last time

assignment Q&A

multi-level page table lookup

pagetable2

will be graded ‘is everything present’

purpose: prepare for code review next week

final submission after code review in lab

some themes in anonymous feedback

pagetable difficulty

quizzes: how many/etc.

lab difficulty

Quiz Q3

1 first-level page table with

- a valid entry pointing to a second-level page table with 512 valid entries
- a valid entry pointing to a second-level page table with (1000-512) valid entries and a few invalid entries and 510 invalid entries

three 4096-byte page tables

Quiz Q4

0x120008 = PTBR + VPN part 1 × PTE size =
0x1200000 + VPN part 1 × 8 → VPN part 1 = 1

0x123040 =
PPN from 1st level × page size + VPN part 2 × PTE size →
VPN part 2 = 8

0x6010 =
PPN from 2nd level × page size + page offset → page offset = 0x10

Quiz Q5

"It then runs a function, whose machine code is loaded at addresses 0x2040-0x2072, which writes 3 8-byte values to the stack at addresses 0xFFF8, 0xFFF0, and 0xFFE8."

page at 0x2000–0x2FFF

- code loaded on first instruction's page fault
- can't tell processor about only part of page being loaded

page at 0xF000–0xFFFF

- whole page of stack allocated on first access

HW difficulty

"...I feel like several components of the assignment we have not fully learned and some we just learned about in lecture today. Additionally, I think while a checkpoint is a reasonable idea, we could all benefit from the extra time and just have the first two parts be due next week. I have been in office hours the last two days and it seems like barely any students know what is going on."

"While the quiz made sense and was related to the lectures and readings, this homework assignment has a lot of things that you need to rely on TA's or word of mouth for. For example, how would we know that we need to memset after posix_memalign if we don't even know how to look that up..."

"I feel like the content of the lectures is too far removed from what we are asked to do in the homeworks...."

mistakes I made with homework (1)

overestimated C familiarity from CSO1

- a lot of problems from C pointer issues
- fails in ways that are not intuitive, especially if you aren't checking every step
- why I assumed understanding manpage for posix_memalign was not big deal
- future: warmup assignment should probably review C pointer stuff somehow
- b/c of this, put halfway point of assignment at wrong place

in future semesters, need to plan more lecture time for virtual memory

mistakes I made with homework (2)

some things in writeup are/were too easy to miss

- page table entry format
- physical page number v physical address
- what things need to be allocated

need more structure re: testing

- students just using code in assignment + autograder was not the intention

lab difficulty

"I wish we could at least get more explanation for what is going on in the networking lab. I understood Tuesday's lecture enough to at least get the concept, but the lab write-up itself was pretty opaque and it felt like we were being thrown into the deep end to actually implement the networking. I spent the whole 75 minutes in lab just going over the reading and trying to figure out what exactly we were supposed to do..."

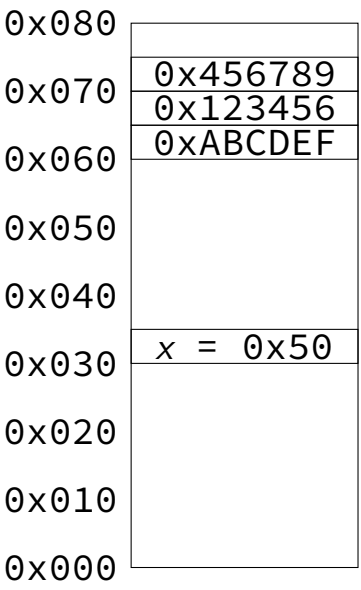
lab difficulty

was surprised by confusion re: recvd() function + setTimeout()

- oops! should have realized you haven't seen these kinds of interfaces before

probably need an introduction to this type of interface in lecture in the future

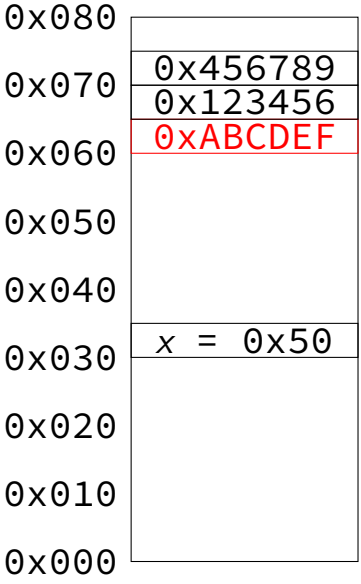
some pointer stuff




```
size_t x = 0x50;
```

~~`**x`~~ (compile-time error)

some pointer stuff



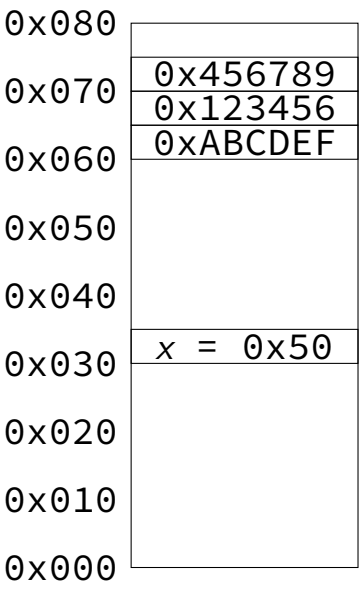

```
size_t x = 0x50;
```

~~`*x`~~ (compile-time error)

```
size_t *ptr;
ptr = (size_t *) x;
*ptr == 0xABCDEF
```

```
*((size_t *) x) == 0xABCDEF
```

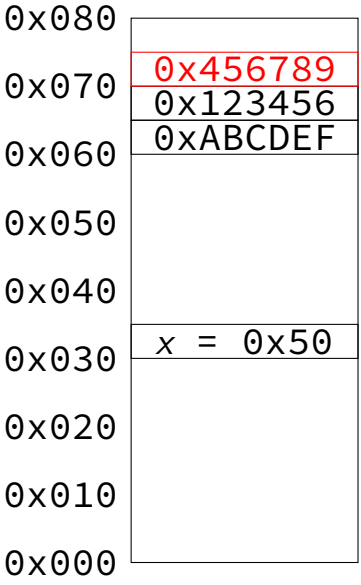
some pointer stuff




```
size_t x = 0x50;
```

~~`x[2]`~~ (compile-time error)

some pointer stuff



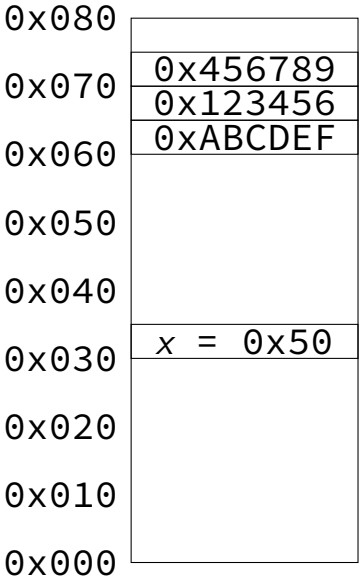

```
size_t x = 0x50;
```

~~`x[2]`~~ (compile-time error)

```
size_t addr = x + 16;
size_t *ptr;
ptr = (size_t *) addr;
*ptr == 0x456789
```

```
size_t *ptr;
ptr = (size_t *) x;
ptr[2] == 0x456789
```

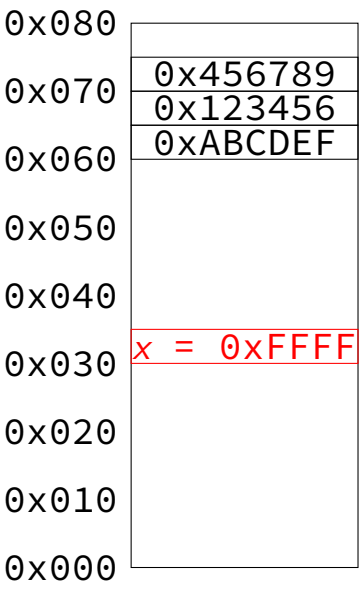
some pointer stuff




```
size_t x = 0x50;

void change_arg(size_t *arg) {
    *arg = 0xFFFF;
}
```

some pointer stuff

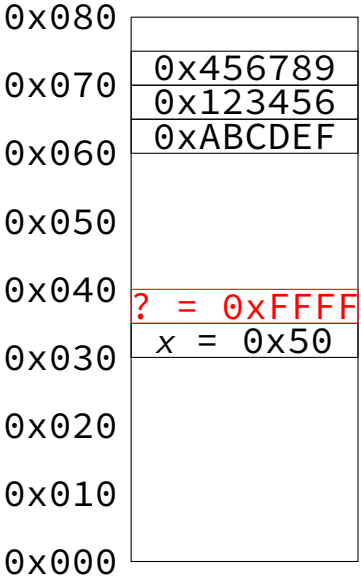



```
size_t x = 0x50;

void change_arg(size_t *arg) {
    *arg = 0xFFFF;
}

change_arg(&x);
change_arg((size_t*) 0x30);
```

some pointer stuff

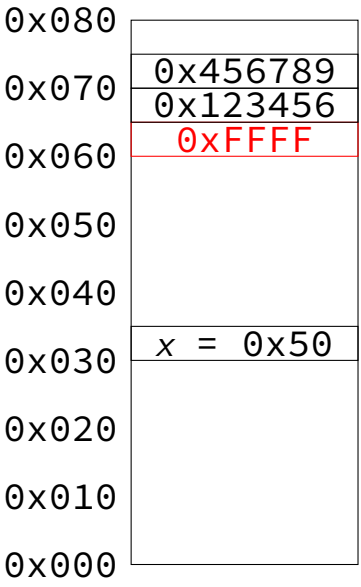



```
size_t x = 0x50;

void change_arg(size_t *arg) {
    *arg = 0xFFFF;
}

change_arg(&x + 1);
change_arg((size_t*) 0x38);
```

some pointer stuff




```
size_t x = 0x50;

void change_arg(size_t *arg) {
    *arg = 0xFFFF;
}

change_arg((size_t *) x);
change_arg((size_t *) 0x50);
```

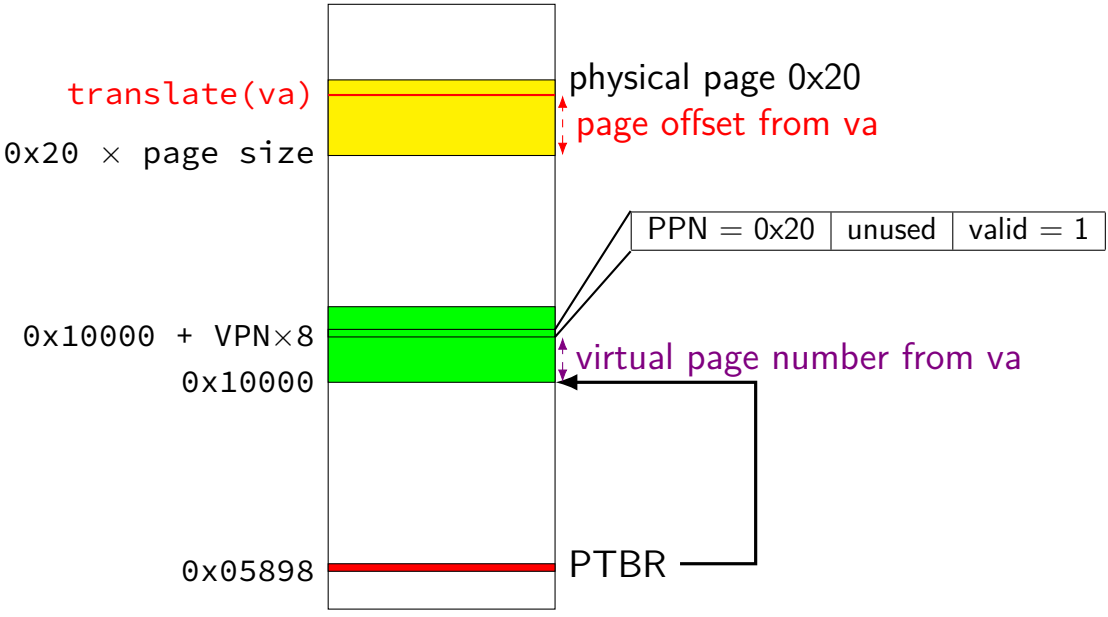
address/page table entry format

(with POBITS=12)

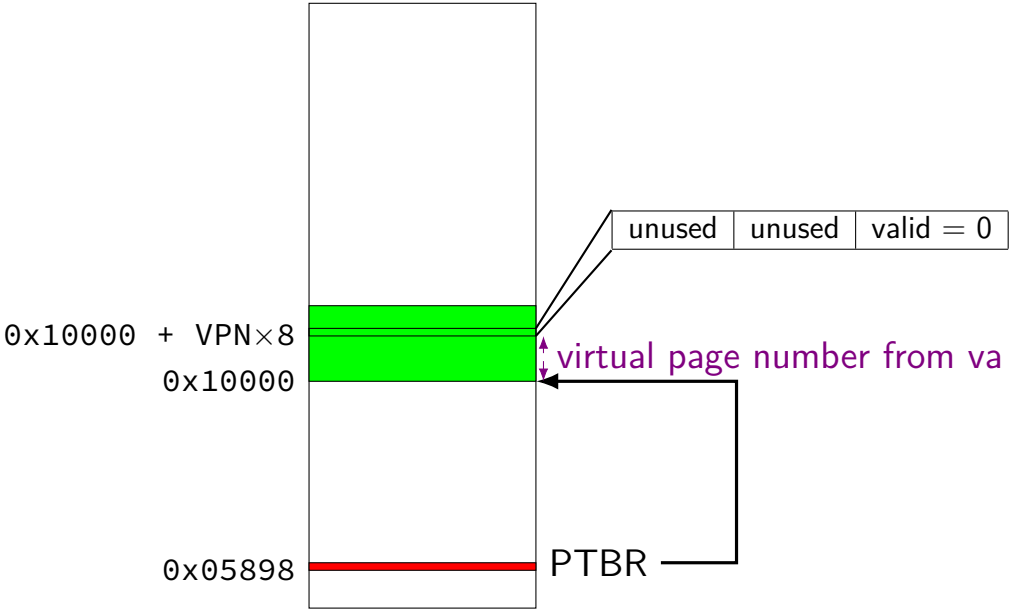
	bits 63–12	bits 11–1	bit 0
page table entry	physical page number	unused	valid bit
virtual address	virtual page number	page offset	
physical address	physical page number	page offset	

in assignment: value from posix_memalign = physical address

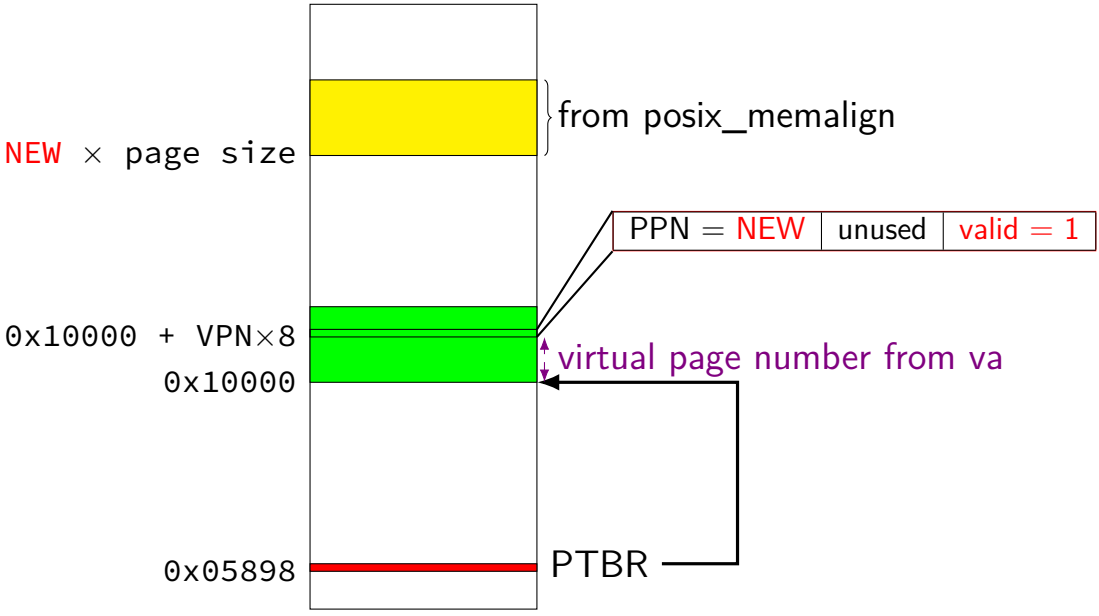
pa = translate(va)



page_allocate(va)

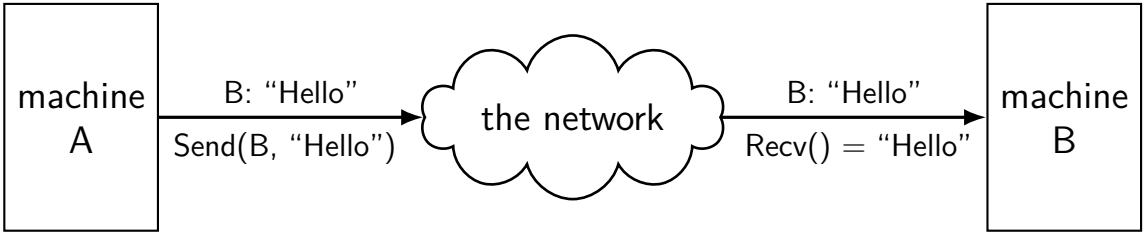


page_allocate(va)



mailbox model

mailbox abstraction: send/receive messages



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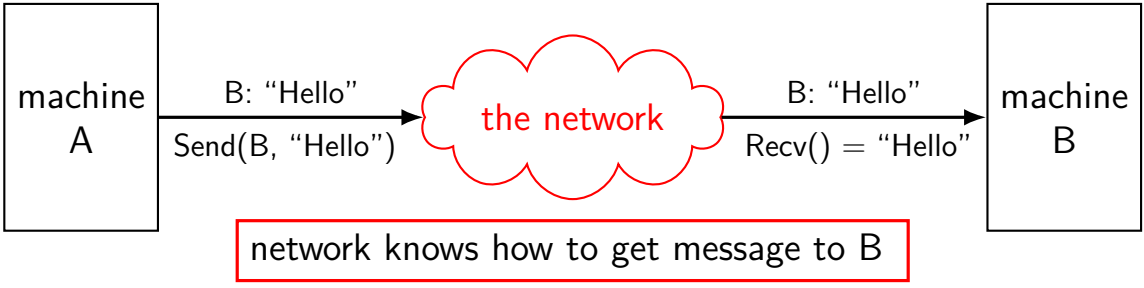

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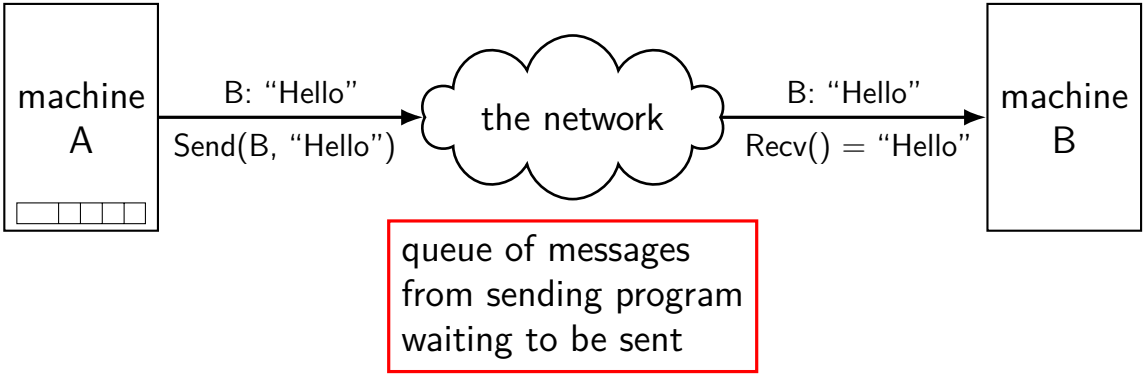

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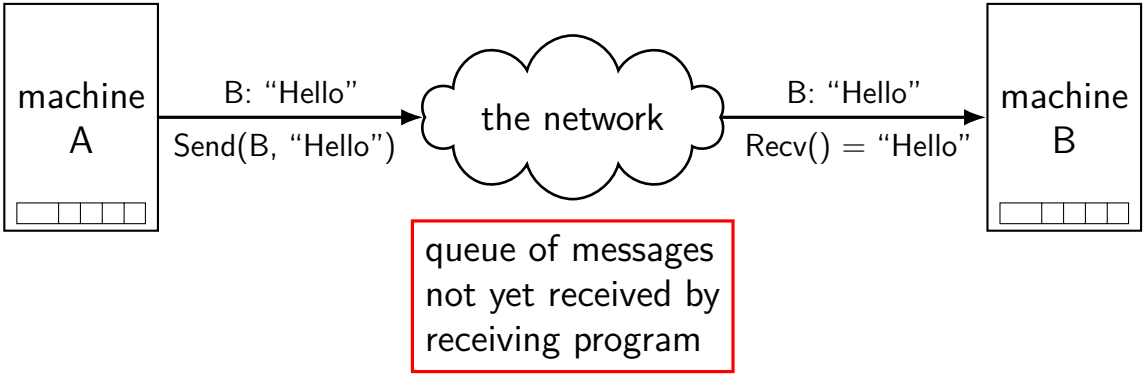


connections over mailboxes

real Internet: mailbox-style communication

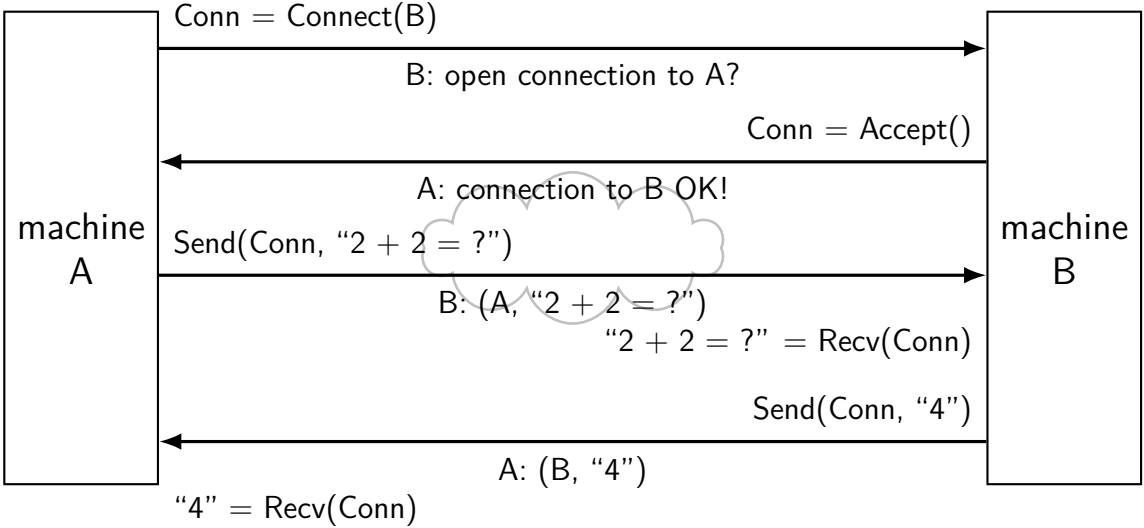
- send packets to particular mailboxes
- no gaurentee on order, when received

sockets implemented on top of this

conections

connections: two-way channel for messages

extra operations: connect, accept



recall: sockets

open connection then ...

read+write just like a terminal file

doesn't look like individual messages

"connection abstraction"

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

application	HTTP, SSH, SMTP, ...	application-defined meanings
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physical	...	encode bits for wire/radio

network limitations/failures

messages lost

messages delayed/reordered

messages limited in size

messages corrupted

network limitations/failures

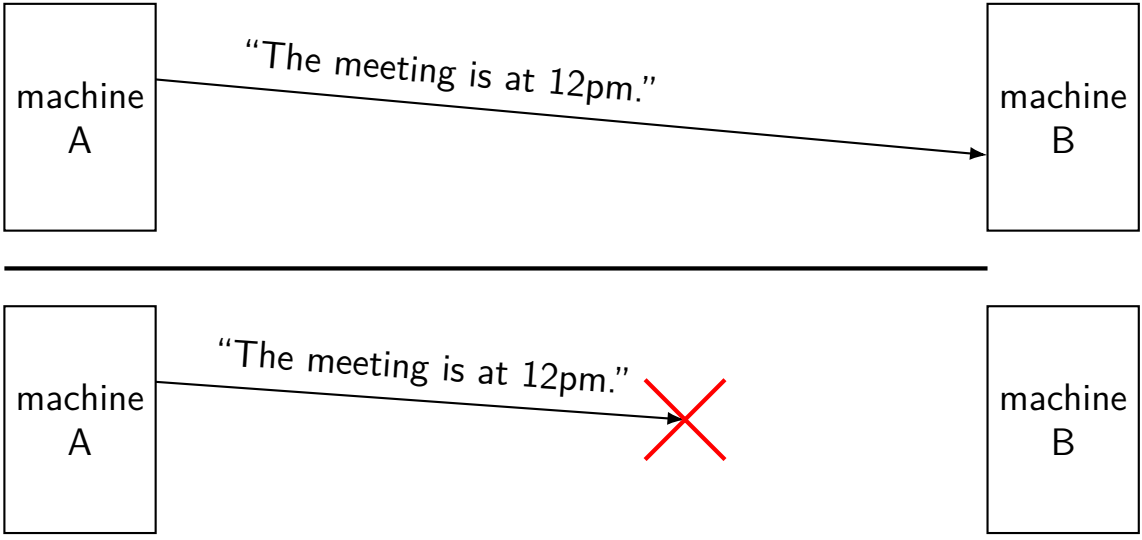
messages lost

messages delayed/reordered

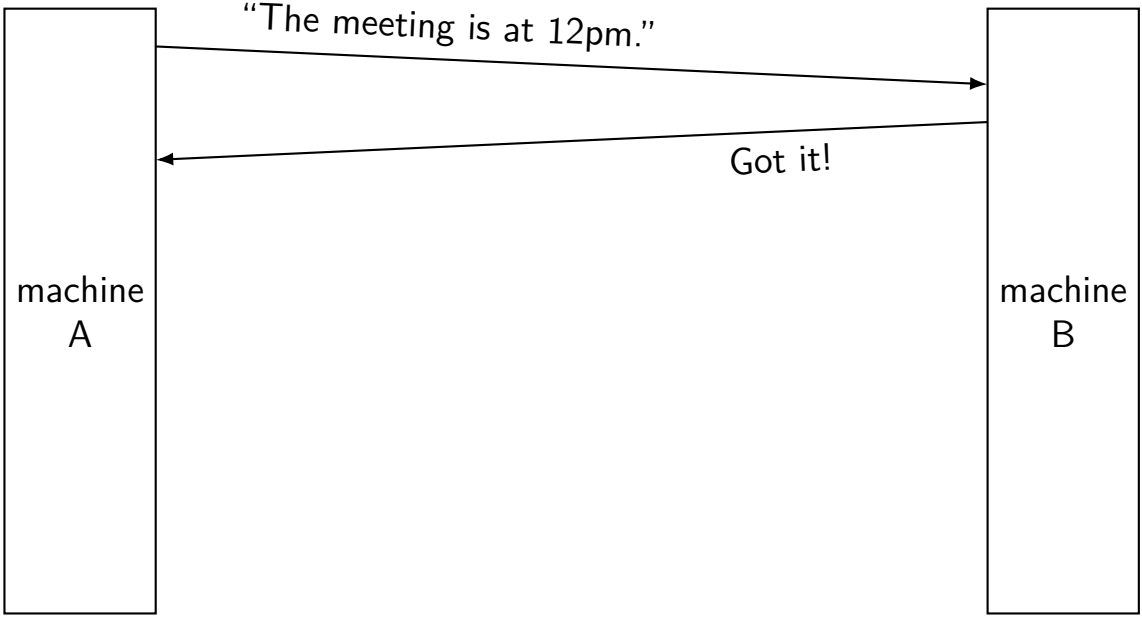
messages limited in size

messages corrupted

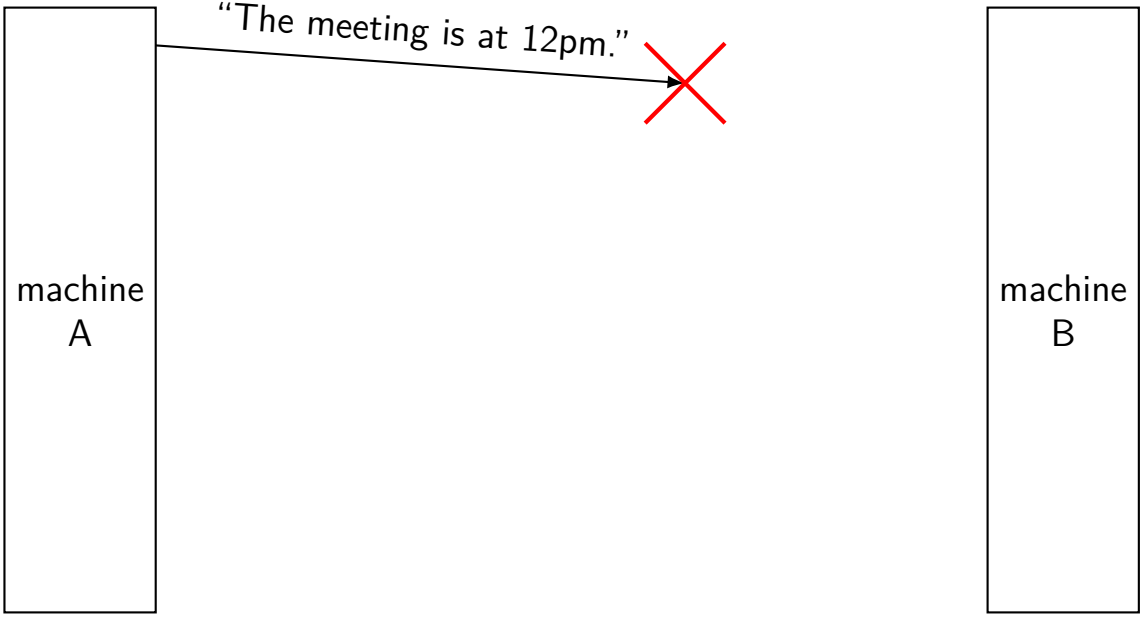
dealing with network message lost



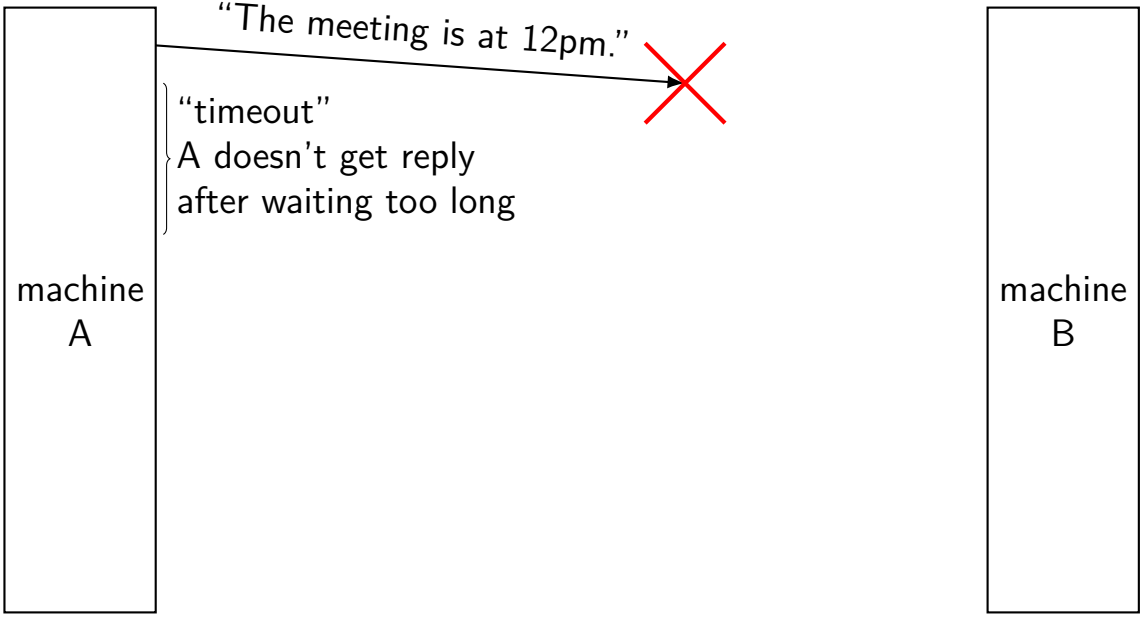
handling lost message: acknowledgements



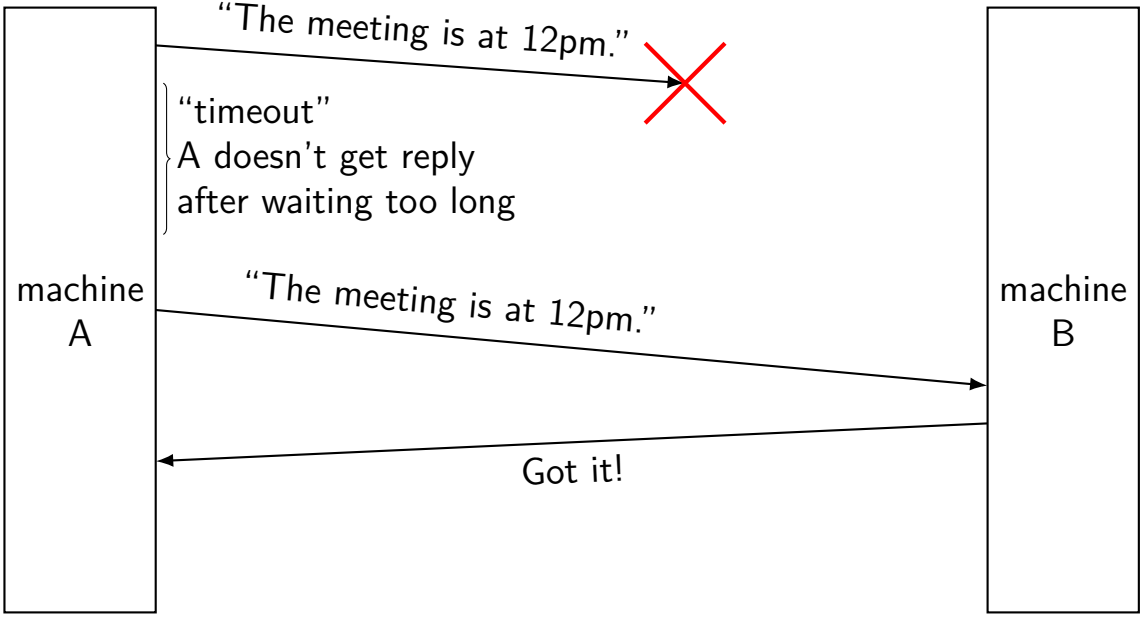
handling lost message



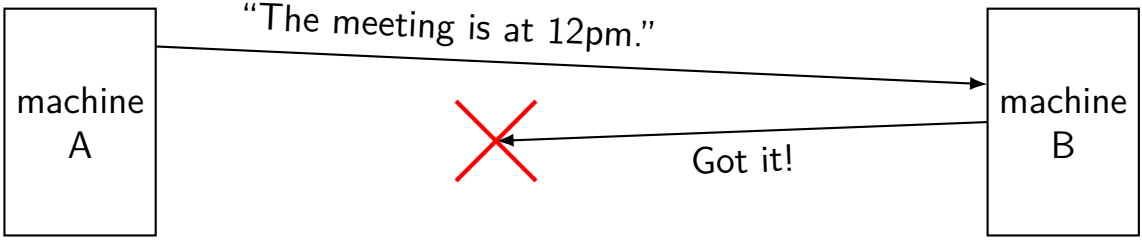
handling lost message



handling lost message



exercise: lost acknowledgement



exercise: how to fix this?

A. machine A needs to send "Got 'got it!' "
B. machine B should resend "Got it!" on its own
C. machine A should resend the original message on its own
D. none of these

network limitations/failures

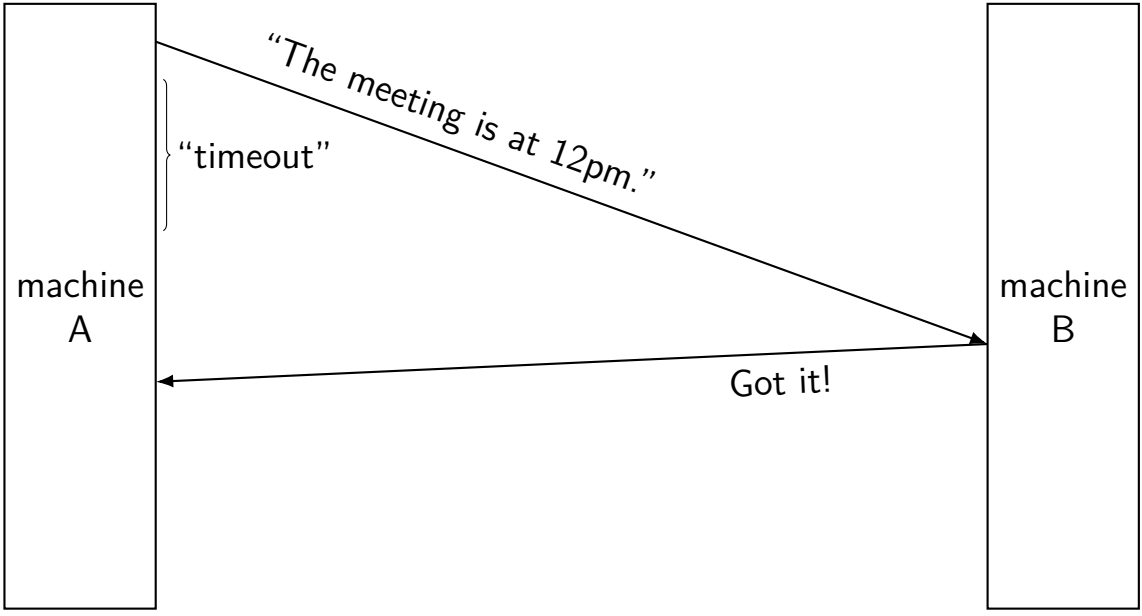
messages lost

messages delayed/reordered

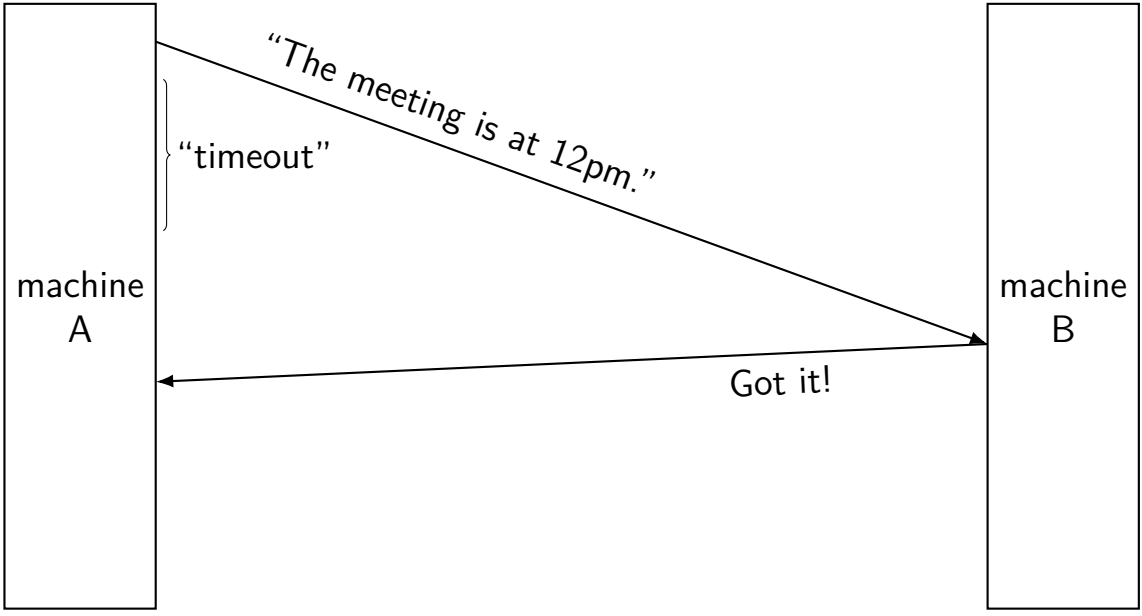
messages limited in size

messages corrupted

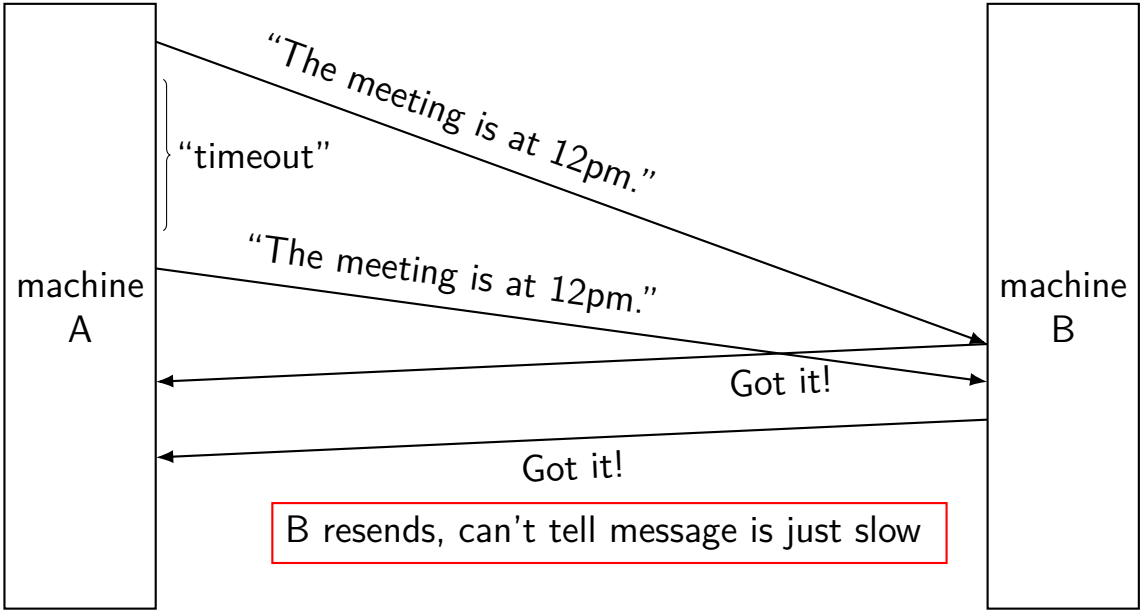
delayed message



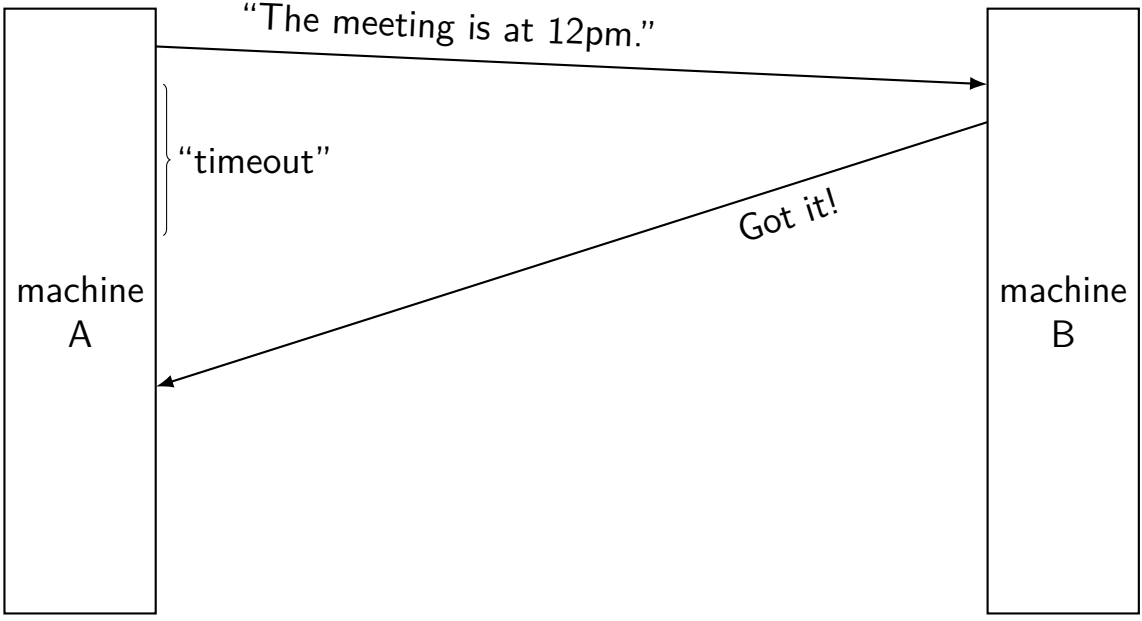
delayed message



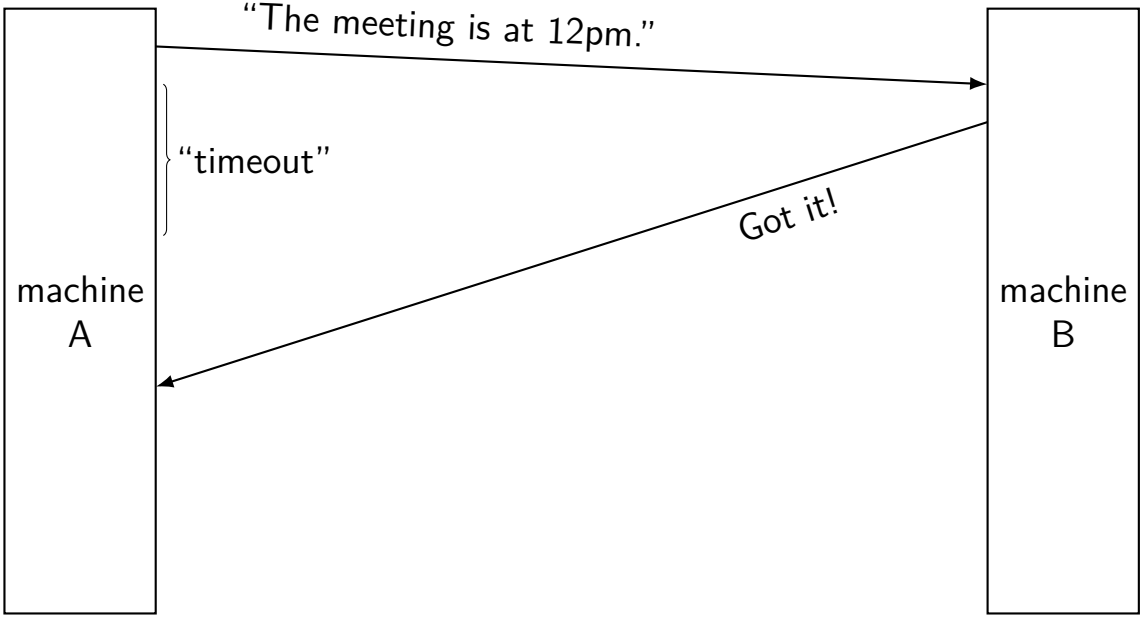
delayed message



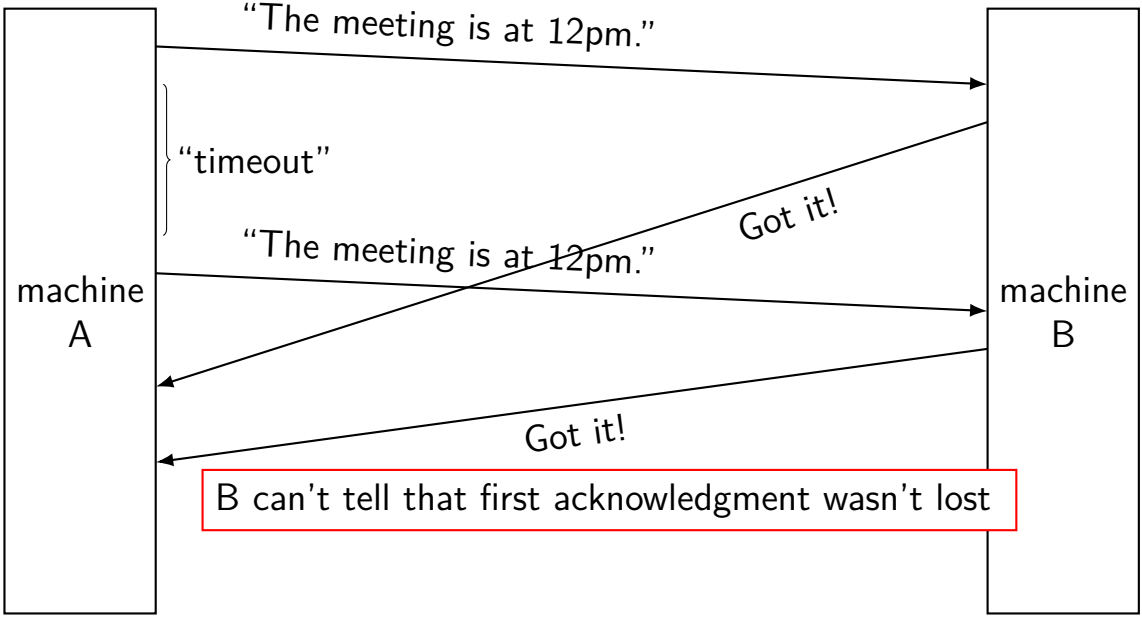
delayed acknowledgements



delayed acknowledgements



delayed acknowledgements



network limitations/failures

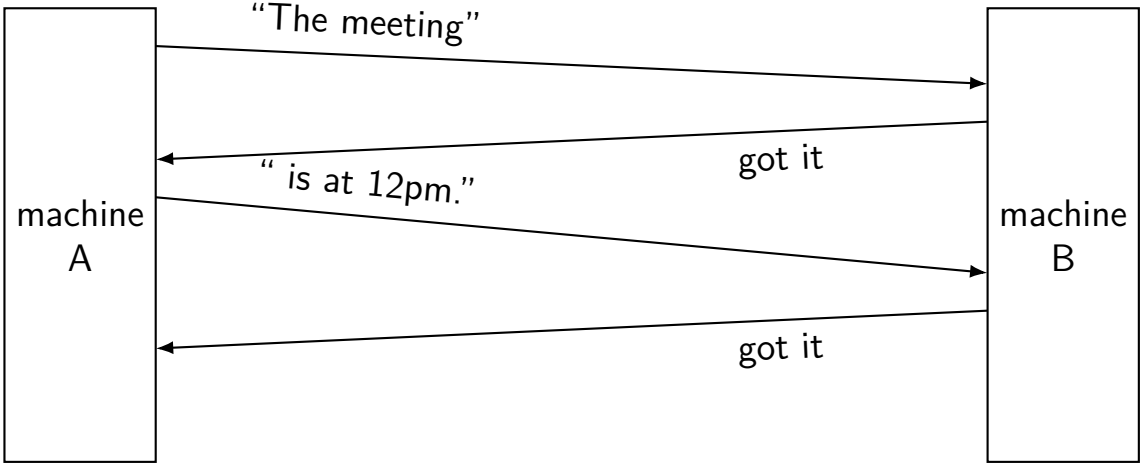
messages lost

messages delayed/reordered

messages limited in size

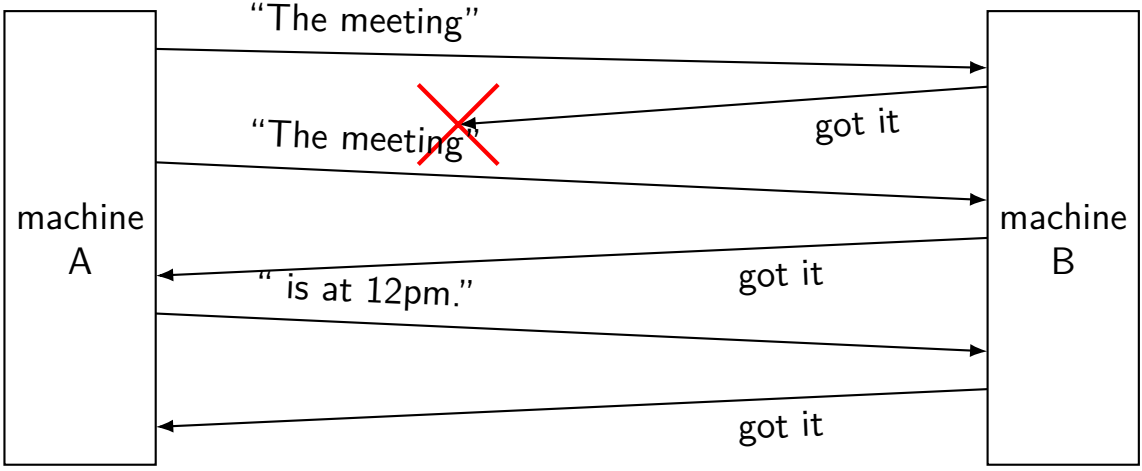
messages corrupted

splitting messages: try 1

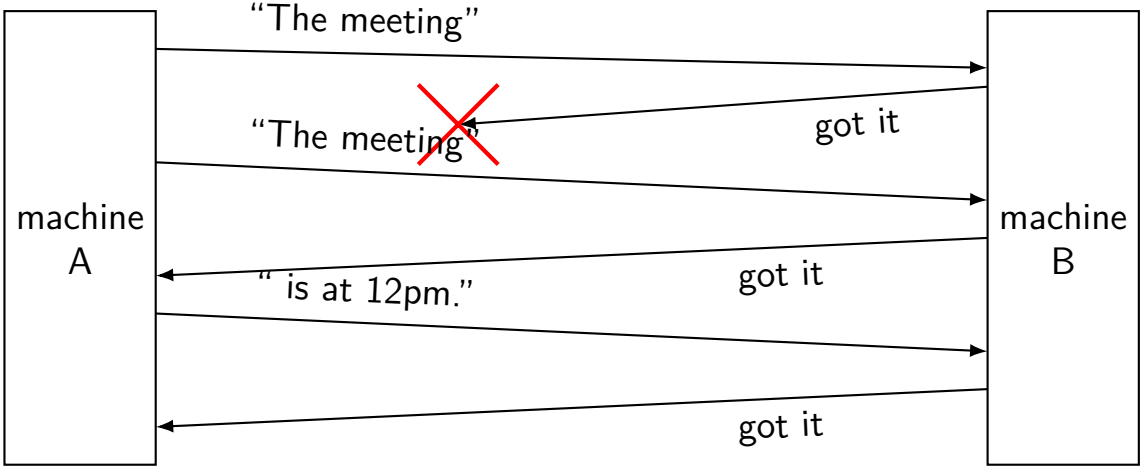


reconstructed message:
The meeting is at 12pm.

splitting messages: try 1 — problem 1



splitting messages: try 1 — problem 1



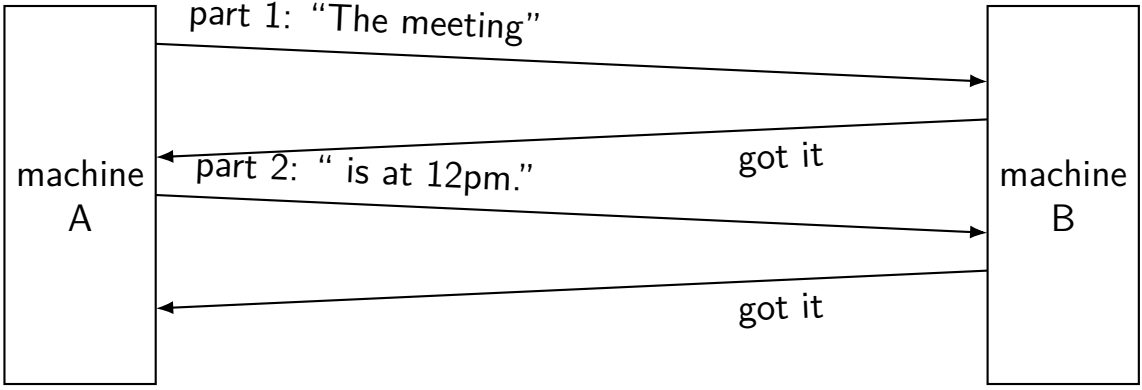
reconstructed message:
The meetingThe meeting is at 12pm.

exercise: other problems?

other scenarios where we'd also have problems?

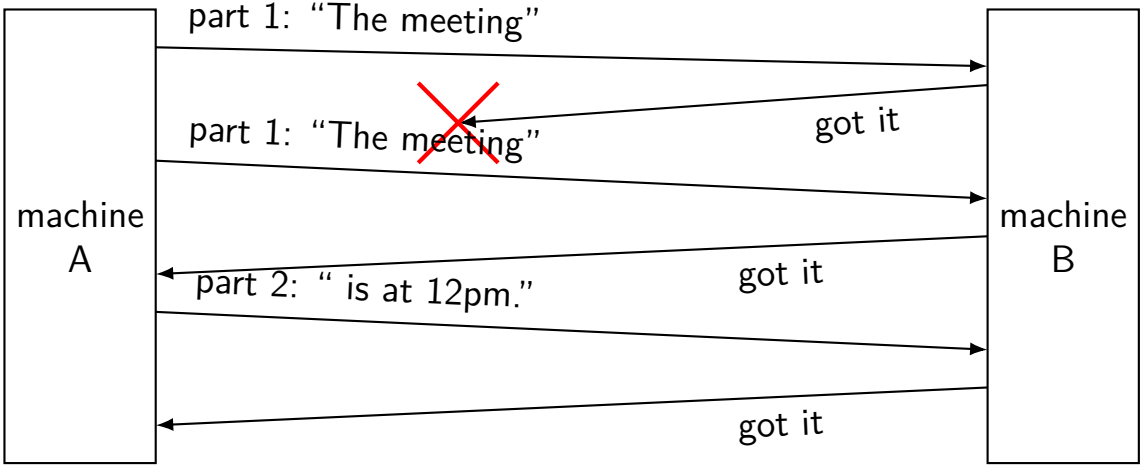
1. message (instead of acknowledgment) is lost
2. first message from machine A is delayed a long time by network
3. acknowledgment of second message lost instead of first

splitting messages: try 2



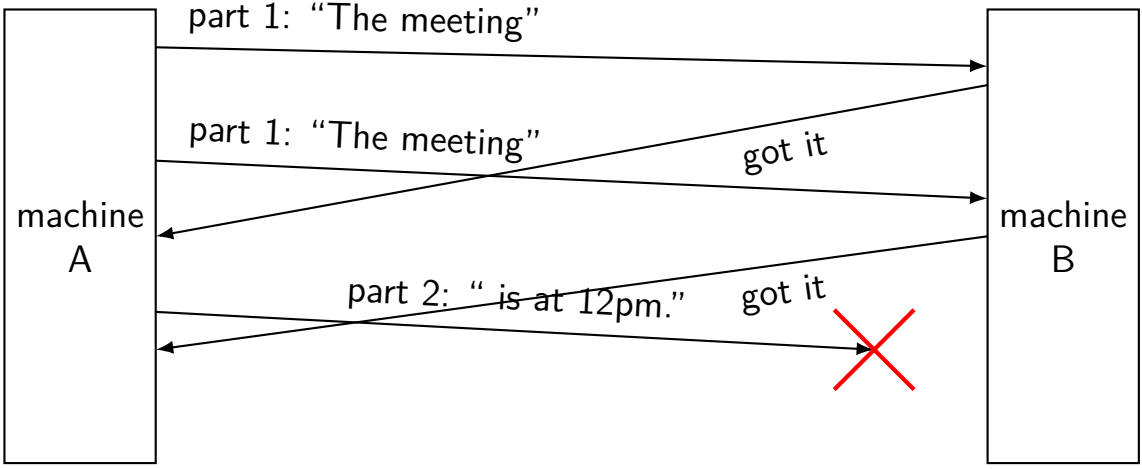
reconstructed message:
The meeting is at 12pm.

splitting messages: try 2 — missed ack



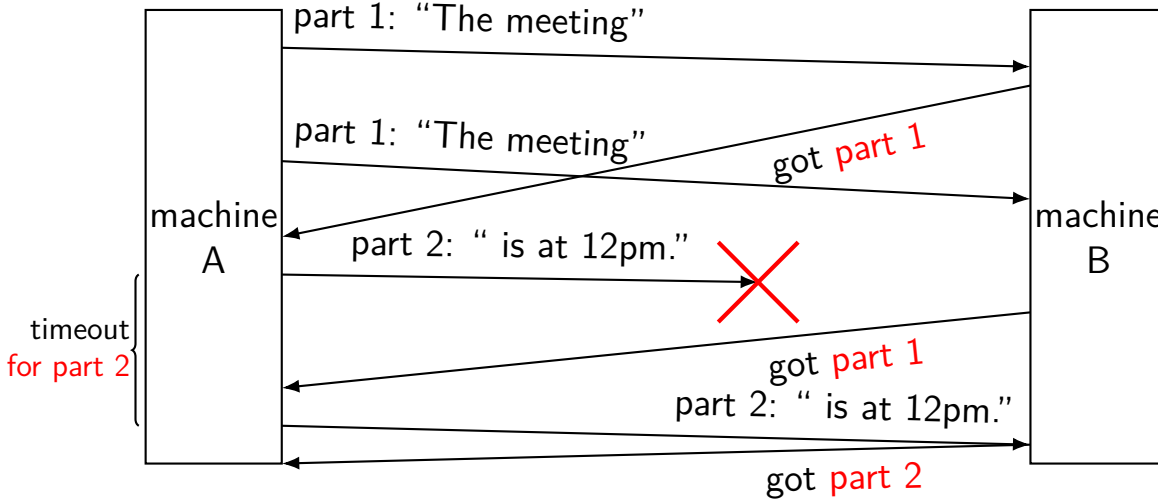
reconstructed message:
The meeting is at 12pm.

splitting messages: try 2 — problem



A thinks: part 1 + part 2 acknowleged!

splitting messages: version 3



network limitations/failures

messages lost

messages delayed/reordered

messages limited in size

messages corrupted

message corrupted

instead of sending “message”

say Hash(“message”) = 0xABCDEF12

then send “0xABCDEF12,message”

when receiving, recompute hash

pretend message lost if does not match

“checksum”

these hashes commonly called “checksums”

in UDP/TCP, hash function: treat bytes of messages as array of integers; then add integers together

going faster

so far: send one message, get acknowledgments

pretty slow

instead, can send a bunch of parts and get them acknowledged together

need to do *congestion control* to avoid overloading network

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

more than four layers?

sometimes more layers above 'application'

e.g. HTTPS:
HTTP (app layer) on TLS (another app layer) on TCP (network) on ...

e.g. DNS over HTTPS:
DNS (app layer) on HTTP on on TLS on TCP on ...

e.g. SFTP:
SFTP (app layer??) on SSH (another app layer) on TCP on ...

e.g. HTTP over OpenVPN:
HTTP on TCP on IP on OpenVPN on UDP on different IP on ...

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`
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`
service name `https`	port number 443
service name `ssh`	port number 22

layers

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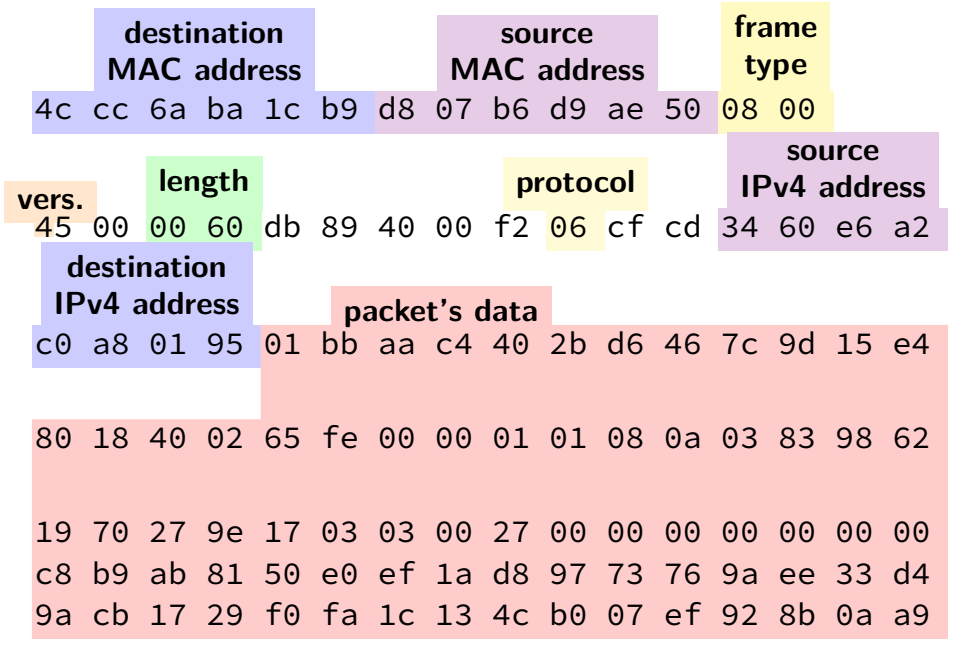
an Ethernet frame

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

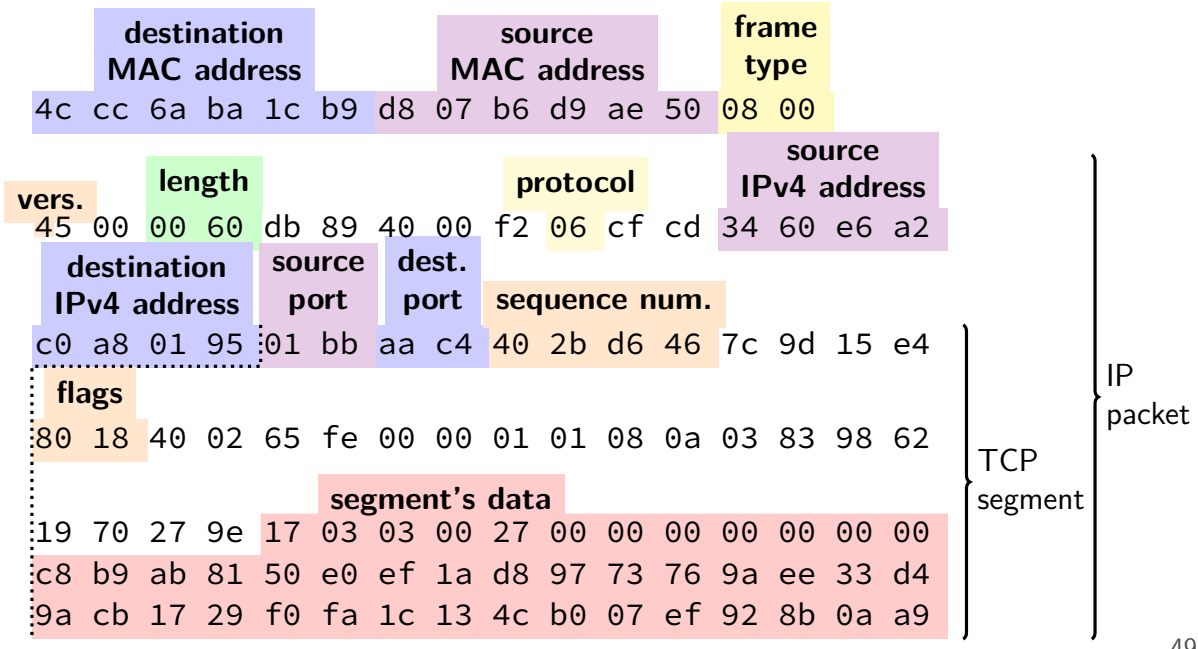
frame's data

```
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
9a cb 17 29 f0 fa 1c 13 4c b0 07 ef 92 8b 0a a9
```

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*)

messages usually called "frames"

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?

layers

application	HTTP, SSH, SMTP, ...	application-defined meanings
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physical	...	encode bits for wire/radio

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"

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)

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`

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

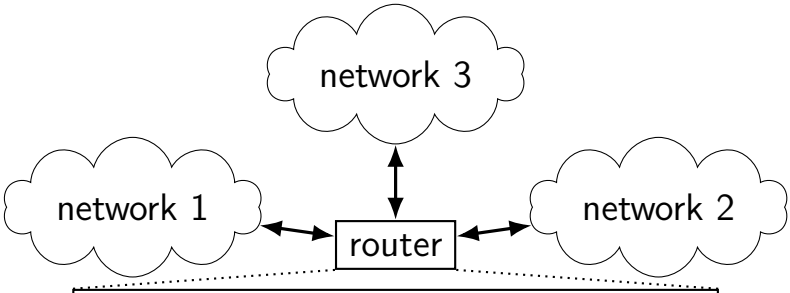
selected special IPv6 addresses

`::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

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)

layers

application	HTTP, SSH, SMTP, ...	application-defined meanings
transport	TCP, UDP, ...	reach correct program, reliablity/streams
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physical	...	encode bits for wire/radio

port numbers

we run multiple programs on a machine

- IP addresses identifying machine — not enough

port numbers

we run multiple programs on a machine

- IP addresses identifying machine — not enough

so, add 16-bit *port numbers*

- think: multiple PO boxes at address

port numbers

we run multiple programs on a machine

- IP addresses identifying machine — not enough

so, add 16-bit *port numbers*

- 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

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

- get assigned port number
- SOCK_DGRAM with socket() instead of SOCK_STREAM
- can sendto()/recvfrom() multiple other programs with one socket
  - (but don't have to)
- send messages which are limited in size, unreliable

TCP: stream to other program

- need to bind() + listen() + accept() or connect() to setup connection
- one socket per connection
- read/write bytes — divided into messages automatically
- reliable — acknowledgments/resending handled for you

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:*
...
udp6       0      0 :::59938                :::*
```

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

URL / URIs

Uniform Resource Locators (URL)

tells how to find “resource” on network

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
```

URI generally

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

scheme: — what protocol

//authority/

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

path

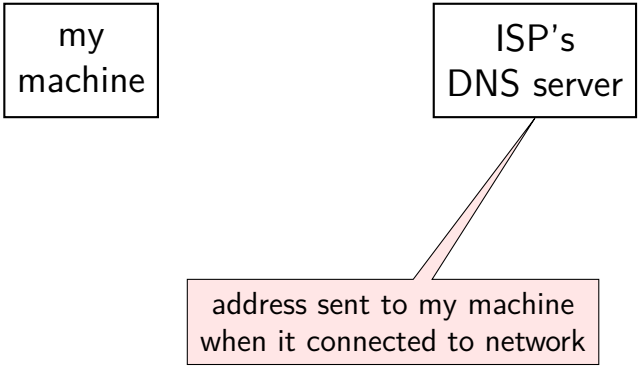
which resource

?query — usually key/value pairs

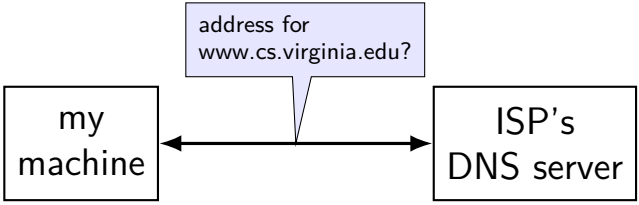
#fragment — place in resource

most components (sometimes) optional

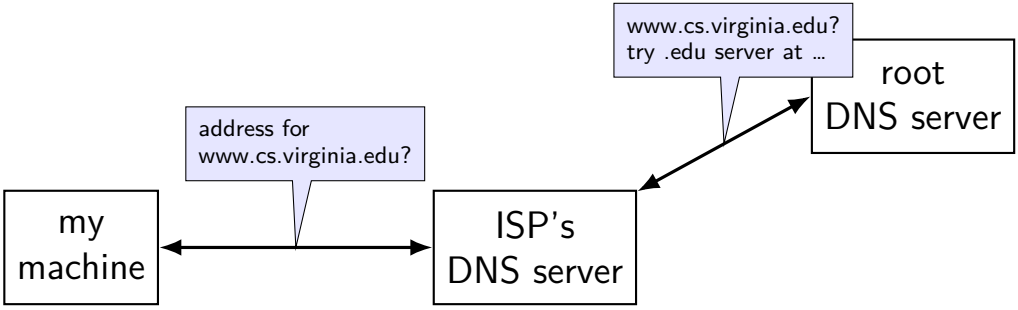
DNS: distributed database



DNS: distributed database



DNS: distributed database



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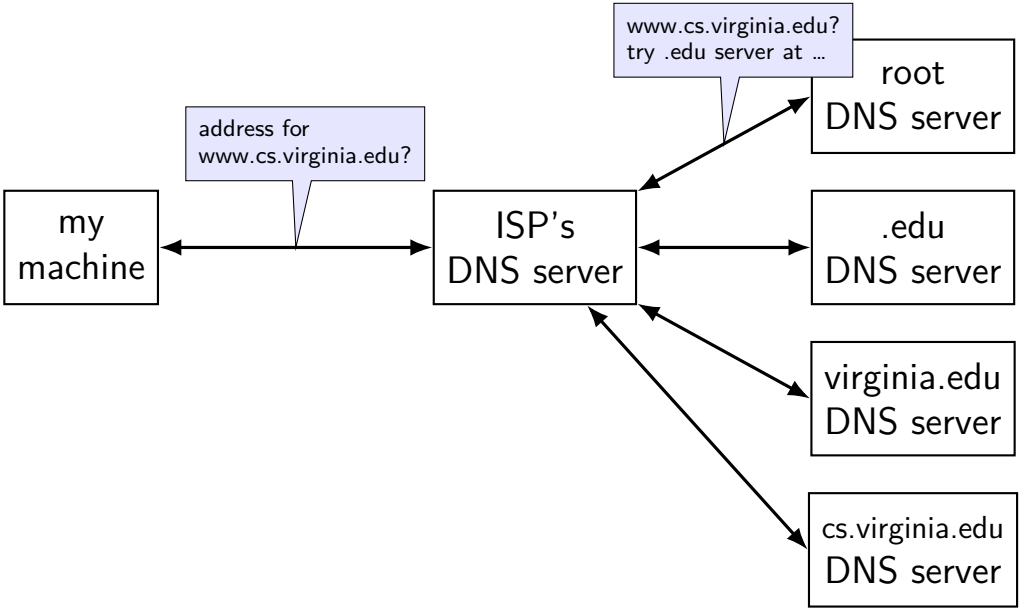

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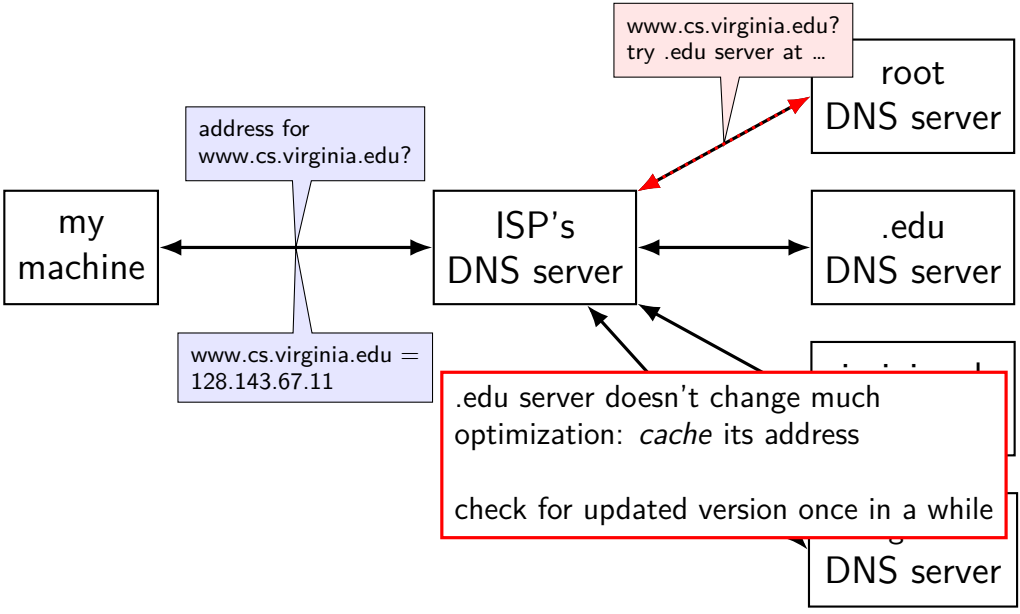

autoconfiguration

problem: how does my machine get IP address

otherwise:

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

autoconfiguration

problem: how does my machine get IP address

otherwise:

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

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

backup slides