

Chapter 2

Application Layer

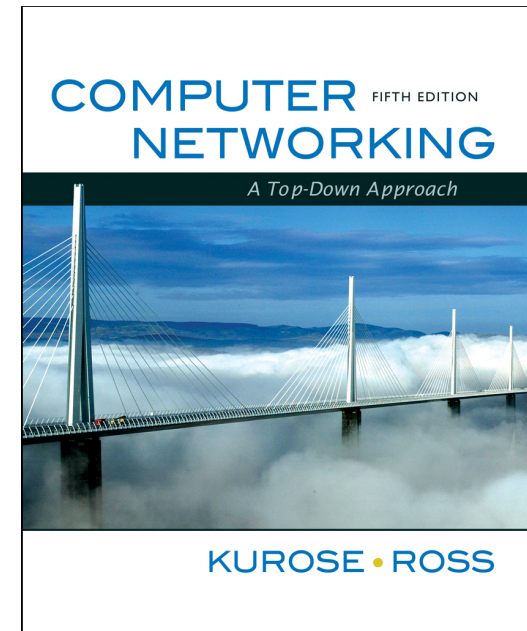
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*Computer Networking:
A Top Down Approach,
5th edition.*
Jim Kurose, Keith Ross
Addison-Wesley, April
2009.

The Bare minimum

- ❖ To code a socket, you will need at least
 - ACCEPT: *block and wait* for CONNECT PKT
 - CONNECT: *establish* a connection
 - RECEIVE: *block and wait* for a SEND PKT
 - SEND: *actually sending* a PKT on the channel
 - DISCONNECT: *putting an end*

- ❖ These are the functions you'll see
 - C, JAVA, for any connection-oriented transport

A first example

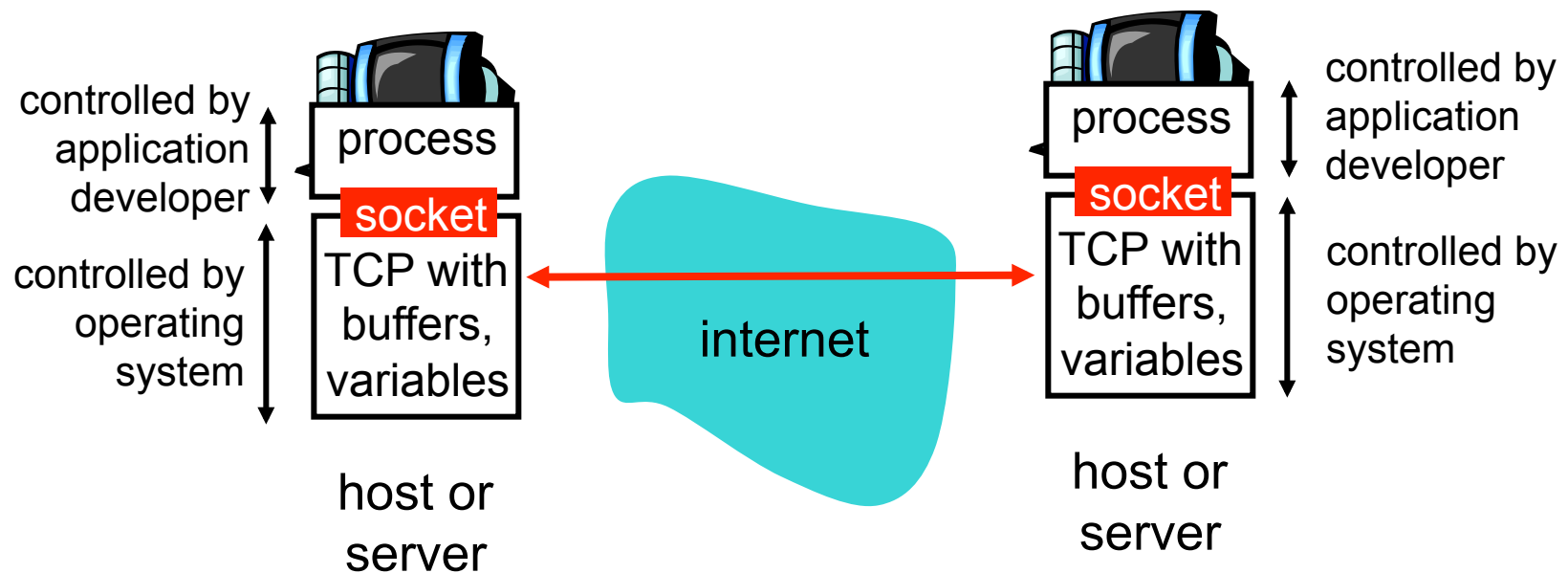
❖ How does it work

- Server LISTEN, wait for CONNECT PKT
- Client send a CONNECT message, and then block until received the answer from server
- Once server received CONNECT message, it becomes unblocked, send an answer, and becomes blocked again in READ
- Once the client received the answer, it becomes unblocked, SENDS a request message, and block again in READ
- The server finally answer with data, and close

Socket-programming using TCP

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

TCP service: reliable transfer of *bytes* from one process to another



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 (more in Chap 3)

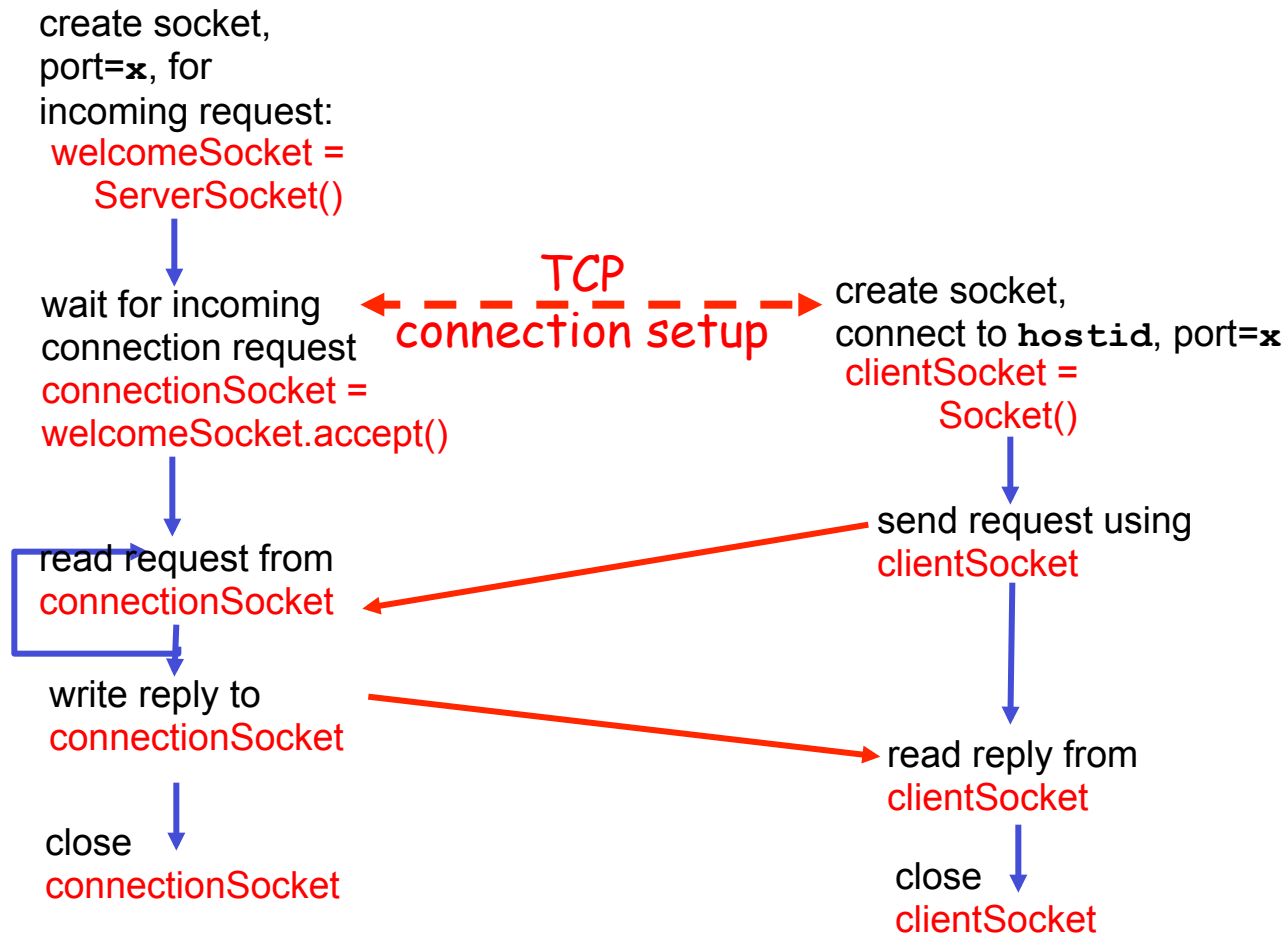
application viewpoint

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

Client/server socket interaction: TCP

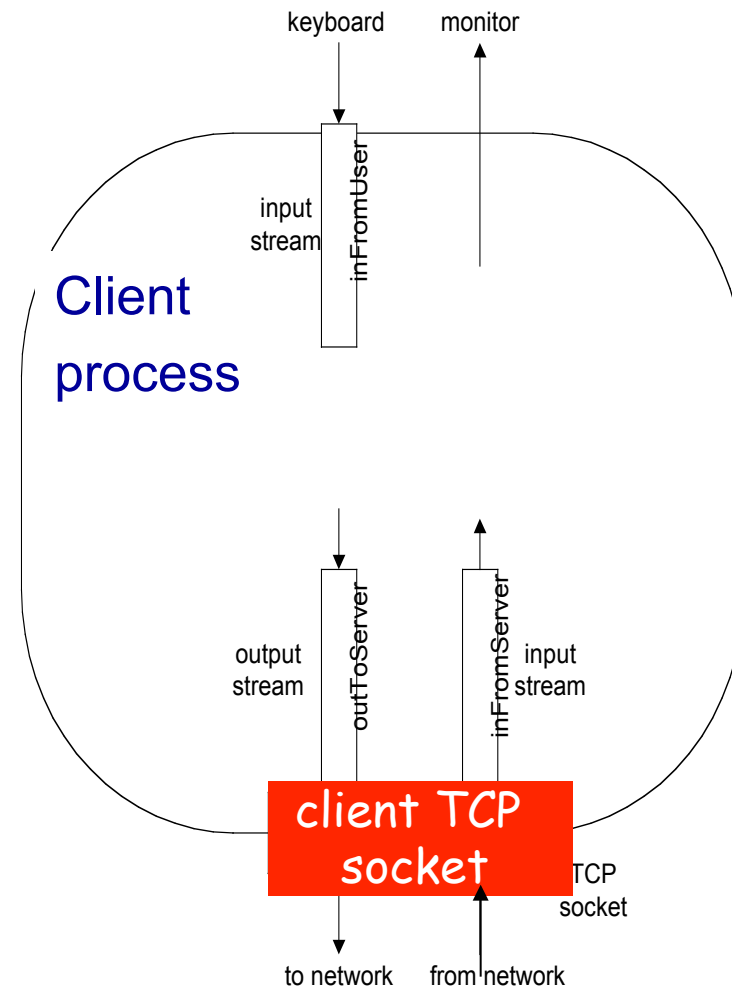
Server (running on `hostid`)

Client



Stream jargon

- ❖ **stream** is a sequence of characters that flow into or out of a process.
- ❖ **input stream** is attached to some input source for the process, e.g., keyboard or socket.
- ❖ **output stream** is attached to an output source, e.g., monitor or socket.



Socket programming with TCP

Example client-server app:

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

Example: Java client (TCP)

```
import java.io.*;
import java.net.*; ← This package defines Socket()
                    and ServerSocket() classes
class TCPClient {
```

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

```
        String sentence;
        String modifiedSentence;
```

create
input stream →

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

create
clientSocket object
of type Socket,
connect to server →

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

create
output stream
attached to socket →

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

server name,
e.g., www.umass.edu
server port #

Example: Java client (TCP), cont.

```
        create  
        input stream → BufferedReader inFromServer =  
        attached to socket → 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);  
  
        close socket → clientSocket.close();  
        (clean up behind yourself!)  
  
        }  
    }
```

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);
```

wait, on welcoming
socket accept() method
for client contact create,
new socket on return

```
        while(true) {
```

```
            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

Chapter 2: Application layer

2.1 Principles of network applications

2.2 Web and HTTP

2.3 FTP

2.4 Electronic Mail

- SMTP, POP3, IMAP

2.5 DNS

2.6 P2P applications

2.7 Socket programming with TCP

2.8 Socket programming with UDP

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`)

Client

create socket,
port= x.
`serverSocket =
DatagramSocket()`

read datagram from
`serverSocket`

write reply to
`serverSocket`
specifying
client address,
port number

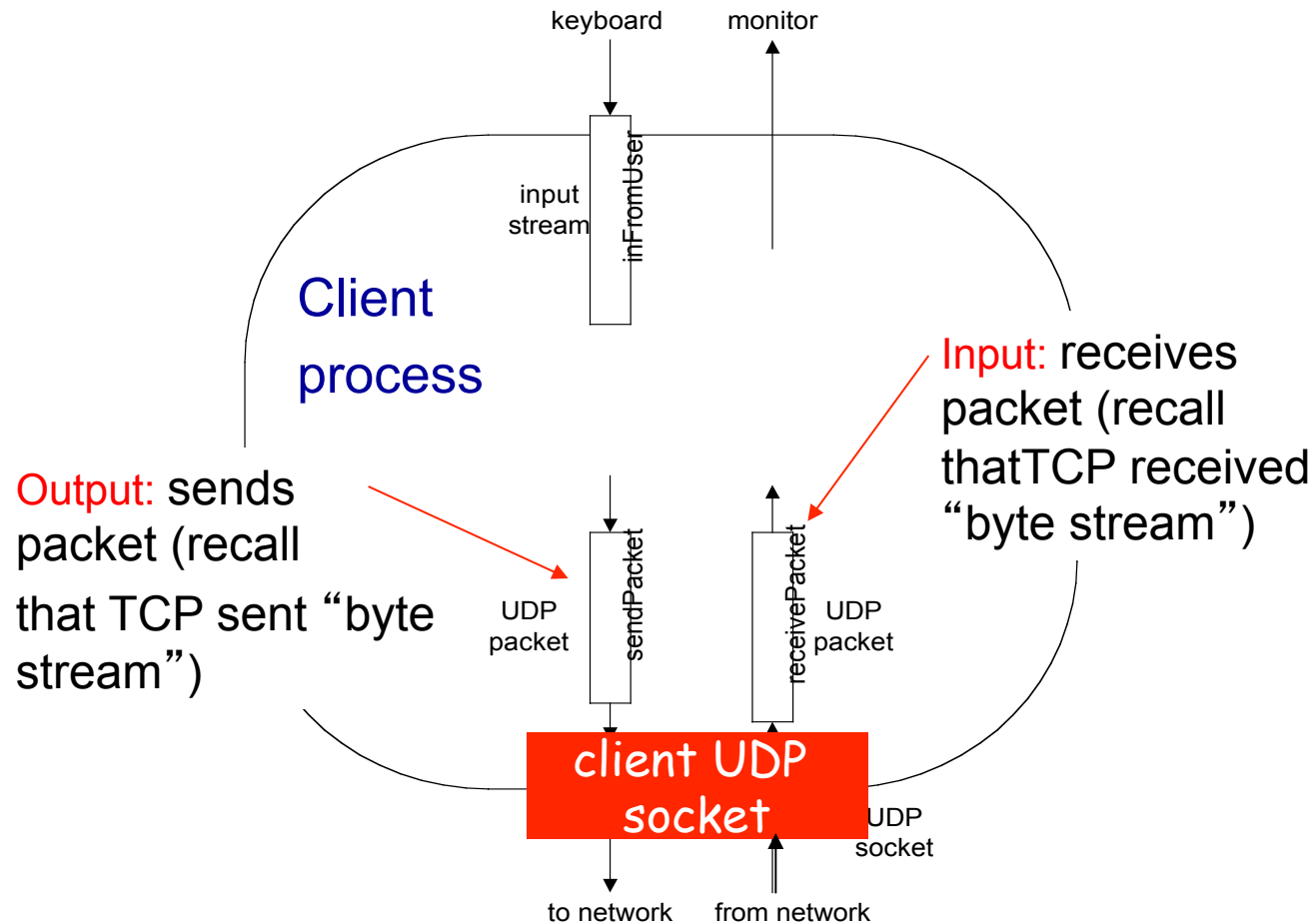
create socket,
`clientSocket =
DatagramSocket()`

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

read datagram from
`clientSocket`

close
`clientSocket`

Example: Java client (UDP)



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);  
  
read datagram  
from server } DatagramPacket receivePacket =  
              } new DatagramPacket(receiveData, receiveData.length);  
              } 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

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+ (Bonus) Same with C

The Bare minimum

- ❖ To code a socket, you will need at least
 - ACCEPT: *block and wait* for CONNECT PKT
 - CONNECT: *establish* a connection
 - RECEIVE: *block and wait* for a SEND PKT
 - SEND: *actually sending* a PKT on the channel
 - DISCONNECT: *putting an end*

- ❖ These are the functions you'll see
 - C, JAVA, etc.

Socket functions overview (C)

- ❖ For TCP with C, the primitives are:
 - **SOCKET**
 - **BIND**
 - **LISTEN:**
 - **ACCEPT:** *block and wait* for CONNECT PKT
 - **CONNECT:** *establish* a connection
 - **RECEIVE:** *block and wait* for a SEND PKT
 - **SEND:** *actually sending* a PKT on the channel
 - **DISCONNECT:** *putting an end*

Socket Creation in C: socket

- ❖ `int s = socket(domain, type, protocol);`
 - `s`: socket descriptor, an integer
 - `domain`: integer, communication domain
 - e.g., `PF_INET` (IPv4 protocol) - typically used
 - `type`: communication type
 - `SOCK_STREAM`: reliable, 2-way, connection-based service
 - `SOCK_DGRAM`: unreliable, connectionless,
 - other values: need root permission, rarely used, or obsolete
 - `protocol`: specifies protocol - usually set to 0
- ❖ NOTE: socket call does not specify where data will be coming from, nor where it will be going to - it just creates the interface!

The bind function

- ❖ associates and (can exclusively) reserves a port for use by the socket
- ❖ `int status = bind(sockid, &addrport, size);`
 - `status`: error status, = -1 if bind failed
 - `sockid`: integer, socket descriptor
 - `addrport`: struct `sockaddr`, the (IP) address and port of the machine (address usually set to `INADDR_ANY` - chooses a local address)
 - `size`: the size (in bytes) of the `addrport` structure
- ❖ `bind` can be skipped for both types of sockets. When and why?

Skipping the bind

❖ SOCK_DGRAM:

- if only sending, no need to bind. The OS finds a port each time the socket sends a pkt
- if receiving, need to bind

❖ SOCK_STREAM:

- At the client - determined during conn. setup
- don't need to know port sending from (during connection setup, receiving end is informed of port)

Connection Setup (SOCK_STREAM)

- ❖ Recall: no connection setup for SOCK_DGRAM
- ❖ A connection occurs between two kinds of participants
 - passive: waits for an active participant to request connection
 - active: initiates connection request to passive side
- ❖ Once connection is established, passive and active participants are “similar”
 - both can send & receive data
 - either can terminate the connection

Connection setup cont' d

❖ Passive participant

- step 1: **listen** (for incoming requests)
- step 3: **accept** (a request)
- step 4: data transfer

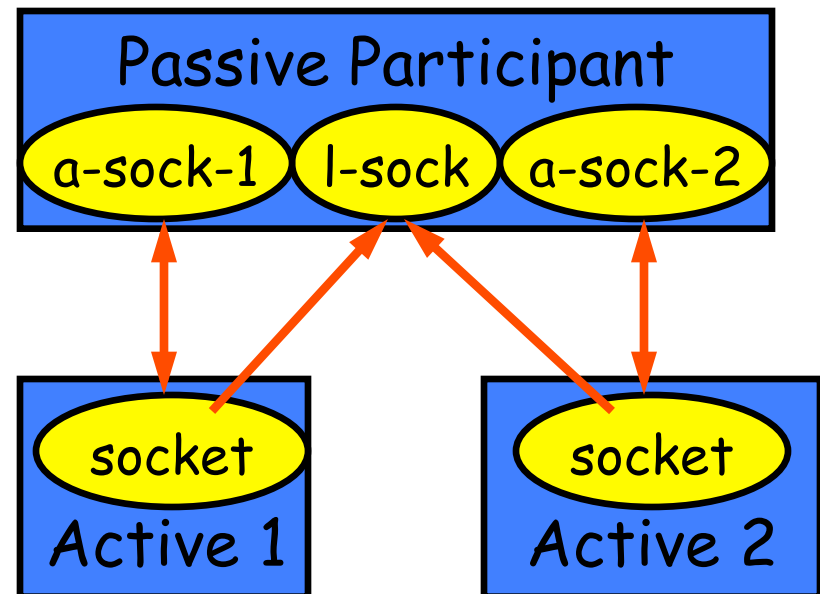
❖ The accepted connection is on a new socket

❖ The old socket continues to listen for other active participants

❖ Why?

❖ Active participant

- step 2: request & establish **connection**
- step 4: data transfer



Connection setup: listen & accept

- ❖ Called by passive participant
- ❖ `int status = listen(sock, queuelen);`
 - `status`: 0 if listening, -1 if error
 - `sock`: integer, socket descriptor
 - `queuelen`: integer, # of active participants that can “wait” for a connection
 - `listen` is **non-blocking**: returns immediately
- ❖ `int s = accept(sock, &name, &namelen);`
 - `s`: integer, the new socket (used for data-transfer)
 - `sock`: integer, the orig. socket (being listened on)
 - `name`: struct `sockaddr`, address of the active participant
 - `namelen`: `sizeof(name)`: value/result parameter
 - must be set appropriately before call
 - adjusted by OS upon return
 - `accept` is **blocking**: waits for connection before returning

connect call

- ❖ `int status = connect(sock, &name, namelen);`
 - `status`: 0 if successful connect, -1 otherwise
 - `sock`: integer, socket to be used in connection
 - `name`: struct `sockaddr`: address of passive participant
 - `namelen`: integer, `sizeof(name)`
- ❖ connect is **blocking**

Sending / Receiving Data

- ❖ With a connection (SOCK_STREAM):
 - `int count = send(sock, &buf, len, flags);`
 - `count`: # bytes transmitted (-1 if error)
 - `buf`: `char[]`, buffer to be transmitted
 - `len`: integer, length of buffer (in bytes) to transmit
 - `flags`: integer, special options, usually just 0
 - `int count = recv(sock, &buf, len, flags);`
 - `count`: # bytes received (-1 if error)
 - `buf`: `void[]`, stores received bytes
 - `len`: # bytes received
 - `flags`: integer, special options, usually just 0
 - Calls are **blocking** [returns only after data is sent (to socket buf) / received]

Sending / Receiving Data (cont' d)

- ❖ Without a connection (SOCK_DGRAM):
 - `int count = sendto(sock, &buf, len, flags, &addr, addrlen);`
 - `count, sock, buf, len, flags`: same as `send`
 - `addr`: `struct sockaddr`, address of the destination
 - `addrlen`: `sizeof(addr)`
 - `int count = recvfrom(sock, &buf, len, flags, &addr, &addrlen);`
 - `count, sock, buf, len, flags`: same as `recv`
 - `addr`: `struct sockaddr`, address of the source
 - `addrlen`: `sizeof(addr)`: value/result parameter
- ❖ Calls are **blocking** [returns only after data is sent (to socket `buf`) / received]

close

- ❖ When finished using a socket, the socket should be closed:
- ❖ `status = close(s);`
 - status: 0 if successful, -1 if error
 - s: the file descriptor (socket being closed)
- ❖ Closing a socket
 - closes a connection (for SOCK_STREAM)
 - frees up the port used by the socket

The struct sockaddr

❖ The generic:

```
struct sockaddr {  
    u_short sa_family;  
    char sa_data[14];  
};
```

- `sa_family`
 - specifies which address family is being used
 - determines how the remaining 14 bytes are used

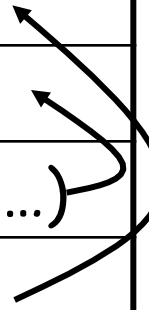
❖ The Internet-specific:

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

- `sin_family` = `AF_INET`
- `sin_port`: port # (0-65535)
- `sin_addr`: IP-address
- `sin_zero`: unused

TCP - Serial Model

Client Side	Server Side
<code>sd=socket(type)</code>	<code>sd=socket(type)</code>
	<code>bind(sd,port)</code>
	<code>listen(sd,len)</code>
<code>connect(sd,dest)</code>	<code>new_sd=accept(sd)</code>
<code>write(sd,...) / send(sd,...)</code>	<code>read(new_sd,...)/recv(new_sd)</code>
<code>read(sd,...)/recv(sd,...)</code>	<code>write(new_sd,...) / send(new_sd,...)</code>
<code>close(sd)</code>	<code>close(new_sd)</code>



TCP - Parallel Model

Client Side	Server Side
<code>sd=socket(type)</code>	<code>sd=socket(type)</code>
	<code>bind(sd,port)</code>
	<code>listen(sd,len)</code>
<code>connect(sd,dest)</code>	<code>new_sd=accept(sd)</code>
	Create another process (e.g., fork)
	<code>close(sd)</code> <code>close(new_sd)</code>
<code>write(sd,...)</code>	<code>read(new_sd,...)</code>
<code>read(sd,...)</code>	<code>write(new_sd,...)</code>
<code>close(sd)</code>	<code>close(new_sd)</code>
	<code>exit()</code>

UDP - Serial Model

Client Side	Server Side
<code>sd=socket(type)</code>	<code>sd=socket(type)</code>
	<code>bind(sd,port)</code>
<code>connect(sd,dest)</code>	
<code>write(sd,...)</code>	<code>recvfrom(sd,...)</code>
<code>read(sd,...)</code>	<code>sendto(sd,...)</code>
<code>close(sd)</code>	<code>close(sd)</code>

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+ (Bonus) Same with C

+ (Bonus) A few more functions

Address and port byte-ordering

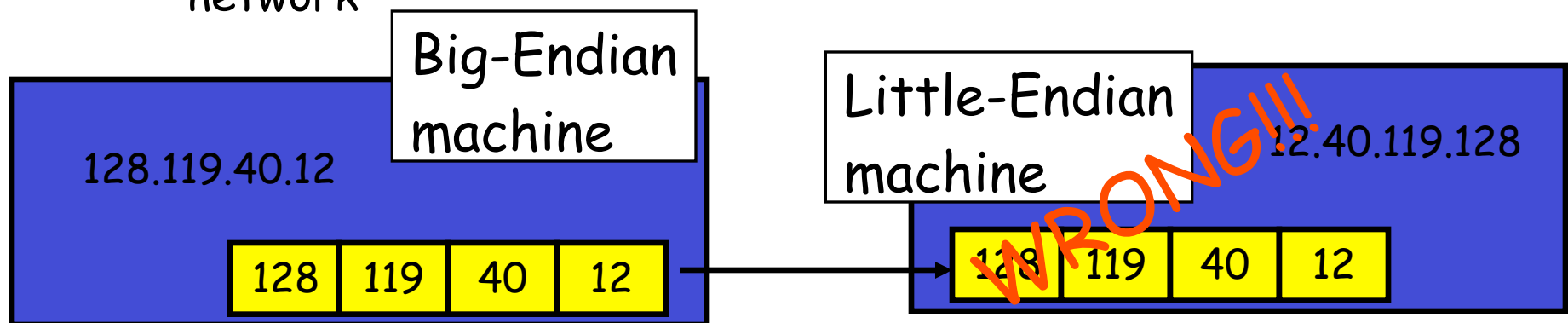
❖ Address and port are stored as integers

- u_short sin_port; (16 bit)
- in_addr sin_addr; (32 bit)

```
struct in_addr {  
    u_long s_addr;  
};
```

□ Problem:

- different machines / OS' s use different word orderings
 - little-endian: lower bytes first
 - big-endian: higher bytes first
- these machines may communicate with one another over the network



Solution: Network Byte-Ordering

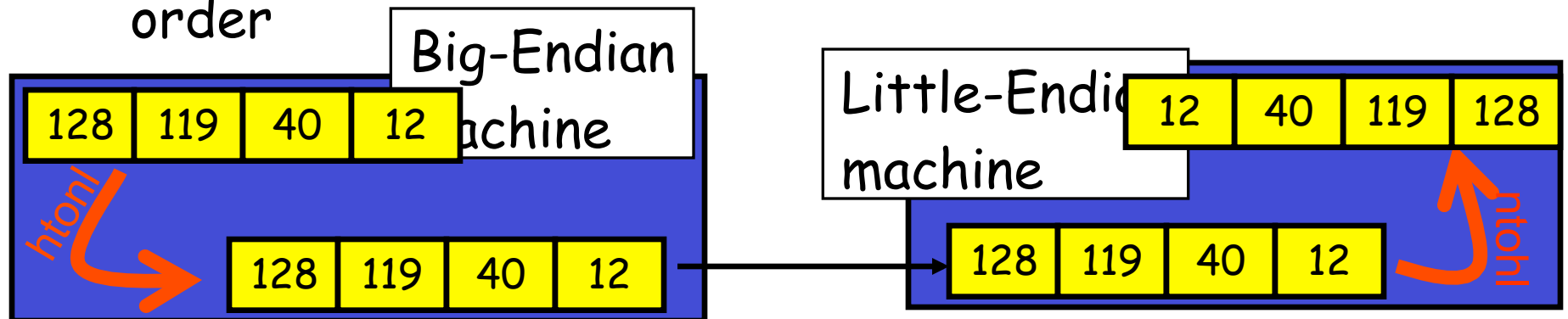
❖ Defs:

- Host Byte-Ordering: the byte ordering used by a host (big or little)
 - Network Byte-Ordering: the byte ordering used by the network - always big-endian
- ❖ Any words sent through the network should be converted to Network Byte-Order prior to transmission (and back to Host Byte-Order once received)
- ❖ Q: should the socket perform the conversion automatically?
- Q: Given big-endian machines don't need conversion routines and little-endian machines do, how do we avoid writing two versions of code?

UNIX's byte-ordering funcs

- ❖ `u_long htonl(u_long x);`
- ❖ `u_long ntohl(u_long x);`
- ❖ `u_short htons(u_short x);`
- ❖ `u_short ntohs(u_short x);`

- ❑ On big-endian machines, these routines do nothing
- ❑ On little-endian machines, they reverse the byte order



- ❑ Same code would have worked regardless of endianness of the two machines

Dealing with blocking calls

- ❖ Many of the functions we saw block until a certain event
 - accept: until a connection comes in
 - connect: until the connection is established
 - recv, recvfrom: until a packet (of data) is received
 - send, sendto: until data is pushed into socket's buffer
 - Q: why not until received?
- ❖ For simple programs, blocking is convenient
- ❖ What about more complex programs?
 - multiple connections
 - simultaneous sends and receives
 - simultaneously doing non-networking processing

Dealing w/ blocking (cont' d)

❖ Options:

- create multi-process or multi-threaded code
- turn off the blocking feature (e.g., using the `fcntl` file-descriptor control function)
- use the `select` function call.

Other useful functions

- ❖ `bzero(char* c, int n)`: 0's n bytes starting at c
- ❖ `gethostname(char *name, int len)`: gets the name of the current host
- ❖ `gethostbyaddr(char *addr, int len, int type)`: converts IP hostname to structure containing long integer
- ❖ `inet_addr(const char *cp)`: converts dotted-decimal char-string to long integer
- ❖ `inet_ntoa(const struct in_addr in)`: converts long to dotted-decimal notation
- ❖ `read()`, `write()`
- ❖ Warning: check function assumptions about byte-ordering (host or network). Often, they assume parameters / return solutions in network byte-order

Release of ports

- ❖ Sometimes, a “rough” exit from a program (e.g., ctrl-c) does not properly free up a port
- ❖ Eventually (after a few minutes), the port will be freed
- ❖ To reduce the likelihood of this problem, include the following code:

```
#include <signal.h>
```

```
void cleanExit(){exit(0);}
```

- in socket code:

```
signal(SIGTERM, cleanExit);
```

```
signal(SIGINT, cleanExit);
```

Final Thoughts

- ❖ Make sure to #include the header files that define used functions
- ❖ Additional info:
 - Ross and Kurose, Computer Networking A Top-Down Approach
 - Comer, Internetworking with TCP/IP, ch. 21
 - Comer and Stevens, Internetworking with TCP/IP - Vol. 3
 - Beej's Guide to Network Programming - <http://www.beej.us/guide/bgnet/>
 - man-pages

Chapter 2: Summary

our study of network apps now complete!

- ❖ application architectures
 - client-server
 - P2P
 - hybrid
- ❖ application service requirements:
 - reliability, bandwidth, delay
- ❖ Internet transport service model
 - connection-oriented, reliable: TCP
 - unreliable, datagrams: UDP
- ❖ specific protocols:
 - HTTP
 - FTP
 - SMTP, POP, IMAP
 - DNS
 - P2P: BitTorrent, Skype
- ❖ socket programming

Chapter 2: Summary

most importantly: learned about protocols

- ❖ typical request/reply message exchange:
 - client requests info or service
 - server responds with data, status code
- ❖ message formats:
 - headers: fields giving info about data
 - data: info being communicated

Important themes:

- ❖ control vs. data msgs
 - ❖ in-band, out-of-band
- ❖ centralized vs. decentralized
- ❖ stateless vs. stateful
- ❖ reliable vs. unreliable msg transfer
- ❖ “complexity at network edge”