Socket programming with TCP &UDP

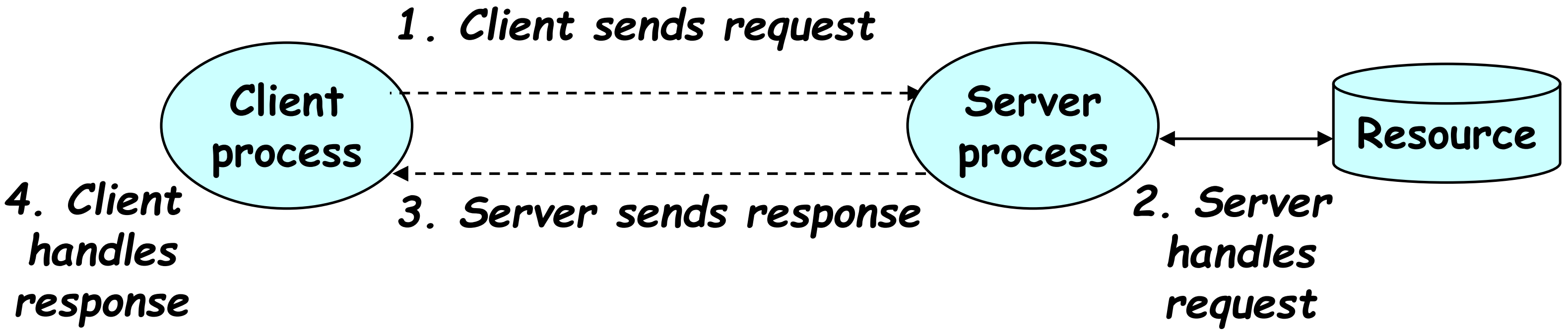
Chapter 2:2.7

Socket programming-Topics

- Client-server model
- Sockets interface: Address structure, byte ordering, port no
- Socket primitives: socket, bind,listen…
- Example code for echoclient and echoserver

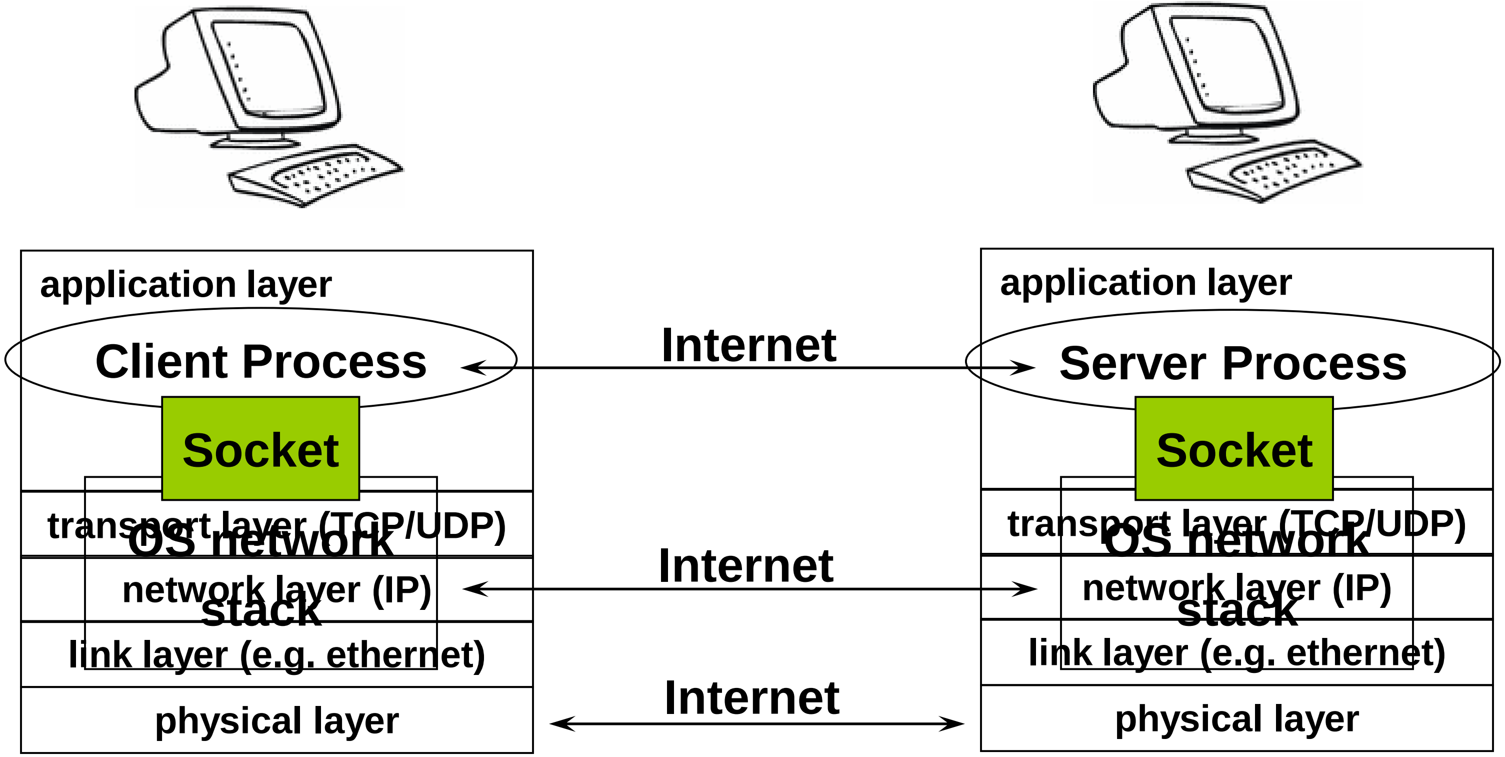
Client/server model

- Client asks (*request*) – server provides (*response*)
- Typically: single server - multiple clients
- The server does not need to know *anything* about the client
  - even that it exists
- The client should always know *something* about the server
  - at least where it is located



Note: clients and servers are processes running on hosts (can be the same or different hosts).

Sockets as means for inter-process communication (IPC)



The interface that the OS provides to its networking subsystem

Sockets

- What is a socket?
  - To the kernel, a socket is an endpoint of communication.
  - To an application, a socket is a file descriptor that lets the application read/write from/to the network.

- Clients and servers communicate with each by reading from and writing to socket descriptors.

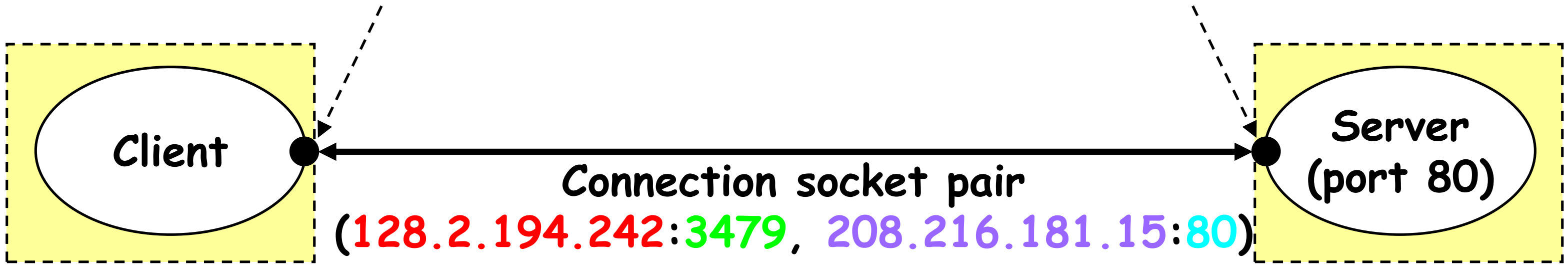
- The main distinction between regular file I/O and socket I/O is how the application “opens” the socket descriptors.

Internet Connections (TCP/IP)

- Address the machine on the network
  - By IP address
- Address the process
  - By the "port"-number
- The pair of *IP-address + port* – makes up a "*socket-address*"

Client socket address
128.2.194.242:3479

Server socket address
208.216.181.15:80



Client

Server (port 80)

Connection socket pair
(128.2.194.242:3479, 208.216.181.15:80)

Client host address
128.2.194.242

Server host address
208.216.181.15

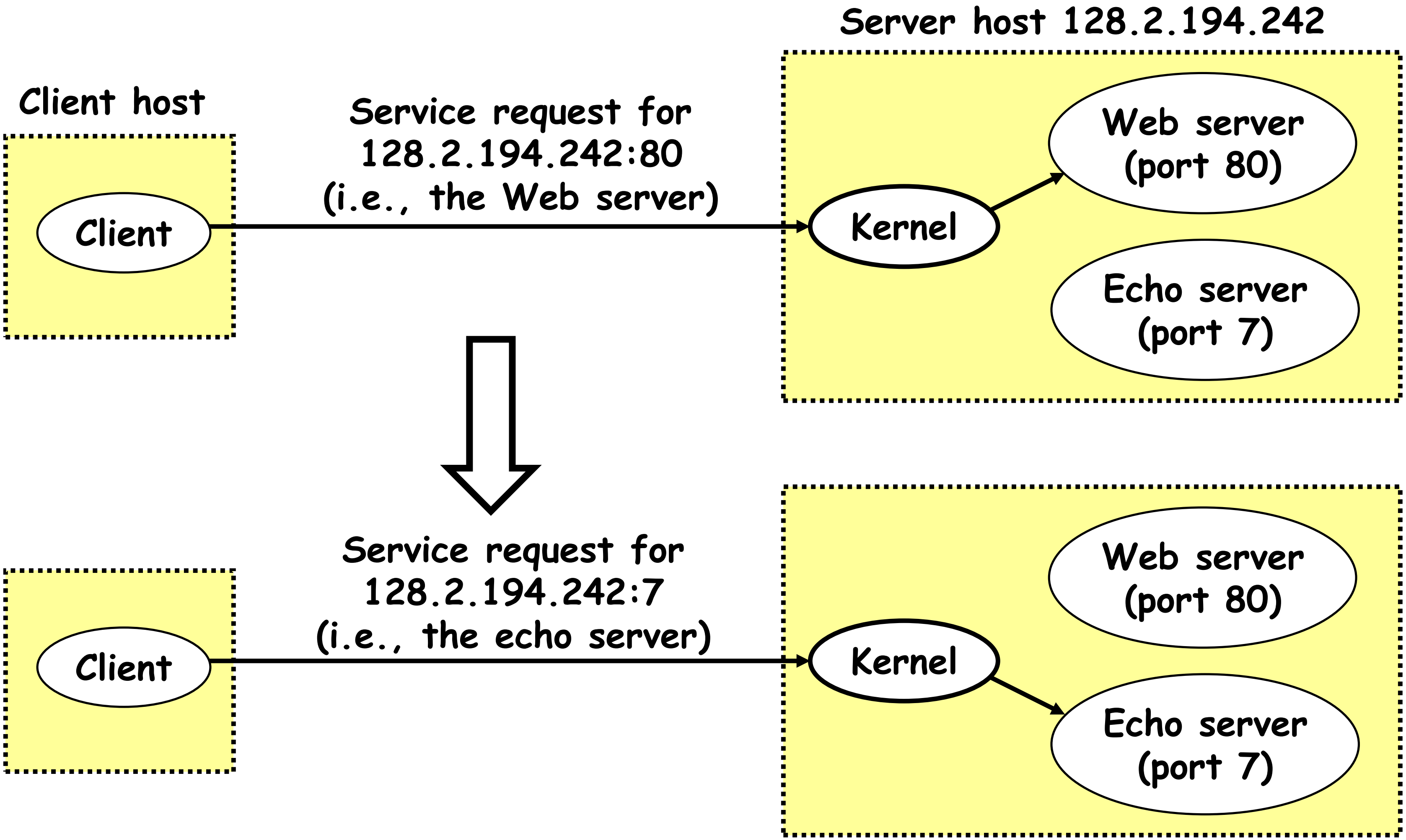
Note: 3479 is an ephemeral port allocated by the kernel

Note: 80 is a well-known port associated with Web servers

Clients

- Examples of client programs
  - Web browsers, `ftp`, `telnet`, `ssh`
- How does a client find the server?
  - The IP address in the server socket address identifies the host
  - The (well-known) port in the server socket address identifies the service, and thus implicitly identifies the server process that performs that service.
  - Examples of well known ports
    - Port 7: Echo server
    - Port 23: Telnet server
    - Port 25: Mail server
    - Port 80: Web server

Using Ports to Identify Services



Socket programming

Two socket types for two transport services:

- *UDP:* unreliable datagram
- *TCP:* reliable, byte stream-oriented

Application Example:

1. Client reads a line of characters (data) from its keyboard and sends the data to the server.
2. The server receives the data and converts characters to uppercase.
3. The server sends the modified data to the client.
4. The client receives the modified data and displays the line on its screen.

Socket programming *with UDP*

UDP: no "connection" between client & server

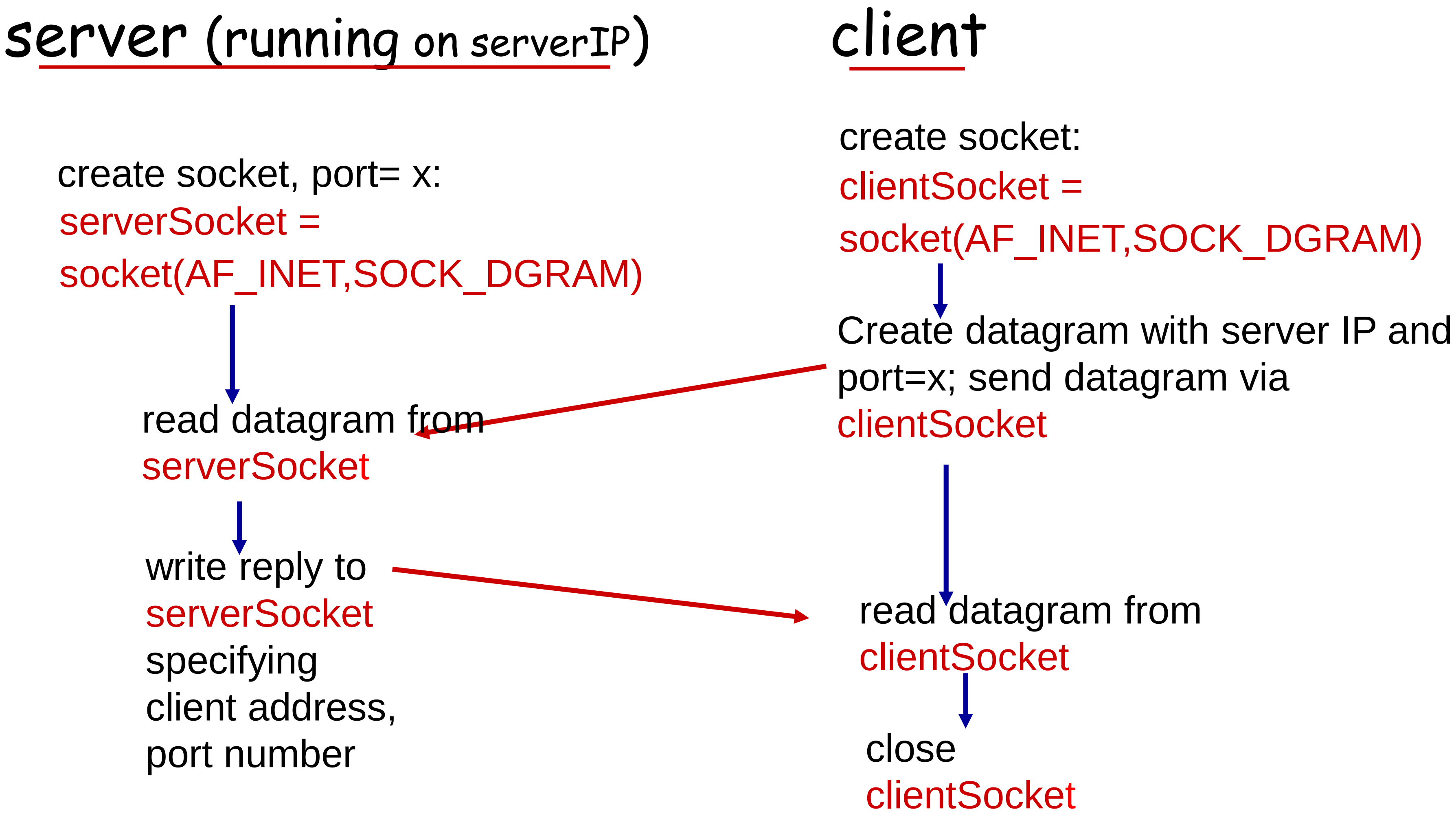
- no handshaking before sending data
- sender explicitly attaches IP destination address and port # to each packet
- rcvr extracts sender IP address and port# from received packet

UDP: transmitted data may be lost or received out-of-order

Application viewpoint:

- UDP provides *unreliable* transfer of groups of bytes ("datagrams") between client and server

Client/server socket interaction: UDP



server (running on serverIP)

create socket, port= x:
serverSocket =
socket(AF_INET,SOCK_DGRAM)

read datagram from
serverSocket

write reply to
serverSocket
specifying
client address,
port number

client

create socket:
clientSocket =
socket(AF_INET,SOCK_DGRAM)

Create datagram with server IP and
port=x; send datagram via
clientSocket

read datagram from
clientSocket

close
clientSocket

Socket programming *with TCP*

client must contact server

- server process must first be running
- server must have created socket (door) that welcomes client's contact

client contacts server by:

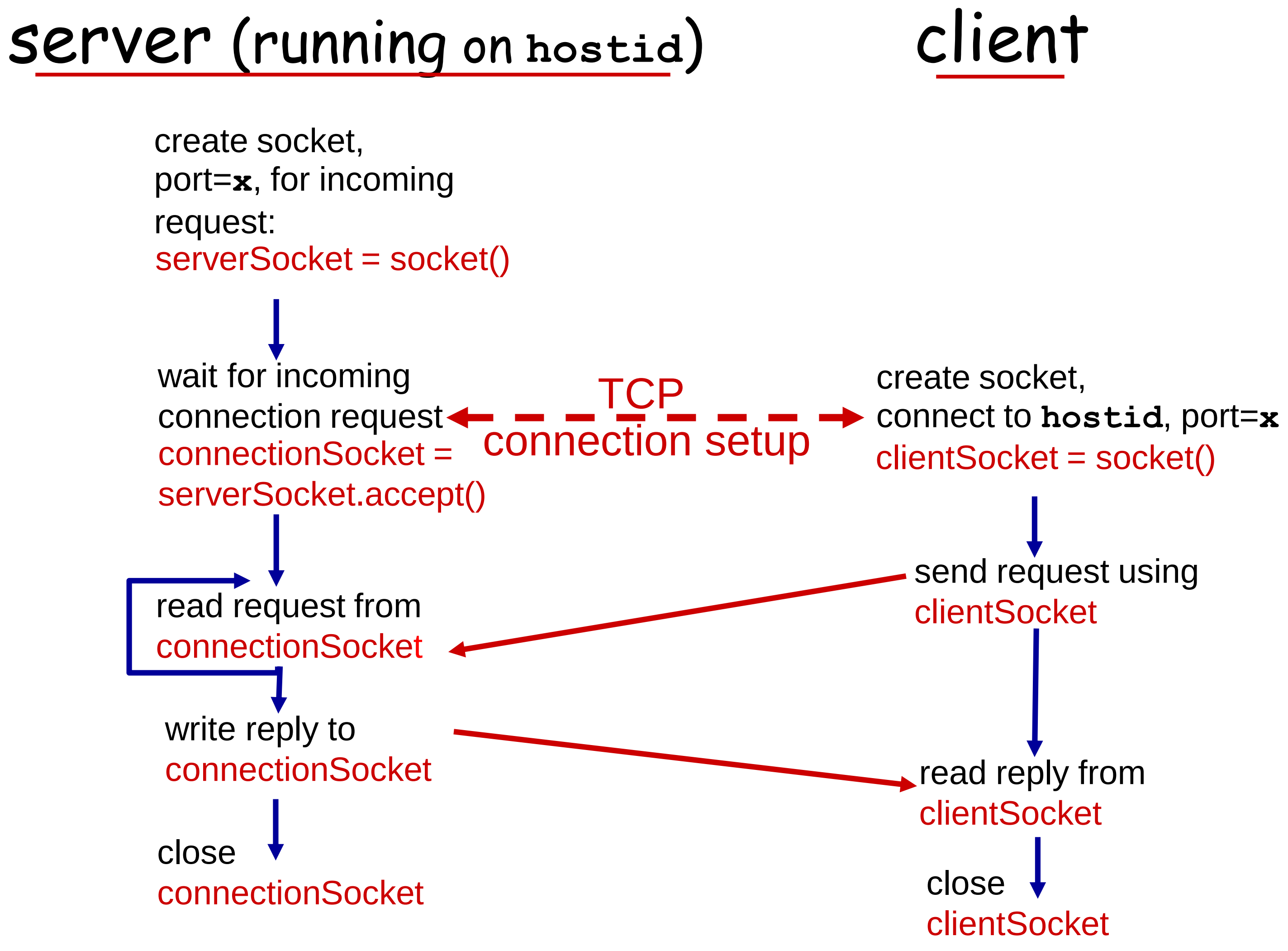
- Creating TCP socket, specifying IP address, port number of server process
- *when client creates socket:* client TCP establishes connection to server TCP

- when contacted by client, *server TCP creates new socket* for server process to communicate with that particular client
  - allows server to talk with multiple clients
  - source port numbers used to distinguish clients

application viewpoint:

TCP provides reliable, in-order byte-stream transfer ("pipe") between client and server

Client/server socket interaction: TCP



server (running on **hostid**)

create socket, port=**x**, for incoming request:
serverSocket = socket()

wait for incoming connection request
connectionSocket = serverSocket.accept()

read request from connectionSocket

write reply to connectionSocket

close connectionSocket

TCP connection setup

client

create socket, connect to **hostid**, port=**x**
clientSocket = socket()

send request using clientSocket

read reply from clientSocket

close clientSocket

Byte Ordering

- Byte ordering is the attribute of a system which indicates whether integers are stored / represented left to right or right to left.

- Example 1: short int x = 0xAABB (hex)

  This can be stored in memory as 2 adjacent bytes as either (0xaa , 0xbb) or as (0xbb, 0xaa).

  Big Endian:

Byte Value	:	[0xAA]	[0xBB]
Memory	:	[0]	[1]

  Little Endian:

Byte Value	:	[0xBB]	[0xAA]
Memory	:	[0]	[1]

Byte Ordering

- Example 2: int x = 0xAABBCCDD

  This 4 byte long integer can be represented in the same 2 orderings:

  Big Endian:

Byte Value:	[0xAA]	[0xBB]	[0xCC]	[0xDD]
Memory:	[0]	[1]	[2]	[3]

  Little Endian:

Byte Value:	[0xDD]	[0xCC]	[0xBB]	[0xAA]
Memory:	[0]	[1]	[2]	[3]

- All Network data is sent in Big Endian format.
- In the networking world we call this representation as Network Byte Order and native representation on the host as Host Byte Order.
- We convert all data into Network Byte Order before transmission.

Some utility functions :

- Byte Ordering:

  Host Byte Order to Network Byte Order:
  htons() , htonl()
  Network Byte Order to Host Byte Order:
  ntohs() , ntohl()

-

Data Structures

Let us now look at the data structures used
to hold all the address Information:

-
  ```
  Struct sockaddr {
          unsigned short sa_family;
          char sa_data[14];
  }
  ```

-
  ```
  Struct sockaddr_in {
          short sin_family;
          unsigned short sin_port; // Port Number
          struct in_addr sin_addr; // IP Address
          char sin_zero[8];
  }
  ```

-
  ```
  Struct in_addr {
          unsigned long s_addr; // 4 bytes long
  }
  ```

syscalls()

We will now describe the following calls in detail :

- Socket()
- Bind()
- Listen()
- Accept()
- Connect()
- Read() / Send() / Sendto()
- Write() / Recv() / Recvfrom()
- Close()

Socket() - A Connection Endpoint

- This creates an endpoint for a network connection.

  int socket(int doman, int type, int protocol)

  domain = AF_INET (IPv4 communication)
  type = SOCK_STREAM (TCP) , SOCK_DGRAM (UDP)
  protocol = 0 (for our discussion)

- Example : socket(AF_INET, SOCK_STREAM, 0);
  This will create a TCP socket.
- The call returns a socket descriptor on success and -1 on an error.

Bind() – Attaching to an IP and Port

- A server process calls bind to attach itself to a specific port and IP address.

  ```
  int bind(int sockfd, struct sockaddr *my_addr, sockaddr_in_addrlen)
  ```

  sockfd = socket descriptor returned by socket()

  my_addr = pointer to a valid sockaddr_in structure cast as a sockaddr * pointer

  addrlen = length of the sockaddr_in structure

- Example :

  ```
  struct sockaddr_in my;
   bzero( (char *)&my, sizeof(my))
  my.sin_family = AF_INET;
  my.sin_port = htons(80);
  my.sin_addr.s_addr =htonl( INADDR_ANY);


  bind(sock, (struct sockaddr *)&my, sizeof(my));
  ```

Listen() - Wait for a connection

- The server process calls listen to tell the kernel to initialize a wait queue of connections for this socket.

  int listen(int sock, int backlog)

  sock = socket returned by socket()
  backlog = Maximum length of the pending connections queue

- Example: Listen(sock, 10);
  This will allow a maximum of 10 connections to be in pending state.

Accept() - A new connection !

- Accept is called by a Server process to accept new connections from new clients trying to connect to the server.

  int accept(int socket, (struct sockaddr *)&client, *client_len)

  socket = the socket in listen state
  client = will hold the new client's information when accept returns
  client_len = pointer to size of the client structure

- Example :

  struct sockaddr_in client;

  int len = sizeof(client);

  Accept(sock, (struct sockaddr *)&client, &len);

Connect() - connect to a service

- Connect is called by a client to connect to a server port.

  ```
  int connect(int sock, (struct sockaddr *)&server_addr, socklen_len)
  ```

  sock: a socket returned by socket()
  server_addr: a sockaddr_in struct pointer filled with all the remote server details and cast as a sockaddr struct pointer
  len: size of the server_addr struct

- Example:

  ```
  connect(sock, (struct sockaddr *)server_addr, len);
  ```

Send / Recv - Finally Data !!

- Send(), Recv() , Read() , Write() etc calls are used to send and receive data .

  ```
  Int send(int sock, void *mesg, size_t len, int flags)
  ```

  ```
  Int recv(int sock, void *mesg, size_t len, int flags)
  ```

  sock = A connected socket
  mesg = Pointer to a buffer to send/receive data from/in .
  len = Size of the message buffer
  flags = 0 (for our purpose)

  The return value is the number of bytes actually sent/received.

- Example:

  ```
  char send_buffer[1024];
  char recv_buffer[1024];
  int sent_bytes;
  int recvd_bytes;
  ```

  ```
  sent_bytes = send(sock, send_buffer, 1024, 0);
  recvd_bytes = recv(sock, recv_buffer, 1024, 0);
  ```

Close() - Bye ..Bye !

- Close signals the end of communication between a server-client pair. This effectively closes the socket.

  int close(int sock)

  sock = the socket to close

- Example :

  close(sock);

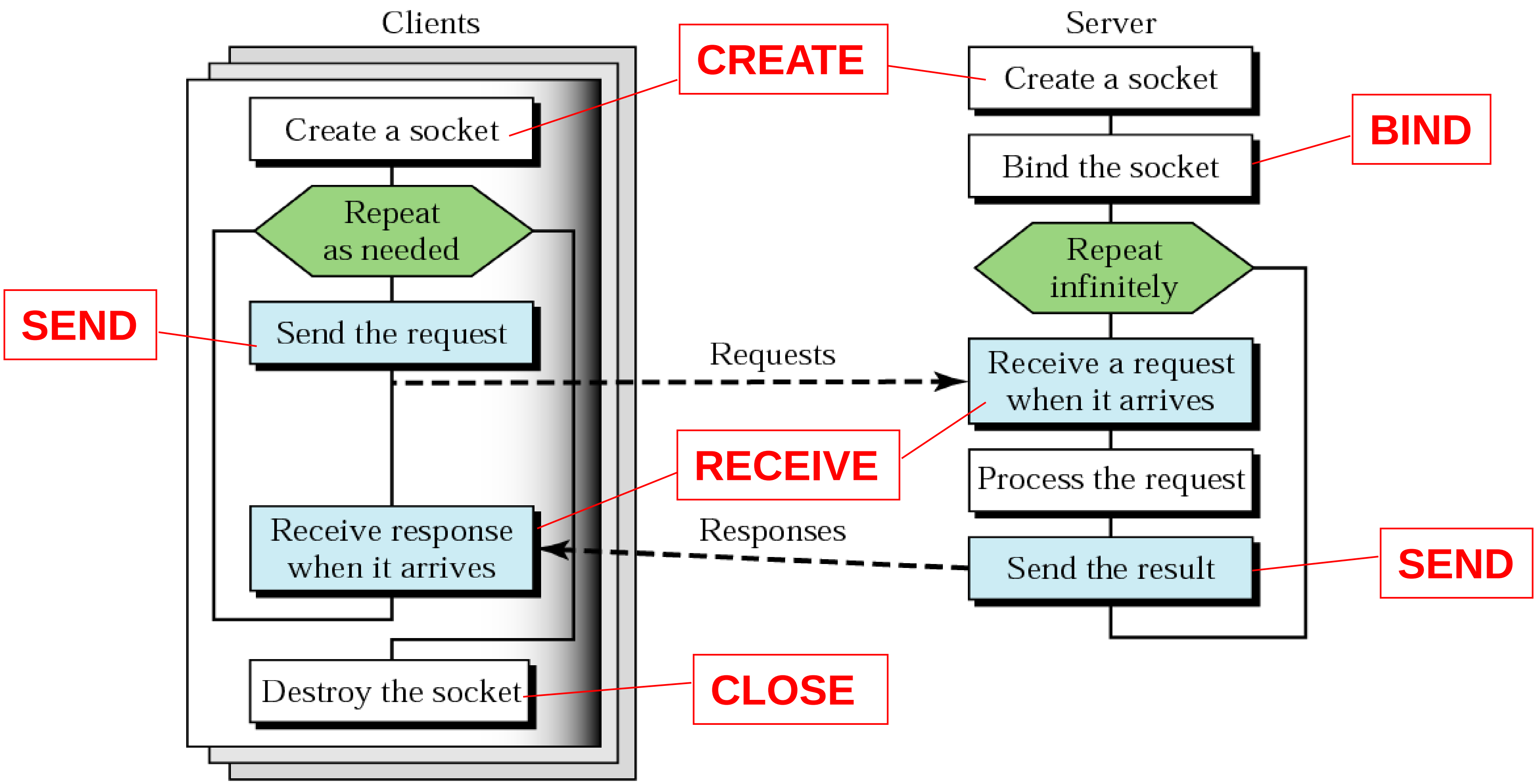
- **SEND** (DGRAM-style): **int sendto(int *sockfd*, const void **msg*, int *len*, int *flags*, const struct sockaddr **to*, int *tolen*);**
  - *msg*: message you want to send
  - *len*: length of the message
  - *flags* := 0
  - *to*: socket address of the remote process
  - *tolen*: = sizeof(struct sockaddr)
  - *returned*: the number of bytes actually sent

- **RECEIVE** (DGRAM-style): **int recvfrom(int *sockfd*, void **buf*, int *len*, unsigned int *flags*, struct sockaddr **from*, int **fromlen*);**
  - *buf*: buffer to receive the message
  - *len*: length of the buffer (“don’t give me more!”)
  - *from*: socket address of the process that sent the data
  - *fromlen*:= sizeof(struct sockaddr)
  - *flags* := 0
  - *returned*: the number of bytes received

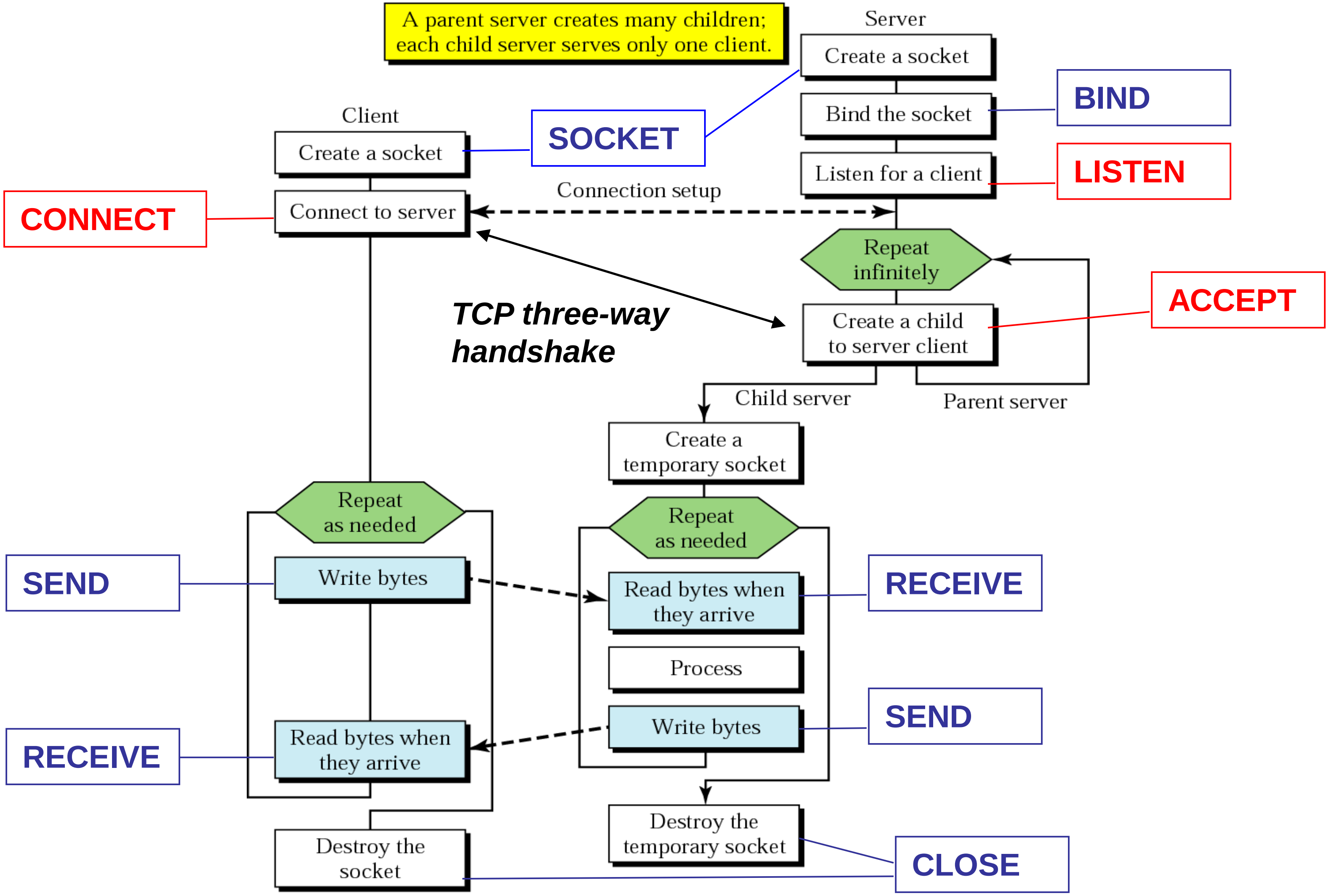
- **CLOSE**: **close (*socketfd*);**

Client+server: connectionless

Each server serves many clients but handles one request at a time.



Client+server: connection-oriented



Concurrent server

EchoClient.c – #include's

```
#include <stdio.h>       /* for printf() and fprintf() */
#include <sys/socket.h> /* for socket(), connect(),
                           sendto(), and recvfrom() */
#include <arpa/inet.h>   /* for sockaddr_in and
                           inet_addr() */
#include <stdlib.h>      /* for atoi() and exit() */
#include <string.h>      /* for memset() */
#include <unistd.h>      /* for close() */

#define ECHOMAX 255      /* Longest string to echo */
```

EchoClient.c -variable declarations

```
int main(int argc, char *argv[])
{
    int sock;                       /* Socket descriptor */
    struct sockaddr_in echoServAddr; /* Echo server address */
    struct sockaddr_in fromAddr;     /* Source address of echo */
    unsigned short echoServPort =10200;     /* Echo server port */
    unsigned int fromSize;          /* address size for recvfrom() */
    char *servIP=“172.24.23.4”;                 /* IP address of server
    */
    char *echoString=“I hope this works”;           /* String to send
    to echo server */
    char echoBuffer[ECHOMAX+1];      /* Buffer for receiving
    echoed string */
    int echoStringLen;              /* Length of string to echo */
    int respStringLen;              /* Length of received response */
```

EchoClient.c - creating the socket and sending

```
/* Create a datagram/UDP socket */
sock = socket(AF_INET, SOCK_DGRAM, 0);

/* Construct the server address structure */
memset(&echoServAddr, 0, sizeof(echoServAddr)); /* Zero out
    structure */
echoServAddr.sin_family = AF_INET; /* Internet addr family */
echoServAddr.sin_addr.s_addr = htonl(servIP); /* Server IP
    address */
echoServAddr.sin_port = htons(echoServPort); /* Server port */

/* Send the string to the server */
sendto(sock, echoString, echoStringLen, 0, (struct sockaddr *)
    &echoServAddr, sizeof(echoServAddr);
/* Recv a response */
```

EchoClient.c – receiving and printing

```
fromSize = sizeof(fromAddr);
recvfrom(sock, echoBuffer, ECHOMAX, 0, (struct sockaddr *)
    &fromAddr, &fromSize);
 /* Error checks like packet is received from the same server*/

/* null-terminate the received data */
echoBuffer[echoStringLen] = '\0';
printf("Received: %s\n", echoBuffer); /* Print the echoed arg */
close(sock);
exit(0);
} /* end of main () */
```

EchoServer.c

```
int main(int argc, char *argv[])
{
    int sock;                        /* Socket */
    struct sockaddr_in echoServAddr; /* Local address */
    struct sockaddr_in echoClntAddr; /* Client address */
    unsigned int cliAddrLen;        /* Length of incoming message */
    char echoBuffer[ECHOMAX];        /* Buffer for echo string */
    unsigned short echoServPort =10200;     /* Server port */
    int recvMsgSize;                    /* Size of received message */
   /* Create socket for sending/receiving datagrams */
   sock = socket(AF_INET, SOCK_DGRAM, 0);
    /* Construct local address structure */
    memset(&echoServAddr, 0, sizeof(echoServAddr));    /* Zero out structure */
    echoServAddr.sin_family = AF_INET;                  /* Internet address family */
    echoServAddr.sin_addr.s_addr = htonl(“172.24.23.4”);
    echoServAddr.sin_port = htons(echoServPort);       /* Local port */

    /* Bind to the local address */
    bind(sock, (struct sockaddr *) &echoServAddr, sizeof(echoServAddr);
for (;;) /* Run forever */
    {
        cliAddrLen = sizeof(echoClntAddr);

        /* Block until receive message from a client */
        recvMsgSize = recvfrom(sock, echoBuffer, ECHOMAX, 0,
            (struct sockaddr *) &echoClntAddr, &cliAddrLen);

        printf("Handling client %s\n", inet_ntoa(echoClntAddr.sin_addr));

        /* Send received datagram back to the client */
        sendto(sock, echoBuffer, recvMsgSize, 0,
             (struct sockaddr *) &echoClntAddr, sizeof(echoClntAddr);
    }

} /* end of main () */
```

Error handling is must

More information…

- Socket programming
  - W. Richard Stevens, UNIX Network Programming
  - Infinite number of online resources
  - http://www.cs.rpi.edu/courses/sysprog/sockets/sock.html
- GDB
  - Official GDB homepage: http://www.gnu.org/software/gdb/gdb.html
  - GDB primer: http://www.cs.pitt.edu/~mosse/gdb-note.html

Example of Stream Server: echo

```
/* stream server: echo what is received from client */
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>
#include <string.h>
#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>
int main (int argc, char *argv[])
{
  int s, t, sinlen;
  struct sockaddr_in sin;
  char msg[80];
```

Example of Stream Server: echo (cont'd)

```
if (argc < 2) {
    printf (”%s port\n”, argv[0] ); /* input error: need port no! */
   return -1;
}
if ( (s = socket(AF_INET, SOCK_STREAM, 0 ) ) < 0) { /* create
     socket*/
  perror(”socket”);  /* socket error */
  return -1;
}
sin.sin_family = AF_INET;              /*set protocol family to Internet */
sin.sin_port = htons(atoi(argv[1]));  /* set port no. */
sin.sin_addr.s_addr  = INADDR_ANY;   /* set IP addr to any interface */
if (bind(s, (struct sockaddr *)&sin, sizeof(sin) ) < 0 ){
     perror(”bind”); return -1;  /* bind error */
}
```

Example of Stream Server: echo (cont’d)

```
/* server indicates it’s ready, max. listen queue is 5 */
if (listen(s, 5)) {
    perror (”listen”); /* listen error*/
   return -1;
}
sinlen = sizeof(sin);
while (1) {
    /* accepting new connection request from client,
    socket id for the new connection is returned in t */
    if ( (t = accept(s, (struct sockaddr *) &sin, &sinlen) ) < 0 ){
           perror(”accept ”);  /* accpet error */
           return -1;
    }
```

Example of Stream Server: echo (cont'd)

```
    printf( ”From %s:%d.\n”,
            inet_ntoa(sin.sin_addr), ntohs(sin.sin_port) );
    if ( read(t, msg, sizeof(msg) ) <0) {  /* read message from client */
            perror(”read”);         /*  read error */
            return -1;
    }
    if ( write(t, msg, strlen(msg) ) < 0 ) {  /* echo message back */
            perror(”write”);    return -1; /*  write error */
    }
    /* close connection, clean up sockets */
    if (close(t) < 0) { perror(”close”); return -1;}
} // not reach below
if (close(s) < 0) { perror(”close”); return -1;}
return 0;
}
```

Example of Stream Client: echo

```
/* stream client: send a message to server */
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>
#include <string.h>
#include <unistd.h>
#include <stdlib.h>
#inlcude <stdio.h>
#include <netdb.h>
int main (int argc, char *argv[] )
{
  int s, n;
  struct sockaddr_in sin; struct hostent *hptr;
  char msg[80] = ”Hello World!”;
```

Example of Stream Client: echo (cont'd)

```
if ( argc < 3 ) {
      printf ( ”%s host port\n”, argv[0] );   /* input error: need host & port */
      return -1;
}
if ( (s = socket(AF_INET, SOCK_STREAM, 0 ) ) < 0) { /* create socket*/
  perror(”socket”);  /* socket error */
  return -1;
}
sin.sin_family = AF_INET;              /*set protocol family to Internet */
sin.sin_port = htons(atoi(argv[2]));  /* set port no. */
if ( (hptr =  gethostbyname(argv[1]) ) == NULL){
       fprintf(stderr, ”gethostname error: %s”, argv[1]);
       return = -1;
 }
memcpy( &sin.sin_addr, hptr->h_addr, hptr->h_length);
```

Example of Stream Client: echo (cont’d)

```
if (connect (s, (struct sockaddr *)&sin, sizeof(sin) ) < 0 ){
    perror(”connect”); return -1;   /* connect error */
}
if ( write(s, msg, strlen(msg) +1) < 0 ) {  /* send message to server */
      perror(”write”);    return -1; /*  write error */
}
if ( ( n = read(s, msg, sizeof(msg) ) ) <0) {  /* read message from server */
    perror(”read”); return -1; /*  read error */
}
printf (” %d bytes: %s\n”, n, msg);  /* print message to screen */
/* close connection, clean up socket */
if (close(s) < 0) {
  perror(”close”);   /* close error */
  return -1;}
return 0;
}
```