Client-side Networking

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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 1: DNS Lookup

- (from last time; details/examples in sections yesterday)
- See `dnsresolve.cc`

```
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
};
```

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
    ```

How long are two "round trips"

- Remember this table?
  - Exact numbers change somewhat over time, but you should know the order-of-magnitudes here

Numbers Everyone Should Know

L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	25 ns
Main memory reference	100 ns
Compress 1K bytes with Zippy	3,000 ns
Send 2K bytes over 1 Gbps network	20,000 ns
Read 1 MB sequentially from memory	250,000 ns
Round trip within same datacenter	500,000 ns
Disk seek	10,000,000 ns
Read 1 MB sequentially from disk	20,000,000 ns
Send packet CA->Netherlands->CA	150,000,000 ns

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;
}
```

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
  - This might cause *deadlock*!
  - Can `read()` return 0?

Step 4: `write()`

- **`write`**`()` enqueues 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

```
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;
}
```

- See `sendreceive.cc`
  - Demo

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

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