[544] Networking

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Learning Objectives

- explain how MAC addresses, IP addresses, and port numbers provide addressing, used to facilitate communicate between processes on different machines
- select IP addresses correctly for binding and using in a browser to achieve connection in the context of a server running behind a NAT
- identify the port number being used by a process
- select between transport methods (TCP and UDP) based on the functionality needed (on top of IP functionality)

Outline

Networks

Internets and "The Internet"

Transport Protocols

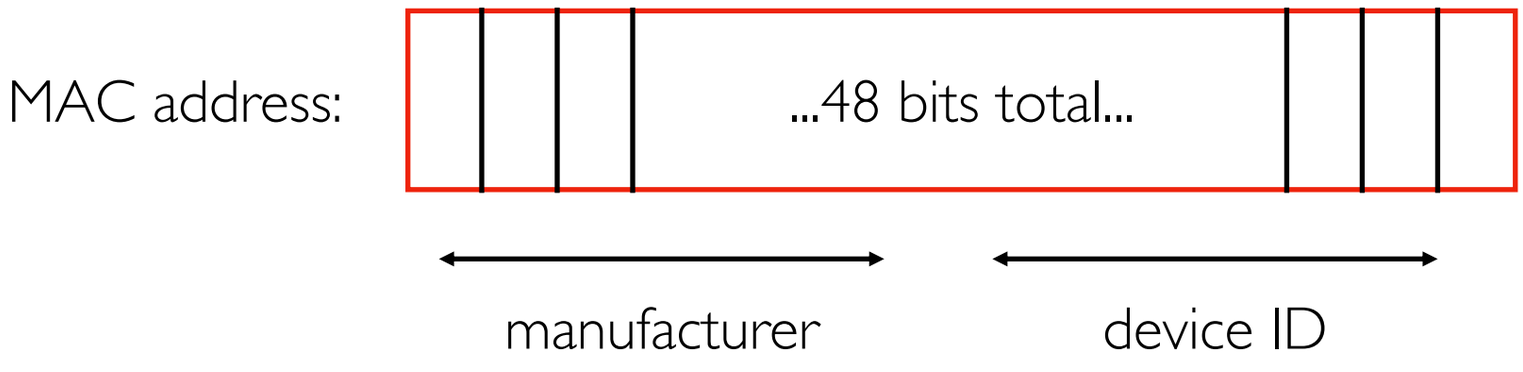
Network Interface Controllers and MAC Addresses

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



`ifconfig` (Interface Config)

interface

MAC address

```
meenakshisyamkumar@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

```
meenakshisyamkumar@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
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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) 10.0.0.2 (nic1)	34.29.220.248 (nic0) 35.202.74.234 (nic1)

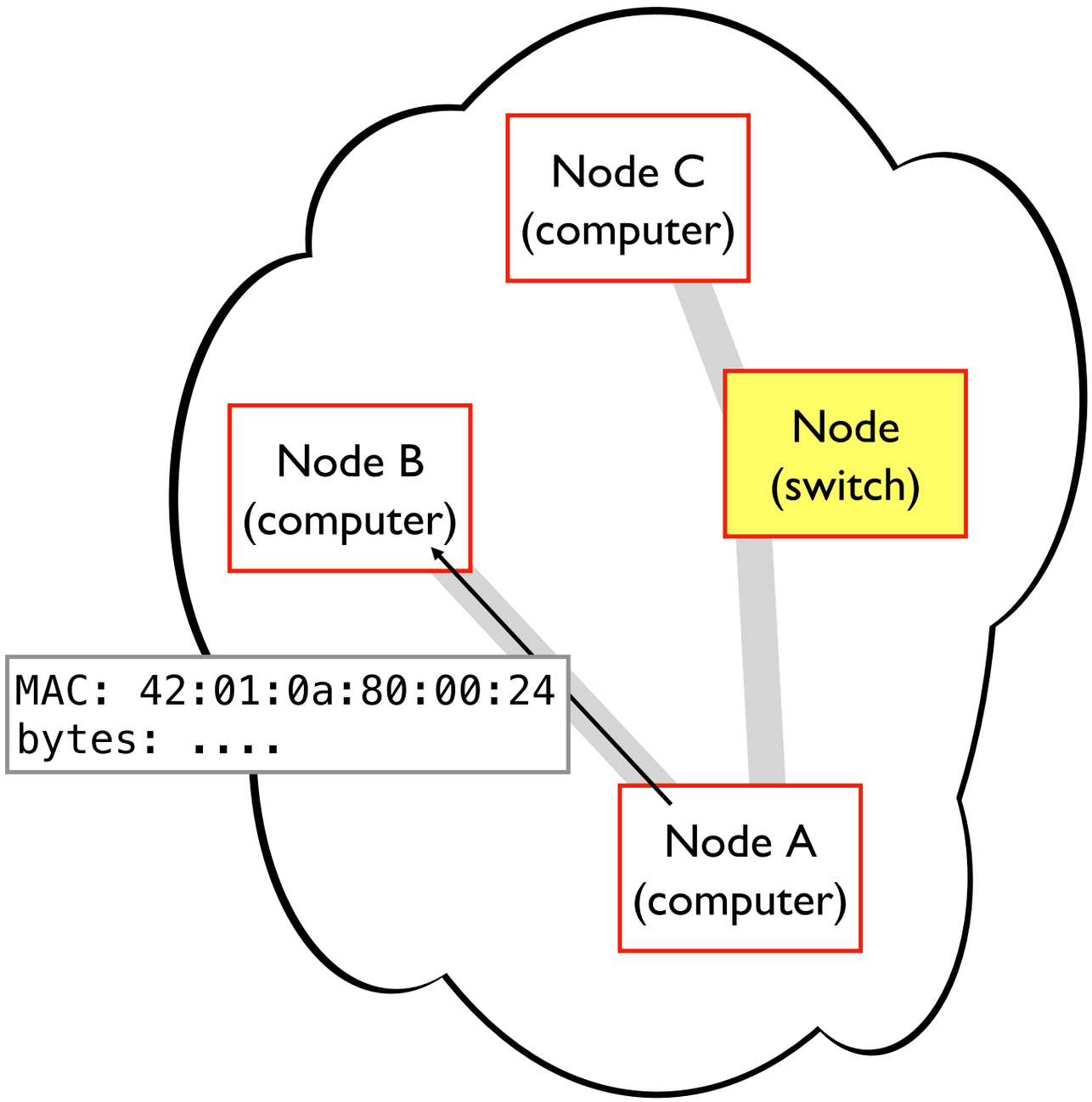
Google Console: Adding Interfaces

```
meenakshisyamkumar@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
```

Networks



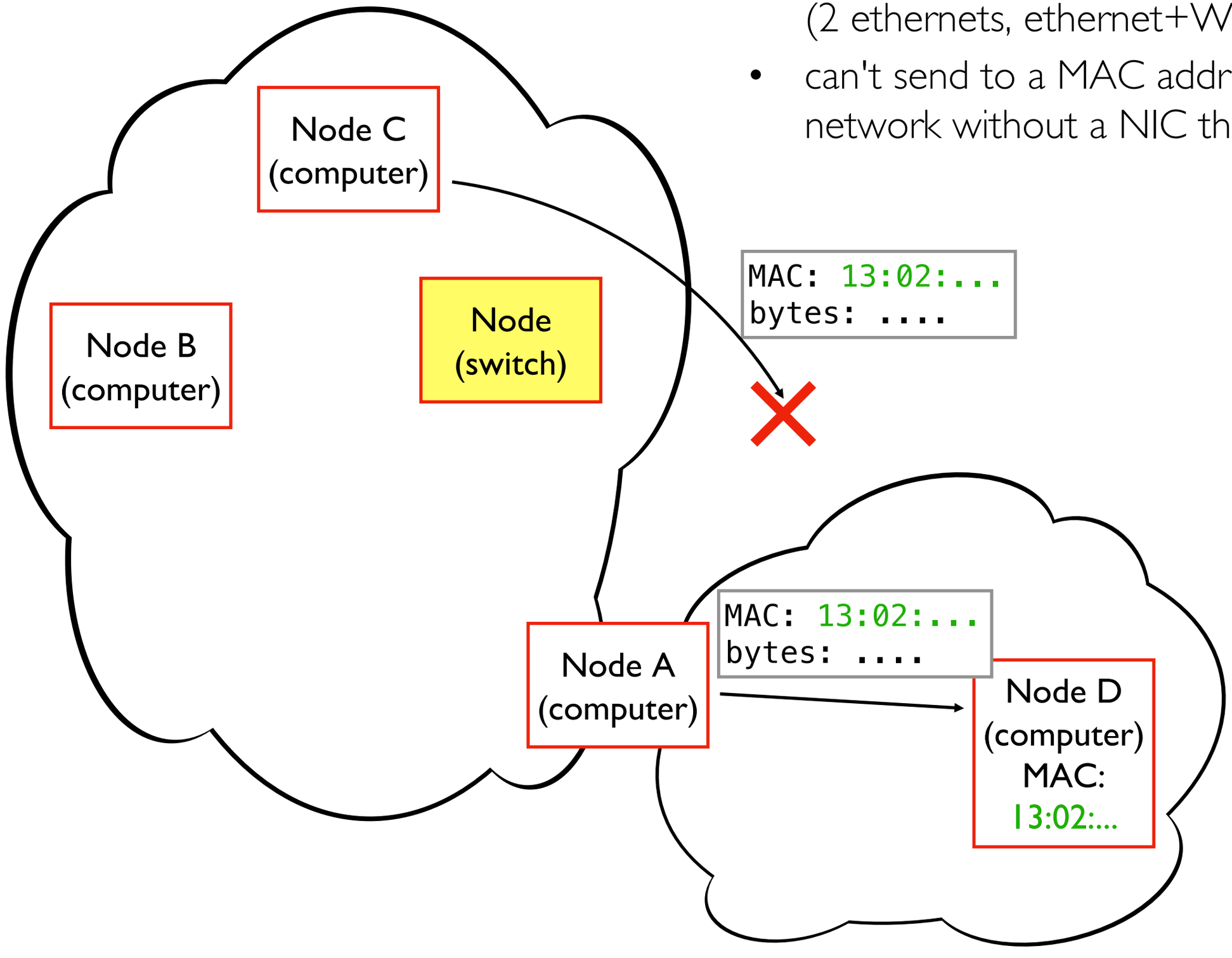
A network has nodes that send bytes to other nodes **by MAC address**

- **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

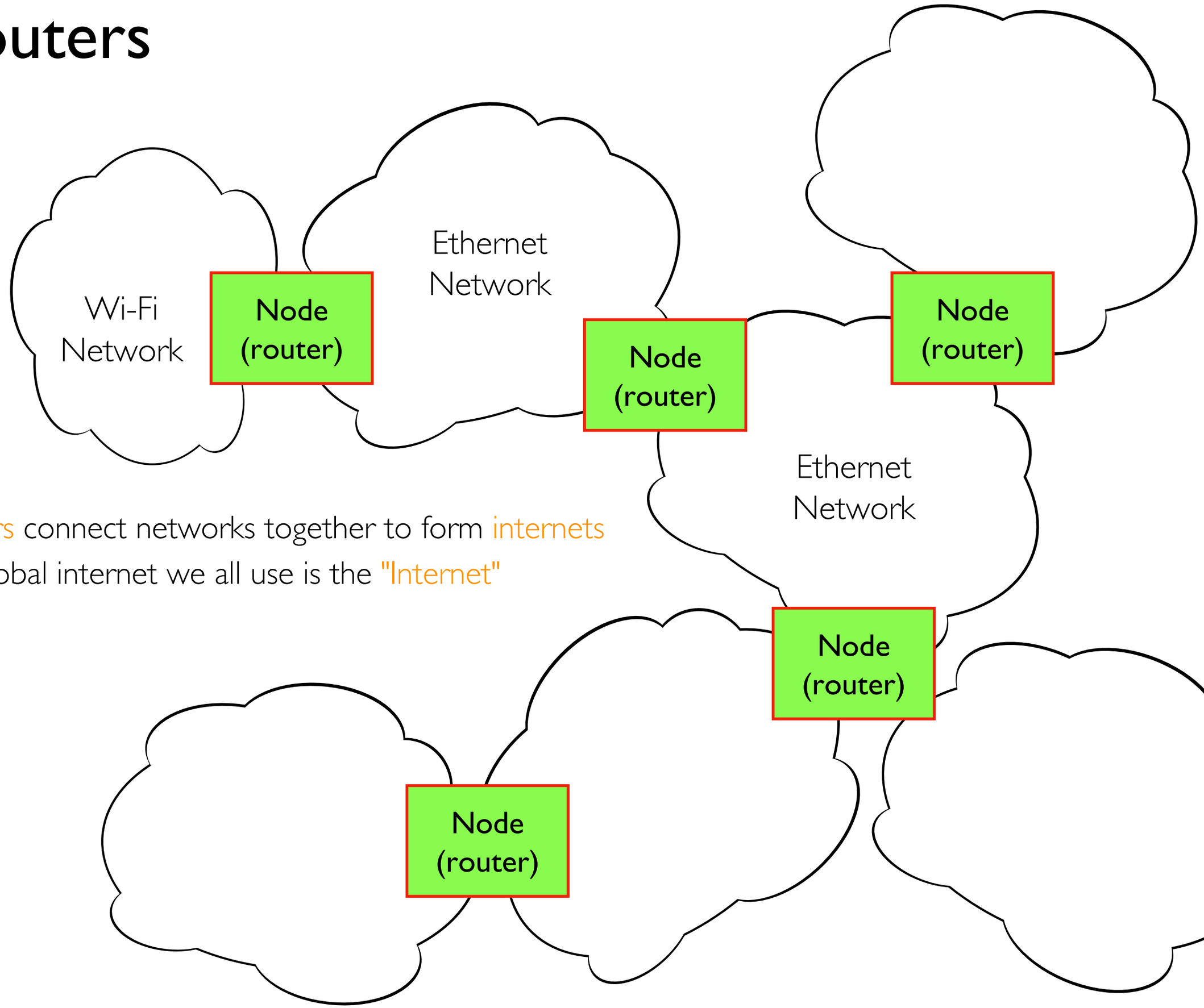
Networks

Internets and "The Internet"

Transport Protocols

Routers

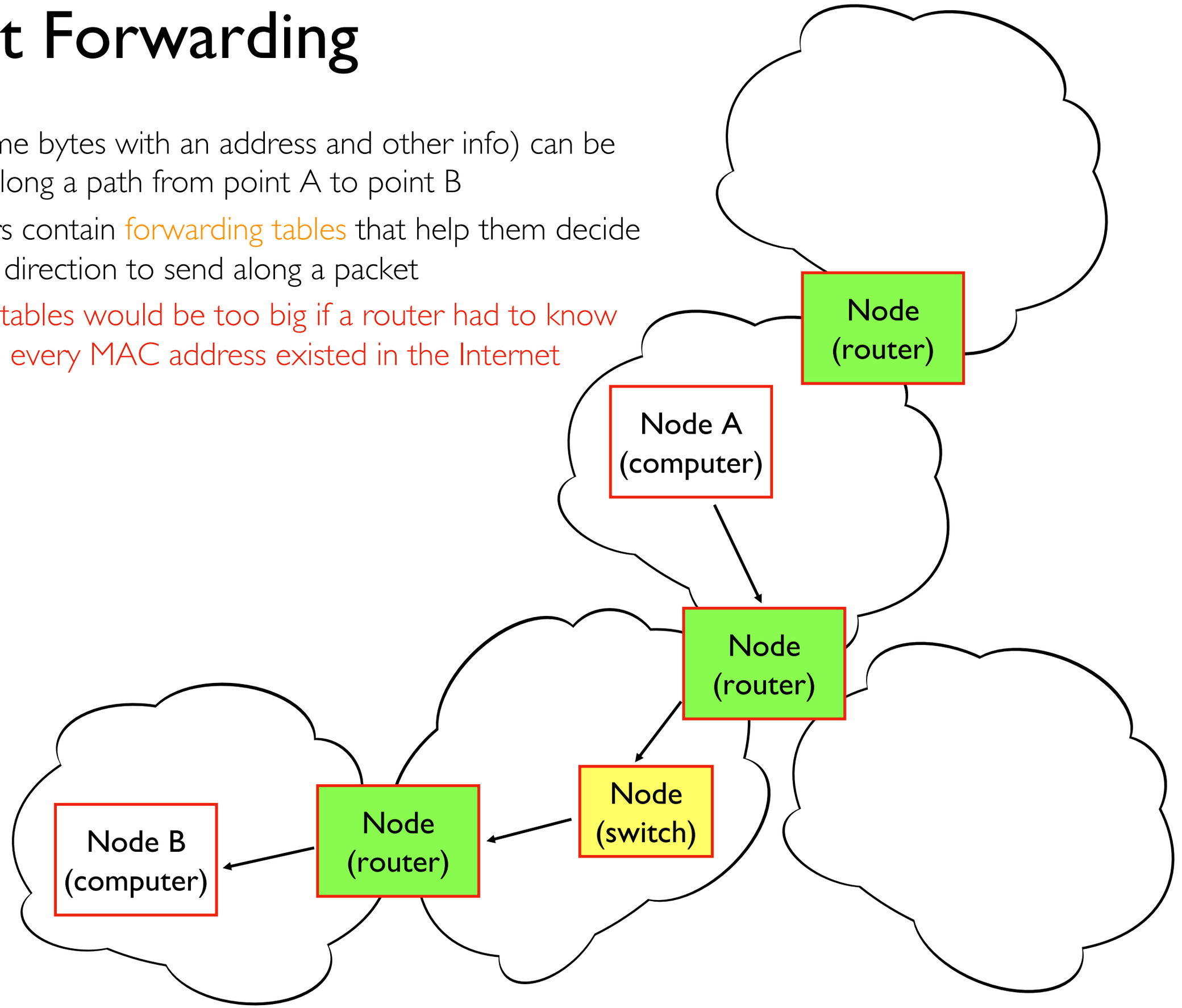
- routers connect networks together to form internets
- the global internet we all use is the "Internet"



Packet Forwarding

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

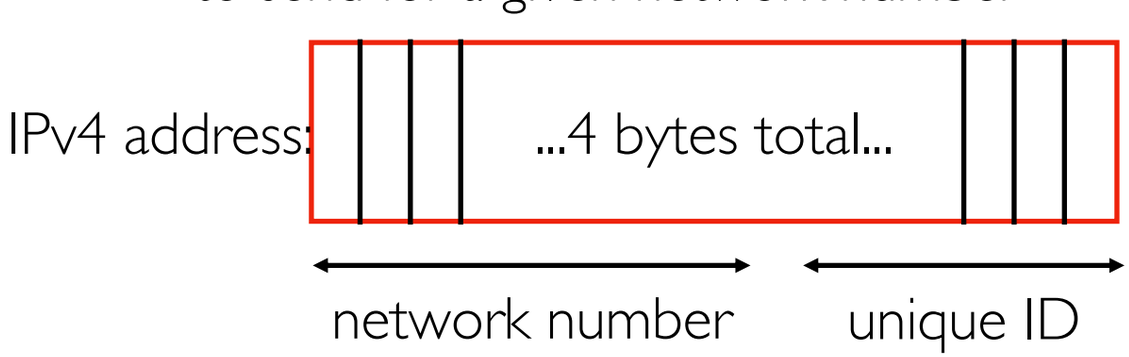
- routers contain forwarding tables that help them decide which direction to send along a packet
- those tables would be too big if a router had to know where every MAC address existed in the Internet

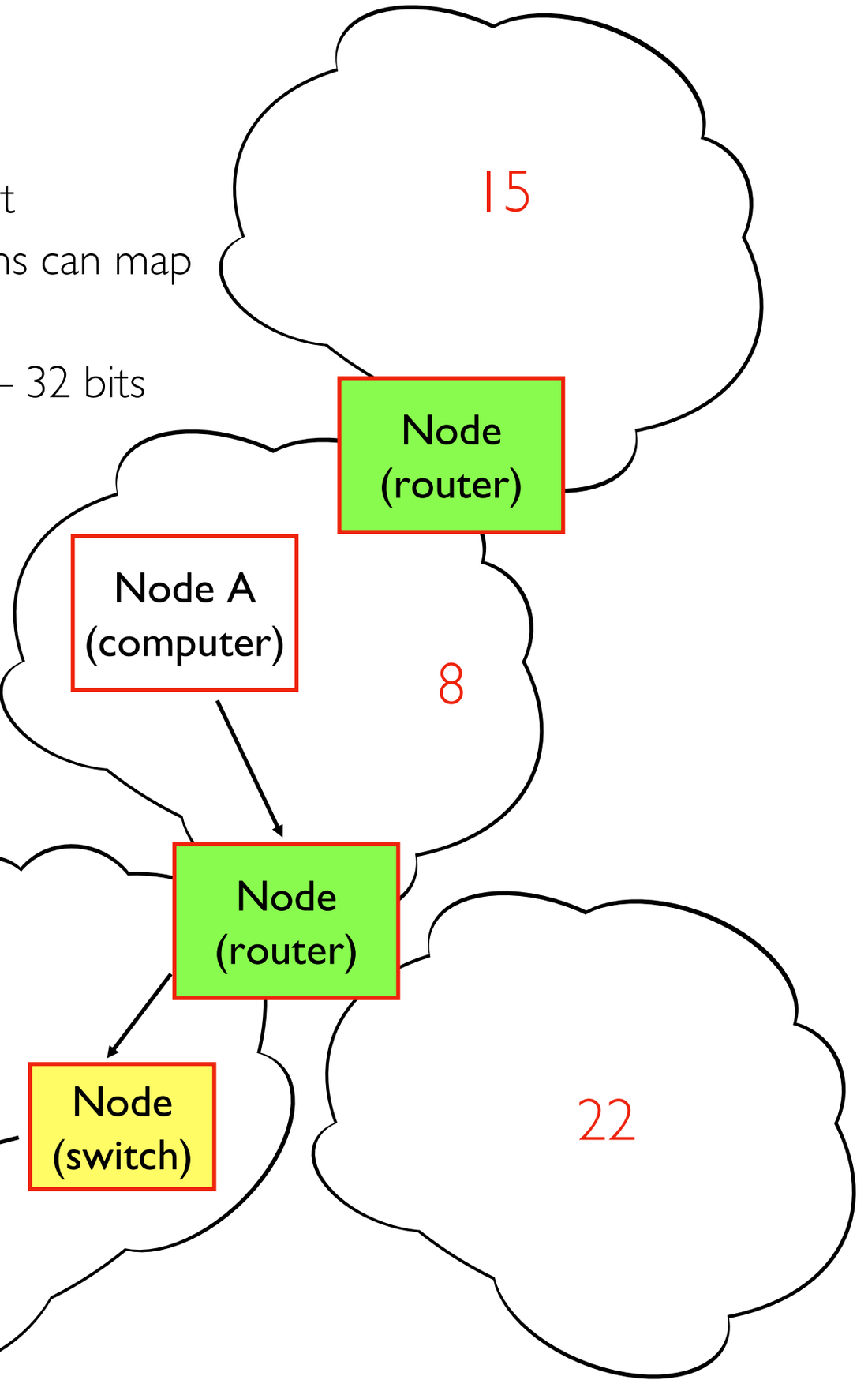


Internet Protocol

IP addresses are used to send packets across an internet

- example IPv4 address: `34.29.237.29` (domains can map to IP addrs)
- there are about 4 billion possible IPv4 addresses – 32 bits
- 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

```
meenakshisyamkumar@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::4001:aff:fe00:102  prefixlen 64  scopeid 0x20<link>
        ether 42:01:0a:00:01:02  txqueuelen 1000  (Ethernet)
        ...

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::4001:aff:fe00:302  prefixlen 64  scopeid 0x20<link>
        ether 42:01:0a:00:03:02  txqueuelen 1000  (Ethernet)
        ...

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)
        ...
```

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

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

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

all of them: `python3 -m http.server --bind 0.0.0.0`

Private Networks

Challenges

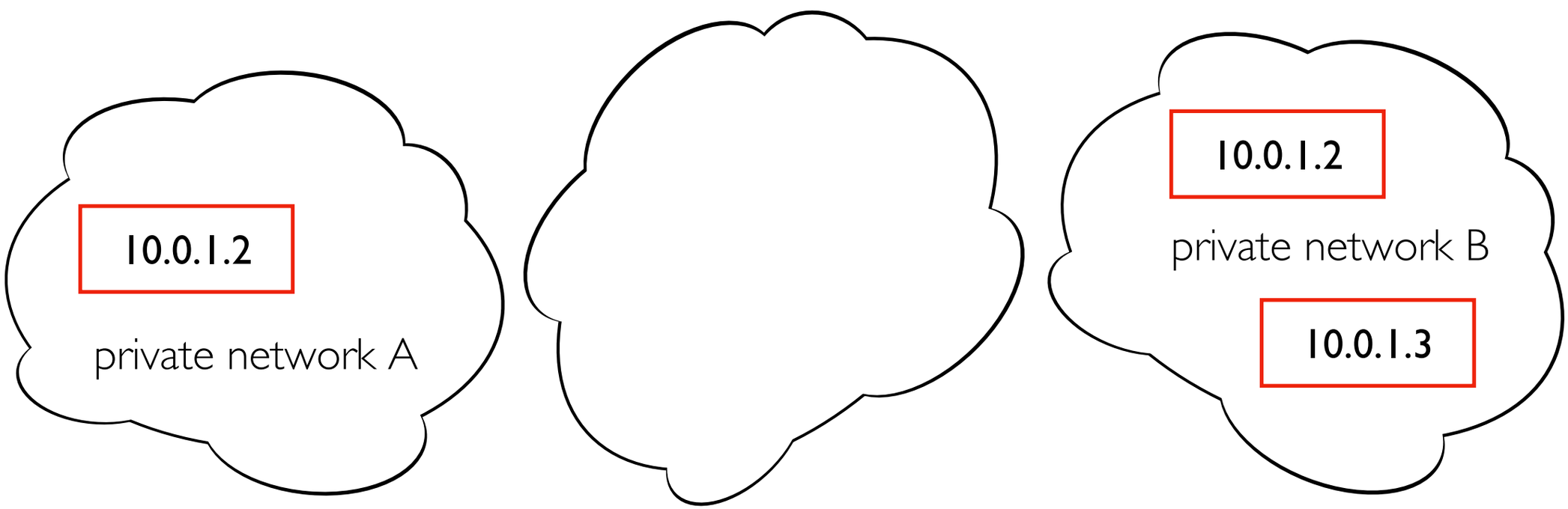
- we don't have enough IPv4 addresses
- we don't want every machine to be able to receive packets from anywhere

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

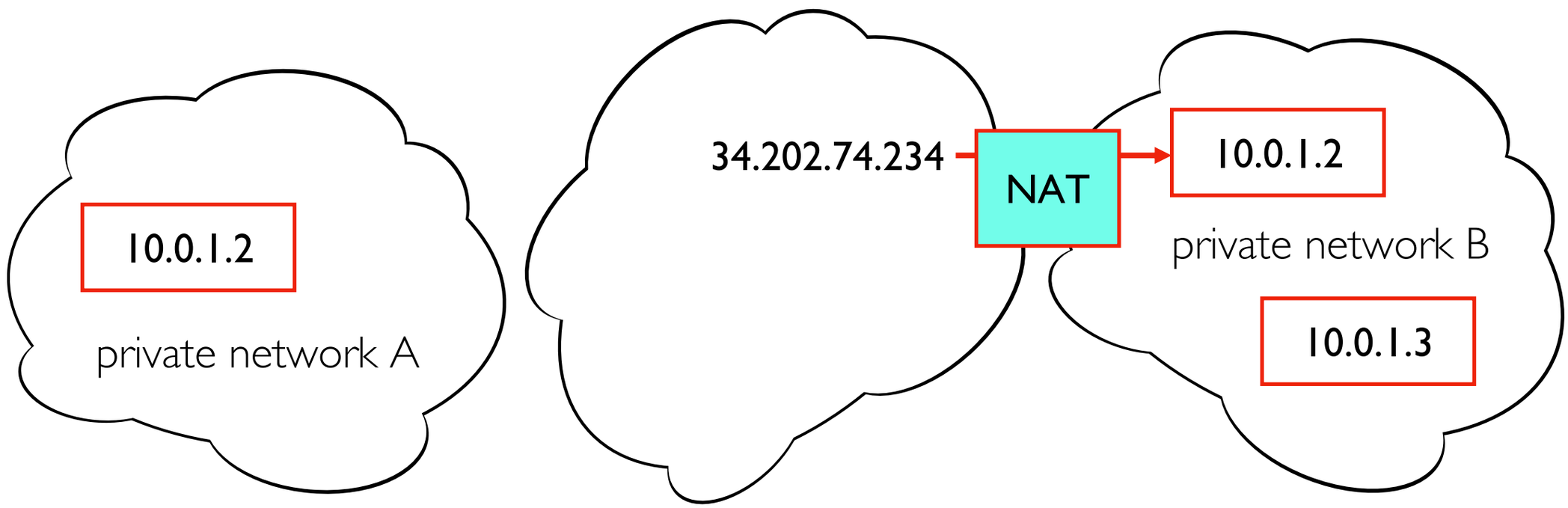
Private networks allow duplicates and unreachable machines



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) 10.0.3.2 (nic1)	35.202.74.234 (nic0) 34.29.220.248 (nic1)



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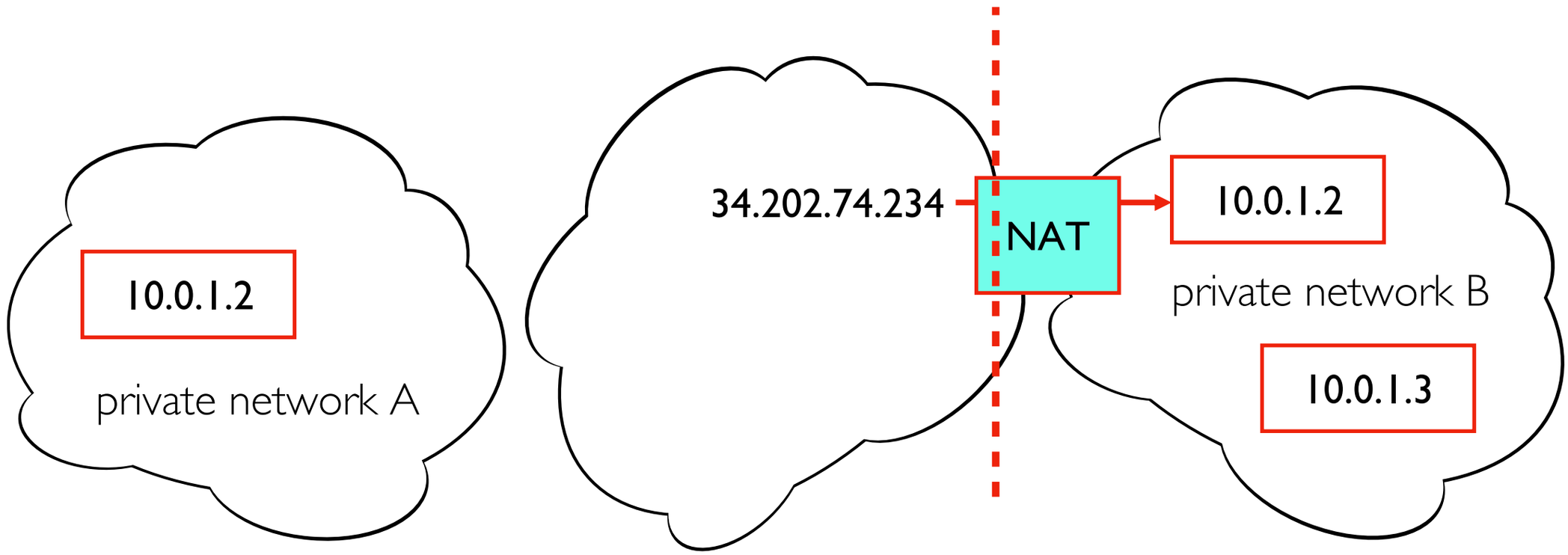
☐	✓	instance-2	10.0.1.2 (nic0) 10.0.3.2 (nic1)	35.202.74.234 (nic0) 34.29.220.248 (nic1)

a firewall can limit what traffic is allowed



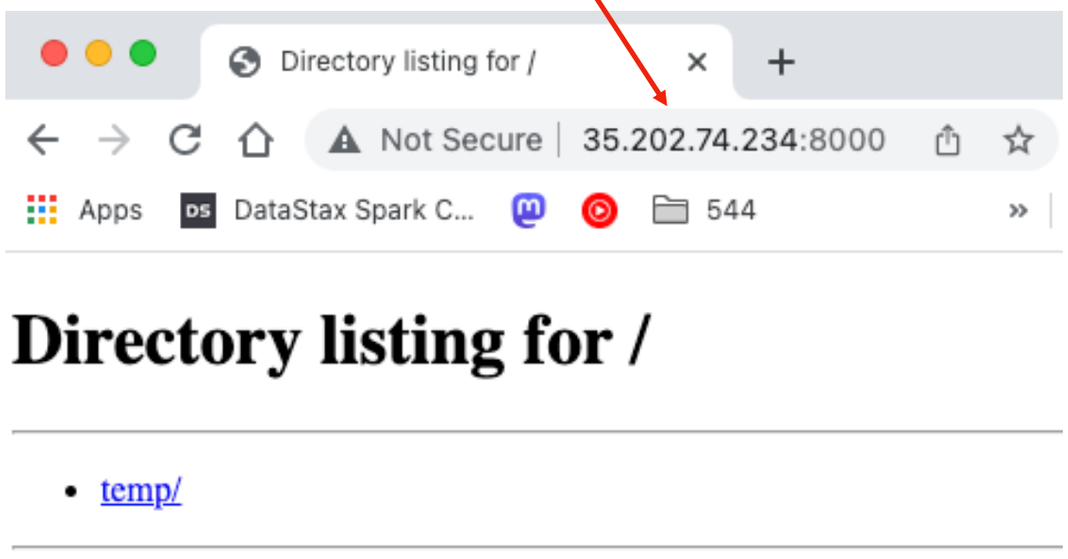
Network Address Translation

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) 10.0.3.2 (nic1)	35.202.74.234 (nic0) 34.29.220.248 (nic1)

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

Browser



Server

```
meenakshisyamkumar@instance-1:~$ 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 -
...
```

Outline

Networks

Internets and "The Internet"

Transport Protocols

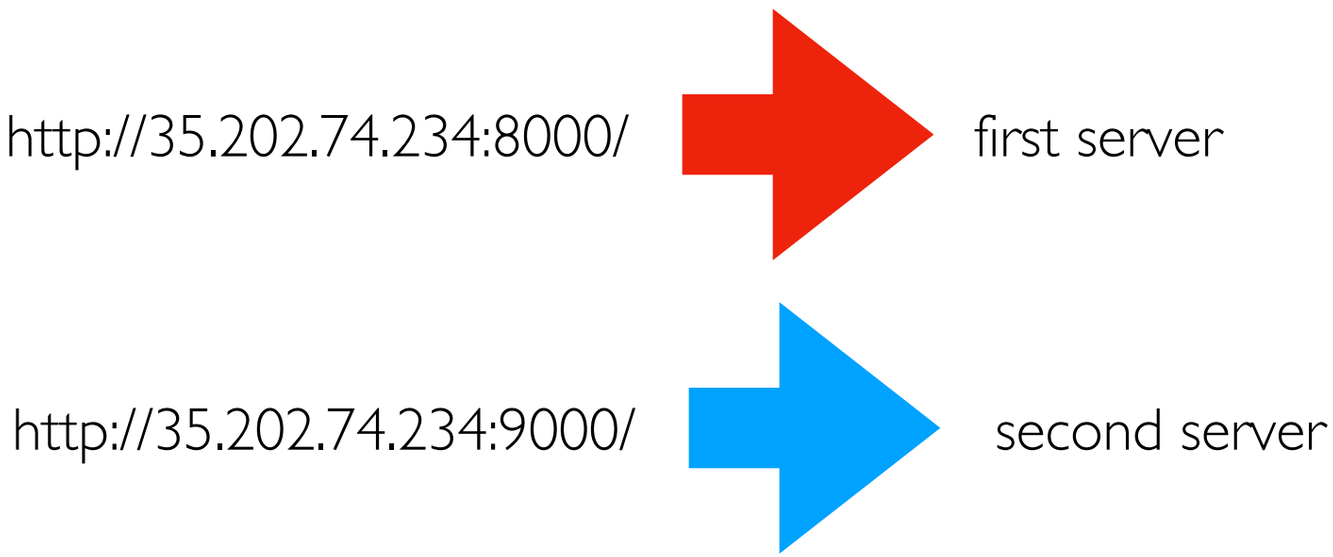
Port Numbers

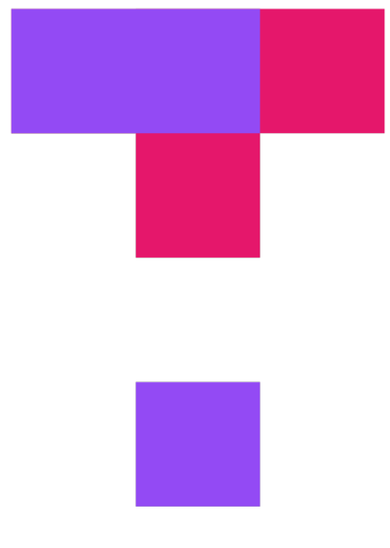
Computers might be running multiple processes using the network

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

```
meenakshisyamkumar@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/) ...
```

```
meenakshisyamkumar@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/) ...
```





TOP HAT

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

```
meenakshisyamkumar@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

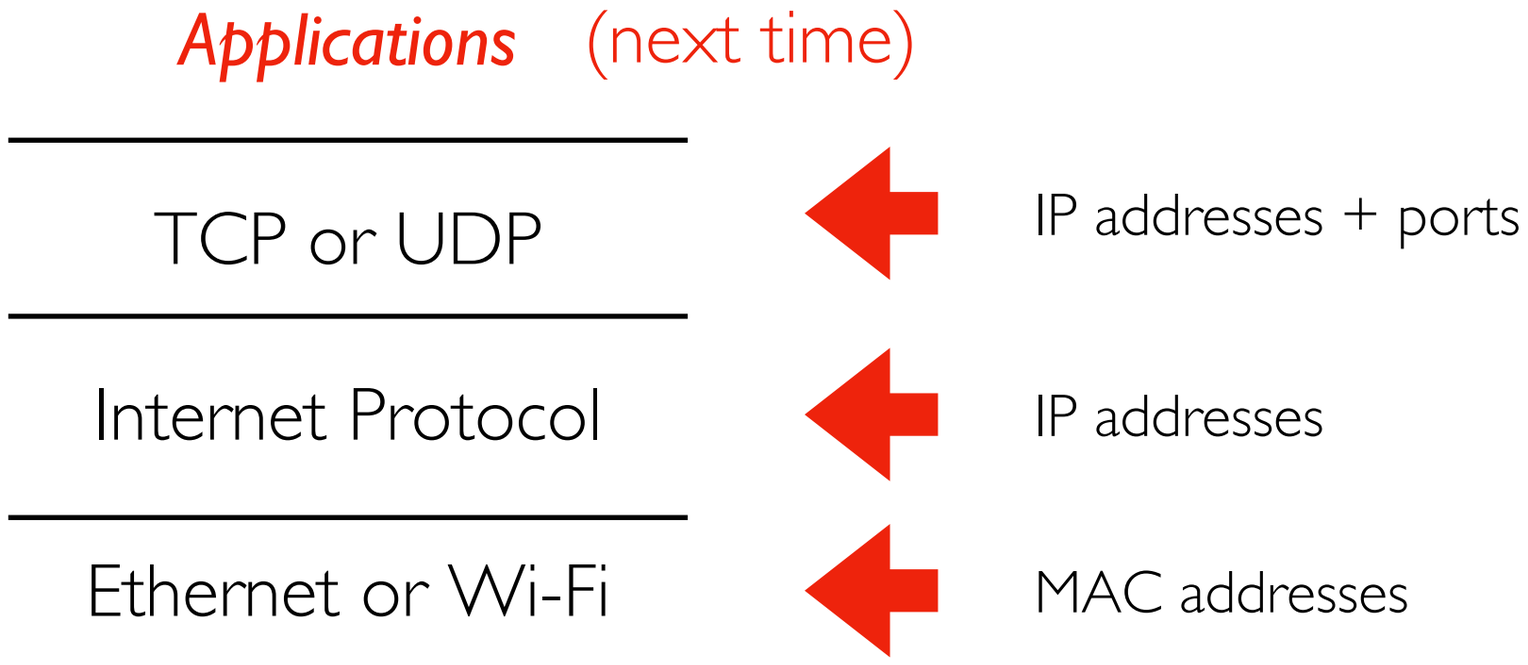
Packets may be

- 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.