Client-side and Server-side Network Programming

CSE 333 Summer 2023

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Relevant Course Information (1/2)

- Homework 3 due tomorrow
  - Usual reminder: **don't forget to tag, clone elsewhere, and recompile** (will need to copy libhw1.a and libhw2.a)
- Homework 4 released Friday
  - Due last Wednesday of quarter (8/16)
  - Can still use 2 late days for hw4 (hard deadline of 8/18)
  - Demo next lecture
- Exercise 10 released today, due Wednesday (3/1)
  - Client-side TCP connection
- Exercise 11 released today, due Friday (3/3)
  - Server-side programming

Relevant Course Information (2/2)

- Quiz 3
  - Open Monday (8/7) @ 2pm to Wednesday (8/9) @ 11:59pm
  - Will include questions about:
    - Exercise 7, 8 and 9
    - Homework 3
- Quiz 4
  - Open Wednesday (8/16) @ 2pm to Friday (8/18) @ 11:59pm
  - Will include questions about:
    - Exercise 10, 11, and 12
    - Homework 4
    - Course wrap-up

Socket API: Client TCP Connection

- There are five steps:
  1) Figure out the IP address and port to connect to
  2) Create a socket
  3) Connect the socket to the remote server
  4) `read()` and `write()` data using the socket
  5) Close the socket

Step 2: Creating a Socket

- `int socket(int domain, int type, int protocol);`
  - Creating a socket doesn't bind it to a local address or port yet
  - Returns file descriptor or -1 on error

socket.cc

```
#include <arpa/inet.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <iostream>

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

Step 3: Connect to the Server

- The **`connect`**`()` system call establishes a connection to a remote host
  - ```
    int connect(int sockfd, const struct sockaddr* addr,
                socklen_t addrlen);
    ```
    - `sockfd`: Socket file description from Step 2
    - `addr` and `addrlen`: Usually from one of the address structures returned by **`getaddrinfo`** in Step 1 (DNS lookup)
    - Returns **`0`** on success and **`-1`** on error
- **`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

```
// Get an appropriate sockaddr structure.
struct sockaddr_storage addr;
size_t addrlen;
LookupName(argv[1], port, &addr, &addrlen);

// Create the socket.
int socket_fd = socket(addr.ss_family, SOCK_STREAM, 0);
if (socket_fd == -1) {
  cerr << "socket() failed: " << strerror(errno) << endl;
  return EXIT_FAILURE;
}

// Connect the socket to the remote host.
int res = connect(socket_fd,
                  reinterpret_cast<sockaddr*>(&addr),
                  addrlen);
if (res == -1) {
  cerr << "connect() failed: " << strerror(errno) << endl;
}
```

Poll Everywhere

pollev.com/cse333

How do we *error* check `read()` and `write()`?

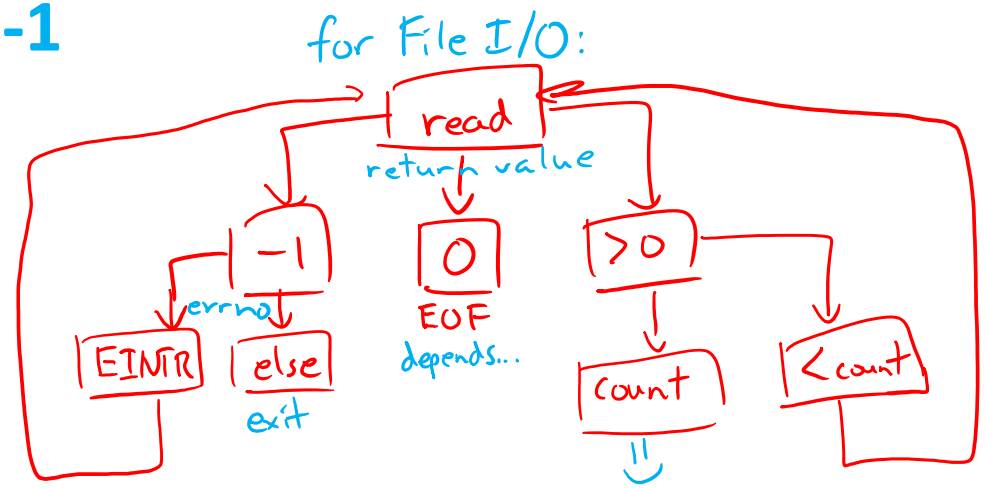
A. `ferror()`

B. Return value less than expected

C. Return value of 0 or NULL

D. Return value of -1

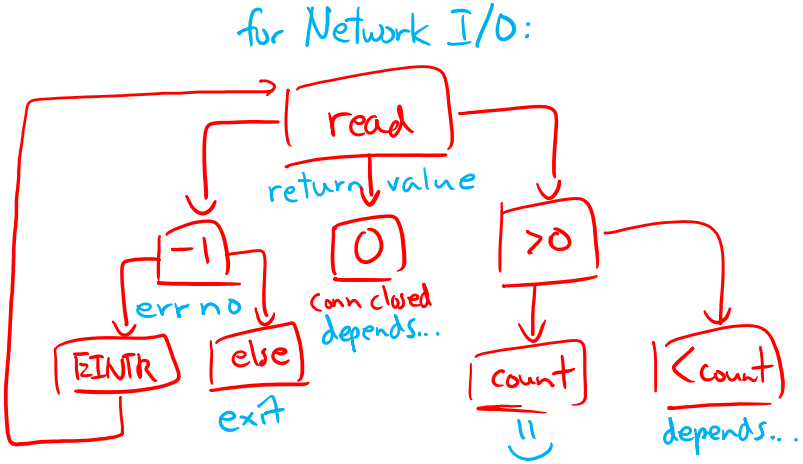
E. We're lost…



Step 4: `read()`

- If there is data that has already been received by the network stack, then read will return immediately with it
  - `read()` might return with *less* data than you asked for

- If there is no data waiting for you, by default `read()` will *block* until something arrives
  - How might this cause *deadlock*? server & client have no data to read, but both call read()
  - Can `read()` return 0? Yes, if connection is closed



Step 4: `write()`

- `write()` queues your data in a send buffer in the OS and then returns
  - The OS transmits the data over the network in the background
  - When `write()` returns, the receiver probably has not yet received the data!

- If there is no more space left in the send buffer, by default `write()` will *block*

Read/Write Example

- See sendreceive.cc

```
while (1) {
  int wres = write(socket_fd, readbuf, res);
  if (wres == 0) {
    cerr << "socket closed prematurely" << endl;
    close(socket_fd);
    return EXIT_FAILURE;
  }
  if (wres == -1) {
    if (errno == EINTR)
      continue;
    cerr << "socket write failure: " << strerror(errno) << endl;
    close(socket_fd);
    return EXIT_FAILURE;
  }
  break;
}
```

Step 5: `close()`

- `int close(int fd);`
  - Nothing special here – it's the same function as with file I/O
  - Shuts down the socket and frees resources and file descriptors associated with it on both ends of the connection

Socket API: Server TCP Connection

- Pretty similar to clients, but with additional steps:

Analogy:

1) Figure out the IP address and port on which to listen — ① find a location/buy land
2) Create a socket — ② build the structure
3) `bind()` the socket to the address(es) and port — ③ prep work & advertising
4) Tell the socket to `listen()` for incoming clients — ④ open the door (customers queue)
5) `accept()` a client connection — ⑤ "next customer in line!"
6) `read()` and `write()` to that connection — ⑥ transaction occurs
7) `close()` the client socket — ⑦ customer leaves

Servers

- Servers can have multiple IP addresses ("*multihoming*")
  - Usually have at least one externally-visible IP address, as well as a local-only address (127.0.0.1)

- The goals of a server socket are different than a client socket
  - Want to bind the socket to a particular *port* of one or more IP addresses of the server
  - Want to allow multiple clients to connect to the same port
    - OS uses client IP address and port numbers to direct I/O to the correct server file descriptor

Step 1: Figure out IP address(es) & Port

- Step 1: `getaddrinfo()` invocation may or may not be needed (but we'll use it)
  - Do you know your IP address(es) already?
    - Static vs. dynamic IP address allocation
    - Even if the machine has a static IP address, don't wire it into the code – either look it up dynamically or use a configuration file
  - Can request listen on all local IP addresses by passing `NULL` as `hostname` and setting `AI_PASSIVE` in `hints.ai_flags`
    - Effect is to use address `0.0.0.0` (IPv4) or `::` (IPv6)

Common and hard-to-find bug is forgetting to set this ☹

Step 2: Create a Socket

- Step 2: `socket()` call is same as before
  - Can directly use constants or fields from result of `getaddrinfo()`
  - Recall that this just returns a file descriptor – IP address and port are not associated with socket yet

Step 3: Bind the socket

```
int bind(int sockfd, const struct sockaddr* addr,
         socklen_t addrlen);
```

- Looks nearly identical to **`connect()`**!
- Returns **`0`** on success, **`-1`** on error

- Some specifics for `addr`:
  - **Address family:** `AF_INET` or `AF_INET6`
    - What type of IP connections can we accept?
    - POSIX systems can handle IPv4 clients via IPv6 ☺
  - **Port:** port in network byte order (**`htons()`** is handy)
  - **Address:** specify *particular* IP address or *any* IP address
    - "Wildcard address" – `INADDR_ANY` (IPv4), `in6addr_any` (IPv6)

Step 4: Listen for Incoming Clients

- `int listen(int sockfd, int backlog);`
  - Tells the OS that the socket is a listening socket that clients can connect to
  - `backlog`: maximum length of connection queue
    - Gets truncated, if necessary, to defined constant `SOMAXCONN`
    - The OS will refuse new connections once queue is full until server **`accept`**`()`s them (removing them from the queue)
  - Returns **`0`** on success, **`-1`** on error
  - Clients can start connecting to the socket as soon as **`listen`**`()` returns
    - Server can't use a connection until you **`accept`**`()` it

Example #1

- See server_bind_listen.cc
  - Takes in a port number from the command line
  - Opens a server socket, prints info, then listens for connections for 20 seconds
    - Can connect to it using netcat (`nc`)

Step 5: Accept a Client Connection

```
int accept(int sockfd, struct sockaddr* addr,
           socklen_t* addrlen);
```

- Returns an active, ready-to-use socket file descriptor connected to a client (or `-1` on error)
  - `sockfd` must have been created, bound, *and* listening
  - Pulls a queued connection or waits for an incoming one
- `addr` and `addrlen` are output parameters
  - `*addrlen` should initially be set to `sizeof(*addr)`, gets overwritten with the size of the client address
  - Address information of client is written into `*addr`
    - Use **`inet_ntop()`** to get the client's printable IP address
    - Use **`getnameinfo()`** to do a *reverse DNS lookup* on the client

Example #2

- See server_accept_rw_close.cc
  - *Takes in a port number from the command line*
  - *Opens a server socket, prints info, then listens for connections*
    - *Can connect to it using netcat (`nc`)*
  - Accepts connections as they come
  - Echoes any data the client sends to it on `stdout` and also sends it back to the client

Something to Note

- Our server code is not concurrent
  - Single thread of execution
  - The thread blocks while waiting for the next connection
  - The thread blocks waiting for the next message from the connection

- A crowd of clients is, by nature, concurrent
  - While our server is handling the next client, all other clients are stuck waiting for it ☹

Extra Exercise #1

- Write a program 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