# [544] Networking

Tyler Caraza-Harter

# Outline

Networks

Internets and "The Internet"

Transport Protocols

# Network Interface Controllers and MAC Addresses

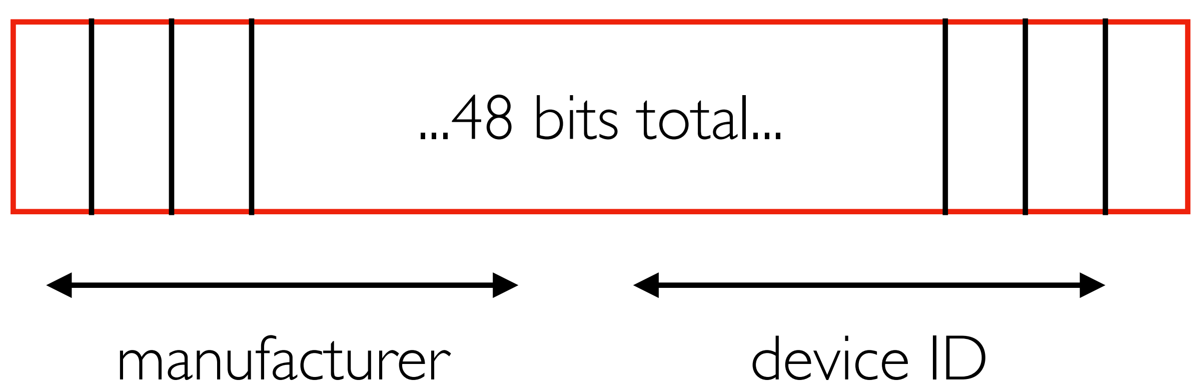
NICs can connect a computer to different physical mediums, such as:

- Ethernet (wired)
- Wi-Fi (wireless)

Every NIC in the world has a unique MAC (media access control) address

- 28 trillion possible addrs
- some devices randomly change their MAC addr for privacy

MAC address:



# `ifconfig` (Interface Config)

interface

MAC address

```
trh@instance-1:~$ ifconfig
ens4: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1460
        inet 10.128.0.36  netmask 255.255.255.255  broadcast 0.0.0.0
        inet6 fe80::4001:aff:fe80:24  prefixlen 64  scopeid 0x20<link>
        ether 42:01:0a:80:00:24  txqueuelen 1000  (Ethernet)
        RX packets 2332795  bytes 6456770667 (6.4 GB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 1994116  bytes 718670305 (718.6 MB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
        inet 127.0.0.1  netmask 255.0.0.0
        inet6 ::1  prefixlen 128  scopeid 0x10<host>
        loop  txqueuelen 1000  (Local Loopback)
        RX packets 407321  bytes 417582056 (417.5 MB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 407321  bytes 417582056 (417.5 MB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

`sudo apt install net-tools`

# Virtual Interfaces

```
trh@instance-1:~$ ifconfig
ens4: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1460
        inet 10.128.0.36  netmask 255.255.255.255  broadcast 0.0.0.0
        inet6 fe80::4001:aff:fe80:24  prefixlen 64  scopeid 0x20<link>
        ether 42:01:0a:80:00:24  txqueuelen 1000  (Ethernet)
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```

loopback (lo) device a virtual interface (not actual hardware)
connecting to a mini network containing just your computer

# Google Console: Adding Interfaces (NICs)

Create Instance > Advanced Options > Networking

### Network interfaces

Network interface is permanent

default default (10.128.0.0/20)

other-net subnet (10.0.0.0/24)

ADD NETWORK INTERFACE

Virtual Machine Summary

| | | | | | |
|---|---|---|---|---|---|
| ☐ | ✓ | instance-2 | us-central1-a | 10.128.0.37 (nic0)<br>10.0.0.2 (nic1) | 34.29.220.248 (nic0)<br>35.202.74.234 (nic1) |

# Google Console: Adding Interfaces

Create Instance > Advanced Options > Networking

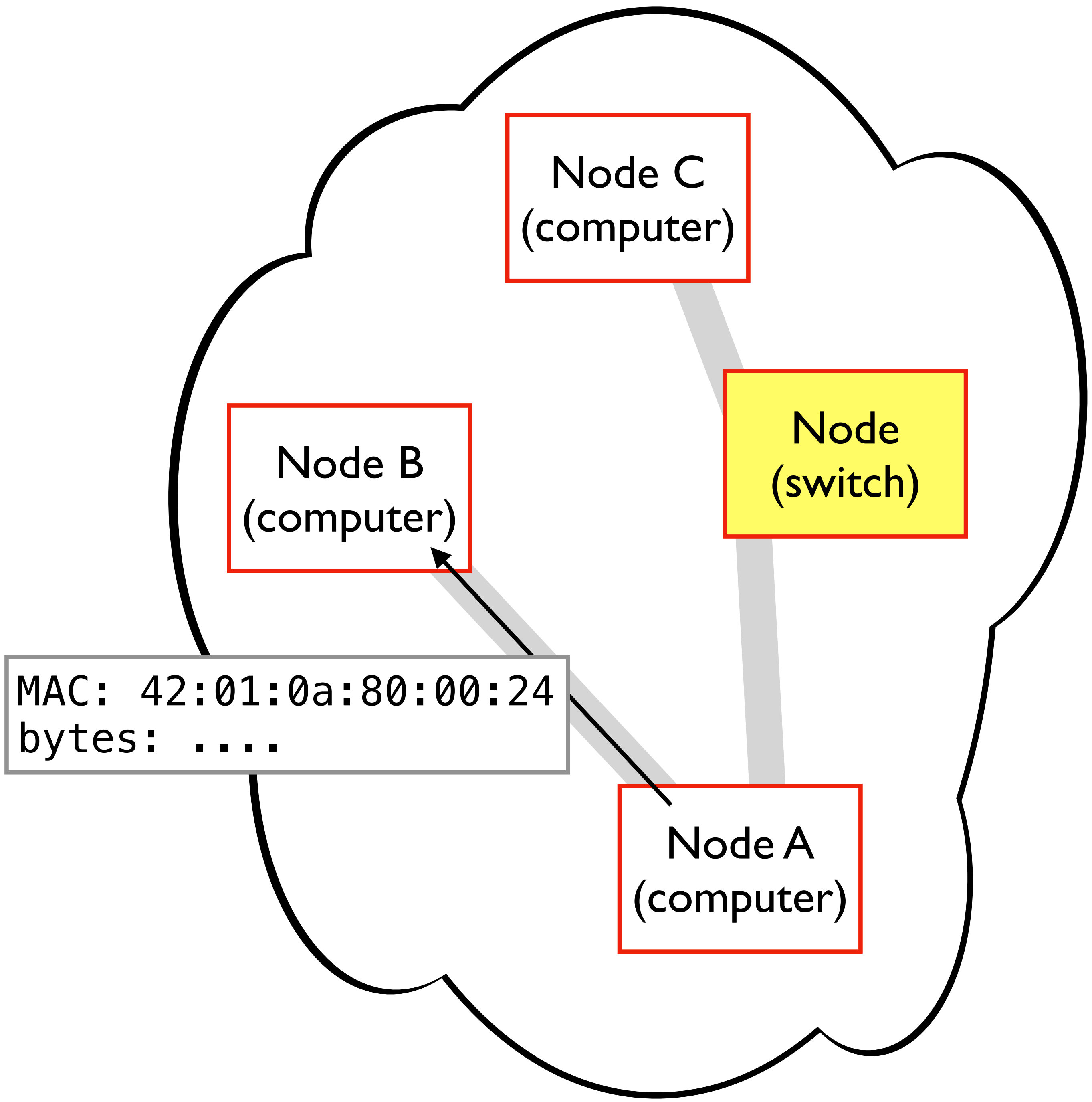
Network interfaces

```
trh@instance-2:~$ ifconfig
ens4: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1460
        inet 10.128.0.37  netmask 255.255.255.255  broadcast 0.0.0.0
        inet6 fe80::4001:aff:fe80:25  prefixlen 64  scopeid 0x20<link>
        ether 42:01:0a:80:00:25  txqueuelen 1000  (Ethernet)
        RX packets 637  bytes 546000 (546.0 KB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 612  bytes 97265 (97.2 KB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

ens5: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1460
        inet 10.0.0.2  netmask 255.255.255.255  broadcast 0.0.0.0
        inet6 fe80::4001:aff:fe00:2  prefixlen 64  scopeid 0x20<link>
        ether 42:01:0a:00:00:02  txqueuelen 1000  (Ethernet)
        RX packets 51  bytes 9955 (9.9 KB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 61  bytes 6834 (6.8 KB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
        inet 127.0.0.1  netmask 255.0.0.0
        inet6 ::1  prefixlen 128  scopeid 0x10<host>
        loop  txqueuelen 1000  (Local Loopback)
        RX packets 120  bytes 13534 (13.5 KB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 120  bytes 13534 (13.5 KB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

7

34.29.220.248
(nic0)
35.202.74.234
(nic1)

# Networks



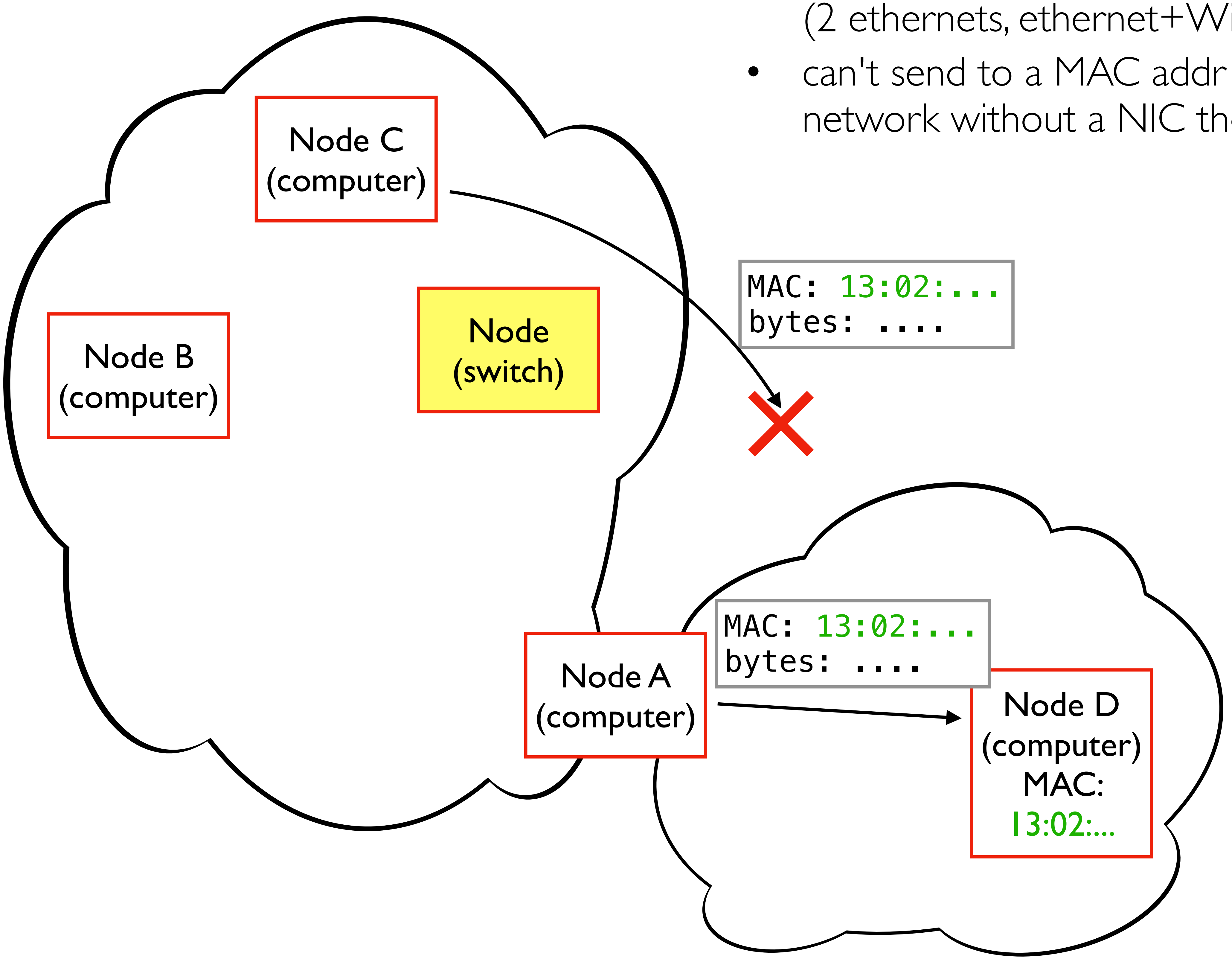

A network has nodes that send bytes to other nodes **by MAC address**

- **nodes**: computer, switch, etc
- direct, or **forwarded by switches**
- whole network uses same physical tech (Wi-Fi, Ethernet, etc)

# Networks

Computers can have multiple NICs

- can be on multiple networks (2 ethernets, ethernet+Wi-FI, etc)
- can't send to a MAC addr in another network without a NIC there



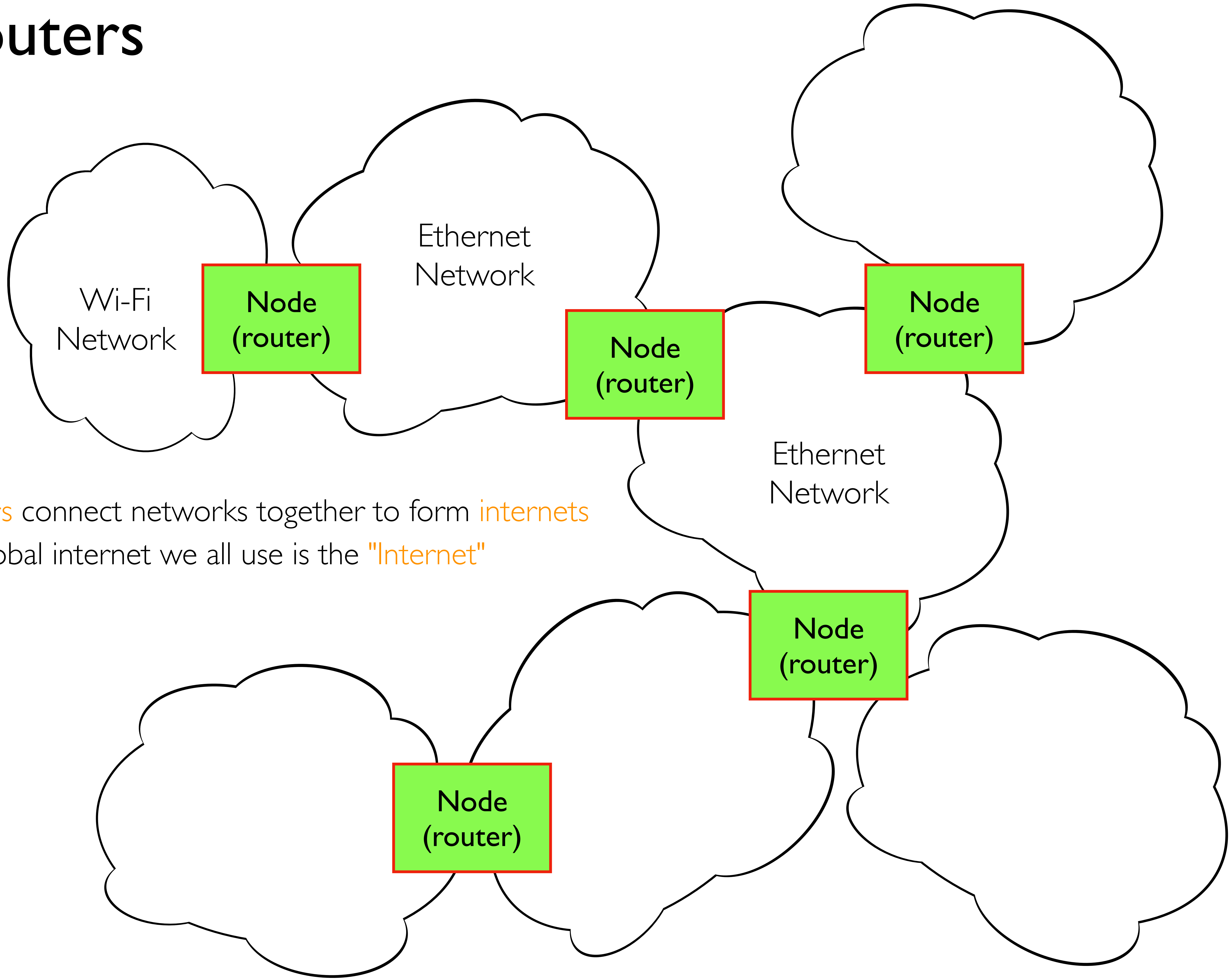
# Outline

Networks

Internets and "The Internet"

Transport Protocols

# Routers

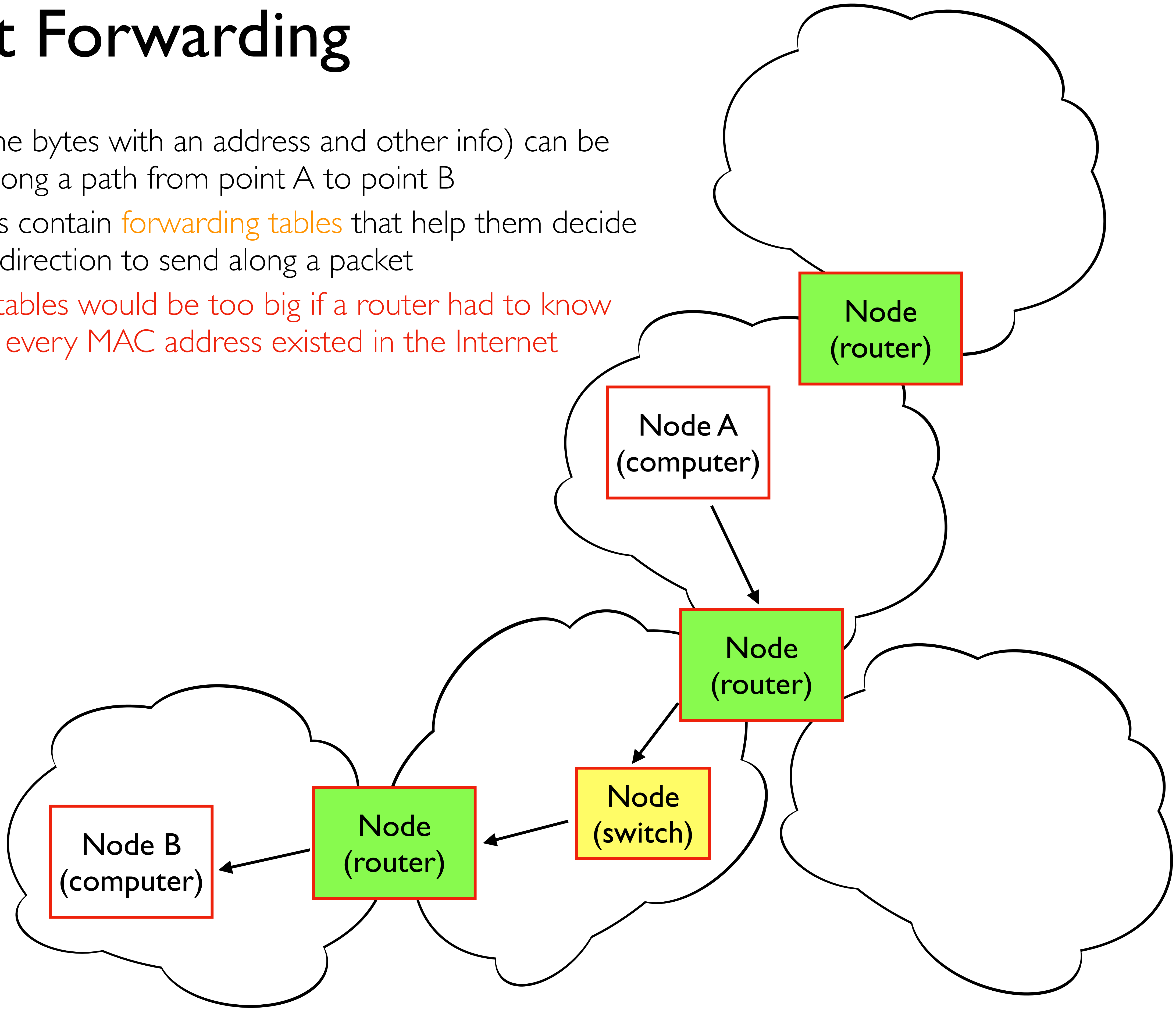



- routers connect networks together to form internets
- the global internet we all use is the "Internet"

# Packet Forwarding

Packets (some bytes with an address and other info) can be forwarded along a path from point A to point B

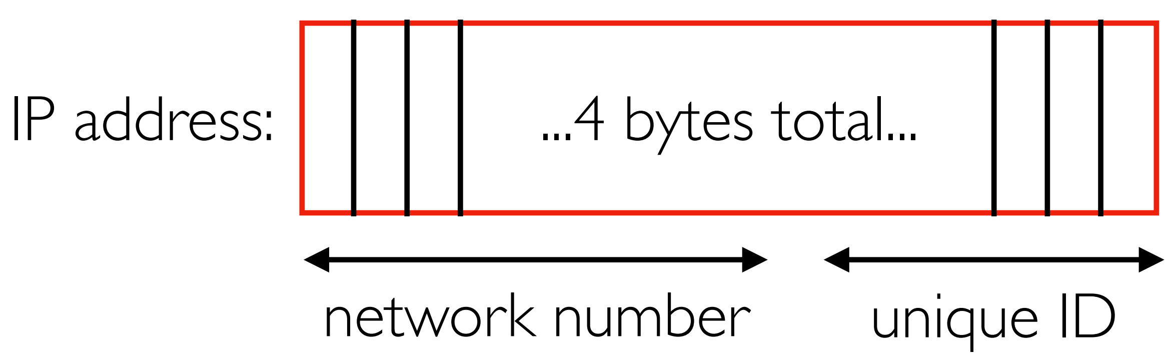
- routers contain forwarding tables that help them decide which direction to send along a packet
- those tables would be too big if a router had to know where every MAC address existed in the Internet

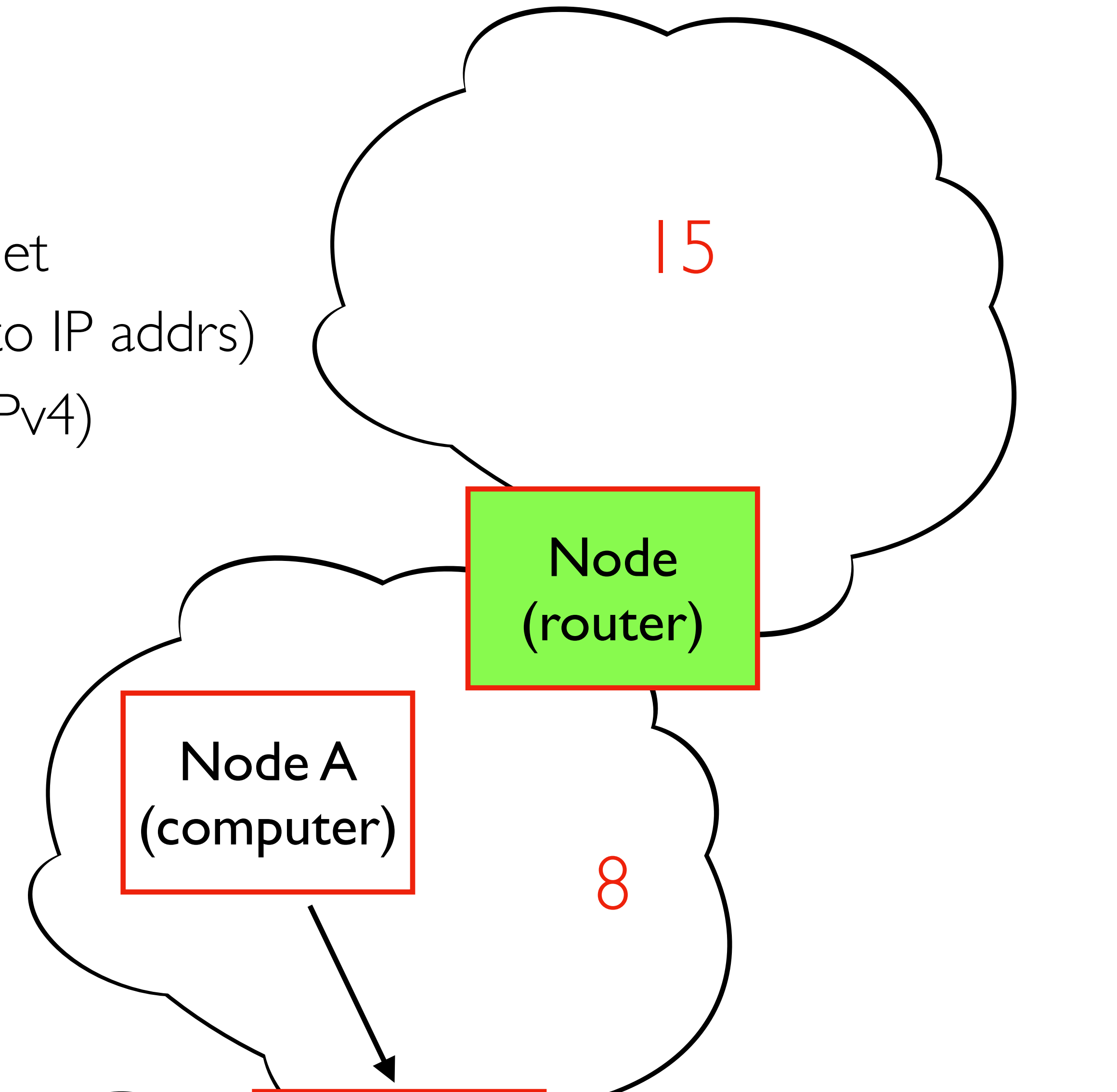


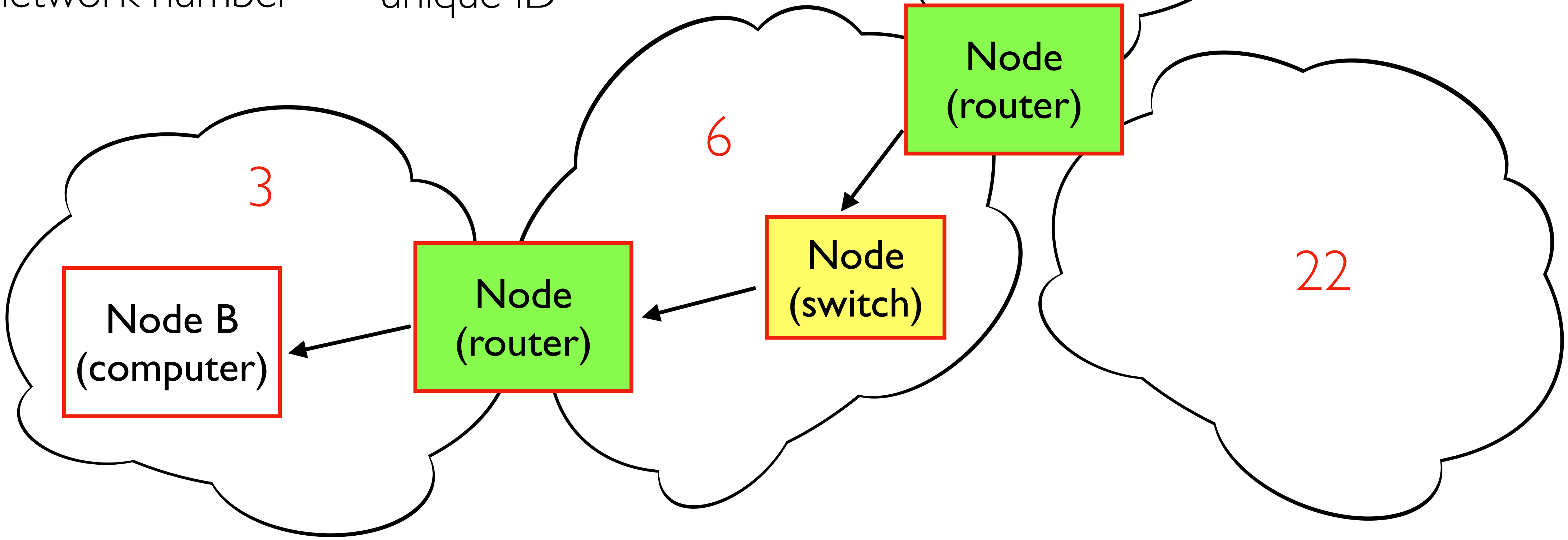
# Internet Protocol

IP addresses are used to send packets across an internet

- example: `34.29.237.29` (domains can map to IP addrs)
- there are about 4 billion possible IP addresses (IPv4)
- IPv6 (less used) are 4x longer
- forwarding tables only need to know which way to send for a given network number



# Listening on an Interface

```
trh@instance-2:~$ ifconfig
ens4: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1460
        inet 10.0.1.2  netmask 255.255.255.255  broadcast 0.0.0.0
        inet6 fe80                                              0<link>
        ether 42:0
        ...
```

```
python3 -m http.server --bind 10.0.1.2
```

```
ens5: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1430
        inet 10.0.3.2  netmask 255.255.255.255  broadcast 10.0.3.2
        inet6 fe80                                              0<link>
        ether 42:0
        ...
```

```
python3 -m http.server --bind 10.0.3.2
```

```
lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
        inet 127.0.0.1  netmask 255.0.0.0
        inet6 ::1
        loop  txqu
        ...
```

```
python3 -m http.server --bind 127.0.0.1
```

all of them:

```
python3 -m http.server --bind 0.0.0.0
```

# Private Networks

Challenges

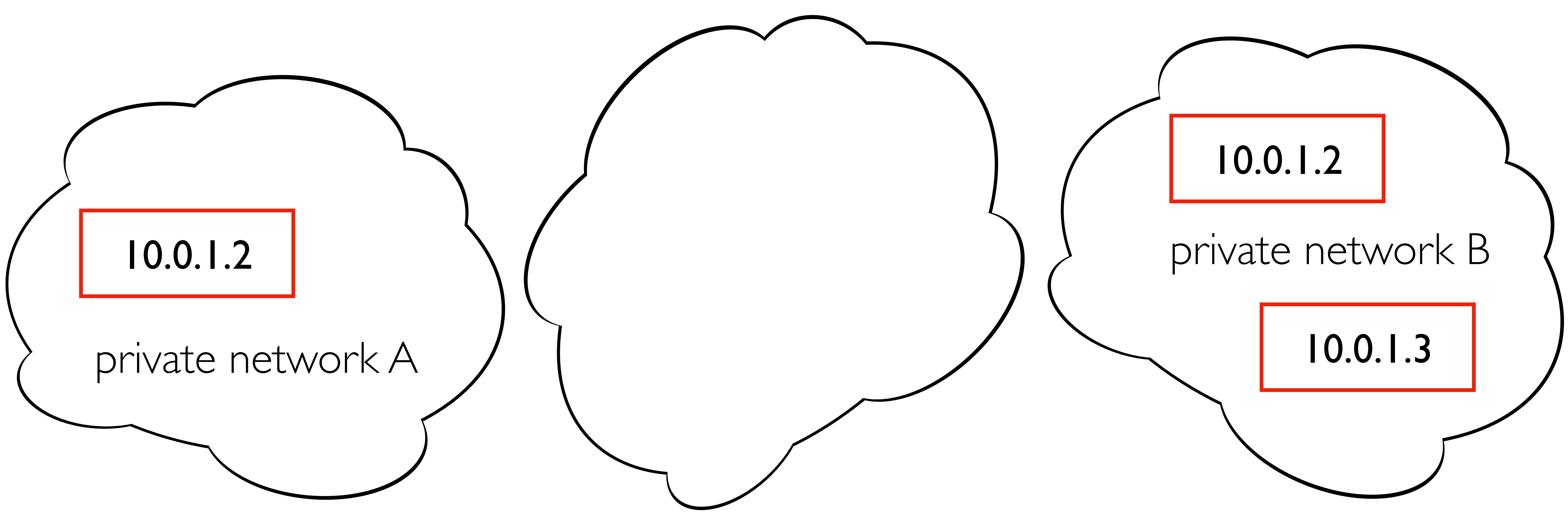
- we don't have enough IPv4 addresses
- we don't want every machine to be able to receive packets from anywhere

Private ranges:

- `192.168.0.0 to 192.168.255.255`
- `172.16.0.0 to 172.31.255.255`
- `10.0.0.0 to 10.255.255.255`

these can be divided into "sub networks" (subnets) to create different networks in a bigger org

Private networks allow duplicates and unreachable machines



# Private Networks

```
trh@instance-2:~$ ifconfig
ens4: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1460
        inet 10.0.1.2
        inet6 fe80::40                                                  nk>
        ether 42:01:0a:00:01:02  txqueuelen 1000  (Ethernet)
        ...
```

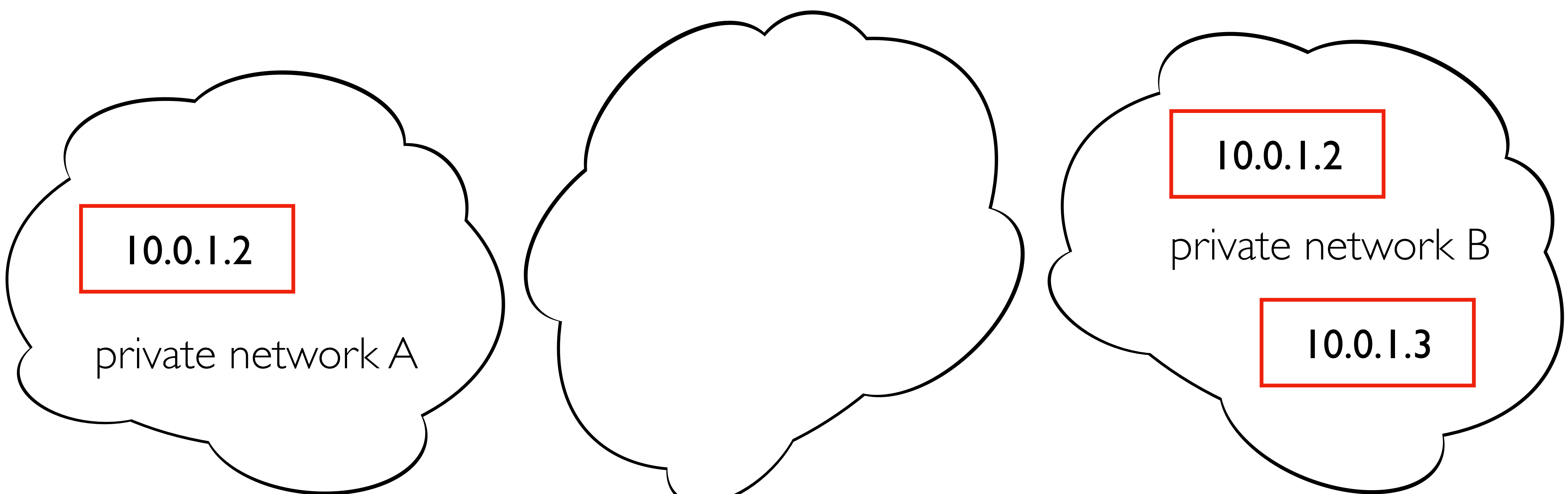
```
python3 -m http.server --bind 10.0.1.2
```

Private ranges:

- 192.168.0.0 to 192.168.255.255
- 172.16.0.0 to 172.31.255.255
- 10.0.0.0 to 10.255.255.255

http://10.0.1.2:...
won't work in web browser!

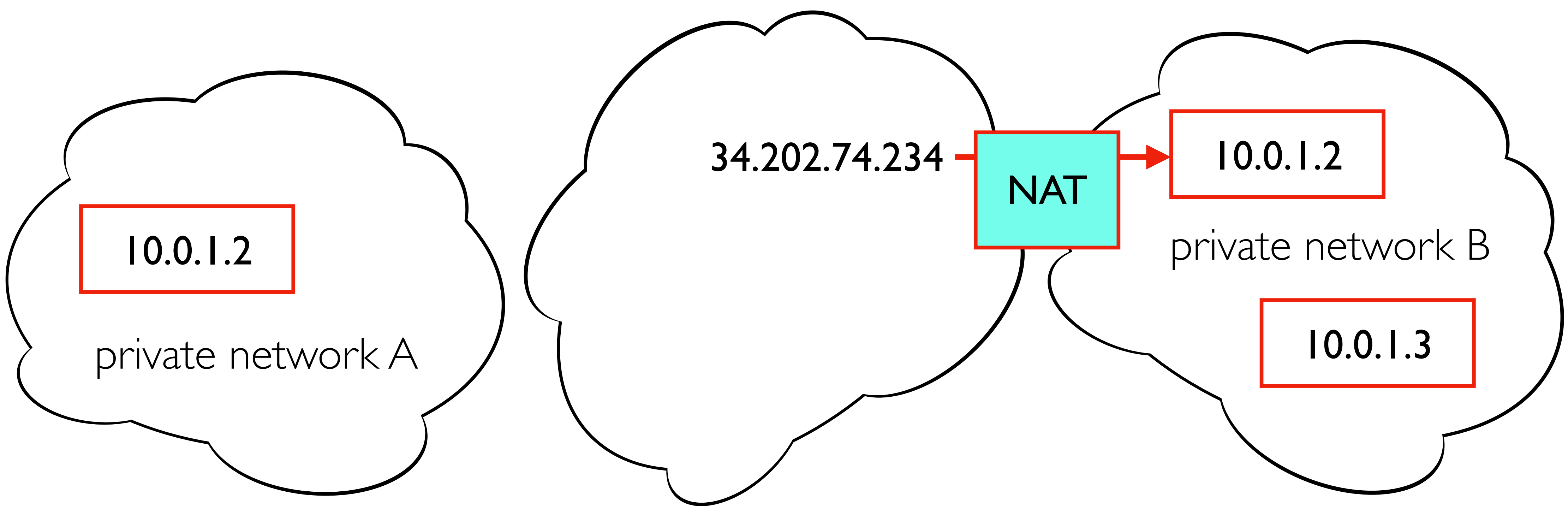
Private networks allow duplicates and unreachable machines



# Network Address Translation

Google Console (view NAT config)

| | Status | Name | Internal IP | External IP |
|---|---|---|---|---|
| | | instance-1 | 10.128.0.36 (nic0) | 34.29.237.29 (nic0) |
| | | instance-2 | 10.0.1.2 (nic0)<br>10.0.3.2 (nic1) | 35.202.74.234 (nic0)<br>34.29.220.248 (nic1) |

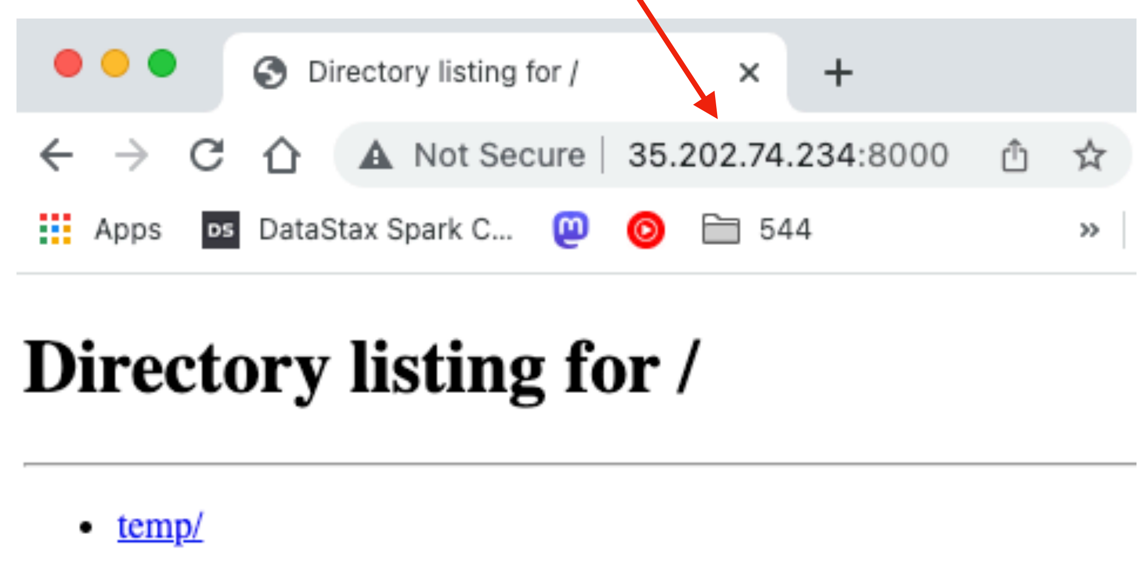


# Network Address Translation

Google Console (view NAT config)

| | Status | Name ↑ | Internal IP | External IP |
|---|---|---|---|---|
| ☐ | ✔ | instance-1 | 10.128.0.36 (nic0) | 34.29.237.29 (nic0) |
| ☐ | ✔ | instance-2 | 10.0.1.2 (nic0)<br>10.0.3.2 (nic1) | 35.202.74.234 (nic0)<br>34.29.220.248 (nic1) |

Browser




By default, the external IPs are "ephemeral" (change upon reboot). You can rent "static" IPs that don't change.

Server

```
trh@instance-2:~/temp$ python3 -m http.server --bind 10.0.1.2
Serving HTTP on 10.0.1.2 port 8000 (http://10.0.1.2:8000/) ...
72.33.0.184 - - [10/Feb/2023 21:12:53] "GET / HTTP/1.1" 200 -
...
```

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# Port Numbers

Computers might be running multiple processes using the network

- IP address => which NIC?
- Port number => which process?

```
trh@instance-2:~$ python3 -m http.server --directory=A --bind 10.0.1.2 8000 &
[1] 13502
Serving HTTP on 10.0.1.2 port 8000 (http://10.0.1.2:8000/) ...

trh@instance-2:~$ python3 -m http.server --directory=B --bind 10.0.1.2 9000 &
[2] 13503
Serving HTTP on 10.0.1.2 port 9000 (http://10.0.1.2:9000/) ...
```

http://35.202.74.234:8000/ → first server

http://35.202.74.234:9000/ → second server

# TopHat

42:01:0a:80:00:25 is an example of what?

# Transport Protocols

Most common

- UDP (User Datagram Protocol)
- TCP (Transmission Control Protocol)

BOTH build on IP networking and BOTH provide port numbers

```
trh@instance-2:~/temp$ sudo lsof -i tcp -P
COMMAND     PID NODE NAME
...
sshd        863 TCP *:22 (LISTEN)
sshd        863 TCP *:22 (LISTEN)
...
python3   13607 TCP instance-2...internal:8000 (LISTEN)
python3   13608 TCP instance-2...internal:9000 (LISTEN)
```

# Reliability: UDP vs. TCP

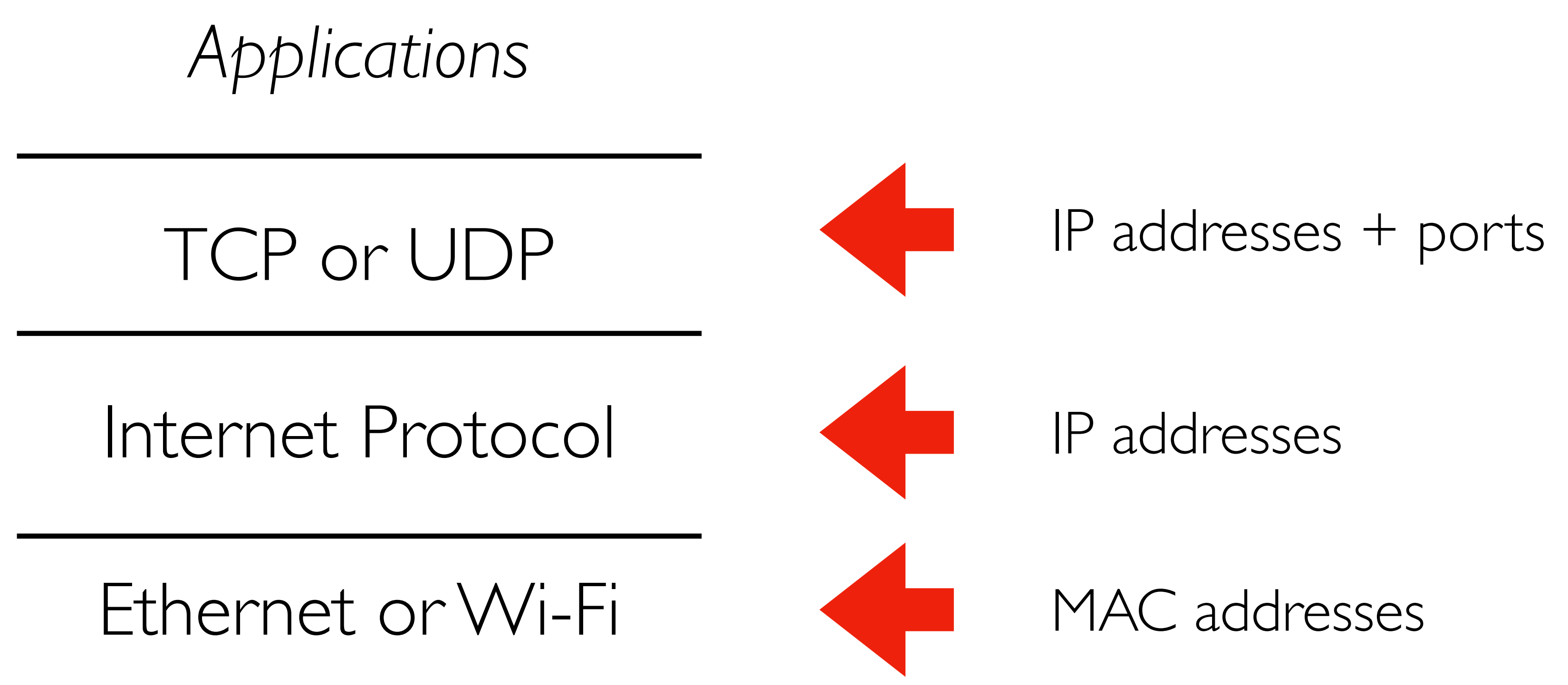
Packets may be

- dropped
- reordered
- split

TCP saves+reassembles packets in order to provide original message (when possible). For packet drops, it retries. We'll mostly use TCP.

UDP doesn't do this extra work. Why ever use UDP?

# Network Stack: Common Implementations




Network applications (like most complex systems) are not built as one single system. Layers are built upon other layers to provide additional functionality.

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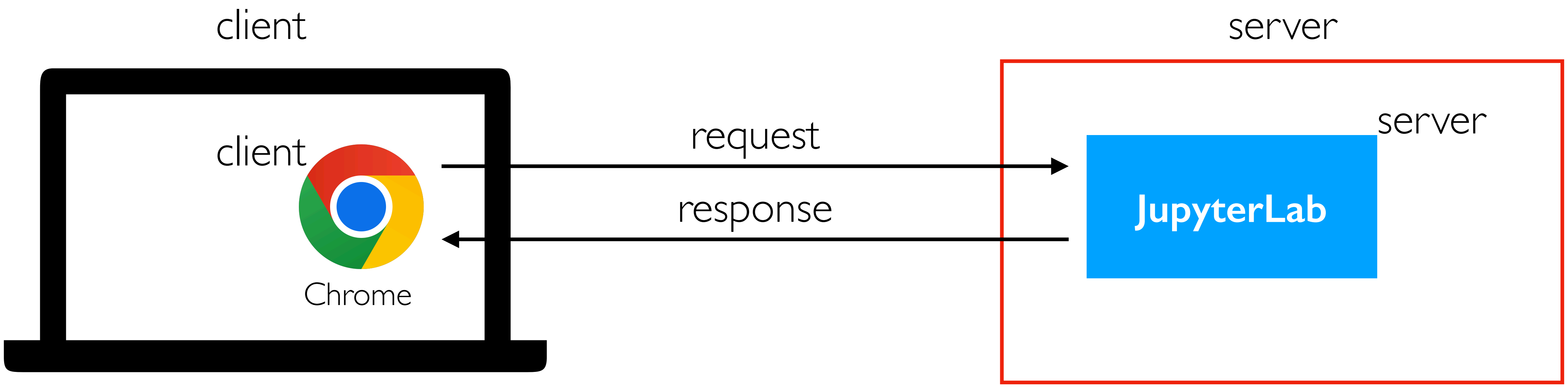
# HTTP (Hypertext Transfer Protocol)

| | |
| --- | --- |
| HTTP | URL (domain/IP + port + resource) |
| TCP or UDP | IP addresses + ports |
| Internet Protocol | IP addresses |
| Ethernet or Wi-Fi | MAC addresses |

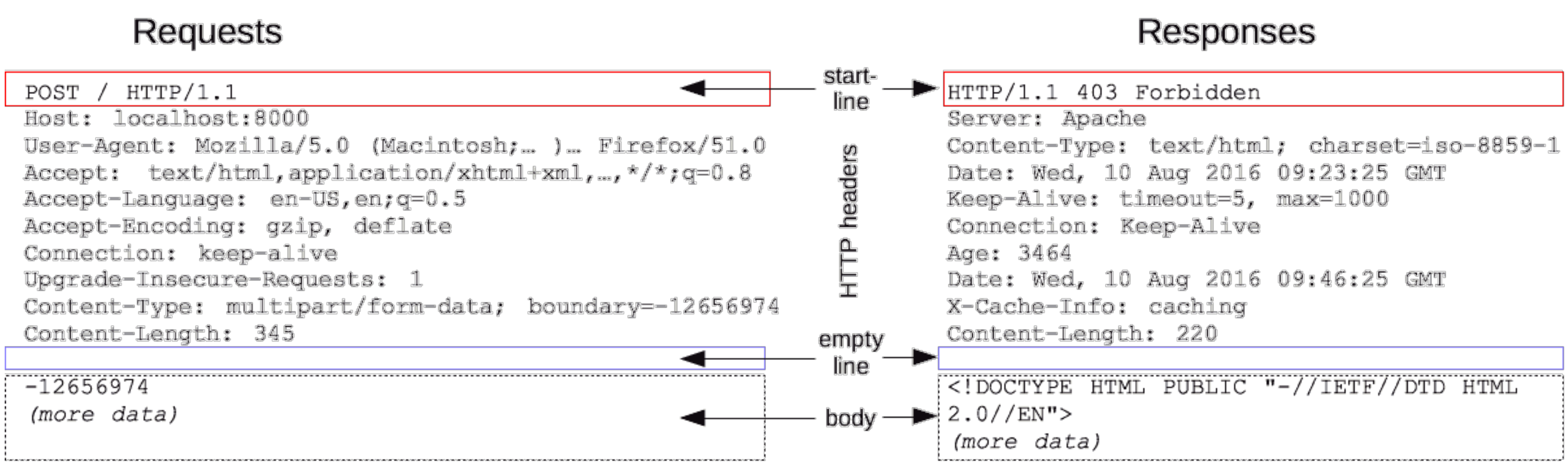
`https://tyler.caraza-harter.com:443/cs544/s23/schedule.html`

| tyler.caraza-harter.com | 443 | /cs544/s23/schedule.html |
| --- | --- | --- |
| **domain name** (mapped to an IP) | **port** (443 is default for https) | **resource** |

# HTTP Messages Betwen Clients and Servers




Parts: method, resource, status code, headers, body




https://developer.mozilla.org/en-US/docs/Web/HTTP/Messages

# HTTP Methods (types of messages)

Types of request

- **POST**: create a new resource (request+response have body)
- **PUT**: update a resource (request+response have body, usually)
- **GET**: fetch a resource (response has body)
- **DELETE**: delete a resource ()
- others...

Canvas API example:

`GET` [`https://canvas.wisc.edu/api/v1/conversations`](https://canvas.wisc.edu/api/v1/conversations)
(see all Canvas conversations in JSON format)

`POST` [`https://canvas.wisc.edu/api/v1/conversations`](https://canvas.wisc.edu/api/v1/conversations)
(create new Canvas conversation)

https://canvas.instructure.com/doc/api/conversations.html

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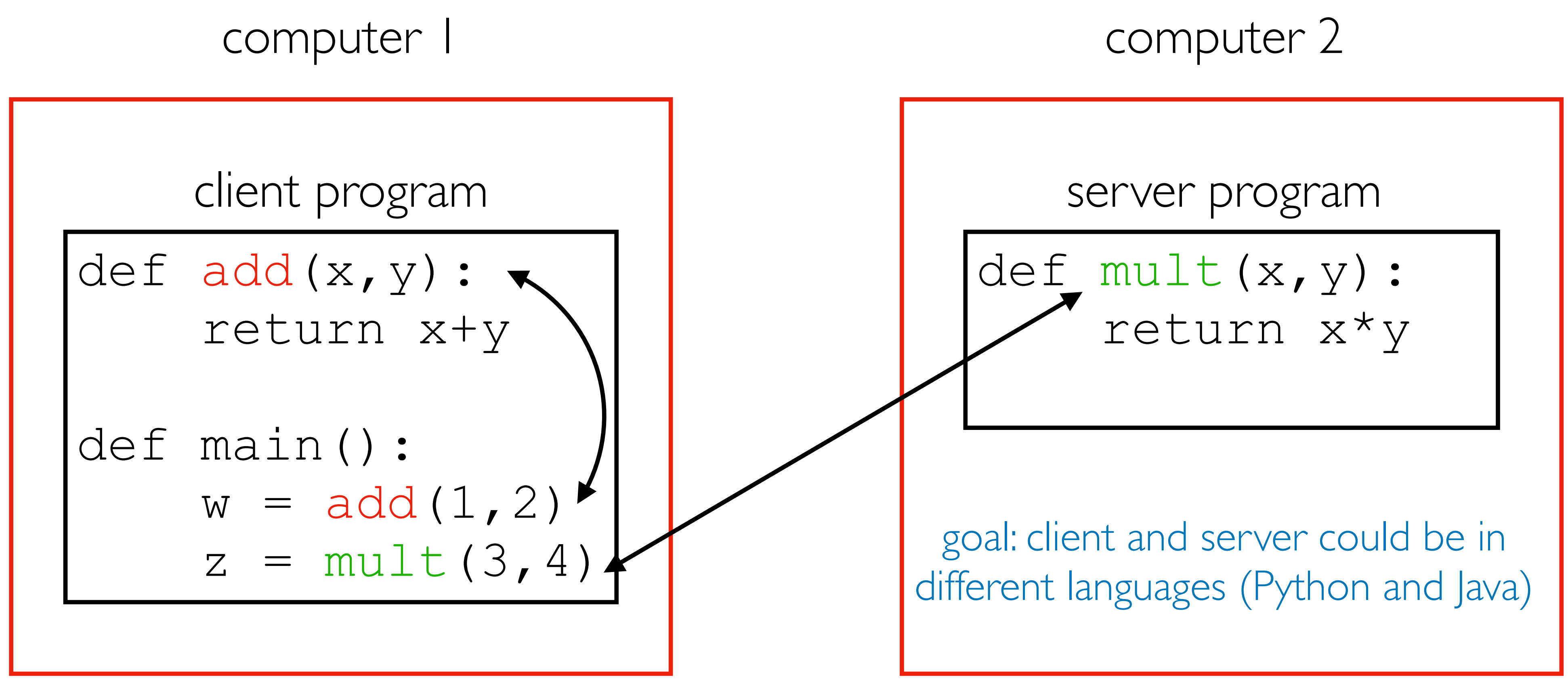
# Remote Procedure Calls (RPCs)



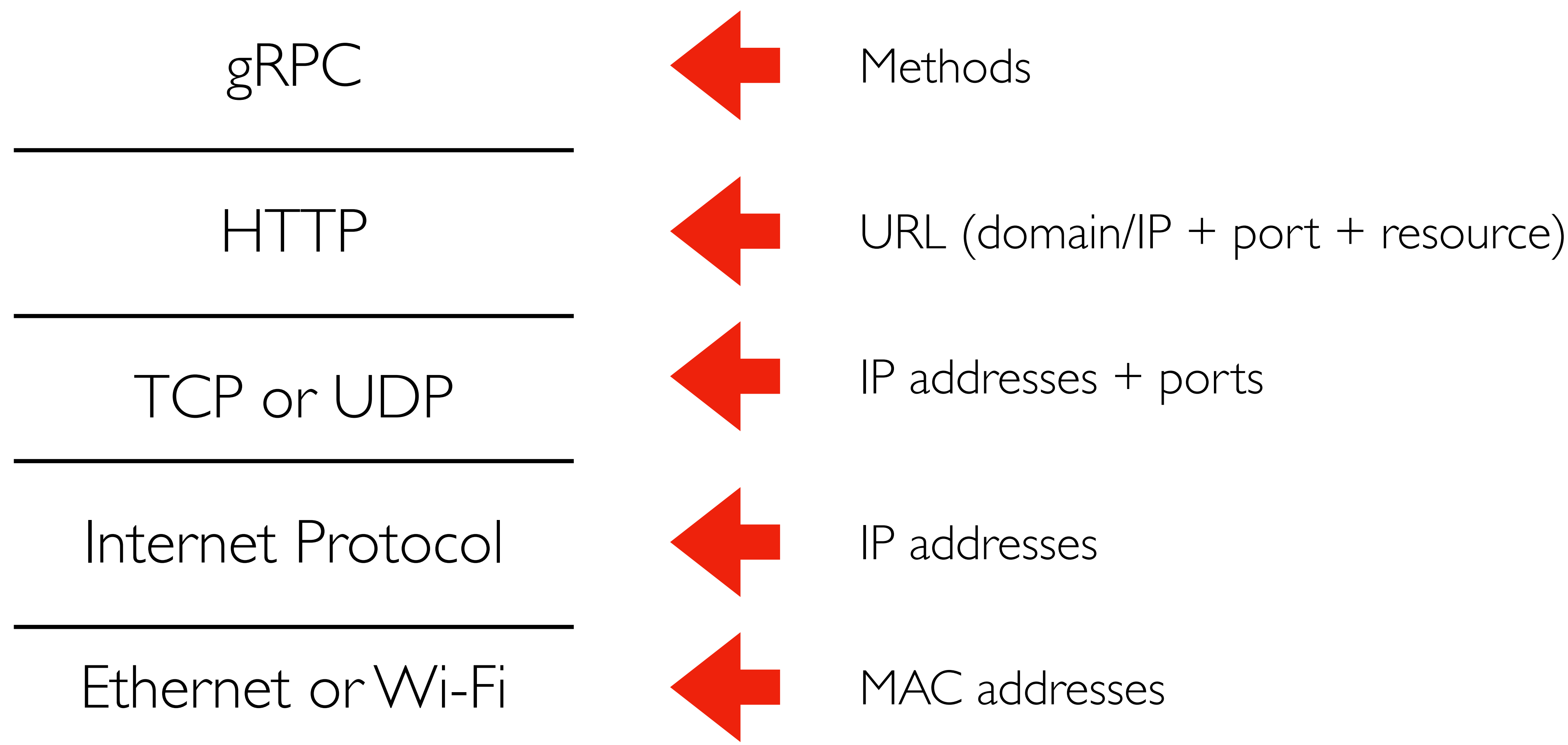

procedure = function

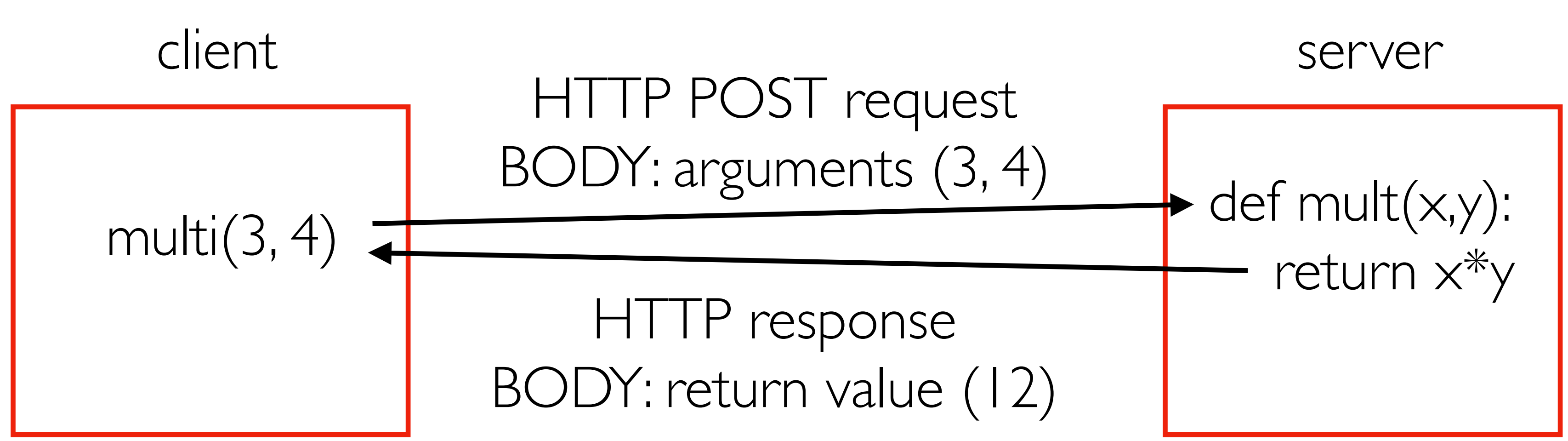
- **main** calling **add** is a regular procedure call
- **main** call **mult** is a remote procedure call

There are MANY tools to do RPCs

- Thrift (developed at Meta)
- gRPC (developed at Google) -- this semester

# gRPC builds on HTTP



# Serialization/deserialization (Protobufs)

*How do we represent arguments and return values as bytes in a request/response body?*

Serialization: various types (ints, strs, lists, etc) to **bytes** ("wire format")
Deserialization: **bytes** to various types

Challenge 1: every language has different types and we want cross-languages calls

gRPC uses Google's Protocol Buffers provide a uniform type system.

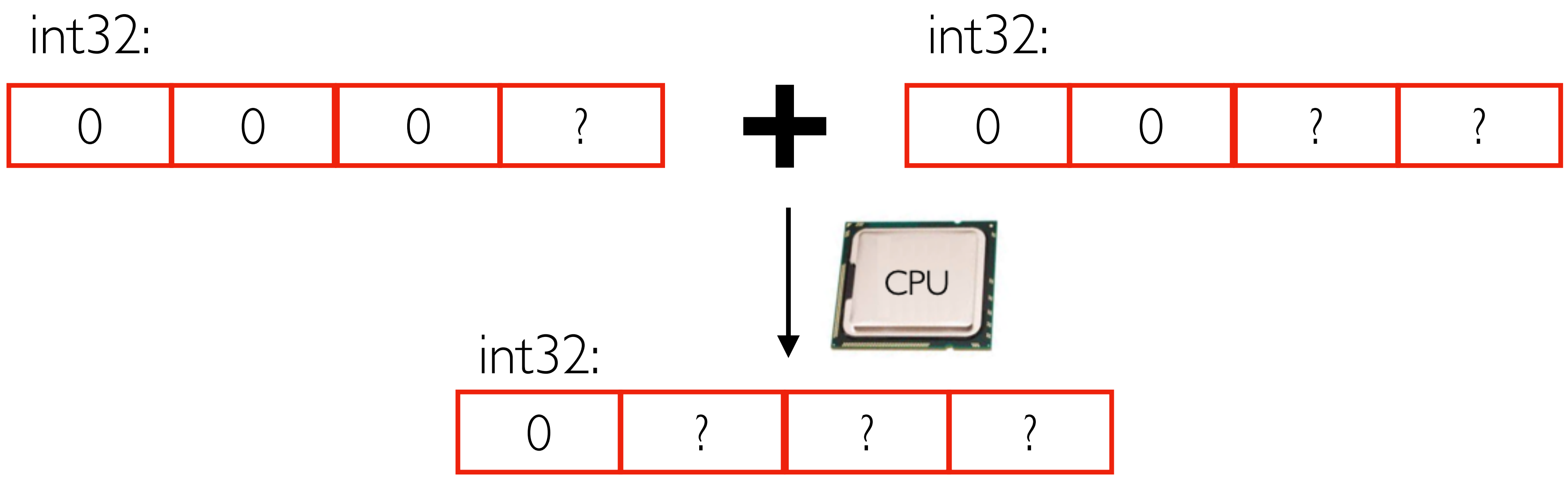
Challenge 2: different CPUs order bytes differently

| | | | | |
|---|---|---|---|---|
| cpu A int32: | byte 1 | byte 2 | byte 3 | byte 4 |
| cpu B int32: | byte 4 | byte 3 | byte 2 | byte 1 |

| .proto | C++ | Java | Pytho |
|---|---|---|---|
| double | double | double | float |
| float | float | float | float |
| int32 | int32 | int | int |
| int64 | int64 | long | int |
| uint32 | uint32 | int | int |
| uint64 | uint64 | long | int |
| sint32 | int32 | int | int |
| sint64 | int64 | long | int |
| bool | bool | boolean | bool |
| string | string | String | str |
| bytes | string | ByteString | bytes |

https://protobuf.dev/programming-guides/proto/

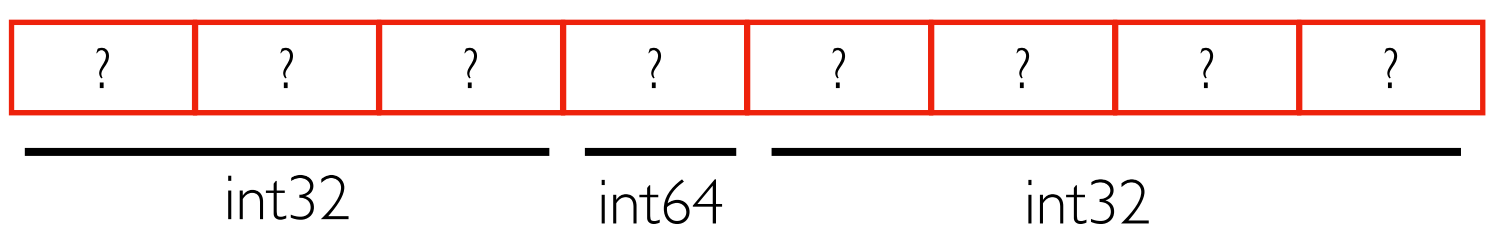
# Variable-Length Encoding




For **computational efficiency**, int32's use 4 bytes during computation. Also helps w/ offsets.

For **space efficiency**, smaller numbers in int32s user fewer bytes (4 bytes is max). This reduces network traffic.

Example nums in a protobuf:



Demos...