distributed 1 / sockets

last time

RAID

ordering writes carefully

- waste space rather than point to unallocated/wrong

fsck (filesystem check) recovery

redo logging ('writeahead logging')

- write intention to log; redo committed parts of logs on reboot

snapshots via copy-on-write

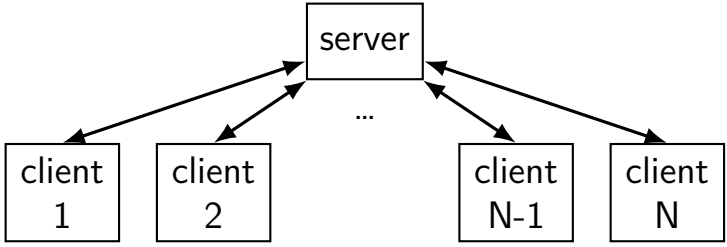
- copy only parts that change
- indirection for inode array

distributed systems

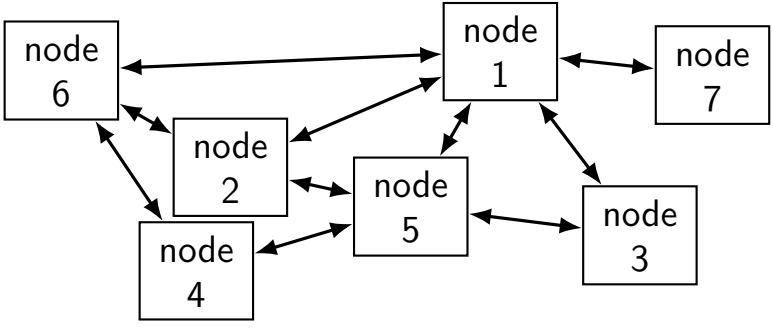
multiple machines working together to perform a single task

called a *distributed system*

some distibuted systems models

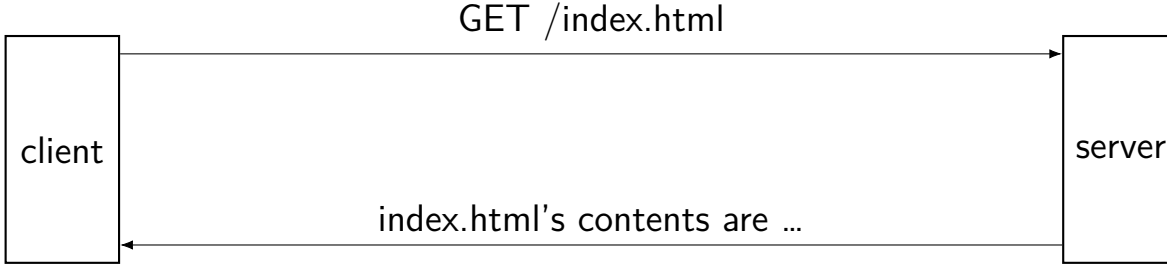


client/server



peer-to-peer

client/server model



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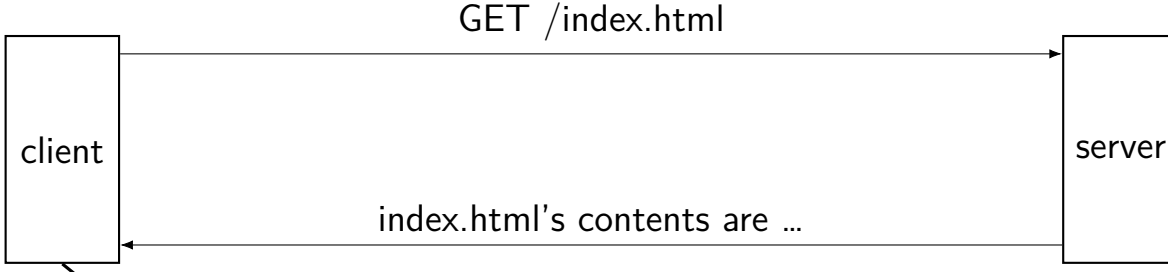
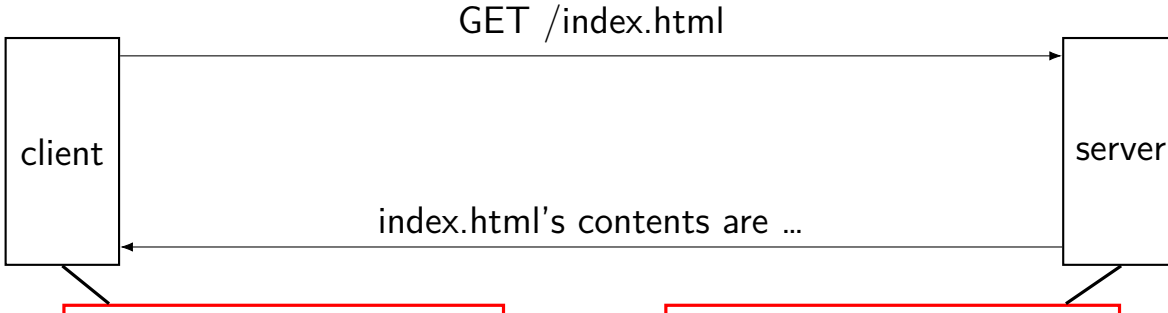


client(s): "sometimes on"

sends requests to server(s)

needs to know
how to contact server

client/server model



client(s): "sometimes on"

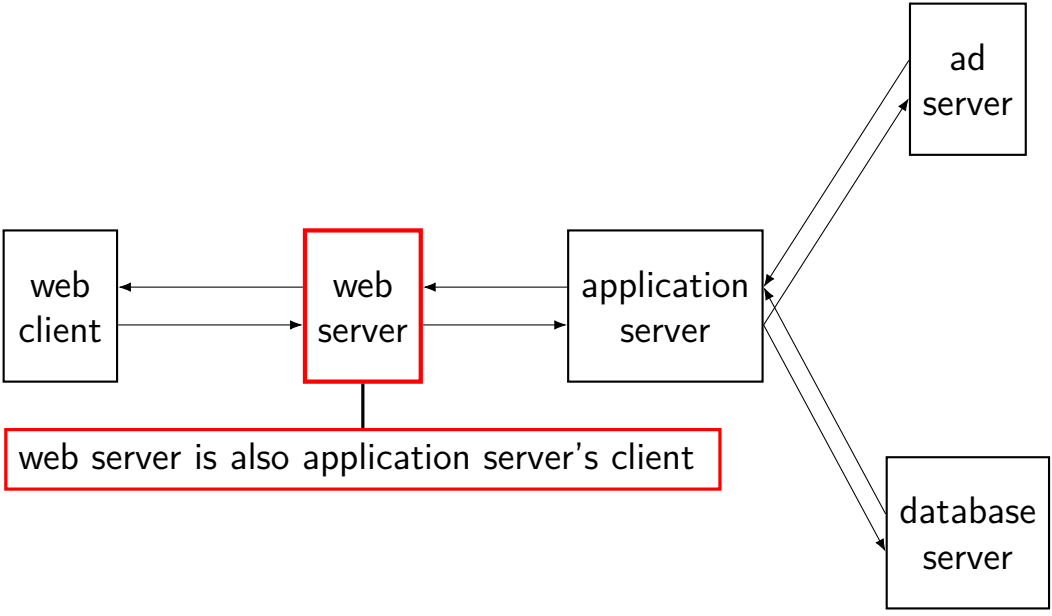
sends requests to server(s)

needs to know
how to contact server

server(s): "always on"

responds to client requests
never initiaties contact
with a client

layers of servers?



example: Wikipedia architecture

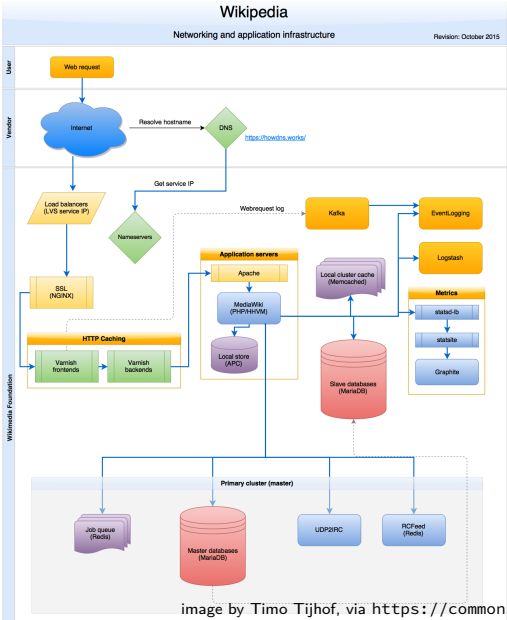


image by Timo Tijhof, via https://commons.wikimedia.org/wiki/File:Wikipedia_webrequest_flow_2015-10.png

example: Wikipedia architecture (zoom)

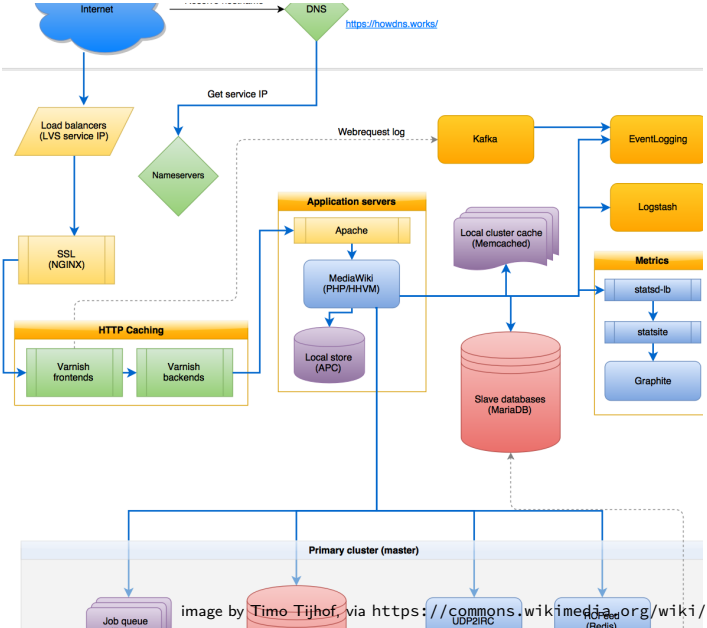


image by Timo Tijhof, via https://commons.wikimedia.org/wiki/File:Wikipedia_webrequest_flow_2015-10.png

peer-to-peer

no always-on server everyone knows about

- hopefully, no one bottleneck — "scalability"

any machine can contact any other machine

- every machine plays an approx. equal role?

set of machines may change over time

why distributed?

multiple machine owners collaborating

delegation of responsiblity to other entity

put (part of) service "in the cloud"

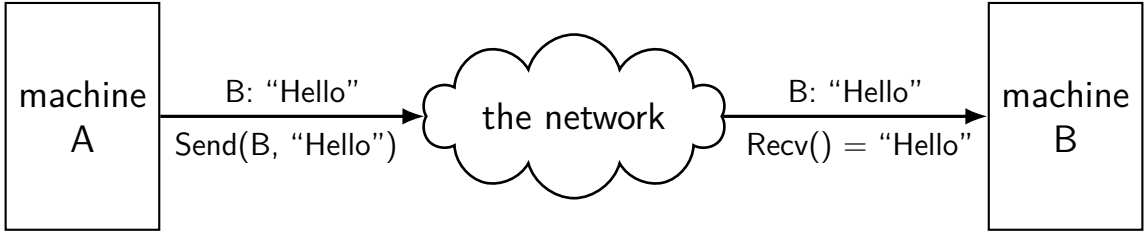
combine many cheap machines to replace expensive machine

easier to add incrementally

redundancy — one machine can fail and *system* still works?

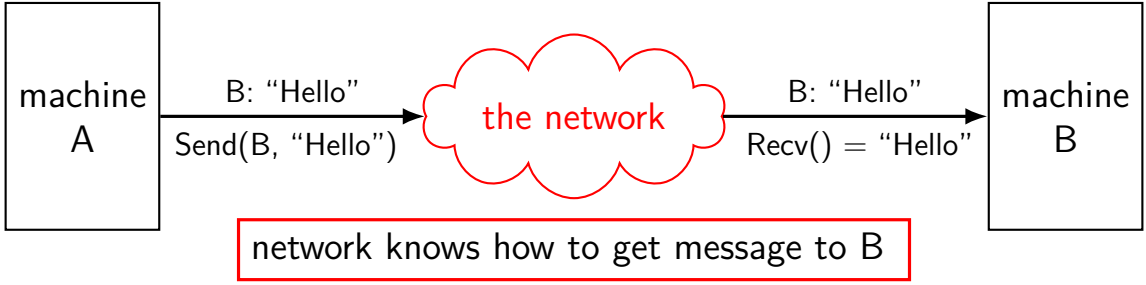
mailbox model

mailbox abstraction: send/receive messages



mailbox model

mailbox abstraction: send/receive messages



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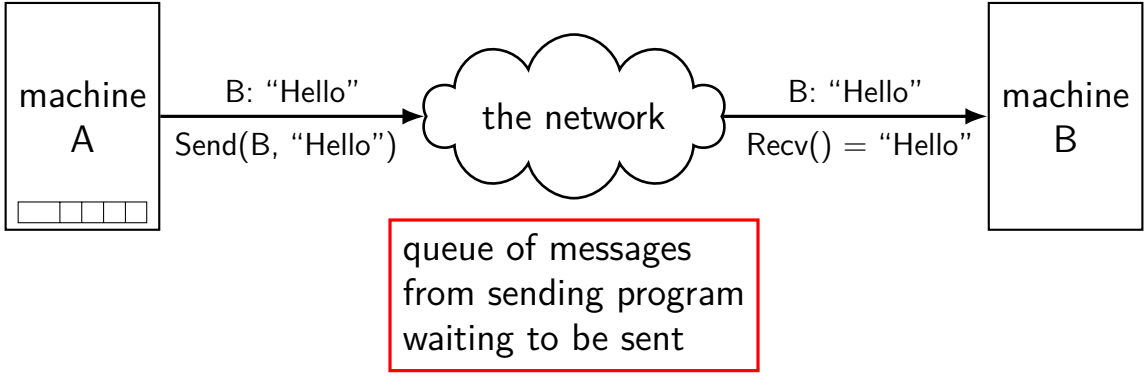
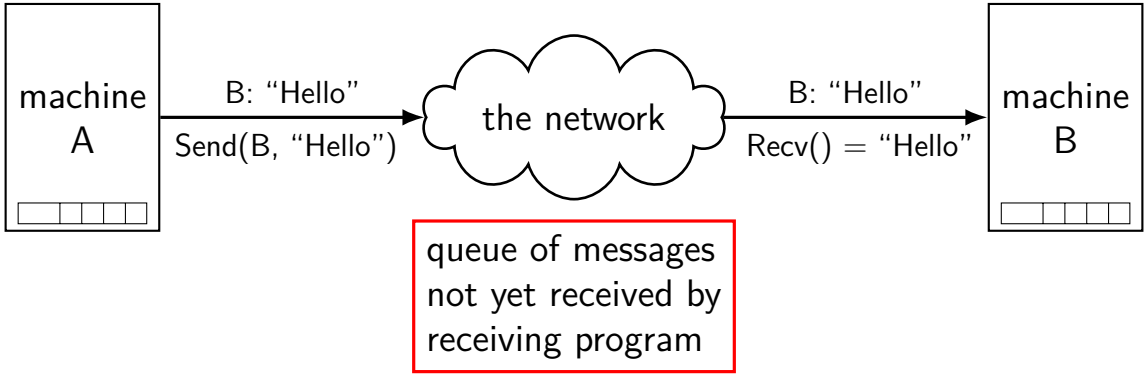
mailbox abstraction: send/receive messages



mailbox model

mailbox abstraction: send/receive messages



what about servers?

client/server model: server wants to reply to clients

might want to send/receive multiple messages

what about servers?

client/server model: server wants to reply to clients

might want to send/receive multiple messages

can build this with mailbox idea

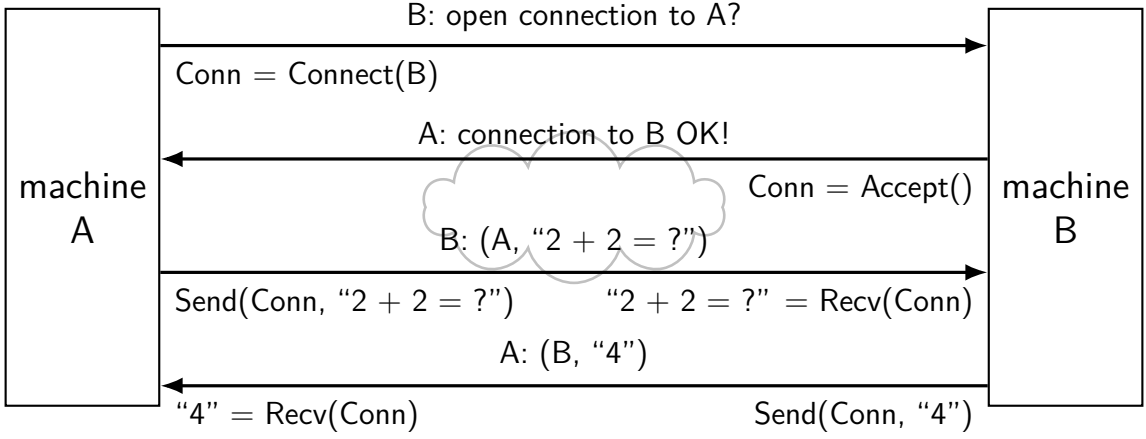
- send a 'return address'
- need to track related messages

common abstraction that does this: the connection

extension: conections

connections: two-way channel for messages

extra operations: connect, accept



connections over mailboxes

real Internet: mailbox-style communication

connections implemented on top of this

- including handling errors, transmitting more data than fits in message, ...

full details: take networking (CS/ECE 4457)

connections versus pipes

connections look kinda like two-direction pipes

in fact, in POSIX will have the same API:

each end gets file descriptor representing connection

can use read() and write()

connection missing pieces?

how to specify the machine?

multiple programs on one machine? who gets the message?

names and addresses

name	**address**
logical identifier	location/how to locate
hostname `www.virginia.edu`	IPv4 address `128.143.22.36`
hostname `mail.google.com`	IPv4 address `216.58.217.69`
hostname `mail.google.com`	IPv6 address `2607:f8b0:4004:80b::2005`
filename `/home/cr4bd/NOTES.txt`	inode# `120800873` and device `0x2eh/0x46d`
variable `counter`	memory address `0x7FFF9430`
service name `https`	port number `443`

hostnames

typically use *domain name system* (DNS) to find machine names

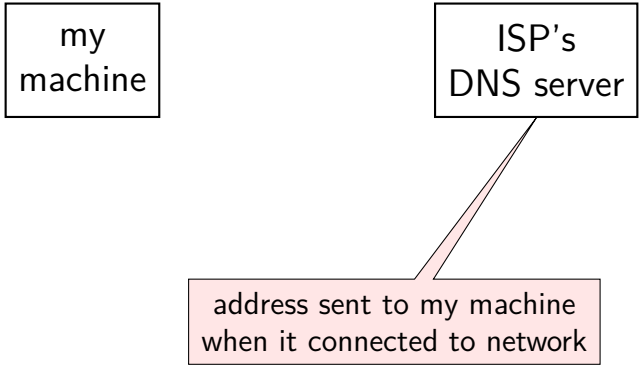
maps logical names like `www.virginia.edu`

- chosen for humans
- hierarchy of names

...to *addresses* the network can use to move messages

- numbers
- ranges of numbers assigned to different parts of the network
- network *routers* knows "send this range of numbers goes this way"

DNS: distributed database



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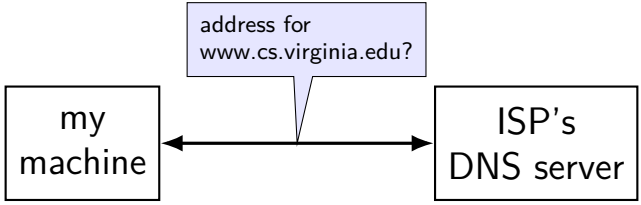

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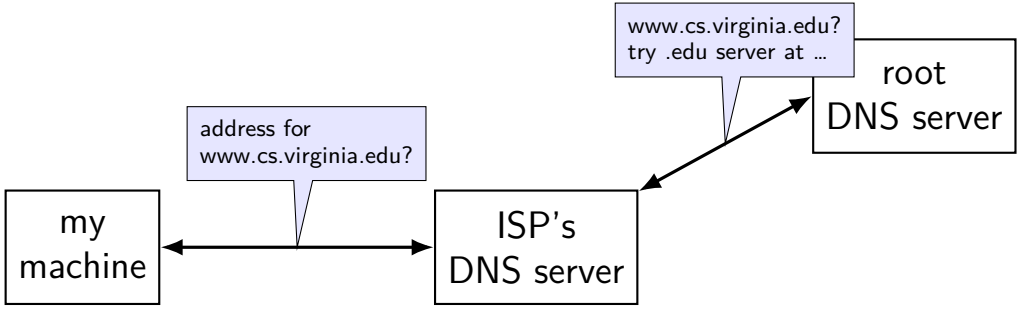

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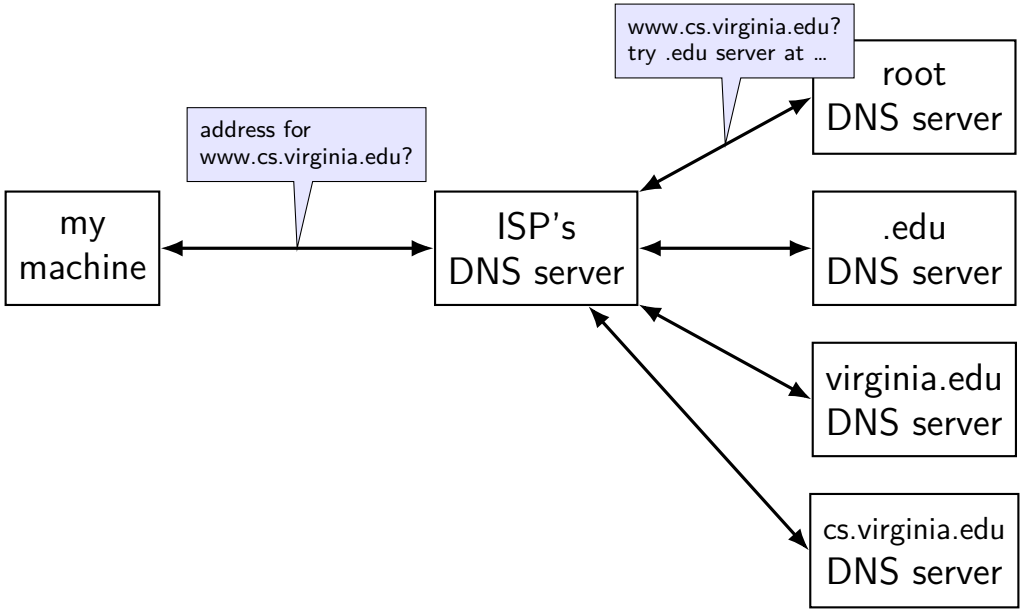

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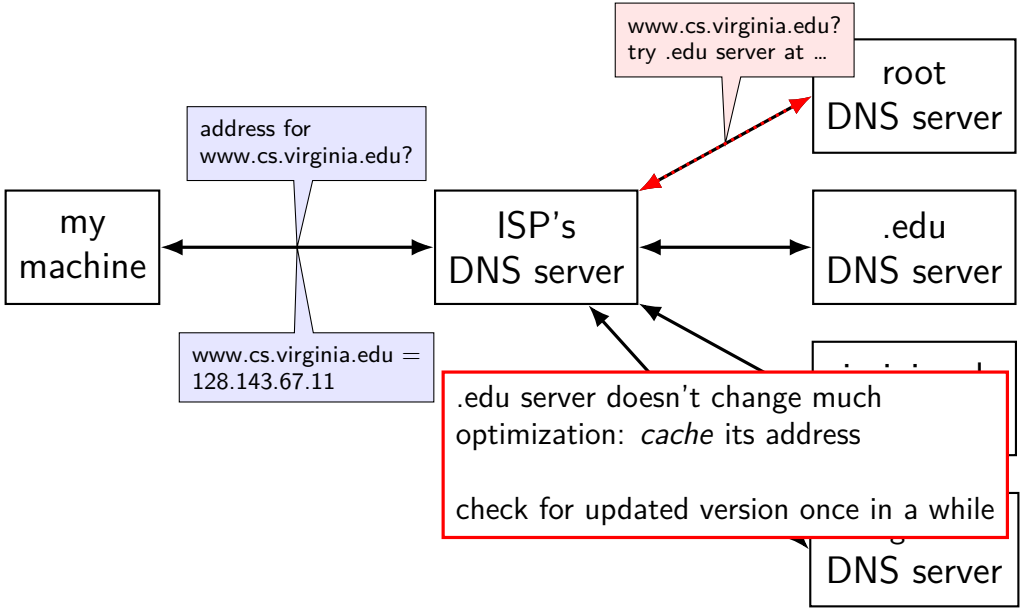


IPv4 addresses

32-bit numbers

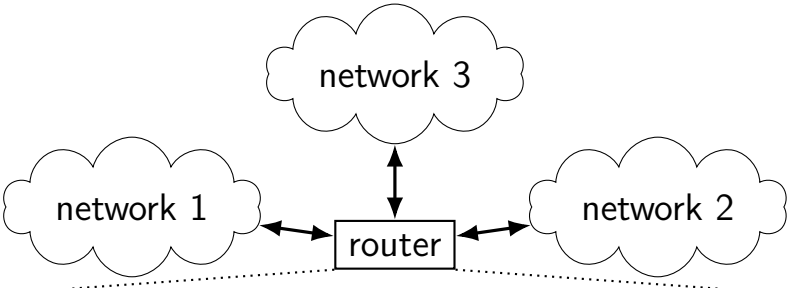
typically written like 128.143.67.11

- 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

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)

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

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

protocols

protocol = agreement on how to comunicate

sytnax (format of messages, etc.)

semantics (meaning of messages — actions to take, etc.)

human protocol: telephone

caller: pick up phone caller: check for service caller: dial caller: wait for ringing	
	callee: “Hello?”
caller: “Hi, it’s Casey...”	
	callee: “Hi, so how about ...”
caller: “Sure, ...”	
...	...
	callee: “Bye!”
caller: “Bye!”	
hang up	hang up

layered protocols

IP: protocol for sending data by IP addresses

- mailbox model
- limited message size

UDP: send *datagrams* built on IP

- still mailbox model, but *with port numbers*

TCP: reliable connections built on IP

- adds port numbers
- adds resending data if error occurs
- splits big amounts of data into many messages

HTTP: protocol for sending files, etc. built on TCP

other notable protocols (transport layer)

TLS: Transport Layer Security — built on TCP

like TCP, but adds encryption + authentication

SSH: secure shell (remote login) — built on TCP

SCP/SFTP: secure copy/secure file transfer — built on SSH

HTTPS: HTTP, but over TLS instead of TCP

FTP: file transfer protocol

...

other notable protocols (transport layer)

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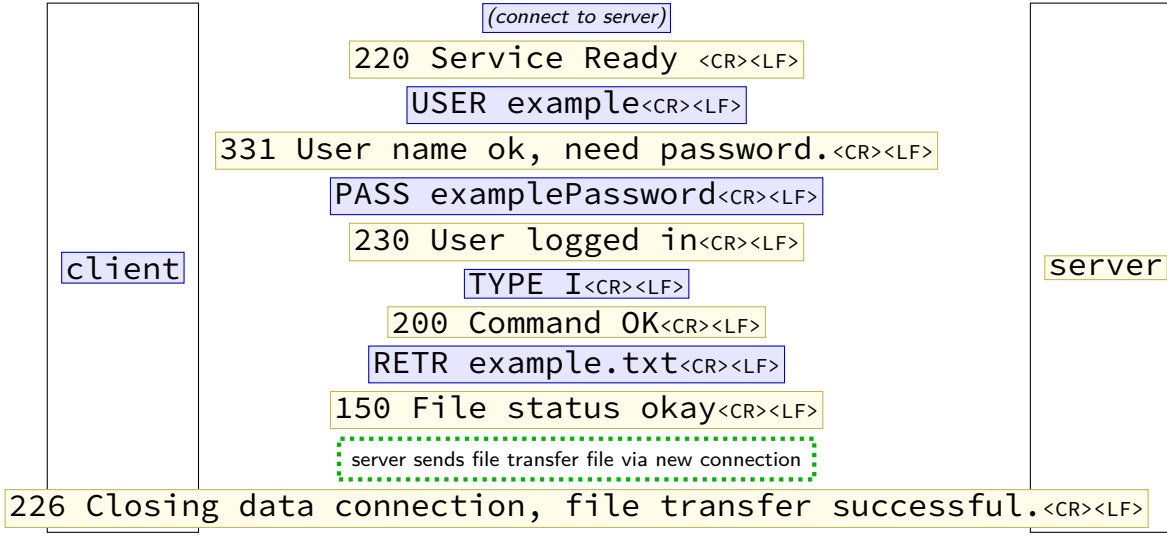
FTP protocol (simplified)



notable things about FTP

FTP is stateful — previous commands change future ones

- logging in for whole connection
- change current directory
- set image file type (binary, not text)

FTP uses separate connections for transferring data

- PASV: client connects separately to server
- PORT: client specifies where server connects
- (+ very rarely used default: connect back to port 20)

status codes for every command

sockets

socket: POSIX abstraction of network I/O queue

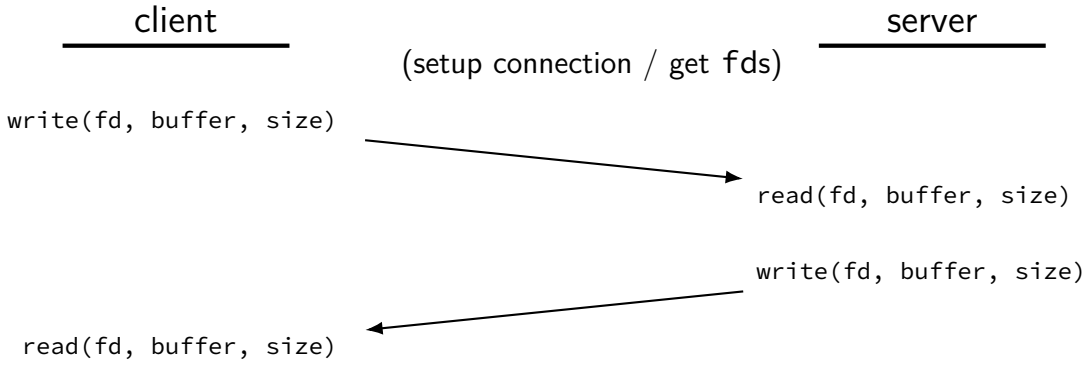
- any kind of network
- can also be used between processes on same machine

a kind of file descriptor

connected sockets

sockets can represent a connection

act like bidirectional pipe



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, MAXSIZE);
        if (read_count <= 0) return; // error or EOF
        write_count = write(socket_fd, request_buf, read_count);
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    }
}
```

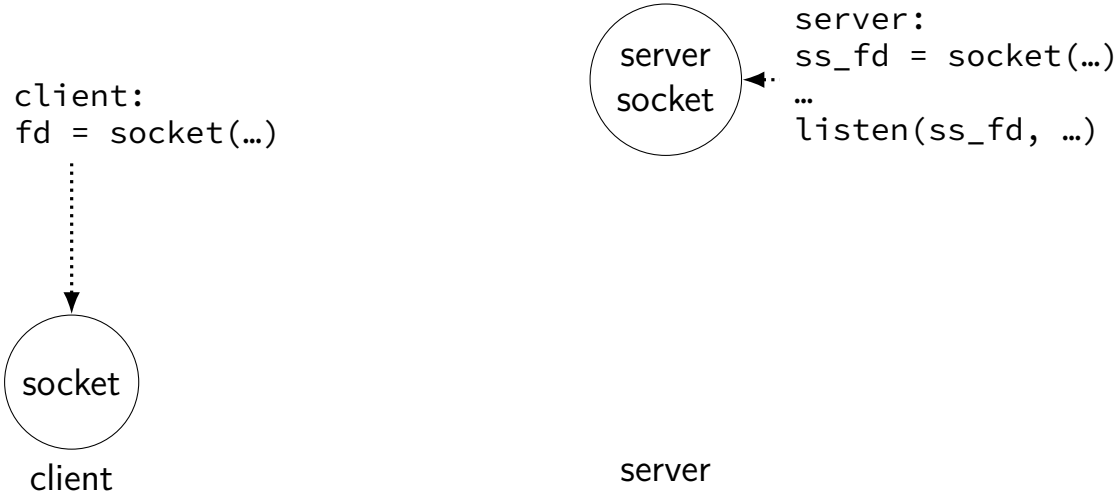
aside: send/recv

sockets have some alternate read/write-like functions:

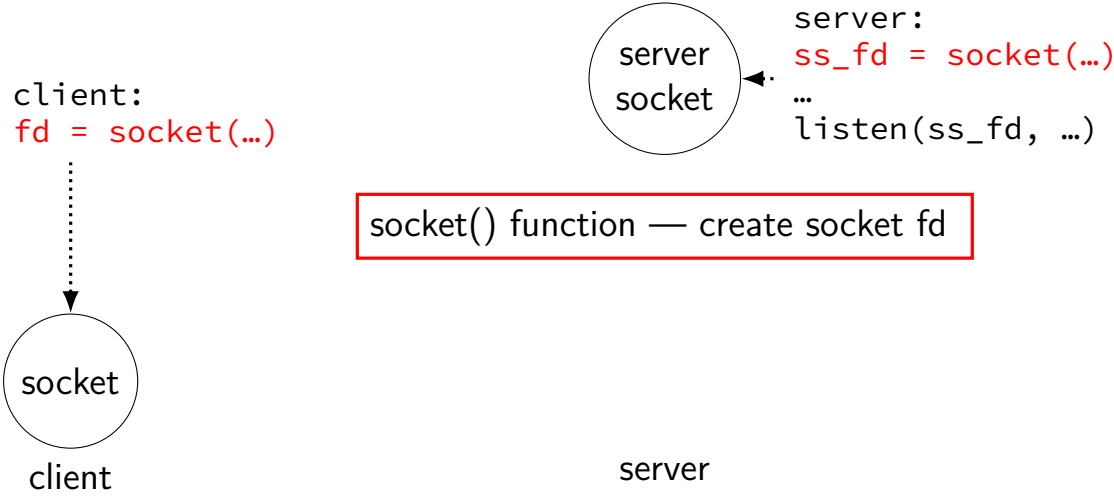
recv, recvfrom, recvmsg
send, sendmsg

have some additional options we won't need in this class

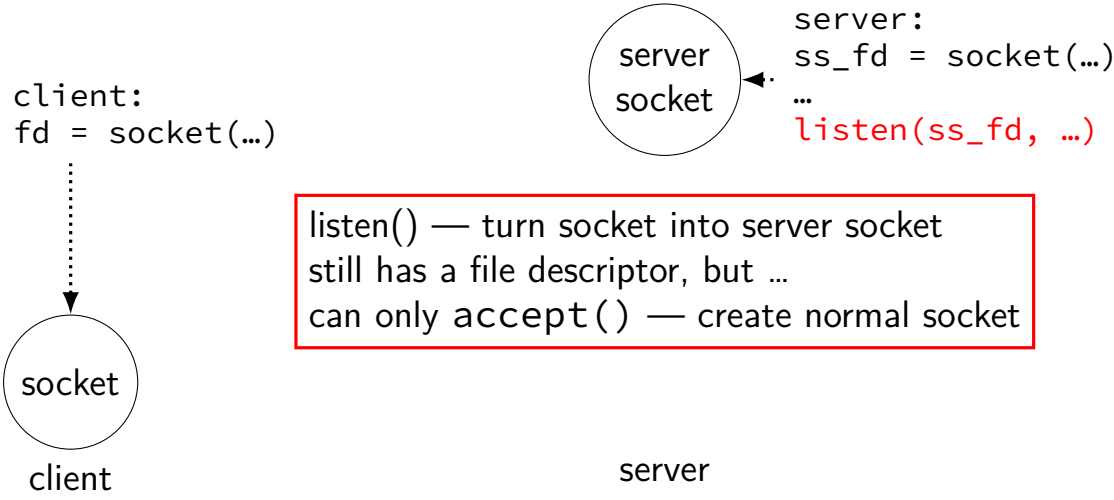
sockets and server sockets



sockets and server sockets

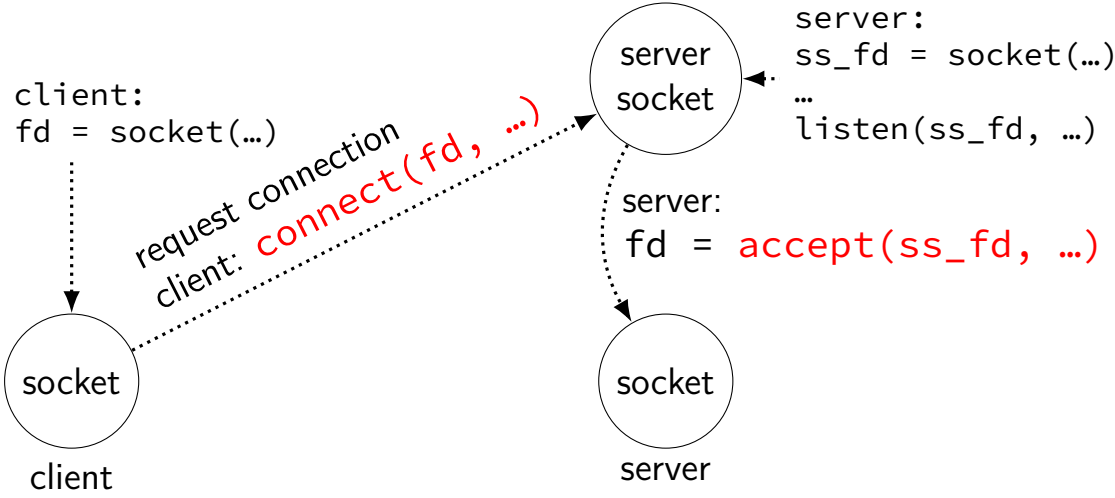


sockets and server sockets



listen() — turn socket into server socket
still has a file descriptor, but ...
can only `accept()` — create normal socket

sockets and server sockets



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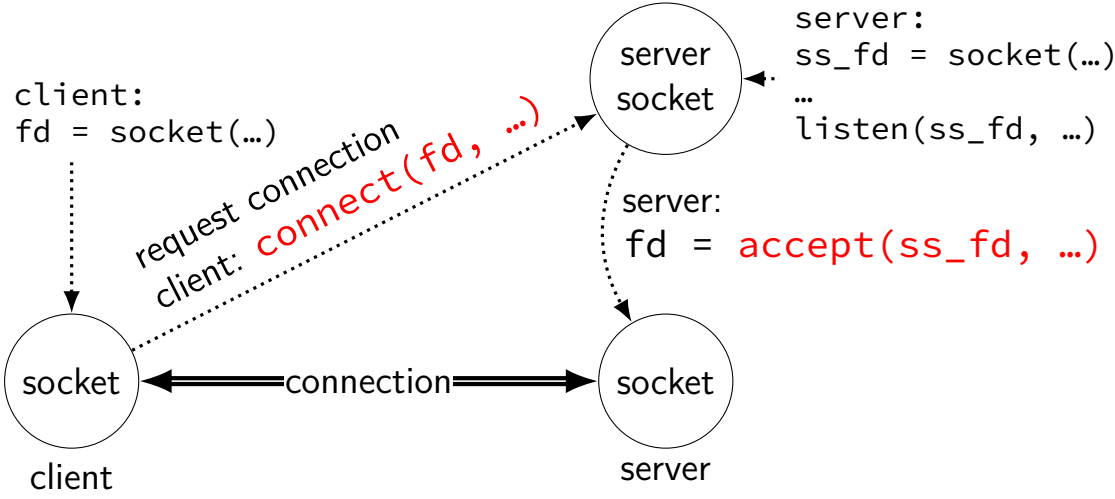


connections in TCP/IP

connection identified by *5-tuple*

used to mark messages sent on network
used by OS to lookup "where is the file descriptor?"

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

how messages are tagged on the network
(other notable protocol value: UDP)

both ends always have an address+port

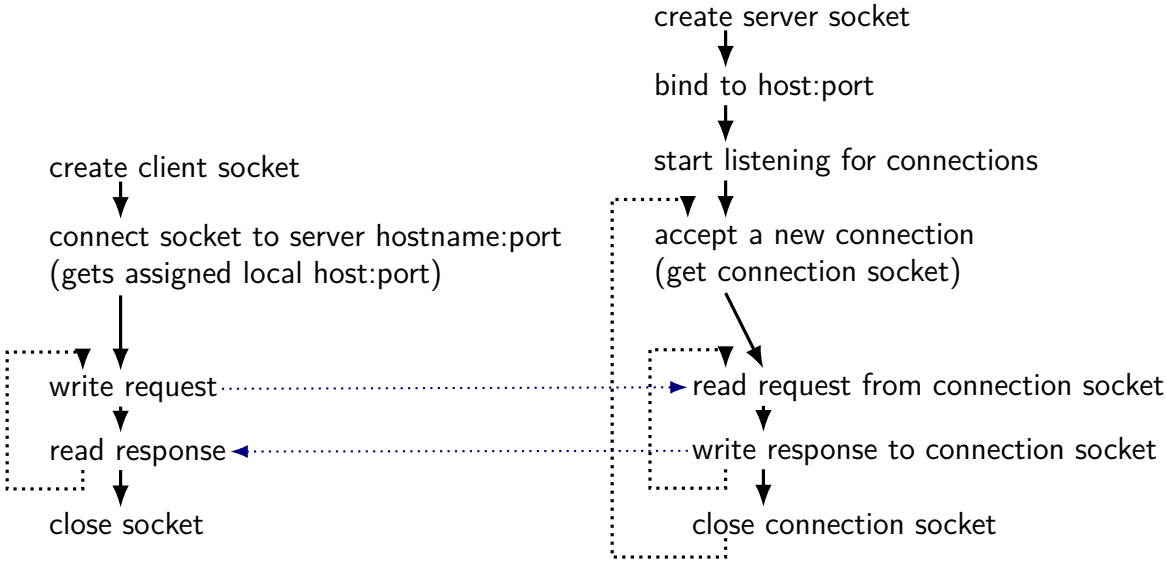
what is the IP address, port number? set with `bind()` function

typically always done for servers, not done for clients
system will choose default if you don't

connections on my desktop

```
cr4bd@reiss-t3620
: /zf14/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
```

client/server flow (one connection at a time)



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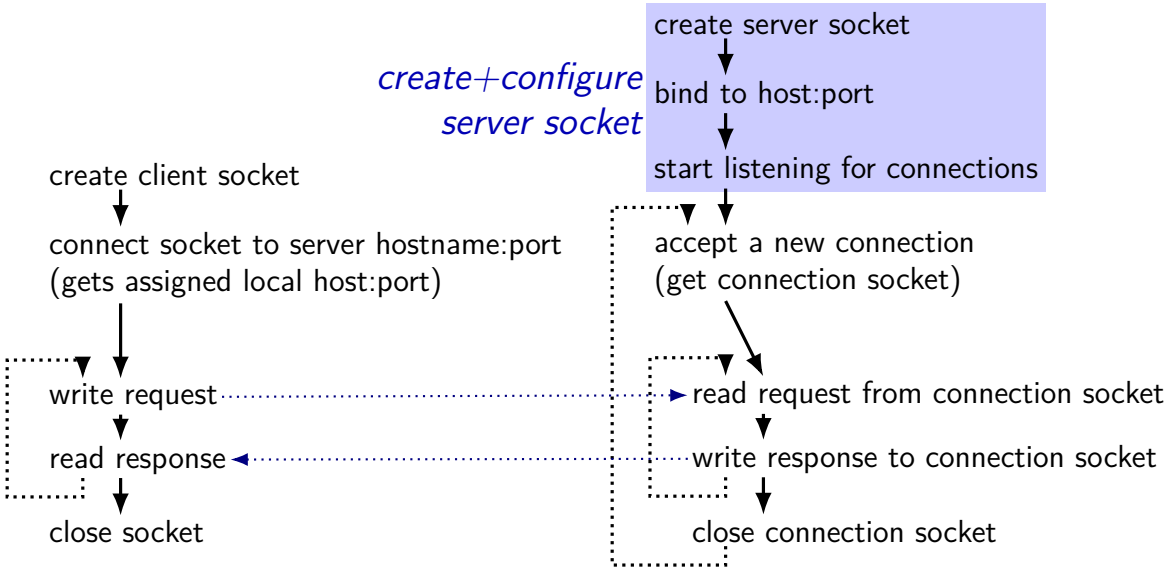

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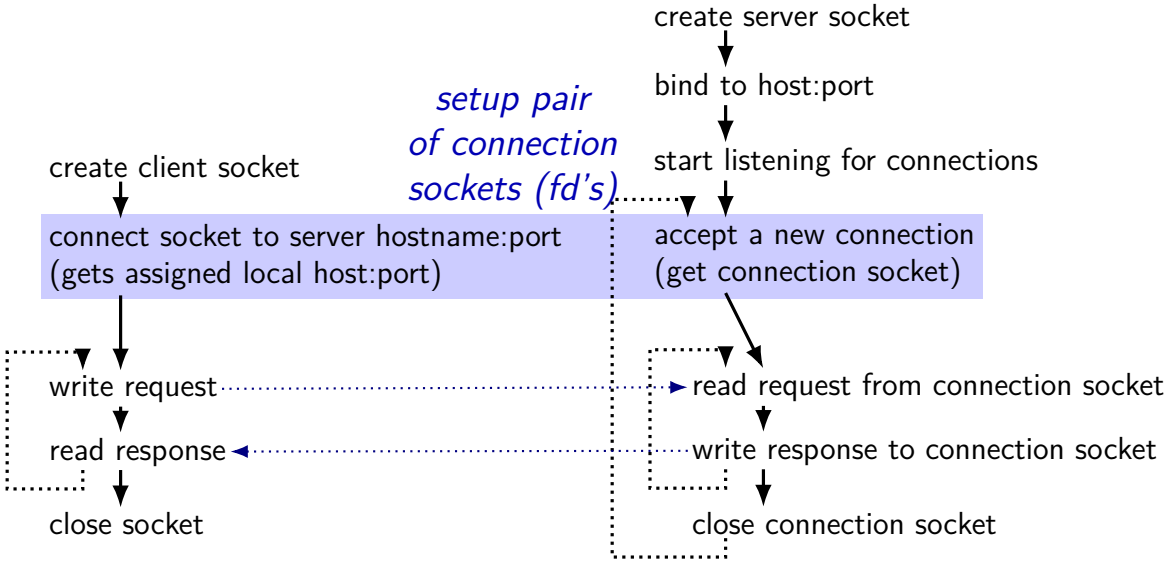
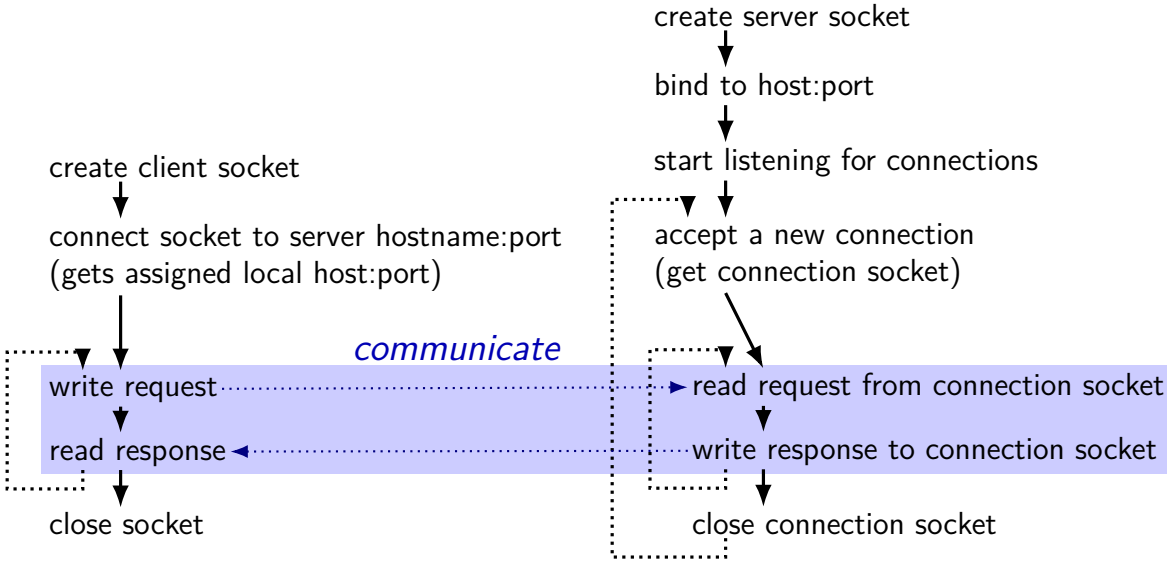
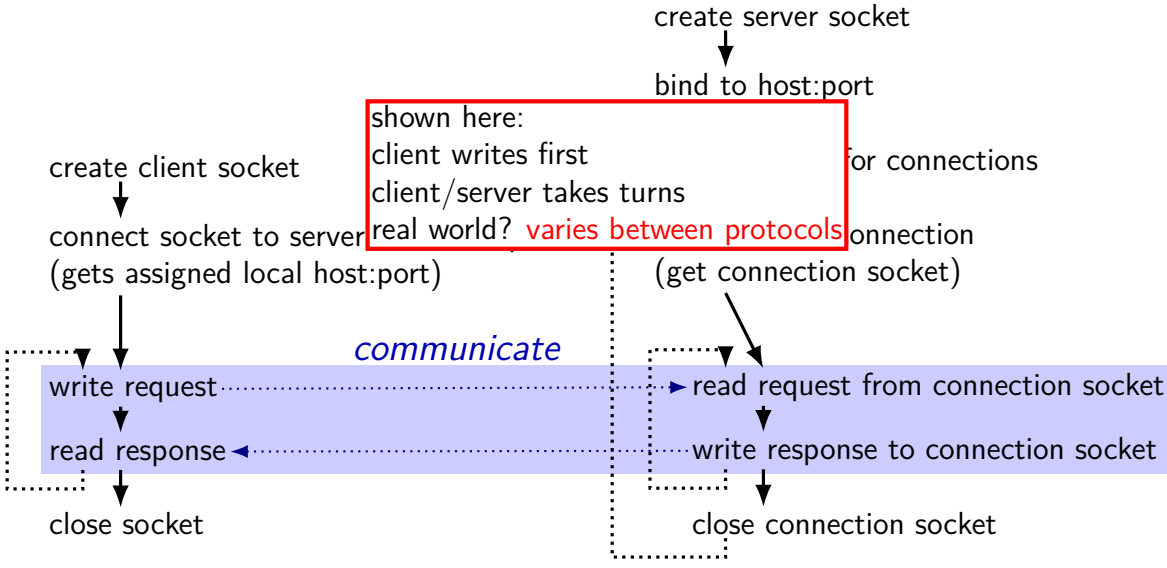


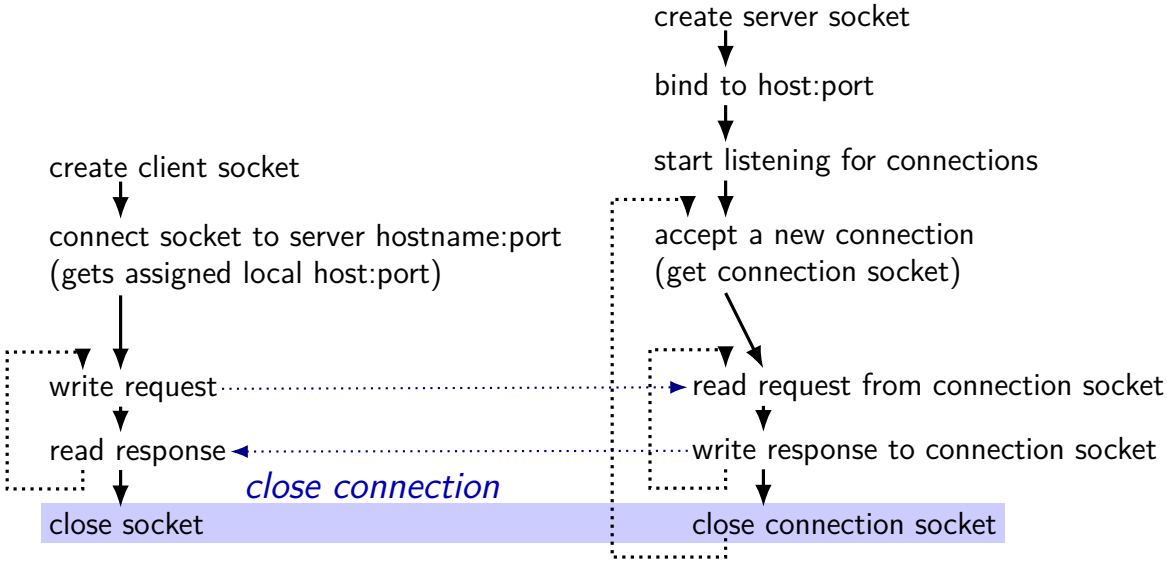
client/server flow (one connection at a time)



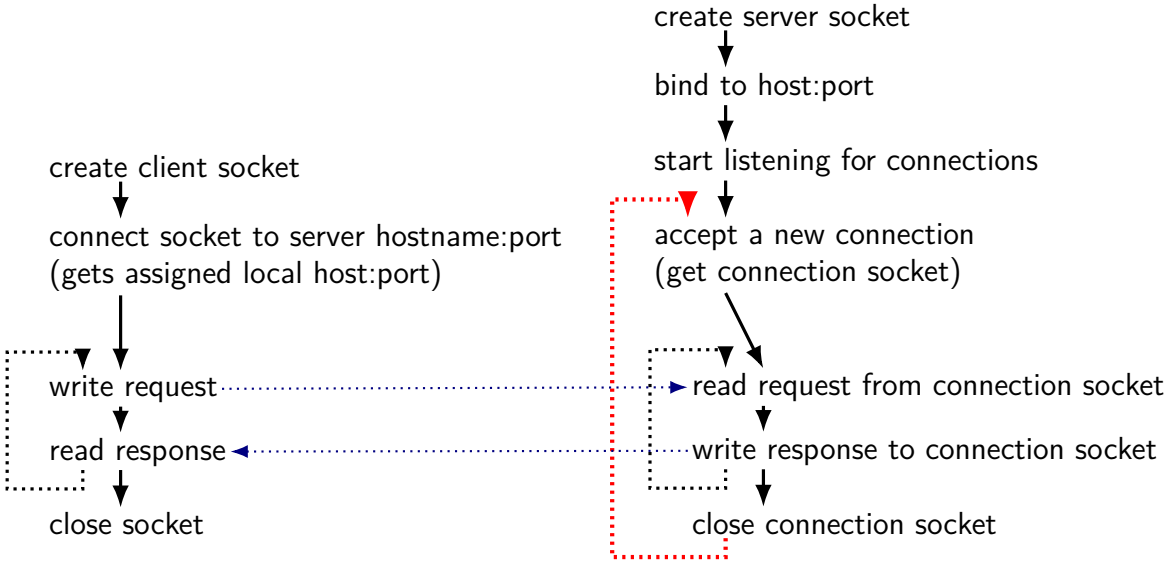
client/server flow (one connection at a time)



client/server flow (one connection at a time)



client/server flow (one connection at a time)



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 */
close(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
str
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 */
close(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 = /* code
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 */
close(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 = s
    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 */
close(sock_fd);
```

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

sockaddr_in

```
/* from 'man 7 ip' */
struct sockaddr_in {
   sa_family_t    sin_family; /* address family: always AF_INET */
   in_port_t      sin_port;   /* port in network byte order */
   struct in_addr sin_addr;   /* internet address */
};

/* Internet address. */
struct in_addr {
   uint32_t       s_addr;     /* address in network byte order */
};
```

sockaddr_in

```
/* from 'man 7 ip' */
struct sockaddr_in {
    sa_family_t    sin_family; /* address family: always AF_INET */
    in_port_t      sin_port;   /* port in network byte order */
    struct in_addr sin_addr;   /* internet address */
};

/* Internet address. */
struct in_addr {
    uint32_t       s_addr;     /* address in network byte order */
};
```

sockaddr_in

```
/* from 'man 7 ip' */
struct sockaddr_in {
    sa_family_t    sin_family; /* address family: always AF_INET */
    in_port_t      sin_port;   /* port in network byte order */
    struct in_addr sin_addr;   /* internet address */
};

/* Internet address. */
struct in_addr {
    uint32_t       s_addr;     /* address in network byte order */
};
```

trick: multiple versions of address struct
each have "type" information in same spot
OS/library checks before using

sockaddr_in6

```
/* from 'man 7 ipv6' */
struct sockaddr_in6 {
    sa_family_t     sin6_family;   /* always AF_INET6 */
    in_port_t       sin6_port;     /* port number */
    uint32_t        sin6_flowinfo; /* IPv6 flow information */
    struct in6_addr sin6_addr;     /* IPv6 address */
    uint32_t        sin6_scope_id; /* Scope ID (new in 2.4) */
};

struct in6_addr {
    unsigned char   s6_addr[16];   /* IPv6 address */
};
```

sockaddr_in6

```
/* from 'man 7 ipv6' */
struct sockaddr_in6 {
    sa_family_t     sin6_family;   /* always AF_INET6 */
    in_port_t       sin6_port;     /* port number */
    uint32_t        sin6_flowinfo; /* IPv6 flow information */
    struct in6_addr sin6_addr;     /* IPv6 address */
    uint32_t        sin6_scope_id; /* Scope ID (new in 2.4) */
};

struct in6_addr {
    unsigned char   s6_addr[16];   /* IPv6 address */
};
```

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,
     //
    ser
     //
);
if (soc
if (con                                                    0) {
    /* handle 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_f
struct add

sock_fd =
    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 a `struct sockaddr_in*` or a `struct sockaddr_in6*` (cast to a `struct sockaddr*`)

connection setup: client, using addrinfo

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

```
int
str
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: 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_f
// hints.a

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

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

```
/* exam                                                    " */
const c
...
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: 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, curre
    if (sock_fd < 0) continue;
    if (connect(sock_fd, current->ai_addr, current->ai_addrlen) == 0
        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, curre
    if (sock_fd < 0) continue;
    if (connect(sock_fd, current->ai_addr, current->ai_addrlen) == 0
        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

example: wired + wireless connection on one machine

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));
...
```

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.a                                  care */
hints.ai_flags =

rv = getaddrinfo(                                  ver);
if (rv != 0) { /* handle error */ }
```

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                                    are */
hints.ai_flags

rv = getaddrinf                                    r);
if (rv != 0) { /* handle error */ }
```

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

connection setup: server, address setup

```
/* example (hos                                          3") */
const char *hos
...
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);
```

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

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 */
}
listen
...
int socket_fd = accept(server_socket_fd, NULL);
```

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 */
}
list
...
int socket_fd = accept(server_socket_fd, NULL);
```

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(server_socket_fd, MAX_NUM_WAITING);
...
int socket_fd = accept(server_socket_fd, NULL);
```

choose the number of unaccepted connections

client/server flow (multiple connections)