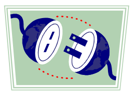
Socket Programming



Rohan Murty
Hitesh Ballani

Last Modified:
2/8/2004 8:30:45 AM

Slides adapted from Prof. Matthews' slides from 2003SP

Socket programming

Goal: learn how to build client/server application that communicate using sockets

Socket API

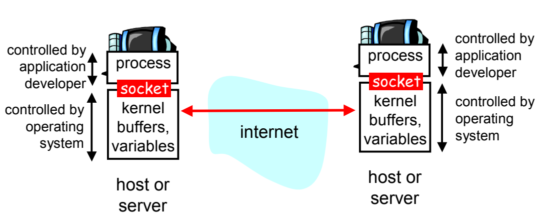
- introduced in BSD4.1 UNIX, 1981
- Sockets are explicitly created, used, released by applications
- client/server paradigm
- two types of transport service via socket API:
  - unreliable datagram
  - reliable, byte stream-oriented

socket

a *host-local*, *application-created/owned*, *OS-controlled* interface (a "door") into which application process can both send and receive messages to/from another (remote or local) application process

Sockets

Socket: a door between application process and end-end-transport protocol (UCP or TCP)



Languages and Platforms

Socket API is available for many languages on many platforms:

- C, Java, Perl, Python,…
- *nix, Windows,…

Socket Programs written in any language and running on any platform can communicate with each other!

Writing communicating programs in different languages is a good exercise

Decisions

- Before you go to write socket code, decide
  - Do you want a TCP-style reliable, full duplex, connection oriented channel? Or do you want a UDP-style, unreliable, message oriented channel?
  - Will the code you are writing be the client or the server?
    - Client: you assume that there is a process already running on another machines that you need to connect to.
    - Server: you will just start up and wait to be contacted

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
  - Frees up incoming port
  - allows server to talk with multiple clients

application viewpoint

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

Pseudo code TCP client

- Create socket, connectSocket
- Do an active connect specifying the IP address and port number of server
- Read and Write Data Into connectSocket to Communicate with server
- Close connectSocket

Pseudo code TCP server

- Create socket (serverSocket)
- Bind socket to a specific port where clients can contact you
- Register with the kernel your willingness to listen that on socket for client to contact you
- Loop

  Accept new connection (connectSocket)

  Read and Write Data Into connectSocket to Communicate with client

  Close connectSocket

  End Loop
- Close serverSocket

Example: Java client (TCP)

```
import java.io.*;
import java.net.*;
class TCPClient {

    public static void main(String argv[]) throws Exception
    {
        String sentence;
        String modifiedSentence;

        BufferedReader inFromUser =
          new BufferedReader(new InputStreamReader(System.in));

        Socket clientSocket = new Socket("hostname", 6789);

        DataOutputStream outToServer =
          new DataOutputStream(clientSocket.getOutputStream());
```

Create input stream → BufferedReader inFromUser

Create client socket, connect to server → Socket clientSocket

Create output stream attached to socket → DataOutputStream outToServer

Example: Java client (TCP), cont.

```
        BufferedReader inFromServer =
          new BufferedReader(new
          InputStreamReader(clientSocket.getInputStream()));

        sentence = inFromUser.readLine();

        outToServer.writeBytes(sentence + '\n');

        modifiedSentence = inFromServer.readLine();

        System.out.println("FROM SERVER: " + modifiedSentence);

        clientSocket.close();

    }
}
```

Create input stream attached to socket → BufferedReader inFromServer

Send line to server → outToServer.writeBytes

Read line from server → modifiedSentence = inFromServer.readLine()

Example: Java server (TCP)

```
import java.io.*;
import java.net.*;

class TCPServer {

  public static void main(String argv[]) throws Exception
    {
      String clientSentence;
      String capitalizedSentence;

      ServerSocket welcomeSocket = new ServerSocket(6789);

      while(true) {

          Socket connectionSocket = welcomeSocket.accept();

          BufferedReader inFromClient =
            new BufferedReader(new
            InputStreamReader(connectionSocket.getInputStream()));
```

Create welcoming socket at port 6789 → ServerSocket welcomeSocket

Wait, on welcoming socket for contact by client

Create input stream, attached to socket → BufferedReader inFromClient

Example: Java server (TCP), cont

```
          DataOutputStream  outToClient =
            new DataOutputStream(connectionSocket.getOutputStream());

          clientSentence = inFromClient.readLine();

          capitalizedSentence = clientSentence.toUpperCase() + '\n';

          outToClient.writeBytes(capitalizedSentence);
        }
    }
}
```

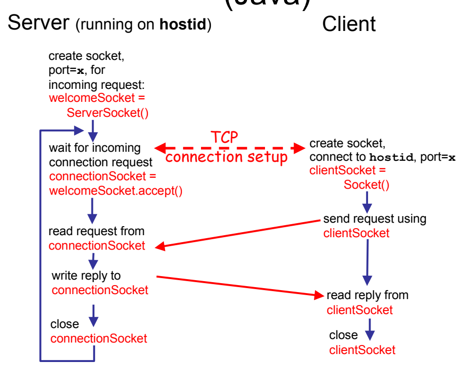
Create output stream, attached to socket → DataOutputStream outToClient

Read in line from socket → clientSentence

Write out line to socket → outToClient.writeBytes

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

Client/server socket interaction: TCP (Java)



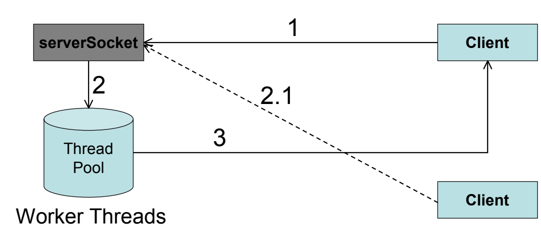
Queues

- We just saw a simple example, with one socket on the server handling incoming connections
- While the server socket is busy, incoming connections are stored in a queue until it can accept them
- Most systems maintain a queue length between 5 and 50
- Once the queue fills up, further incoming connections are refused until space in the queue opens up
- This is a problem in a situation where our server has to handle many concurrent incoming connections. Example: HTTP servers
  - Solution? Use concurrency

Concurrent TCP Servers

- Benefit comes in ability to hand off processing to another process
  - Parent process creates the "door bell" or "welcome" socket on well-known port and waits for clients to request connection
  - When a client does connect, fork off a child process to handle that connection so that parent process can return to waiting for connections as soon as possible
- Multithreaded server: same idea, just spawn off another thread rather than a full process
  - Threadpools?

Threadpools



Socket programming with UDP

UDP: very different mindset than TCP

- no connection just independent messages sent
- no handshaking
- sender explicitly attaches IP address and port of destination
- server must extract IP address, port of sender from received datagram to know who to respond to

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

Pseudo code UDP server

- Create socket
- Bind socket to a specific port where clients can contact you
- Loop

  (Receive UDP Message from client x)+

  (Send UDP Reply to client x)*
- Close Socket

Pseudo code UDP client

- Create socket
- Loop

  (Send Message To Well-known port of server)+

  (Receive Message From Server)
- Close Socket

Example: Java client (UDP)

```
import java.io.*;
import java.net.*;

class UDPClient {
   public static void main(String args[]) throws Exception
   {
```

Create input stream →

```
     BufferedReader inFromUser =
       new BufferedReader(new InputStreamReader(System.in));
```

Create client socket →

```
     DatagramSocket clientSocket = new DatagramSocket();
```

Translate hostname to IP address using DNS →

```
     InetAddress IPAddress = InetAddress.getByName("hostname");

     byte[] sendData = new byte[1024];
     byte[] receiveData = new byte[1024];

     String sentence = inFromUser.readLine();
     sendData = sentence.getBytes();
```

Example: Java client (UDP), cont.

Create datagram with data-to-send, length, IP addr, port

```
DatagramPacket sendPacket =
  new DatagramPacket(sendData, sendData.length, IPAddress, 9876);
```

Send datagram to server

```
clientSocket.send(sendPacket);

DatagramPacket receivePacket =
  new DatagramPacket(receiveData, receiveData.length);
```

Read datagram from server

```
clientSocket.receive(receivePacket);

String modifiedSentence =
   new String(receivePacket.getData());

System.out.println("FROM SERVER:" + modifiedSentence);
clientSocket.close();
}
}
```

Example: Java server (UDP)

```
import java.io.*;
import java.net.*;

class UDPServer {
  public static void main(String args[]) throws Exception
   {
```

Create datagram socket at port 9876

```
   DatagramSocket serverSocket = new DatagramSocket(9876);

   byte[] receiveData = new byte[1024];
   byte[] sendData  = new byte[1024];

   while(true)
    {
```

Create space for received datagram

```
     DatagramPacket receivePacket =
       new DatagramPacket(receiveData, receiveData.length);
```

Receive datagram

```
     serverSocket.receive(receivePacket);
```

Example: Java server (UDP), cont

```
String sentence = new String(receivePacket.getData());
```

Get IP addr port #, of sender

```
InetAddress IPAddress = receivePacket.getAddress();

int port = receivePacket.getPort();

        String capitalizedSentence = sentence.toUpperCase();

sendData = capitalizedSentence.getBytes();
```

Create datagram to send to client

```
DatagramPacket sendPacket =
  new DatagramPacket(sendData, sendData.length, IPAddress,
            port);
```

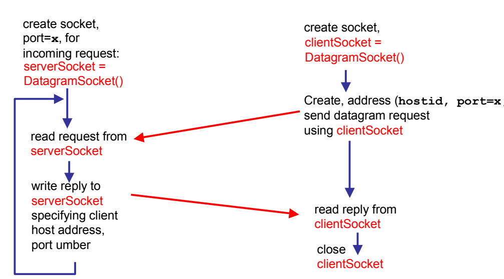
Write out datagram to socket

```
serverSocket.send(sendPacket);
 }
}
}
```

End of while loop, loop back and wait for another datagram

Client/server socket interaction: UDP

Server (running on **hostid**)   Client



UDP Server vs Client

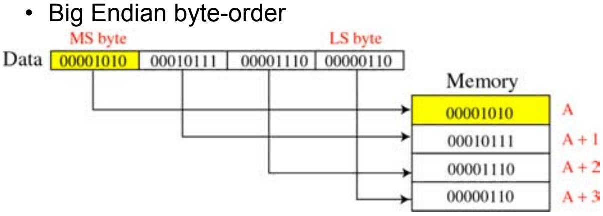
- Server has a well-known port number
- Client initiates contact with the server
- Less difference between server and client code than in TCP
  - Both client and server bind to a UDP socket
  - Not accept for server and connect for client
- Client send to the well-known server port; server extracts the client's address from the datagram it receives

TCP vs UDP

- TCP can use read/write (or recv/send) and source and destination are implied by the connection; UDP must specify destination for each datagram
  - Sendto, recvfrm include address of other party
- TCP server and client code look quite different; UDP server and client code vary mostly in who sends first

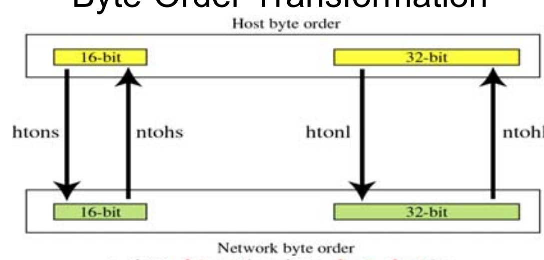
Byte ordering

- Big Endian byte-order



The byte order for the TCP/IP protocol suite is big endian.

Byte-Order Transformation



u_short **htons** (u_short *host_short*) ;

u_short **ntohs** (u_short *network_short*) ;

u_long **htonl** (u_long *host_long*) ;

u_long **ntohl** (u_long *network_long*) ;

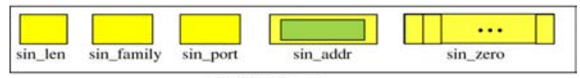
Some Definitions

- Internet Address Structure

```
struct in_addr
{
    in_addr_t s_addr;
};
```

in_addr_t is defined as a long on linux machines, implying 32 bit addresses!

Socket address structure

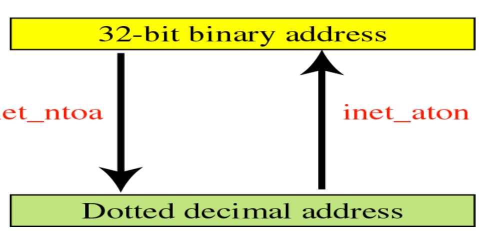


sockaddr_in

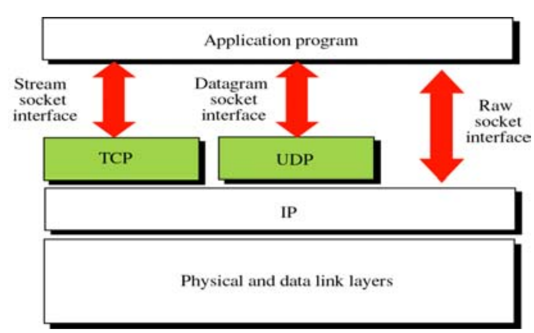
```
struct    sockaddr_in
{
          u_char                          sin_len ;
          u_short                         sin_family ;
          u_short                         sin_port ;
          struct  in_addr                 sin_addr ;
          char                            sin_zero [8] ;
} ;
```

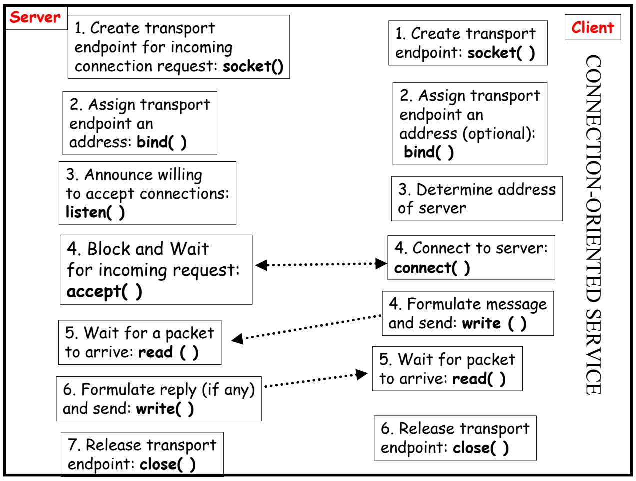
Address Transformation

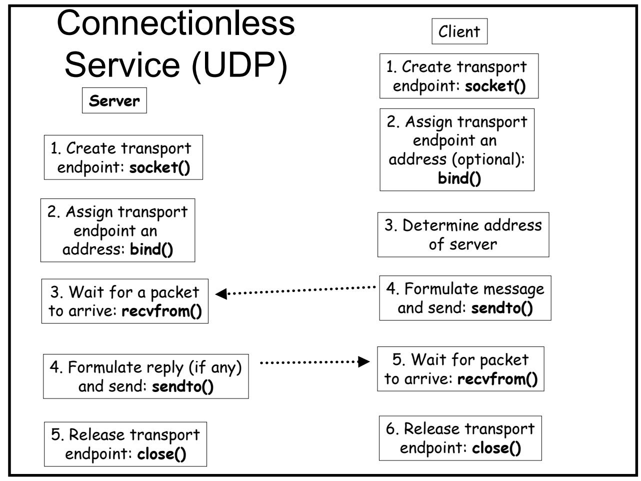
```
int     inet_aton ( const char  *strptr , struct in_addr  *addrptr ) ;
char   *inet_ntoa  (struct in_addr   inaddr ) ;
```



Socket Types







Procedures That Implement The Socket API

Creating and Deleting Sockets

- `fd=`**`socket`**`(protofamily, type, protocol)`
  Creates a new socket. Returns a file descriptor (fd). Must specify:
  - the protocol family (e.g. TCP/IP)
  - the type of service (e.g. STREAM or DGRAM)
  - the protocol (e.g. TCP or UDP)
- **`close`**(fd)
  Deletes socket.
  For connected STREAM sockets, sends EOF to close connection.

Procedures That Implement The Socket API

Putting Servers “on the Air”

- **`bind`**(fd,laddress,laddresslen)
  Used by server to establish port to listen on.
  When server has >1 IP addrs, can specify “IF_ANY”, or a specific one
- **`listen`** (fd, queuesize)
  Used by connection-oriented servers only, to put server “on the air”
  Queuesize parameter: how many pending connections can be waiting

(cont …)

- afd = **`accept`** (lfd, caddress, caddresslen)
  Used by connection-oriented servers to accept one new connection
  - There must already be a listening socket (lfd)
  - Returns afd, a new socket for the new connection, and
  - The address of the caller (e.g. for security, log keeping. etc.)

Procedures That Implement The Socket API

How Clients Communicate with Servers?

- **`connect`** (fd, saddress, saddreslen)

  Used by connection-oriented clients to connect to server
  - There must already be a socket bound to a connection-oriented service on the fd
  - There must already be a listening socket on the server
  - You pass in the address (IP address, and port number) of the server.

  Used by connectionless clients to specify a "default send to address"
  - Subsequent "sends" don't have to specify a destination address

Procedures That Implement The Socket API

How Clients Communicate with Servers? (TCP)

- int **`write`** (fd, data, length)
  Used to send data
  - write is the "normal" write function; can be used with both files and sockets
- int **`read`** (fd, data,length)
  Used to receive data… parameters are similar!

NOTE : both functions can return a value less than the length

Procedures That Implement The Socket API

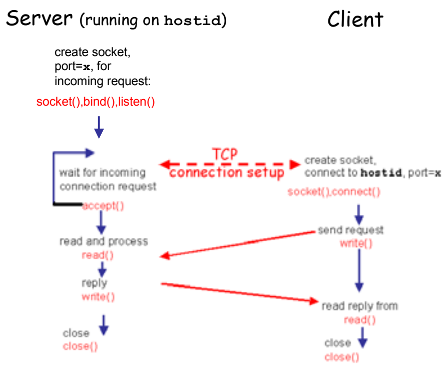
How Clients Communicate with Servers(UDP)

- **`int sendto`** (fd, data, length, flags, destaddress, addresslen)

  Used to send data.
  - Connectionless socket, so we need to specify the dest address
- **`int recvfrom`**(fd,data,length,flags,srcaddress,addresslen)

  Used to receive data… parameters are similar, but in reverse

Concurrent Server: TCP (C/C++)



Non-blocking I/O

- By default, `accept()`, `recv()`, etc block until there's input
- What if you want to do something else while you're waiting?
- We can set a socket to not block (i.e. if there's no input an error will be returned)
- … or, we can tell the kernel to let us know when a socket is ready, and deal with it only then

`non-blocking/select`

- The host uses `select()` to get the kernel to tell it when the peer has sent a message that can be `recv()`'d

- Can specify multiple sockets on which to wait

  -- select returns when one or more sockets are ready

  -- operation can time out !

Java vs C

- Java hides more of the details
  - new ServerSocket of Java = socket, bind and listen of C
  - new Socket hides the getByName (or gethostbyname) of C; Unable to hide this in the UDP case though
  - Socket API first in C for BSD; more options and choices exposed by the interface than in Java ?

PROJECT 1 : BASIC SOCKETS

AIM: Write a program (referred to as the **IP box**) that opens four sockets, two TCP and two UDP

2 TCP SOCKETS :

1. A **receive-config** socket : IP BOX acts as a Server (must be bound to a port you have to find, and the interface IP address)

2. A **send-config** socket : IP BOX acts a reciever

(CONT …)

- 2 UDP SOCKETS
- App -- acts as the interface between the IP layer and the application
- Iface – represents the network interface
- Both must be bound to an used port and the interface address

IP BOX OPERATION

- Send-config sockets connects to the Test Box and sends a “ready-to-test” command
- The Test Box then connects to recv-config socket and send a ‘\n’ terminated command which must be echoed
- The Test Box then sends UDP packets to app and iface sockets which must be echoed (Note : If the Test Box does not receive your echo, it retransmits the packet)

(cont …)

- On receiving both the echoes, the Test Box sends a “send-stat” command to the send-config socket
- The IP box sends a “list-of-stats”
- The Test Box then sends an exit message (during final test, this will have a 40 character hex string representing a hashed timestamp, which your program must RECORD!)