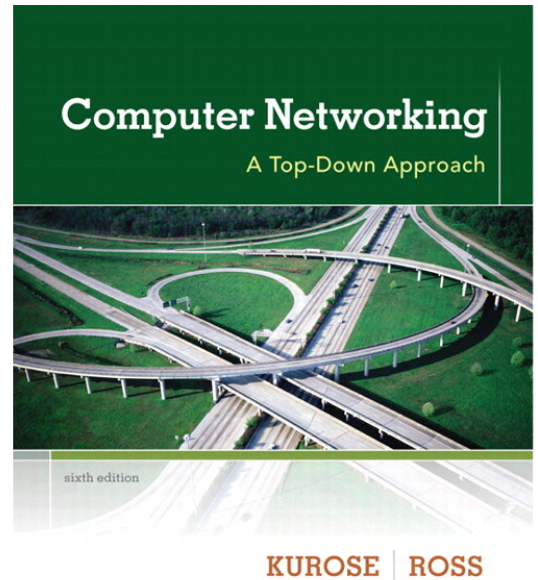
CSEE 4119 Computer Networks

Chapter 2
Application (5/5)



Chapter 3 outline

3.1 Transport-layer services

3.2 Multiplexing and demultiplexing

3.3 Connectionless transport: UDP

3.4 Principles of reliable data transfer

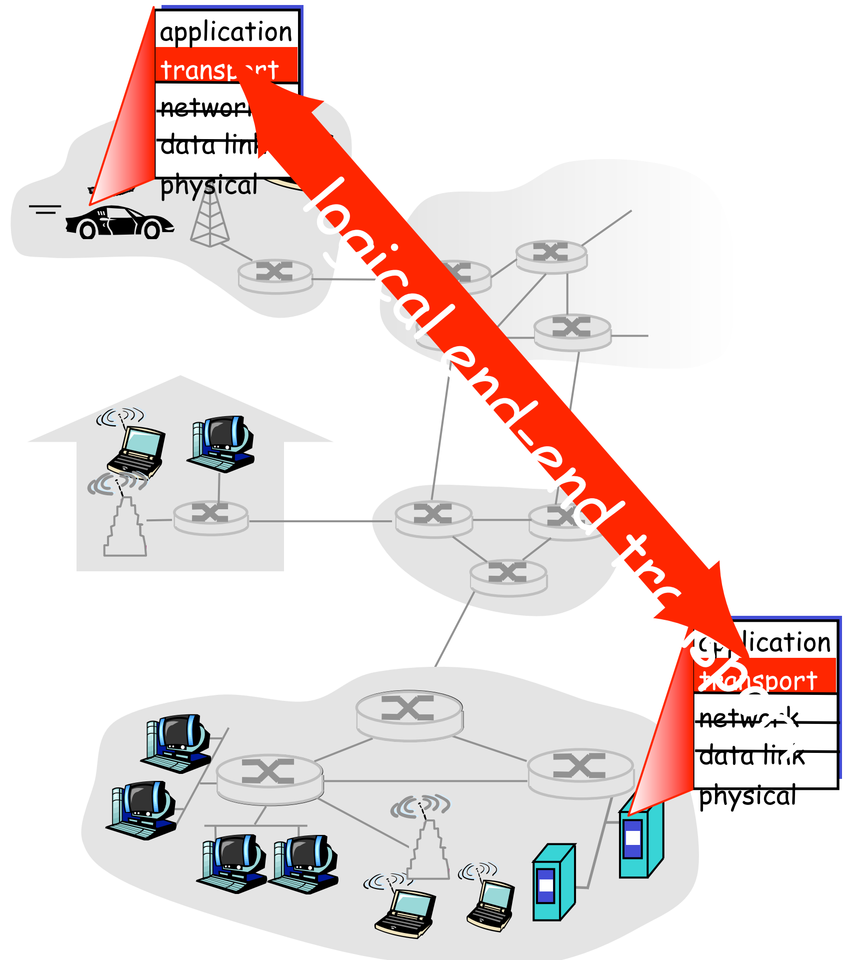
3.5 Connection-oriented transport: TCP
- segment structure
- reliable data transfer
- flow control
- connection management

3.6 Principles of congestion control

3.7 TCP congestion control

Transport services and protocols

- provide *logical communication* between app processes running on different hosts
- transport protocols run in end systems
  - send side: breaks app messages into segments, passes to network layer
  - rcv side: reassembles segments into messages, passes to app layer
- more than one transport protocol available to apps
  - Internet: TCP and UDP



Transport vs. network layer

- *network layer:* logical communication between hosts
- *transport layer:* logical communication between processes
  - relies on, enhances, network layer services

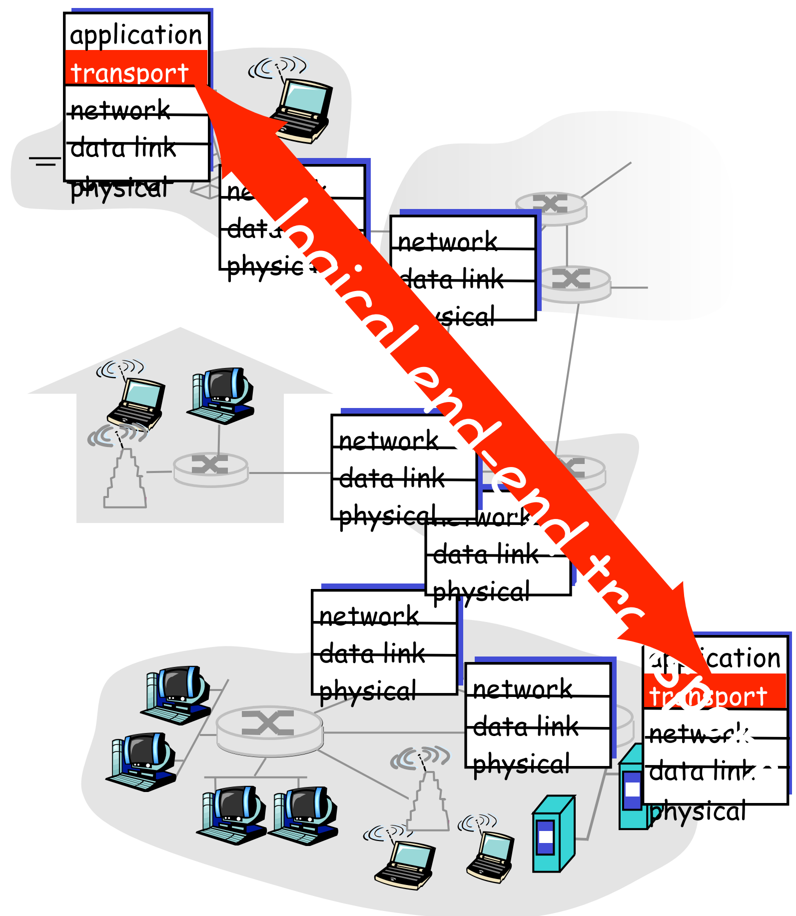
Household analogy:

12 kids sending letters to 12 kids

- processes = kids
- app messages = letters in envelopes
- hosts = houses
- transport protocol = Ann and Bill who demux to in-house siblings
- network-layer protocol = postal service

Internet transport-layer protocols

- reliable, in-order delivery (TCP)
  - congestion control
  - flow control
  - connection setup
- unreliable, unordered delivery: UDP
  - no-frills extension of "best-effort" IP
- services not available:
  - delay guarantees
  - bandwidth guarantees



Chapter 3 outline

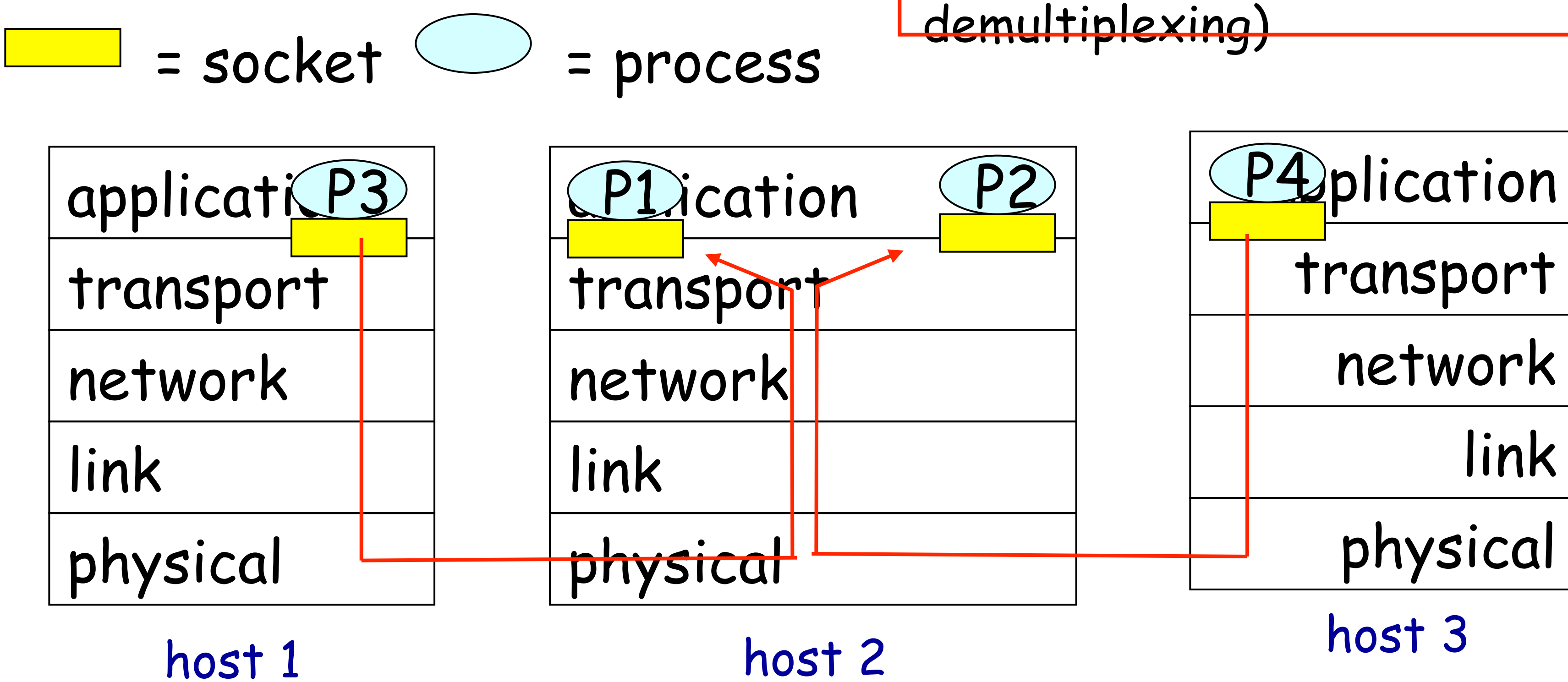
Multiplexing/demultiplexing

Demultiplexing at rcv host:

delivering received segments to correct socket

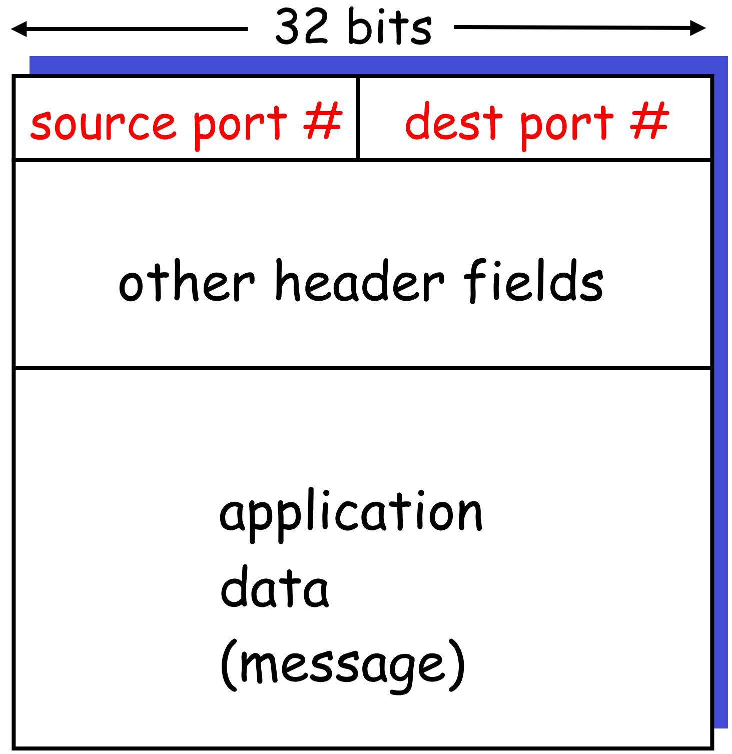
Multiplexing at send host:

gathering data from multiple sockets, enveloping data with header (later used for demultiplexing)



How demultiplexing works

- host receives IP datagrams
  - each datagram has source IP address, destination IP address
  - each datagram carries 1 transport-layer segment
  - each segment has source, destination port number
- host uses IP addresses & port numbers to direct segment to appropriate socket



TCP/UDP segment format

Connectionless demultiplexing

- *recall:* create sockets with host-local port numbers:

```
DatagramSocket mySocket1 = new
   DatagramSocket(12534);
DatagramSocket mySocket2 = new
   DatagramSocket(12535);
```

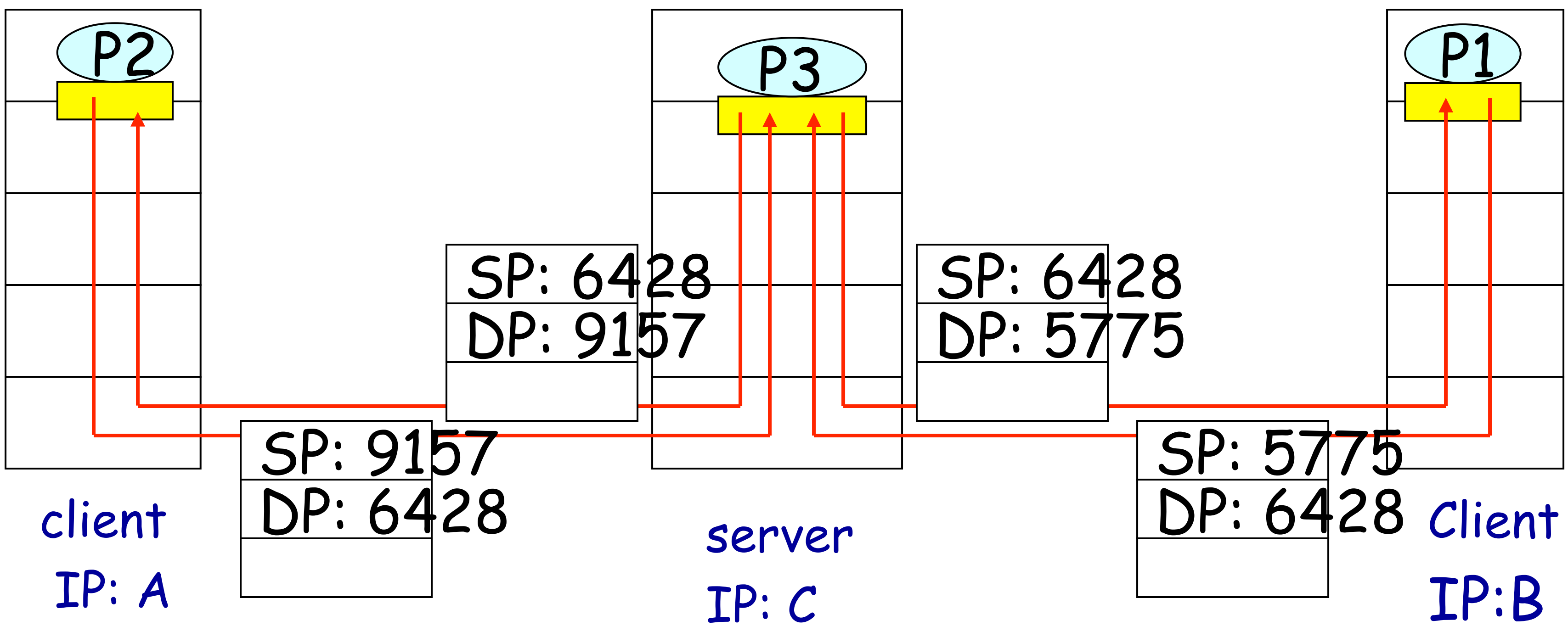
- *recall:* when creating datagram to send into UDP socket, must specify

(dest IP address, dest port number)

- when host receives UDP segment:
  - checks destination port number in segment
  - directs UDP segment to socket with that port number
- IP datagrams with different source IP addresses and/or source port numbers directed to same socket

Connectionless demux (cont)

```
DatagramSocket serverSocket = new DatagramSocket(6428);
```

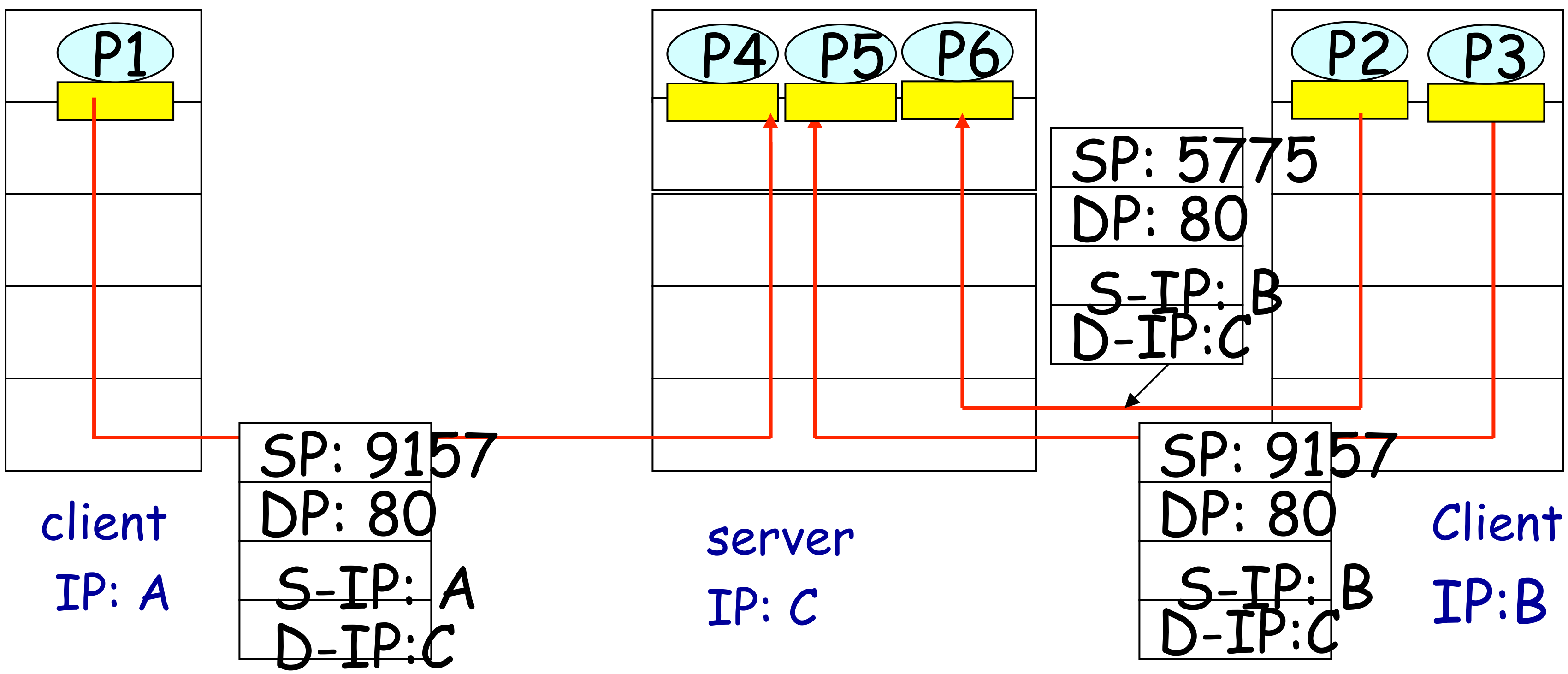


SP provides "return address"

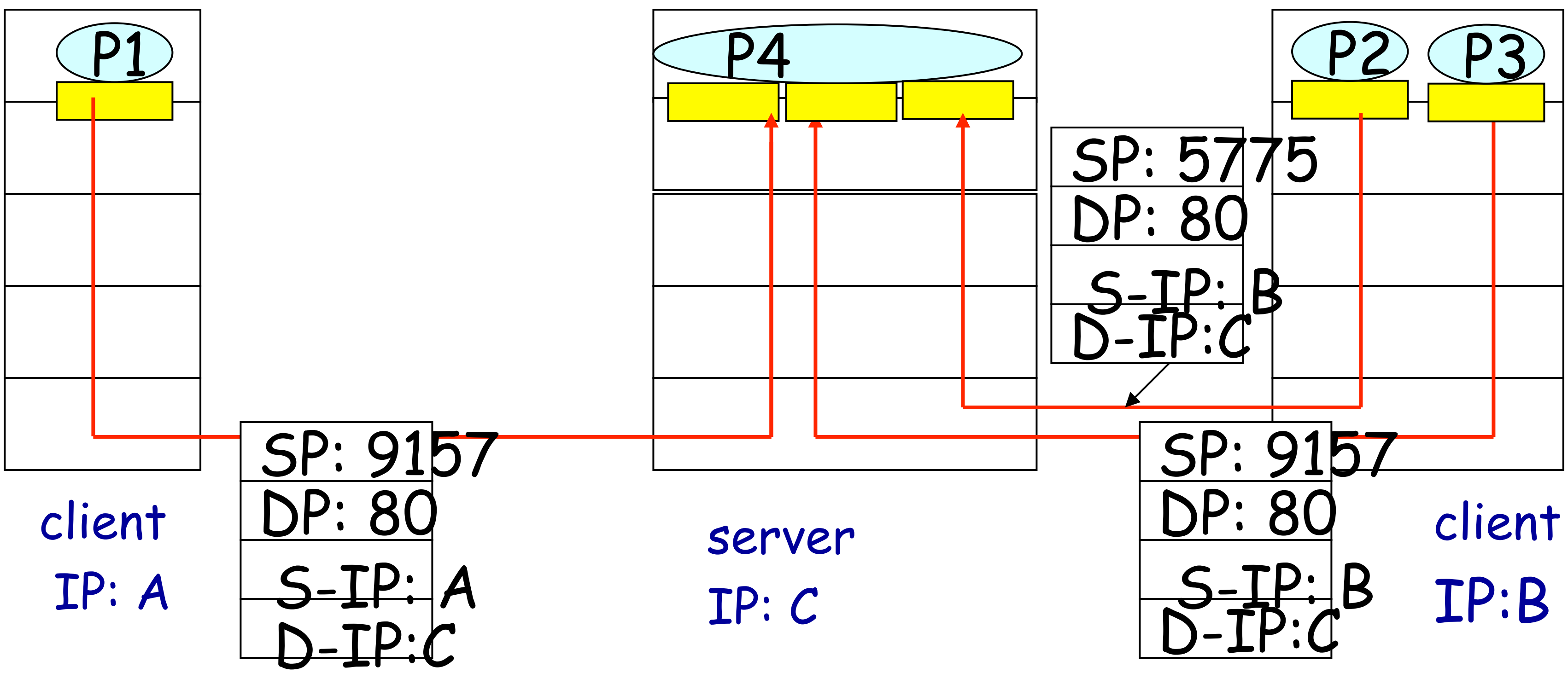
Connection-oriented demux

- TCP socket identified by 4-tuple:
  - source IP address
  - source port number
  - dest IP address
  - dest port number
- recv host uses all four values to direct segment to appropriate socket
- server host may support many simultaneous TCP sockets:
  - each socket identified by its own 4-tuple
- web servers have different sockets for each connecting client
  - non-persistent HTTP will have different socket for each request

Connection-oriented demux (cont)



Connection-oriented demux: Threaded Web Server



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

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

Socket API

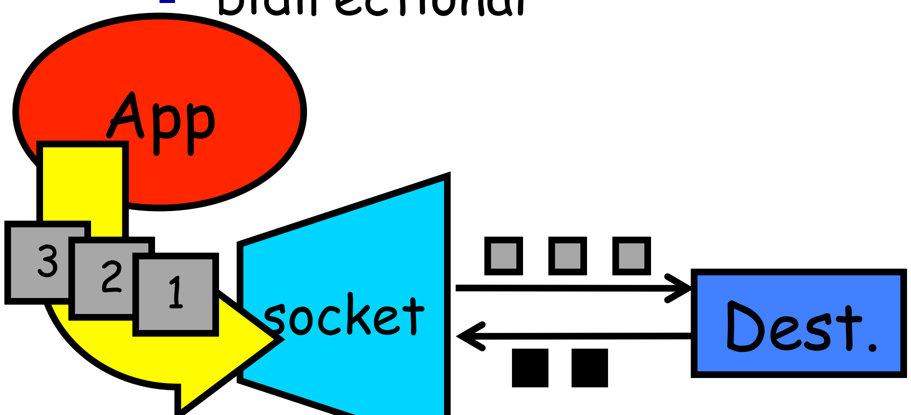
- introduced in BSD4.1 UNIX, 1981
- explicitly created, used, released by apps
- client/server paradigm
- two types of transport service via socket API:
  - unreliable datagram
  - reliable, byte stream-oriented

socket

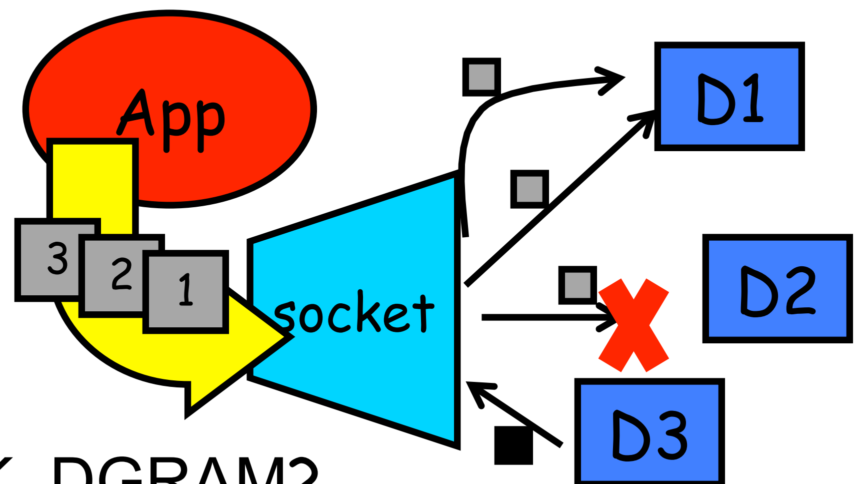
a *host-local*, *application-created*, *OS-controlled* interface (a "door") into which application process can both send and receive messages to/from another application process

Two essential types of sockets

- C: SOCK_STREAM
  JAVA: Socket
  - a.k.a. TCP
  - reliable delivery
  - in-order guaranteed
  - connection-oriented
  - bidirectional

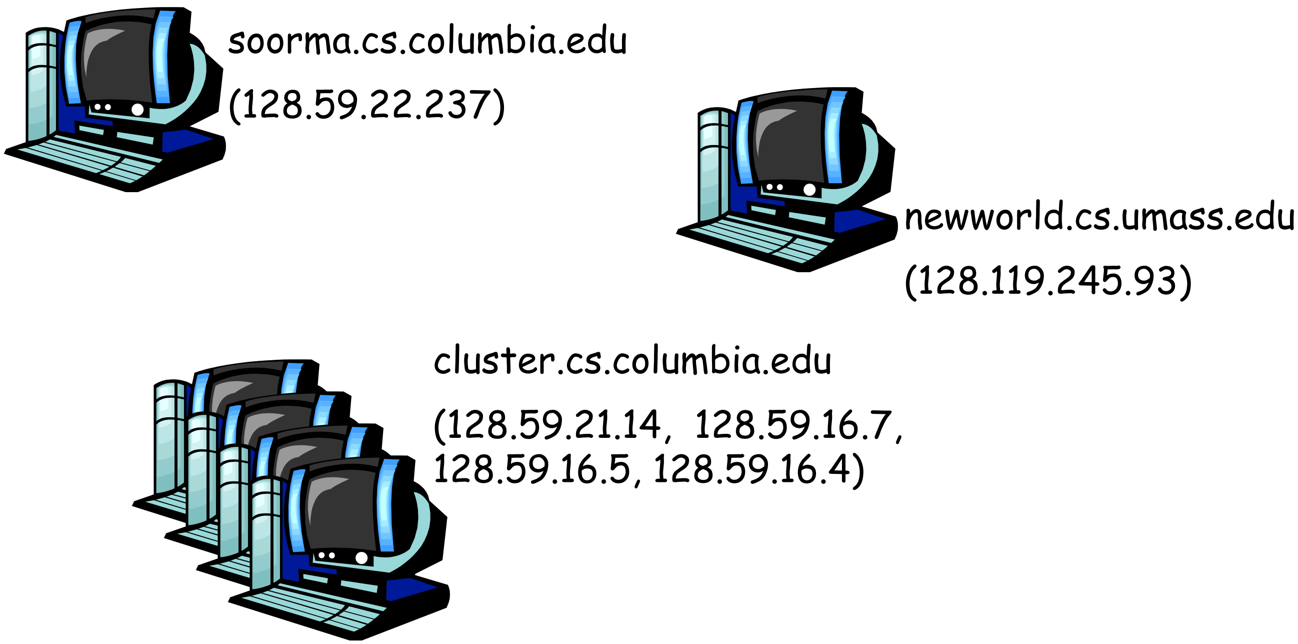


- C: SOCK_DGRAM
  JAVA: DatagramSocket
  - a.k.a. UDP
  - unreliable delivery
  - no order guarantees
  - no notion of "connection" – app includes dest. in packets
  - can send or receive



Q: why have type SOCK_DGRAM?

A Socket-eye view of the Internet



- Each host machine has an IP address
- When a packet arrives at a host

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

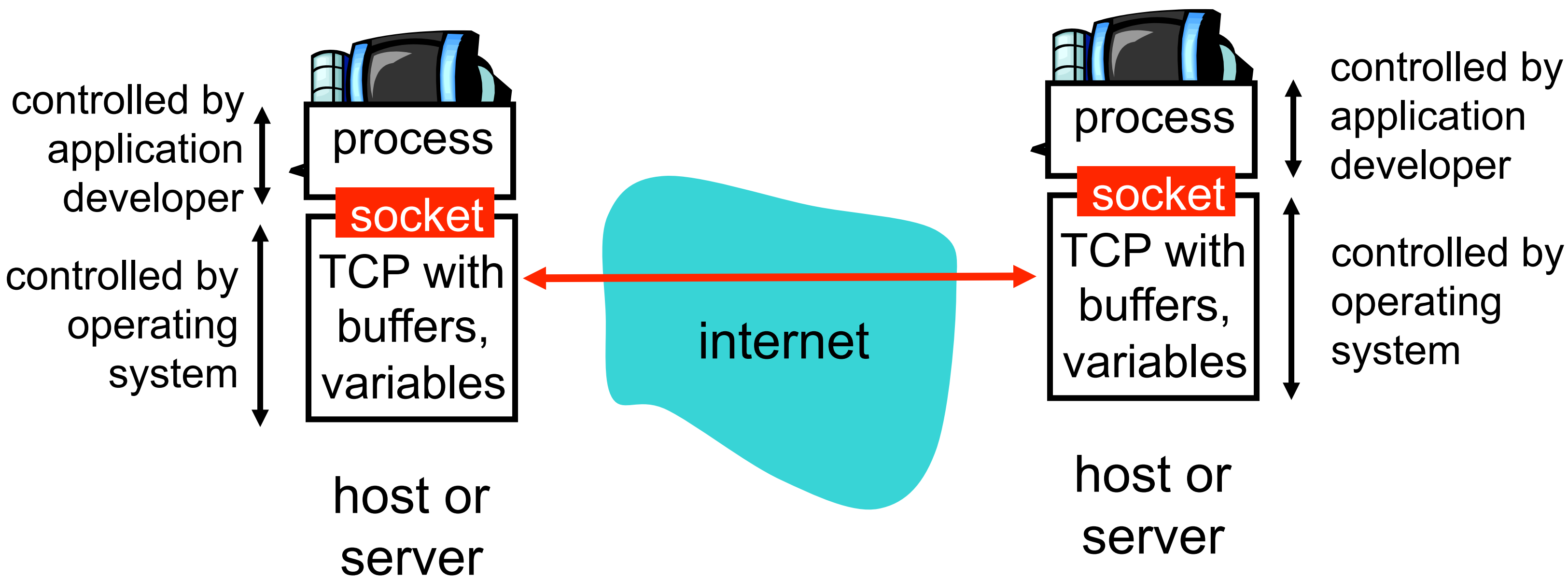
A first example

- 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:

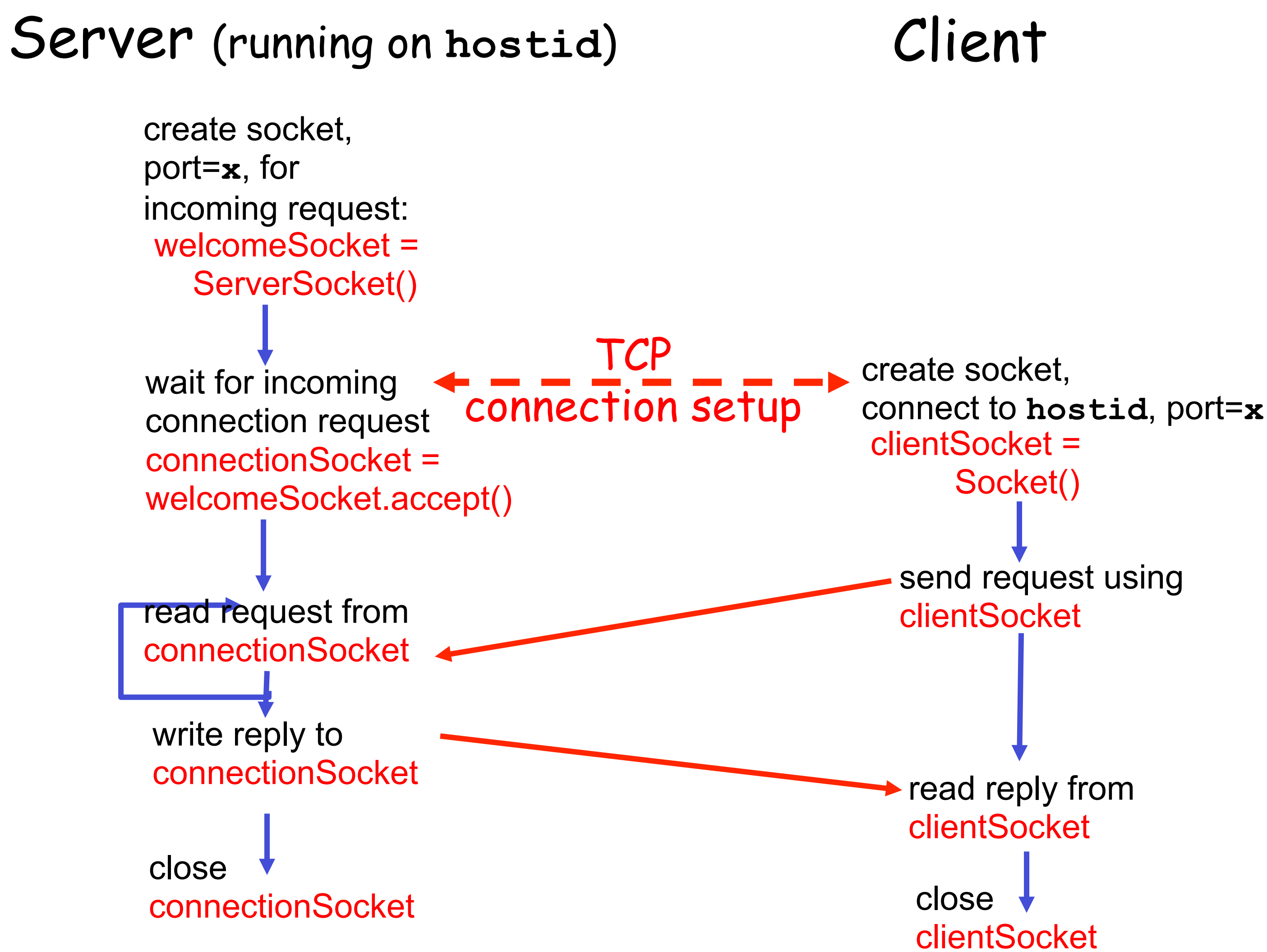
- creating client-local TCP socket
- specifying IP address, port number of server process
- when client creates socket: client TCP establishes connection to server TCP

- 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

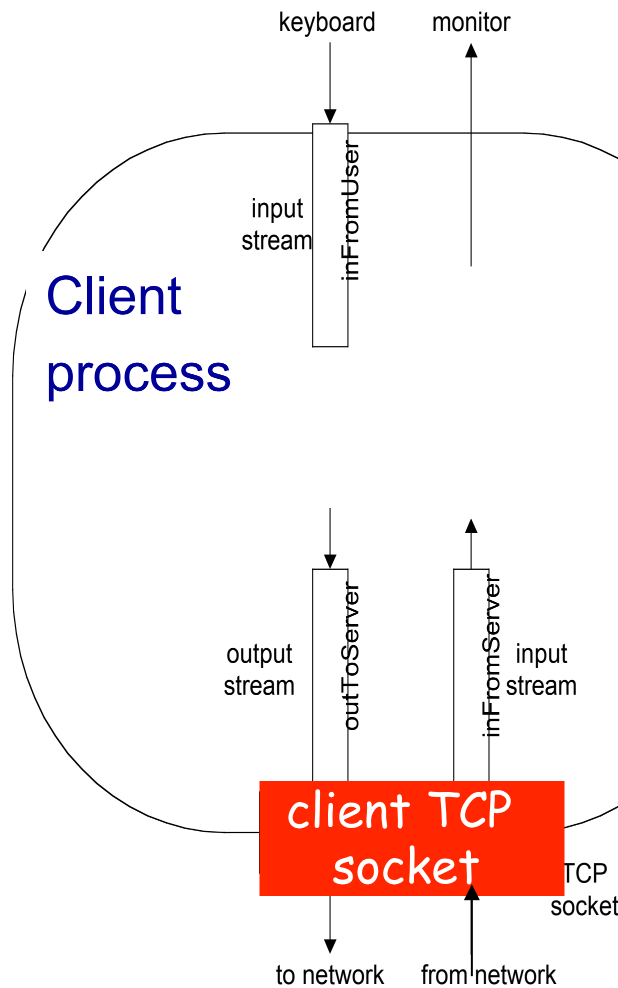
TCP provides reliable, in-order transfer of bytes ("pipe") between client and server

Client/server socket interaction: TCP



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)

```java
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());
```

This package defines Socket() and ServerSocket() classes

create input stream

create clientSocket object of type Socket, connect to server

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

server port #

create output stream attached to socket

Example: Java client (TCP), cont.

create
input stream
attached to socket

send line
to server

read line
from server

close socket
(clean up behind yourself!)

```
        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();

     }
 }
```

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

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

create input stream, attached to socket

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

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2.8 Socket programming with UDP

Socket programming *with UDP*

UDP: no "connection" between client and server

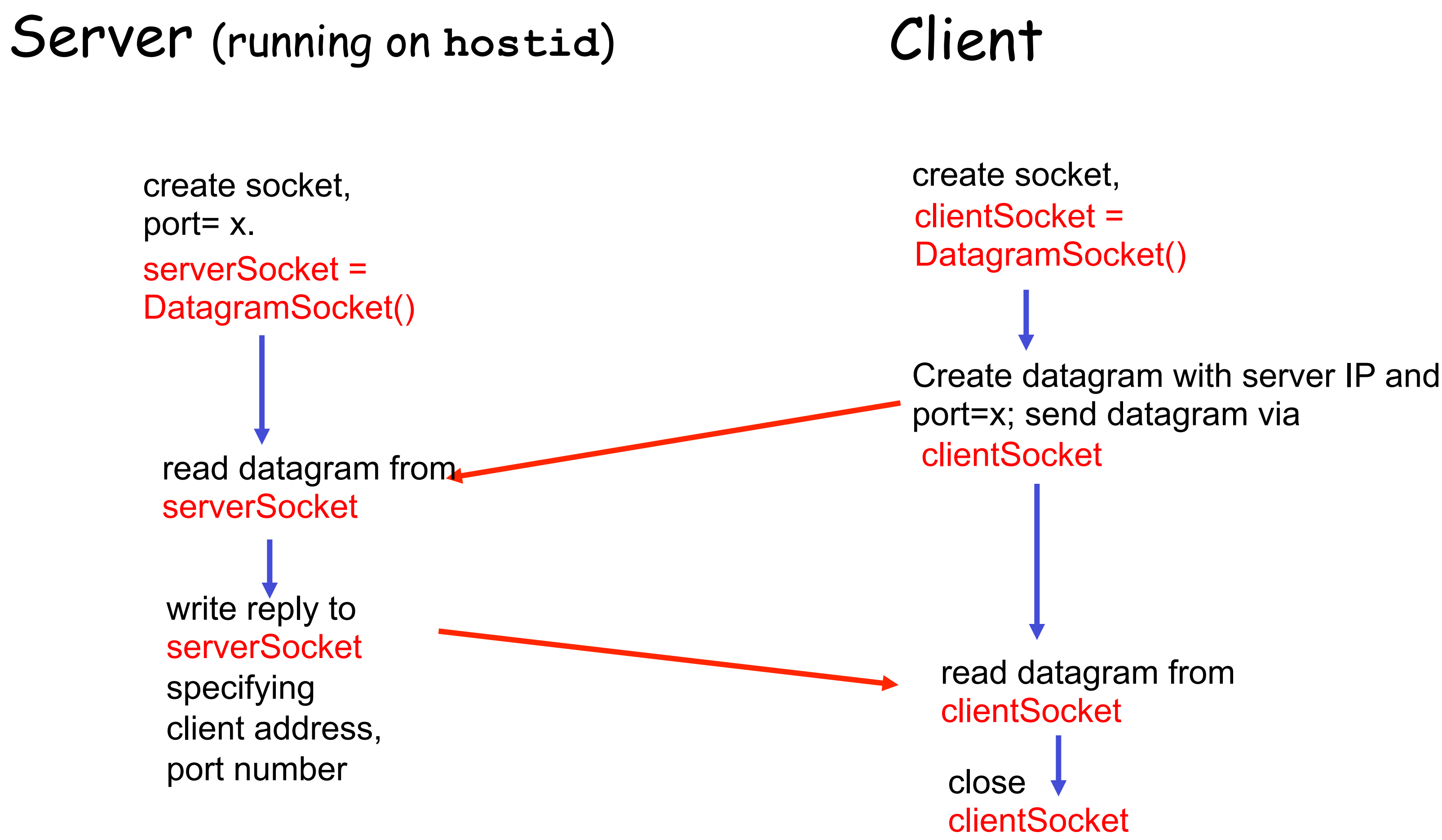
- no handshaking
- sender explicitly attaches IP address and port of destination to each packet
- server must extract IP address, port of sender from received packet

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

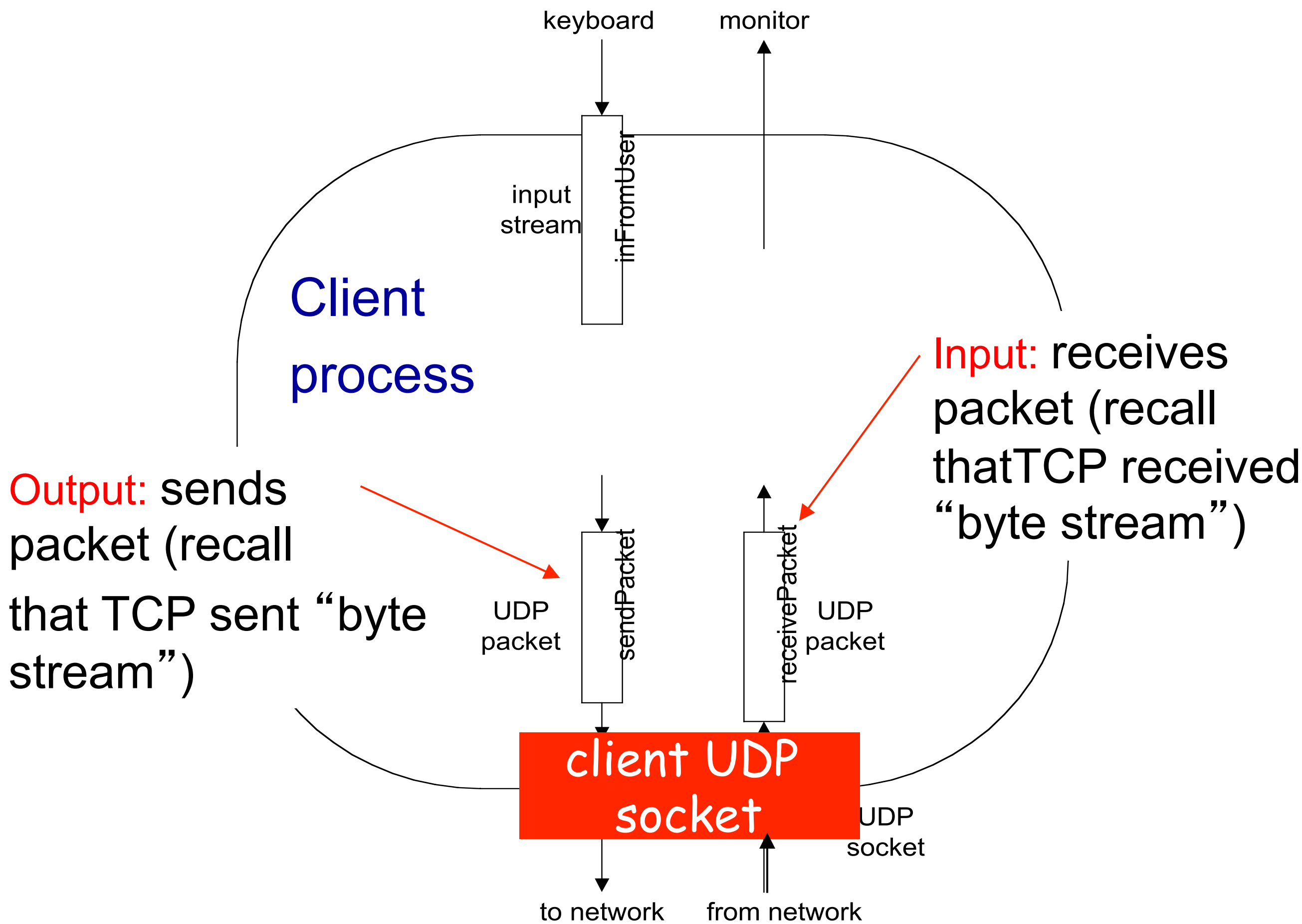
application viewpoint:

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

Client/server socket interaction: UDP



Example: Java client (UDP)



Example: Java client (UDP)

create
input stream

create
client socket

translate
hostname to IP
address using DNS

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

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

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

      DatagramSocket clientSocket = new DatagramSocket();

      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

send datagram
to server

read datagram
from server

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

clientSocket.send(sendPacket);

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)

create datagram socket at port 9876

create space for received datagram

receive datagram

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

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

      DatagramSocket serverSocket = new DatagramSocket(9876);

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

      while(true)
        {

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

          serverSocket.receive(receivePacket);
```

Example: Java server (UDP), cont

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

      InetAddress IPAddress = receivePacket.getAddress();

      int port = receivePacket.getPort();

              String capitalizedSentence = sentence.toUpperCase();

      sendData = capitalizedSentence.getBytes();

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

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

get IP addr
port #, of
sender

create datagram
to send to client

write out
datagram
to socket

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

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+ (Bonus) Same with C

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  - 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)

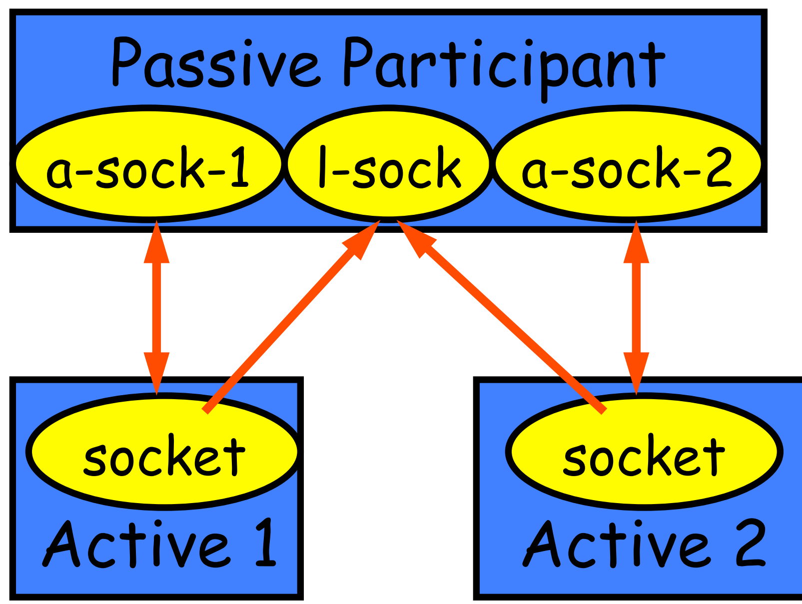
Connection Setup (SOCK_STREAM)

- 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**
sd=socket(type)	sd=socket(type)
	bind(sd,port)
	listen(sd,len)
connect(sd,dest)	new_sd=accept(sd)
write(sd,…) /send(sd,…)	read(new_sd,…)/recv(new_sd)
read(sd,…)/recv(sd,…)	write(new_sd,…) /send(new_sd,…)
close(sd)	close(new_sd)

TCP - Parallel Model

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

UDP - Serial Model

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

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+ (Bonus) Same with C

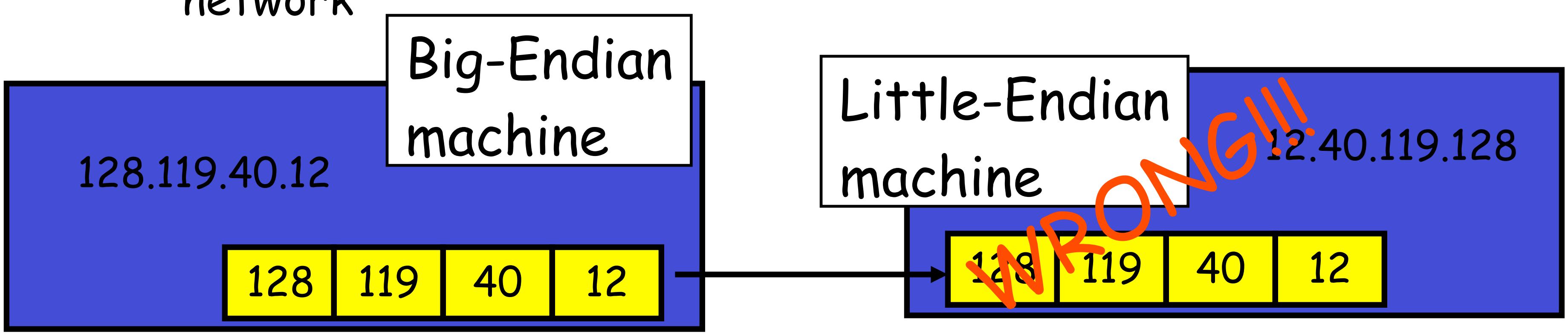
+ (Bonus) A few more functions

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

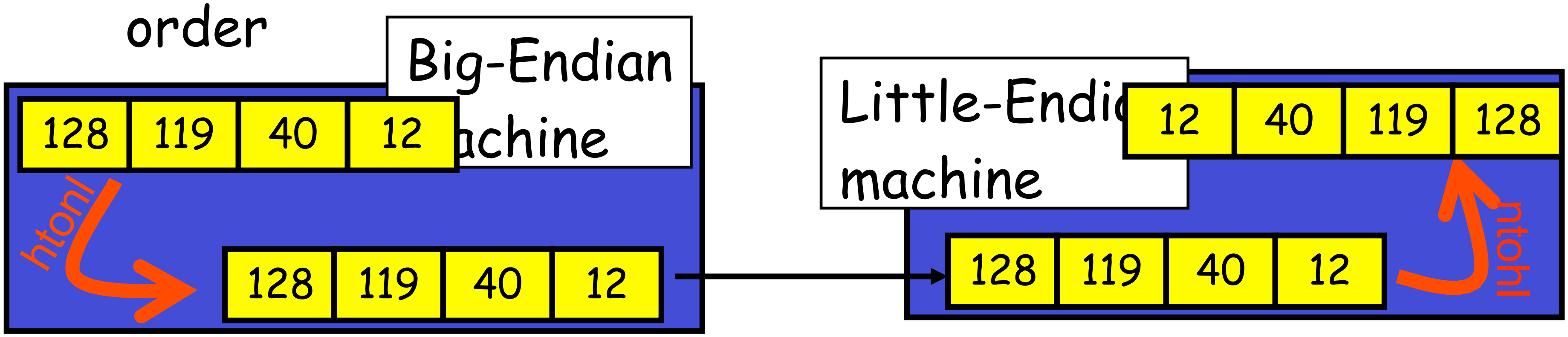
- Defs:
  - Host Byte-Ordering: the byte ordering used by a host (big or little)
  - Network Byte-Ordering: the byte ordering used by the network – always big-endian
- Any words sent through the network should be converted to Network Byte-Order prior to transmission (and back to Host Byte-Order once 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_short htons(u_short x);
- u_long ntohl(u_long 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 endian-ness 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"