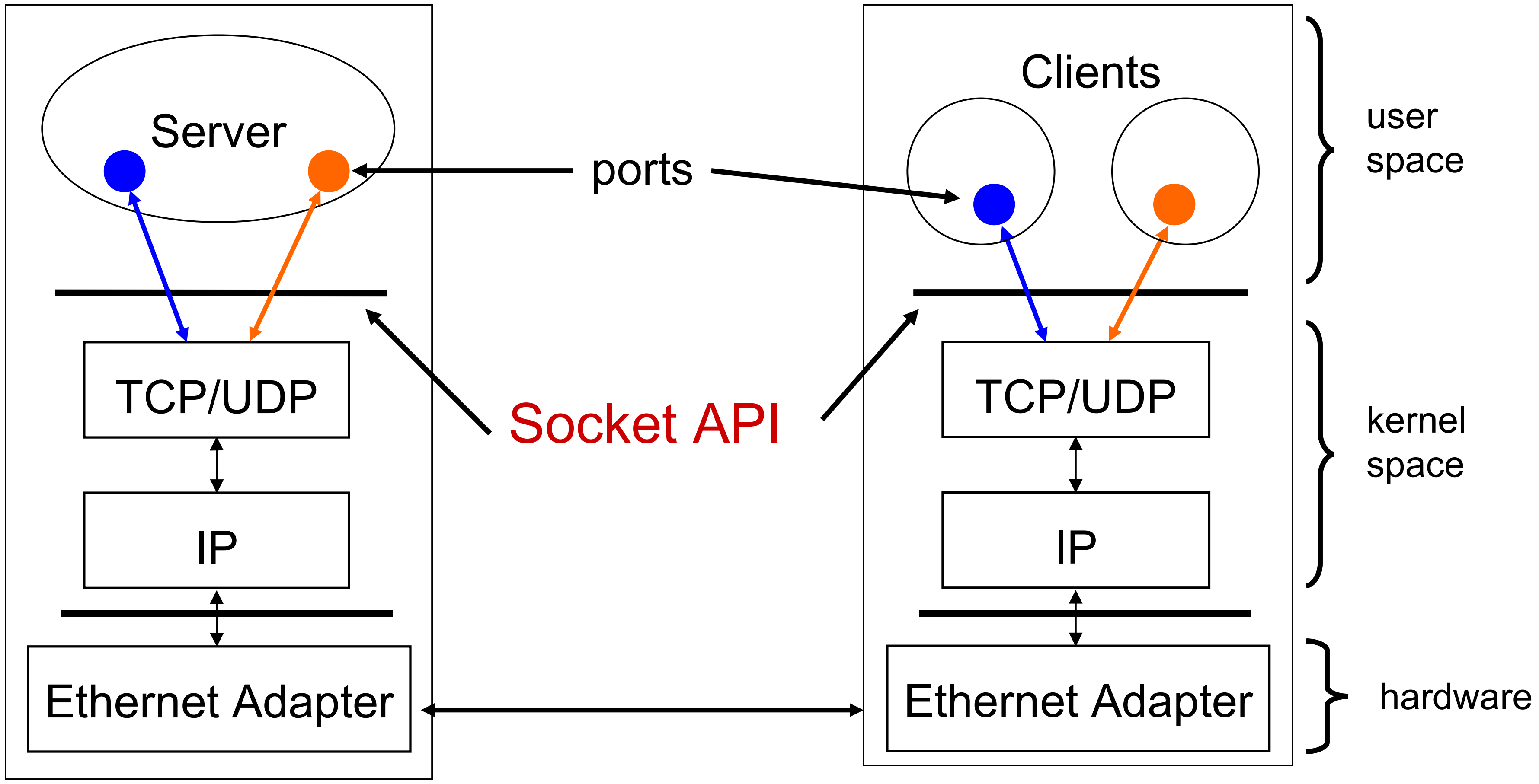
Computer Networks Lab

Socket programming in C and Java

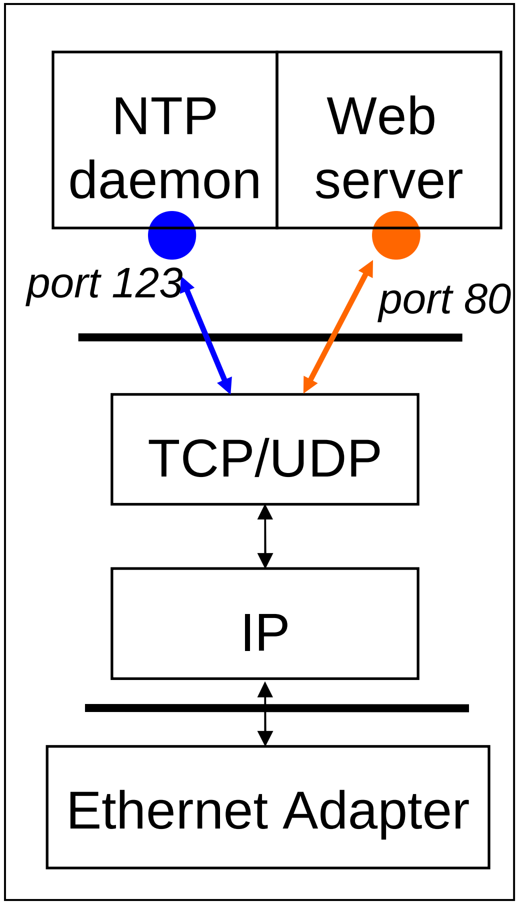
Server and Client

Server and Client exchange messages over the network through a common Socket API



Concept of Port Numbers

- Port numbers are used to identify "entities" on a host (16 bit)
- Port numbers can be
  - Well-known (port 0-1023)
  - Registered (port 1024 – 49151)
  - Dynamic or private (port 49152-65535)
- Servers/daemons usually use well-known ports
  - Any client can identify the server/service
  - HTTP = 80, FTP = 21, Telnet = 23, ...
  - /etc/service defines well-known ports
- Clients usually use dynamic ports
  - Assigned by the kernel at run time



Names and Addresses

- Each attachment point on Internet is given unique address
  - Based on location within network – like phone numbers
- Humans prefer to deal with names not addresses
  - DNS provides mapping of name to address
  - Name based on administrative ownership of host

Internet Addressing Data Structure

```
#include <netinet/in.h>

/* Internet address structure */
struct in_addr {
        u_long s_addr;        /* 32-bit IPv4 address */
};                            /* network byte ordered */

/* Socket address, Internet style. */
struct sockaddr_in {
      u_char  sin_family;     /* Address Family */
      u_short sin_port;       /* UDP or TCP Port# */
                              /* network byte ordered */
      struct in_addr sin_addr;       /* Internet Address */
      char    sin_zero[8];    /* unused */
};
```

- sin_family = AF_INET selects Internet address family

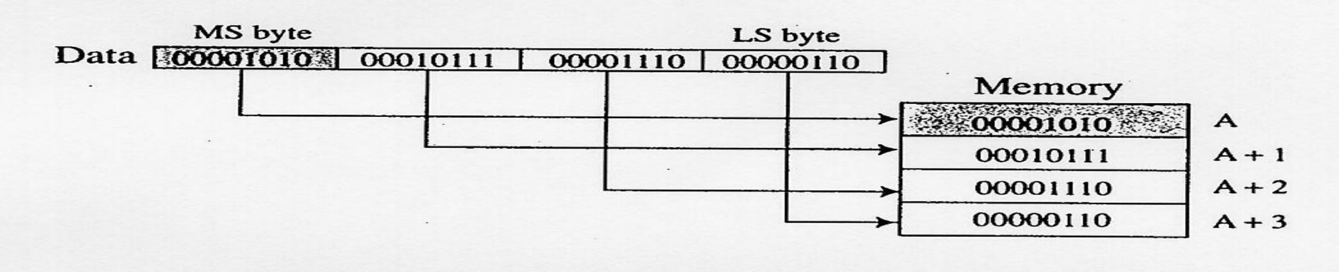
Byte Ordering

```
union {
   u_int32_t addr;  /* unsigned long int, 4
                          bytes address */
   unsigned char c[4];
} un;
/* 128.2.194.95 */
un.addr = 0x8002c25f;
/* un.c[0] = ? */
```

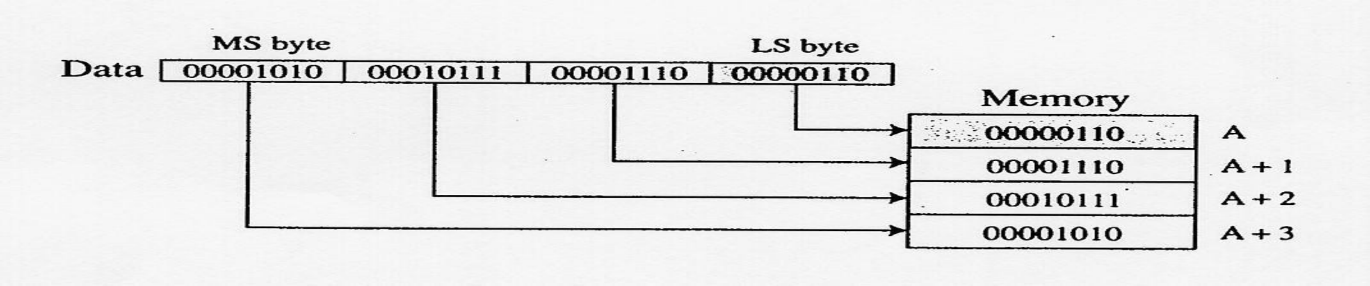
- Big Endian
  - Sun Solaris, PowerPC, ...
- Little Endian
  - i386, alpha, ...
- Network byte order = Big Endian

	c[0]	c[1]	c[2]	c[3]
Big Endian	128	2	194	95
Little Endian	95	194	2	128

- Byte Order
  - Different computers may have different internal representation of 16 / 32-bit integer (called **host byte order**).
  - Examples
    - Big-Endian byte order (e.g., used by Motorola 68000):



    - Little-Endian byte order (e.g., used by Intel 80x86):



Byte Ordering Functions

- Converts between **host byte order** and **network byte order**
  - ‘h’ = host byte order
  - ‘n’ = network byte order
  - ‘l’ = long (4 bytes), converts IP addresses
  - ‘s’ = short (2 bytes), converts port numbers

```
#include <netinet/in.h>

unsigned long int htonl(unsigned long int hostlong);
unsigned short int htons(unsigned short int hostshort);
unsigned long int ntohl(unsigned long int netlong);
unsigned short int ntohs(unsigned short int netshort);
```

What is a Socket?

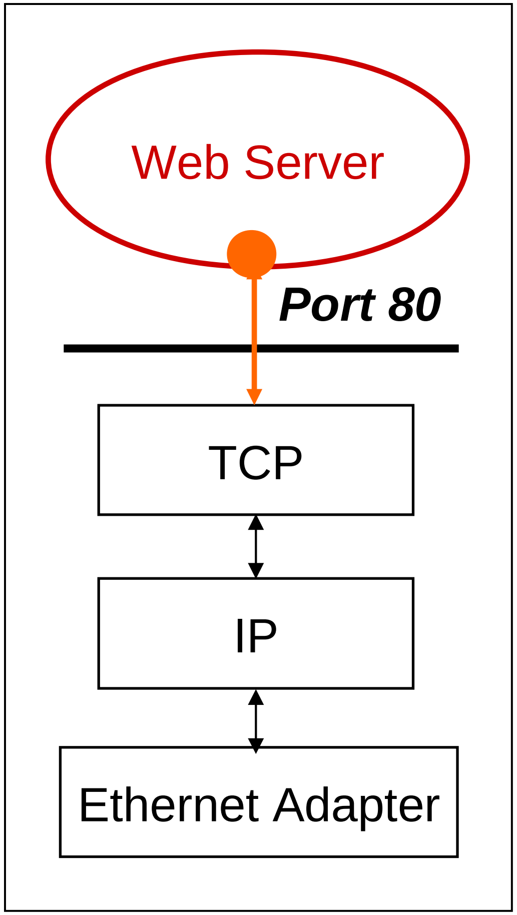
- A socket is a file descriptor that lets an application read/write data from/to the network

```
int fd;        /* socket descriptor */
if ((fd = socket(AF_INET, SOCK_STREAM, 0)) < 0) }
      perror(“socket”);
      exit(1);
}
```

- ***socket*** returns an integer (socket descriptor)
  - fd < 0 indicates that an error occurred
  - socket descriptors are similar to file descriptors

- AF_INET: associates a socket with the Internet protocol family
- SOCK_STREAM: selects the TCP protocol
- SOCK_DGRAM: selects the UDP protocol

TCP Server



- For example: web server

- **What does a *web server* need to do so that a *web client* can connect to it?**

Socket I/O: socket()

- Since web traffic uses TCP, the web server must create a socket of type SOCK_STREAM

```
int fd;            /* socket descriptor */

if((fd = socket(AF_INET, SOCK_STREAM, 0)) < 0) {
     perror(“socket”);
     exit(1);
}
```

- *socket* returns an integer (**socket descriptor**)
  - *fd* < 0 indicates that an error occurred
- AF_INET associates a socket with the Internet protocol family
- SOCK_STREAM **selects the TCP protocol**

Socket I/O: bind()

- A ***socket*** can be bound to a ***port***

```
int fd;                           /* socket descriptor */
struct sockaddr_in srv;           /* used by bind() */

/* create the socket */

srv.sin_family = AF_INET; /* use the Internet addr family */

srv.sin_port = htons(80); /* bind socket ‘fd’ to port 80*/

/* bind: a client may connect to any of server addresses */
srv.sin_addr.s_addr = htonl(INADDR_ANY);

if(bind(fd, (struct sockaddr*) &srv, sizeof(srv)) < 0) {
       perror("bind"); exit(1);
}
```

- **Still not quite ready to communicate with a client...**

Socket I/O: listen()

- ***listen*** indicates that the server will accept a connection

```
int fd;                           /* socket descriptor */
struct sockaddr_in srv;           /* used by bind() */

/* 1) create the socket */
/* 2) bind the socket to a port */

if(listen(fd, 5) < 0) {
      perror(“listen”);
      exit(1);
}
```

- **Still not quite ready to communicate with a client...**

Socket I/O: accept()

- ***accept*** blocks waiting for a connection

```
int fd;                      /* socket descriptor */
struct sockaddr_in srv;      /* used by bind() */
struct sockaddr_in cli;      /* client's add used by accept() */
int newfd;                   /* returned by accept() */
int cli_len = sizeof(cli);   /* used by accept() */

/* 1) create the socket */
/* 2) bind the socket to a port */
/* 3) listen on the socket */

newfd = accept(fd, (struct sockaddr*) &cli, &cli_len);
if(newfd < 0) {
       perror("accept");   exit(1);
}
```

- ***accept*** returns a new socket (***newfd***) with the same properties as the original socket (***fd***)
  - ***newfd*** < 0 indicates that an error occurred

Socket I/O: accept() continued...

```
struct sockaddr_in cli;       /* used by accept() */
int newfd;                    /* returned by accept() */
int cli_len = sizeof(cli);    /* used by accept() */

newfd = accept(fd, (struct sockaddr*) &cli, &cli_len);
if(newfd < 0) {
      perror("accept");
      exit(1);
}
```

- How does the server know which client it is?
  - **cli.sin_addr.s_addr** contains the client's ***IP address***
  - **cli.sin_port** contains the client's ***port number***
- Now the server can exchange data with the client by using ***read*** and ***write*** on the descriptor ***newfd***.
- Why does ***accept*** need to return a new descriptor?

Socket I/O: read()

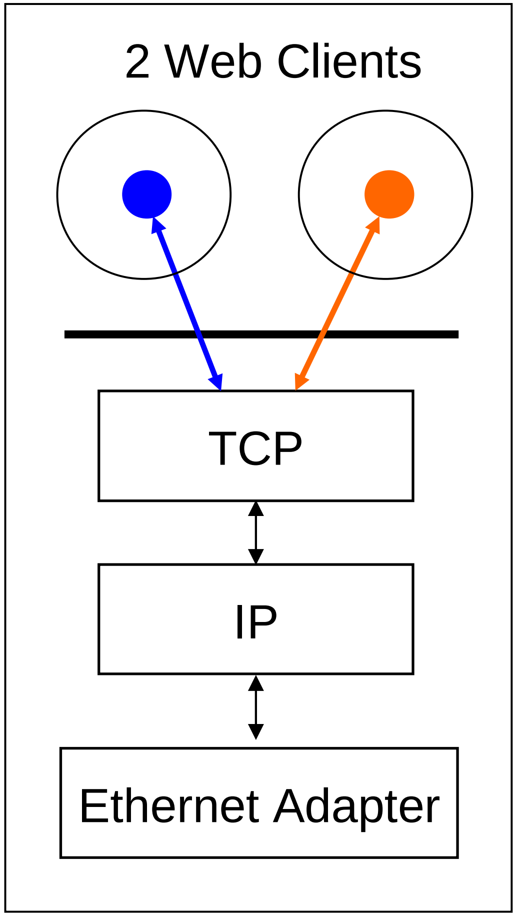
- ***read*** can be used with a socket
- ***read* <u>blocks</u> waiting for data from the client but does not guarantee that sizeof(buf) is read**

```
int fd;                           /* socket descriptor */
char buf[512];                    /* used by read() */
int nbytes;                      /* used by read() */

/* 1) create the socket */
/* 2) bind the socket to a port */
/* 3) listen on the socket */
/* 4) accept the incoming connection */
/* 5) Create a child process to attend the connection */
/*  Child will close fd, and continue communication with client */
/*  parent will close newfd, and continue with accepting connection*/

if((nbytes = read(newfd, buf, sizeof(buf))) < 0) {
       perror(“read”); exit(1);
}
```

TCP Client

- For example: web client

- **How does a *web client* connect to a *web server?***



Dealing with IP Addresses

- IP Addresses are commonly written as strings (“128.2.35.50”), but programs deal with IP addresses as integers.

Converting strings to numerical address:

```
struct sockaddr_in srv;

srv.sin_addr.s_addr = inet_addr(“128.2.35.50”);
if(srv.sin_addr.s_addr == (in_addr_t) -1) {
      fprintf(stderr, "inet_addr failed!\n"); exit(1);
}
```

Converting a numerical address to a string:

```
struct sockaddr_in srv;
char *t = inet_ntoa(srv.sin_addr);
if(t == 0) {
      fprintf(stderr, “inet_ntoa failed!\n”); exit(1);
}
```

Translating Names to Addresses

- Gethostbyname provides interface to DNS
- Additional useful calls
  - Gethostbyaddr – returns `hostent` given sockaddr_in
  - Getservbyname
    - Used to get service description (typically port number)
    - Returns `servent` based on name

```
#include <netdb.h>

struct hostent *hp; /*ptr to host info for remote*/
struct sockaddr_in peeraddr;
char *name = “www.tezu.ernet.in”;

peeraddr.sin_family = AF_INET;
hp = gethostbyname(name)
peeraddr.sin_addr.s_addr = ((struct in_addr*)(hp->h_addr))->s_addr;
```

Socket I/O: connect()

- ***connect*** allows a client to connect to a server...

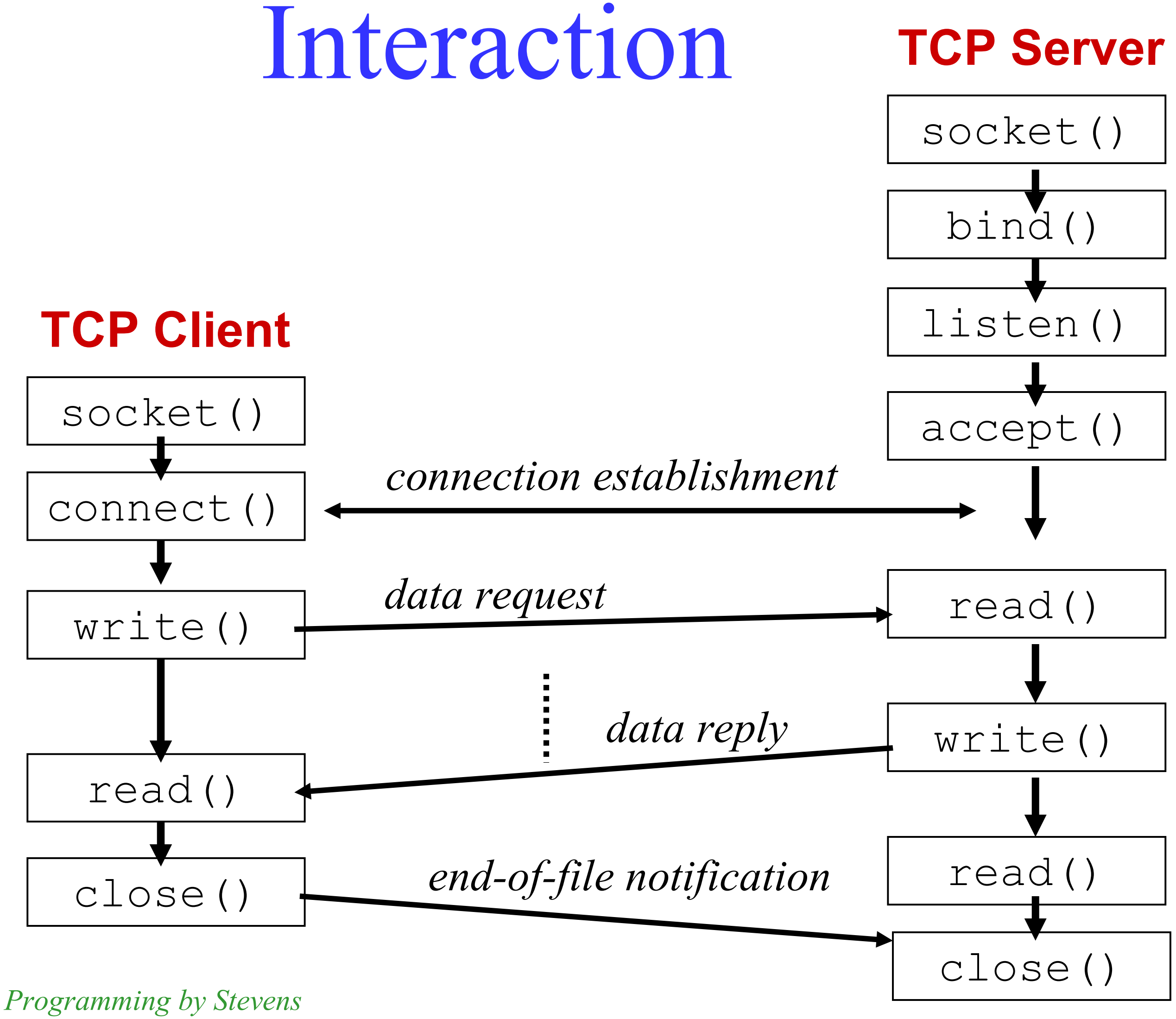
```
int fd;                           /* socket descriptor */
struct sockaddr_in srv;           /* used by connect() */

/* create the socket */

/* connect: use the Internet address family */
srv.sin_family = AF_INET;

/* connect: socket ‘fd’ to port 80 */
srv.sin_port = htons(80);

/* connect: connect to IP Address “202.141.129.22” */
srv.sin_addr.s_addr = inet_addr(“202.141.129.22”);

if(connect(fd, (struct sockaddr*) &srv, sizeof(srv)) < 0) {
       perror(”connect"); exit(1);
}
```

Socket I/O: write()

- ***write*** can be used with a socket

```
int fd;                       /* socket descriptor */
struct sockaddr_in srv;       /* used by connect() */
char buf[512];                /* used by write() */
int nbytes;                   /* used by write() */

/* 1) create the socket */
/* 2) connect() to the server */

/* Example: A client could “write” a request to a server
*/
if((nbytes = write(fd, buf, sizeof(buf))) < 0) {
      perror(“write”);
      exit(1);
}
```

Review: TCP Client-Server Interaction



from UNIX Network Programming by Stevens

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 client-local 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 client
  - allows server to talk with multiple clients
  - source port numbers used to distinguish clients.

application viewpoint

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

Example: C client (TCP)

```
/* client.c  */
void main(int argc, char *argv[])
{
struct sockaddr_in sad; /* structure to hold an IP address */
int clientSocket;  /* socket descriptor */
struct hostent *ptrh;  /* pointer to a host table entry */

char Sentence[128];
char modifiedSentence[128];

host = argv[1]; port = atoi(argv[2]);

clientSocket = socket(PF_INET, SOCK_STREAM, 0);
        memset((char *)&sad,0,sizeof(sad)); /* clear sockaddr structure
*/
        sad.sin_family = AF_INET; /* set family to Internet */
        sad.sin_port = htons((u_short)port);
        ptrh = gethostbyname(host); /* Convert host name to IP address
*/
        memcpy(&sad.sin_addr, ptrh->h_addr, ptrh->h_length);
connect(clientSocket, (struct sockaddr *)&sad, sizeof(sad));
```

Create client socket,
connect to server

Example: C client (TCP), cont.

Get
input stream
from user

```
gets(Sentence);
```

Send line
to server

```
n=write(clientSocket, Sentence, strlen(Sentence)+1);
```

Read line
from server

```
n=read(clientSocket, modifiedSentence,
sizeof(modifiedSentence));


printf("FROM SERVER: %s\n”,modifiedSentence);
```

Close
connection

```
close(clientSocket);

}
```

Example: C server (TCP)

```
/* server.c  */
void main(int argc, char *argv[])
{
struct sockaddr_in sad; /* structure to hold an IP address */
struct sockaddr_in cad;
int welcomeSocket, connectionSocket; /* socket descriptor */
struct hostent *ptrh; /* pointer to a host table entry */

char clientSentence[128];
char capitalizedSentence[128];

port = atoi(argv[1]);

welcomeSocket = socket(PF_INET, SOCK_STREAM, 0);
            memset((char *)&sad,0,sizeof(sad)); /* clear sockaddr structure */
            sad.sin_family = AF_INET; /* set family to Internet */
            sad.sin_addr.s_addr = INADDR_ANY; /* set the local IP address */
            sad.sin_port = htons((u_short)port);/* set the port number */
bind(welcomeSocket, (struct sockaddr *)&sad, sizeof(sad));
```

Create welcoming socket at port
&
Bind a local address

Example: C server (TCP), cont

```
/* Specify the maximum number of clients that can be queued */
listen(welcomeSocket, 10)

while(1) {

    connectionSocket=accept(welcomeSocket, (struct sockaddr *)&cad,
&alen);

    n=read(connectionSocket, clientSentence, sizeof(clientSentence));

   /* capitalize Sentence and store the result in capitalizedSentence*/


   n=write(connectionSocket, capitalizedSentence,
strlen(capitalizedSentence)+1);

   close(connectionSocket);
   }
}
```

Wait, on welcoming socket
for contact by a client

Write out the result to socket

End of while loop,
loop back and wait for
another client connection

Socket programming *with UDP*

UDP: no “connection” between client and server

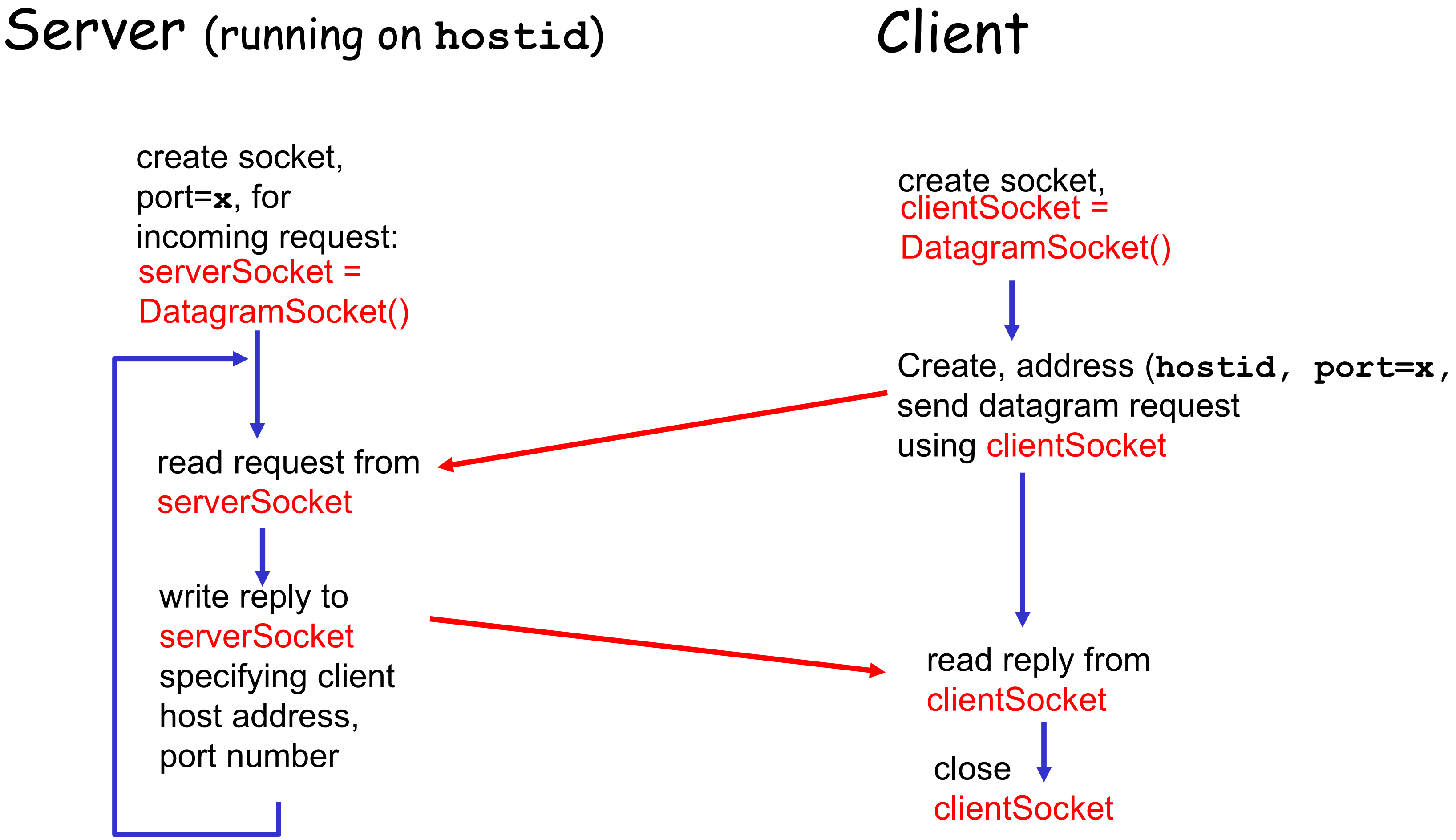
- no handshaking
- sender explicitly attaches IP address and port of destination to each packet
- server must extract IP address, port of sender from received packet

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

application viewpoint

UDP provides unreliable transfer of groups of bytes (“datagrams”) between client and server

Client/server socket interaction: UDP



Server (running on `hostid`)

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

read request from serverSocket

write reply to serverSocket specifying client host address, port number

Client

create socket, clientSocket = DatagramSocket()

Create, address (**`hostid, port=x`**, send datagram request using clientSocket

read reply from clientSocket

close clientSocket

Example: C client (UDP)

```
/* client.c  */
void main(int argc, char *argv[])
{
struct sockaddr_in sad; /* structure to hold an IP address */
int clientSocket; /* socket descriptor */
struct hostent *ptrh; /* pointer to a host table entry */

char Sentence[128];
char modifiedSentence[128];

host = argv[1]; port = atoi(argv[2]);

clientSocket = socket(PF_INET, SOCK_DGRAM, 0);

/* determine the server's address */
        memset((char *)&sad,0,sizeof(sad));   /* clear sockaddr structure
*/
        sad.sin_family = AF_INET; /* set family to Internet */
        sad.sin_port = htons((u_short)port);
        ptrh = gethostbyname(host); /* Convert host name to IP address
*/
        memcpy(&sad.sin_addr, ptrh->h_addr, ptrh->h_length);
```

Create client socket,
NO connection to server

Example: C client (UDP), cont.

Get input stream from user

```
gets(Sentence);
```

Send line to server

```
addr_len =sizeof(struct sockaddr);
n=sendto(clientSocket, Sentence, strlen(Sentence)+1,
              (struct sockaddr *) &sad, addr_len);
```

Read line from server

```
n=recvfrom(clientSocket, modifiedSentence,
sizeof(modifiedSentence).
                (struct sockaddr *) &sad, &addr_len);

printf("FROM SERVER: %s\n”,modifiedSentence);
```

Close connection

```
close(clientSocket);
}
```

Example: C server (UDP)

```
/* server.c  */
void main(int argc, char *argv[])
{
struct sockaddr_in sad; /* structure to hold an IP address */
struct sockaddr_in cad;
int serverSocket; /* socket descriptor */
struct hostent *ptrh; /* pointer to a host table entry */

char clientSentence[128];
char capitalizedSentence[128];

port = atoi(argv[1]);

serverSocket = socket(PF_INET, SOCK_DGRAM, 0);
        memset((char *)&sad,0,sizeof(sad)); /* clear sockaddr structure */
        sad.sin_family = AF_INET;            /* set family to Internet */
        sad.sin_addr.s_addr = INADDR_ANY; /* set the local IP address */
        sad.sin_port = htons((u_short)port);/* set the port number */
bind(serverSocket, (struct sockaddr *)&sad, sizeof(sad));
```

Create welcoming socket at port
&
Bind a local address

Example: C server (UDP), cont

```
while(1) {

    n=recvfrom(serverSocket, clientSentence, sizeof(clientSentence), 0
                        (struct sockaddr *) &cad, &addr_len );

    /* capitalize Sentence and store the result in capitalizedSentence*/

    n=sendto(connectionSocket, capitalizedSentence,
strlen(capitalizedSentence)+1,0
                    (struct sockaddr *) &cad, &addr_len);

    close(connectionSocket);
    }
}
```

Receive messages from clients

Write out the result to socket

End of while loop,
loop back and wait for
another client connection

A Few Programming Notes: Representing Packets

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             Type                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Length            |            Checksum           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Address                            |

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

Type: 4-byte integer
Length: 2-byte integer
Checksum: 2-byte integer
Address: 4-byte IP address
```

A Few Programming Notes: Building a Packet in a Buffer

```
struct packet {
      u_int32_t type;
      u_int16_t length;
      u_int16_t checksum;
      u_int32_t address;
};

/* ================================================== */
char buf[1024];
struct packet *pkt;

pkt = (struct packet*) buf;
pkt->type = htonl(1);
pkt->length = htons(2);
pkt->checksum = htons(3);
pkt->address = htonl(4);
```

Socket Programming References

- Man page
  - usage: man <function name>
- Textbook
  - Stevens, Unix Network Programming, PHI

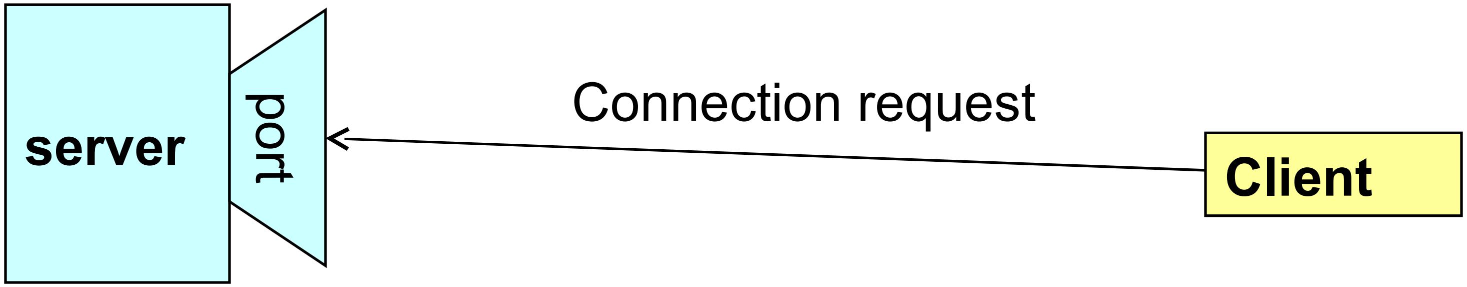
Socket Programming in Java

Sockets

- Sockets provide an interface for programming networks at the transport layer.
- Network communication using Sockets is very much similar to performing file I/O
  - In fact, socket handle is treated like file handle.
  - The streams used in file I/O operation are also applicable to socket-based I/O
- Socket-based communication is programming language independent.
  - That means, a socket program written in Java language can also communicate to a program written in Java or non-Java socket program.

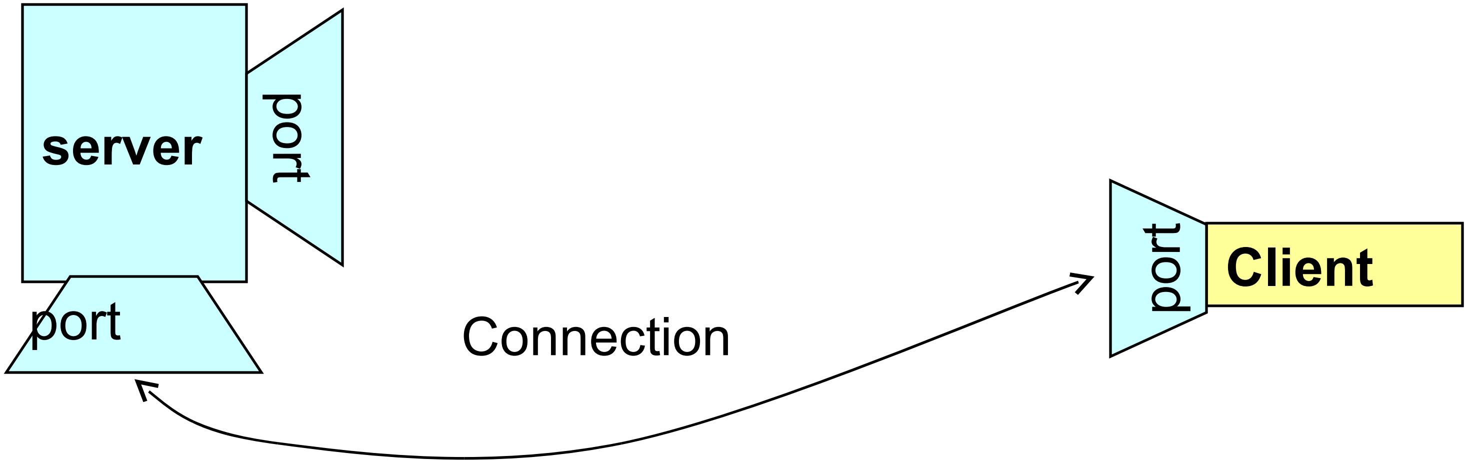
Socket Communication

- A server (program) runs on a specific computer and has a socket that is bound to a specific port. The server waits and listens to the socket for a client to make a connection request.



Socket Communication

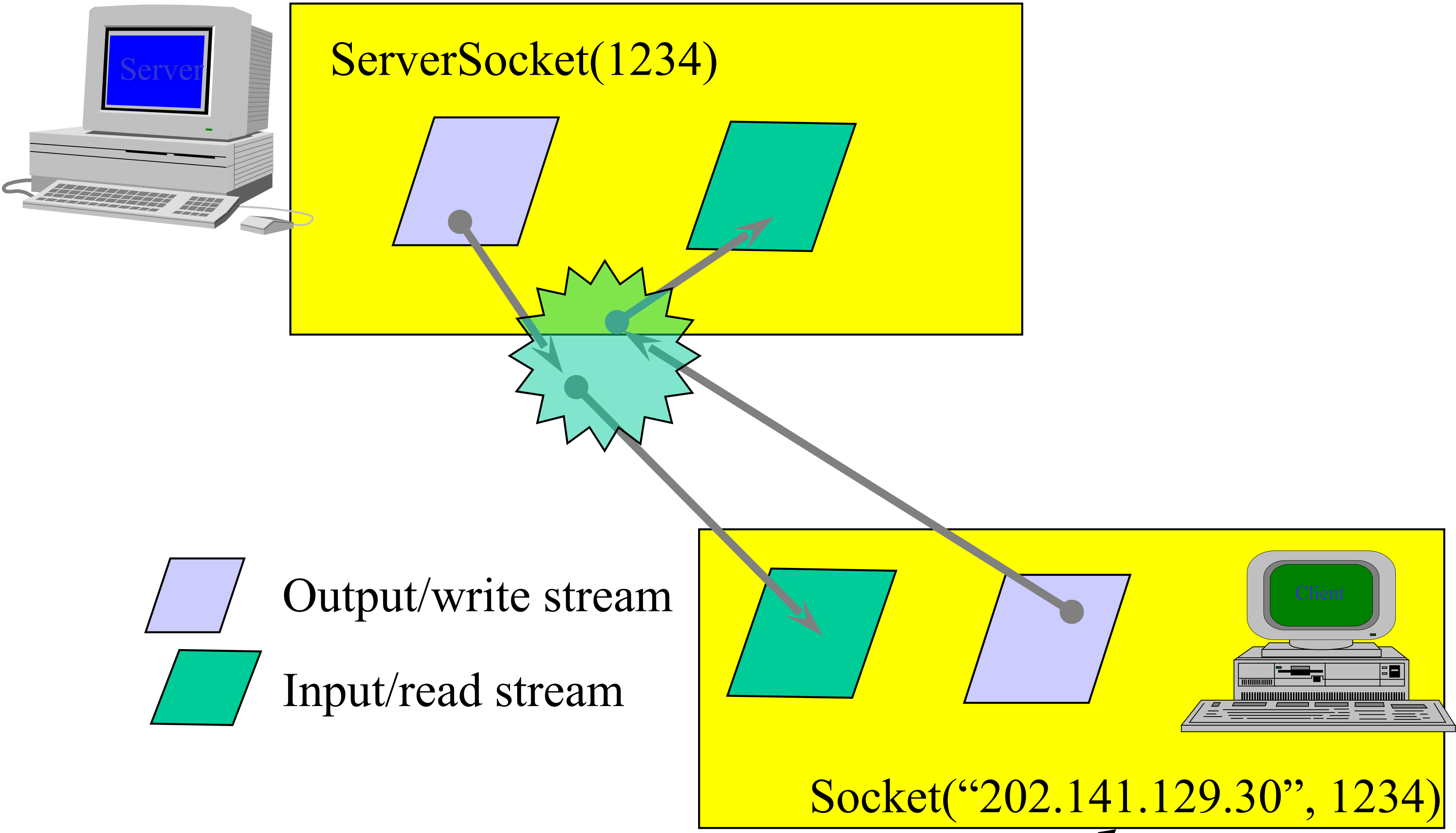
- If everything goes well, the server accepts the connection. Upon acceptance, the server gets a new socket bounds to a different port. It needs a new socket (consequently a different port number) so that it can continue to listen to the original socket for connection requests while serving the connected client.



Sockets and Java Socket Classes

- A socket is an endpoint of a two-way communication link between two programs running on the network.
- A socket is bound to a port number so that the TCP layer can identify the application that data destined to be sent.
- Java's .net package provides two classes:
  - Socket – for implementing a client
  - ServerSocket – for implementing a server

Java Sockets



ServerSocket(1234)

Output/write stream

Input/read stream

Socket(“202.141.129.30”, 1234)

It can be host_name like “agnee.tezu.ernet.in”

Implementing a Server

1. Open the Server Socket:

```
ServerSocket server;
DataOutputStream os;
DataInputStream is;
server = new ServerSocket( PORT );
```

2. Wait for the Client Request:

```
Socket client = server.accept();
```

3. Create I/O streams for communicating to the client

```
is = new DataInputStream( client.getInputStream() );
os = new DataOutputStream( client.getOutputStream() );
```

4. Perform communication with client

```
Receive from client: String line = is.readLine();
Send to client: os.writeBytes("Hello\n");
```

5. Close sockets: `client.close();`

For multithreaded server:

```
while(true) {
  i. wait for client requests (step 2 above)
  ii. create a thread with “client” socket as parameter (the thread creates streams (as in step (3) and does
      communication as stated  in (4). Remove thread once service is provided.
}
```

Implementing a Client

1. Create a Socket Object:

```
client = new Socket(server, port_id );
```

2. Create I/O streams for communicating with the server.

```
 is = new DataInputStream(client.getInputStream() );
os = new DataOutputStream( client.getOutputStream() );
```

3. Perform I/O or communication with the server:

```
 – Receive data from the server:
String line = is.readLine();
 – Send data to the server:
os.writeBytes("Hello\n");
```

4. Close the socket when done:

```
client.close();
```

A simple server (simplified code)

```
// SimpleServer.java: a simple server program
import java.net.*;
import java.io.*;
public class SimpleServer {
  public static void main(String args[]) throws IOException {
    // Register service on port 1234
    ServerSocket s = new ServerSocket(1234);
    Socket s1=s.accept(); // Wait and accept a connection
    // Get a communication stream associated with the socket
    OutputStream s1out = s1.getOutputStream();
    DataOutputStream dos = new DataOutputStream (s1out);
    // Send a string!
    dos.writeUTF("Hi there");
    // Close the connection, but not the server socket
    dos.close();
    s1out.close();
    s1.close();
  }
}
```

A simple client (simplified code)

```
// SimpleClient.java: a simple client program
import java.net.*;
import java.io.*;
public class SimpleClient {
  public static void main(String args[]) throws IOException {
    // Open your connection to a server, at port 1234
    Socket s1 = new Socket("mundroo.cs.mu.oz.au",1234);
    // Get an input file handle from the socket and read the input
    InputStream s1In = s1.getInputStream();
    DataInputStream dis = new DataInputStream(s1In);
    String st = new String (dis.readUTF());
    System.out.println(st);
    // When done, just close the connection and exit
    dis.close();
    s1In.close();
    s1.close();
  }
}
```

Run

- Run Server on agnee.tezu.ernet.in
  - java SimpleServer &

- Run Client on any machine (including agnee):
  - java SimpleClient
    Hi there

- If you run client when server is not up:
  - sockets [1:147] java SimpleClient

```
Exception in thread "main" java.net.ConnectException: Connection refused
        at java.net.PlainSocketImpl.socketConnect(Native Method)
        at java.net.PlainSocketImpl.doConnect(PlainSocketImpl.java:320)
        at java.net.PlainSocketImpl.connectToAddress(PlainSocketImpl.java:133)
        at java.net.PlainSocketImpl.connect(PlainSocketImpl.java:120)
        at java.net.Socket.<init>(Socket.java:273)
        at java.net.Socket.<init>(Socket.java:100)
        at SimpleClient.main(SimpleClient.java:6)
```

Socket Exceptions

```
try {
    Socket client = new Socket(host, port);
    handleConnection(client);
}
catch(UnknownHostException uhe)
    { System.out.println("Unknown host: " + host);
    uhe.printStackTrace();
}
catch(IOException ioe) {
System.out.println("IOException: " + ioe); ioe.printStackTrace();
}
```

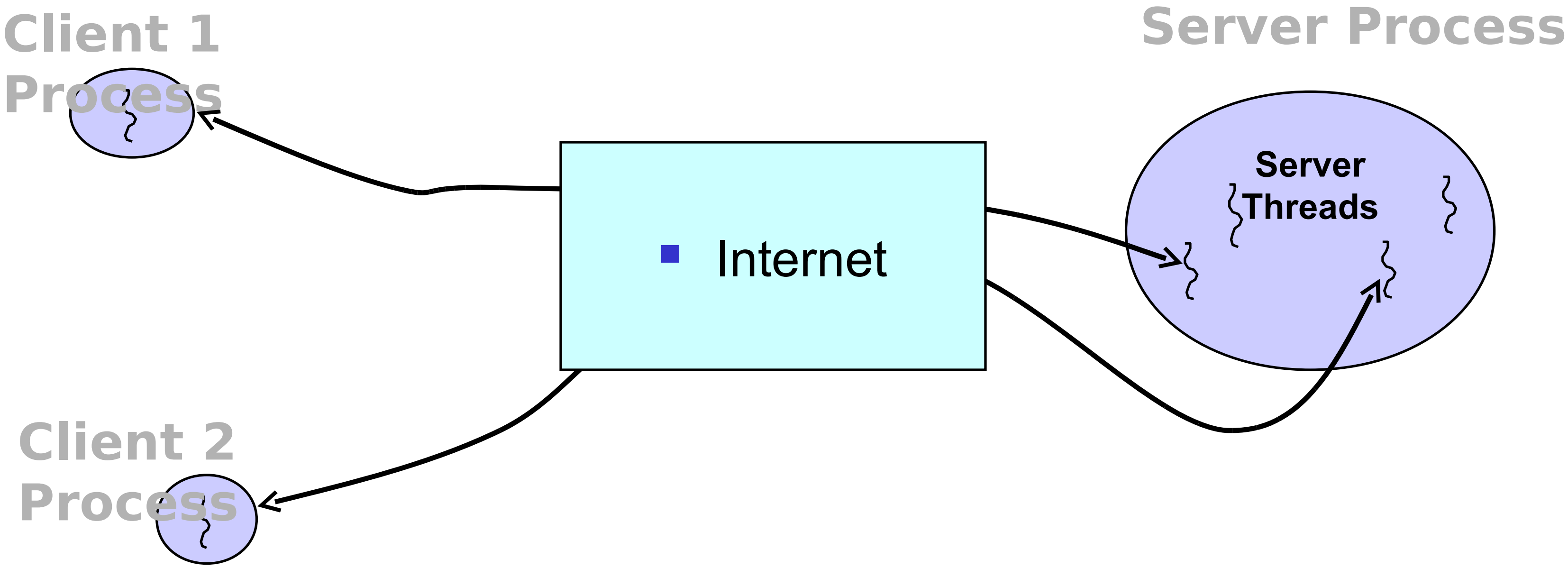
ServerSocket & Exceptions

- public **ServerSocket**(int port) throws IOException
  - Creates a server socket on a specified port.
  - A port of 0 creates a socket on any free port. You can use getLocalPort() to identify the (assigned) port on which this socket is listening.
  - The maximum queue length for incoming connection indications (a request to connect) is set to 50. If a connection indication arrives when the queue is full, the connection is refused.
- Throws:
  - IOException - if an I/O error occurs when opening the socket.
  - SecurityException - if a security manager exists and its checkListen method doesn't allow the operation.

Server in Loop: Always up

```
// SimpleServerLoop.java: a simple server program that runs forever in a single thead
import java.net.*;
import java.io.*;
public class SimpleServerLoop {
  public static void main(String args[]) throws IOException {
    // Register service on port 1234
    ServerSocket s = new ServerSocket(1234);
    while(true)
    {
            Socket s1=s.accept(); // Wait and accept a connection
            // Get a communication stream associated with the socket
            OutputStream s1out = s1.getOutputStream();
            DataOutputStream dos = new DataOutputStream (s1out);
            // Send a string!
            dos.writeUTF("Hi there");
            // Close the connection, but not the server socket
            dos.close();
            s1out.close();
            s1.close();
    }
  }
}
```

Multithreaded Server: For Serving Multiple Clients Concurrently



Conclusion

- Programming client/server applications in Java is fun and challenging.
- Programming socket programming in Java is much easier than doing it in other languages such as C.
- Keywords:
  - Clients, servers, TCP/IP, port number, sockets, Java sockets