last time

review: monitors

building connections in layers

- layers implemented using 'lower' one
- 4-layer internet-style model

transport layer: reliable streams

- acknowledgments and timeouts
- sequence numbers

names v addresses

assingments

TLB

openmp lab

life

anonymous feedback

what's the black thing — audio recorder

layers

application	HTTP, SSH, SMTP, ...	application-defined meanings
transport	TCP, UDP, ...	reach correct program, reliablity/streams
network	IPv4, IPv6, ...	reach correct machine (across networks)
link	Ethernet, Wi-Fi, ...	coordinate shared wire/radio
physical	...	encode bits for wire/radio

layers terminology

application	application-defined meanings	
transport	reach correct program, reliablity/streams	segments/datagrams
network	reach correct machine (across networks)	packets
link	coordinate shared wire/radio	frames
physical	encode bits for wire/radio	

names and addresses

name	address
logical identifier	location/how to locate
variable `counter`	memory address `0x7FFF9430`
DNS name `www.virginia.edu`	IPv4 address `128.143.22.36`
DNS name `mail.google.com`	IPv4 address `216.58.217.69`
DNS name `mail.google.com`	IPv6 address `2607:f8b0:4004:80b::2005`
DNS name `reiss-t3620.cs.virginia.edu`	IPv4 address `128.143.67.91`
DNS name `reiss-t3620.cs.virginia.edu`	MAC address `18:66:da:2e:7f:da`
service name `https`	port number 443
service name `ssh`	port number 22

layers

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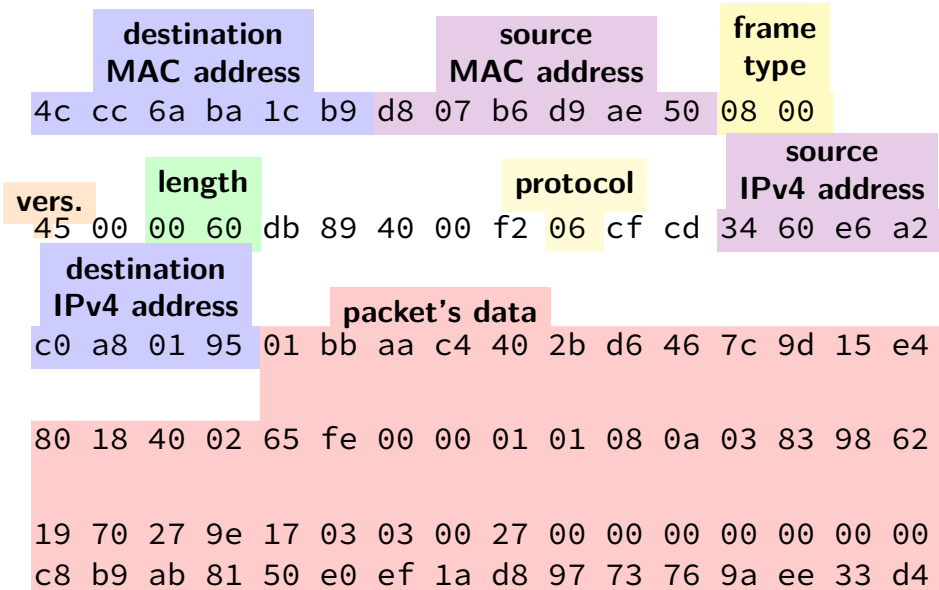
an Ethernet frame

destination MAC address	source MAC address	frame type
4c cc 6a ba 1c b9	d8 07 b6 d9 ae 50	08 00

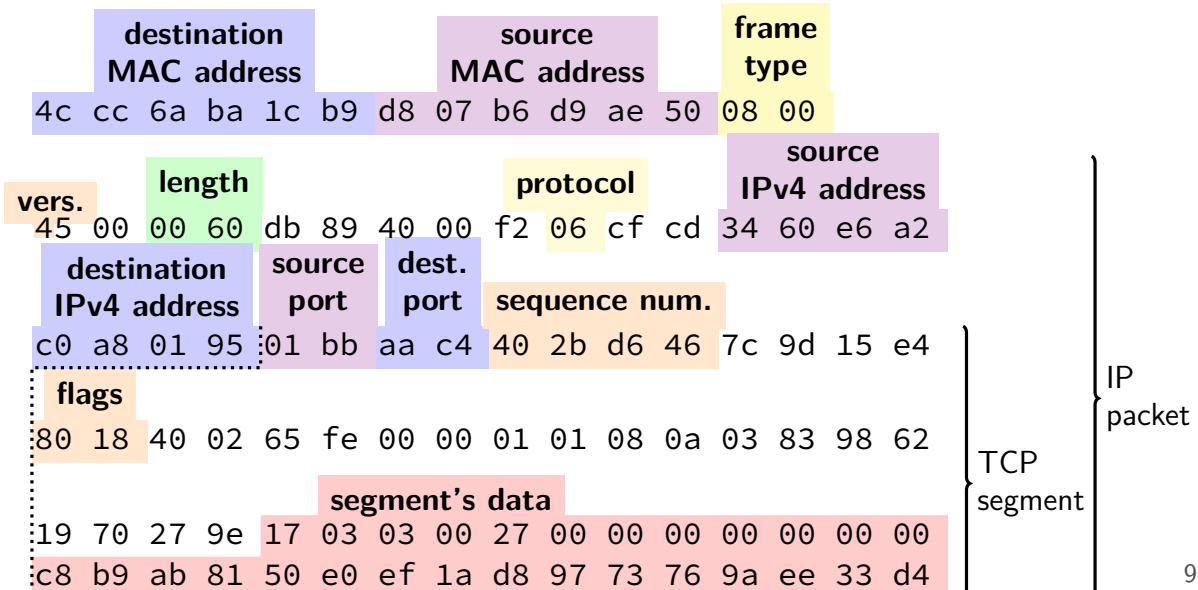
frame's data

```
45 00 00 60 db 89 40 00 f2 06 cf cd 34 60 e6 a2

c0 a8 01 95 01 bb aa c4 40 2b d6 46 7c 9d 15 e4

80 18 40 02 65 fe 00 00 01 01 08 0a 03 83 98 62

19 70 27 9e 17 03 03 00 27 00 00 00 00 00 00 00
c8 b9 ab 81 50 e0 ef 1a d8 97 73 76 9a ee 33 d4
```

an Ethernet frame



an Ethernet frame



the link layer

Ethernet, Wi-Fi, Bluetooth, DOCSIS (cable modems), ...

allows send/recv messages to machines on "same" network segment

- typically: wireless range+channel or connected to a single switch/router
- could be larger (if *bridging* multiple network segments)
- could be smaller (switch/router uses "virtual LANs")

typically: source+destination specified with MAC addresses

- MAC = media access control
- usually manufacturer assigned / hard-coded into device
- unique address per port/wifi transmitter/etc.

can specify destination of "anyone" (called *broadcast*)

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link layer jobs

divide raw bits into messages

identify who message is for on shared radio/wire

handle if two+ machines use radio/wire at same time

drop/resend messages if corruption detected

- resending more common in radio schemes (wifi, etc.)

layers

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the network layer

the Internet Protocool (IP) version 4 or version 6

- there are also others, but quite uncommon today

allows send messages to/recv messages from other networks

- "internetwork"

messages usually called "packets"

IPv4 addresses

32-bit numbers

typically written like 128.143.67.11

- four 8-bit decimal values separated by dots
- first part is most significant
- same as $128 \cdot 256^3 + 143 \cdot 256^2 + 67 \cdot 256 + 11 = 2\,156\,782\,459$

organizations get blocks of IPs

- e.g. UVa has 128.143.0.0–128.143.255.255
- e.g. Google has 216.58.192.0–216.58.223.255 and 74.125.0.0–74.125.255.255 and 35.192.0.0–35.207.255.255

some IPs reserved for non-Internet use (127.*, 10.*, 192.168.*)

IPv6 addresses

IPv6 like IPv4, but with 128-bit numbers

written in hex, 16-bit parts, seperated by colons (`:`)

strings of 0s represented by double-colons (`::`)

typically given to users in blocks of 2^{80} or 2^{64} addresses

- no need for address translation?

`2607:f8b0:400d:c00::6a` =
`2607:f8b0:400d:0c00:0000:0000:0000:006a`

- `2607f8b0400d0c0000000000000006a`$_{\text{SIXTEEN}}$

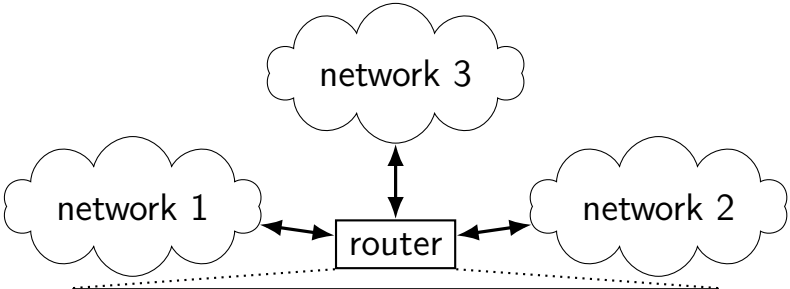
selected special IPv6 addresses

`::1` = localhost

anything starting with `fe80` = link-local addresses

- never forwarded by routers

IPv4 addresses and routing tables



if I receive data for...	send it to...
128.143.0.0—128.143.255.255	network 1
192.107.102.0–192.107.102.255	network 1
...	...
4.0.0.0–7.255.255.255	network 2
64.8.0.0–64.15.255.255	network 2
...	...
anything else	network 3

selected special IPv4 addresses

127.0.0.0 — 127.255.255.255 — localhost

- AKA loopback
- the machine we're on
- typically only 127.0.0.1 is used

192.168.0.0–192.168.255.255 and
10.0.0.0–10.255.255.255 and
172.16.0.0–172.31.255.255

- "private" IP addresses
- not used on the Internet
- commonly connected to Internet with network address translation
- also 100.64.0.0–100.127.255.255 (but with restrictions)

169.254.0.0-169.254.255.255

- link-local addresses — 'never' forwarded by routers

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port numbers

we run multiple programs on a machine

- IP addresses identifying machine — not enough

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so, add 16-bit *port numbers*

- think: multiple PO boxes at address

port numbers

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- think: multiple PO boxes at address

0–49151: typically assigned for particular services

- 80 = http, 443 = https, 22 = ssh, ...

49152–65535: allocated on demand

- default "return address" for client connecting to server

UDP v TCP

TCP: stream to other program

- reliable transmission of as much data as you want
- "connecting" fails if server not responding
- write(fd, "a", 1); write(fd, "b", 1) = write(fd, "ab", 2)
- (at least) one socket per remote program being talked to

UDP: messages sent to program, but no reliablity/streams

- unreliable transmission of short messages
- write(fd, "a", 1); write(fd, "b", 1) $\neq$ write(fd, "ab", 2)
- "connecting" just sets default destination
- can sendto()/recvfrom() multiple other programs with one socket
  - (but don't have to)

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  - (but don't have to)

exercise

suppose A connected to network 1

network 1 connected via router to network 2

and B connected to network 2

A already has TCP connection open to B

A sends 2000 bytes of data, which is split into 2 segments (of 1400 + 600 bytes)

how many frames sent?

connections in TCP/IP

connection identified by *5-tuple*

used by OS to lookup "where is the socket?"

(protocol=TCP/UDP, local IP addr., local port, remote IP addr., remote port)

local IP address, port number can be set with `bind()` function

typically always done for servers, not done for clients

system will choose default if you don't

connections on my desktop

```
cr4bd@reiss-t3620>/u/cr4bd
$ netstat --inet --inet6 --numeric
Active Internet connections (w/o servers)
Proto Recv-Q Send-Q Local Address           Foreign Address         State
tcp        0      0 128.143.67.91:49202     128.143.63.34:22        ESTABLISHE
tcp        0      0 128.143.67.91:803       128.143.67.236:2049     ESTABLISHE
tcp        0      0 128.143.67.91:50292     128.143.67.226:22       TIME_WAIT
tcp        0      0 128.143.67.91:54722     128.143.67.236:2049     TIME_WAIT
tcp        0      0 128.143.67.91:52002     128.143.67.236:111      TIME_WAIT
tcp        0      0 128.143.67.91:732       128.143.67.236:63439    TIME_WAIT
tcp        0      0 128.143.67.91:40664     128.143.67.236:2049     TIME_WAIT
tcp        0      0 128.143.67.91:54098     128.143.67.236:111      TIME_WAIT
tcp        0      0 128.143.67.91:49302     128.143.67.236:63439    TIME_WAIT
tcp        0      0 128.143.67.91:50236     128.143.67.236:111      TIME_WAIT
tcp        0      0 128.143.67.91:22        172.27.98.20:49566      ESTABLISHE
tcp        0      0 128.143.67.91:51000     128.143.67.236:111      TIME_WAIT
tcp        0      0 127.0.0.1:50438         127.0.0.1:631           ESTABLISHE
tcp        0      0 127.0.0.1:631           127.0.0.1:50438         ESTABLISHE
```

non-connection sockets

TCP servers waiting for connections +
UDP sockets with no particular remote host

Linux: OS keeps 5-tuple with “wildcard” remote address

“listening” sockets on my desktop

```
cr4bd@reiss-t3620>/u/cr4bd
$ netstat --inet --inet6 --numeric --listen
Active Internet connections (only servers)
Proto Recv-Q Send-Q Local Address           Foreign Address         State
tcp        0      0 127.0.0.1:38537         0.0.0.0:*               LISTEN
tcp        0      0 127.0.0.1:36777         0.0.0.0:*               LISTEN
tcp        0      0 0.0.0.0:41099           0.0.0.0:*               LISTEN
tcp        0      0 0.0.0.0:45291           0.0.0.0:*               LISTEN
tcp        0      0 127.0.0.1:51949         0.0.0.0:*               LISTEN
tcp        0      0 127.0.0.1:41071         0.0.0.0:*               LISTEN
tcp        0      0 0.0.0.0:111             0.0.0.0:*               LISTEN
tcp        0      0 127.0.0.1:32881         0.0.0.0:*               LISTEN
tcp        0      0 127.0.0.1:38673         0.0.0.0:*               LISTEN
....
tcp6       0      0 :::42689                :::*                    LISTEN
udp        0      0 128.143.67.91:60001     0.0.0.0:*
udp        0      0 128.143.67.91:60002     0.0.0.0:*
```

TCP state machine

TIME_WAIT, ESTABLISHED, ...?

OS tracks "state" of TCP connection

- am I just starting the connection?
- is other end ready to get data?
- am I trying to close the connection?
- do I need to resend something?

standardized set of state names

TIME_WAIT

remember delayed messages?

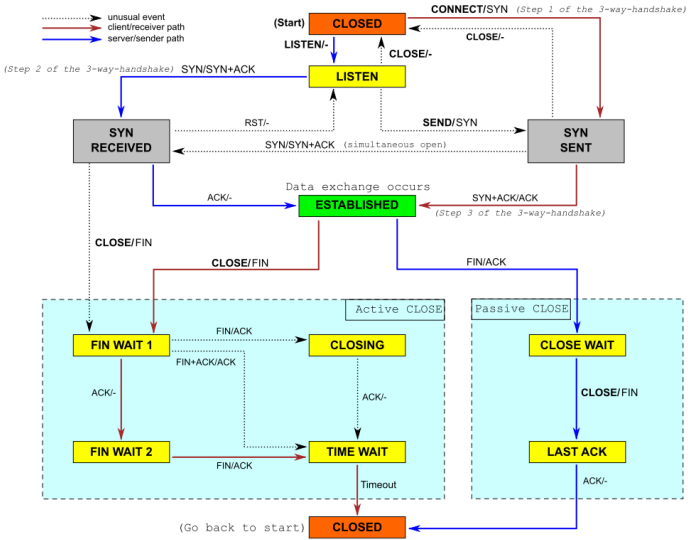
problem for TCP ports

if I reuse port number, I can get message from old connection

solution: TIME_WAIT to make sure connection really done

- done after sending last message in connection

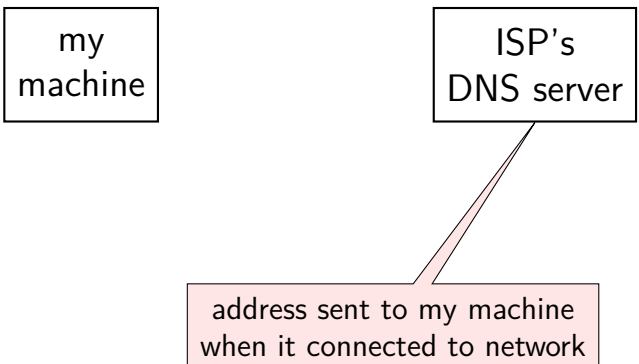
TCP state machine picture



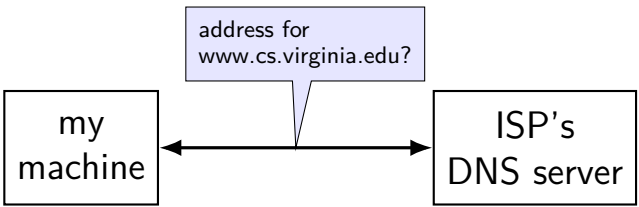
names and addresses

name	address
logical identifier	location/how to locate
variable `counter`	memory address `0x7FFF9430`
DNS name `www.virginia.edu`	IPv4 address `128.143.22.36`
DNS name `mail.google.com`	IPv4 address `216.58.217.69`
DNS name `mail.google.com`	IPv6 address `2607:f8b0:4004:80b::2005`
DNS name `reiss-t3620.cs.virginia.edu`	IPv4 address `128.143.67.91`
DNS name `reiss-t3620.cs.virginia.edu`	MAC address `18:66:da:2e:7f:da`
service name `https`	port number 443
service name `ssh`	port number 22

DNS: distributed database



DNS: distributed database



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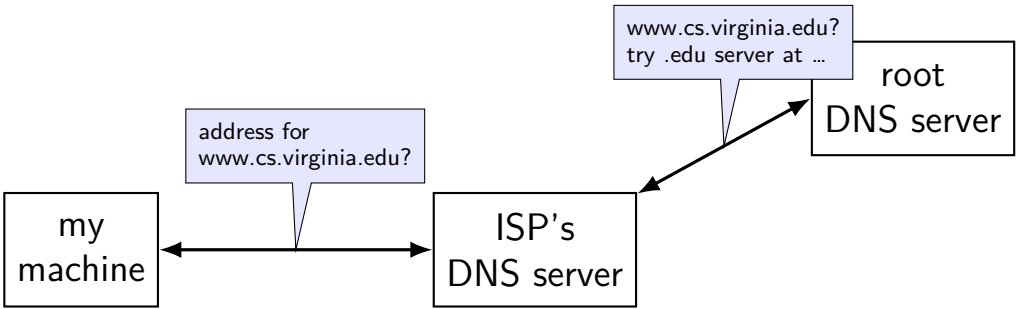

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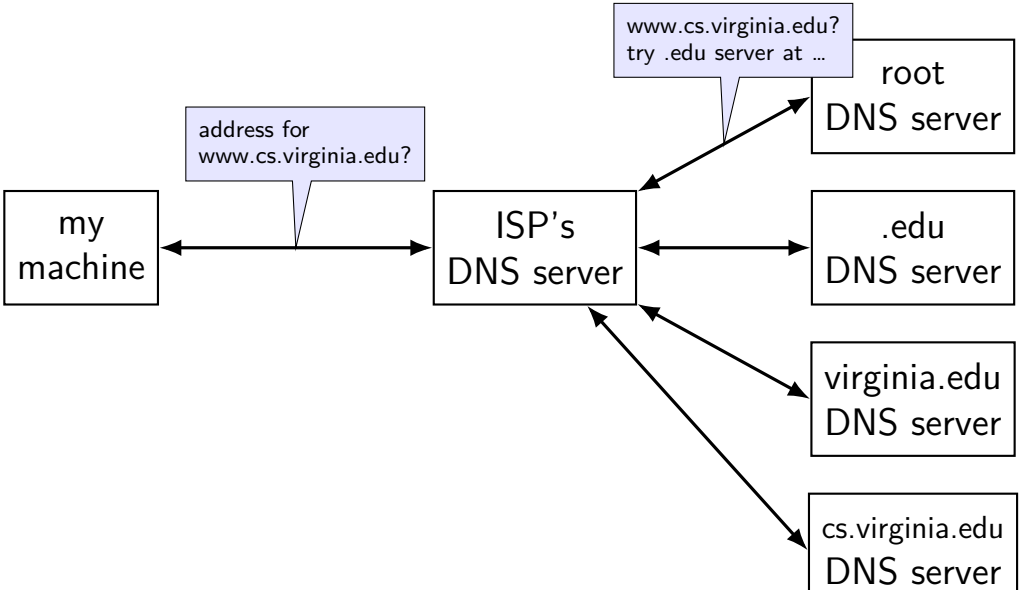

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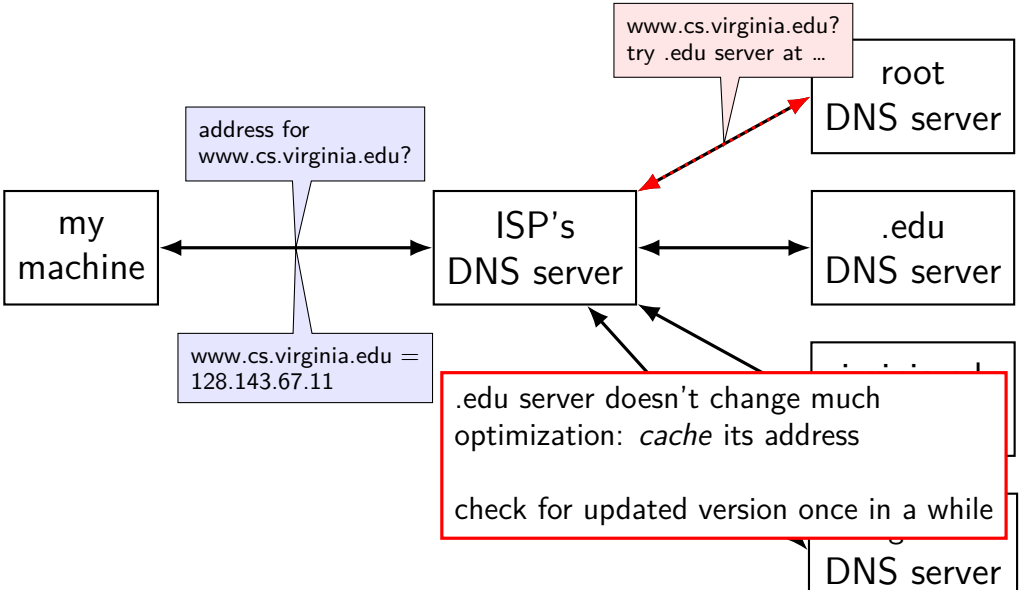

querying the root

```
$ dig +trace +all www.cs.virginia.edu
...
edu.                    172800      IN      NS      b.edu-servers.net.
edu.                    172800      IN      NS      f.edu-servers.net.
edu.                    172800      IN      NS      i.edu-servers.net.
edu.                    172800      IN      NS      a.edu-servers.net.
...
b.edu-servers.net.      172800      IN      A       191.33.14.30
b.edu-servers.net.      172800      IN      AAAA       2001:503:231d::2:30
f.edu-servers.net.      172800      IN      A       192.35.51.30
f.edu-servers.net.      172800      IN      AAAA       2001:503:d414::30
...
;; Received 843 bytes from 198.97.190.53#53(h.root-servers.net) in 8 ms
...
```

querying the edu

```
$ dig +trace +all www.cs.virginia.edu
...
virginia.edu.                 172800        IN        NS        nom.virginia.edu.
virginia.edu.                 172800        IN        NS        uvaarpa.virginia.edu.
virginia.edu.                 172800        IN        NS        eip-01-aws.net.virginia.edu.
nom.virginia.edu.        172800        IN        A        128.143.107.101
uvaarpa.virginia.edu.         172800        IN        A        128.143.107.117
eip-01-aws.net.virginia.edu. 172800 IN        A        44.234.207.10
;; Received 165 bytes from 192.26.92.30#53(c.edu-servers.net) in 40 ms
...
```

querying virginia.edu+cs.virginia.edu

```
$ dig +trace +all www.cs.virginia.edu
...
cs.virginia.edu.        3600        IN        NS        coresrv01.cs.virginia.edu.
coresrv01.cs.virginia.edu. 3600        IN        A        128.143.67.11
;; Received 116 bytes from 44.234.207.10#53(eip-01-aws.net.virginia.edu) in 72 ms

www.cs.Virginia.EDU.        172800        IN        A        128.143.67.11
cs.Virginia.EDU.        172800        IN        NS        coresrv01.cs.Virginia.EDU.
coresrv01.cs.Virginia.EDU. 172800 IN        A        128.143.67.11
;; Received 151 bytes from 128.143.67.11#53(coresrv01.cs.virginia.edu) in 4 ms
```

querying typical ISP's resolver

```
$ dig www.cs.virginia.edu
...
;; ANSWER SECTION:
www.cs.Virginia.EDU.          7183        IN        A        128.143.67.11
..
```

cached response

valid for 7183 more seconds

after that everyone needs to check again

exercise

suppose initially

*.foo.com DNS server ('nameserver') = 10.2.3.4, valid 200 s

www.foo.com = 10.1.2.3, valid 100 s

if at time 0 seconds, changed to:

*.foo.com DNS server = 10.3.4.5, valid 100 s

www.foo.com DNS server = 10.3.5.1, valid 400 s

ex 0: when will new DNS server/www.foo.com start being used?

ex 1: when can we shut down old DNS server?

ex 2: when can we shut down old www.foo.com?

names and addresses

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logical identifier	location/how to locate
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DNS name `reiss-t3620.cs.virginia.edu`	MAC address `18:66:da:2e:7f:da`
service name `https`	port number 443
service name `ssh`	port number 22

two types of addresses?

MAC addreses: on link layer

IP addresses: on network layer

how do we know which MAC address to use?

a table on my desktop

my desktop:

```
$ arp -an
? (128.143.67.140) at 3c:e1:a1:18:bd:5f [ether] on enp0s31f6
? (128.143.67.236) at <incomplete> on enp0s31f6
? (128.143.67.11) at 30:e1:71:5f:39:10 [ether] on enp0s31f6
? (128.143.67.92) at <incomplete> on enp0s31f6
? (128.143.67.5) at d4:be:d9:b0:99:d1 [ether] on enp0s31f6
```

...

network address to link-layer address + interface

only tracks things directly connected to my local network

- non-local traffic sent to local router

how is that table made?

ask all machines on local network (same switch)

"Who has 128.148.67.140"

the correct one replies

URL / URIs

Uniform Resource Locators (URL)

- tells how to find "resource" on network
- uniform — one syntax for multiple protocols (types of servers, etc.)

Unifrom Resources Identifiers

- superset of URLs

URI examples

```
https://kytos02.cs.virginia.edu:443/cs3130-spring2023/
                quizzes/quiz.php?qid=02#q2

https://kytos02.cs.virginia.edu/cs3130-spring2023/
                quizzes/quiz.php?qid=02

https://www.cs.virginia.edu/

sftp://cr4bd@portal.cs.virginia.edu/u/cr4bd/file.txt

tel:+1-434-982-2200

//www.cs.virginia.edu/~cr4bd/3130/S2023/
/~cr4bd/3130/S2023
```

scheme and/or host implied from context

URI generally

`scheme://authority/path?query#fragment`

scheme: — what protocol

//authority/

authoirty = user@host:port OR host:port OR user@host OR host

path

which resource

?query — usually key/value pairs

#fragment — place in resource

most components (sometimes) optional

URLs and HTTP (1)

`http://www.foo.com:80/foo/bar?quux#q1`

lookup IP address of www.foo.com

connect via TCP to port 80:

```
GET /foo/bar?quux HTTP/1.1
Host: www.foo.com:80
```

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```

exercise: why include the Host there?

autoconfiguration

problem: how does my machine get IP address

otherwise:

- have sysadmin type one in?
- just choose one?
- ask machine on local network to assign it

autoconfiguration

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otherwise:

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- just choose one?
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often local router machine runs service to assign IP addresses

- knows what IP addresses are available
- sysadmin might configure in mapping from MAC addresses to IP addresses

DHCP high-level

protocol done over UDP

but since we don't have IP address yet, use `0.0.0.0`

and since we don't know server address, use `255.255.255.255`
= "everyone on the local network"

local server replies to request with address + time limit

later: can send messages to local server to renew/give up address

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= "everyone on the local network"

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exercise: why time limit?

DHCP “lease”

rather than getting address forever

but DHCP has way of releasing taken address

why impose a time limit

network address translation

IPv4 addresses are kinda scarce

solution: *convert* many private addrs. to one public addr.

locally: use private IP addresses for machines

outside: private IP addresses become a single public one

commonly how home networks work (and some ISPs)

implementing NAT

remote host + port	outside local port number	inside IP	inside port number
128.148.17.3:443	54033	192.168.1.5	43222
11.7.17.3:443	53037	192.168.1.5	33212
128.148.31.2:22	54032	192.168.1.37	43010
128.148.17.3:443	63039	192.168.1.37	32132

table of the translations

need to update as new connections made

spoofing

if I only allow connections from my desktop's IP addresses, how would you attack this?

hint: how do we know what address messages come from?

upcoming lab

request + receive message split into pieces

you are responsible for:

- requesting parts in order
- resending requests if messages lost/corrupted

"acknowledge" receiving part X to request part X+1

upcoming lab

request + receive message split into pieces

you are responsible for:

- requesting parts in order
- resending requests if messages lost/corrupted

"acknowledge" receiving part X to request part X+1

protocol

GETx — retrieve message x (x = 0, 1, 2, or 3)

other end acknowledges by giving data

if they don't acknowledge, you need to send again

higher numbered messages have errors/etc. that are harder to handle

ACKn

request message $n + 1$ by acknowledging message n

not quite same purpose as acknowledgments in prior examples

(in lab, the response is your 'acknowledgment' of your request;
you retry if you don't get it)

callback-based programming (1)

```
/* library code you don't write */
/* in the lab: part of waitForAllTimeoutsAndMessagesThenExit(
void mainLoop() {
    while (notExiting) {
        Event event = waitForAndGetNextEvent();
        if (event.type == RECIEVED) {
            recvd(...);
        } else if (event.type == TIMEOUT) {
            (event.timeout_function)(...);
        }
        ...
    }
}
```

callback-based programming (2)

```
/* your code, called by library */
void recvd(...) {
    ...
    setTimeout(..., timerCallback, ...);
}

void timerCallback(...) {
    ...
}

int main() {
    send(.../* first message */);
    ... /* other initial setup */
    waitForAllTimeoutsAndMessagesThenExit(); // runs mainLoop
}
```

callback-based programming

writing scripts in a webpage

many graphical user interface libraries

sometimes servers that handle lots of connections

firewalls

don't want to expose network service to everyone?

solutions:

- service picky about who it accepts connections from
- filters in OS on machine with services
- filters on router

later two called "firewalls"

firewall rules examples?

ALLOW tcp port 443 (https) FROM everyone

ALLOW tcp port 22 (ssh) FROM my desktop's IP address

BLOCK tcp port 22 (ssh) FROM everyone else

ALLOW from address X to address Y

...

backup slides

link layer reliablity?

Ethernet + Wifi have checksums

Q1: Why doesn't this give us uncorrupted messages?
Why do we still have checksums at the higher layers?

Q2: What's a benefit of doing this if we're also doing it in the higher layer?

link layer quality of service

if frame gets...

event	on Ethernet	on WiFi
collides with another	detected + may resend	resend
not received	lose silently	resent
header corrupted	usually discard silently	usually resend
data corrupted	usually discard silently	usually resend
too long	not allowed to send	not allowed to send
reordered (v. other messages)	received out of order	received out of order
destination unknown	lose silently	usually resend??
too much being sent	discard excess?	discard excess?

network layer quality of service

if packet ...

event	on IPv4/v6
collides with another	out of scope — handled by link layer
not received	lost silently
header corrupted	usually discarded silently
data corrupted	received corrupted
too long	dropped with notice or "fragmented" + recombined
reordered (v. other messages)	received out of order
destination unknown	usually dropped with notice
too much being sent	discard excess

network layer quality of service

if packet ...

event	on IPv4/v6
collides with another	out of scope — handled by link layer
not received	lost silently
header corrupted	usually discarded silently
data corrupted	received corrupted
too long	dropped with notice or "fragmented" + recombined
reordered (v. other messages)	received out of order
destination unknown	usually dropped with notice
too much being sent	discard excess

includes dropped by link layer
(e.g. if detected corrupted there)

firewalls

don't want to expose network service to everyone?

solutions:

- service picky about who it accepts connections from
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- filters on router

later two called "firewalls"

firewall rules examples?

ALLOW tcp port 443 (https) FROM everyone

ALLOW tcp port 22 (ssh) FROM my desktop's IP address

BLOCK tcp port 22 (ssh) FROM everyone else

ALLOW from address X to address Y

...

t

querying the root

```
$ dig +trace +all www.cs.virginia.edu
...
edu.                    172800      IN      NS      b.edu-servers.net.
edu.                    172800      IN      NS      f.edu-servers.net.
edu.                    172800      IN      NS      i.edu-servers.net.
edu.                    172800      IN      NS      a.edu-servers.net.
...
b.edu-servers.net.      172800      IN      A       191.33.14.30
b.edu-servers.net.      172800      IN      AAAA       2001:503:231d::2:30
f.edu-servers.net.      172800      IN      A       192.35.51.30
f.edu-servers.net.      172800      IN      AAAA       2001:503:d414::30
...
;; Received 843 bytes from 198.97.190.53#53(h.root-servers.net) in 8 ms
...
```

querying the edu

```
$ dig +trace +all www.cs.virginia.edu
...
virginia.edu.                172800        IN        NS        nom.virginia.edu.
virginia.edu.                172800        IN        NS        uvaarpa.virginia.edu.
virginia.edu.                172800        IN        NS        eip-01-aws.net.virginia.edu.
nom.virginia.edu.        172800        IN        A        128.143.107.101
uvaarpa.virginia.edu.        172800        IN        A        128.143.107.117
eip-01-aws.net.virginia.edu. 172800 IN        A        44.234.207.10
;; Received 165 bytes from 192.26.92.30#53(c.edu-servers.net) in 40 ms
...
```

querying virginia.edu+cs.virginia.edu

```
$ dig +trace +all www.cs.virginia.edu
...
cs.virginia.edu.        3600        IN        NS        coresrv01.cs.virginia.edu.
coresrv01.cs.virginia.edu. 3600        IN        A        128.143.67.11
;; Received 116 bytes from 44.234.207.10#53(eip-01-aws.net.virginia.edu) in 72 ms

www.cs.Virginia.EDU.        172800        IN        A        128.143.67.11
cs.Virginia.EDU.        172800        IN        NS        coresrv01.cs.Virginia.EDU.
coresrv01.cs.Virginia.EDU. 172800 IN        A        128.143.67.11
;; Received 151 bytes from 128.143.67.11#53(coresrv01.cs.virginia.edu) in 4 ms
```

querying typical ISP's resolver

```
$ dig www.cs.virginia.edu
...
;; ANSWER SECTION:
www.cs.Virginia.EDU.          7183        IN        A        128.143.67.11
..
```

cached response

valid for 7183 more seconds

after that everyone needs to check again

‘connected’ UDP sockets

```
int fd = socket(AF_INET, SOCK_DGRAM, 0);
struct sockaddr_in my_addr= ...;
/* set local IP address + port */
bind(fd, &my_addr, sizeof(my_addr))
struct sockaddr_in to_addr = ...;
connect(fd, &to_addr); /* set remote IP address + port */
    /* doesn't actually communicate with remote address yet */
...
int count = write(fd, data, data_size);
// OR
int count = send(fd, data, data_size, 0 /* flags */);
    /* single message -- sent ALL AT ONCE */

int count = read(fd, buffer, buffer_size);
// OR
int count = recv(fd, buffer, buffer_size, 0 /* flags */);
    /* receives whole single message ALL AT ONCE */
```

UDP sockets on IPv4

```
int fd = socket(AF_INET, SOCK_DGRAM, 0);
struct sockaddr_in my_addr= ...;
/* set local IP address + port */
if (0 != bind(fd, &my_addr, sizeof(my_addr)))
    handle_error();
...
struct sockaddr_in to_addr = ...;
    /* send a message to specific address */
int bytes_sent = sendto(fd, data, data_size, 0 /* flags */,
    &to_addr, sizeof(to_addr));

struct sockaddr_in from_addr = ...;
    /* receive a message + learn where it came from */
int bytes_recvd = recvfrom(fd, &buffer[0], buffer_size, 0,
    &from_addr, sizeof(from_addr));
...
```

what about non-local machines?

when configuring network specify:

range of addresses to expect on local network

- 128.148.67.0-128.148.67.255 on my desktop
- "netmask"

gateway machine to send to for things outside my local network

- 128.143.67.1 on my desktop
- my desktop looks up the corresponding MAC address

routes on my desktop

```
$ /sbin/route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         128.143.67.1    0.0.0.0         UG    100    0        0 enp0s31f6
128.143.67.0    0.0.0.0         255.255.255.0   U     100    0        0 enp0s31f6
169.254.0.0     0.0.0.0         255.255.0.0     U     1000   0        0 enp0s31f6
```

network configuration says:

(line 2) to get to 128.143.67.0–128.143.67.255, send directly on local network

"genmask" is mask (for bitwise operations) to specify how big range is

(line 3) to get to 169.254.0.0–169.254.255.255, send directly on local network

(line 1) to get anywhere else, use "gateway" 128.143.67.1

querying the root

```
$ dig +trace +all www.cs.virginia.edu
...
edu.                    172800      IN      NS      b.edu-servers.net.
edu.                    172800      IN      NS      f.edu-servers.net.
edu.                    172800      IN      NS      i.edu-servers.net.
edu.                    172800      IN      NS      a.edu-servers.net.
...
b.edu-servers.net.      172800      IN      A       191.33.14.30
b.edu-servers.net.      172800      IN      AAAA       2001:503:231d::2:30
f.edu-servers.net.      172800      IN      A       192.35.51.30
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...
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querying the edu

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$ dig +trace +all www.cs.virginia.edu
...
virginia.edu.                 172800        IN        NS        nom.virginia.edu.
virginia.edu.                 172800        IN        NS        uvaarpa.virginia.edu.
virginia.edu.                 172800        IN        NS        eip-01-aws.net.virginia.edu.
nom.virginia.edu.        172800        IN        A        128.143.107.101
uvaarpa.virginia.edu.         172800        IN        A        128.143.107.117
eip-01-aws.net.virginia.edu. 172800 IN        A        44.234.207.10
;; Received 165 bytes from 192.26.92.30#53(c.edu-servers.net) in 40 ms
...
```

querying virginia.edu+cs.virginia.edu

```
$ dig +trace +all www.cs.virginia.edu
...
cs.virginia.edu.        3600        IN        NS        coresrv01.cs.virginia.edu.
coresrv01.cs.virginia.edu. 3600        IN        A        128.143.67.11
;; Received 116 bytes from 44.234.207.10#53(eip-01-aws.net.virginia.edu) in 72 ms

www.cs.Virginia.EDU.        172800        IN        A        128.143.67.11
cs.Virginia.EDU.        172800        IN        NS        coresrv01.cs.Virginia.EDU.
coresrv01.cs.Virginia.EDU. 172800 IN        A        128.143.67.11
;; Received 151 bytes from 128.143.67.11#53(coresrv01.cs.virginia.edu) in 4 ms
```

querying typical ISP's resolver

```
$ dig www.cs.virginia.edu
...
;; ANSWER SECTION:
www.cs.Virginia.EDU.          7183        IN        A        128.143.67.11
..
```

cached response

valid for 7183 more seconds

after that everyone needs to check again

connection setup: server, manual

```
int server_socket_fd = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
struct sockaddr_in addr;
addr.sin_family = AF_INET;
addr.sin_addr.s_addr = INADDR_ANY; /* "any address I can use" */
    /* or: addr.s_addr.in_addr = INADDR_LOOPBACK (127.0.0.1) */
    /* or: addr.s_addr.in_addr = htonl(...); */
addr.sin_port = htons(9999); /* port number 9999 */

if (bind(server_socket_fd, &addr, sizeof(addr)) < 0) {
    /* handle error */
}
listen(server_socket_fd, MAX_NUM_WAITING);
...
int socket_fd = accept(server_socket_fd, NULL);
```

connection setup: server, manual

```
int server_socket_fd = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
struct sockaddr_in addr;
addr.sin_family = AF_INET;
addr.sin_addr.s_addr = INADDR_ANY; /* "any address I can use" */
    /* or: addr.s_addr.in_addr = INADDR_LOOPBACK (127.0.0.1) */
    /* or: addr.s_addr.in_addr = htonl(...); */
addr.sin_port = htons(9999); /* port number 9999 */

if (bind(server_socket_fd, &addr, sizeof(addr)) < 0) {
    /* handle error */
}
lister
...
int so
```

INADDR_ANY: accept connections for any address I can!
alternative: specify specific address

connection setup: server, manual

```
int server_socket_fd = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
struct sockaddr_in addr;
addr.sin_family = AF_INET;
addr.sin_addr.s_addr = INADDR_ANY; /* "any address I can use" */
    /* or: addr.s_addr.in_addr = INADDR_LOOPBACK (127.0.0.1) */
    /* or: addr.s_addr.in_addr = htonl(...); */
addr.sin_port = htons(9999); /* port number 9999 */

if (bind(server_socket_fd, &addr, sizeof(addr)) < 0) {
    /* handle error */
}
lis
...
int
```

bind to 127.0.0.1? only accept connections from same machine

what we recommend for FTP server assignment

connection setup: server, manual

```
int server_socket_fd = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
struct sockaddr_in addr;
addr.sin_family = AF_INET;
addr.sin_addr.s_addr = INADDR_ANY; /* "any address I can use" */
    /* or: addr.s_addr.in_addr = INADDR_LOOPBACK (127.0.0.1) */
    /* or: addr.s_addr.in_addr = htonl(...); */
addr.sin_port = htons(9999); /* port number 9999 */

if (bind(server_socket_fd, &addr, sizeof(addr)) < 0) {
    /* handle error */
}
listen(serv
...
int socket_fd = accept(server_socket_fd, NULL);
```

choose the number of unaccepted connections

connection setup: client — manual addresses

```
int sock_fd;

server = /* code on later slide */;
sock_fd = socket(
    AF_INET, /* IPv4 */
    SOCK_STREAM, /* byte-oriented */
    IPPROTO_TCP
);
if (sock_fd < 0) { /* handle error */ }

struct sockaddr_in addr;
addr.sin_family = AF_INET;
addr.sin_addr.s_addr = htonl(2156872459); /* 128.143.67.11 */
addr.sin_port = htons(80); /* port 80 */
if (connect(sock_fd, (struct sockaddr*) &addr, sizeof(addr)) {
    /* handle error */
}
DoClientStuff(sock_fd); /* read and write from sock_fd */
```

connection setup: client — manual addresses

```
int sock_fd;

server = /* code on later slide */;
sock_fd = socket(
    AF_INET, /* IPv4 */
    SOCK_STREAM, /* byte-oriented */
    IPPROTO_TCP
);
if (sock_fd < 0) { /* handle error */ }
st
ad
addr.sin_addr.s_addr = htonl(2156872459); /* 128.143.67.11 */
addr.sin_port = htons(80); /* port 80 */
if (connect(sock_fd, (struct sockaddr*) &addr, sizeof(addr)) {
    /* handle error */
}
DoClientStuff(sock_fd); /* read and write from sock_fd */
```

specify IPv4 instead of IPv6 or local-only sockets

specify TCP (byte-oriented) instead of UDP ('datagram' oriented)

connection setup: client — manual addresses

```
int sock_fd;

server = /* cod
sock_fd = socke
    AF_INET, /*
    SOCK_STREAM, /* byte-oriented */
    IPPROTO_TCP
);
if (sock_fd < 0) { /* handle error */ }

struct sockaddr_in addr;
addr.sin_family = AF_INET;
addr.sin_addr.s_addr = htonl(2156872459); /* 128.143.67.11 */
addr.sin_port = htons(80); /* port 80 */
if (connect(sock_fd, (struct sockaddr*) &addr, sizeof(addr)) {
    /* handle error */
}
DoClientStuff(sock_fd); /* read and write from sock_fd */
```

htonl/s = host-to-network long/short
network byte order = big endian

connection setup: client — manual addresses

```
int sock_fd;

server = /
sock_fd =
    AF_INE
    SOCK_S
    IPPROTO_TCP
);
if (sock_fd < 0) { /* handle error */ }

struct sockaddr_in addr;
addr.sin_family = AF_INET;
addr.sin_addr.s_addr = htonl(2156872459); /* 128.143.67.11 */
addr.sin_port = htons(80); /* port 80 */
if (connect(sock_fd, (struct sockaddr*) &addr, sizeof(addr)) {
    /* handle error */
}
DoClientStuff(sock_fd); /* read and write from sock_fd */
```

struct representing IPv4 address + port number
declared in <netinet/in.h>
see man 7 ip on Linux for docs

echo client/server

```
void client_for_connection(int socket_fd) {
    int n; char send_buf[MAX_SIZE]; char recv_buf[MAX_SIZE];
    while (prompt_for_input(send_buf, MAX_SIZE)) {
        n = write(socket_fd, send_buf, strlen(send_buf));
        if (n != strlen(send_buf)) {...error?...}
        n = read(socket_fd, recv_buf, MAX_SIZE);
        if (n <= 0) return; // error or EOF
        write(STDOUT_FILENO, recv_buf, n);
    }
}
```

```
void server_for_connection(int socket_fd) {
    int read_count, write_count; char request_buf[MAX_SIZE];
    while (1) {
        read_count = read(socket_fd, request_buf, MAX_SIZE);
        if (read_count <= 0) return; // error or EOF
        write_count = write(socket_fd, request_buf, read_count);
        if (read_count != write_count) {...error?...}
    }
```

echo client/server

```
void client_for_connection(int socket_fd) {
    int n; char send_buf[MAX_SIZE]; char recv_buf[MAX_SIZE];
    while (prompt_for_input(send_buf, MAX_SIZE)) {
        n = write(socket_fd, send_buf, strlen(send_buf));
        if (n != strlen(send_buf)) {...error?...}
        n = read(socket_fd, recv_buf, MAX_SIZE);
        if (n <= 0) return; // error or EOF
        write(STDOUT_FILENO, recv_buf, n);
    }
}
```

```
void server_for_connection(int socket_fd) {
    int read_count, write_count; char request_buf[MAX_SIZE];
    while (1) {
        read_count = read(socket_fd, request_buf, MAX_SIZE);
        if (read_count <= 0) return; // error or EOF
        write_count = write(socket_fd, request_buf, read_count);
        if (read_count != write_count) {...error?...}
    }
```

echo client/server

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    int n; char send_buf[MAX_SIZE]; char recv_buf[MAX_SIZE];
    while (prompt_for_input(send_buf, MAX_SIZE)) {
        n = write(socket_fd, send_buf, strlen(send_buf));
        if (n != strlen(send_buf)) {...error?...}
        n = read(socket_fd, recv_buf, MAX_SIZE);
        if (n <= 0) return; // error or EOF
        write(STDOUT_FILENO, recv_buf, n);
    }
}
```

```
void server_for_connection(int socket_fd) {
    int read_count, write_count; char request_buf[MAX_SIZE];
    while (1) {
        read_count = read(socket_fd, request_buf, MAX_SIZE);
        if (read_count <= 0) return; // error or EOF
        write_count = write(socket_fd, request_buf, read_count);
        if (read_count != write_count) {...error?...}
    }
```

connection setup: server, address setup

```
/* example (hostname, portname) = ("127.0.0.1", "443") */
const char *hostname; const char *portname;
...
struct addrinfo *server;
struct addrinfo hints;
int rv;

memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET; /* for IPv4 */
/* or: */ hints.ai_family = AF_INET6; /* for IPv6 */
/* or: */ hints.ai_family = AF_UNSPEC; /* I don't care */
hints.ai_flags = AI_PASSIVE;

rv = getaddrinfo(hostname, portname, &hints, &server);
if (rv != 0) { /* handle error */ }
```

connection setup: server, address setup

```
/* example (hostname, portname) = ("127.0.0.1", "443") */
const char *hostname; const char *portname;
...
struct addrinfo *server;
struct addrinfo hints;
int rv;

memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET; /* for IPv4 */
/* or: */ hints.ai_family = AF_INET6; /* for IPv6 */
/* or: */ hints.ai_family = AF_UNSPEC; /* I don't care */
hints.ai_flags =

rv = getaddrinfo                                    rver);
if (rv != 0) { /
```

hostname could also be NULL
means “use all possible addresses”
only makes sense for servers

connection setup: server, address setup

```
/* example (hostname, portname) = ("127.0.0.1", "443") */
const char *hostname; const char *portname;
...
struct addrinfo *server;
struct addrinfo hints;
int rv;

memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET; /* for IPv4 */
/* or: */ hints.ai_family = AF_INET6; /* for IPv6 */
/* or: */ hints.ai_family = AF_UNSPEC; /* I don't care */
hints.ai_flags

rv = getaddrin                                    er);
if (rv != 0) {
```

portname could also be NULL
means “choose a port number for me”
only makes sense for servers

connection setup: server, address setup

```
/* example (hostname, portname) = ("127.0.0.1", "443") */
const char *ho
...
struct addrinfo *server;
struct addrinfo hints;
int rv;

memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET; /* for IPv4 */
/* or: */ hints.ai_family = AF_INET6; /* for IPv6 */
/* or: */ hints.ai_family = AF_UNSPEC; /* I don't care */
hints.ai_flags = AI_PASSIVE;

rv = getaddrinfo(hostname, portname, &hints, &server);
if (rv != 0) { /* handle error */ }
```

AI_PASSIVE: “I’m going to use bind”

connection setup: server, addrinfo

```
struct addrinfo *server;
... getaddrinfo(...) ...

int server_socket_fd = socket(
    server->ai_family,
    server->ai_sockttype,
    server->ai_protocol
);

if (bind(server_socket_fd, ai->ai_addr, ai->ai_addr_len)) < 0) {
    /* handle error */
}
listen(server_socket_fd, MAX_NUM_WAITING);
...
int socket_fd = accept(server_socket_fd, NULL);
```

connection setup: client, using addrinfo

```
int sock_fd;
struct addrinfo *server = /* code on next slide */;

sock_fd = socket(
    server->ai_family,
     // ai_family = AF_INET (IPv4) or AF_INET6 (IPv6) or ...
    server->ai_socktype,
     // ai_socktype = SOCK_STREAM (bytes) or ...
    server->ai_prototcol
     // ai_protocol = IPPROTO_TCP or ...
);
if (sock_fd < 0) { /* handle error */ }
if (connect(sock_fd, server->ai_addr, server->ai_addrlen) < 0) {
    /* handle error */
}
freeaddrinfo(server);
DoClientStuff(sock_fd); /* read and write from sock_fd */
close(sock_fd);
```

connection setup: client, using addrinfo

```
int sock_fd;
struct addrinfo *server = /* code on next slide */;

sock_fd = socket(
    server->ai_family,
     // ai_family = AF_INET (IPv4) or AF_INET6 (IPv6) or ...
    server->ai_socktype,
     // ai_socktype = SOCK_STREAM (bytes) or ...
    server->ai_protocol
     // ai_protocol = 0 (default) or ...
);
if (sock_fd < 0) {
if (connect(sock_fd, server->ai_addr, server->ai_addrlen) < 0) {
    /* error */
}
freeaddrinfo(server);
DoClientStuff(sock_fd); /* read and write from sock_fd */
close(sock_fd);
```

addrinfo contains all information needed to setup socket

set by `getaddrinfo` function (next slide)

handles IPv4 and IPv6

handles DNS names, service names

connection setup: client, using addrinfo

```
int sock_fd;
struct addrinfo *server = /* code on next slide */;

sock_fd = socket(
    server->ai_family,
     // ai_family = AF_INET (IPv4) or AF_INET6 (IPv6) or ...
    server->ai_socktype,
     // ai_socktype = SOCK_STREAM (bytes) or ...
    server->ai_prototcol
     // ai_protocol = IPPROTO_TCP or ...
);
if (sock_fd < 0) { /* handle error */ }
if (connect(sock_fd, server->ai_addr, server->ai_addrlen) < 0) {
    /* handle error */
}
freeaddrinfo(server);
DoClientStuff(sock_fd); /* read and write from sock_fd */
close(sock_fd);
```

connection setup: client, using addrinfo

```
int sock_fd;
struct addrinfo *server; /* ... */

sock_fd = so
    server->
     // ai_family = AF_INET (IPv4) or AF_INET6 (IPv6) or ...
    server->ai_socktype,
     // ai_socktype = SOCK_STREAM (bytes) or ...
    server->ai_prototcol
     // ai_protocol = IPPROTO_TCP or ...
);
if (sock_fd < 0) { /* handle error */ }
if (connect(sock_fd, server->ai_addr, server->ai_addrlen) < 0) {
    /* handle error */
}
freeaddrinfo(server);
DoClientStuff(sock_fd); /* read and write from sock_fd */
close(sock_fd);
```

ai_addr points to struct representing address
type of struct depends whether IPv6 or IPv4

connection setup: client, using addrinfo

since addrinfo contains pointers to dynamically allocated memory, call this function to free everything

```
int sock_fd;
st
so
      // ai_family = AF_INET (IPv4) or AF_INET6 (IPv6) or ...
    server->ai_socktype,
      // ai_socktype = SOCK_STREAM (bytes) or ...
    server->ai_prototcol
      // ai_protocol = IPPROTO_TCP or ...
);
if (sock_fd < 0) { /* handle error */ }
if (connect(sock_fd, server->ai_addr, server->ai_addrlen) < 0) {
    /* handle error */
}
freeaddrinfo(server);
DoClientStuff(sock_fd); /* read and write from sock_fd */
close(sock_fd);
```

connection setup: lookup address

```
/* example hostname, portname = "www.cs.virginia.edu", "443" */
const char *hostname; const char *portname;
...
struct addrinfo *server;
struct addrinfo hints;
int rv;
memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_UNSPEC; /* for IPv4 OR IPv6 */
// hints.ai_family = AF_INET4; /* for IPv4 only */

hints.ai_socktype = SOCK_STREAM; /* byte-oriented --- TCP */
rv = getaddrinfo(hostname, portname, &hints, &server);
if (rv != 0) { /* handle error */ }

/* eventually freeaddrinfo(result) */
```

connection setup: lookup address

```
/* example hostname, portname = "www.cs.virginia.edu", "443" */
const char *hostname; const char *portname;
...
struct addrinfo *server;
struct addrinfo hints;
int rv;
memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_UNSPEC; /* for IPv4 OR IPv6 */
// hints.ai_family = AF_INET4; /* for IPv4 only */
hints.ai_socktype = SOCK_STREAM; /* byte-oriented --- TCP */
rv = getaddrinfo(hostname, portname, &hints, &server);
if (rv != 0) { /* handle error */ }

/* eventually freeaddrinfo(result) */
```

NB: pass pointer *to pointer* to addrinfo to fill in

connection setup: lookup address

```
/* example hostname, portname = "www.cs.virginia.edu", "443" */
const
...
struct
struct
int rv;
memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_UNSPEC; /* for IPv4 OR IPv6 */
// hints.ai_family = AF_INET4; /* for IPv4 only */

hints.ai_socktype = SOCK_STREAM; /* byte-oriented --- TCP */
rv = getaddrinfo(hostname, portname, &hints, &server);
if (rv != 0) { /* handle error */ }

/* eventually freeaddrinfo(result) */
```

AF_UNSPEC: choose between IPv4 and IPv6 for me
AF_INET, AF_INET6: choose IPv4 or IPV6 respectively

connection setup: multiple server addresses

```
struct addrinfo *server;
...
rv = getaddrinfo(hostname, portname, &hints, &server);
if (rv != 0) { /* handle error */ }

for (struct addrinfo *current = server; current != NULL;
      current = current->ai_next) {
    sock_fd = socket(current->ai_family, current->ai_socktype, curr
    if (sock_fd < 0) continue;
    if (connect(sock_fd, current->ai_addr, current->ai_addrlen) ==
        break;
    }
    close(sock_fd); // connect failed
}
freeaddrinfo(server);
DoClientStuff(sock_fd);
close(sock_fd);
```

connection setup: multiple server addresses

```
struct addrinfo *server;
...
rv = getaddrinfo(hostname, portname, &hints, &server);
if (rv != 0) { /* handle error */ }

for (struct addrinfo *current = server; current != NULL;
       current = current->ai_next) {
    sock_fd = socket(current->ai_family, current->ai_socktype, curr
    if (sock_fd < 0) continue;
    if (connect(sock_fd, current->ai_addr, current->ai_addrlen) ==
        break;
    }
    clos
}
freeaddr
DoClient
close(so
```

addrinfo is a linked list

name can correspond to multiple addresses

example: redundant copies of web server

example: an IPv4 address and IPv6 address

connection setup: old lookup function

```
/* example hostname, portnum= "www.cs.virginia.edu", 443*/
const char *hostname; int portnum;
...
struct hostent *server_ip;
server_ip = gethostbyname(hostname);

if (server_ip == NULL) { /* handle error */ }

struct sockaddr_in addr;
addr.s_addr = *(struct in_addr*) server_ip->h_addr_list[0];
addr.sin_port = htons(portnum);
sock_fd = socket(AF_INET, SOCK_STREAM, IPPROTO_TCP);
connect(sock_fd, &addr, sizeof(addr));
...
```

aside: on server port numbers

Unix convention: must be `root` to use ports 0–1023

root = superuser = 'adminstrator user' = what sudo does

so, for testing: probably ports > 1023