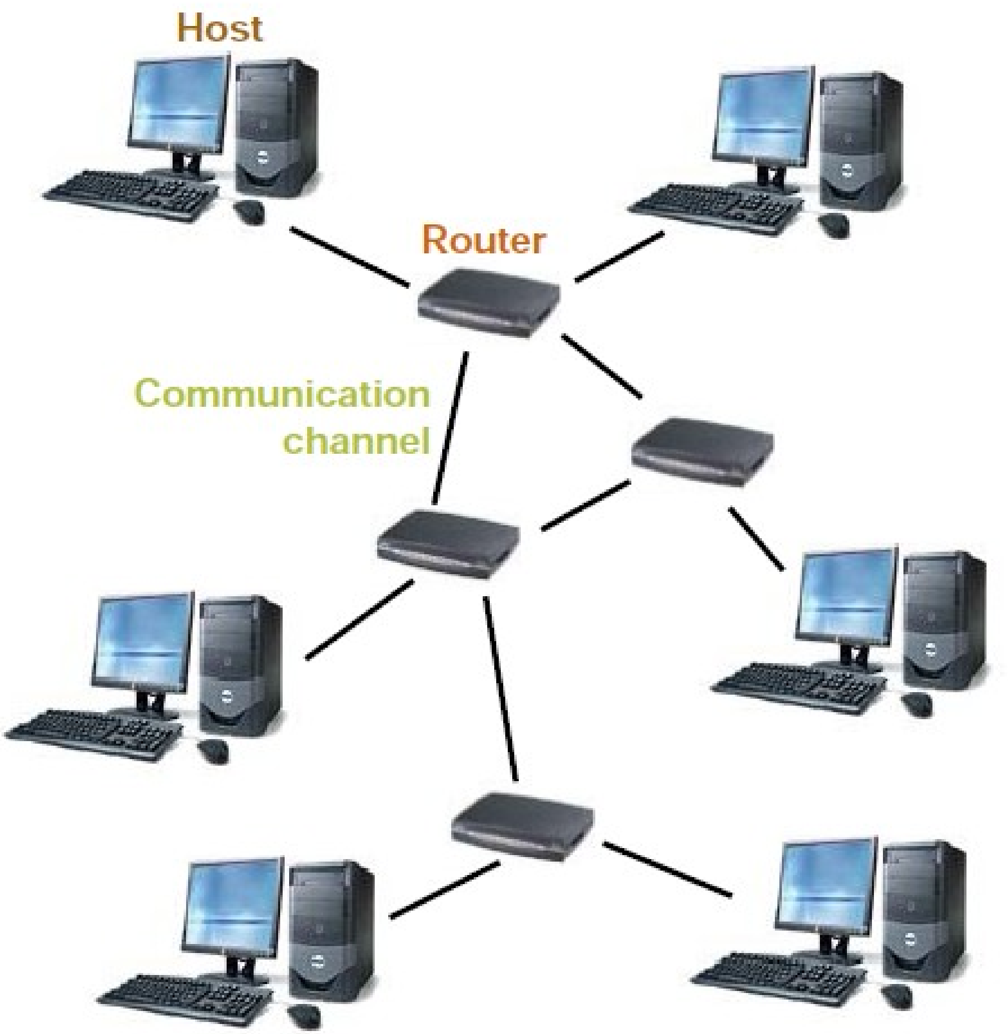
Introduction to Sockets Programming in C using TCP/IP

Introduction

- Computer Network
  - hosts, routers, communication channels
- Hosts run applications
- Routers forward information
- Packets: sequence of bytes
  - contain control information
  - e.g. destination host
- Protocol is an agreement
  - meaning of packets
  - structure and size of packets

  e.g. Hypertext Transfer Protocol (HTTP)

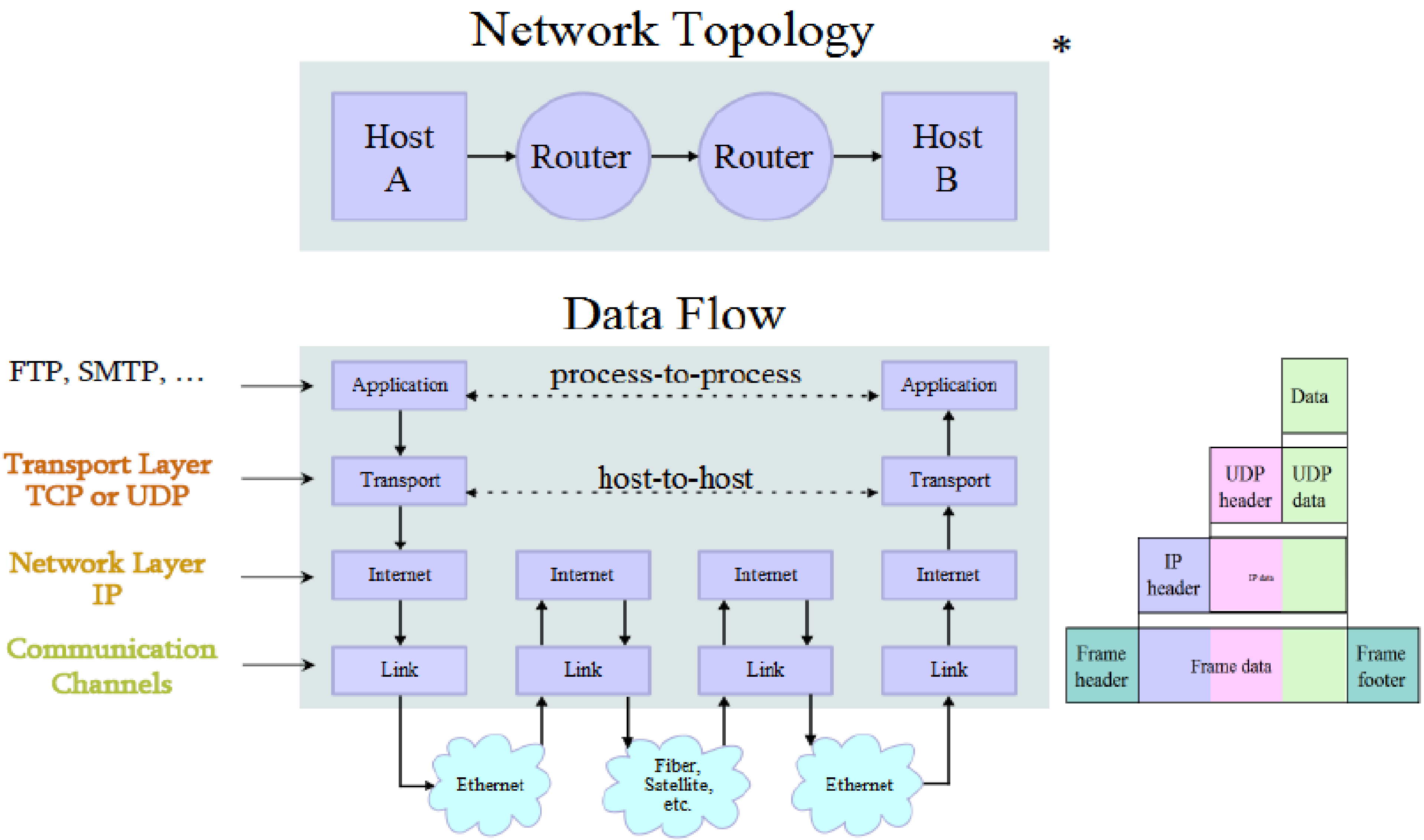


Protocol Families - TCP/IP

- Several protocols for different problems
- ☞ **Protocol Suites** or **Protocol Families**: TCP/IP

- TCP/IP provides **end-to-end** connectivity specifying how data should be
  - formatted,
  - addressed,
  - transmitted,
  - routed, and
  - received at the destination
- can be used in the internet and in stand-alone private networks
- it is organized into **layers**

TCP/IP



* Image is taken from "http://en.wikipedia.org/wiki/TCP/IP_model"

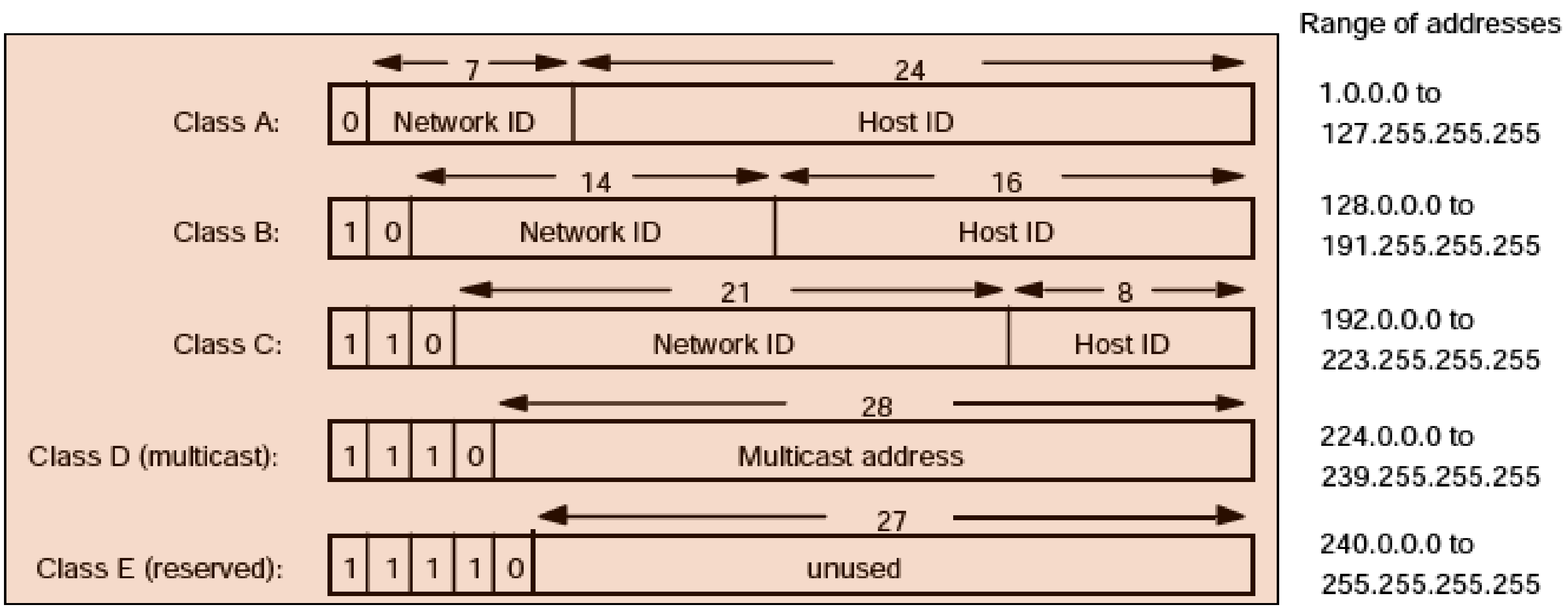
Internet Protocol (IP)

- provides a **datagram** service
  - packets are handled and delivered independently
- **best-effort** protocol
  - may loose, reorder or duplicate packets

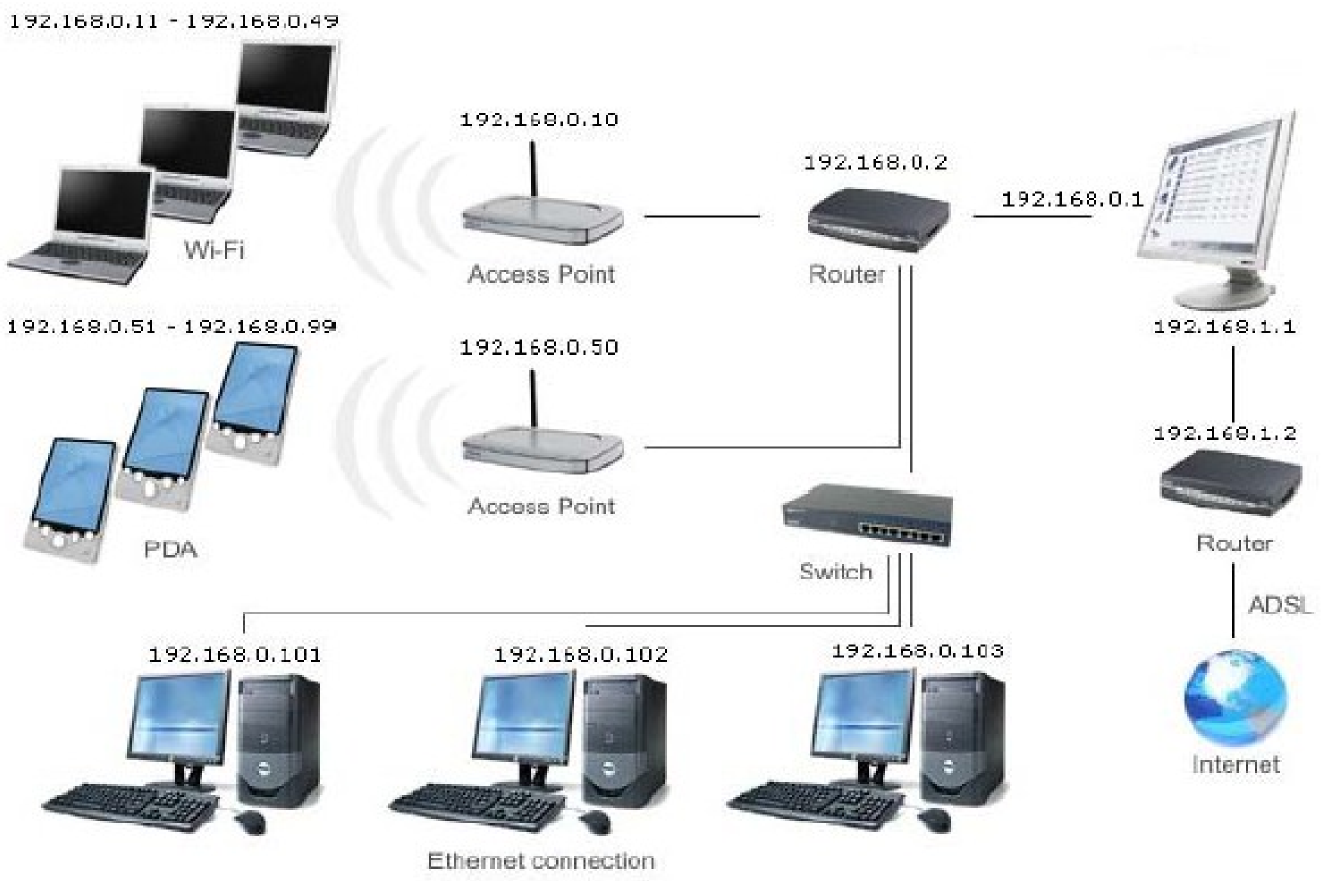
- each packet must contain an **IP address** of its destination

Addresses - IPv4

- The **32** bits of an IPv4 address are broken into **4 octets**, or 8 bit fields (0-255 value in decimal notation).
- For networks of different size,
  - the first one (for large networks) to three (for small networks) octets can be used to identify the **network**, while
  - the rest of the octets can be used to identify the **node** on the network.



Local Area Network Addresses - IPv4



TCP vs UDP

- Both use **port numbers**
  - application-specific construct serving as a communication endpoint
  - 16-bit unsigned integer, thus ranging from 0 to 65535
  - ☞ to provide **end-to-end** transport
- UDP: User Datagram Protocol
  - no acknowledgements
  - no retransmissions
  - out of order, duplicates possible
  - connectionless, i.e., app indicates destination for each packet
- TCP: Transmission Control Protocol
  - reliable **byte-stream channel** (in order, all arrive, no duplicates)
    - similar to file I/O
  - flow control
  - connection-oriented
  - bidirectional

TCP vs UDP

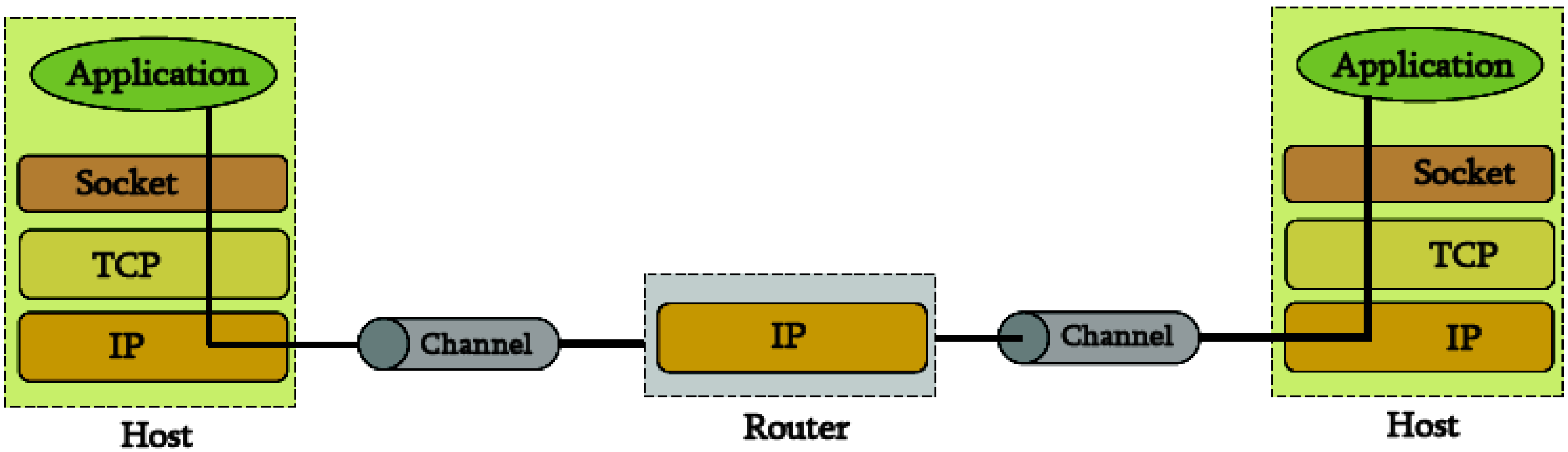
- TCP is used for services with a large data capacity, and a persistent connection
- UDP is more commonly used for quick lookups, and single use query-reply actions.

- Some common examples of TCP and UDP with their default ports:

DNS lookup	UDP	53
FTP	TCP	21
HTTP	TCP	80
POP3	TCP	110
Telnet	TCP	23

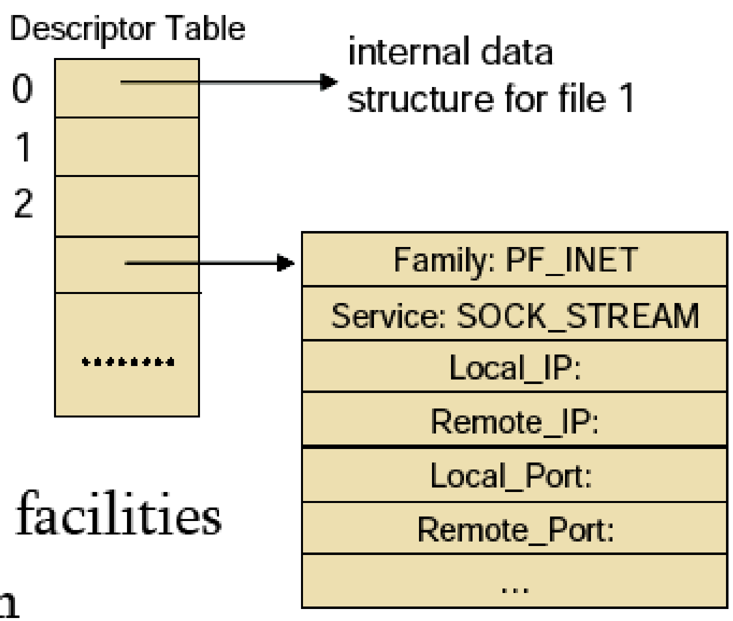
Berkley Sockets

- Universally known as **Sockets**
- It is an abstraction through which an application may send and receive data
- Provide **generic access** to interprocess communication services
  - e.g. IPX/SPX, Appletalk, TCP/IP
- Standard API for networking

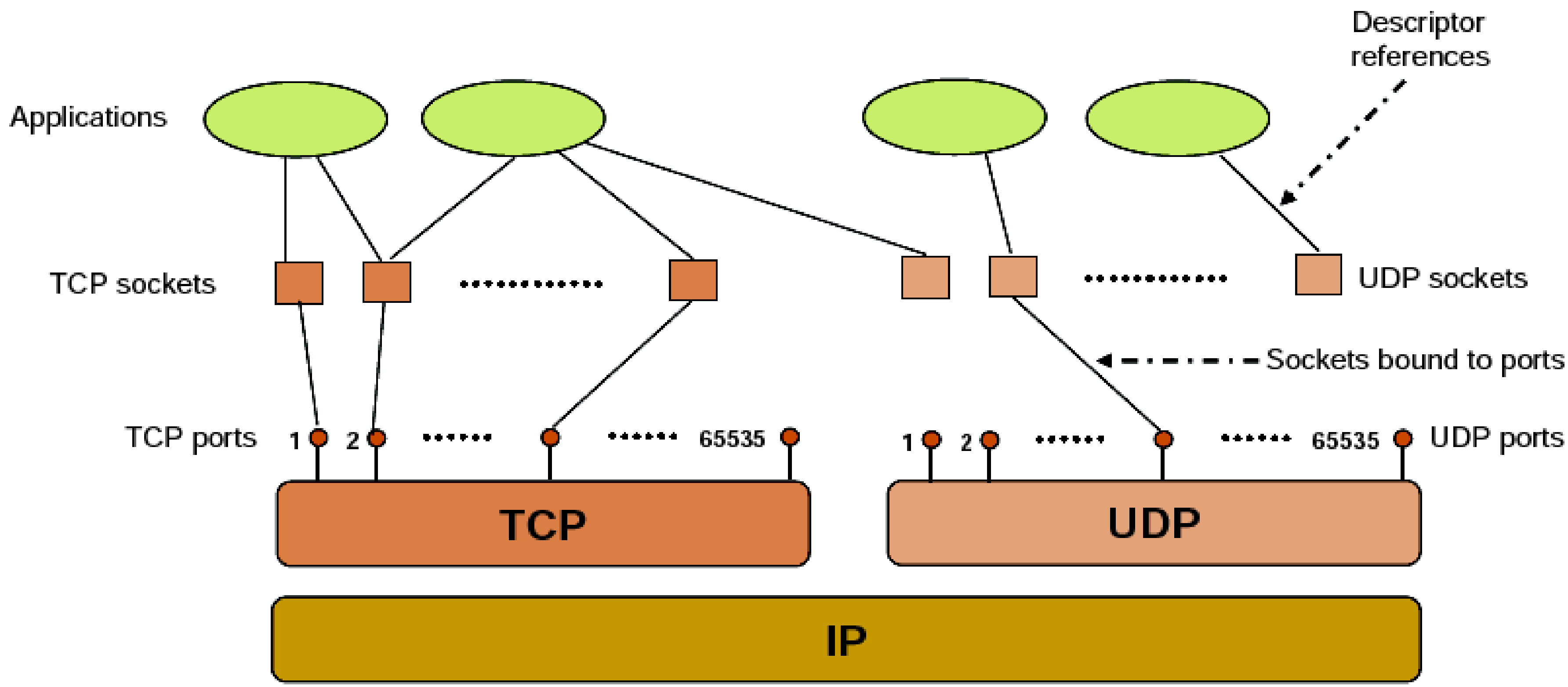


Sockets

- Uniquely identified by
  - an internet address
  - an end-to-end protocol (e.g. TCP or UDP)
  - a port number
- Two types of (TCP/IP) sockets
  - **Stream** sockets (e.g. uses TCP)
    - provide reliable byte-stream service
  - **Datagram** sockets (e.g. uses UDP)
    - provide best-effort datagram service
    - messages up to 65.500 bytes
- Socket extend the convectional UNIX I/O facilities
  - file descriptors for network communication
  - extended the read and write system calls

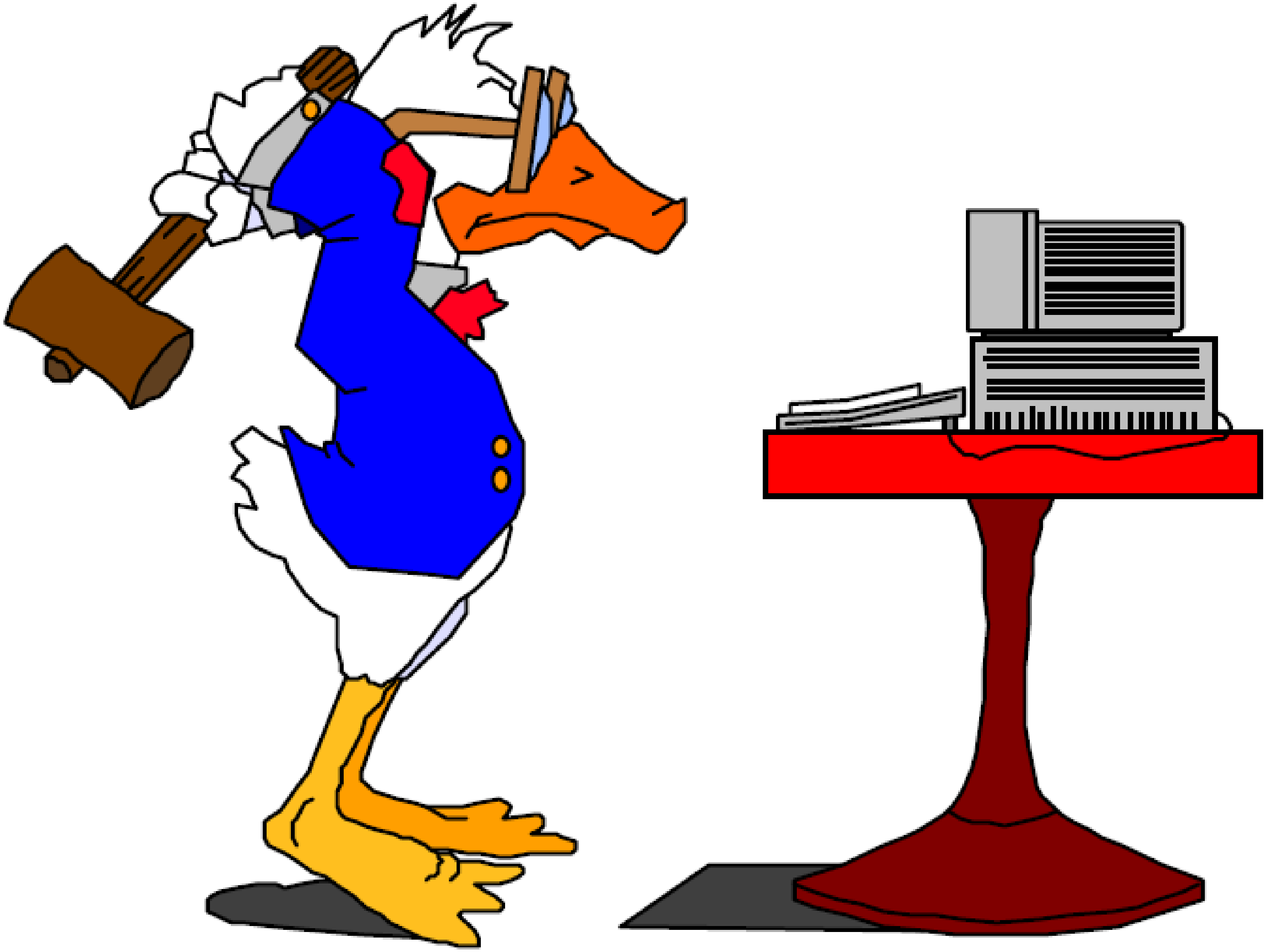


Sockets



Descriptor references
Applications
TCP sockets
UDP sockets
Sockets bound to ports
TCP ports
1
2
65535
1
2
65535
UDP ports
TCP
UDP
IP

Socket Programming



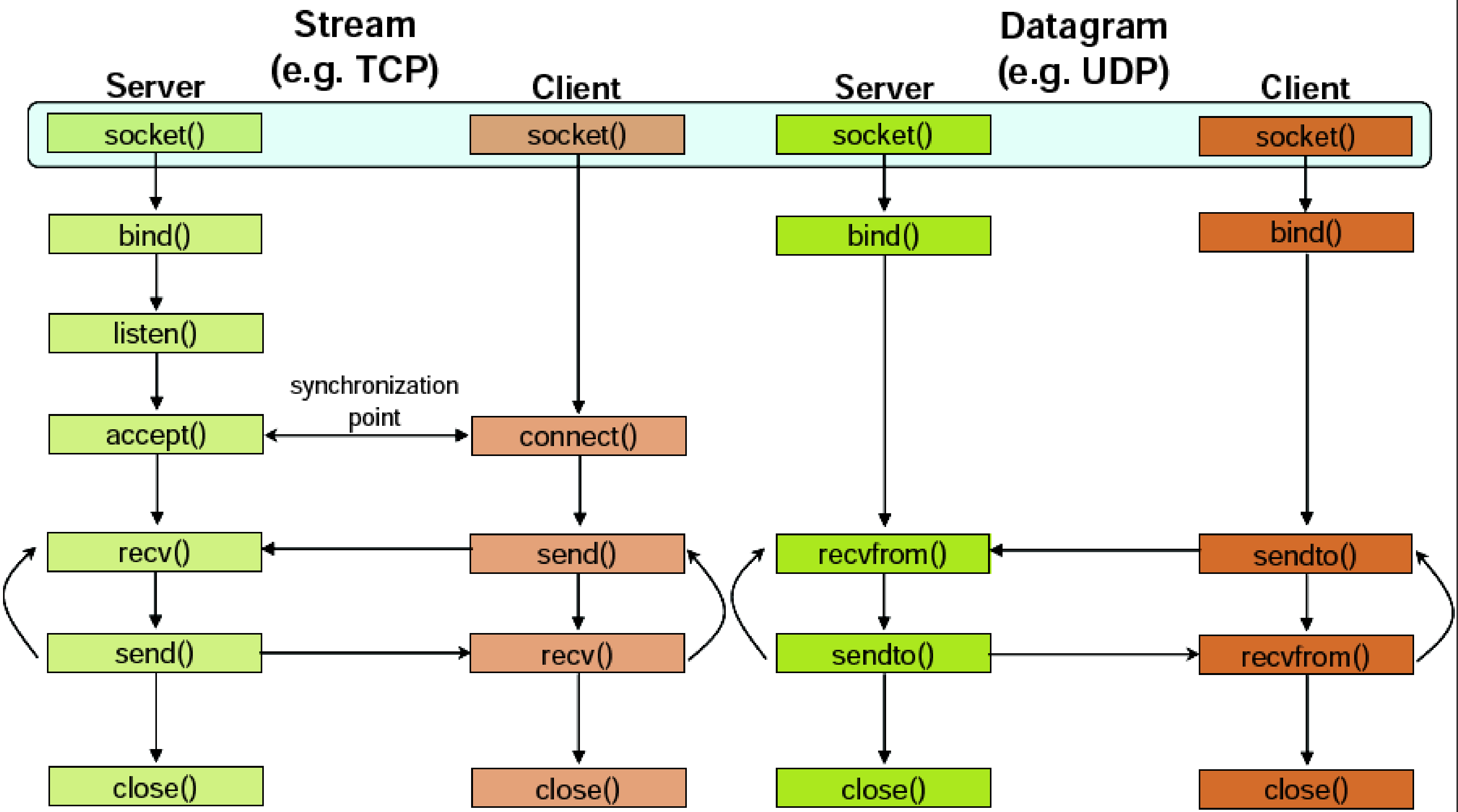
Client-Server communication

- Server
  - passively waits for and responds to clients
  - passive socket
- Client
  - initiates the communication
  - must know the address and the port of the server
  - active socket

Sockets - Procedures

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

Client - Server Communication - Unix

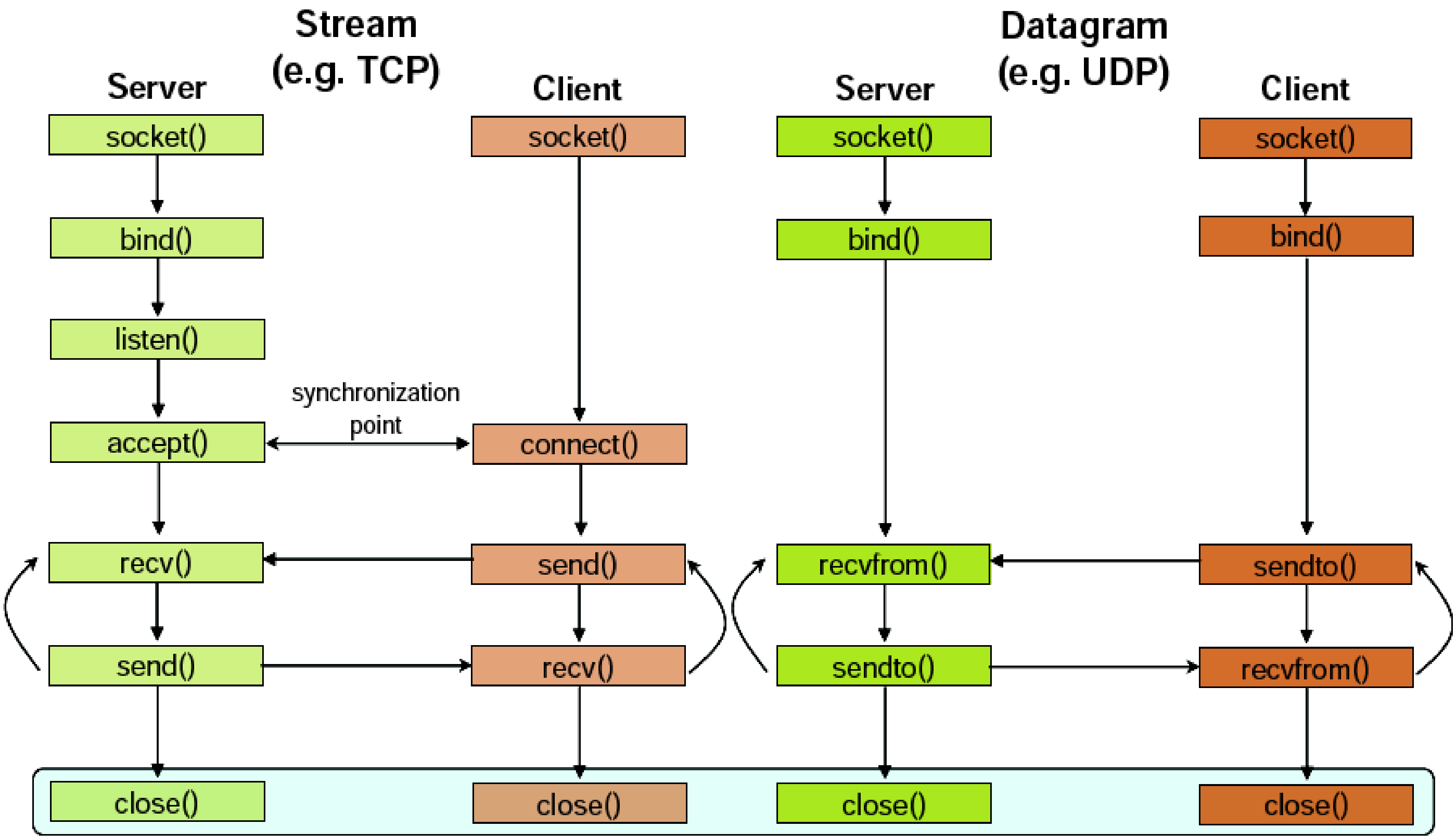


Socket creation in C: socket ( )

- `int sockid = socket(family, type, protocol);`
  - sockid: socket descriptor, an integer (like a file-handle)
  - family: integer, communication domain, e.g.,
    - PF_INET, IPv4 protocols, Internet addresses (typically used)
    - PF_UNIX, Local communication, File addresses
  - type: communication type
    - SOCK_STREAM - reliable, 2-way, connection-based service
    - SOCK_DGRAM - unreliable, connectionless, messages of maximum length
  - protocol: specifies protocol
    - IPPROTO_TCP IPPROTO_UDP
    - usually set to 0 (i.e., use default protocol)
  - upon failure returns -1

☞ NOTE: socket call does not specify where data will be coming from, nor where it will be going to – it just creates the interface!

Client - Server Communication - Unix



Socket close in C: `close()`

- When finished using a socket, the socket should be closed

- `status = close(sockid);`
  - **sockid**: the file descriptor (socket being closed)
  - **status**: 0 if successful, -1 if error

- Closing a socket
  - closes a connection (for stream socket)
  - frees up the port used by the socket

Specifying Addresses

- Socket API defines a **generic** data type for addresses:

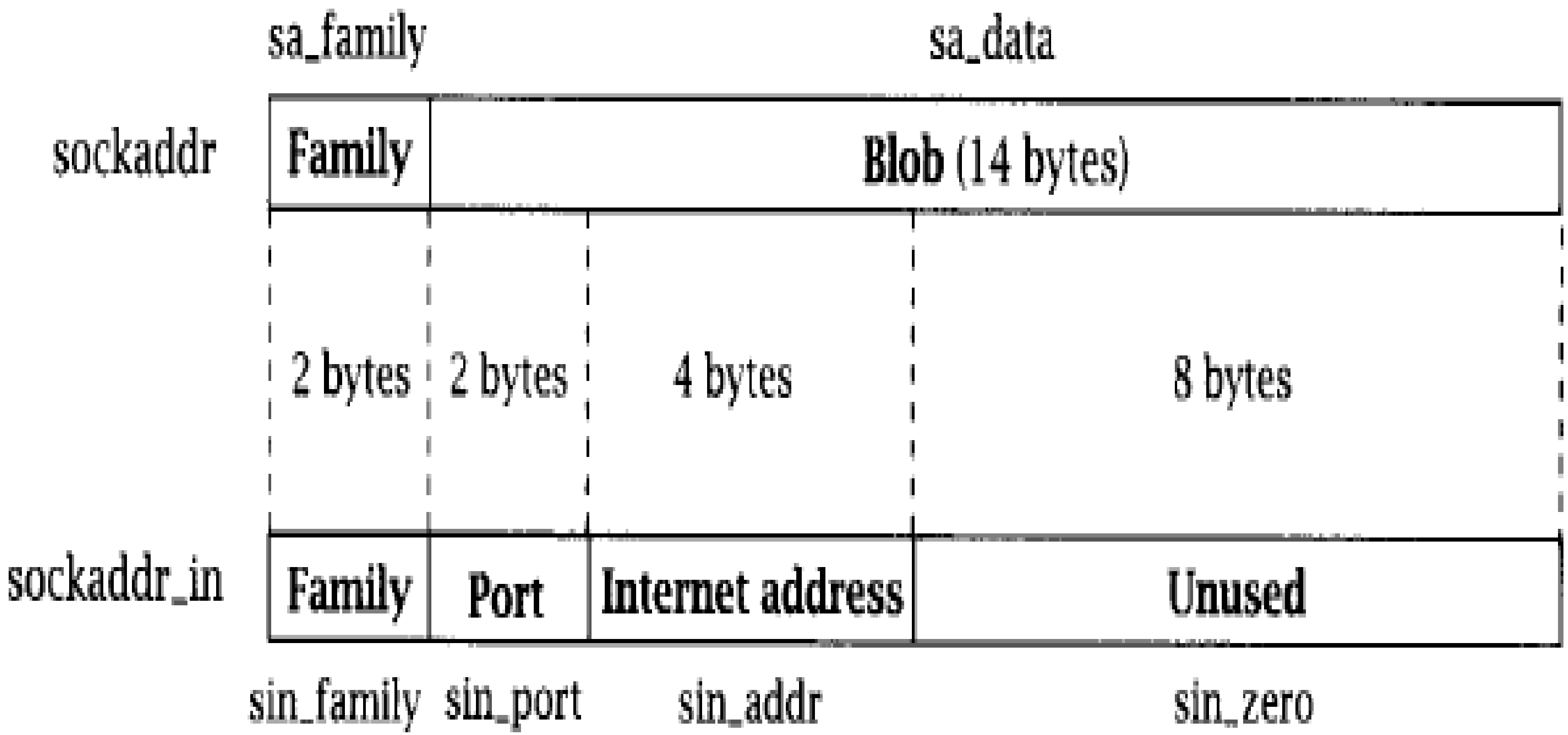
```
struct sockaddr {
    unsigned short sa_family;   /* Address family (e.g. AF_INET) */
    char sa_data[14];           /* Family-specific address information */
}
```

- Particular form of the sockaddr used for **TCP/IP** addresses:

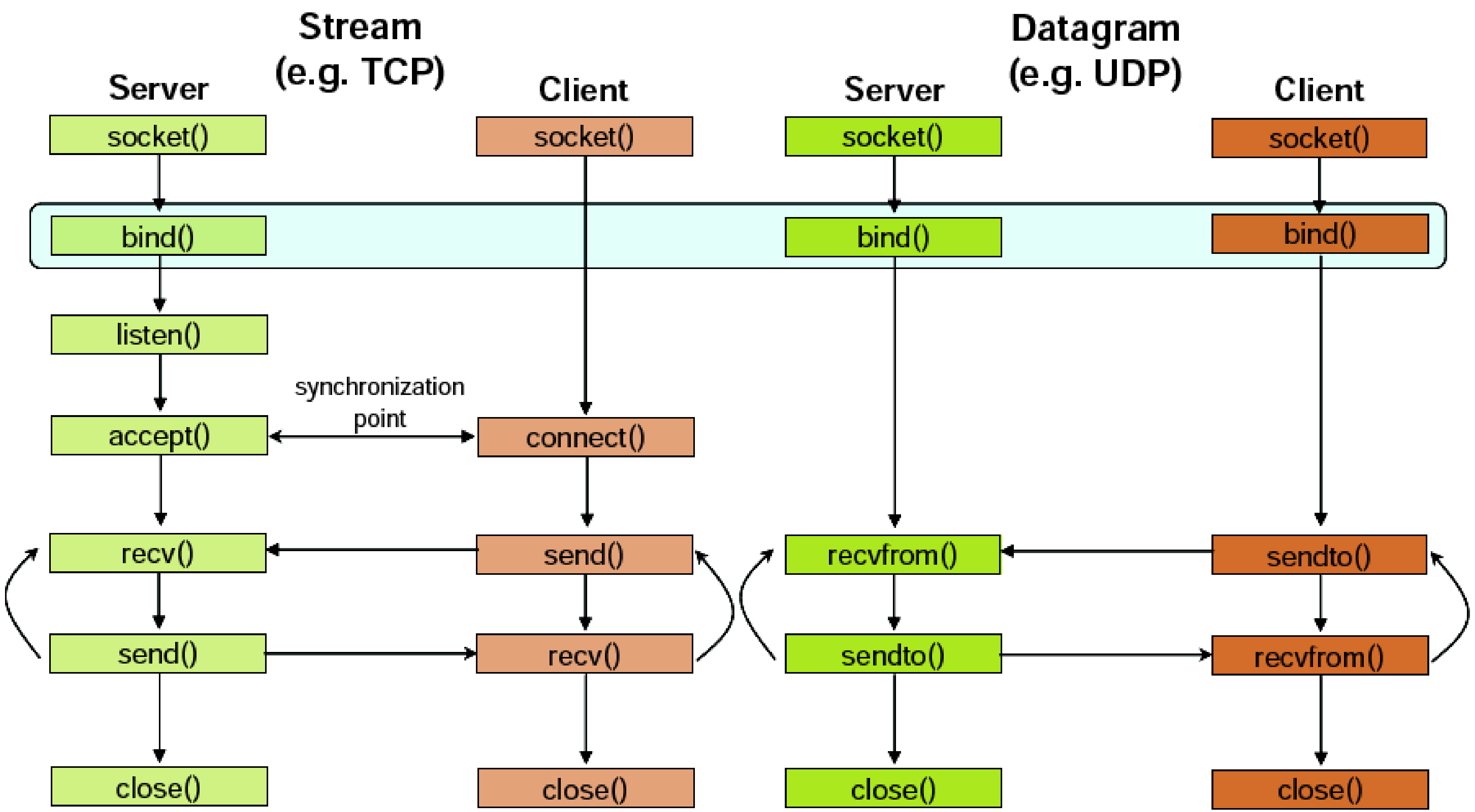
```
struct in_addr {
    unsigned long s_addr;            /* Internet address (32 bits) */
}
struct sockaddr_in {
    unsigned short sin_family;       /* Internet protocol (AF_INET) */
    unsigned short sin_port;         /* Address port (16 bits) */
    struct in_addr sin_addr;         /* Internet address (32 bits) */
    char sin_zero[8];                /* Not used */
}
```

☞ **Important**: sockaddr_in can be casted to a sockaddr

Specifying Addresses



Client - Server Communication - Unix



Assign address to socket: `bind()`

- associates and reserves a port for use by the socket

- `int status = bind(sockid, &addrport, size);`
  - sockid: integer, socket descriptor
  - addrport: struct sockaddr, the (IP) address and port of the machine
    - for TCP/IP server, internet address is usually set to INADDR_ANY, i.e., chooses any incoming interface
  - size: the size (in bytes) of the addrport structure
  - **status**: upon failure -1 is returned

bind() - Example with TCP

```
int sockid;
struct sockaddr_in addrport;
sockid = socket(PF_INET, SOCK_STREAM, 0);

addrport.sin_family = AF_INET;
addrport.sin_port = htons(5100);
addrport.sin_addr.s_addr = htonl(INADDR_ANY);
if(bind(sockid, (struct sockaddr *) &addrport, sizeof(addrport))!= -1) {
    …}
```

Skipping the `bind()`

- bind can be skipped for both types of sockets

- Datagram socket:
  - if only sending, no need to bind. The OS finds a port each time the socket sends a packet
  - if receiving, need to bind
- Stream socket:
  - destination determined during connection setup
  - don't need to know port sending from (during connection setup, receiving end is informed of port)

Exchanging data with stream socket

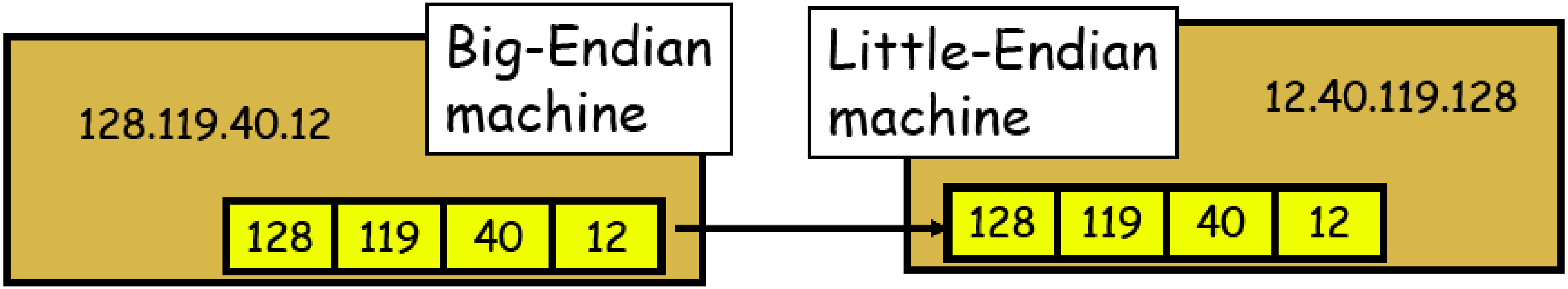
- `int count = send(sockid, msg, msgLen, flags);`
  - msg: const void[], message to be transmitted
  - msgLen: integer, length of message (in bytes) to transmit
  - flags: integer, special options, usually just 0
  - count: # bytes transmitted (-1 if error)
- `int count = recv(sockid, recvBuf, bufLen, flags);`
  - recvBuf: void[], stores received bytes
  - bufLen: # bytes received
  - flags: integer, special options, usually just 0
  - count: # bytes received (-1 if error)
- Calls are **blocking**
  - returns only after data is sent / received

Exchanging data with datagram socket

- ```
  int count = sendto(sockid, msg, msgLen, flags,
  &foreignAddr, addrlen);
  ```
  - msg, msgLen, flags, count: same with `send()`
  - **foreignAddr**: struct sockaddr, address of the destination
  - **addrLen**: sizeof(foreignAddr)
- ```
  int count = recvfrom(sockid, recvBuf, bufLen,
  flags, &clientAddr, addrlen);
  ```
  - recvBuf, bufLen, flags, count: same with `recv()`
  - **clientAddr**: struct sockaddr, address of the client
  - **addrLen**: sizeof(clientAddr)
- Calls are **blocking**
  - returns only after data is sent / received

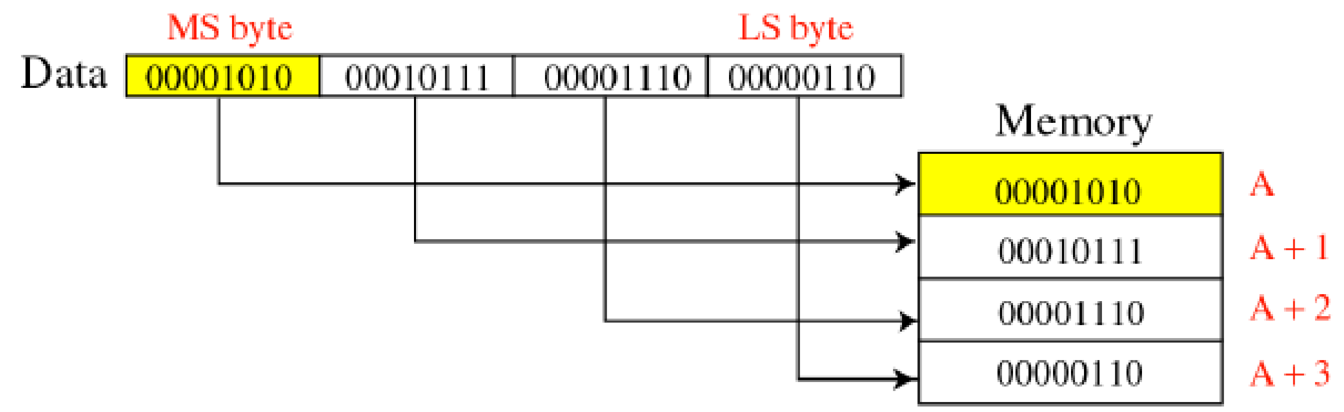
Constructing Messages - Byte Ordering

- Address and port are stored as integers
  - u_short sin_port; (16 bit)
  - in_addr sin_addr; (32 bit)
- 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

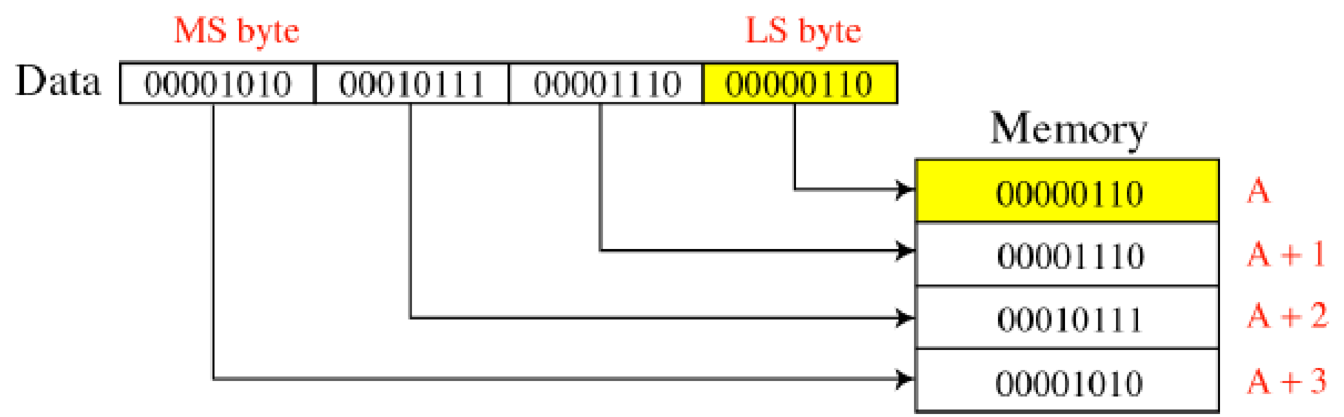


Constructing Messages - Byte Ordering

- Big-Endian:



- Little-Endian:

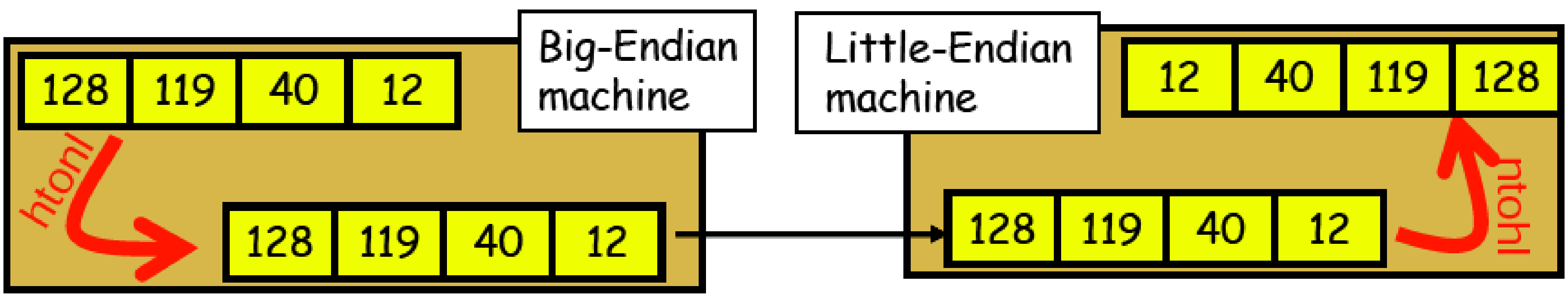


Constructing Messages - Byte Ordering - Solution: Network Byte Ordering

- **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

- `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



Constructing Messages - Byte Ordering - Example

Client

```
unsigned short clientPort, message;   unsigned int messageLenth;

servPort = 1111;
message = htons(clientPort);
messageLength = sizeof(message);

if (sendto( clientSock, message, messageLength, 0,
           (struct sockaddr *) &echoServAddr, sizeof(echoServAddr))
         != messageLength)
     DieWithError("send() sent a different number of bytes than expected");
```

Server

```
unsigned short clientPort, rcvBuffer;
unsigned int recvMsgSize ;

if ( recvfrom(servSock, &rcvBuffer, sizeof(unsigned int), 0),
      (struct sockaddr *) &echoClientAddr, sizeof(echoClientAddr)) < 0)
      DieWithError("recvfrom() failed");

clientPort = ntohs(rcvBuffer);
printf ("Client's port: %d", clientPort);
```

Example - Echo

- A client communicates with an “echo” server
- The server simply echoes whatever it receives back to the client

Example - Echo using datagram socket

```
/* Create socket for sending/receiving datagrams */
if ((servSock = socket(PF_INET, SOCK_DGRAM, IPPROTO_UDP)) < 0)
     DieWithError("socket() failed");
```

```
/* Create a datagram/UDP socket */
if ((clientSock = socket(PF_INET, SOCK_DGRAM, IPPROTO_UDP)) < 0)
     DieWithError("socket() failed");
```

Client

1. **Create a UDP socket**
2. Assign a port to socket
3. Communicate
4. Close the socket

Server

1. **Create a UDP socket**
2. Assign a port to socket
3. Repeatedly
   - Communicate

Example - Echo using datagram socket

```
echoServAddr.sin_family = AF_INET;                    /* Internet address family */
echoServAddr.sin_addr.s_addr = htonl(INADDR_ANY);    /* Any incoming interface */
echoServAddr.sin_port = htons(echoServPort);         /* Local port */

if (bind(servSock, (struct sockaddr *) &echoServAddr, sizeof(echoServAddr)) < 0)
    DieWithError("bind() failed");
```

```
echoClientAddr.sin_family = AF_INET;                    /* Internet address family */
echoClientAddr.sin_addr.s_addr = htonl(INADDR_ANY);    /* Any incoming interface */
echoClientAddr.sin_port = htons(echoClientPort);       /* Local port */

if(bind(clientSock,(struct sockaddr *)&echoClientAddr,sizeof(echoClientAddr))<0)
    DieWithError("connect() failed");
```

Client

1. Create a UDP socket
2. **Assign a port to socket**
3. Communicate
4. Close the socket

Server

1. Create a UDP socket
2. **Assign a port to socket**
3. Repeatedly
   - Communicate

Example - Echo using datagram socket

```
echoServAddr.sin_family = AF_INET;                          /* Internet address family */
echoServAddr.sin_addr.s_addr = inet_addr(echoservIP);  /* Server IP address*/
echoServAddr.sin_port = htons(echoServPort);                /* Server port */

echoStringLen = strlen(echoString);     /* Determine input length */

/* Send the string to the server */
if (sendto( clientSock, echoString, echoStringLen, 0,
            (struct sockaddr *) &echoServAddr, sizeof(echoServAddr))
         != echoStringLen)
     DieWithError("send() sent a different number of bytes than expected");
```

Client

1. Create a UDP socket
2. Assign a port to socket
3. **Communicate**
4. Close the socket

Server

1. Create a UDP socket
2. **Assign a port to socket**
3. Repeatedly
   - Communicate

Example - Echo using datagram socket

```
for (;;) /* Run forever */
{
   clientAddrLen = sizeof(echoClientAddr)   /* Set the size of the in-out parameter */
   /*Block until receive message from client*/
    if ((recvMsgSize = recvfrom(servSock, echoBuffer, ECHOMAX, 0),
         (struct sockaddr *) &echoClientAddr, sizeof(echoClientAddr))) < 0)
         DieWithError("recvfrom() failed");

    if (sendto(servSock, echobuffer, recvMsgSize, 0,
              (struct sockaddr *) &echoClientAddr, sizeof(echoClientAddr))
           != recvMsgSize)
         DieWithError("send() failed");
}
```

Client

1. Create a UDP socket
2. Assign a port to socket
3. **Communicate**
4. Close the socket

Server

1. Create a UDP socket
2. Assign a port to socket
3. Repeatedly
   - **Communicate**

Example - Echo using datagram socket

Similarly, the client receives the data from the server

Client

1. Create a UDP socket
2. Assign a port to socket
3. **Communicate**
4. Close the socket

Server

1. Create a UDP socket
2. Assign a port to socket
3. Repeatedly
   - **Communicate**

Example - Echo using datagram socket

```
close(clientSock);
```

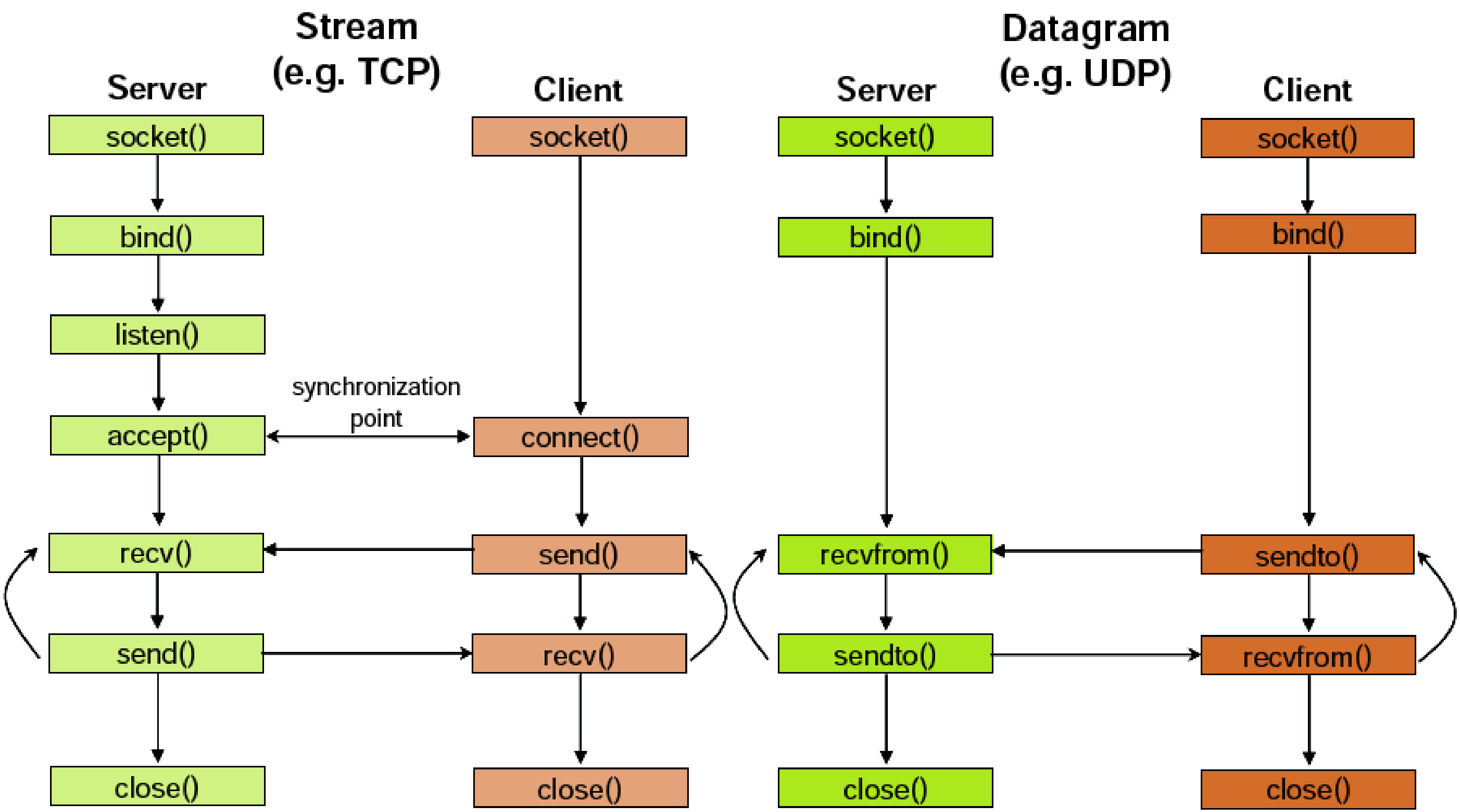
Client

1. Create a UDP socket
2. Assign a port to socket
3. Communicate
4. **Close the socket**

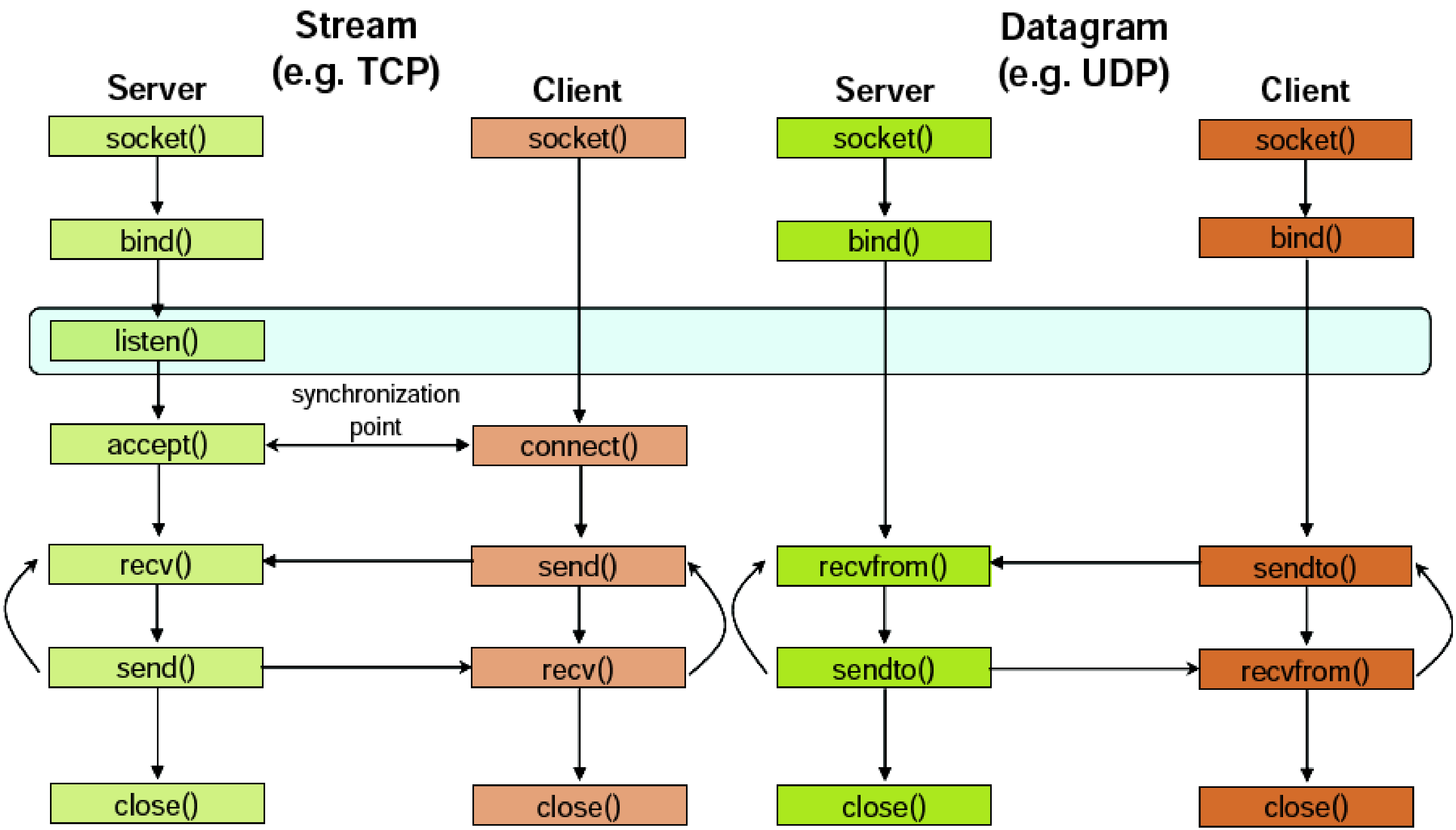
Server

1. Create a UDP socket
2. Assign a port to socket
3. **Repeatedly**
   - Communicate

Client - Server Communication - Unix



Client - Server Communication - Unix



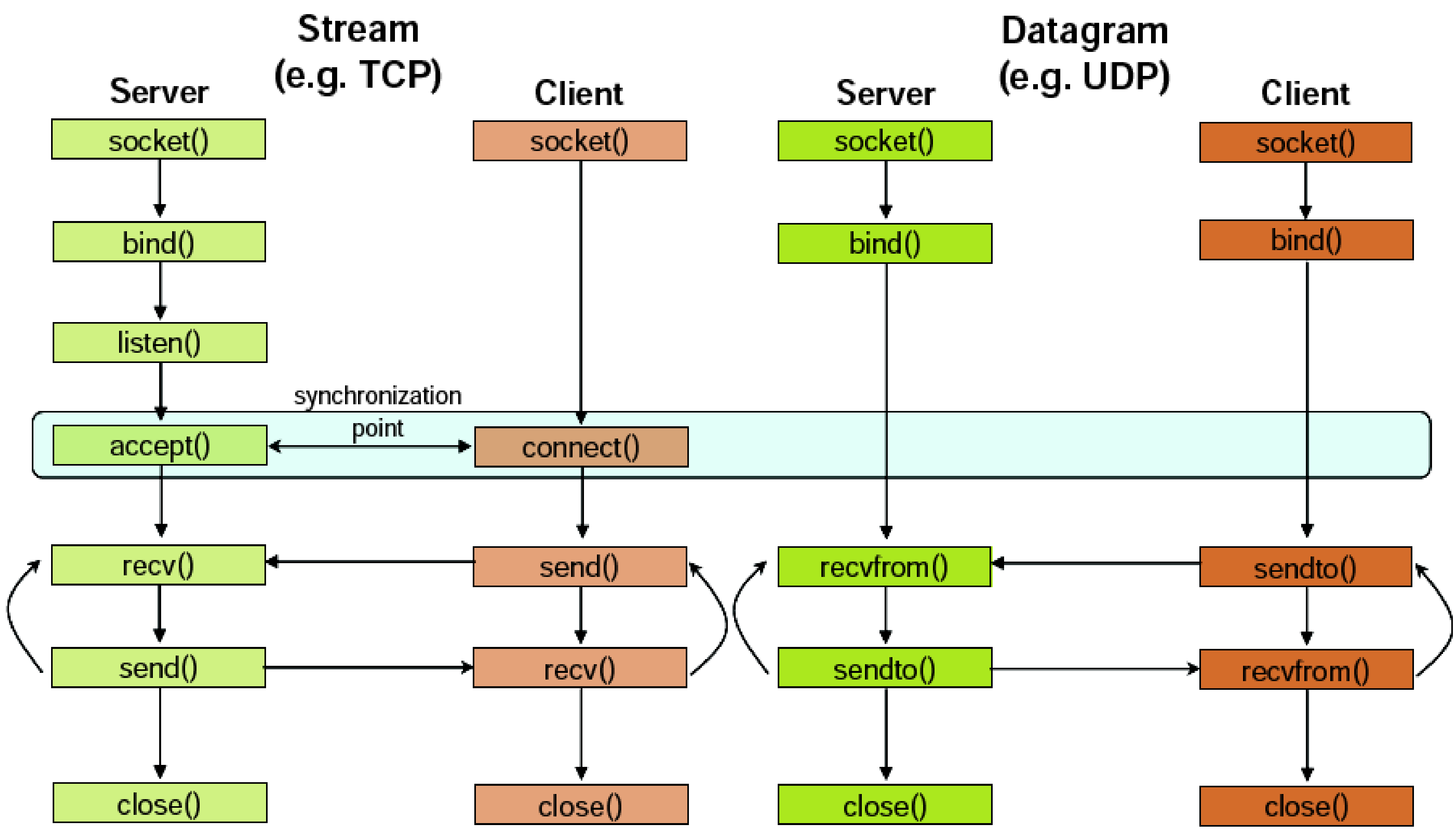
Assign address to socket: `bind()`

- Instructs TCP protocol implementation to listen for connections

- `int status = listen(sockid, queueLimit);`
  - **sockid**: integer, socket descriptor
  - **queuelen**: integer, # of active participants that can "wait" for a connection
  - **status**: 0 if listening, -1 if error
- `listen()` is **non-blocking**: returns immediately

- The listening socket (sockid)
  - is never used for sending and receiving
  - is used by the server only as a way to get new sockets

Client - Server Communication - Unix



Establish Connection: connect ( )

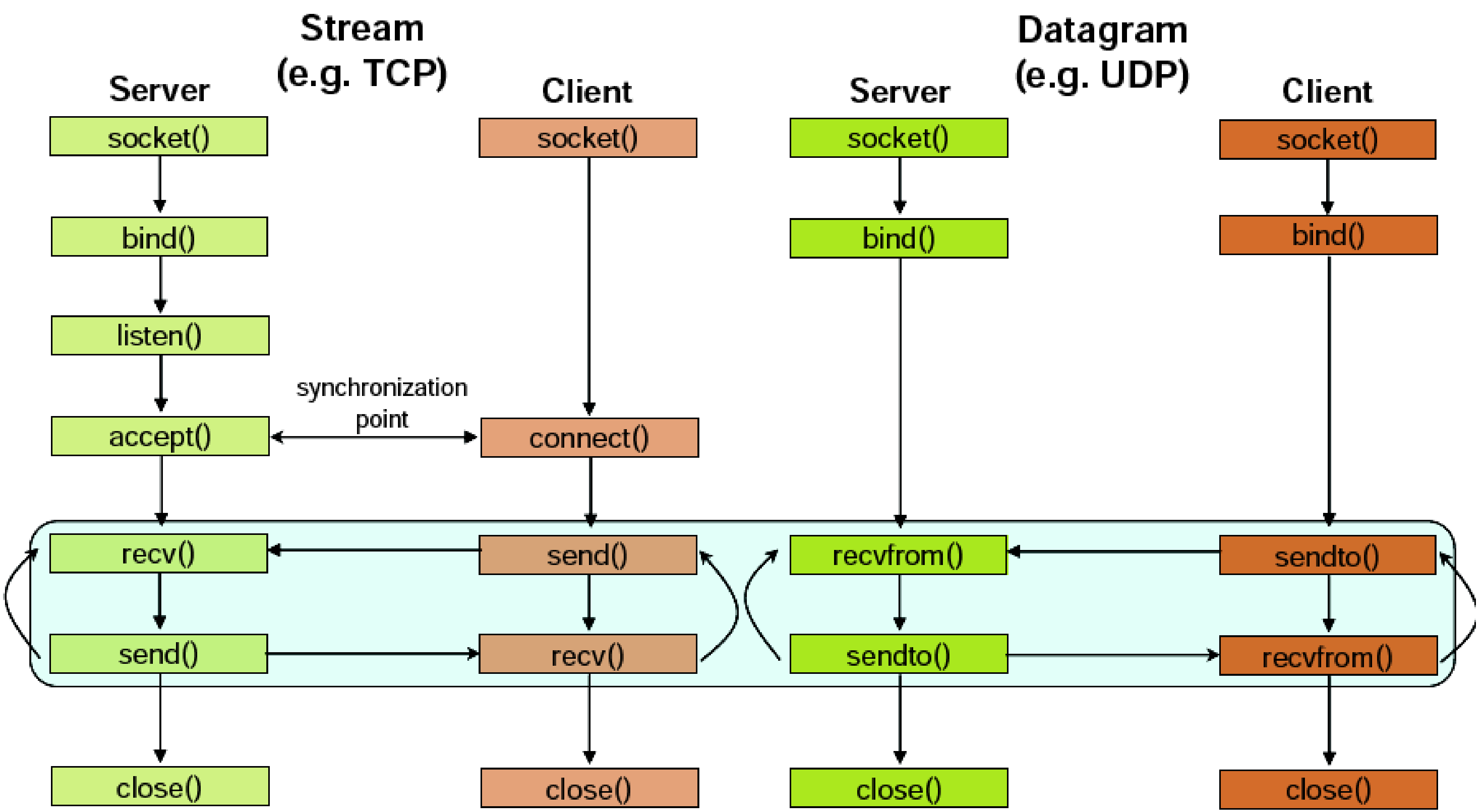
- The client establishes a connection with the server by calling `connect()`

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

Incoming Connection: accept ( )

- The server gets a socket for an incoming client connection by calling `accept()`
- `int s = accept(sockid, &clientAddr, &addrLen);`
  - s: integer, the new socket (used for data-transfer)
  - sockid: integer, the orig. socket (being listened on)
  - clientAddr: struct sockaddr, address of the active participant
    - filled in upon return
  - addrLen: sizeof(clientAddr): value/result parameter
    - must be set appropriately before call
    - adjusted upon return
- `accept()`
  - is **blocking**: waits for connection before returning
  - dequeues the next connection on the queue for socket (sockid)

Client - Server Communication - Unix



Exchanging data with stream socket

- `int count = send(sockid, msg, msgLen, flags);`
  - msg: const void[], message to be transmitted
  - msgLen: integer, length of message (in bytes) to transmit
  - flags: integer, special options, usually just 0
  - count: # bytes transmitted (-1 if error)
- `int count = recv(sockid, recvBuf, bufLen, flags);`
  - recvBuf: void[], stores received bytes
  - bufLen: # bytes received
  - flags: integer, special options, usually just 0
  - count: # bytes received (-1 if error)
- Calls are **blocking**
  - returns only after data is sent / received

Example - Echo using stream socket

The server starts by getting ready to receive client connections...

Client

1. Create a TCP socket
2. Establish connection
3. Communicate
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. Accept new connection
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

```
/* Create socket for incoming connections */
if ((servSock = socket(PF_INET, SOCK_STREAM, IPPROTO_TCP)) < 0)
     DieWithError("socket() failed");
```

Client

1. Create a TCP socket
2. Establish connection
3. Communicate
4. Close the connection

Server

1. **Create a TCP socket**
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. Accept new connection
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

```
echoServAddr.sin_family = AF_INET;                    /* Internet address family */
echoServAddr.sin_addr.s_addr = htonl(INADDR_ANY);     /* Any incoming interface */
echoServAddr.sin_port = htons(echoServPort);          /* Local port */

if (bind(servSock, (struct sockaddr *) &echoServAddr, sizeof(echoServAddr)) < 0)
    DieWithError("bind() failed");
```

Client

1. Create a TCP socket
2. Establish connection
3. Communicate
4. Close the connection

Server

1. Create a TCP socket
2. **Assign a port to socket**
3. Set socket to listen
4. Repeatedly:
   a. Accept new connection
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

```
/* Mark the socket so it will listen for incoming connections */
if (listen(servSock, MAXPENDING) < 0)
      DieWithError("listen() failed");
```

Client

1. Create a TCP socket
2. Establish connection
3. Communicate
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. **Set socket to listen**
4. Repeatedly:
   a. Accept new connection
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

```
for (;;) /* Run forever */
{
  clntLen = sizeof(echoClntAddr);

  if ((clientSock=accept(servSock,(struct sockaddr *)&echoClntAddr,&clntLen))<0)
      DieWithError("accept() failed");
  ...
```

Client

1. Create a TCP socket
2. Establish connection
3. Communicate
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. **Accept new connection**
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

Server is now blocked waiting for connection from a client

...

A client decides to talk to the server

Client

1. Create a TCP socket
2. Establish connection
3. Communicate
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. **Accept new connection**
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

```
/* Create a reliable, stream socket using TCP */
if ((clientSock = socket(PF_INET, SOCK_STREAM, IPPROTO_TCP)) < 0)
    DieWithError("socket() failed");
```

Client

1. **Create a TCP socket**
2. Establish connection
3. Communicate
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. **Accept new connection**
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

```
echoServAddr.sin_family = AF_INET;                          /* Internet address family */
echoServAddr.sin_addr.s_addr = inet_addr(echoservIP);       /* Server IP address*/
echoServAddr.sin_port = htons(echoServPort);                /* Server port */

if (connect(clientSock, (struct sockaddr *) &echoServAddr,
                        sizeof(echoServAddr)) < 0)
    DieWithError("connect() failed");
```

Client

1. Create a TCP socket
2. **Establish connection**
3. Communicate
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. **Accept new connection**
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

Server's accept procedure in now unblocked and returns client's socket

```
for (;;) /* Run forever */
{
  clntLen = sizeof(echoClntAddr);

  if ((clientSock=accept(servSock,(struct sockaddr *)&echoClntAddr,&clntLen))<0)
     DieWithError("accept() failed");
  ...
```

Client

1. Create a TCP socket
2. **Establish connection**
3. Communicate
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. **Accept new connection**
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

```
echoStringLen = strlen(echoString);     /* Determine input length */

/* Send the string to the server */
if (send(clientSock, echoString, echoStringLen, 0) != echoStringLen)
     DieWithError("send() sent a different number of bytes than expected");
```

Client

1. Create a TCP socket
2. Establish connection
3. **Communicate**
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. **Accept new connection**
   b. Communicate
   c. Close the connection

Example - Echo using stream socket

```
/* Receive message from client */
if ((recvMsgSize = recv(clntSocket, echoBuffer, RCVBUFSIZE, 0)) < 0)
    DieWithError("recv() failed");
/* Send received string and receive again until end of transmission */
while (recvMsgSize > 0) { /* zero indicates end of transmission */
   if (send(clientSocket, echobuffer, recvMsgSize, 0) != recvMsgSize)
      DieWithError("send() failed");
   if ((recvMsgSize = recv(clientSocket, echoBuffer, RECVBUFSIZE, 0)) < 0)
      DieWithError("recv() failed");
}
```

Client

1. Create a TCP socket
2. Establish connection
3. **Communicate**
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. Accept new connection
   b. **Communicate**
   c. Close the connection

Example - Echo using stream socket

Similarly, the client receives the data from the server

Client

1. Create a TCP socket
2. Establish connection
3. **Communicate**
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. Accept new connection
   b. **Communicate**
   c. Close the connection

Example - Echo using stream socket

```
close(clientSock);
```

```
close(clientSock);
```

Client

1. Create a TCP socket
2. Establish connection
3. Communicate
4. **Close the connection**

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. Accept new connection
   b. Communicate
   c. **Close the connection**

Example - Echo using stream socket

Server is now blocked waiting for connection from a client ...

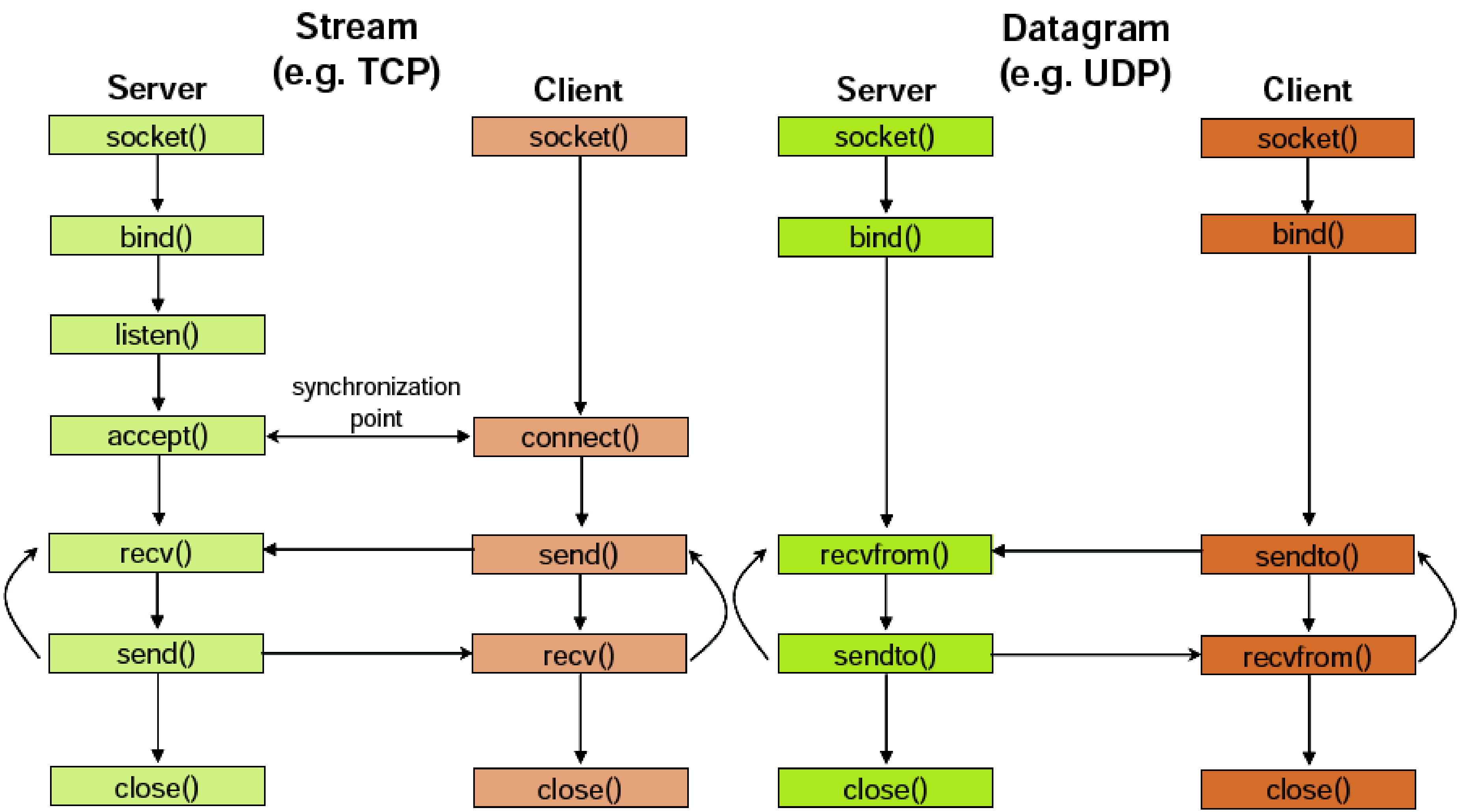
Client

1. Create a TCP socket
2. Establish connection
3. Communicate
4. Close the connection

Server

1. Create a TCP socket
2. Assign a port to socket
3. Set socket to listen
4. Repeatedly:
   a. **Accept new connection**
   b. Communicate
   c. Close the connection

Client - Server Communication - Unix



Socket Options

- `getsockopt` and `setsockopt` allow socket options values to be queried and set, respectively
- `int getsockopt (sockid, level, optName, optVal, optLen);`
  - sockid: integer, socket descriptor
  - level: integer, the layers of the protocol stack (socket, TCP, IP)
  - optName: integer, option
  - optVal: pointer to a buffer; upon return it contains the value of the specified option
  - optLen: integer, in-out parameter

  it returns -1 if an error occured
- `int setsockopt (sockid, level, optName, optVal, optLen);`
  - optLen is now only an input parameter

Socket Options
- Table

optName	Type	Values	Description
SOL_SOCKET Level			
SO_BROADCAST	int	0,1	Broadcast allowed
SO_KEEPALIVE	int	0,1	Keepalive messages enabled (if implemented by the protocol)
SO_LINGER	linger{}	time	Time to delay close() return waiting for confirmation (see Section 6.4.2)
SO_RCVBUF	int	bytes	Bytes in the socket receive buffer (see code on page 44 and Section 6.1)
SO_RCVLOWAT	int	bytes	Minimum number of available bytes that will cause recv() to return
SO_REUSEADDR	int	0,1	Binding allowed (under certain conditions) to an address or port already in use (see Section 6.4 and 6.5)
SO_SNDLOWAT	int	bytes	Minimum bytes to send a packet
SO_SNDBUF	int	bytes	Bytes in the socket send buffer (see Section 6.1)
IPPROTO_TCP Level			
TCP_MAX	int	seconds	Seconds between keepalive messages.
TCP_NODELAY	int	0,1	Disallow delay for data merging (Nagle's algorithm)
IPPROTO_IP Level			
IP_TTL	int	0-255	Time-to-live for unicast IP packets
IP_MULTICAST_TTL	unsigned char	0-255	Time-to-live for multicast IP packets (see MulticastSender.c on page 81)
IP_MULTICAST_LOOP	int	0,1	Enables multicast socket to receive packets it sent
IP_ADD_MEMBERSHIP	ip_mreq{}	group address	Enables reception of packets addressed to the specified multicast group (see MulticastReceiver.c on page 83)—set only
IP_DROP_MEMBERSHIP	ip_mreq{}	group address	Disables reception of packets addressed to the specified multicast group—set only

Socket Options - Example

- Fetch and then double the current number of bytes in the socket's receive buffer

```
int rcvBufferSize;
int sockOptSize;
…
/* Retrieve and print the default buffer size */
sockOptSize = sizeof(recvBuffSize);
if (getsockopt(sock, SOL_SOCKET, SO_RCVBUF, &rcvBufferSize, &sockOptSize) < 0)
   DieWithError("getsockopt() failed");
printf("Initial Receive Buffer Size: %d\n", rcvBufferSize);

/* Double the buffer size */
recvBufferSize *= 2;

/* Set the buffer size to new value */
if (setsockopt(sock, SOL_SOCKET, SO_RCVBUF, &rcvBufferSize,
               sizeof(rcvBufferSize)) < 0)
 DieWithError("getsockopt() failed");
```

Iterative Stream Socket Server

- Handles one client at a time
- Additional clients can connect while one is being served
  - connections are established
  - they are able to send requests

  but, the server will respond after it finishes with the first client
- Works well if each client required a small, bounded amount of work by the server
- otherwise, the clients experience long delays

Iterative Server - Example: echo using stream socket

```
#include <stdio.h>      /* for printf() and fprintf() */
#include <sys/socket.h> /* for socket(), bind(), connect(), recv() and send() */
#include <arpa/inet.h>  /* for sockaddr_in and inet_ntoa() */
#include <stdlib.h>     /* for atoi() and exit() */
#include <string.h>     /* for memset() */
#include <unistd.h>     /* for close() */

#define MAXPENDING 5    /* Maximum outstanding connection requests */

void DieWithError(char *errorMessage);  /* Error handling function */
void HandleTCPClient(int clntSocket);   /* TCP client handling function */

int main(int argc, char *argv[]) {
    int servSock;                    /* Socket descriptor for server */
    int clntSock;                    /* Socket descriptor for client */
    struct sockaddr_in echoServAddr; /* Local address */
    struct sockaddr_in echoClntAddr; /* Client address */
    unsigned short echoServPort;     /* Server port */
    unsigned int clntLen;            /* Length of client address data structure */

    if (argc != 2) {     /* Test for correct number of arguments */
        fprintf(stderr, "Usage:  %s <Server Port>\n", argv[0]);
        exit(1);
    }

    echoServPort = atoi(argv[1]);  /* First arg:  local port */

    /* Create socket for incoming connections */
    if ((servSock = socket(PF_INET, SOCK_STREAM, IPPROTO_TCP)) < 0)
        DieWithError("socket() failed");

    ...
```

Iterative Server - Example: echo using stream socket

```
    ...

    /* Construct local address structure */
    memset(&echoServAddr, 0, sizeof(echoServAddr));   /* Zero out structure */
    echoServAddr.sin_family = AF_INET;                /* Internet address family */
    echoServAddr.sin_addr.s_addr = htonl(INADDR_ANY); /* Any incoming interface */
    echoServAddr.sin_port = htons(echoServPort);      /* Local port */

    /* Bind to the local address */
    if (bind(servSock, (struct sockaddr *) &echoServAddr, sizeof(echoServAddr)) < 0)
        DieWithError("bind() failed");

    /* Mark the socket so it will listen for incoming connections */
    if (listen(servSock, MAXPENDING) < 0)
        DieWithError("listen() failed");

    for (;;) /* Run forever */
    {
        /* Set the size of the in-out parameter */
        clntLen = sizeof(echoClntAddr);

        /* Wait for a client to connect */
        if ((clntSock = accept(servSock, (struct sockaddr *) &echoClntAddr,
                               &clntLen)) < 0)
            DieWithError("accept() failed");

        /* clntSock is connected to a client! */

        printf("Handling client %s\n", inet_ntoa(echoClntAddr.sin_addr));

        HandleTCPClient(clntSock);
    }
    /* NOT REACHED */
}
```

Iterative Server - Example: echo using stream socket

```
#define RCVBUFSIZE 32   /* Size of receive buffer */

void HandleTCPClient(int clntSocket)
{
    char echoBuffer[RCVBUFSIZE];        /* Buffer for echo string */
    int recvMsgSize;                    /* Size of received message */

    /* Receive message from client */
    if ((recvMsgSize = recv(clntSocket, echoBuffer, RCVBUFSIZE, 0)) < 0)
        DieWithError("recv() failed");

    /* Send received string and receive again until end of transmission */
    while (recvMsgSize > 0)      /* zero indicates end of transmission */
    {
        /* Echo message back to client */
        if (send(clntSocket, echoBuffer, recvMsgSize, 0) != recvMsgSize)
            DieWithError("send() failed");

        /* See if there is more data to receive */
        if ((recvMsgSize = recv(clntSocket, echoBuffer, RCVBUFSIZE, 0)) < 0)
            DieWithError("recv() failed");
    }

    close(clntSocket);    /* Close client socket */
}
```

Multitasking - Per-Client Process

- For each client connection request, a new process is created to handle the communication
- `int fork();`
  - a new process is created, identical to the calling process, except for its process ID and the return value it receives from `fork()`
  - returns 0 to **child** process, and the process ID of the new child to **parent**

Caution:

- when a child process terminates, it does not automatically disappears
- use `waitpid()` to parent in order to "harvest" zombies

Multitasking - Per-Client Process

- Example: echo using stream socket

```
#include <sys/wait.h>                /* for waitpid() */

int main(int argc, char *argv[]) {
   int servSock;                     /* Socket descriptor for server */
   int clntSock;                     /* Socket descriptor for client */
   unsigned short echoServPort;      /* Server port */
   pid_t processID;                  /* Process ID from fork()*/
   unsigned int childProcCount = 0;  /* Number of child processes */

   if (argc != 2) {      /* Test for correct number of arguments */
      fprintf(stderr, "Usage:  %s <Server Port>\n", argv[0]);
      exit(1);
   }
   echoServPort = atoi(argv[1]);     /* First arg:  local port */

   servSock = CreateTCPServerSocket(echoServPort);

   for (;;) { /* Run forever */
      clntSock = AcceptTCPConnection(servSock);

      if ((processID = fork()) < 0) DieWithError ("fork() failed");  /* Fork child process */
      else if (processID = 0) {      /* This is the child process */
         close(servSock);            /* child closes listening socket */
         HandleTCPClient(clntSock);
         exit(0);                    /* child process terminates */
      }

      close(clntSock);               /* parent closes child socket */
      childProcCount++;              /* Increment number of outstanding child processes */

      ...
```

Multitasking - Per-Client Process

- Example: echo using stream socket

```
      ...
      while (childProcCount) {                            /* Clean up all zombies */
         processID = waitpid((pid_t) -1, NULL, WHOANG);    /* Non-blocking wait */
         if (processID < 0) DieWithError ("...");
         else if (processID == 0) break;                  /* No zombie to wait */
         else childProcCount--;                           /* Cleaned up after a child */
      }
   }
   /* NOT REACHED */
}
```

Multitasking - Per-Client Thread

- Forking a new process is expensive
  - duplicate the entire state (memory, stack, file/socket descriptors, …)
- Threads decrease this cost by allowing multitasking within the same process
  - threads share the same address space (code and data)

An example is provided using POSIX Threads

Multitasking - Per-Client Thread

- Example: echo using stream socket

```
#include <pthread.h>              /* for POSIX threads */

void *ThreadMain(void *arg)       /* Main program of a thread */

struct ThreadArgs {               /* Structure of arguments to pass to client thread */
   int clntSock;                  /* socket descriptor for client */
};

int main(int argc, char *argv[]) {
   int servSock;                  /* Socket descriptor for server */
   int clntSock;                  /* Socket descriptor for client */
   unsigned short echoServPort;   /* Server port */
   pthread_t threadID;            /* Thread ID from pthread_create()*/
   struct ThreadArgs *threadArgs; /* Pointer to argument structure for thread */

   if (argc != 2) {      /* Test for correct number of arguments */
      fprintf(stderr, "Usage:  %s <Server Port>\n", argv[0]);
      exit(1);
   }
   echoServPort = atoi(argv[1]);  /* First arg:  local port */

   servSock = CreateTCPServerSocket(echoServPort);

   for (;;) { /* Run forever */
      clntSock = AcceptTCPConnection(servSock);

      /* Create separate memory for client argument */
      if ((threadArgs = (struct ThreadArgs *) malloc(sizeof(struct ThreadArgs)))) == NULL) DieWithError("…");
      threadArgs -> clntSock = clntSock;

      /* Create client thread */
      if (pthread_create (&threadID, NULL, ThreadMain, (void *) threadArgs) != 0) DieWithError("…");
   }
   /* NOT REACHED */
}
```

Multitasking - Per-Client Thread

- Example: echo using stream socket

```
void *ThreadMain(void *threadArgs)
{
    int clntSock;                    /* Socket descriptor for client connection */

    pthread_detach(pthread_self()); /* Guarantees that thread resources are deallocated upon return */

    /* Extract socket file descriptor from argument */
    clntSock = ((struct ThreadArgs *) threadArgs) -> clntSock;
    free(threadArgs);               /* Deallocate memory for argument */

    HandleTCPClient(clntSock);

    return (NULL);
}
```

Multitasking - Constrained

- Both process and thread incurs **overhead**
  - creation, scheduling and context switching
- As their numbers increases
  - this overhead increases
  - after some point it would be better if a client was blocked
- Solution: **Constrained multitasking**. The server:
  - begins, creating, binding and listening to a socket
  - creates a number of processes, each loops forever and accept connections from the same socket
  - when a connection is established
    - the client socket descriptor is returned to only one process
    - the other remain blocked

Multitasking - Constrained

- Example: echo using stream socket

```
void ProcessMain(int servSock);       /* Main program of process */

int main(int argc, char *argv[]) {
    int servSock;                     /* Socket descriptor for server*/
    unsigned short echoServPort;      /* Server port */
    pid_t processID;                  /* Process ID */
    unsigned int processLimit;        /* Number of child processes to create */
    unsigned int processCt;           /* Process counter */

    if (argc != 3) {      /* Test for correct number of arguments */
        fprintf(stderr,"Usage:  %s <SERVER PORT> <FORK LIMIT>\n", argv[0]);
        exit(1);
    }

    echoServPort = atoi(argv[1]);  /* First arg: local port */
    processLimit = atoi(argv[2]);  /* Second arg:  number of child processes */

    servSock = CreateTCPServerSocket(echoServPort);

    for (processCt=0; processCt < processLimit; processCt++)
        if ((processID = fork()) < 0) DieWithError("fork() failed");    /* Fork child process */
        else if (processID == 0) ProcessMain(servSock);                /* If this is the child process */

    exit(0);  /* The children will carry on */
}

void ProcessMain(int servSock) {
    int clntSock;                   /* Socket descriptor for client connection */

    for (;;) { /* Run forever */
        clntSock = AcceptTCPConnection(servSock);
        printf("with child process: %d\n", (unsigned int) getpid());
        HandleTCPClient(clntSock);
    }
}
```

The End - Questions