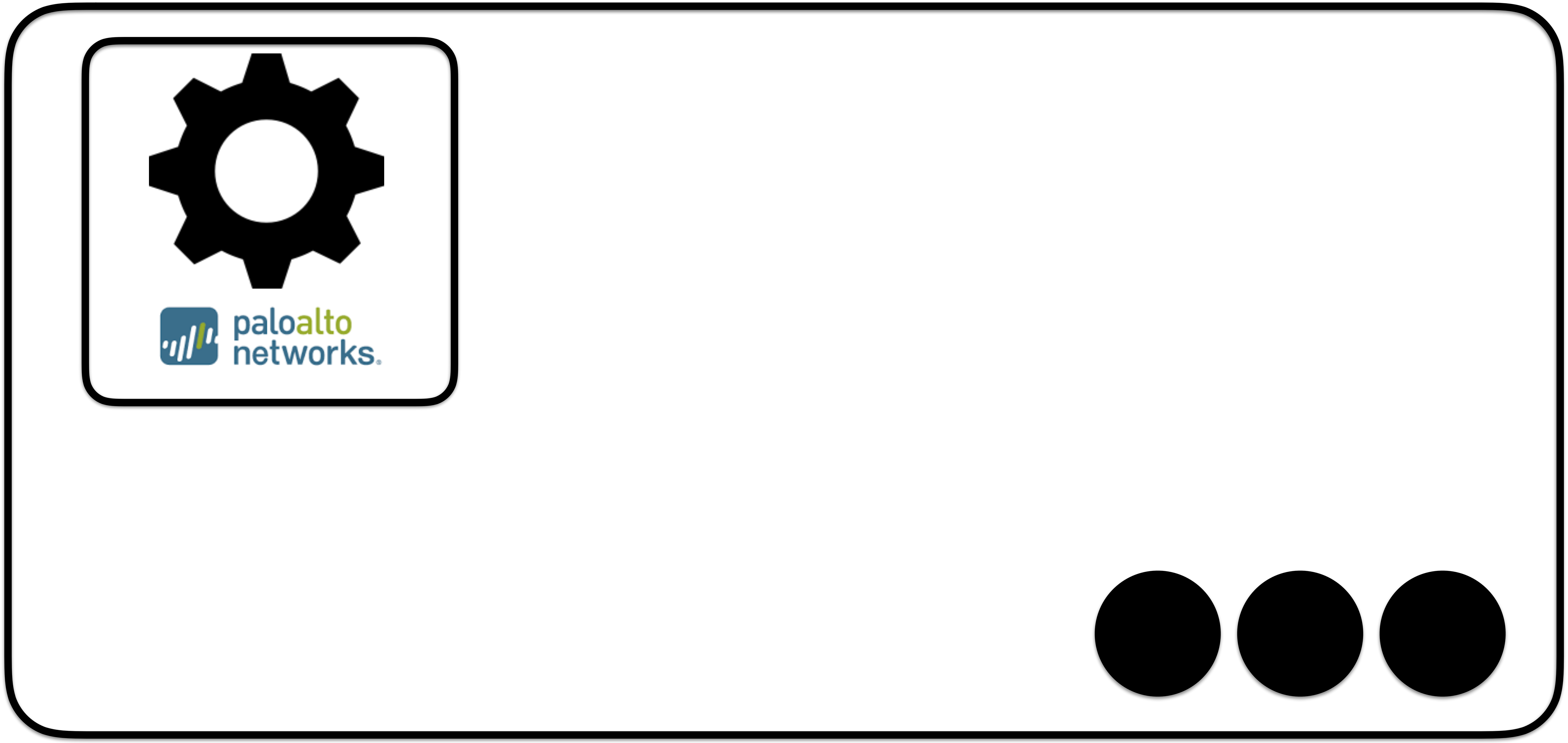

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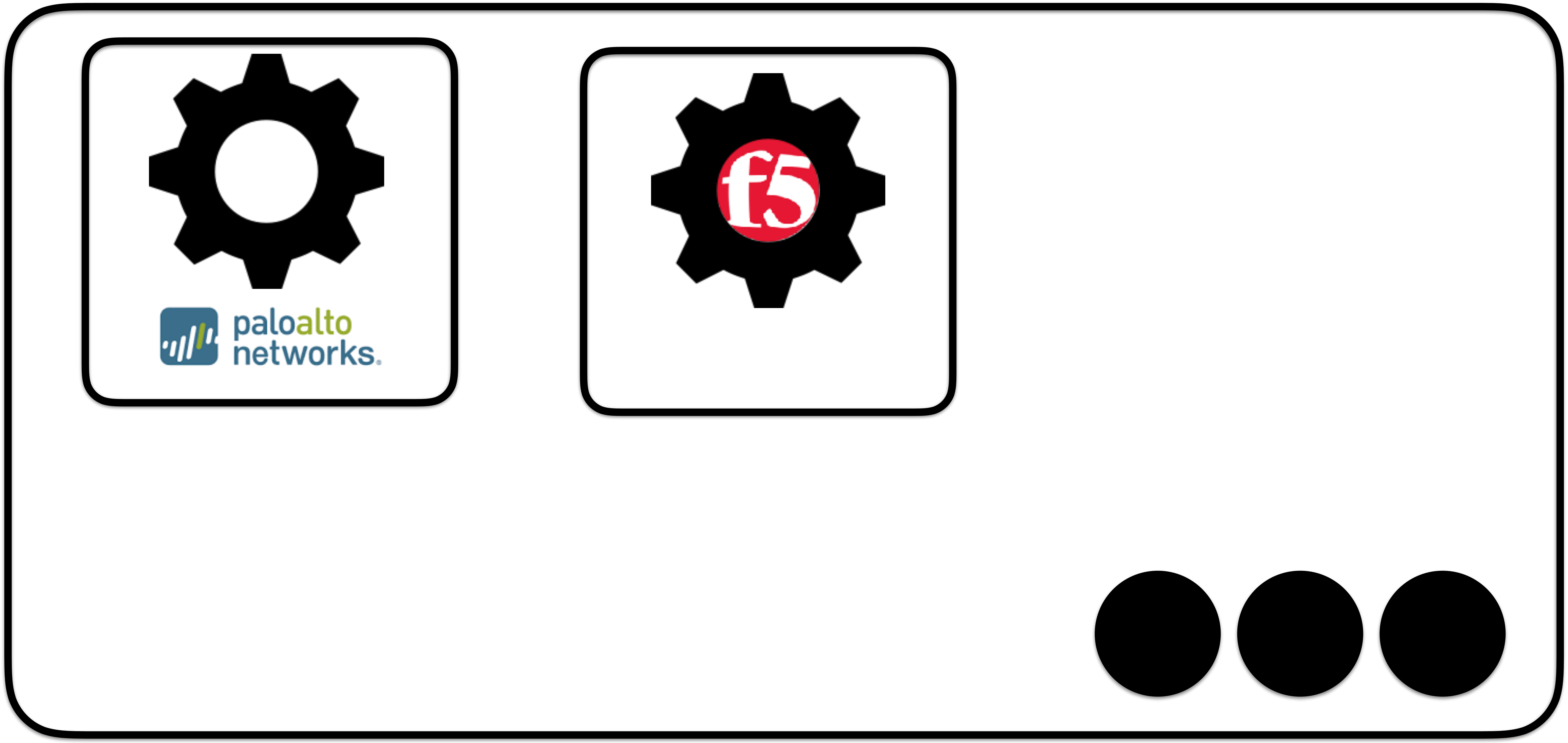

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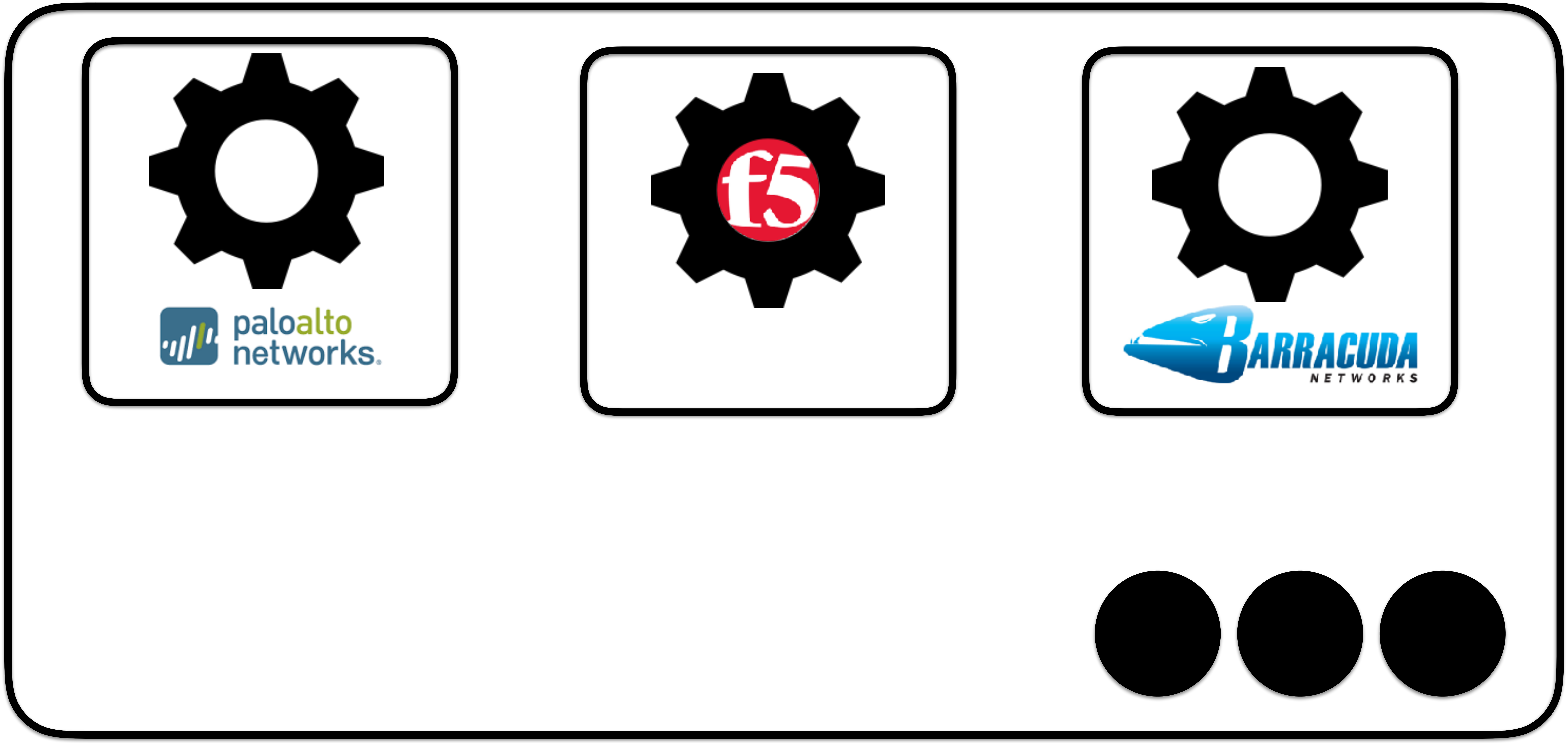

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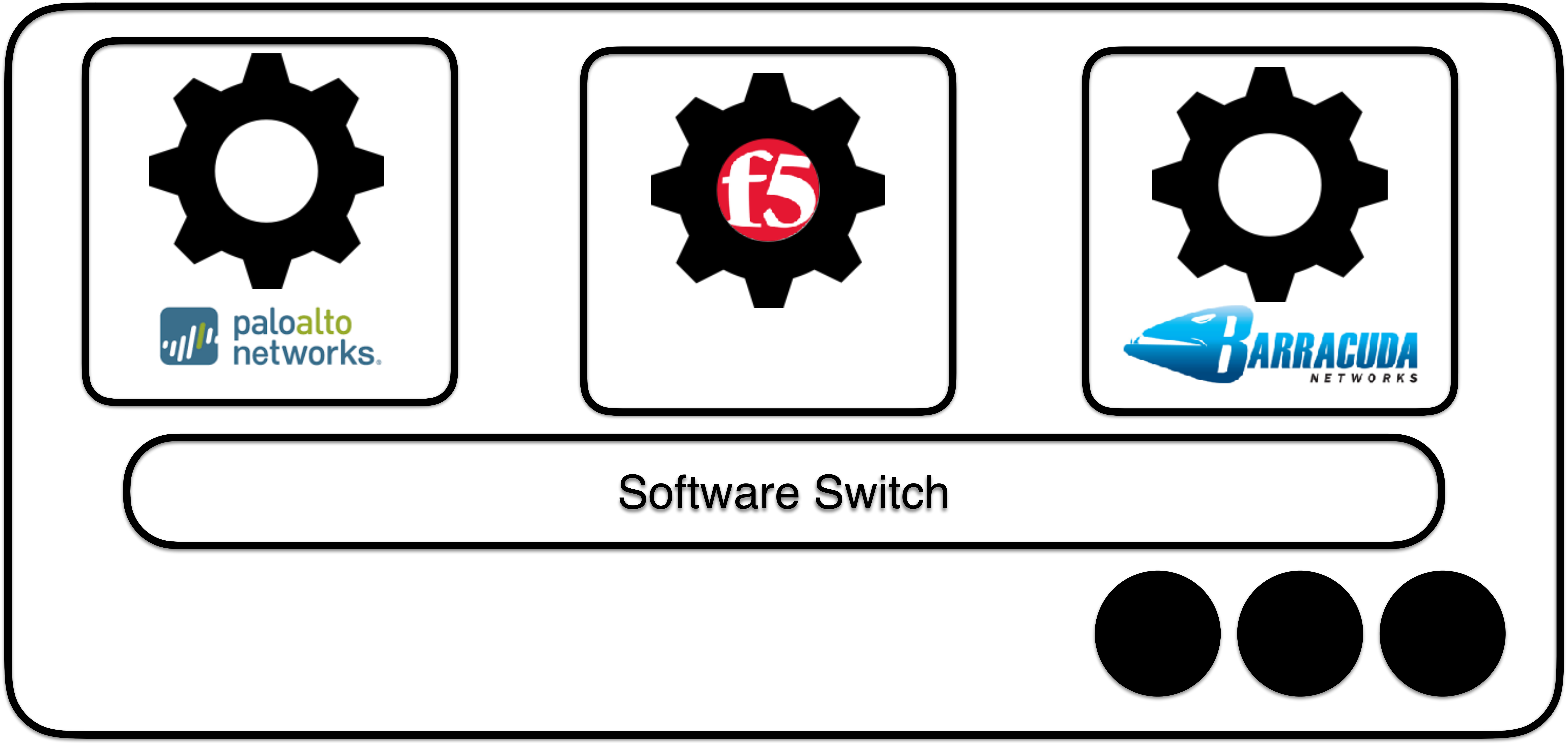

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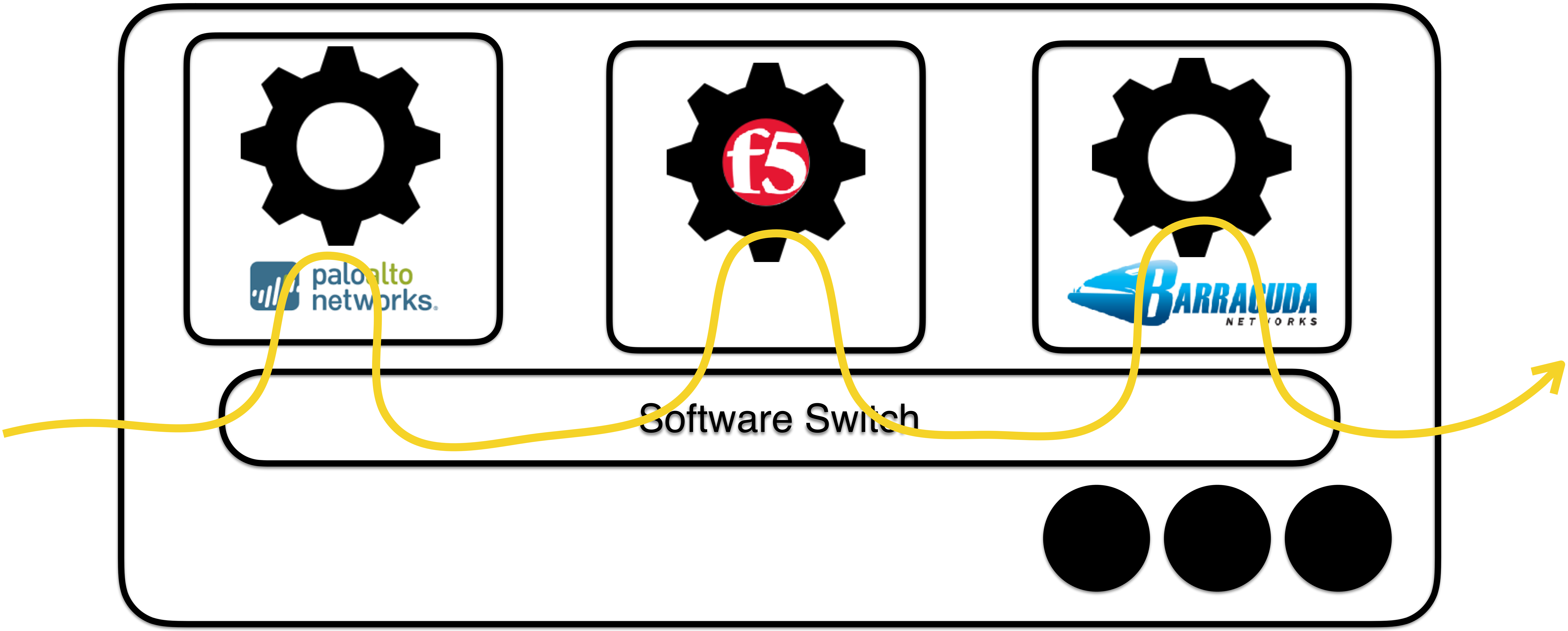
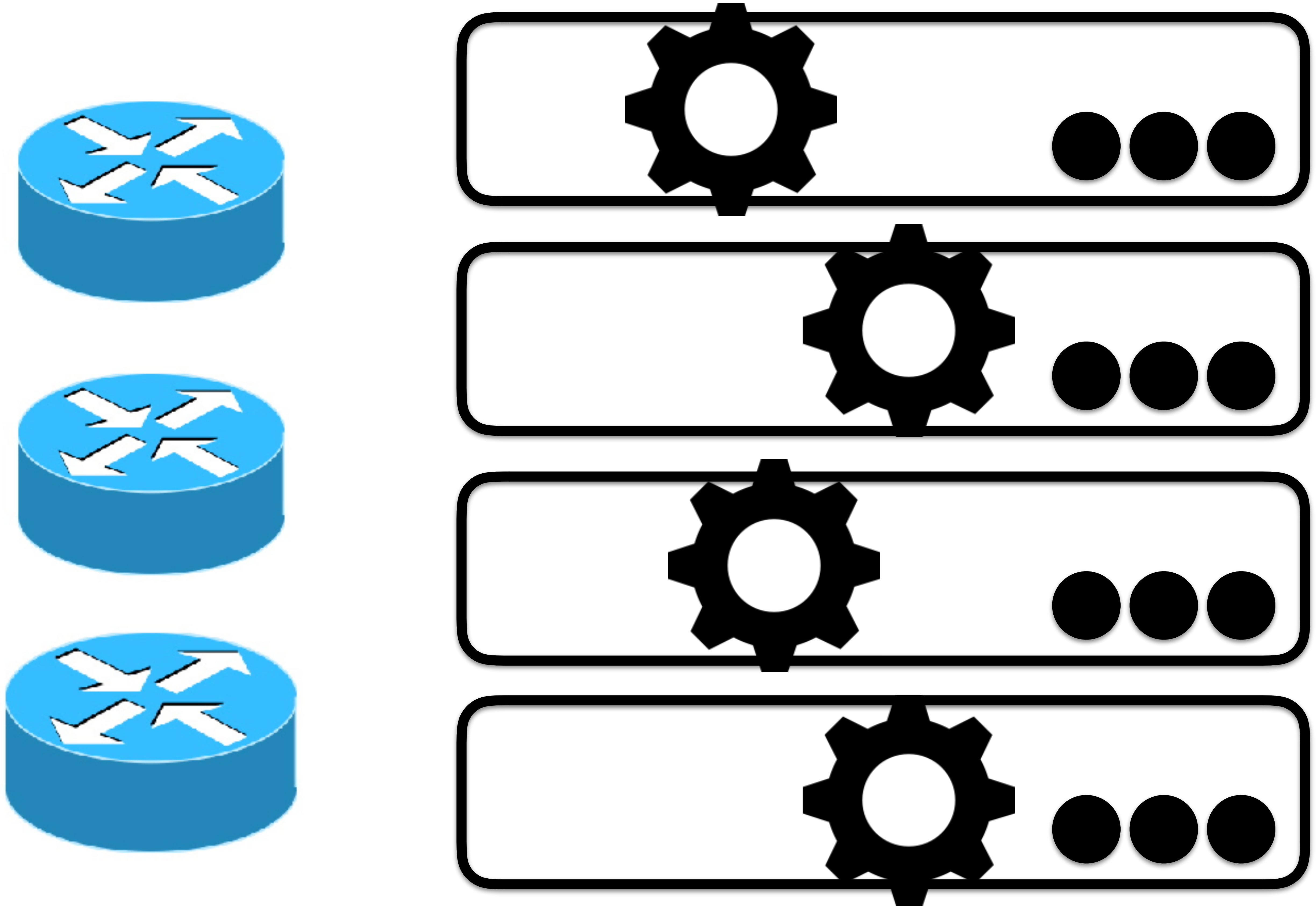


Multi-node NFV Architecture



Somehow we should stitch together multiple servers, too!

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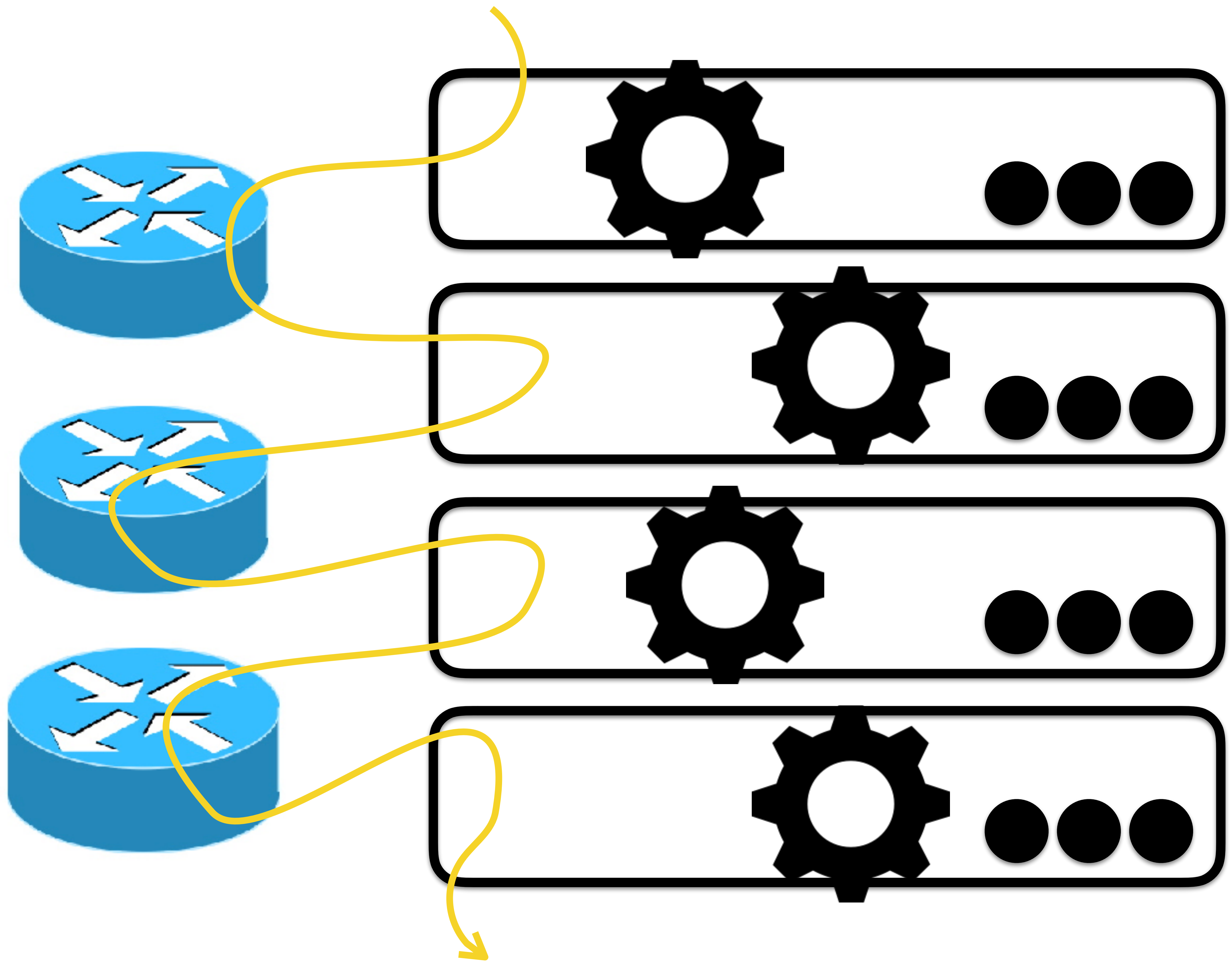

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NFV is a big trend in industry right now!

ETSI

NFV standardization body

Startup I worked at last year

NEFELI NETWORKS

Open Source MANO

Open Source project to develop NFV platform

Middleboxes: Summary

- Middleboxes are the de-facto way to insert new functionality into networks.
- Very widely deployed: 1/3 network devices is a middlebox
- Challenging to manage (upgrades, compatibility, complexity) and at times controversial (tussle).
- NFV is a new movement to build middleboxes in software using lessons from cloud computing.