Lecture 4
Socket Programming

George Nychis
Carnegie Mellon University

15-441 Networking, Fall 2006
http://www.cs.cmu.edu/~srini/15-441/F06/

Outline of Lecture

- Project 1 – Questions?
- Motivation for Sockets
- Introduction to Sockets
- Nitty Gritty of Sockets
- Break
  - » Find a project partner!
- Concurrent Connections
- Select
- Roundup

Last Time

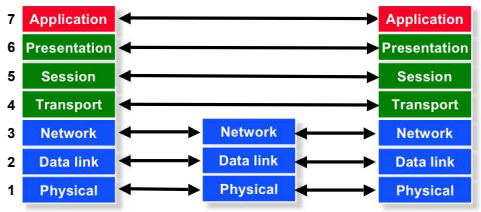
- What is a network?
- Lets start simple...
  - » What is a motivation of a computer network?
  - » What do we use networks for?
  - » How do we share data?

Let's Share Data!

- Suppose we have a 5MB file ...
  - » How can we transfer it?
  - » What type of applications and services can we use?
  - » Where do these services run?

Where do these processes exist?

- Lets take a step back:

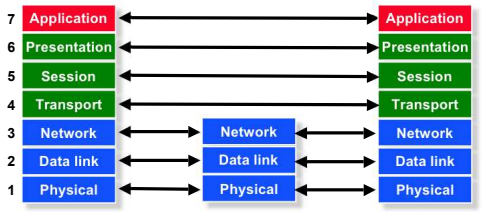


IPC: Interprocess Communication

- Overall Goal: Interprocess communication
  - » So what is the problem?
- No problem when both processes on a single machine...
- Network services such as FTP servers and HTTP servers typically run on seperate machines from the clients that access them

Back to the Application Layer

- Lets revisit this one more time... why a layered abstraction again?



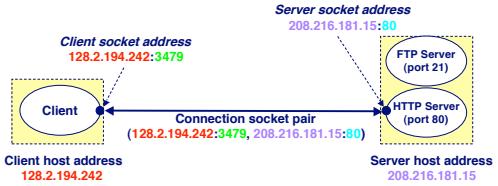
Just pass it down...

- Author of an FTP server does not need to worry about:
  - How frames are formed
  - How the data is routed through the network
  - How reliability is ensured
- Author only needs a method of passing the data down to the next layer

Lower Layers Need Info

- OK, we pass the data down... what else do the lower layers need to know?
- Where does the data go?
- Once it gets there, where does it then go? What process gets the data?

Identifying the Destination



Why Should You Care?

- You've all read the project 1 description... *winking smiley face*
- You're going to be writing an application level service! (IRC server)
- You will need to do all of what we talked about:
  - Pass messages
  - Share data
- This is all done between the servers you write, and clients we will use to test them on seperate machines! (IPC)

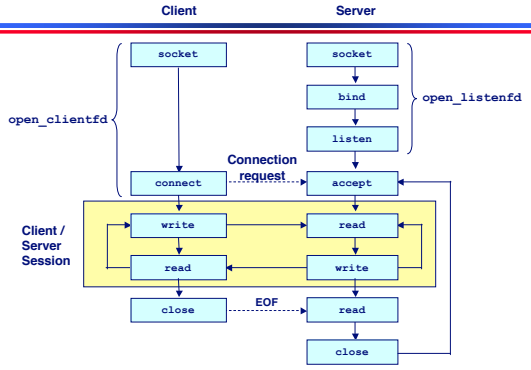
Sockets

- Lucky for you, someone made it easy...
- Sockets!
  - Set up the socket
    - Where is the remote machine? (IP address)
    - What service gets the data? (Port number)
  - Send and Receive
    - Designed to be simple, just like any other I/O in unix, read and write to the socket like a file
    - Send -> write()
    - Receive <- read()
  - Close the socket

Client / Server

- **Socket setup depends on application**
- **Both client and server applications need to request a socket descriptor**
  - » **Specify domain like IPv4 and then the type TCP/UDP**
- **Server**
  - » **Bind: assign a local address and port to the socket, like "127.0.0.1" and "80"**
  - » **Listen: ready to accept incoming connections**
  - » **Accept: take the first incoming connection out of a queue and get a new descriptor for communicating with it**
- **Client**
  - » **Connect: connect to a server in the listening state, specified by address and port**

Overview



Step 1: Setup the Socket

- **Both client and server applications need to setup the socket (*man socket*)**
  - » *int socket(int domain, int type, int protocol);*
- *Domain:*
  - » *"AF_INET" -- IPv4*
- *Type:*
  - » *"SOCK_STREAM" -- TCP (Your IRC server)*
  - » *"SOCK_DGRAM" -- UDP (Routing Daemon -> Routing Daemon)*
- *Protocol:*
  - » *"0"*
- *For example...*
  - » *int sock = socket(AF_INET, SOCK_STREAM, 0);*

Step 2 (Server): Binding the Socket

- **Only the server needs to bind (*man bind*)**
  - » *int bind(int sockfd, const struct sockaddr *my_addr, socklen_t addrlen);*
- *sockfd:*
  - » *Whatever socket() returned!*
- *my_addr:*
  - » *For Internet addresses, must cast (struct sockaddr_in *) to (struct sockaddr *)*

```
struct sockaddr_in {
    short          sin_family;   // e.g. AF_INET
    unsigned short sin_port;     // e.g. htons(3490)
    struct in_addr sin_addr;     // see struct in_addr, below
    char           sin_zero[8];  // zero this if you want to
};
struct in_addr {
    unsigned long s_addr;  // load with inet_aton()
};
```


Step 2 (Server): Binding the Socket ... Continued

- **addrlen:**
  - » **sizeof(your_sockaddr_in_struct)**
- **For example...**

```
struct sockaddr_in saddr;
int sockfd;
unsigned short port = 80;

if((sockfd=socket(AF_INET, SOCK_STREAM, 0) < 0) {        // from back a couple slides
        printf("Error creating socket\n");
        ...
}

memset(&saddr, '\0', sizeof(saddr));              // zero structure out
saddr.sin_family = AF_INET;                       // match the socket() call
saddr.sin_addr.s_addr = htonl(INADDR_ANY);        // bind to any local address
saddr.sin_port = htons(port);                     // specify port to listen on

if((bind(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) { // bind!
        printf("Error binding\n");
        ...
}
```


Network Byte Ordering

- **Wait wait... what was that "htons()/htonl()" thing?**
- **Network Byte Ordering**
  - » **Network is big-endian, host may be big- or little-endian**
  - » **Functions work on 16-bit (short) and 32-bit (long) values**
  - » **htons() / htonl() : convert host byte order to network byte order**
  - » **ntohs() / ntohl(): convert network byte order to host byte order**
  - » **Use these to convert network addresses, ports, …**

Step 3 (Server): Listen

- **Now we have a socket descriptor and address/port associated with the socket**
- **Lets listen in!** (*man listen)*
  - int listen(int sockfd, int backlog);
- sockfd:
  - Again, whatever socket() returned
- backlog:
  - Total number of hosts we want to queue
- Example...
  - listen(sockfd, 5); // pass it sockfd, no more than a queue of 5

Step 4 (Server): Accept

- **Server must accept incoming connections (*man 2 accept)***
  - *int accept(int sockfd, struct sockaddr *addr, socklen_t *addrlen)*
- *sockfd:*
  - *The usual culprit, socket() return*
- *addr:*
  - *A pointer to a struct sockaddr_in, cast as (struct sockaddr *)*
- *addrlen:*
  - *Pointer to an integer to store the returned size of addr, should be initialized as original sizeof(addr);*
- *Example:*
  - *int isock=accept(sockfd, (struct sockaddr_in *) &caddr, &clen);*

Lets put the server together...

```
struct sockaddr_in saddr, caddr;
int sockfd, clen, isock;
unsigned short port = 80;

if((sockfd=socket(AF_INET, SOCK_STREAM, 0) < 0) {        // from back a couple slides
        printf("Error creating socket\n");
        ...
}

memset(&saddr, '\0', sizeof(saddr));                  // zero structure out
saddr.sin_family = AF_INET;                           // match the socket() call
saddr.sin_addr.s_addr = htonl(INADDR_ANY);  // bind to any local address
saddr.sin_port = htons(port);                         // specify port to listen on

if((bind(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) { // bind!
        printf("Error binding\n");
        ...
}

if(listen(sockfd, 5) < 0) {           // listen for incoming connections
        printf("Error listening\n");
        ...
}

clen=sizeof(caddr)
if((isock=accept(sockfd, (struct sockaddr *) &caddr, &clen)) < 0) {      // accept one
        printf("Error accepting\n");
        ...
}
```


What happened to the client?

- **The last thing the client did was socket() !**
- **The client need not do bind, listen, and accept**
- **All the client does now is connect (*man connect)***
  - *int connect(int sockfd, const struct sockaddr *saddr, socklen_t addrlen);*
- *Example...*
  - *connect(sockfd, (struct sockaddr *) &saddr, sizeof(saddr));*

Piecing the Client Together

```
struct sockaddr_in saddr;
struct hostent *h;
int sockfd, connfd;
unsigned short port = 80;

if((sockfd=socket(AF_INET, SOCK_STREAM, 0) < 0) {        // from back a couple slides
        printf("Error creating socket\n");
        ...
}

if((h=gethostbyname("www.slashdot.org")) == NULL) { // Lookup the hostname
        printf("Unknown host\n");
        ...
}

memset(&saddr, '\0', sizeof(saddr));                  // zero structure out
saddr.sin_family = AF_INET;                           // match the socket() call
memcpy((char *) &saddr.sin_addr.s_addr, h->h_addr_list[0], h->h_length); // copy the address
saddr.sin_port = htons(port);                         // specify port to connect to

if((connfd=connect(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) { // connect!
        printf("Cannot connect\n");
        ...
}
```

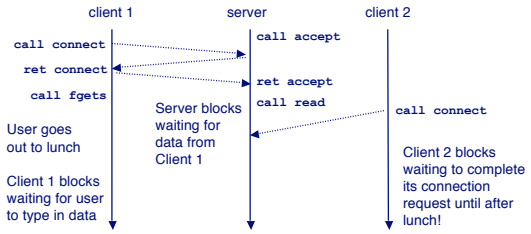

We're Connected!

- **Great, server accepting connections, and client connecting to servers.**
- **Now what? Lets send and receive data!**
  - read()
  - write()
- **Both functions are used by client and server:**
  - ssize_t read(int fd, void *buf, size_t len);
  - ssize_t write(int fd, const void *buf, size_t len);
- Example...
  - read(sockfd, buffer, sizeof(buffer));
  - write(sockfd, "hey\n", strlen("hey\n"));

Finally, Close Up Shop

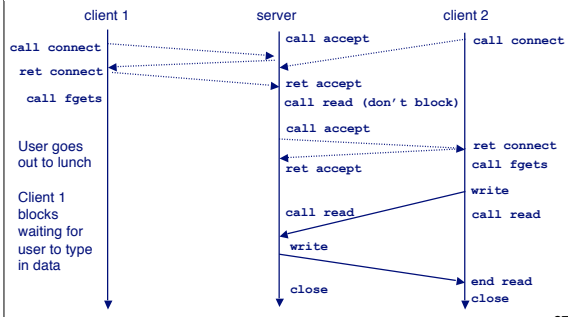
- **Don't forget, like a file, you must close it (*man close)***
  - int close(int sockfd);
- That's it!
- Loop around the accept() on the server to accept a new connection once one has finished
- But what's wrong with this?

Server Flaw



Taken from D. Murray, R. Bryant, and G. Langale 15-441/213 slides

Concurrent Servers



Taken from D. Murray, R. Bryant, and G. Langale 15-441/213 slides

Solutions to Concurrency

- **Threads – first thing that comes to mind**
  - **(+) Threads allow concurrency**
  - **(+) Easier methodology**
  - **(-) Threads increase design complexity (race conditions)**
  - **(-) Concurrency slightly more complicated**
- **Select()**
  - **(+) Select allows concurrency**
  - **(+) Does not introduce race conditions**
  - **(-) Default control flow is more complicated**
- **Nobody has won the battle... but... .... you MUST you use select() !!**

What Does Select Do?

- **Allows you to monitor multiple file descriptors (straight from the "man"!)**
- **Why is this helpful?**
  - **accept() returns a new file descriptor for the incoming connection**
  - **set sockets to non-blocking... select does not specify how much we can write**
  - **"collect" incoming file descriptors and monitor all of them!**

Setting Socket to Not Block

- **Before we even get to use select, we need to set all sockets to non-blocking**
- **Also need to allow reuse of the socket**

```
int sock, opts=1;

sock = socket(...);  // To give you an idea of where the new code goes

setsockopt(sock, SOL_SOCKET, SO_REUSEADDR, &opts, sizeof(opts));

if((opts = fcntl(sock, F_GETFL)) < 0) { // Get current options
        printf("Error...\n");
        ...
}
opts = (opts | O_NONBLOCK);  // Don't clobber your old settings
if(fcntl(sock, F_SETFL, opts) < 0) {
        printf("Error...\n");
        ...
}

bind(...);  // To again give you an idea where the new code goes
```

Select()

- int select(int maxfdp1, fd_set *readset, fd_set *writeset, NULL, struct timeval *timeout);
- fd_set – bit vector with max FD_SETSIZE bits
  - » bit k is set to 1 if descriptor k is a member of the set
- readset – bit vector for read descriptors
- writeset – bit vector for write descriptors
- maxfdp1 – max file descriptor + 1

How does this change things?

```
// socket() call and non-blocking code is above this point

if((bind(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) { // bind!
        printf("Error binding\n");
        ...
}
if(listen(sockfd ,5) < 0) {             // listen for incoming connections
        printf("Error listening\n");
        ...
}
clen=sizeof(caddr)

while(1) {
        pool.ready_set = &pool.read_set;  // Save the current state
        pool.nready = select(pool.maxfd+1, &pool.read_set, &pool.write_set, NULL, NULL);

        if(FD_ISSET(sockfd, &pool.ready_set)) {  // Check if there is an incoming conn
                isock=accept(sockfd, (struct sockaddr *) &caddr, &clen); // accept it
                add_client(isock, &pool);    // add the client by the incoming socket fd
        }

        check_clients(&pool);  // check if any data needs to be sent/received from clients
}
...

close(sockfd);
```


How to Set Your Bit Vectors

- **void FD_ZERO(fd_set *fdset);**
  - » **Clear out all the bits in the set *fdset***
- **void FD_SET(int fd, fd_set *fdset);**
  - » **Set the bit for *fd to 1 in the set fdset***
- **void FD_CLR(int fd, fd_set *fdset);**
  - » **Set the bit for *fd to 0 in the set fdset***
- **int FD_ISSET(int fd, fd_set *fdset);**
  - » **Test whether the bit for *fd is set to 1 in fdset***

Use a Structure of Sets

```
typedef struct { /* represents a pool of connected descriptors */
    int maxfd;        /* largest descriptor in read_set */
    fd_set read_set;  /* set of all active read descriptors */
    fd_set write_set;  /* set of all active read descriptors */
    fd_set ready_set; /* subset of descriptors ready for reading  */
    int nready;       /* number of ready descriptors from select */
    int maxi;         /* highwater index into client array */
    int clientfd[FD_SETSIZE];    /* set of active descriptors */
    rio_t clientrio[FD_SETSIZE]; /* set of active read buffers */
    ...     // ADD WHAT WOULD BE HELPFUL FOR PJ1
} pool;
```


What Was check_clients() ?

- **The main loop tests for incoming connections with FD_ISSET() only**
  - » **But we have so many other file descriptors to test!**
- **Store your client file descriptors in pool.clientfd[ ] and test all of them with FD_ISSET()**
  - » **Clients may be trying to send us data**
  - » **We may have pending data to send to clients**

Suggestions

- **Woah, all this code... now what?**
- **Start simple, get yourself familiar (a first revision!)**
  - » **Code a server to accept a single connection**
  - » **Use a telnet client to connect and send data**
  - » **Have the server read the message and display it**
- **Write a simple client to send messages instead of telnet**
- **Take it to the next level... modify it a bit (a new revision!)**
  - » **Add the non-blocking socket code**
  - » **Add select() functionality**
  - » **Have server echo back to the clients**

Routes for Line by Line

- **a read() won't always give you everything you want!**
- **IRC is on a line by line basis**
- **If you get half a line from a read() (aka. no \n in what you read), then buffer what you have so far and wait to process the line**

Roundup

- **Sockets**
  1. Setup -- <DMACHINE,DSERVICE> -- <IP,PORT>
  2. I/O – read() / write()
  3. Close – close()
- **Client:** socket() ----------> connect() -> I/O -> close()
- **Server:** socket() -> bind() -> listen() -> accept() -> I/O -> close()
- Concurrency: select()
- Bit Vectors: fd_set, FD_ZERO(), FD_SET(), FD_CLR(), FD_ISSET()

Confusion?

- **The more organized you keep your file descriptors, the better off you'll be**
- **Keep your while(1){ } thin, have functions check the bit vectors**
- **Questions?**

Get Started Early

- **Find your partner if you have not done so already**
- **Share your schedules and share what days and times you are free to meet**
- **Lots of c0d3 ...**
  - **"Official Solution" -> ~5,000 lines of code by: | wc**
- **Work** ahead of the checkpoints!