Poll Everywhere

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What optional topics would most interest you?

A. Benchmarking / Optimizing C++ code for *speed*
B. Rust: a modern systems programming language
C. A and B
D. Neither! I'm done with systems programming!

Client-side Networking

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Administrivia

- Check canvas gradebook (ex1-ex10)
  - Lowest exercise excused if survey was completed
- Homework 3 is due Nov. 24
  - Usual reminders: don't forget to tag, clone elsewhere, and recompile
- Homework 4 will be released on Monday (Nov. 22)
- Exercise 14 released today and due Monday (Nov. 22)
  - Client-side TCP connection
  - Section this week will help!

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

Let's review

Resolving DNS Names

- The POSIX way is to use **`getaddrinfo()`**
  - A complicated system call found in `#include <netdb.h>`
  - ```
    int getaddrinfo(const char* hostname,
                    const char* service,
                    const struct addrinfo* hints,
                    struct addrinfo** res);
    ```
    - Tell **`getaddrinfo()`** which host and port you want resolved
      - String representation for host: DNS name or IP address
    - Set up a "`hints`" structure with constraints you want respected
    - **`getaddrinfo()`** gives you a list of results packed into an "`addrinfo`" structure/linked list
      - Returns **0** on success; returns *negative number* on failure
    - Free the `struct addrinfo` later using **`freeaddrinfo()`**

Recursively frees res linked list
    ```

getaddrinfo

"don't care" options

- **getaddrinfo()** arguments:
  - `hostname` – domain name or IP address string
  - `service` – port # (*e.g.*, `"80"`) or service name (*e.g.*, `"www"`) or `NULL`/`nullptr`
  -

```
struct addrinfo {
  int      ai_flags;          // additional flags
  int      ai_family;         // AF_INET, AF_INET6, AF_UNSPEC
  int      ai_socktype;       // SOCK_STREAM, SOCK_DGRAM, 0
  int      ai_protocol;       // IPPROTO_TCP, IPPROTO_UDP, 0
  size_t   ai_addrlen;        // length of socket addr in bytes
  struct sockaddr* ai_addr;   // pointer to socket addr
  char*    ai_canonname;      // canonical name
  struct addrinfo* ai_next;   // can form a linked list
};
```

DNS Lookup Procedure

```
struct addrinfo {
  int      ai_flags;          // additional flags
  int      ai_family;         // AF_INET, AF_INET6, AF_UNSPEC
  int      ai_socktype;       // SOCK_STREAM, SOCK_DGRAM, 0
  int      ai_protocol;       // IPPROTO_TCP, IPPROTO_UDP, 0
  size_t   ai_addrlen;        // length of socket addr in bytes
  struct sockaddr* ai_addr;   // pointer to socket addr
  char*    ai_canonname;      // canonical name
  struct addrinfo* ai_next;   // can form a linked list
};
```

1) Create a `struct addrinfo hints`
2) Zero out `hints` for "defaults"
3) Set specific fields of `hints` as desired
4) Call **`getaddrinfo`**`()` using `&hints`
5) Resulting linked list `res` will have all fields appropriately set

- See dnsresolve.cc

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Step 2: Creating a Socket

IPPROTO_TCP, IPPROTO_UDP, 0

- `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) {  // check for error
    std::cerr << strerror(errno) << std::endl;
    return EXIT_FAILURE;
  }
  close(socket_fd);  // close when done
  return EXIT_SUCCESS;
}
```

Step 3: Connect to the Server

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

usually: struct sockaddr_storage ss;
reinterpret_cast<sockaddr*>(&ss)

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

socket()

getaddrinfo()
struct addrinfo

  - `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 — waits on an event before returning
  - 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;
}
```

// does the getaddrinfo() call

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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…

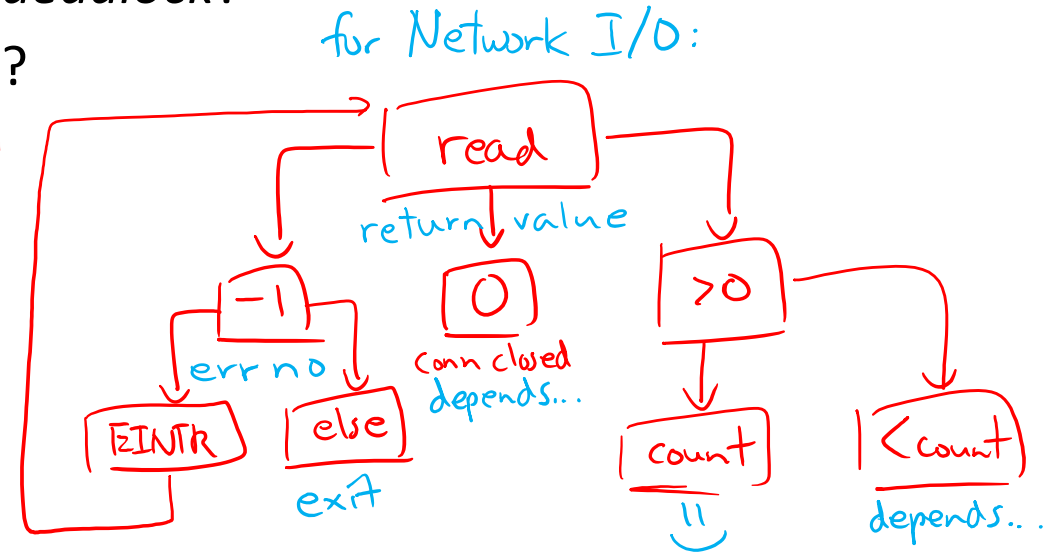
Step 4: `read()`

- 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*?
  - Can `read()` return `0`?

server & client have no data to read but both call read()

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*

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When we call `write()`, what data do we need to pass to it when writing over the network?

A. Any data our application needs to send

B. All of the above + TCP info (sequence number, port, …)

C. All of the above + IP info (source & dest IP addresses…)

D. All of the above + Ethernet info (source & dest MAC addresses)

E. We're lost…

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

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;
}
```

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