

CSE 333

Lecture 17 -- network programming intro

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Administrivia

HW3 due Thursday night

HW4 out Friday morning

Due last Thursday of the quarter

OK to use up to 2 late days if you still have them

Section this week: networking (DNS, TCP client side, ...)

No more exercises due this week

Next exercise out Thur. afternoon, due Mon. morning

Today

Network programming

dive into the Berkeley / POSIX sockets API

Files and file descriptors

Remember open, read, write, and close?

POSIX system calls for interacting with files

open() returns a *file descriptor*

an integer that represents an open file

inside the OS, it's an index into a table that keeps track of any state associated with your interactions, such as the file position

you pass the file descriptor into read, write, and close

Networks and sockets

UNIX likes to make all I/O look like file I/O

the good news is that you can use `read()` and `write()` to interact with remote computers over a network!

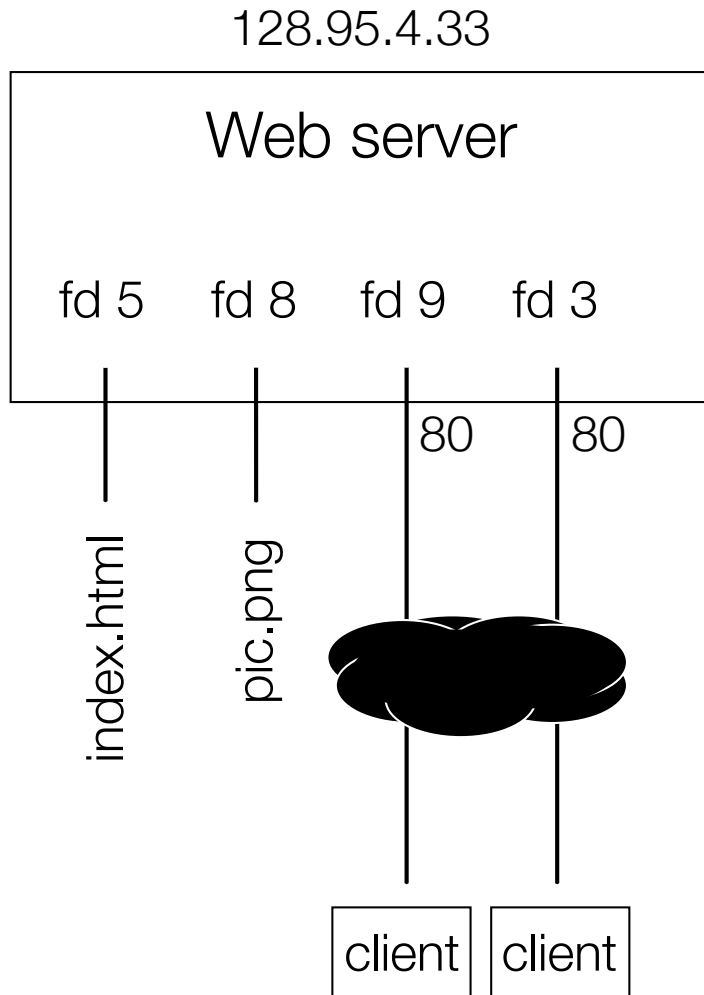
just like with files....

your program can have multiple network channels open at once

you need to pass `read()` and `write()` a ***file descriptor*** to let the OS know which network channel you want to write to or read from

a file descriptor used for network communications is a **socket**

Pictorially



OS's descriptor table

file descriptor	type	connected to?
0	pipe	stdin (console)
1	pipe	stdout (console)
2	pipe	stderr (console)
3	TCP socket	local: 128.95.4.33:80 remote: 44.1.19.32:7113
5	file	index.html
8	file	pic.png
9	TCP socket	local: 128.95.4.33:80 remote: 102.12.3.4:5544

Types of sockets

Stream sockets

for connection-oriented, point-to-point, reliable bytestreams

uses TCP, SCTP, or other stream transports

Datagram sockets

for connection-less, one-to-many, unreliable packets

uses UDP or other packet transports

Raw sockets

for layer-3 communication (raw IP packet manipulation)

Stream sockets

Typically used for client / server communications

but also for other architectures,
like peer-to-peer

Client

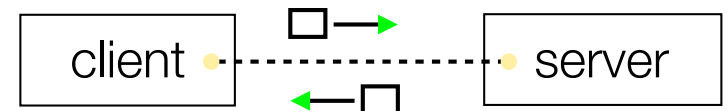
an application that establishes a
connection to a server

Server

an application that receives
connections from clients



1. establish connection



2. communicate



3. close connection

Datagram sockets

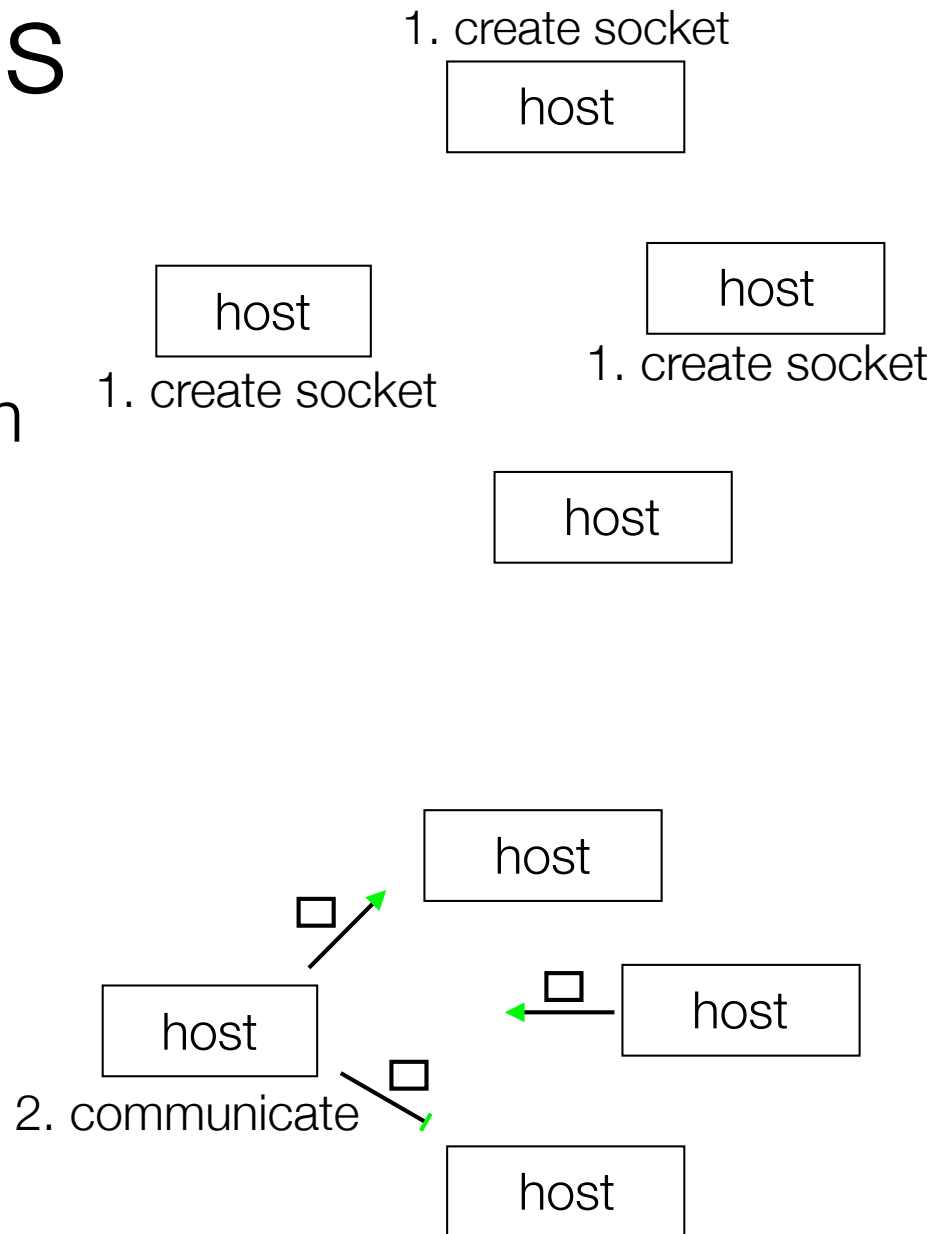
Used less frequently than stream sockets

they provide no flow control,
ordering, or reliability

Often used as a building block

streaming media applications

sometimes, DNS lookups



The sockets API

Berkeley sockets originated in 4.2 BSD Unix circa 1983

it is the standard API for network programming

available on most OSs

POSIX socket API

a slight updating of the Berkeley sockets API

a few functions were deprecated or replaced

better support for multi-threading was added

Let's dive into it!

We'll start by looking at the API from the point of view of a client connecting to a server over TCP

there are five steps:

- figure out the IP address and port to which to connect

- create a socket

- connect the socket to the remote server

- read() and write() data using the socket

- close the socket

Connecting from a client to a server.

Step 1. Figure out the IP address and port to which to connect.

Network addresses

For IPv4, an IP address is a 4-byte tuple

e.g., 128.95.4.1 (80:5f:04:01 in hex)

For IPv6, an IP address is a 16-byte tuple

e.g., 2d01:0db8:f188:0000:0000:0000:0000:1f33

2d01:0db8:f188::1f33 in shorthand

IPv4 address structures

```
// Port numbers and addresses are in *network order*.

// A mostly-protocol-independent address structure.
struct sockaddr {
    short int      sa_family;    // Address family; AF_INET, AF_INET6
    char           sa_data[14]; // 14 bytes of protocol address
};

// An IPv4 specific address structure.
struct sockaddr_in {
    short int      sin_family; // Address family, AF_INET == IPv4
    unsigned short int sin_port; // Port number
    struct in_addr sin_addr;    // Internet address
    unsigned char  sin_zero[8]; // Same size as struct sockaddr
};

struct in_addr {
    uint32_t s_addr; // IPv4 address
};
```

IPv6 address structures

```
// A structure big enough to hold either IPv4 or IPv6 structures.
struct sockaddr_storage {
    sa_family_t  ss_family;      // address family

    // a bunch of padding; safe to ignore it.
    char        __ss_pad1[_SS_PAD1SIZE];
    int64_t     __ss_align;
    char        __ss_pad2[_SS_PAD2SIZE];
};

// An IPv6 specific address structure.
struct sockaddr_in6 {
    u_int16_t   sin6_family;     // address family, AF_INET6
    u_int16_t   sin6_port;       // Port number
    u_int32_t   sin6_flowinfo;   // IPv6 flow information
    struct in6_addr sin6_addr;    // IPv6 address
    u_int32_t   sin6_scope_id;   // Scope ID
};

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

Generating these structures

Often you have a string representation of an address

how do you generate one of the address structures?

```
#include <stdlib.h>
#include <arpa/inet.h>

int main(int argc, char **argv) {
    struct sockaddr_in sa; // IPv4
    struct sockaddr_in6 sa6; // IPv6

    // IPv4 string to sockaddr_in.
    inet_pton(AF_INET, "192.0.2.1", &(sa.sin_addr));

    // IPv6 string to sockaddr_in6.
    inet_pton(AF_INET6, "2001:db8:63b3:1::3490", &(sa6.sin6_addr));

    return EXIT_SUCCESS;
}
```

genaddr.cc

Generating these structures

How about going in reverse?

```
genstring.cc
#include <stdlib.h>
#include <arpa/inet.h>
#include <iostream>

int main(int argc, char **argv) {
    struct sockaddr_in6 sa6;          // IPv6
    char astring[INET6_ADDRSTRLEN]; // IPv6

    // IPv6 string to sockaddr_in6.
    inet_pton(AF_INET6, "2001:db8:63b3:1::3490", &(sa6.sin6_addr));

    // sockaddr_in6 to IPv6 string.
    inet_ntop(AF_INET6, &(sa6.sin6_addr), astring, INET6_ADDRSTRLEN);
    std::cout << astring << std::endl;

    return EXIT_SUCCESS;
}
```

DNS

People tend to use DNS names, not IP addresses

the sockets API lets you convert between the two

it's a complicated process, though:

- a given DNS name can have many IP addresses

- many different DNS names can map to the same IP address

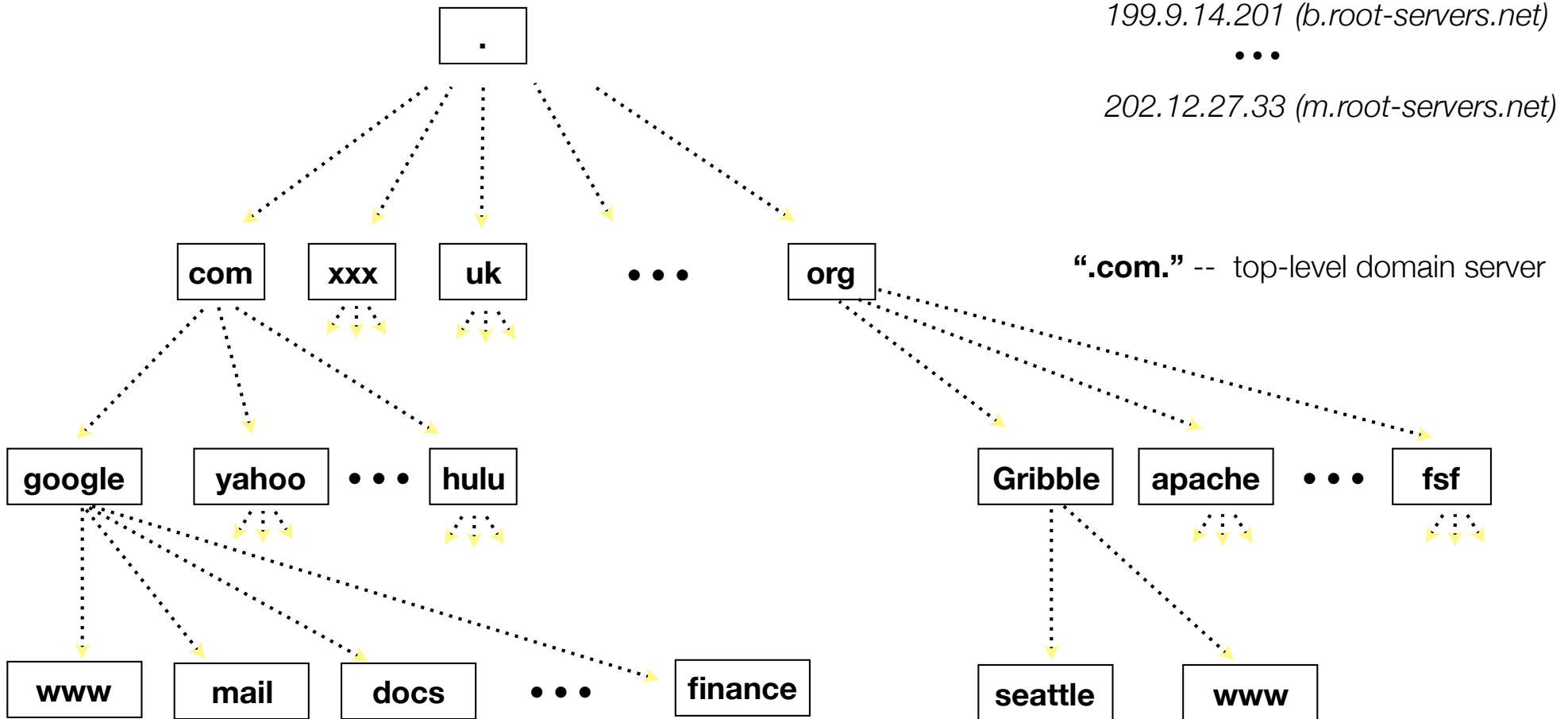
- an IP address will reverse map into at most one DNS name, and maybe none

- a DNS lookup may require interacting with many DNS servers

You can use the “dig” Linux program to explore DNS

“man dig”

DNS hierarchy



Resolving DNS names

The POSIX way is to use **getaddrinfo()**

a pretty complicated system call; the basic idea...

set up a “hints” structure with constraints you want respected

e.g., IPv6, IPv4, or either

tell getaddrinfo() which host and port you want resolved

host: a string representation; DNS name or IP address

getaddrinfo() gives you a list of results packet in an “addrinfo” struct

free the addrinfo structure using freeaddrinfo()

DNS lookup example

see dnsresolve.cc

Connecting from a client to a server.

Step 2. Create a socket.

Creating a socket

Use the **socket** system call

creating a socket doesn't yet bind it to a local address or port

```
#include <errno.h>
#include <stdlib.h>
#include <string.h>
#include <sys/socket.h>
#include <sys/types.h>
#include <iostream>

int main(int argc, char **argv) {
    int socket_fd = socket(PF_INET, SOCK_STREAM, 0);
    if (socket_fd == -1) {
        std::cerr << strerror(errno) << std::endl;
        return EXIT_FAILURE;
    }
    close(socket_fd);
    return EXIT_SUCCESS;
}
```

socket.cc

Connecting from a client to a server.

Step 3. Connect the socket to the remote server.

connect()

The **connect()** system call establishes a connection to a remote host

you pass the following arguments to connect():

- the socket file descriptor you created in step 2

- one of the address structures you created in step 1

connect may take some time to return

- it is a **blocking** call by default

- the network stack within the OS will communicate with the remote host to establish a TCP connection to it

- this involves *~2 round trips* across the network

connect example

see connect.cc

Connecting from a client to a server.

Step 4. `read()` and `write()` data using the socket.

read()

By default, a blocking call

if there is data that has already been received by the network stack, then read will return immediately with it

thus, read might return with less data than you asked for

if there is no data waiting for you, by default read() will block until some arrives

pop quiz: how might this cause **deadlock**?

write()

By default, a blocking call

but, in a more sneaky way

when write() returns, the receiver (i.e., the other end of the connection) probably has not yet received the data

in fact, the data might not have been sent on the network yet!

write() enqueues your data in a send buffer in the OS, and then returns; the OS will transmit the data in the background

if there is no more space left in the send buffer, by default write() will block

how might this cause **deadlock**?

read/write example

see sendreceive.cc

Connecting from a client to a server.

Step 5. `close()` the socket.

See you on Friday!

Exercise 1

Write a client that:

- reads DNS names, one per line, from stdin

- translates each name to one or more IP addresses

- prints out each IP address to stdout, one per line