Socket Programming

Nikhil Shetty

GSI, EECS122

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Outline

- *APIs – Motivation*
- *Sockets*
- *C Socket APIs*
- *Tips for programming*

What is an API?

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- *A connection to the transport layer.*
- *WHY DO WE NEED IT?*

Need for API

- *One Word - Layering*
- *Functions at transport layer and below very complex.*
- *E.g. Imagine having to worry about errors on the wireless link and signals to be sent on the radio.*
- *Helps in code reuse.*

APPLICATION
API
TRANSPORT
NETWORK
LINK
PHYSICAL

Layering Diagramatically

Application

API

System Calls

LAN Card

Radio

What is a socket then?

- *What is a socket?*

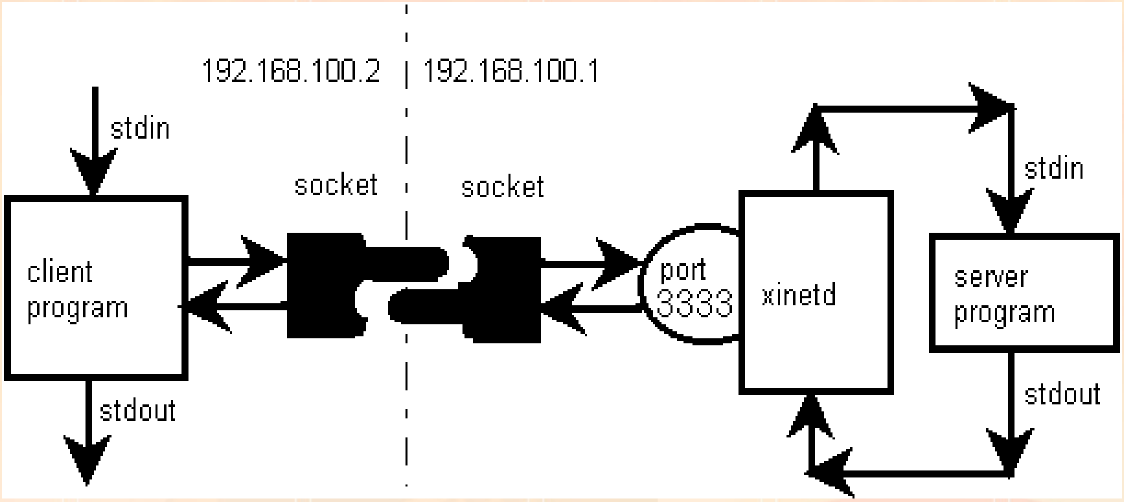
Introduction

- *What is a socket?*
- *It is an abstraction that is provided to an application programmer to send or receive data to another process.*

Introduction

- *What is a socket?*
- *It is an abstraction that is provided to an application programmer to send or receive data to another process.*
- *Data can be sent to or received from another process running on the same machine or a different machine.*
- *In short, it is an end point of a data connection.*

Socket – An Abstraction



Adapted from http://www.troubleshooters.com/codecorn/sockets/

Sockets

- *It is like an endpoint of a connection*
- *Exists on either side of connection*
- *Identified by IP Address and Port number*
- *E.g. Berkeley Sockets in C*
  - *Released in 1983*
  - *Similar implementations in other languages*

Engineers working on Sockets!!!

http://www.fotosearch.com/MDG238/frd1404/

Ports

- Sending process must identify the receiver
  - Address of the receiving end host
  - Plus identifier (port) that specifies the receiving process
- Receiving host
  - Destination address uniquely identifies the host
- Receiving process
  - Host may be running many different processes
- Destination port uniquely identifies the socket
  - Port number is a 16-bit quantity

Port Usage

- Popular applications have "well-known ports"
  - E.g., port 80 for Web and port 25 for e-mail
  - Well-known ports listed at http://www.iana.org
- Well-known vs. ephemeral ports
  - Server has a well-known port (e.g., port 80)
- By convention, between 0 and 1023; privileged
  - Client gets an unused "ephemeral" (i.e., temporary) port
  - By convention, between 1024 and 65535
- Flow identification
  - The two IP addresses plus the two port numbers
    - Sometimes called the "four-tuple"
  - Underlying transport protocol (e.g., TCP or UDP)
  - The "five-tuple"

Ports (Main Points)

- *Not related to the physical architecture of the computer.*
- *Just a number maintained by the operating system to identify the end point of a connection.*

TCP (stream) sockets

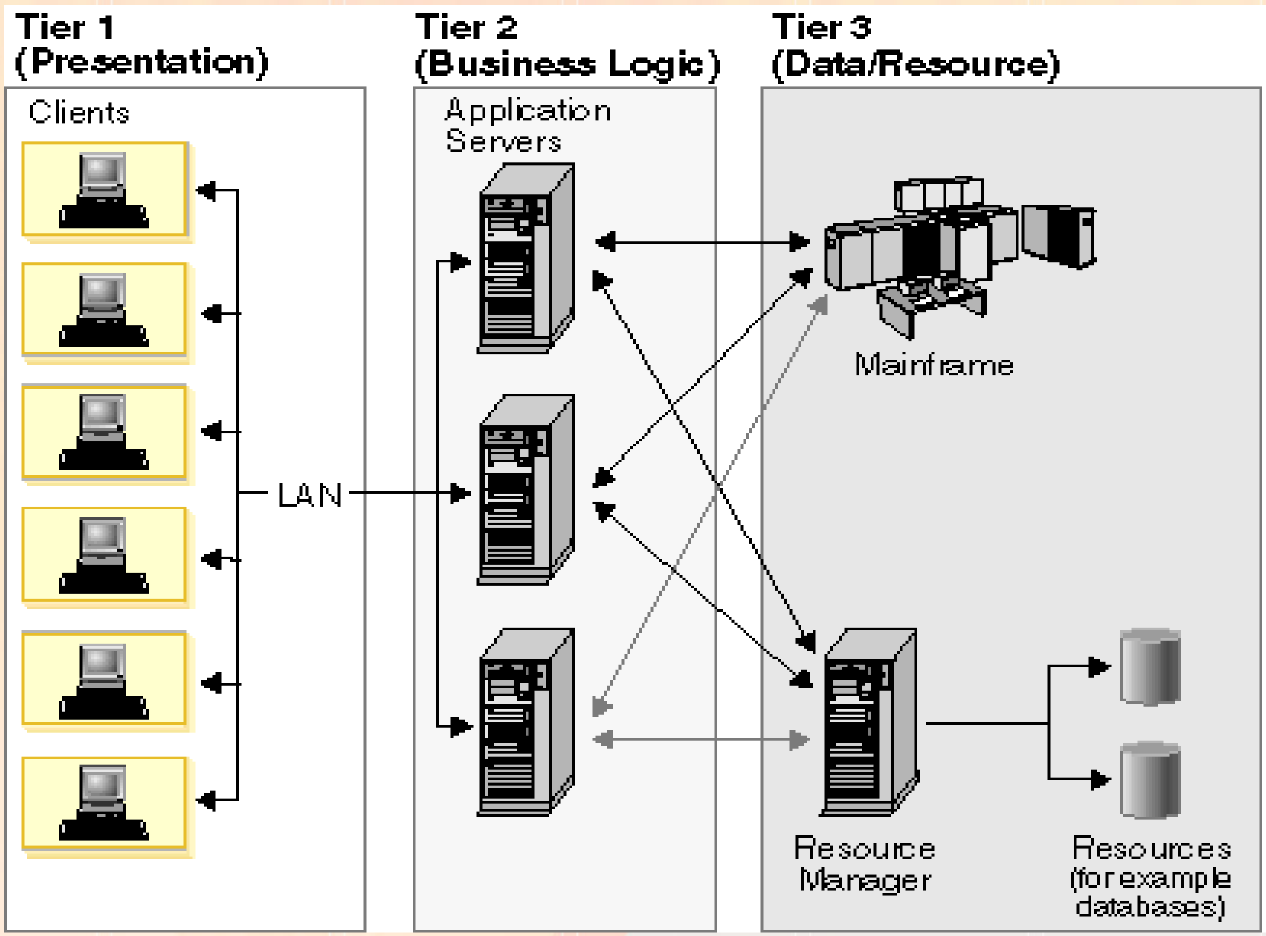
- *Also known as SOCK_STREAM*
- *TCP is a connection-oriented byte-stream protocol*
  - *During data packet. transmission, no packetization and addressing required by application.*
  - *Formatting has to be provided by application.*
  - *Two or more successive data sends on the pipe connected to socket may be combined together by TCP in a single packet.*
  - *E.g. Send “Hi” then send “Hello Nikhil” is combined by TCP to send as “HiHello Nikhil”*

UDP (datagram) sockets

- *Also known as SOCK_DGRAM*
- *UDP is connectionless and packet-oriented.*
  - *Info sent in packet format as needed by app.*
  - *Every packet requires address information.*
  - *Lightweight, no connection required.*
  - *Overhead of adding destination address with each packet at the application layer. (Can be eliminated by "connecting" – see later)*

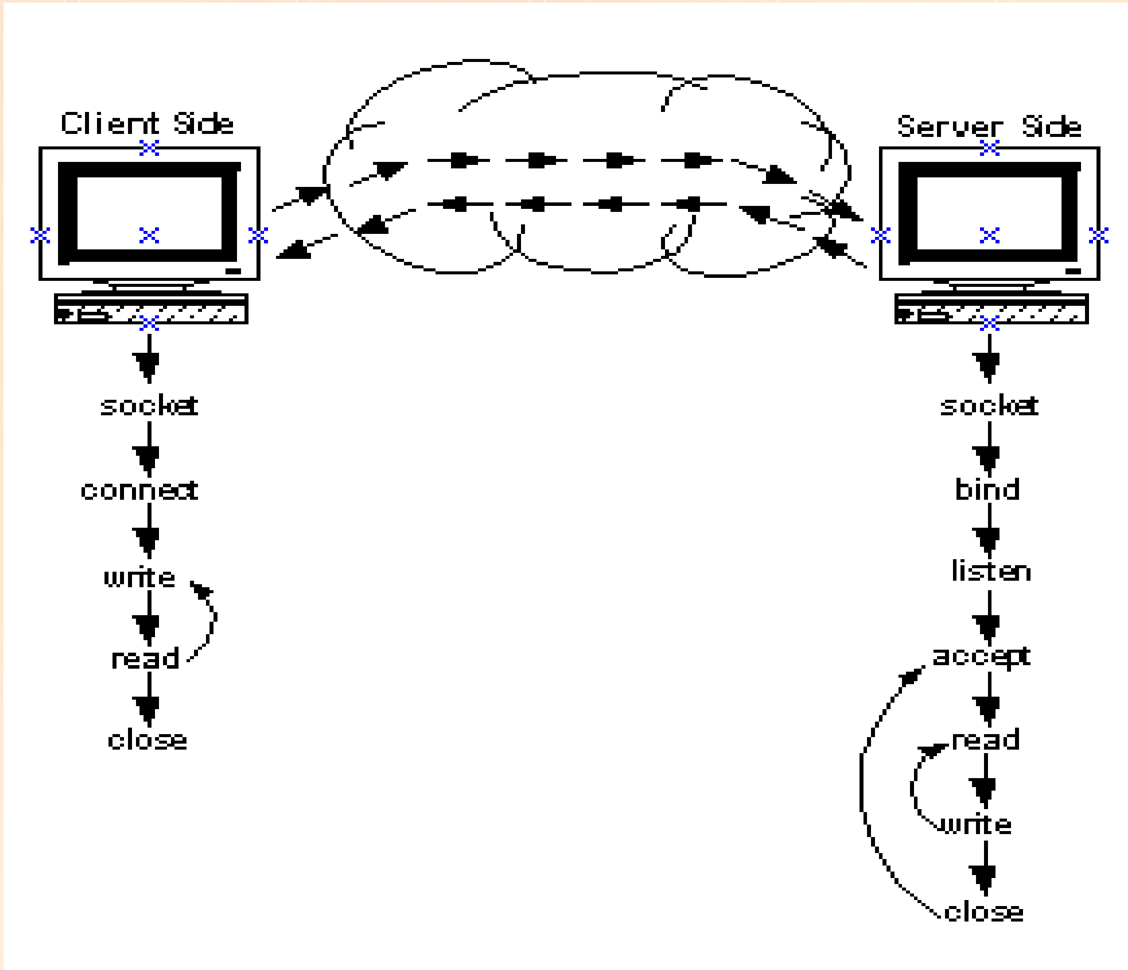
- *Distinction in the way these sockets are used by different hosts – client and server.*

Client – Server Architecture



From http://publib.boulder.ibm.com/infocenter/txen/topic/com.ibm.txseries510.doc/atshak0011.htm

Flow in client-server model



- *http://www.process.com/tcpip/tcpware57docs/Programmer/fig1-2.gif*

Typical Client Program

- Prepare to communicate.
  - Create a socket.
  - Determine server address and port number.
  - Initiate the connection to the server (TCP).
- Exchange data with the server.
  - Write data to the socket.
  - Read data from the socket.
- Note, single socket supports both reading *and* writing.
  - Manipulate the data (e.g., display email, play music)
- Close the socket.

Typical Server Program

- Prepare to communicate
  - Create a socket
  - Associate local address and port with the socket
- Wait to hear from a client (passive open)
  - Indicate how many clients-in-waiting to permit
  - Accept an incoming connection from a client
- Exchange data with the client over new socket
  - Receive data from the socket
  - Do stuff to handle the request (e.g., get a file)
  - Send data to the socket
  - Close the socket
- Repeat with the next connection request

One Server One port Many clients

- *Consider a webserver running on port 80.*
- *All clients connect to the same port number.*
- *How do you distinguish between clients?*

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- *Source IP Address!*

- *How do you distinguish between multiple connections from the same IP Address?*

One Server One port Many clients

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- *All clients connect to the same port number.*
- *How do you distinguish between clients?*
- *Source IP Address!*

- *How do you distinguish between multiple connections from the same IP Address?*
- *OS uses the incoming packet's source IP address and port number to distinguish.*

Going into the APIs

- *Will look into programming from now on.*
- *Stop me when not clear.*
- *Or if I am too fast.*
- *Or if you have never seen something and I am assuming you have!*
- *Most examples from "Beej's guide" – link posted online.*
- *More examples in there. You should look into them.*
  - *Helpful for the project.*

Creating a socket

- Operation to create a socket
  - *int socket(int domain, int type, int protocol)*
  - Returns a descriptor (or handle) for the socket
  - Originally designed to support any protocol suite
- Domain: protocol family
  - Use PF_INET for the Internet
- Type: semantics of the communication
  - SOCK_STREAM: reliable byte stream
  - SOCK_DGRAM: message-oriented service
- Protocol: specific protocol
  - UNSPEC: unspecified. No need for us to specify, since PF_INET plus SOCK_STREAM already implies TCP, or SOCK_DGRAM implies UDP.
- *Used by both server and client to create socket.*

Connecting to server

- Establishing the connection
  - *int connect(int sockfd, struct sockaddr *server_address, socketlen_t addrlen)*
  - Arguments: socket descriptor, server address, and address size
  - Returns 0 on success, and -1 if an error occurs
- sockfd stands for socket file decriptor.
  - Remember everything in Unix is a file.
- What is sockaddr?
  - *struct to store the IP address and port number you want to connect to.*

Struct sockaddr_in

- Struct sockaddr_in has information about the destination IP address and port.
  - Same size as sockaddr.
- Must be used in the following way.
- Use AF_INET in sockaddr and not PF_INET.

```
int sockfd;
struct sockaddr_in dest_addr; // will hold the destination addr
sockfd = socket(PF_INET, SOCK_STREAM, 0); // do some error checking!
dest_addr.sin_family = AF_INET; // host byte order
dest_addr.sin_port = htons(DEST_PORT); // short, network byte order
dest_addr.sin_addr.s_addr = inet_addr(DEST_IP);
memset(&(dest_addr.sin_zero), '\0', 8); // zero the rest of the struct
// don't forget to error check the connect()!
connect(sockfd, (struct sockaddr *)&dest_addr, sizeof(struct sockaddr));
```

Byte Ordering

- The networking API provides us the following functions:
  - **uint16_t htons(uint16_t host16bitvalue);**
  - **uint32_t htonl(uint32_t host32bitvalue);**
  - **uint16_t ntohs(uint16_t net16bitvalue);**
  - **uint32_t ntohl(uint32_t net32bitvalue);**
- Use for all 16-bit and 32-bit binary numbers (*short*, *int*) to be sent across network
- ‘h’ stands for “host order”
- These routines do nothing on big-endian hosts

IP Addresses

- IP Addresses should be in network format in a packet.
- We need to convert between ascii (dot format) and network format.
- Accomplished by inet_aton and inet_ntoa

```
struct sockaddr_in antelope;
char *some_addr;
inet_aton("10.0.0.1", &antelope.sin_addr); // store IP in
  antelope
some_addr = inet_ntoa(antelope.sin_addr); // return the IP
printf("%s\n", some_addr); // prints "10.0.0.1"
```

Sending Data

- Sending data
  - *ssize_t write(int sockfd, void *buf, size_t len)*
  - Arguments: socket descriptor, pointer to buffer of data to send, and length of the buffer
  - Returns the number of characters written, and -1 on error
- Receiving data
  - *ssize_t read(int sockfd, void *buf, size_t len)*
  - – Arguments: socket descriptor, pointer to buffer to place the data, size of the buffer
  - Returns the number of characters read (where 0 implies “end of file”), and -1 on error
- Closing the socket
  - *int close(int sockfd)*

Sending and Receiving (contd)

- Note: instead of using ***write()***, you can instead use ***send()***, which is intended for use with sockets.
  - Only difference is ***send()*** takes one additional argument of flags, which for most purposes don't matter
- Similarly, instead of using ***read()***, you can instead use ***recv().***
  - Again, only difference is one additional argument of flags
- Important to realize they're basically equivalent, since you see both pairs of calls used (sometimes intermingled).

Example

```
char *msg = "I was here!";
int len, bytes_sent; ...
len = strlen(msg);
bytes_sent = send(sockfd, msg, len, 0);
```

- *If the return value is -1 there is some error.*
- *If return value is less than the length of the message, it means the whole message was not sent for some reason.*
- *Then resend the remaining message.*

```
int total = 0; // how many bytes we've sent
int bytesleft = *len; // how many we have left to send
int n;
while(total < *len) {
   n = send(s, buf+total, bytesleft, 0);
   if (n == -1) { break; }
   total += n;
   bytesleft -= n;
}
```

Server – Passive listening

- Passive open
  - Prepare to accept connections
  - … but don't actually establish one
  - … until hearing from a client
- Hearing from multiple clients
  - Allow a backlog of waiting clients
  - ... in case several try to start a connection at once
- Create a socket for each client
  - Upon accepting a new client
  - … create a *new* socket for the communication

Preparing a socket

- Bind socket to the local address and port number
  - *int bind (int sockfd, struct sockaddr *my_addr, socklen_t addrlen)*
  - Arguments: socket descriptor, server address, address length
  - Returns 0 on success, and -1 if an error occurs
- Define how many connections can be pending
  - *int listen(int sockfd, int backlog)*
  - Arguments: socket descriptor and acceptable backlog
  - Returns 0 on success, and -1 on error

Accepting a connection

- Accept a new connection from a client
  - *int accept(int sockfd, struct sockaddr *addr, socklen_t *addrlen)*
  - Arguments: socket descriptor, structure that will provide client address and port, and length of the structure.
- Returns descriptor for a new socket for this connection.
- *Accept will block the process if there are no clients trying to connect.*

Example

```
int sockfd, new_fd;
struct sockaddr_in my_addr; // my address information
struct sockaddr_in their_addr; // connector’s address
   information
int sin_size; // size of sockaddr
sockfd = socket(PF_INET, SOCK_STREAM, 0); my_addr.sin_family =
   AF_INET; // host byte order
my_addr.sin_port = htons(MYPORT); // short, network byte order
my_addr.sin_addr.s_addr = INADDR_ANY; // auto-fill with my IP
memset(&(my_addr.sin_zero), ’\0’, 8); // zero the rest of the
   struct
bind(sockfd, (struct sockaddr *)&my_addr, sizeof(struct
   sockaddr));
listen(sockfd, BACKLOG);
sin_size = sizeof(struct sockaddr_in);
new_fd = accept(sockfd, (struct sockaddr *)&their_addr,
   &sin_size);
```

Datagram sockets

- *Datagram sockets may be used with/without* ***connect.***
  - *Connecting a data socket does not create a connection.*
    - *Only fills in the address everytime you use a* ***send()****.*
  - *In this case, use* ***sendto()*** *and* ***recvfrom().***

Advanced Aspects

- *A general program may have many sockets open.*
- *Also it could have other sources of input like stdin or timers.*
- *What options does a program have for keeping a check on all these sources?*
- *Polling*
  - *Very inefficient – Don't use.*
- *Using* ***select()***
  - *Efficient and preferred method.*

Select()

- Select()
  - Wait on multiple file descriptors/sockets and timeout
  - Application does not consume CPU while waiting
  - Return when file descriptors/sockets are ready to beread or written or they have an error, or timeout exceeded
- Disadvantages
- Does not scale to large number of descriptors/sockets
- More awkward to use than it needs to be

Select() - contd

```
FD_ZERO(fd_set *set) - clears a file descriptor set
FD_SET(int fd, fd_set *set) - adds fd to the set
FD_CLR(int fd, fd_set *set) - removes fd from the set
FD_ISSET(int fd, fd_set *set) - tests to see if fd is
   in the set
```

- int select(int numfds, fd_set *readfds, fd_set *writefds, fd_set *exceptfds, struct timeval *timeout);
- The macros are used to set, clear and check conditions on the fds in the set.

Example

- `#include <stdio.h>`
- `#include <sys/time.h>`
- `#include <sys/types.h>`
- `#include <unistd.h>`
- `#define STDIN 0 // file descriptor for standard input`
- `int main(void)`
- `{`
  - `struct timeval tv;`
  - `fd_set readfds;`
  - `tv.tv_sec = 2;`
  - `tv.tv_usec = 500000;`
  - `FD_ZERO(&readfds);`
  - `FD_SET(STDIN, &readfds);`
- `// don’t care about writefds and exceptfds:`
  - `select(STDIN+1, &readfds, NULL, NULL, &tv);`
  - `if (FD_ISSET(STDIN, &readfds))`
    - `printf("A key was pressed!\n");`
  - `else`
    - `printf("Timed out.\n");`
  - `return 0;`
- `}`

Some Programming Hints

- *Check Beej's guide (it is on the syllabus page)*
  - *Has information on all the APIs available.*
  - *Also tells you which header files to include for the different APIs.*
- *Also, it is best to catch errors using the returning values of the APIs.*
  - *Makes things easier to debug*
  - *And you know where the program fails.*

```
if (bind(sockfd, (struct sockaddr *)&my_addr, sizeof(struct
   sockaddr)) == -1) {
   perror("bind");
   exit(1);
}
```

Perror and strerror

- *Use perror and strerror*
- *If there is an error errno variable is set to a value and that gives more info on the error.*
- *Ofcourse there are also the man pages!*

```
int s;
s = socket(PF_INET, SOCK_STREAM, 0);
if (s == -1) { // some error has occurred
// prints "socket error: " + the error message:
   perror("socket error");
}
// similarly:
if (listen(s, 10) == -1) {
// this prints "an error: " + the error message from errno:
   printf("an error: %s\n", strerror(errno));
}
```

Network Programming Tips (contd)

- *How to check if particular port is listening*
  - *Windows – use netstat*
    - *netstat -an*
  - *Linux – use nmap*
    - *nmap -sT -O localhost*
- *Tip: Use port numbers greater than 1024.*
- Server can’t bind because old connection hasn’t yet gone away.
  - Use setsockopt with the SO_REUSEADDR option.
- Not knowing what exactly gets transmitted on the wire
  - Use **tcpdump** or **Ethereal (www.ethereal.com)**
- *Check RFCs if in doubt about protocols.*
  - *http://www.ietf.org/rfc*