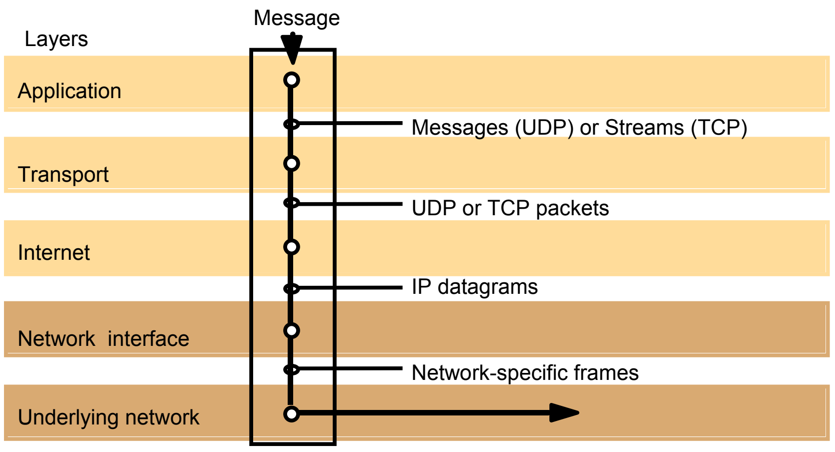
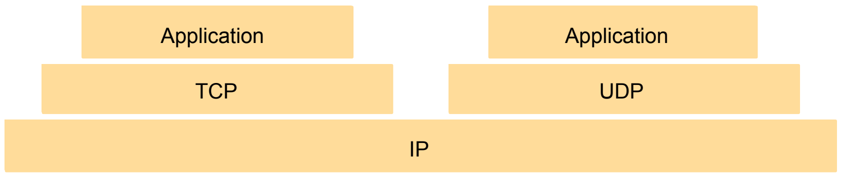
Communication in distributed systems: network programming using sockets

Operating Systems

TCP/IP layers



The programmer's conceptual view of a TCP/IP Internet



Socket programming

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

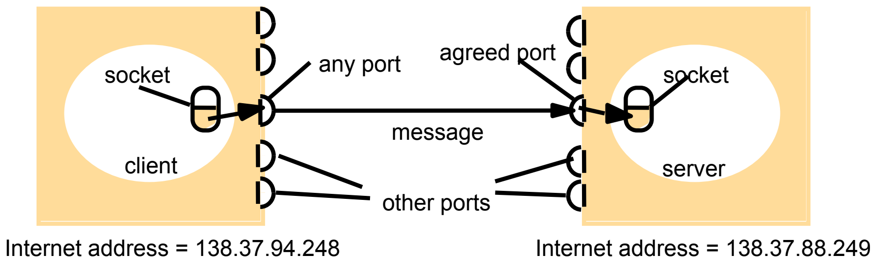
Socket API

- introduced in BSD4.1 UNIX, 1981
- explicitly created, used, released by apps
- 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 and ports


socket
client
any port
agreed port
message
other ports
socket
server
Internet address = 138.37.94.248
Internet address = 138.37.88.249

Berkeley Sockets (1)

- Socket primitives for TCP/IP.

Primitive	**Meaning**
Socket	Create a new communication endpoint
Bind	Attach a local address to a socket
Listen	Announce willingness to accept connections
Accept	Block caller until a connection request arrives
Connect	Actively attempt to establish a connection
Send	Send some data over the connection
Receive	Receive some data over the connection
Close	Release the connection

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

application viewpoint

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

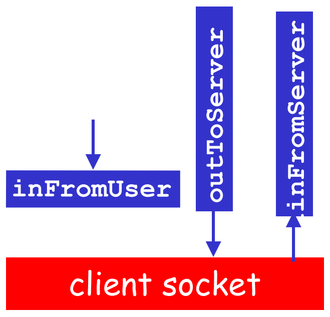
Socket programming with TCP

Example client-server app:

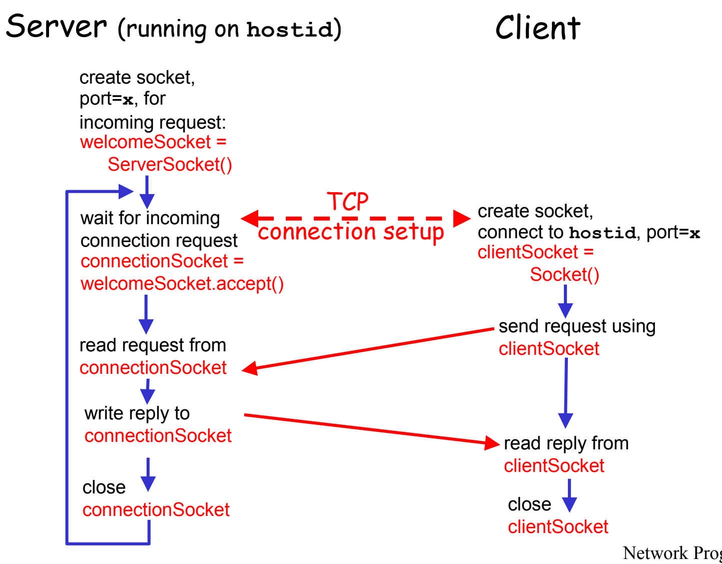
- client reads line from standard input (**inFromUser** stream) , sends to server via socket (**outToServer** stream)
- server reads line from socket
- server converts line to uppercase, sends back to client
- client reads, prints modified line from socket (**inFromServer** stream)

Input stream: sequence of bytes into process

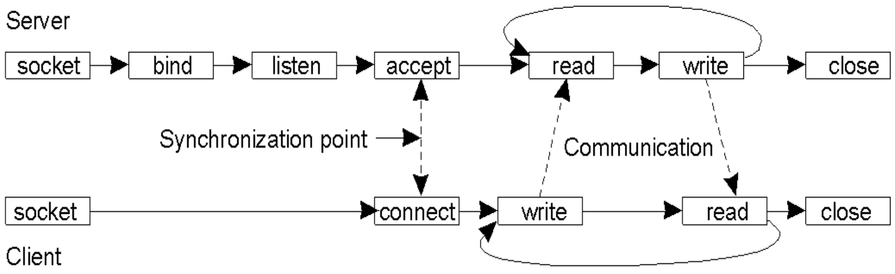
Output stream: sequence of bytes out of process



Client/server socket interaction: TCP

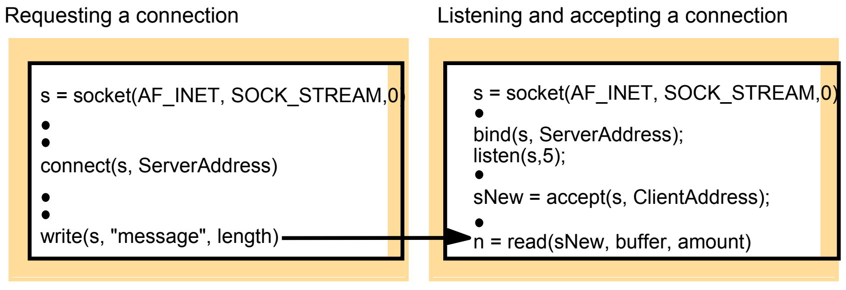

Server (running on hostid)
Client
create socket, port=x, for incoming request:
welcomeSocket = ServerSocket()
wait for incoming connection request
connectionSocket = welcomeSocket.accept()
TCP connection setup
create socket, connect to hostid, port=x
clientSocket = Socket()
send request using clientSocket
read request from connectionSocket
write reply to connectionSocket
read reply from clientSocket
close connectionSocket
close clientSocket

Berkeley Sockets (2)



❒ Connection-oriented communication pattern using sockets.

Sockets used for streams



```
s = socket(AF_INET, SOCK_STREAM,0)
•
•
connect(s, ServerAddress)
•
•
write(s, "message", length)
```

```
s = socket(AF_INET, SOCK_STREAM,0)
•
bind(s, ServerAddress);
listen(s,5);
•
sNew = accept(s, ClientAddress);
•
n = read(sNew, buffer, amount)
```

ServerAddress and *ClientAddress* are socket addresses

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.

Create input stream attached to socket

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

```
sentence = inFromUser.readLine();
```

Send line to server

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

Read line from server

```
modifiedSentence = inFromServer.readLine();

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

clientSocket.close();

 }
}
```

Example: Java server (TCP)

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

class TCPServer {

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

Create welcoming socket at port 6789

```
    ServerSocket welcomeSocket = new ServerSocket(6789);

    while(true) {
```

Wait, on welcoming socket for contact by client

```
        Socket connectionSocket = welcomeSocket.accept();
```

Create input stream, attached to socket

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

Example: Java server (TCP), cont

Create output stream, attached to socket

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

Read in line from socket

```
clientSentence = inFromClient.readLine();

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

Write out line to socket

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

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

Socket programming with UDP

UDP: no "connection" between client and server

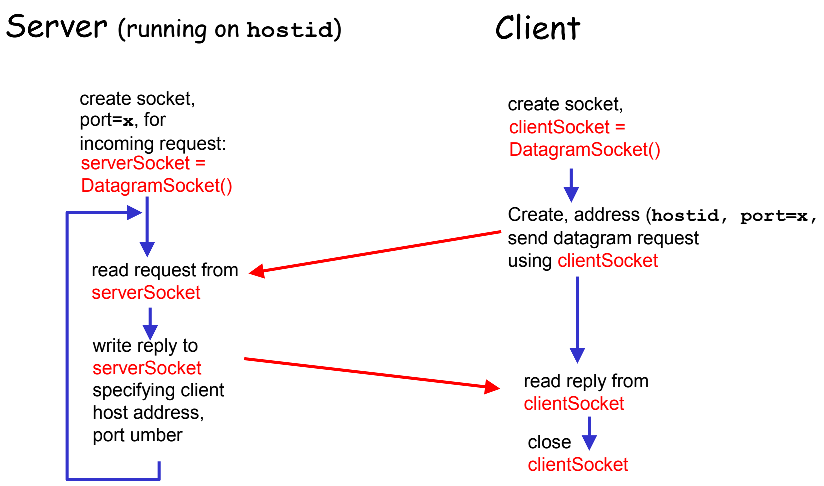
- ❒ no handshaking
- ❒ sender explicitly attaches IP address and port of destination
- ❒ server must extract IP address, port of sender from received datagram

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

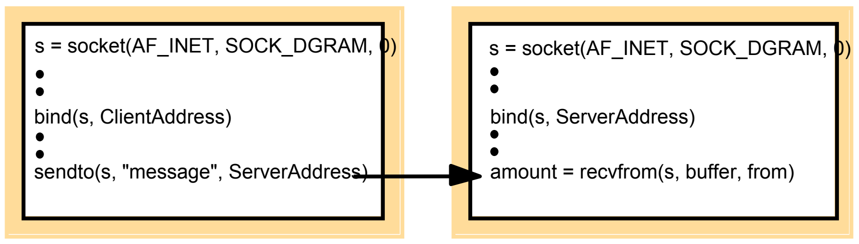
Client/server socket interaction: UDP


Server (running on **hostid**)
Client
create socket, port=**x**, for incoming request: serverSocket = DatagramSocket()
create socket, clientSocket = DatagramSocket()
Create, address (**hostid, port=x**, send datagram request using clientSocket
read request from serverSocket
write reply to serverSocket specifying client host address, port umber
read reply from clientSocket
close clientSocket

Sockets used for datagrams

Sending a message

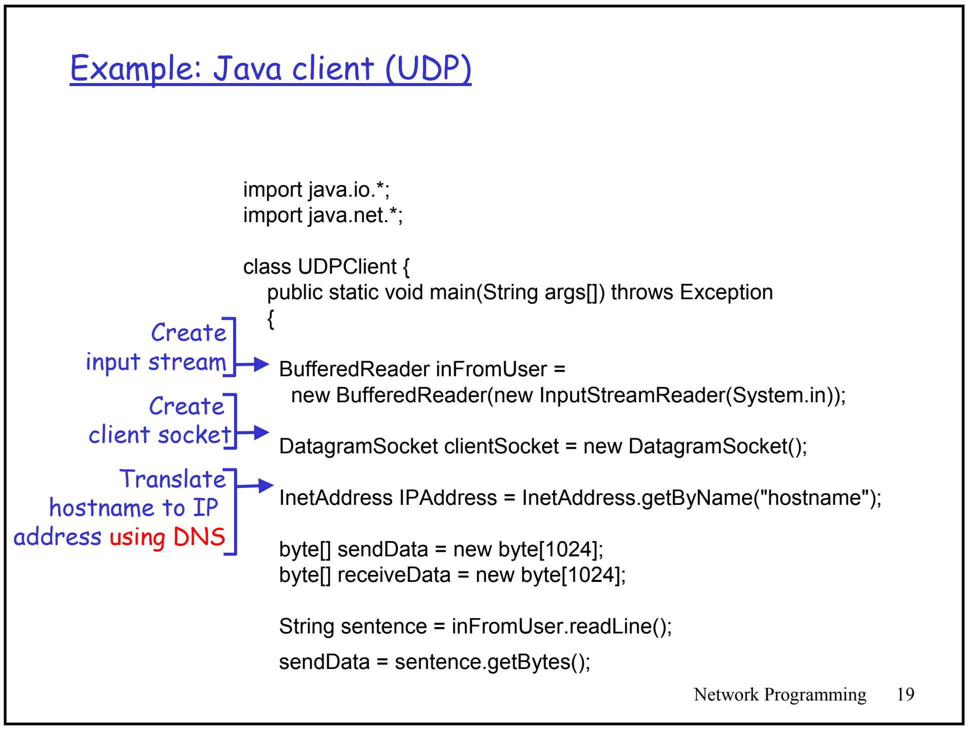
Receiving a message



```
s = socket(AF_INET, SOCK_DGRAM, 0)
•
•
bind(s, ClientAddress)
•
•
sendto(s, "message", ServerAddress)
```

```
s = socket(AF_INET, SOCK_DGRAM, 0)
•
•
bind(s, ServerAddress)
•
•
amount = recvfrom(s, buffer, from)
```

ServerAddress and *ClientAddress* are socket addresses



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

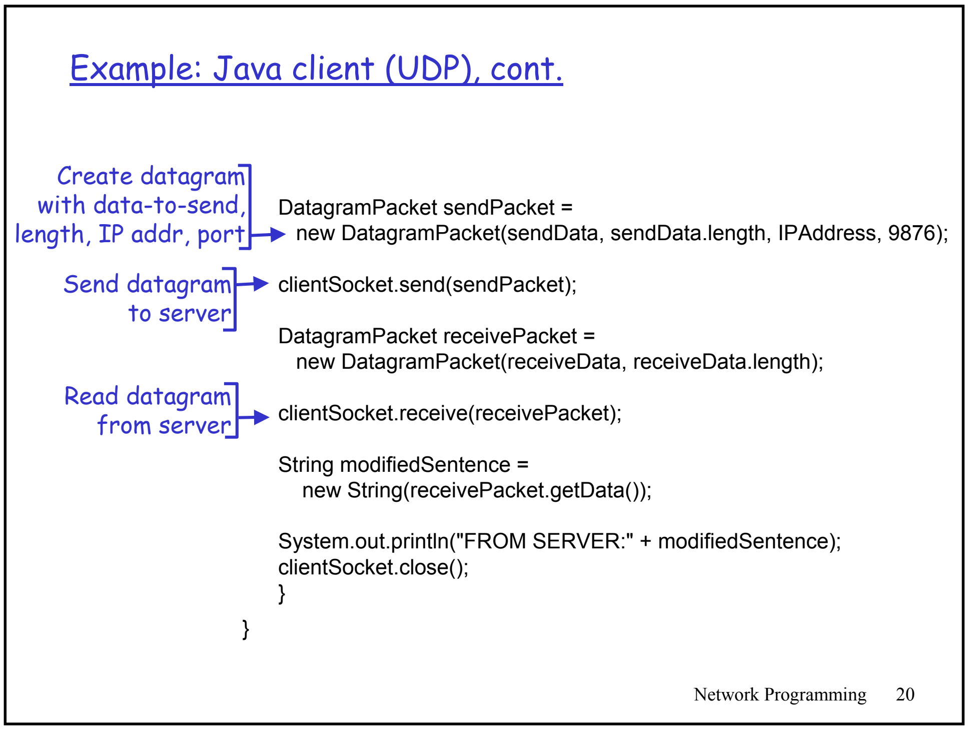
```
      DatagramSocket clientSocket = new DatagramSocket();
```

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