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# Introduction to Sockets Programming in C using TCP/IP

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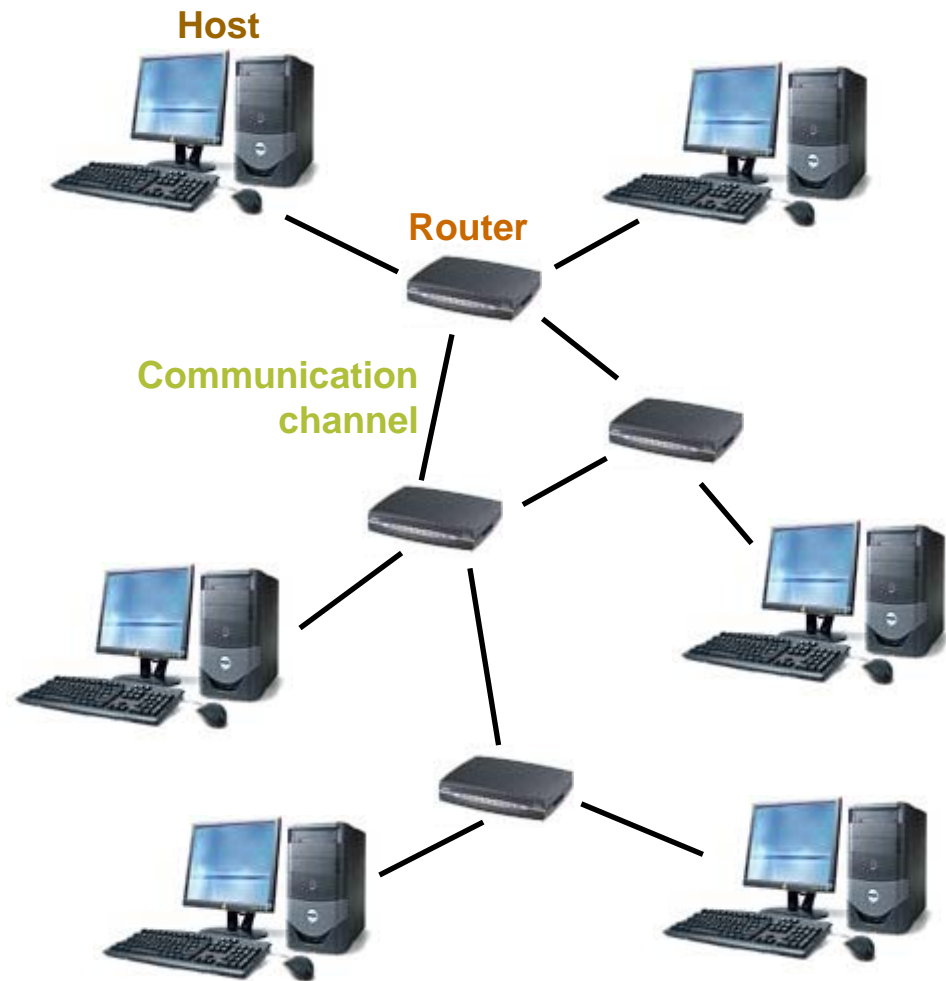
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CSD - May 2012

# 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 packetse.g. Hypertext Transfer Protocol (HTTP)



# Protocol Families - TCP/IP

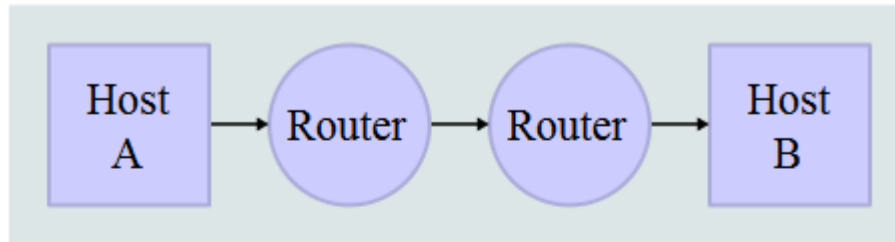
- Several protocols for different problems

## 👉 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



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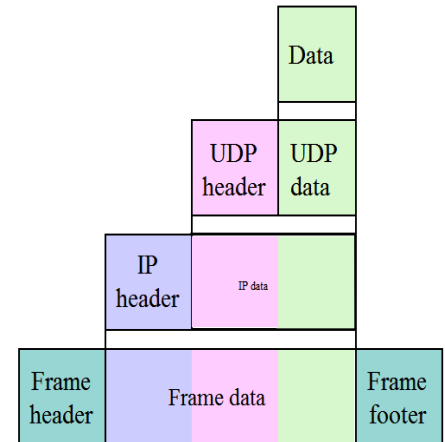
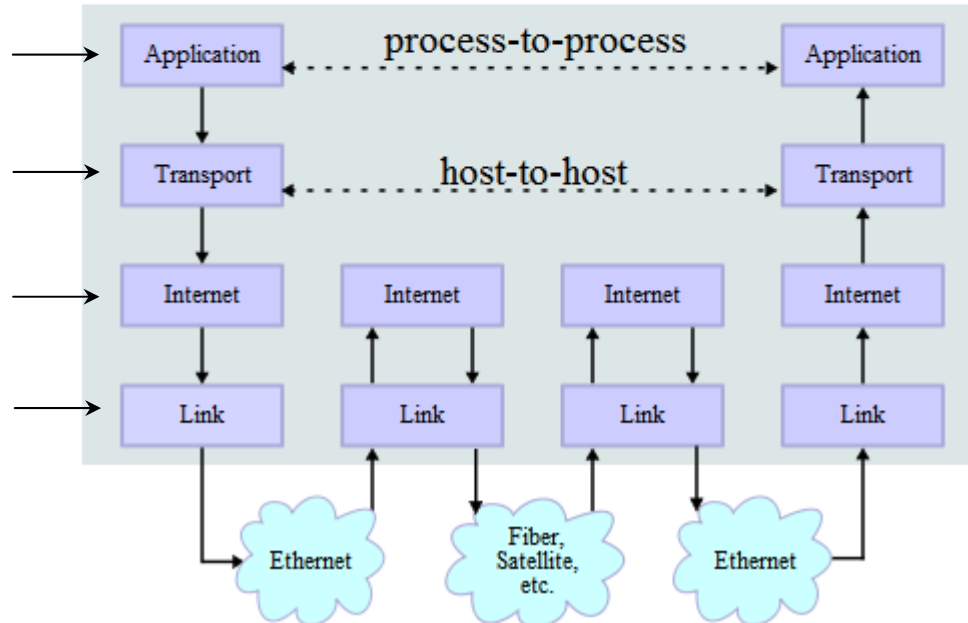
## Data Flow

FTP, SMTP, ...

Transport Layer  
TCP or UDP

Network Layer  
IP

Communication  
Channels



\* image is taken from "[http://en.wikipedia.org/wiki/TCP/IP\\_model](http://en.wikipedia.org/wiki/TCP/IP_model)"

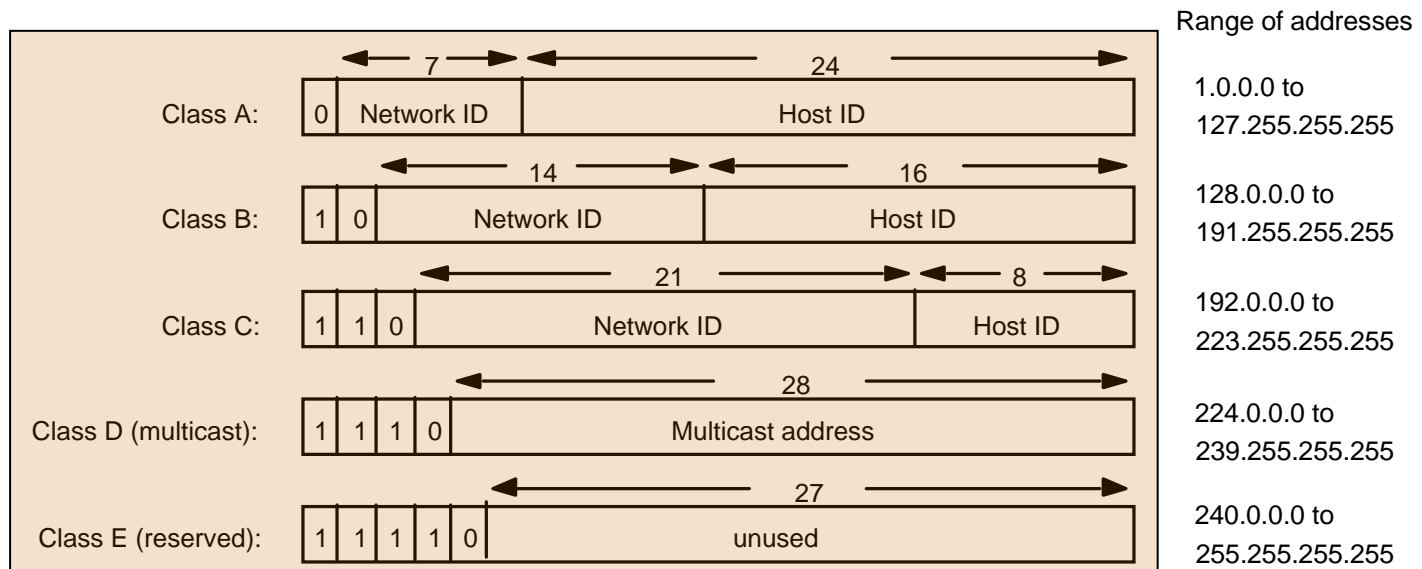
# Internet Protocol (IP)

- provides a **datagram** service
  - packets are handled and delivered independently
- **best-effort** protocol
  - may lose, reorder or duplicate packets
- each packet must contain an **IP address** of its destination

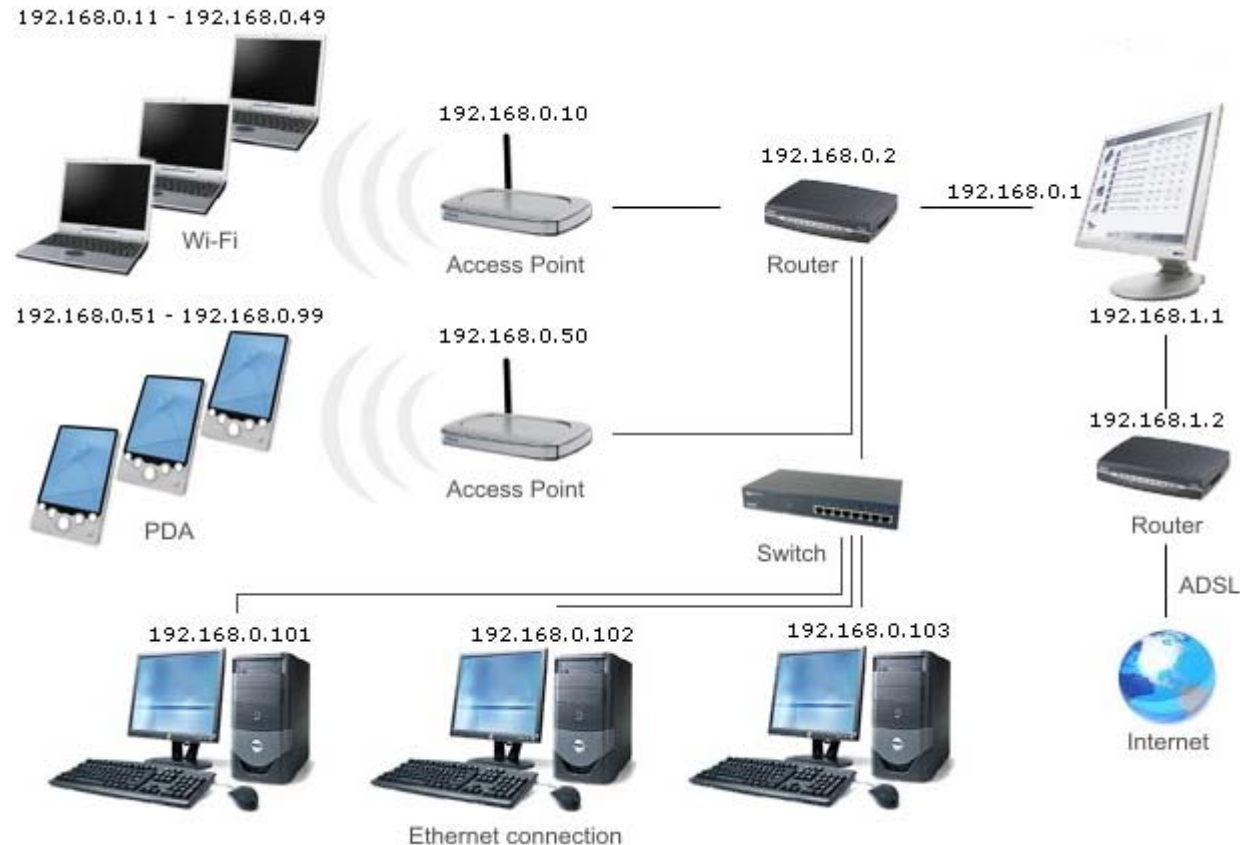


# Addresses - IPv4

- 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

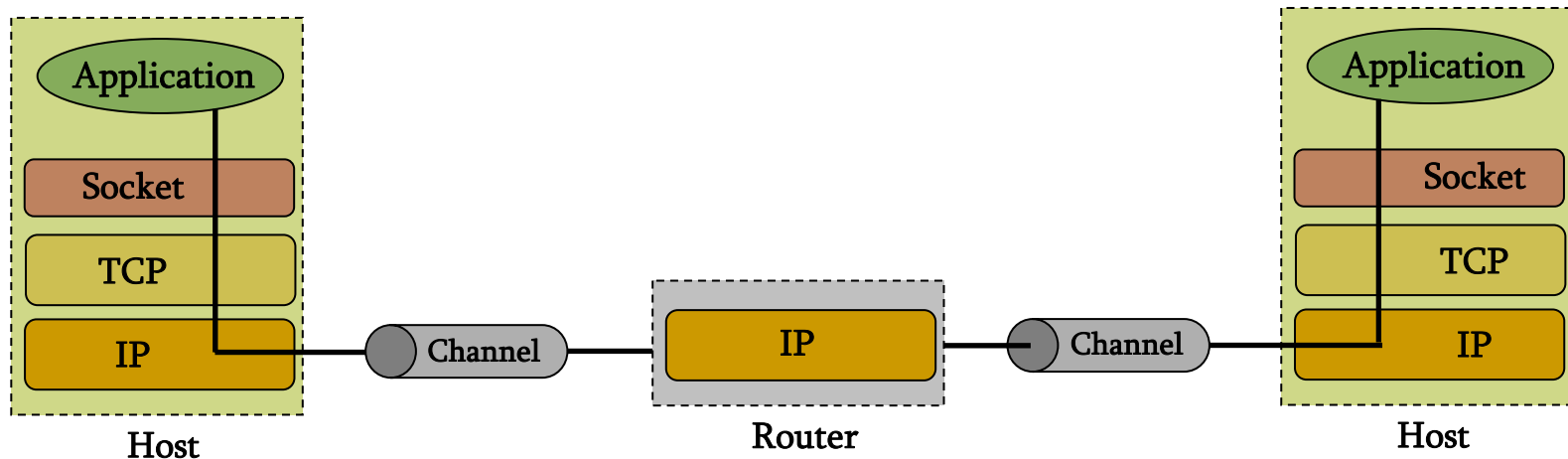
# TCP vs UDP

- 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

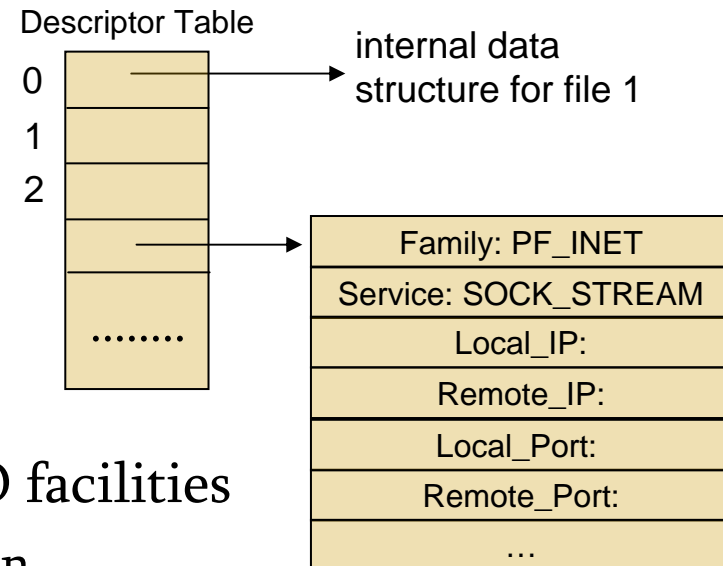
# Berkley Sockets

- 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

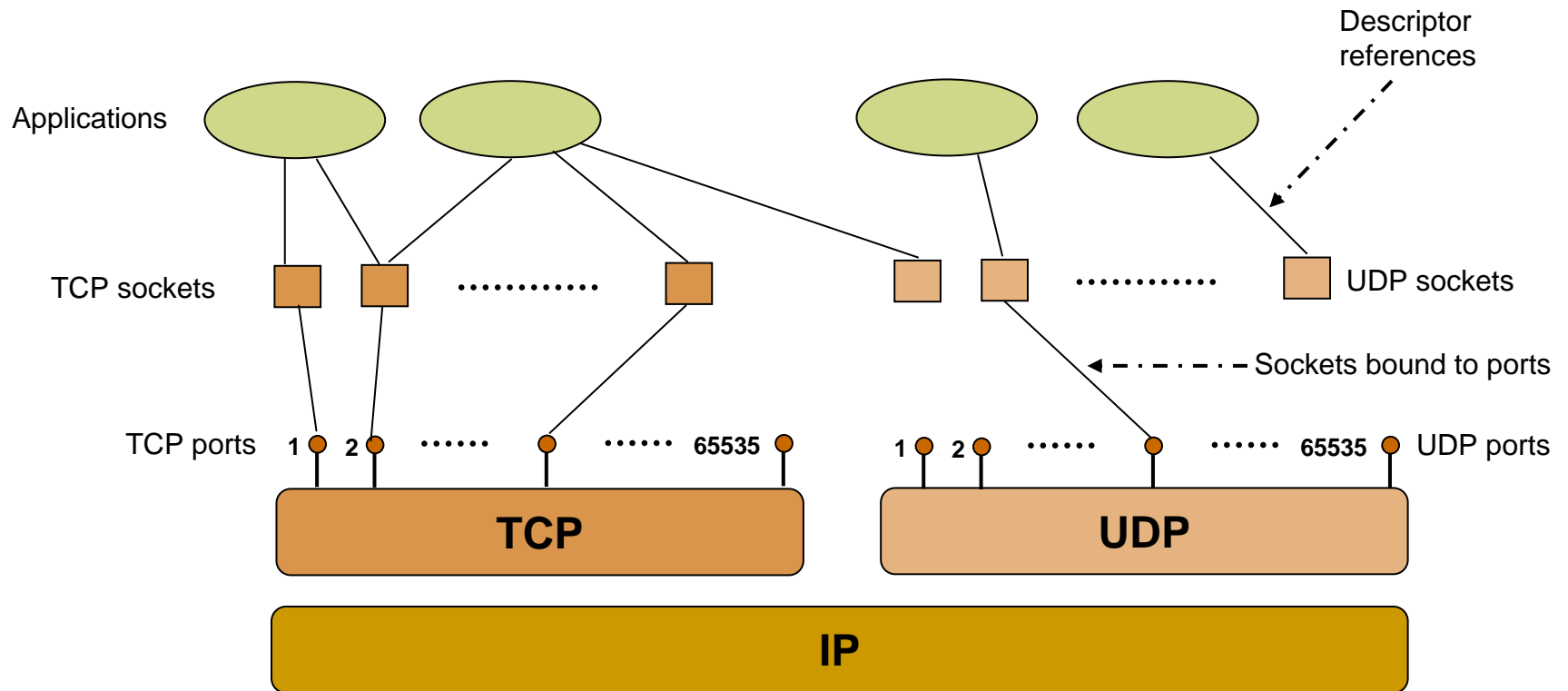


# Sockets

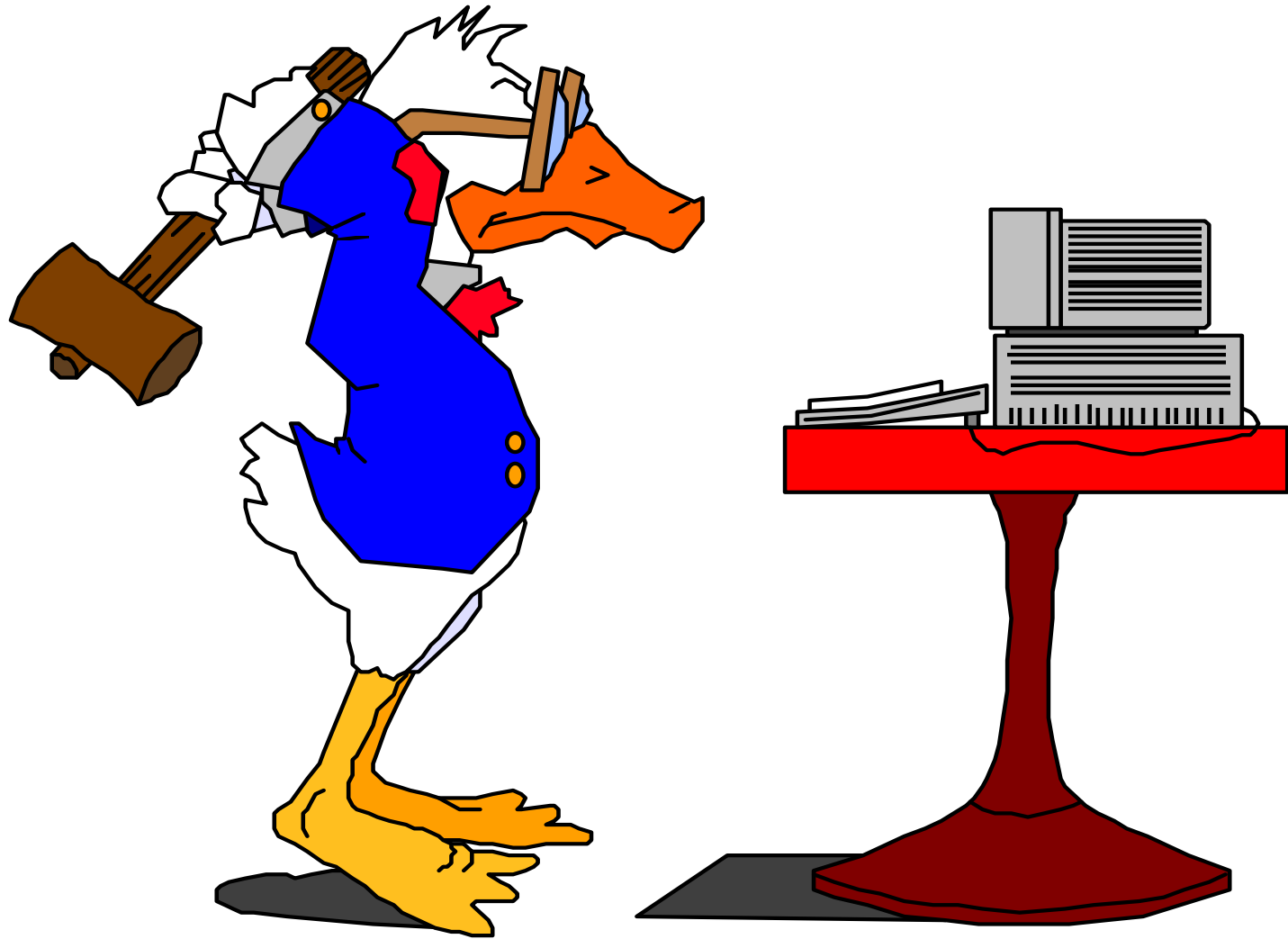
- Uniquely identified by
  - an internet address
  - an end-to-end protocol (e.g. TCP or UDP)
  - a port number
- Two types of (TCP/IP) sockets
  - **Stream** sockets (e.g. uses TCP)
    - provide reliable byte-stream service
  - **Datagram** sockets (e.g. uses UDP)
    - provide best-effort datagram 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



# Socket Programming



# Client-Server communication

## ■ Server

- ❑ passively waits for and responds to clients
- ❑ **passive** socket

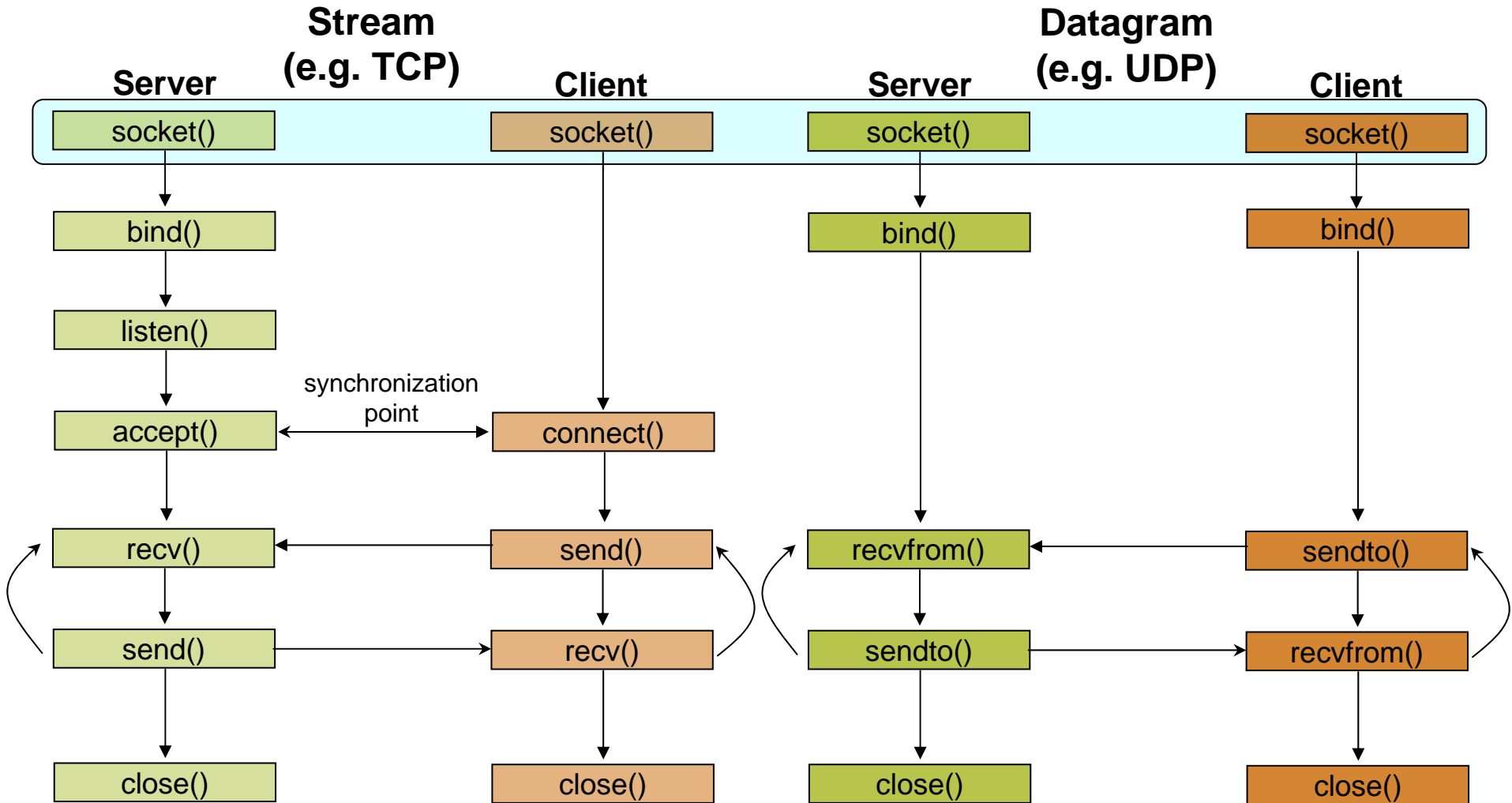
## ■ Client

- ❑ 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

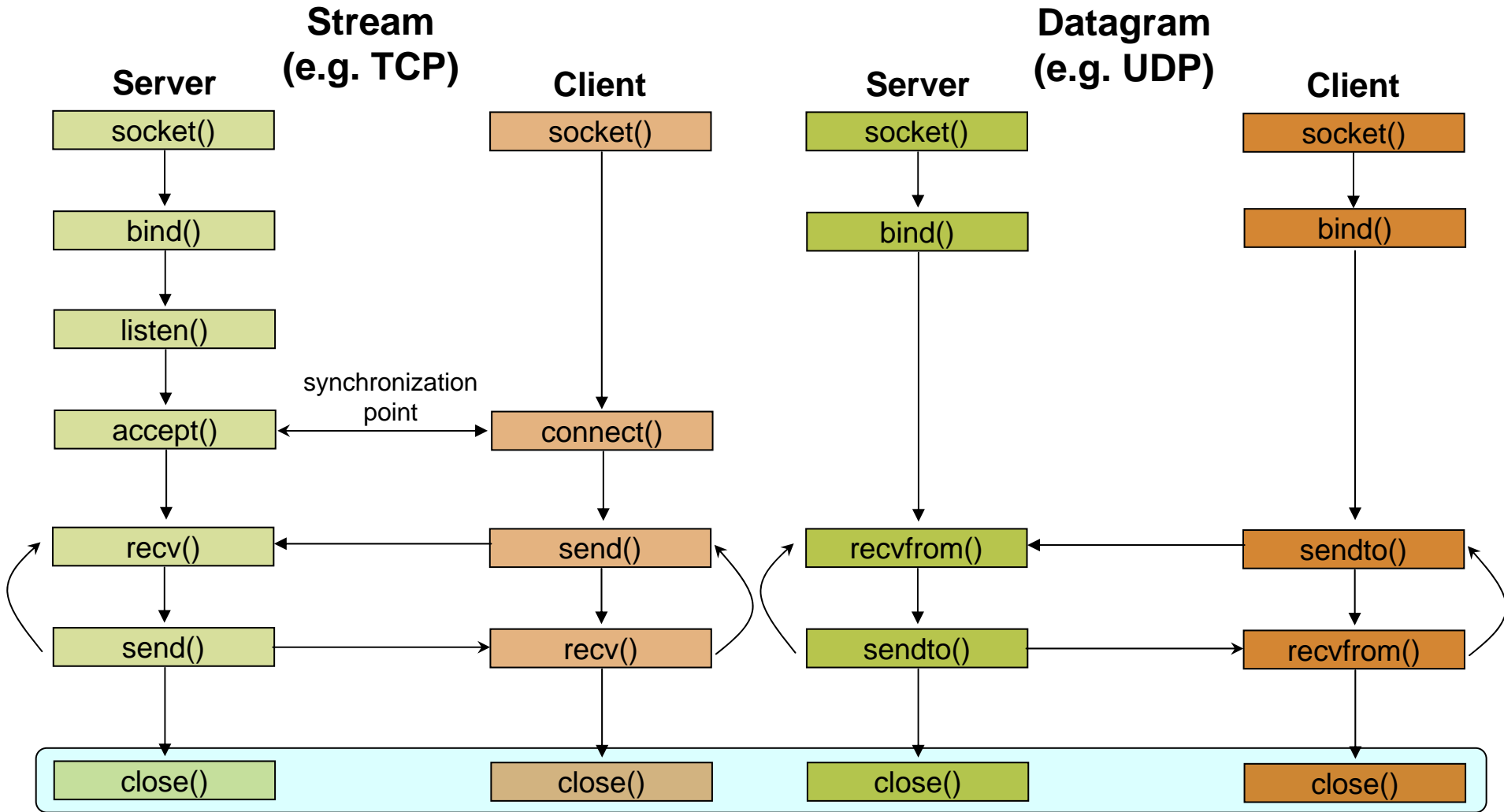
# Client - Server Communication - Unix



# 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:

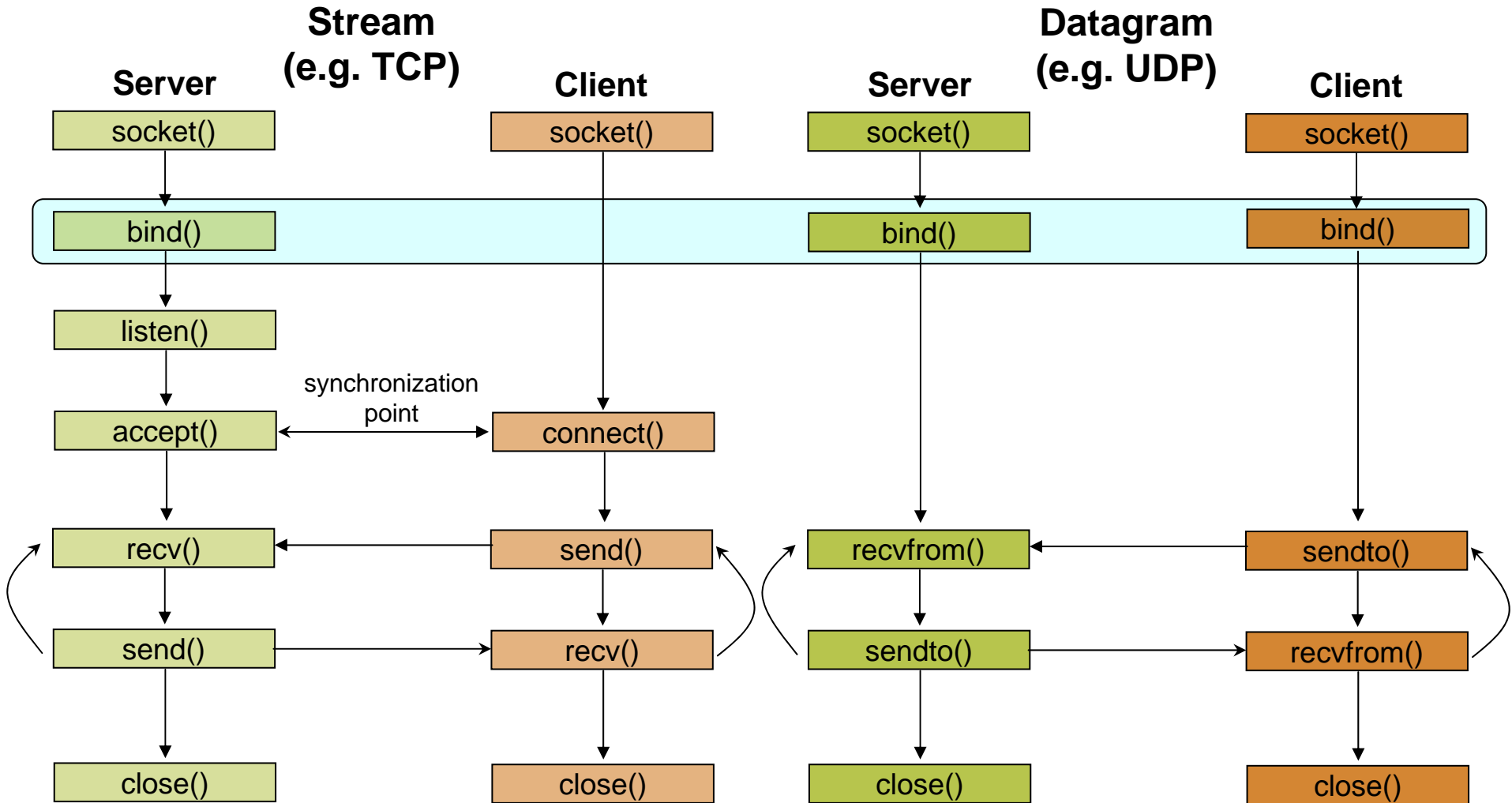
```
struct sockaddr {  
    unsigned short sa_family; /* Address family (e.g. AF_INET) */  
    char sa_data[14];         /* Family-specific address information */  
}
```

- 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

# 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

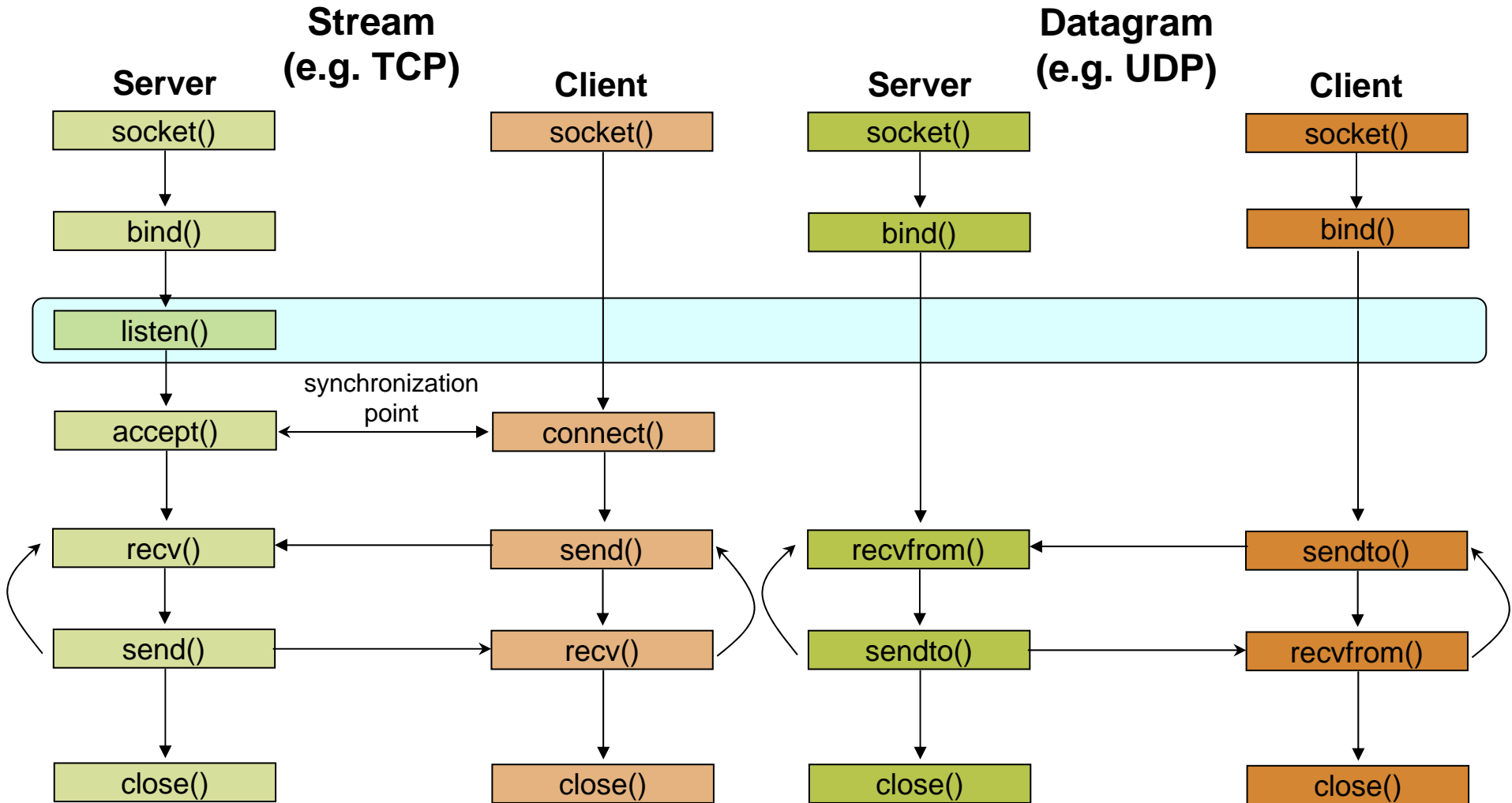
```
int sockid;
struct sockaddr_in addrport;
sockid = socket(PF_INET, SOCK_STREAM, 0);

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)

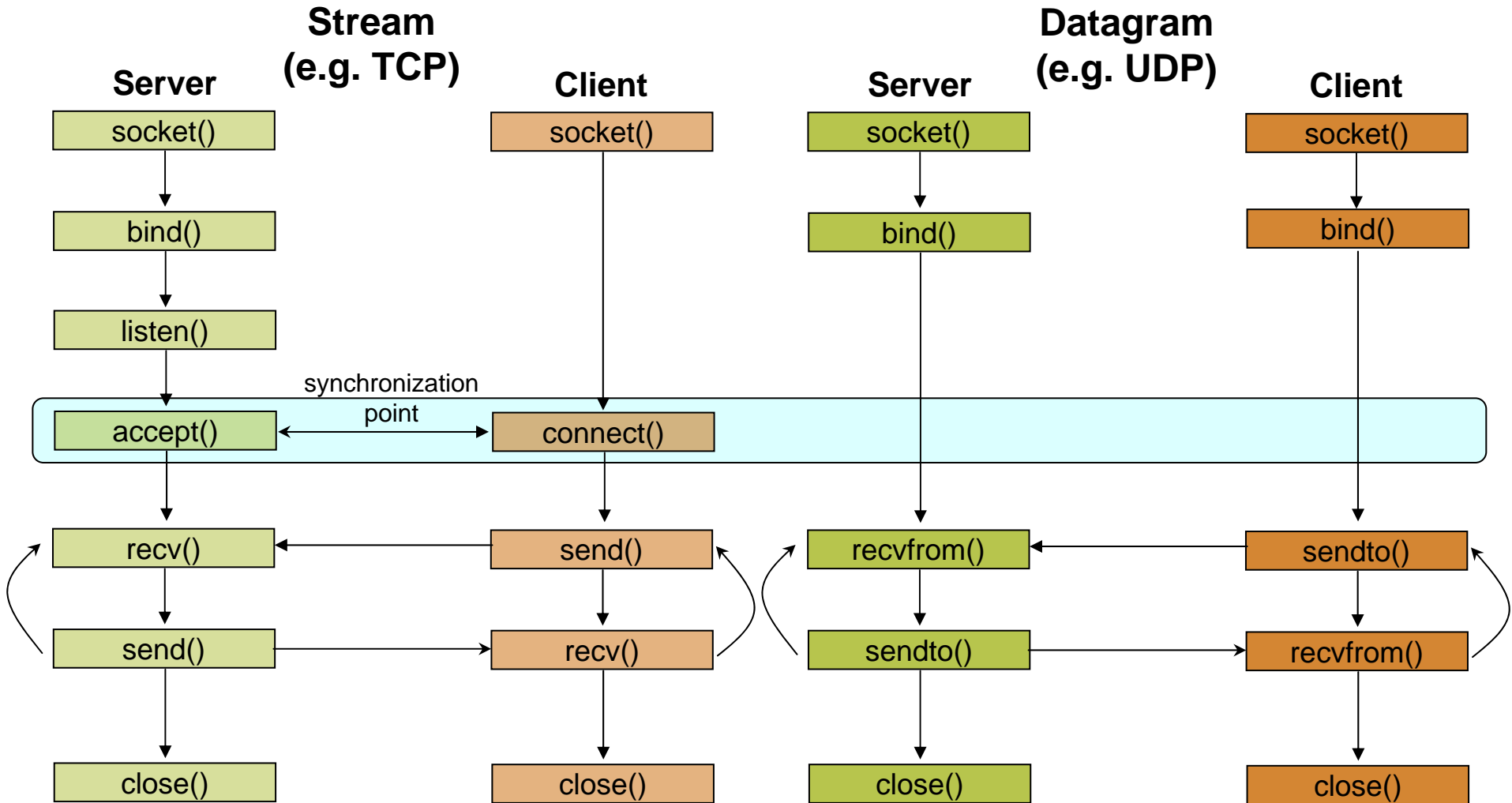
# Client - Server Communication - Unix



# 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 ( )`

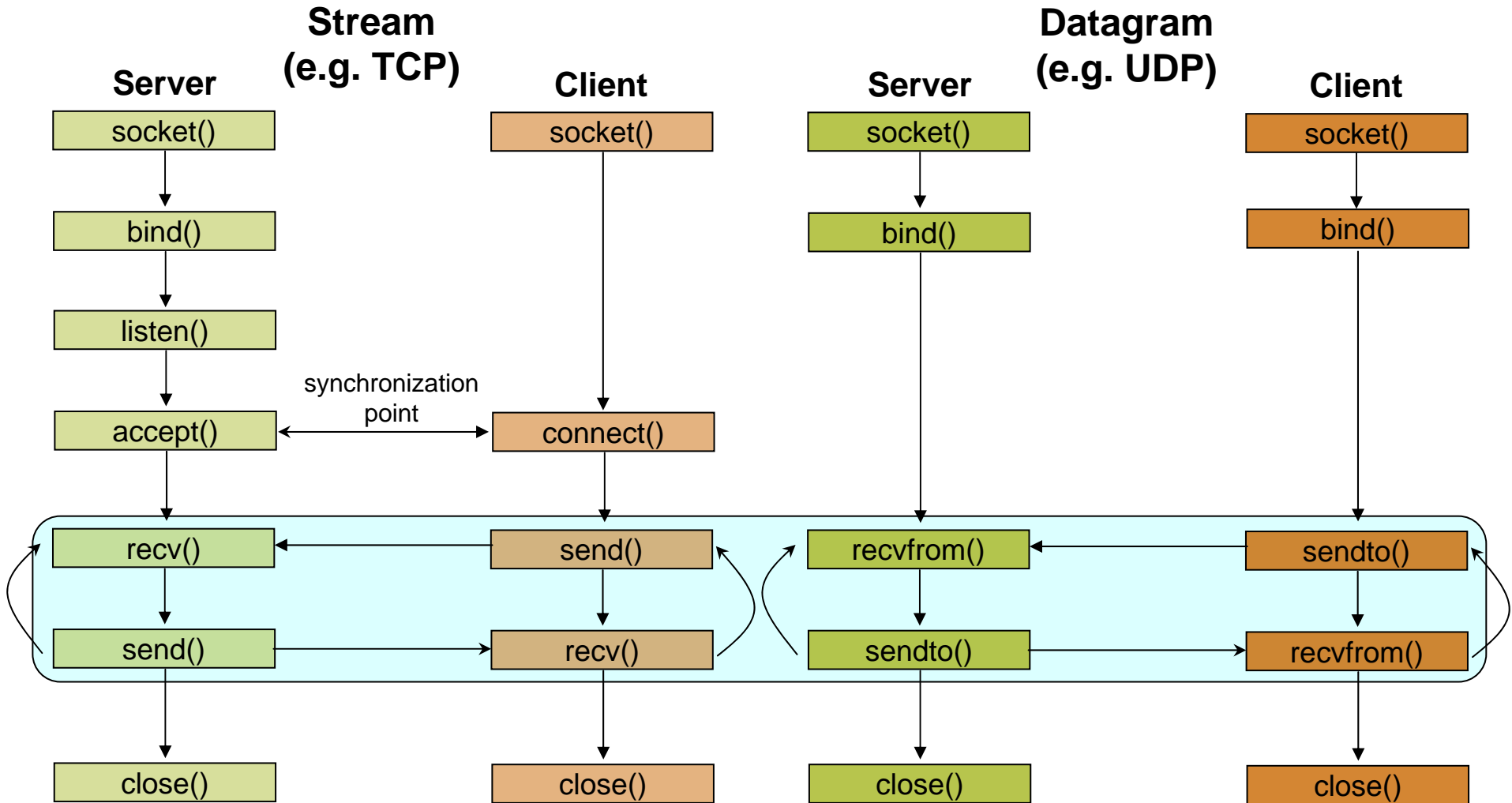
- ```
int status = connect(sockid, &foreignAddr, addrlen);
```

  - `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 is 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**
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## 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, RCVBUFSIZE, 0)) < 0)
        DieWithError("recv() failed");
}
```

## Client

1. Create a TCP socket
2. Establish connection
3. **Communicate**
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## 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);
```

## Client

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

```
close(clientSock);
```

## 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

# 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 */

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

/* Send the string to the server */
if (sendto( clientSock, echoString, echoStringLength, 0,
           (struct sockaddr *) &echoServAddr, sizeof(echoServAddr))
    != echoStringLength)
    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);
```

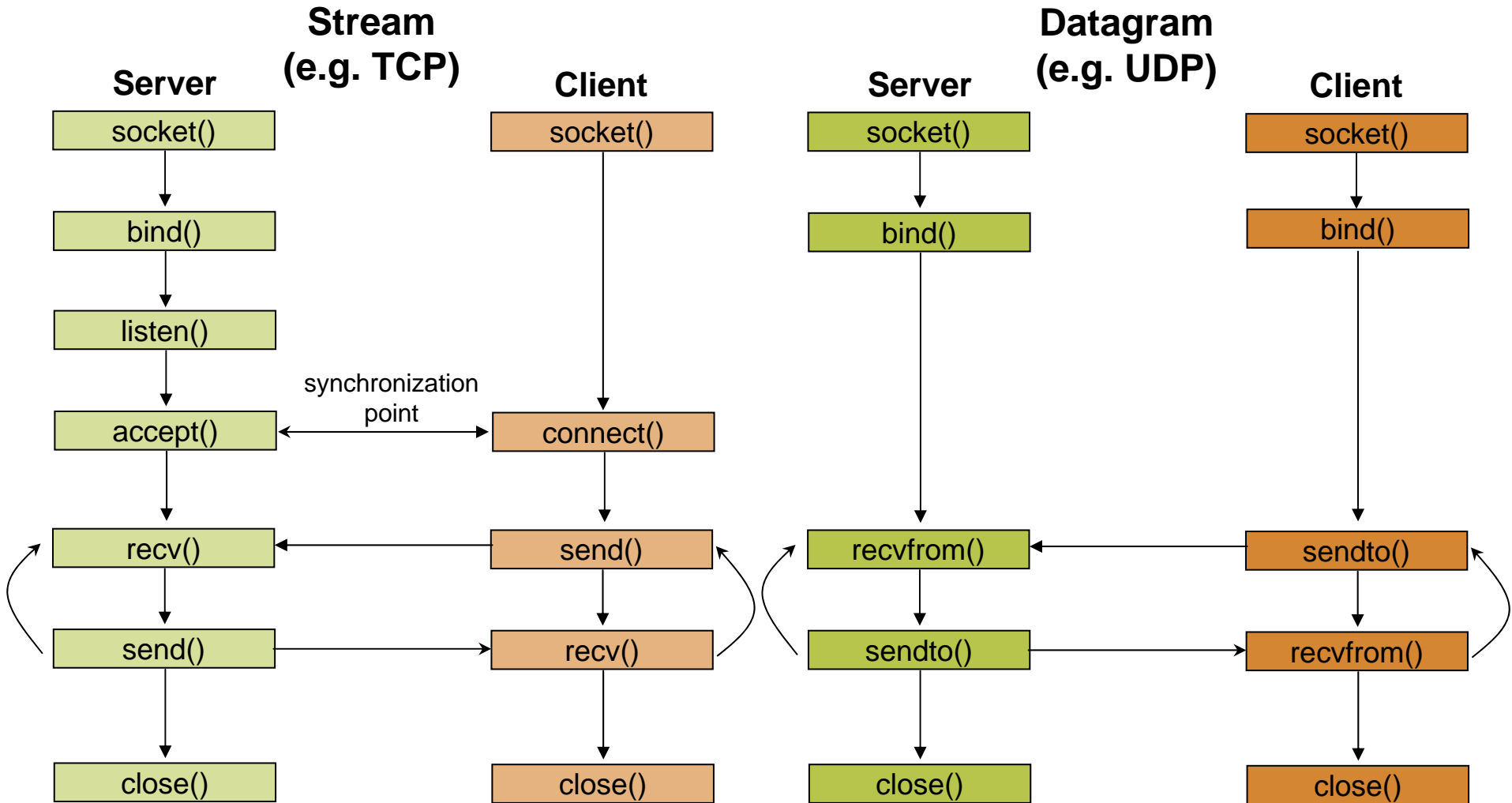
## Client

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
- 1<sup>st</sup> 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

■ 2<sup>nd</sup> Solution: **Sending the values** of `x` and `y`

# Constructing Messages - Encoding Data

- 2<sup>nd</sup> 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)

## 1<sup>st</sup> Implementation

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

## 2<sup>nd</sup> Implementation

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

**2<sup>nd</sup> implementation  
works in any case?**

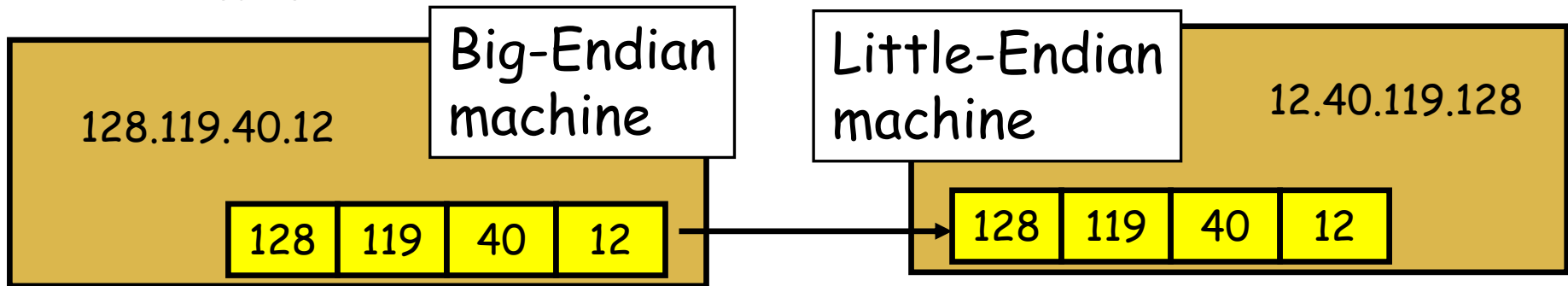
# Constructing Messages - Byte Ordering

- Address and port are stored as integers

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

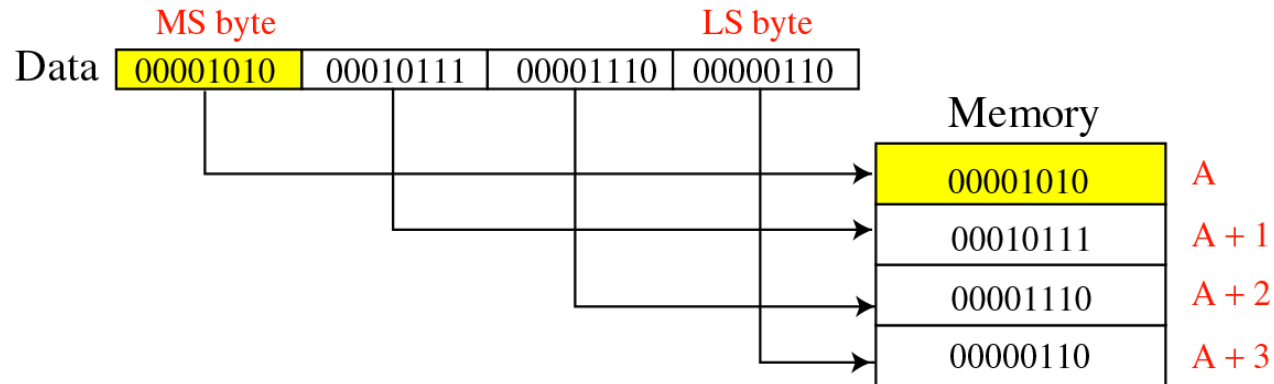
## □ Problem:

- 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

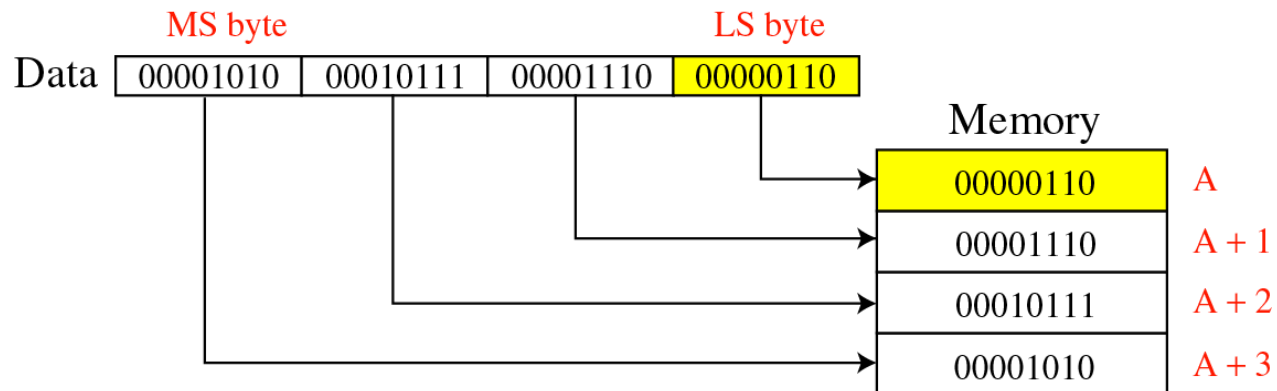


# Constructing Messages - Byte Ordering

## ■ Big-Endian:

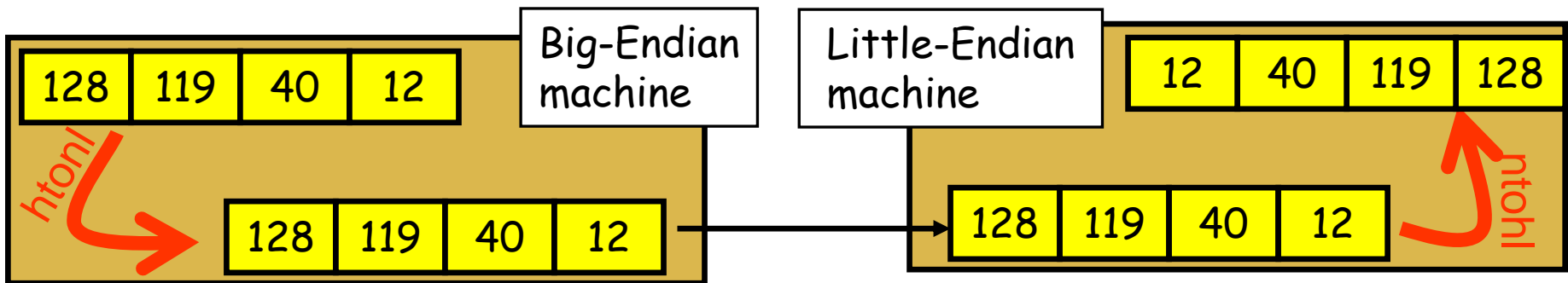


## ■ Little-Endian:



# 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_long ntohl(u_long x);`
- `u_short htons(u_short x);`      ■ `u_short ntohs(u_short x);`
- ❑ On big-endian machines, these routines do nothing
- ❑ On little-endian machines, they reverse the byte order



# 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 rcvMsgSize ;

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

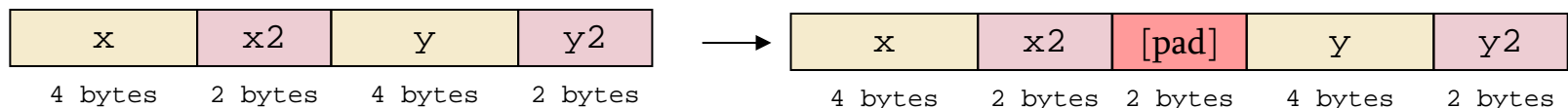
clientPort = ntohs(rcvBuffer);
printf ("Client's port: %d", clientPort);
```

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

# Socket Options

## - Table

| <i>optName</i>           | Type          | Values        | Description                                                                                                           |
|--------------------------|---------------|---------------|-----------------------------------------------------------------------------------------------------------------------|
| <b>SOL_SOCKET Level</b>  |               |               |                                                                                                                       |
| 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)                                                                     |
| <b>IPPROTO_TCP Level</b> |               |               |                                                                                                                       |
| TCP_MAX                  | int           | seconds       | Seconds between keepalive messages.                                                                                   |
| TCP_NODELAY              | int           | 0,1           | Disallow delay for data merging (Nagle's algorithm)                                                                   |
| <b>IPPROTO_IP Level</b>  |               |               |                                                                                                                       |
| 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(rcvBuffSize);
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 */
rcvBufferSize *= 2;

/* Set the buffer size to new value */
if (setsockopt(sock, SOL_SOCKET, SO_RCVBUF, &rcvBufferSize,
              sizeof(rcvBufferSize)) < 0)
    DieWithError("setsockopt() 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)
- 1<sup>st</sup> 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);`
- 2<sup>nd</sup> 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 UDP 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 **SIGALRM** 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 requestsbut, 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 disappear
- 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) {
    processID = waitpid((pid_t) -1, NULL, WHOANG);
    if (processID < 0) DieWithError ("...");
    else if (processID == 0) break;
    else childProcCount--;
}
/* NOT REACHED */
}
```

```
/* Clean up all zombies */
/* Non-blocking wait */
/* No zombie to wait */
/* Cleaned up after a child */
```

# 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 (maxDescsPlus1, &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?
- **1<sup>st</sup> 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
- **2<sup>nd</sup> 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

