Introduction to Sockets Programming in C using TCP/IP

Esta presentación se tomó del libro:
TCP/IP Sockets in C. Practical guide for programmers
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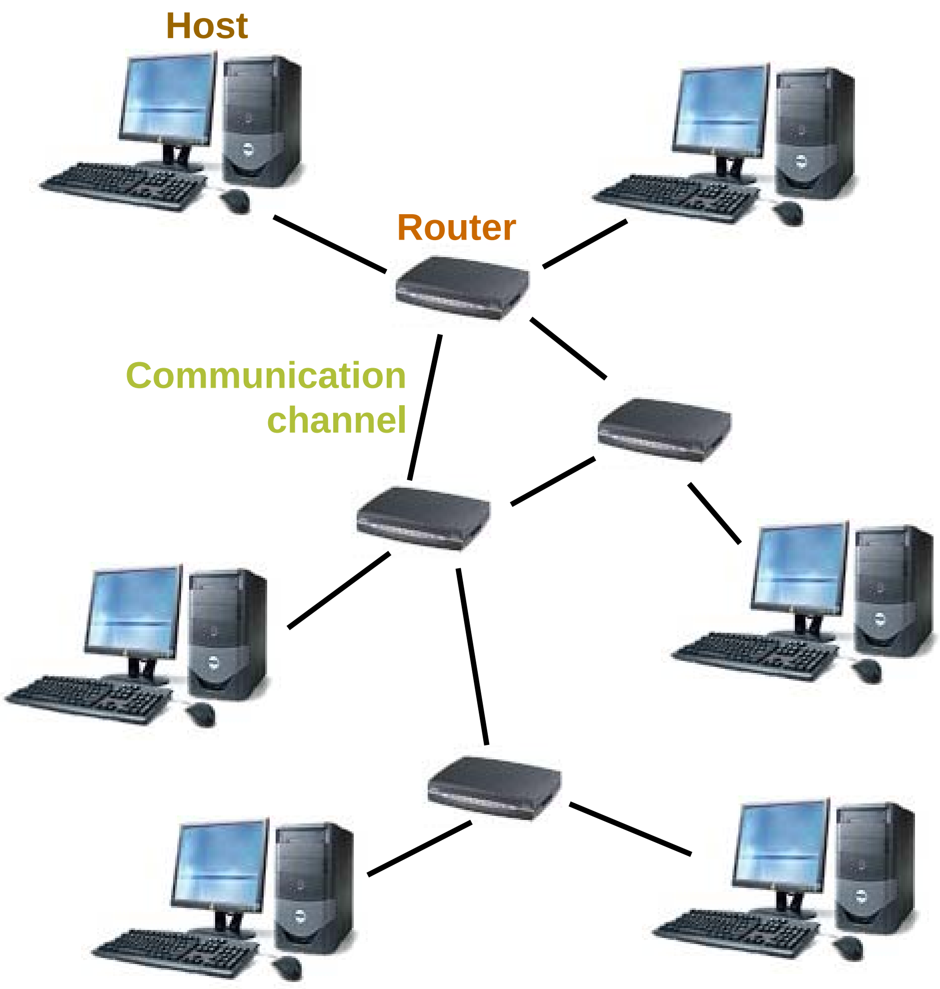
Introduction

- 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

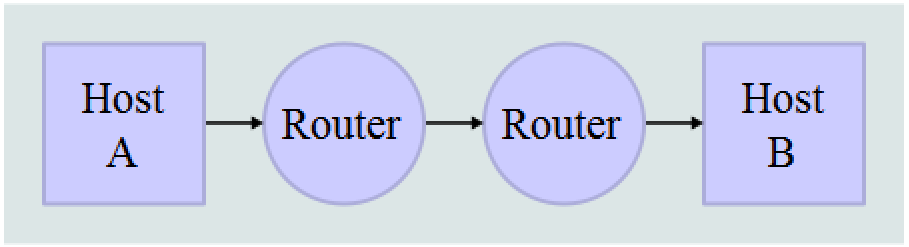
☞ **Protocol Suites** or **Protocol Families:** TCP/IP

- 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

Network Topology

*



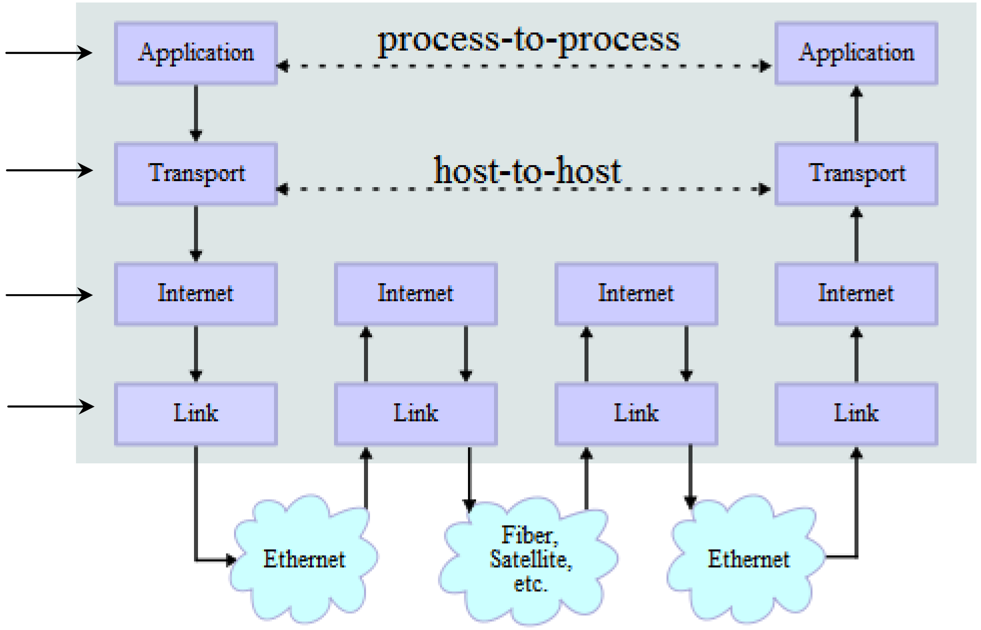
Data Flow

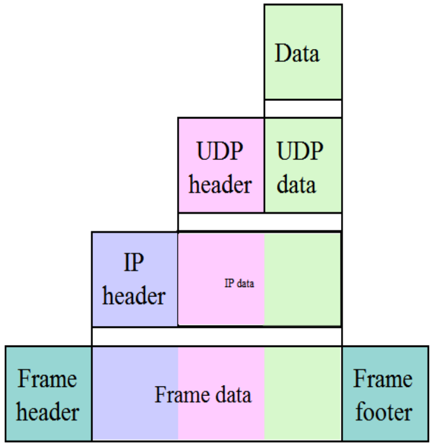
FTP, SMTP, …

Transport Layer
TCP or UDP

Network Layer
IP

Communication
Channels



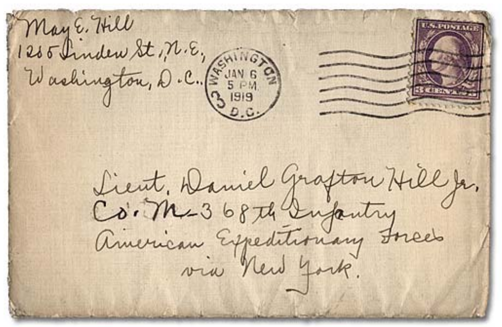


* image is taken from "http://en.wikipedia.org/wiki/TCP/IP_model"

Internet Protocol (IP)

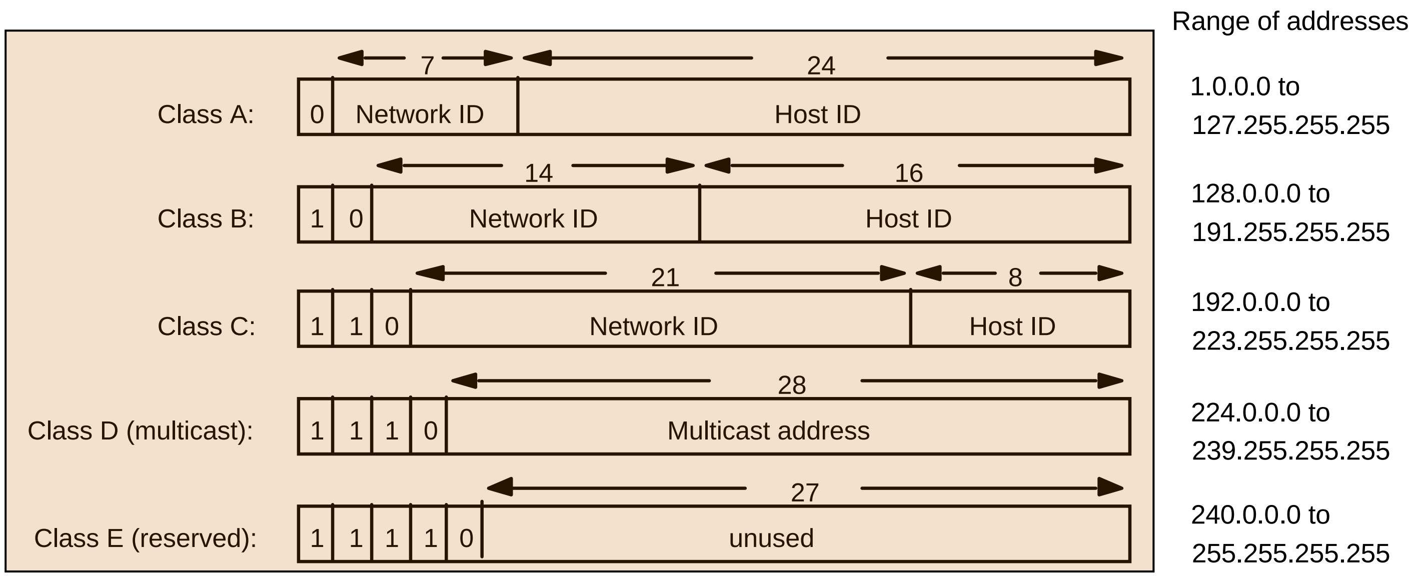
- provides a datagram service
  - packets are handled and delivered independently
- best-effort protocol
  - may loose, reorder or duplicate packets

- each packet must contain an IP address of its destination

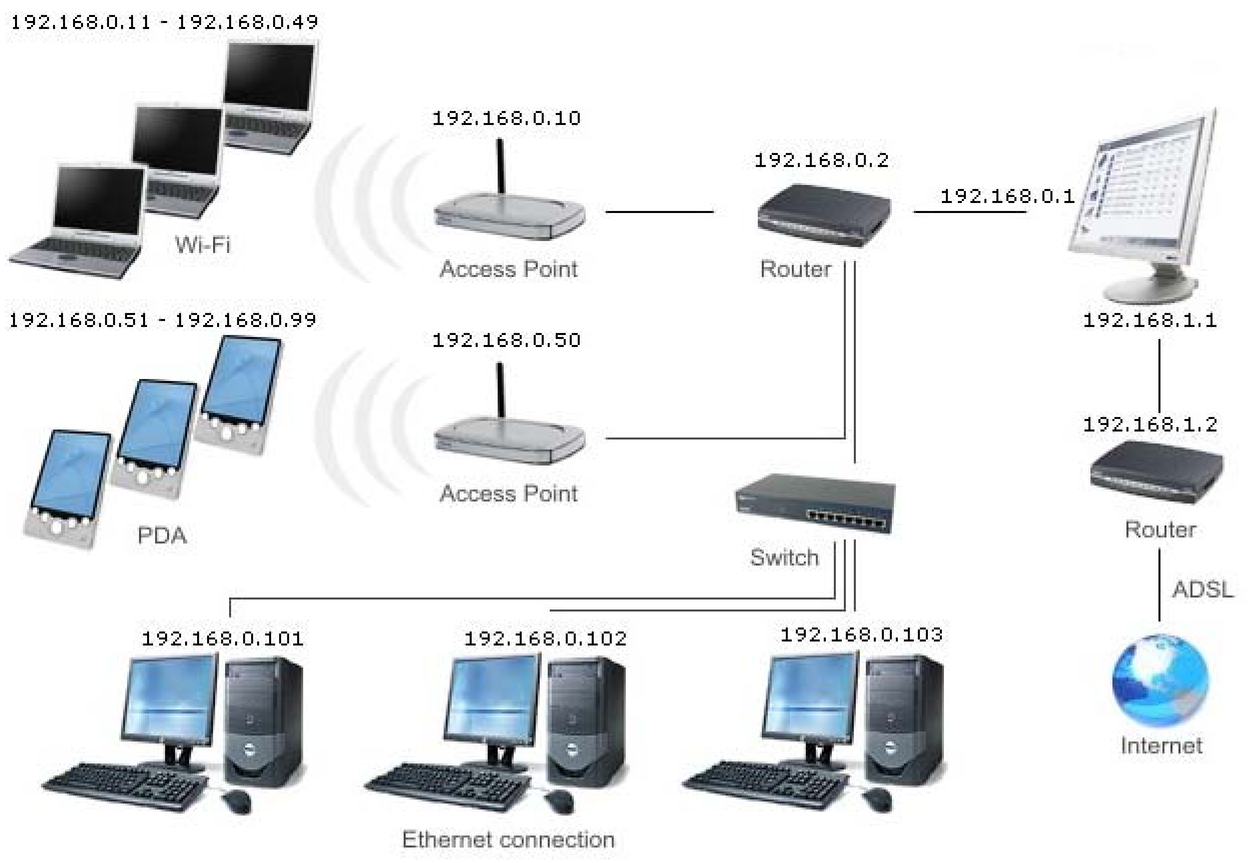


Addresses - IPv4

- 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

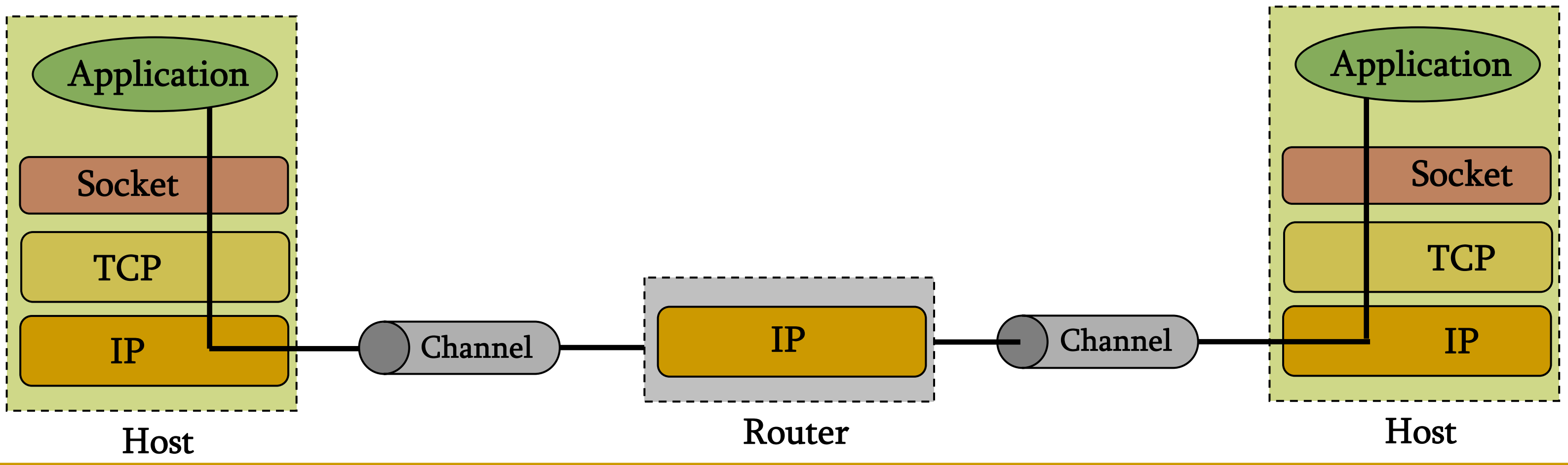
- TCP is used for services with a large data capacity, and a persistent connection
- UDP is more commonly used for quick lookups, and single use query-reply actions.

- 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

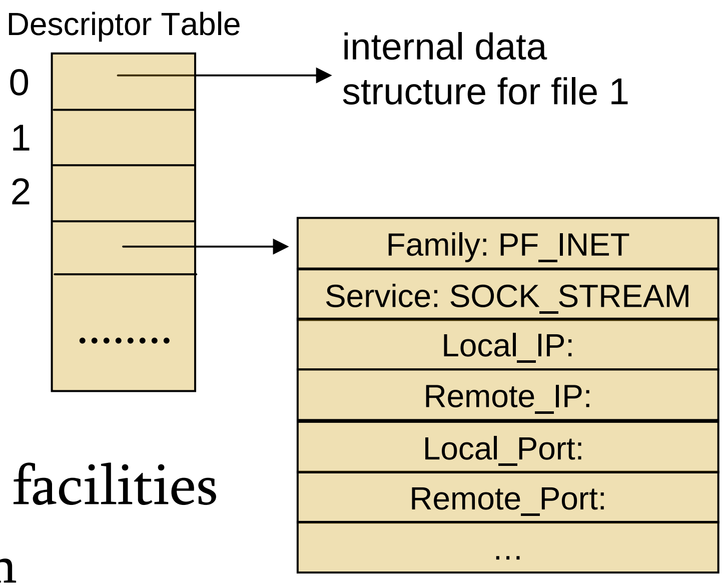
Berkley Sockets

- 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



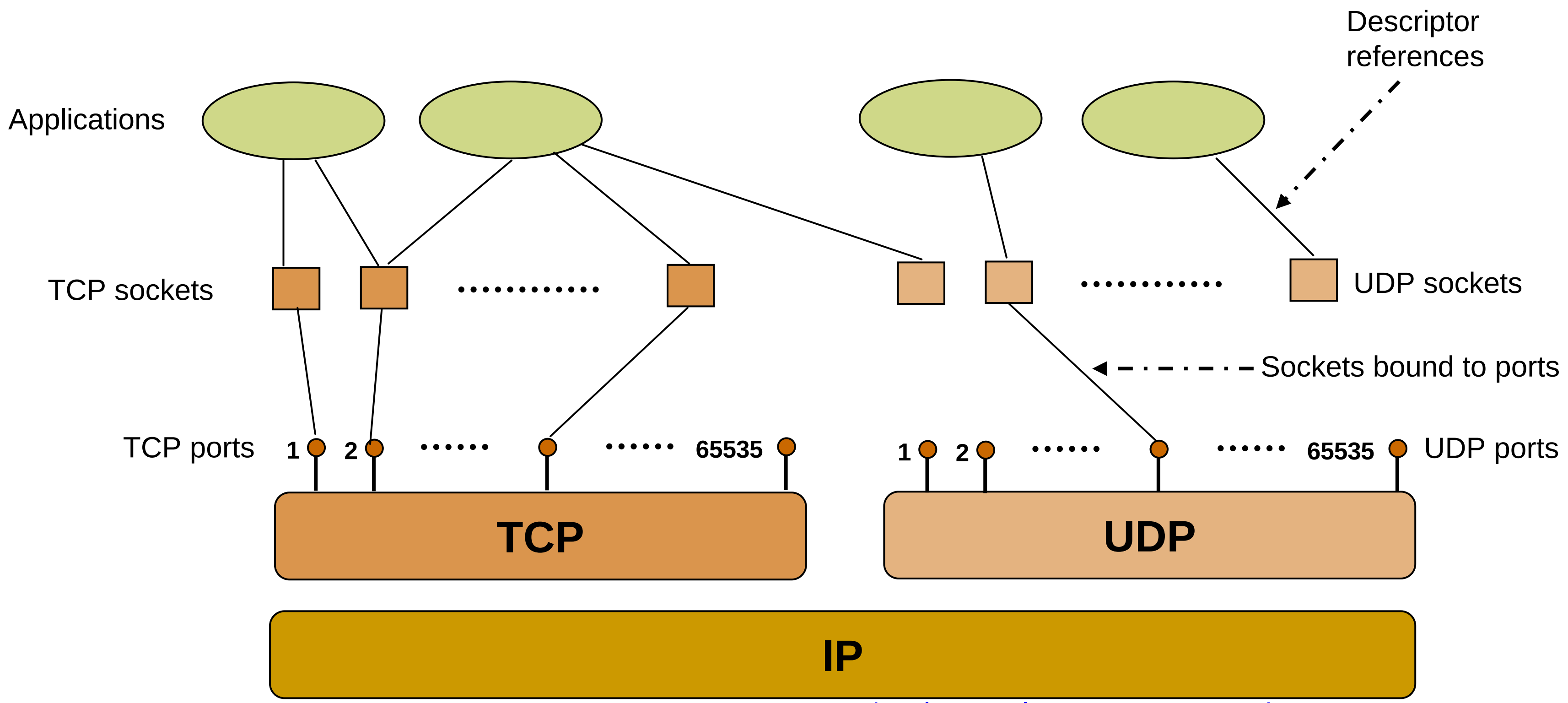
Sockets

- 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



Cuando un socket es creado, tiene asociado un protocolo pero aún no una dirección IP ni un puerto, esto se hace con la función Bind.
Hasta que un socket es ligado o asociado a un número de puerto, no puedo recibir mensajes de una aplicación remota.

Sockets



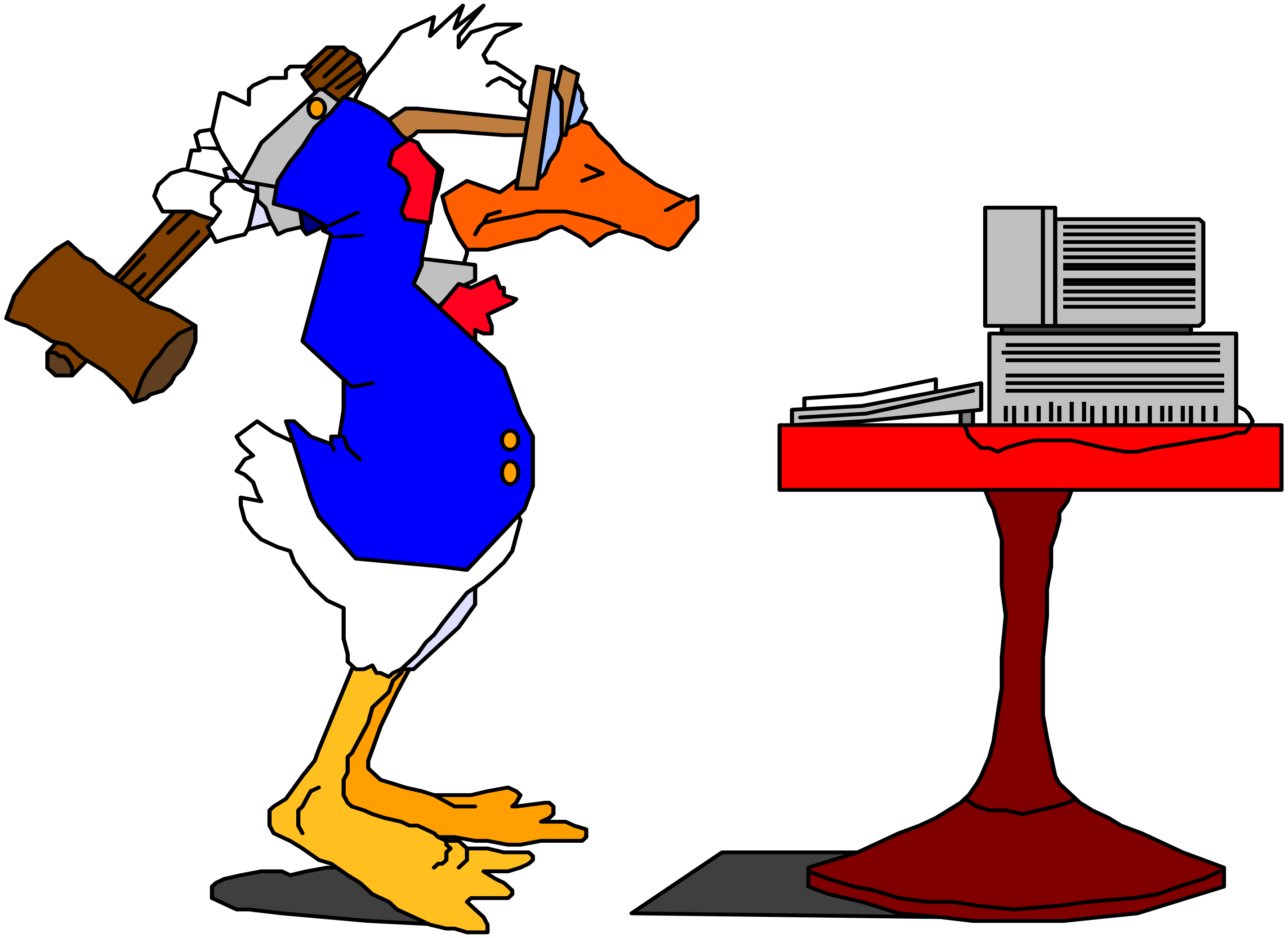
Cada programa que tiene una referencia (descriptor) con un socket en particular puede comunicarse a través del socket. Desde el punto de vista del host, un puerto identifica a un socket en ese host.

De acuerdo a la IANA los puertos se organizan en:

0 - 1023	--- puertos de sistema
1024 - 49151	--- puertos de usuario
49152 - 65535	--- puertos dinámicos o privados

generalmente un cliente establece comunicación con un servidor a través de un socket usando un puerto de usuario o un puerto dinámico.

Socket Programming



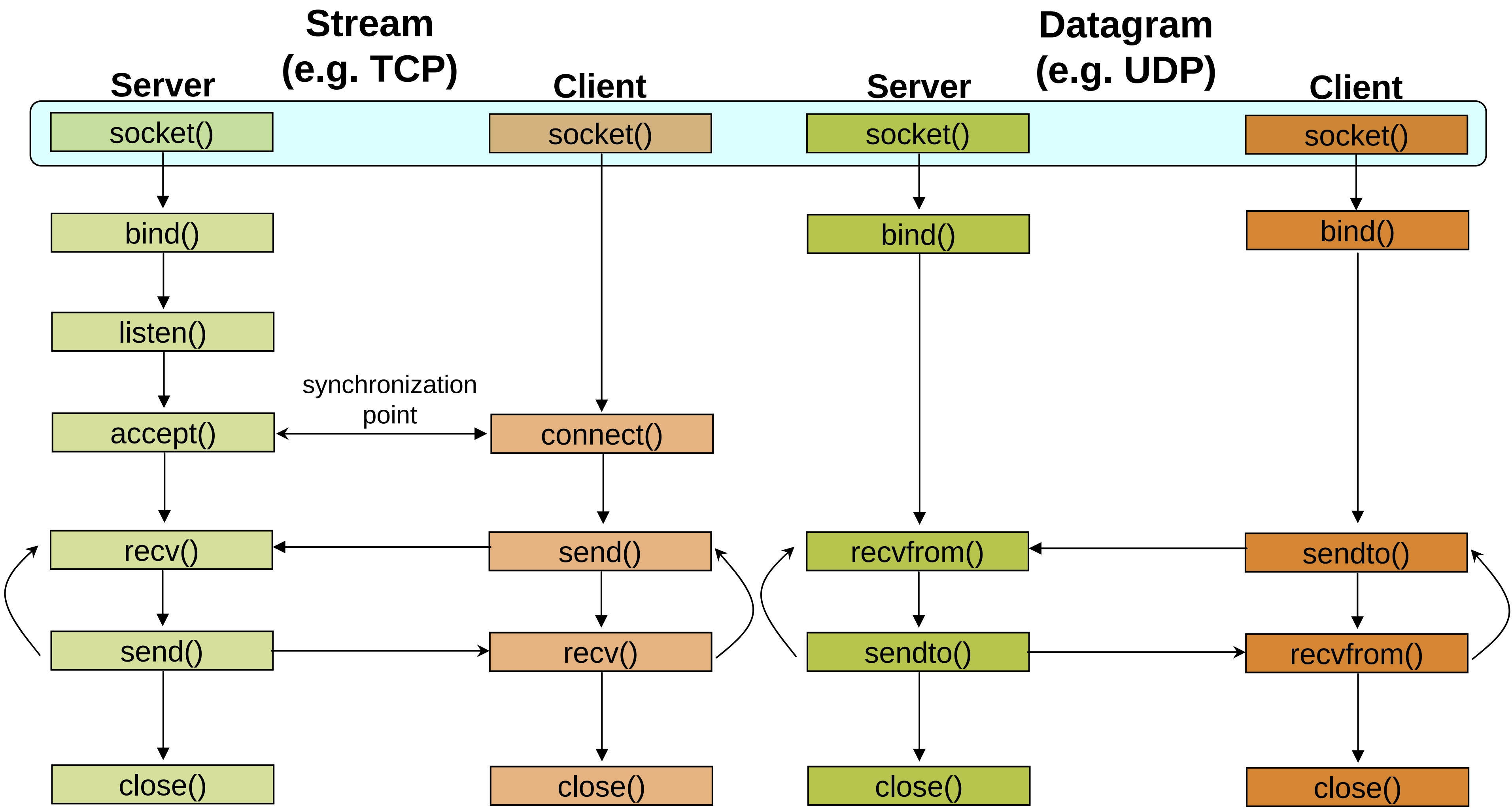
Client-Server communication

- 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



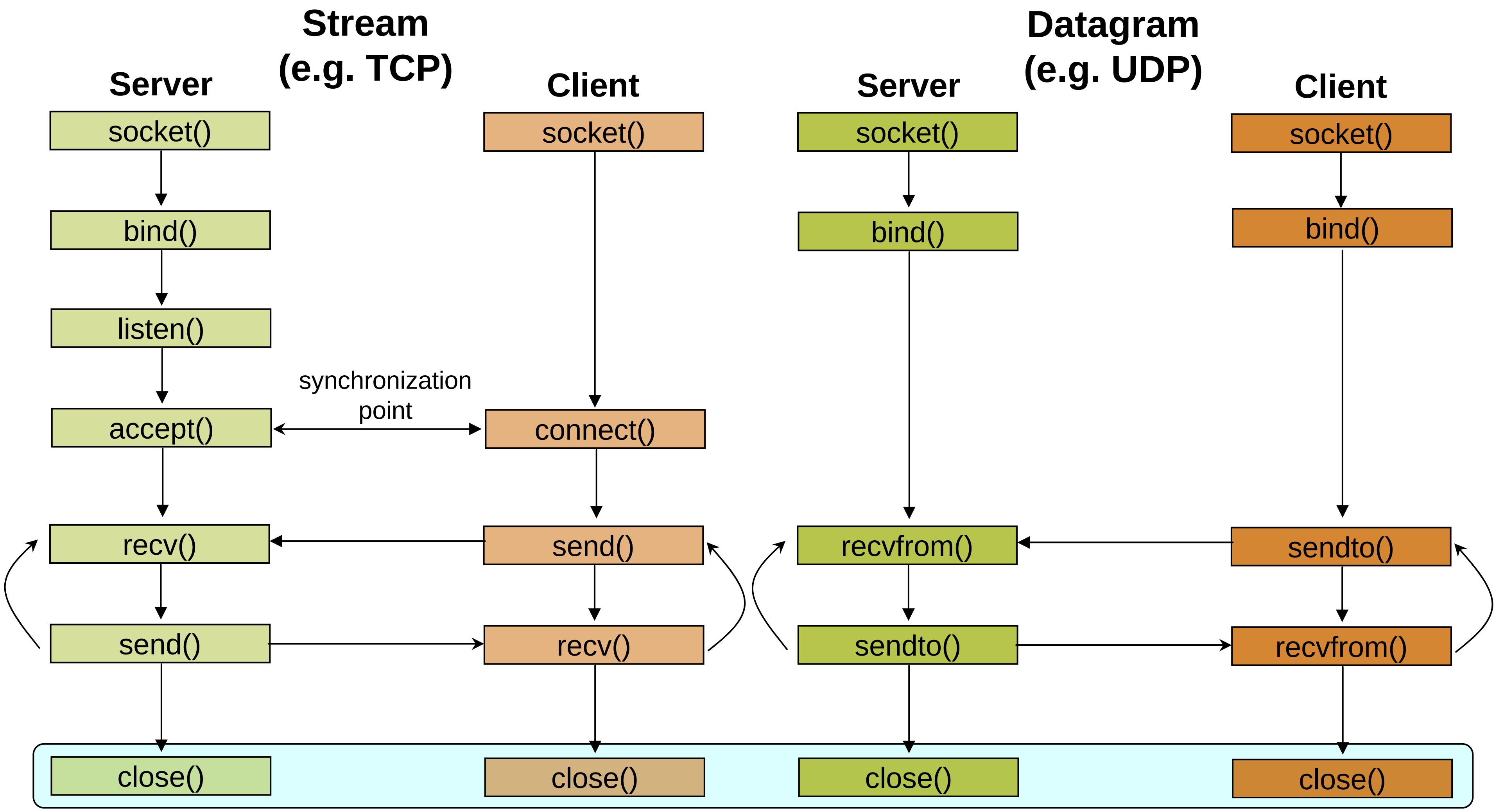
Socket creation in C: `socket()`

El programa solicita al SO la creación de una instancia de la "abstracción 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:

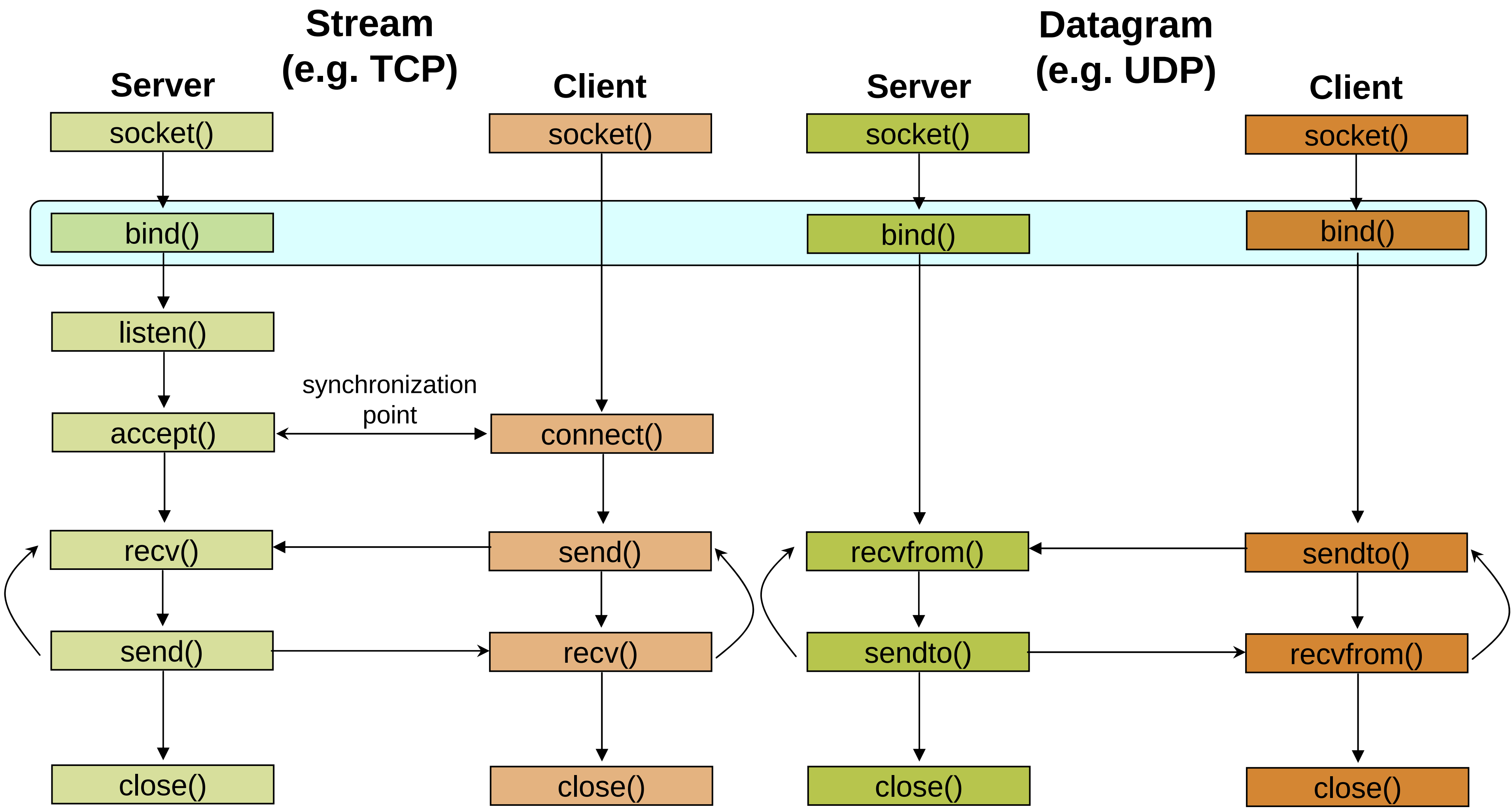
```
struct sockaddr {
    unsigned short sa_family;  /* Address family (e.g. AF_INET) */
    char sa_data[14];          /* Family-specific address information */
}
```

- 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

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

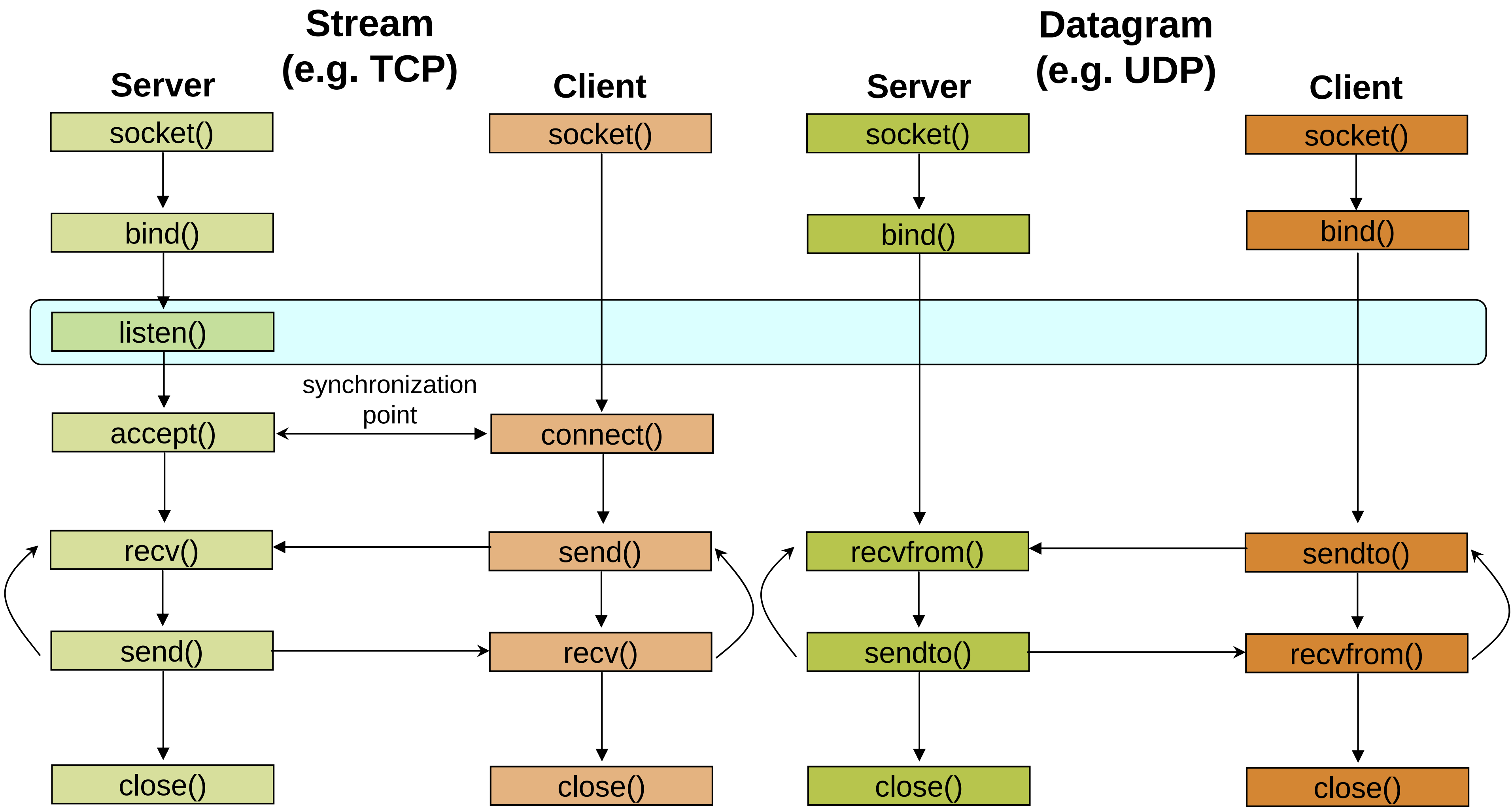
bind()- Example with TCP

```
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)

Client - Server Communication - Unix



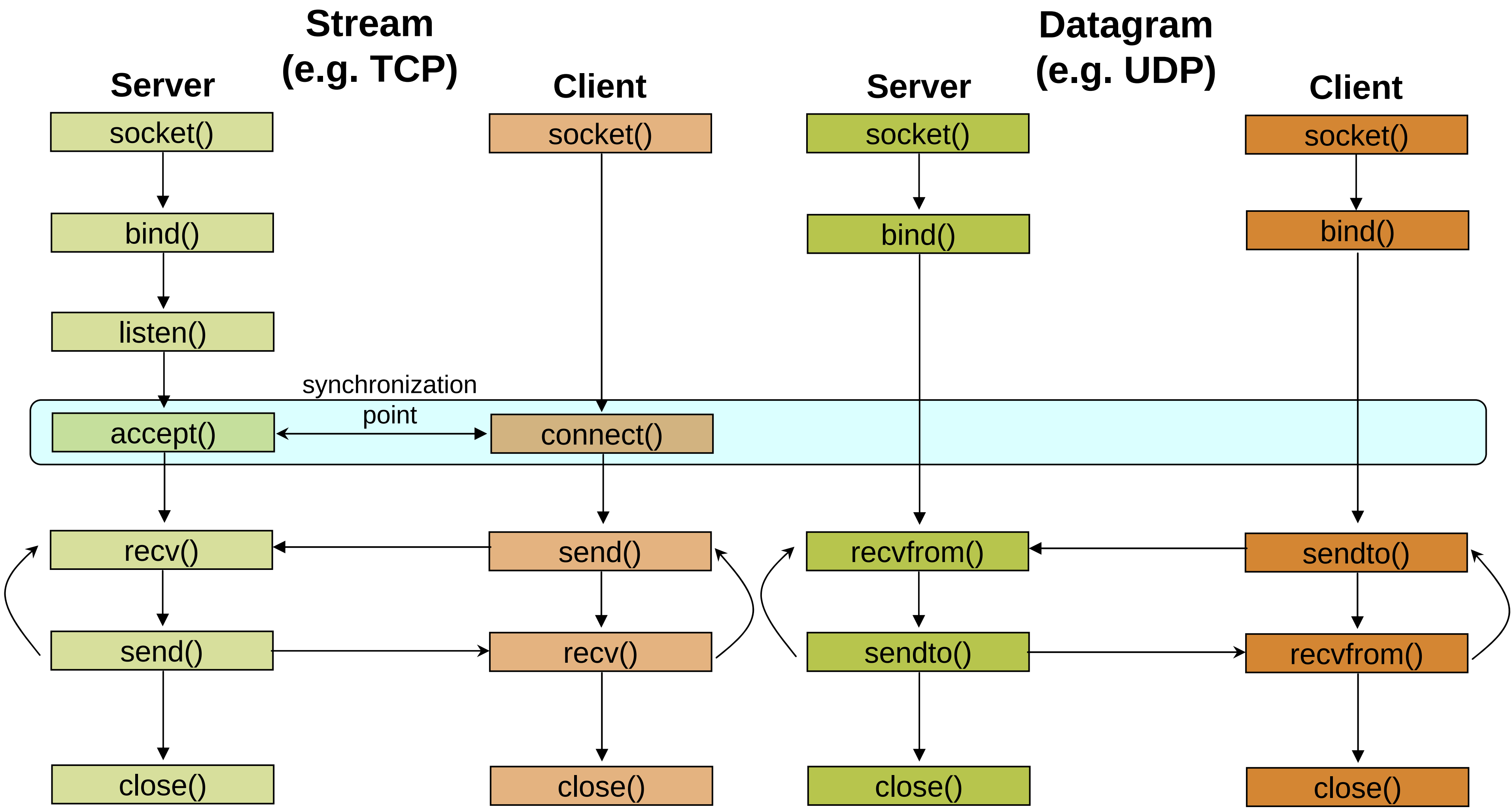
Assign address to socket: `bind()`

- 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



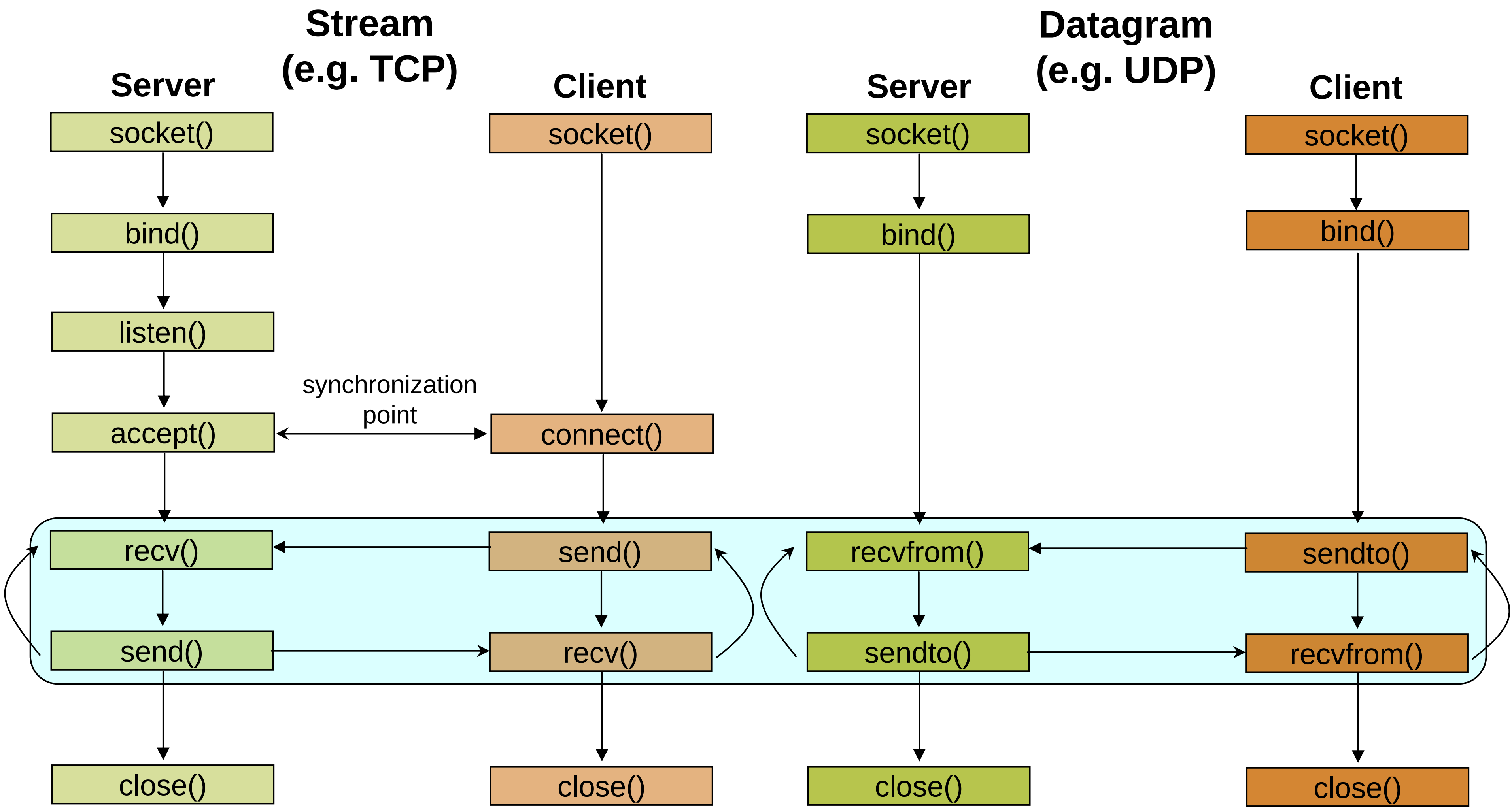
Establish Connection: `connect()`

- 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

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

Example - Echo

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

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:
   1. Accept new connection
   2. Communicate
   3. **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

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);
```

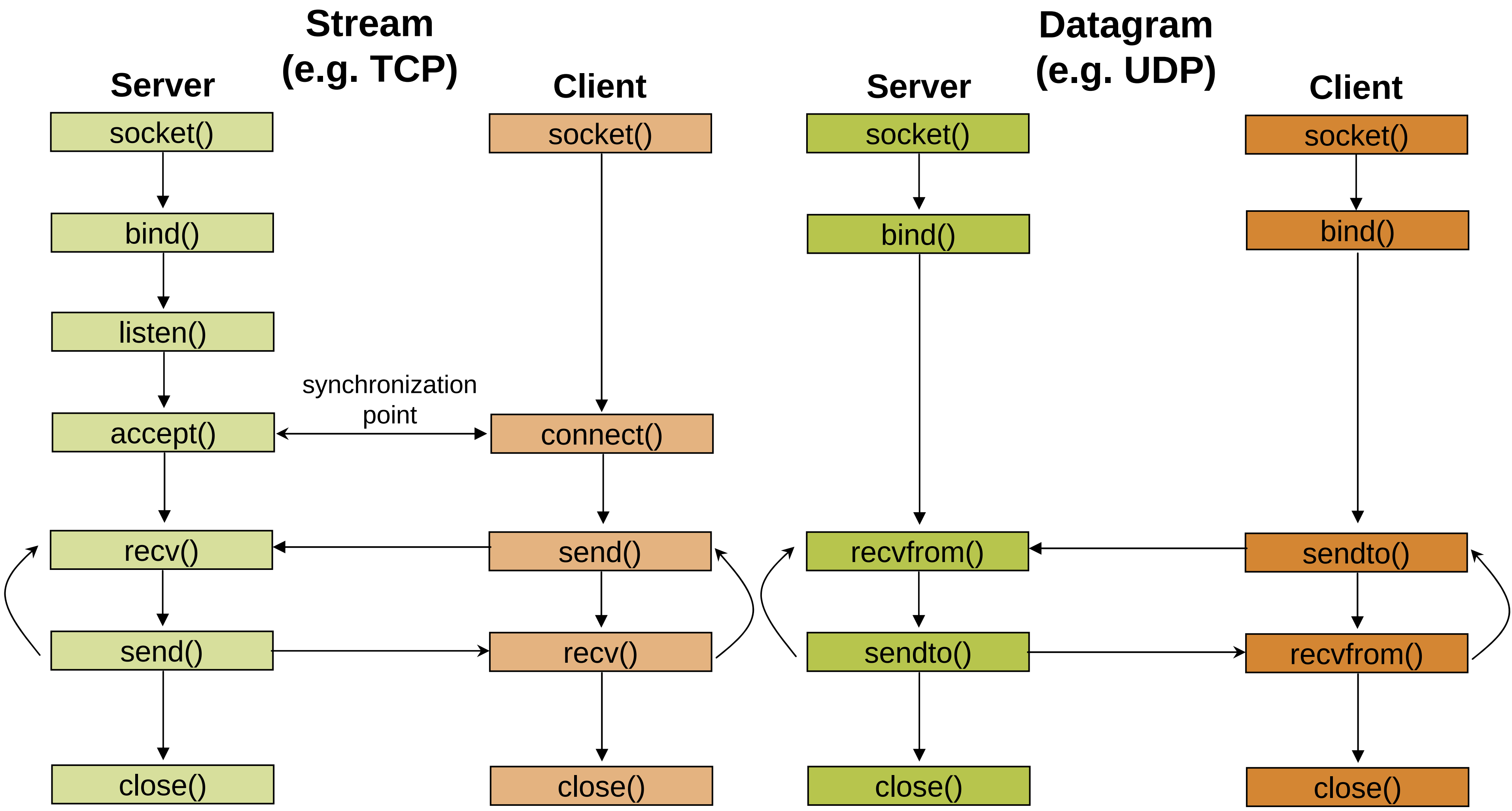
Client

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



Constructing Messages - Encoding Data

- Client wants to send two integers `x` and `y` to server
- 1st Solution: **Character Encoding**
  - e.g. ASCII
  - 👍 the same representation is used to print or display them to screen
  - 👍 allows sending arbitrarily large numbers (at least in principle)
- e.g. `x = 17,998,720` and `y = 47,034,615`

49	**55**	**57**	**57**	**56**	**55**	**50**	**48**	**32**	**52**	**55**	**48**	**51**	**52**	**54**	**49**	**53**	**32**
1	7	9	9	8	7	2	0	_	4	7	0	3	4	6	1	5	_

```
sprintf(msgBuffer, “%d %d ”, x, y);
send(clientSocket, strlen(msgBuffer), 0);
```

Constructing Messages - Encoding Data

- Pitfalls
  - the second delimiter is required
    - otherwise the server will not be able to separate it from whatever it follows
  - `msgBuffer` must be large enough
  - strlen counts only the bytes of the message
    - not the null at the end of the string
- This solution is not efficient
  - each digit can be represented using 4 bits, instead of one byte
  - it is inconvenient to manipulate numbers
- 2nd Solution: Sending the values of `x` and `y`

Constructing Messages - Encoding Data

- 2nd Solution: Sending the values of `x` and `y`
  - pitfall: native integer format
  - ☞ a **protocol** is used
    - how many bits are used for each integer
    - what type of encoding is used (e.g. two's complement, sign/magnitude, unsigned)

1st Implementation

```
typedef struct {
  int x,y;
} msgStruct;
…
msgStruct.x = x;  msgStruct.y = y;
send(clientSock, &msgStruct, sizeof(msgStruct), 0);
```

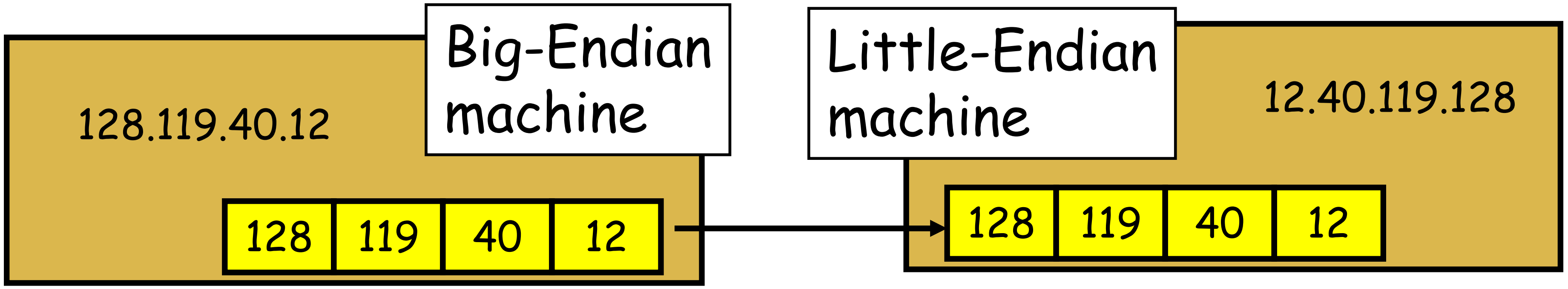
2nd Implementation

```
send(clientSock, &x, sizeof(x)), 0);
send(clientSock, &y, sizeof(y)), 0);
```

2nd implementation works in any case?

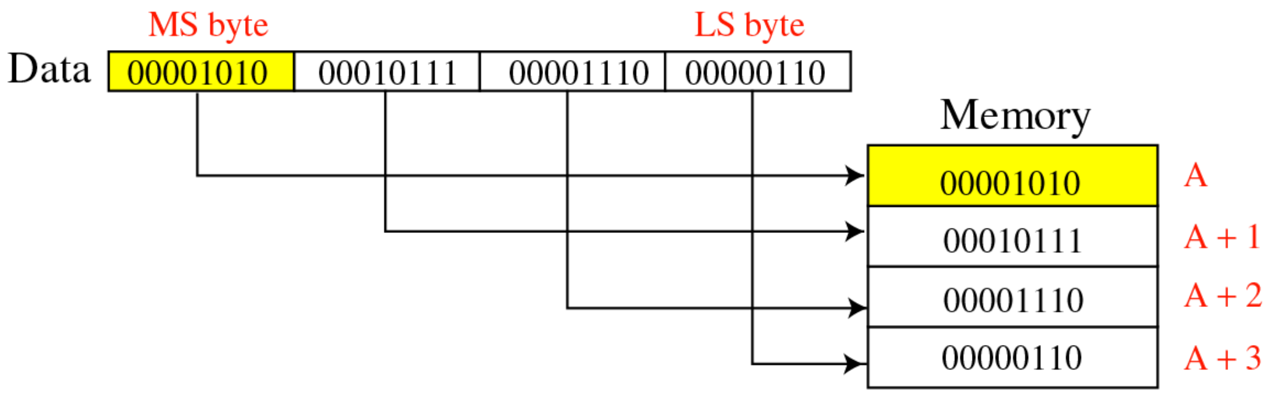
Constructing Messages - Byte Ordering

- 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

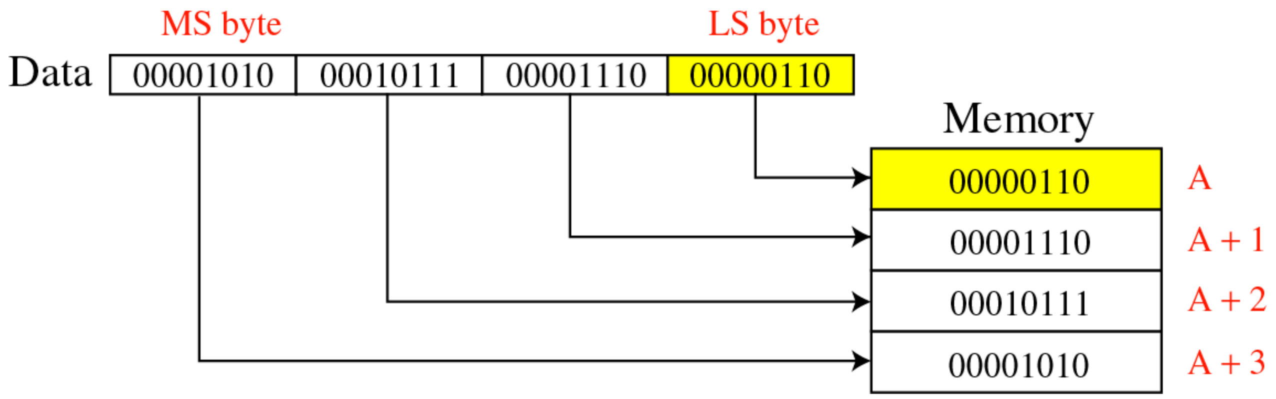


Constructing Messages - Byte Ordering

- Big-Endian:



- Little-Endian:

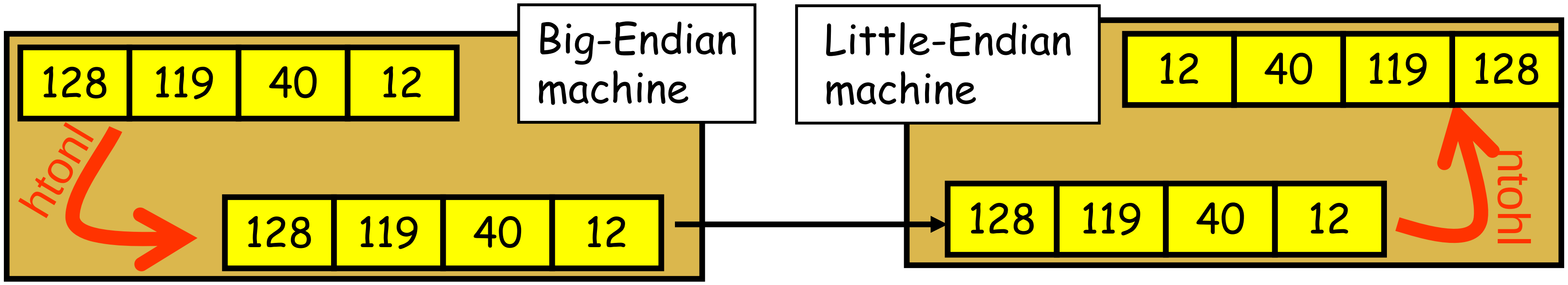


Constructing Messages - Byte Ordering - Solution: Network Byte Ordering

- 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

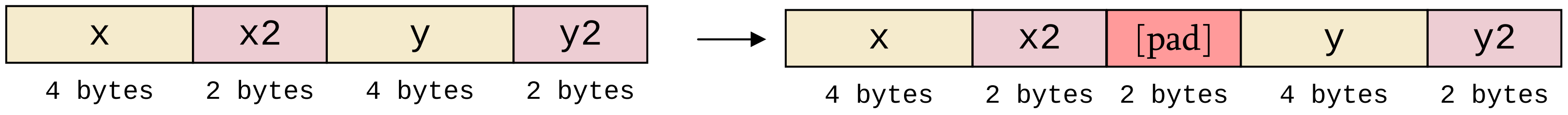
```
unsigned short clientPort, rcvBuffer;
unsigned int recvMsgSize ;

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);
```

Constructing Messages - Alignment and Padding

- consider the following 12 byte structure

```
typedef struct {
   int x;
   short x2;
   int y;
   short y2;
} msgStruct;
```

- After compilation it will be a 14 byte structure!
- Why? → Alignment!
- Remember the following rules:
  - data structures are maximally aligned, according to the size of the largest native integer
  - other multibyte fields are aligned to their size, e.g., a four-byte integer's address will be divisible by four



- This can be avoided
  - include padding to data structure
  - reorder fields

```
typedef struct {
   int x;
   short x2;
   char pad[2];
   int y;
   short y2;
} msgStruct;
```

```
typedef struct {
   int x;
   int y;
   short x2;
   short y2;
} msgStruct;
```

Constructing Messages - Framing and Parsing

- **Framing** is the problem of formatting the information so that the receiver can **parse** messages
- **Parse** means to locate the beginning and the end of message

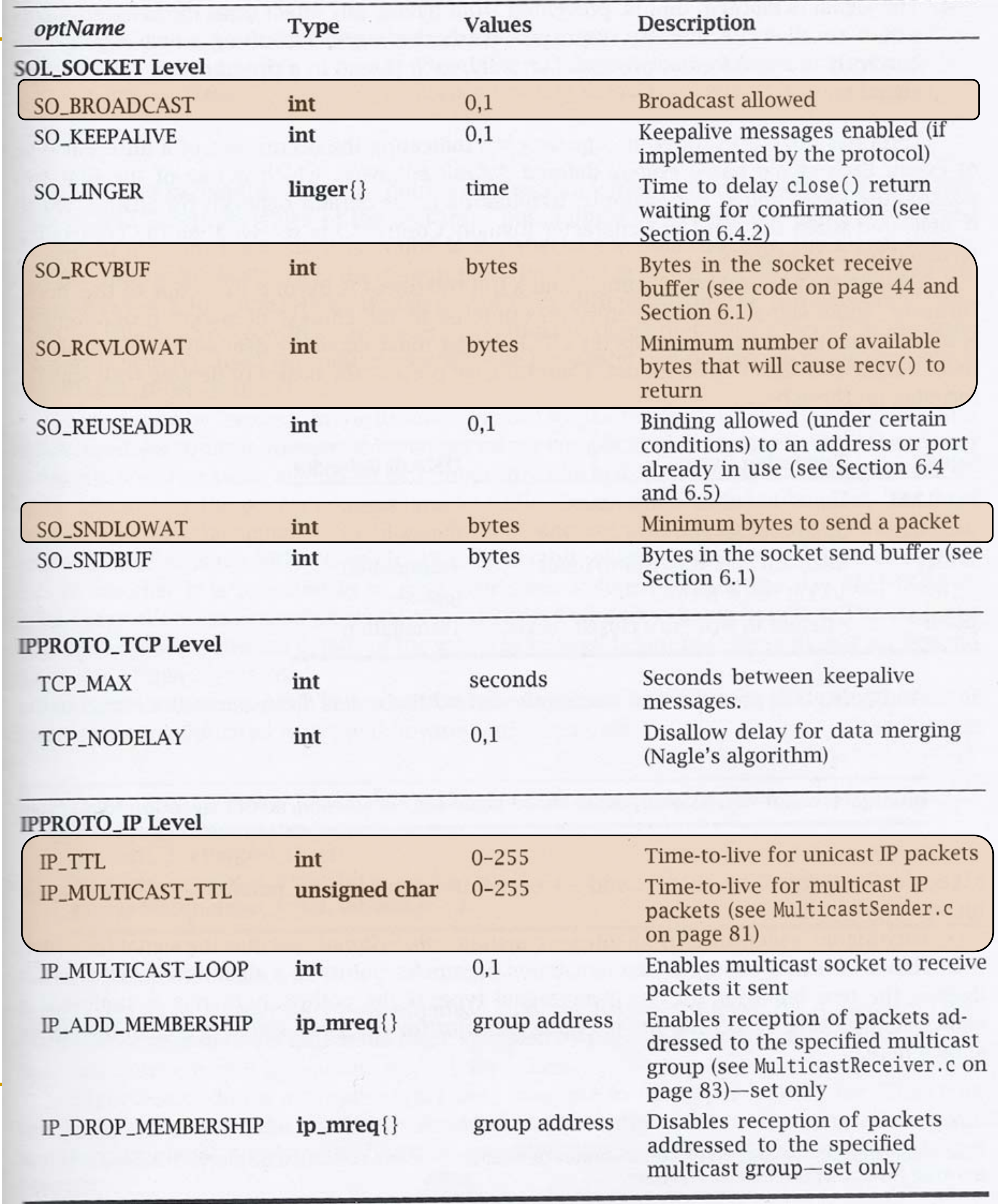
- This is easy if the fields have fixed sizes
  - e.g., `msgStruct`
- For text-string representations is harder
  - Solution: use of appropriate delimiters
  - caution is needed since a call of `recv` may return the messages sent by multiple calls of `send`

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");
```

Dealing with blocking calls

- Many of the functions we saw block (by default) 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
    - what if a packet is lost (in datagram socket)?
  - **send**: until data are pushed into socket's buffer
  - **sendto**: until data are given to the network subsystem
- For **simple programs**, blocking is convenient
- What about more **complex programs**?
  - multiple connections
  - simultaneous sends and receives
  - simultaneously doing non-networking processing

Dealing with blocking calls

- Non-blocking Sockets
- Asynchronous I/O
- Timeouts

Non-blocking Sockets

- If an operation can be completed immediately, success is returned; otherwise, a failure is returned (usually -1)
  - `errno` is properly set, to distinguish this (blocking) failure from other - (`EINPROGRESS` for `connect`, `EWOULDBLOCK` for the other)
- 1st Solution: `int fcntl (sockid, command, argument);`
  - sockid: integer, socket descriptor
  - command: integer, the operation to be performed (`F_GETFL`, `F_SETFL`)
  - argument: long, e.g. `O_NONBLOCK`
  - ☞ `fcntl (sockid, F_SETFL, O_NONBLOCK);`
- 2nd Solution: flags parameter of `send`, `recv`, `sendto`, `recvfrom`
  - `MSG_DONTWAIT`
  - not supported by all implementations

Signals

- Provide a mechanism for operating system to notify processes that certain events occur
  - e.g., the user typed the "interrupt" character, or a timer expired
- signals are delivered asynchronously
- upon signal delivery to program
  - it may be ignored, the process is never aware of it
  - the program is forcefully terminated by the OS
  - a signal-handling routine, specified by the program, is executed
    - this happens in a different thread
  - the signal is blocked, until the program takes action to allow its delivery
    - each process (or thread) has a corresponding mask
- Each signal has a default behavior
  - e.g. SIGINT (i.e., Ctrl+C) causes termination
  - it can be changed using `sigaction()`
- Signals can be nested (i.e., while one is being handled another is delivered)

Signals

- `int sigaction(whichSignal, &newAction, &oldAction);`
  - whichSignal: integer
  - newAction: `struct sigaction`, defines the new behavior
  - oldAction: `struct sigaction`, if not NULL, then previous behavior is copied
  - it returns 0 on success, -1 otherwise

```
struct sigaction {
   void (*sa_handler)(int);  /* Signal handler */
   sigset_t sa_mask;         /* Signals to be blocked during handler execution */
   int sa_flags;             /* Flags to modify default behavior */
};
```

- `sa_handler` determines which of the first three possibilities occurs when signal is delivered, i.e., it is not masked
  - `SIG_IGN`, `SIG_DFL`, address of a function
- `sa_mask` specifies the signals to be blocked while handling whichSignal
  - whichSignal is always blocked
  - it is implemented as a set of boolean flags

```
int sigemptyset (sigset_t *set); /* unset all the flags */
int sigfullset (sigset_t *set);  /* set all the flags */
int sigaddset(sigset_t *set, int whichSignal); /* set individual flag */
int sigdelset(sigset_t *set, int whichSignal); /* unset individual flag */
```

Signals - Example

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

void DieWithError(char *errorMessage);
void InterruptSignalHandler(int signalType);

int main (int argc, char *argv[]) {
   struct sigaction handler;                          /* Signal handler specification structure */
   handler.sa_handler = InterruptSignalHandler;       /* Set handler function */
   if (sigfillset(&handler.sa_mask) < 0)              /* Create mask that masks all signals */
      DieWithError (“sigfillset() failed”);
   handler.sa_flags = 0;
   if (sigaction(SIGINT, &handler, 0) < 0)            /* Set signal handling for interrupt signals */
      DieWithError (“sigaction() failed”);
   for(;;) pause();                                   /* Suspend program until signal received */
   exit(0);
}

void InterruptHandler (int signalType) {
   printf (“Interrupt received. Exiting program.\n);
   exit(1);
}
```

Asynchronous I/O

- Non-blocking sockets require "polling"
- With asynchronous I/O the operating system informs the program when a socket call is completed
  - the `SIGIO` signal is delivered to the process, when some I/O-related event occurs on the socket
- Three steps:

/* i. inform the system of the desired disposition of the signal */

```
struct sigaction handler;
handler.sa_handler = SIGIOHandler;
if (sigfillset(&handler.sa_mask) < 0) DiewithError("…");
handler.sa_flags = 0;
if (sigaction(SIGIO, &handler, 0) < 0) DieWithError("…");
```

/* ii. ensure that signals related to the socket will be delivered to this process */

```
if (fcntl(sock, F_SETOWN, getpid()) < 0) DieWithError();
```

/* iii. mark the socket as being primed for asynchronous I/O */

```
if (fcntl(sock, F_SETFL, O_NONBLOCK | FASYNC) < 0) DieWithError()
```

Timeouts

- Using asynchronous I/O the operating system informs the program for the occurrence of an I/O related event
  - what happens if a UPD packet is lost?
- We may need to know if something doesn't happen after some time
- **`unsigned int alarm (unsigned int secs);`**
  - starts a timer that expires after the specified number of seconds (**`secs`**)
  - returns
    - the number of seconds remaining until any previously scheduled alarm was due to be delivered,
    - or zero if there was no previously scheduled alarm
  - process receives **`SIGALARM`** signal when timer expires and `errno` is set to **`EINTR`**

Asynchronous I/O - Example

/* Inform the system of the desired disposition of the signal */

```
struct sigaction myAction;
myAction.sa_handler = CatchAlarm;
if (sigfillset(&myAction.sa_mask) < 0) DiewithError("…");
myAction.sa_flags = 0;
if (sigaction(SIGALARM, &handler, 0) < 0) DieWithError("…");
```

/* Set alarm */

```
alarm(TIMEOUT_SECS);
```

/* Call blocking receive */

```
if (recvfrom(sock, echoBuffer, ECHOMAX, 0, … ) < 0) {
   if (errno = EINTR) …  /*Alarm went off */
   else DieWithError("recvfrom() 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);
    }
}
```

Multiplexing

- So far, we have dealt with a single I/O channel
- We may need to cope with multiple I/O channels
  - e.g., supporting the echo service over multiple ports
- **Problem**: from which socket the server should accept connections or receive messages?
  - it can be solved using non-blocking sockets
    - but it requires polling
- **Solution**: `select()`
  - specifies a list of descriptors to check for pending I/O operations
  - blocks until one of the descriptors is ready
  - returns which descriptors are ready

Multiplexing

- `int select (maxDescPlus1, &readDescs, &writeDescs, &exceptionDescs, &timeout);`
  - maxDescsPlus1: integer, hint of the maximum number of descriptors
  - readDescs: `fd_set`, checked for immediate input availability
  - writeDescs: `fd_set`, checked for the ability to immediately write data
  - exceptionDescs: `fd_set`, checked for pending exceptions
  - timeout: `struct timeval`, how long it blocks (NULL → forever)

  - **returns** the total number of ready descriptors, -1 in case of error

  - **changes** the descriptor lists so that only the corresponding positions are set

```
int FD_ZERO  (fd_set *descriptorVector);                 /* removes all descriptors from vector */
int FD_CLR   (int descriptor, fd_set *descriptorVector); /* remove descriptor from vector */
int FD_SET   (int descriptor, fd_set *descriptorVector); /* add descriptor to vector */
int FD_ISSET (int descriptor, fd_set *descriptorVector); /* vector membership check */
```

```
struct timeval {
   time_t tv_sec;   /* seconds */
   time_t tv_usec;  /* microseconds */
};
```

Multiplexing - Example: echo using stream socket

```
#include <sys/time.h>       /* for struct timeval {} */

int main(int argc, char *argv[])
{
    int *servSock;                    /* Socket descriptors for server */
    int maxDescriptor;                /* Maximum socket descriptor value */
    fd_set sockSet;                   /* Set of socket descriptors for select() */
    long timeout;                     /* Timeout value given on command-line */
    struct timeval selTimeout;        /* Timeout for select() */
    int running = 1;                  /* 1 if server should be running; 0 otherwise */
    int noPorts;                      /* Number of port specified on command-line */
    int port;                         /* Looping variable for ports */
    unsigned short portNo;            /* Actual port number */

    if (argc < 3) {     /* Test for correct number of arguments */
        fprintf(stderr, "Usage:  %s <Timeout (secs.)> <Port 1> ...\n", argv[0]);
        exit(1);
    }

    timeout = atol(argv[1]);         /* First arg: Timeout */
    noPorts = argc - 2;              /* Number of ports is argument count minus 2 */

    servSock = (int *) malloc(noPorts * sizeof(int)); /* Allocate list of sockets for incoming connections */
    maxDescriptor = -1;                               /* Initialize maxDescriptor for use by select() */

    for (port = 0; port < noPorts; port++) {          /* Create list of ports and sockets to handle ports */
        portNo = atoi(argv[port + 2]);                /* Add port to port list. Skip first two arguments */
        servSock[port] = CreateTCPServerSocket(portNo); /* Create port socket */

        if (servSock[port] > maxDescriptor)           /* Determine if new descriptor is the largest */
            maxDescriptor = servSock[port];
    }
    ...
```

Multiplexing - Example: echo using stream socket

```
    printf("Starting server:  Hit return to shutdown\n");
    while (running) {
        /* Zero socket descriptor vector and set for server sockets */
        /* This must be reset every time select() is called */
        FD_ZERO(&sockSet);
        FD_SET(STDIN_FILENO, &sockSet); /* Add keyboard to descriptor vector */
        for (port = 0; port < noPorts; port++) FD_SET(servSock[port], &sockSet);

        /* Timeout specification */
        /* This must be reset every time select() is called */
        selTimeout.tv_sec = timeout;       /* timeout (secs.) */
        selTimeout.tv_usec = 0;            /* 0 microseconds */

        /* Suspend program until descriptor is ready or timeout */
        if (select(maxDescriptor + 1, &sockSet, NULL, NULL, &selTimeout) == 0)
            printf("No echo requests for %ld secs...Server still alive\n", timeout);
        else  {
            if (FD_ISSET(0, &sockSet)) { /* Check keyboard */
                printf("Shutting down server\n");
                getchar();
                running = 0;
            }
            for (port = 0; port < noPorts; port++)
                if (FD_ISSET(servSock[port], &sockSet)) {
                    printf("Request on port %d:  ", port);
                    HandleTCPClient(AcceptTCPConnection(servSock[port]));
                }
        }
    }
    for (port = 0; port < noPorts; port++) close(servSock[port]);  /* Close sockets */
    free(servSock);                                                /* Free list of sockets */
    exit(0);
}
```

Multiple Recipients

- So far, all sockets have dealt with unicast communication
  - i.e., an one-to-one communication, where one copy ("uni") of the data is sent ("cast")
- what if we want to send data to multiple recipients?
- 1st **Solution**: unicast a copy of the data to each recipient
  - inefficient, e.g.,
    - consider we are connected to the internet through a 3Mbps line
    - a video server sends 1-Mbps streams
    - then, server can support only three clients simultaneously
- 2nd **Solution**: using network support
  - broadcast, all the hosts of the network receive the message
  - multicast, a message is sent to some subset of the host
  - for IP: only UDP sockets are allowed to broadcast and multicast

Multiple Recipients - Broadcast

- Only the IP address changes
- Local broadcast: to address `255.255.255.255`
  - send the message to every host on the same broadcast network
  - not forwarded by the routers
- Directed broadcast:
  - for network identifier `169.125` (i.e., with subnet mask `255.255.0.0`)
  - the directed broadcast address is `169.125.255.255`
- No network-wide broadcast address is available
  - why?

✍ In order to use broadcast the options of socket must change:

```
int broadcastPermission = 1;
setsockopt(sock, SOL_SOCKET, SO_BROADCAST, (void*)
   &broadcastPermission, sizeof(broadcastPermission));
```

Multiple Recipients - Multicast

- Using class D addresses
  - range from `224.0.0.0` to `239.255.255.255`
- hosts send multicast requests for specific addresses
- a multicast group is formed

✍ we need to set TTL (time-to-live), to limit the number of hops - using `sockopt()`

✍ no need to change the options of socket

Useful Functions

- **`int atoi(const char *nptr);`**
  - converts the initial portion of the string pointed to by `nptr` to int
- **`int inet_aton(const char *cp, struct in_addr *inp);`**
  - converts the Internet host address `cp` from the IPv4 numbers-and-dots notation into binary form (in network byte order)
  - stores it in the structure that `inp` points to.
  - it returns nonzero if the address is valid, and 0 if not
- **`char *inet_ntoa(struct in_addr in);`**
  - converts the Internet host address `in`, given in network byte order, to a string in IPv4 dotted-decimal notation

```
typedef uint32_t in_addr_t;

struct in_addr {
   in_addr_t s_addr;
};
```

Useful Functions

- **`int getpeername(int sockfd, struct sockaddr *addr, socklen_t *addrlen);`**
  - returns the address (IP and port) of the peer connected to the socket `sockfd`, in the buffer pointed to by `addr`
  - 0 is returned on success; -1 otherwise

- **`int getsockname(int sockfd, struct sockaddr *addr, socklen_t *addrlen);`**
  - returns the current address to which the socket `sockfd` is bound, in the buffer pointed to by `addr`
  - 0 is returned on success; -1 otherwise

Domain Name Service

- `struct hostent *gethostbyname(const char *name);`
  - returns a structure of type `hostent` for the given host name
  - `name` is a hostname, or an IPv4 address in standard dot notation

  e.g. `gethostbyname(“www.csd.uoc.gr”);`

- `struct hostent *gethostbyaddr(const void *addr, socklen_t len, int type);`
  - returns a structure of type hostent for the given host address addr of length len and address type `type`

```
struct hostent {
   char   *h_name;         /* official name of host */
   char  **h_aliases;      /* alias list (strings) */
   int     h_addrtype;     /* host address type (AF_INET) */
   int     h_length;       /* length of address */
   char  **h_addr_list;    /* list of addresses (binary in network byte order) */
}

#define h_addr h_addr_list[0]  /* for backward compatibility */
```

Domain Name Service

- **`struct servent *getservbyname(const char *name, const char *proto);`**
  - returns a `servent` structure for the entry from the database that matches the service name using protocol `proto`.
  - if `proto` is NULL, any protocol will be matched.

  e.g. **`getservbyname(“echo”, “tcp”)`** ;

- **`struct servent *getservbyport(int port, const char *proto);`**
  - returns a `servent` structure for the entry from the database that matches the service name using port `port`

```
struct servent {
   char   *s_name;         /* official service name */
   char  **s_aliases;      /* list of alternate names (strings)*/
   int     s_port;         /* service port number */
   char   *s_proto;        /* protocol to use (“tcp” or “udp”)*/
}
```

Compiling and Executing

- include the required header files
- Example:

```
milo:~/CS556/sockets> gcc -o TCPEchoServer TCPEchoServer.c DieWithError.c HandleTCPClient.c
milo:~/CS556/sockets> gcc -o TCPEchoClient TCPEchoClient.c DieWithError.c
milo:~/CS556/sockets> TCPEchoServer 3451 &
[1] 6273
milo:~/CS556/sockets> TCPEchoClient 0.0.0.0 hello! 3451
Handling client 127.0.0.1
Received: hello!
milo:~/CS556/sockets> ps
  PID TTY          TIME CMD
 5128 pts/9    00:00:00 tcsh
 6273 pts/9    00:00:00 TCPEchoServer
 6279 pts/9    00:00:00 ps
milo:~/CS556/sockets> kill 6273
milo:~/CS556/sockets>
[1]    Terminated                    TCPEchoServer 3451
milo:~/CS556/sockets>
```

The End - Questions