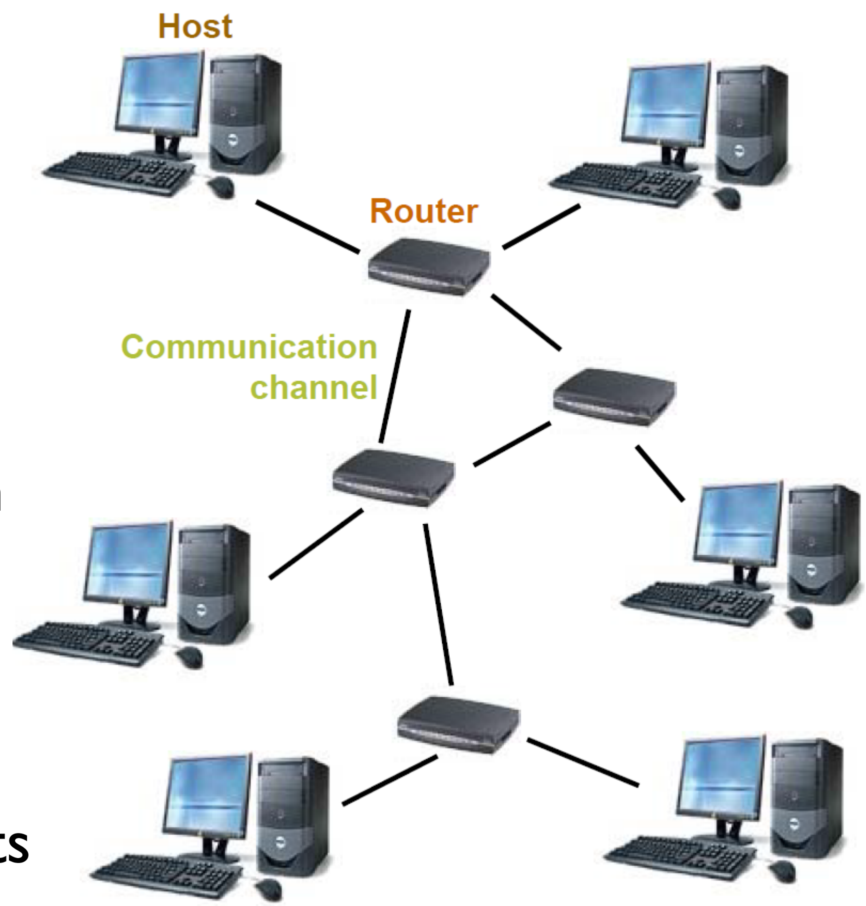
# Introduction to Sockets Programming in C using TCP/IP

# Introduction

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

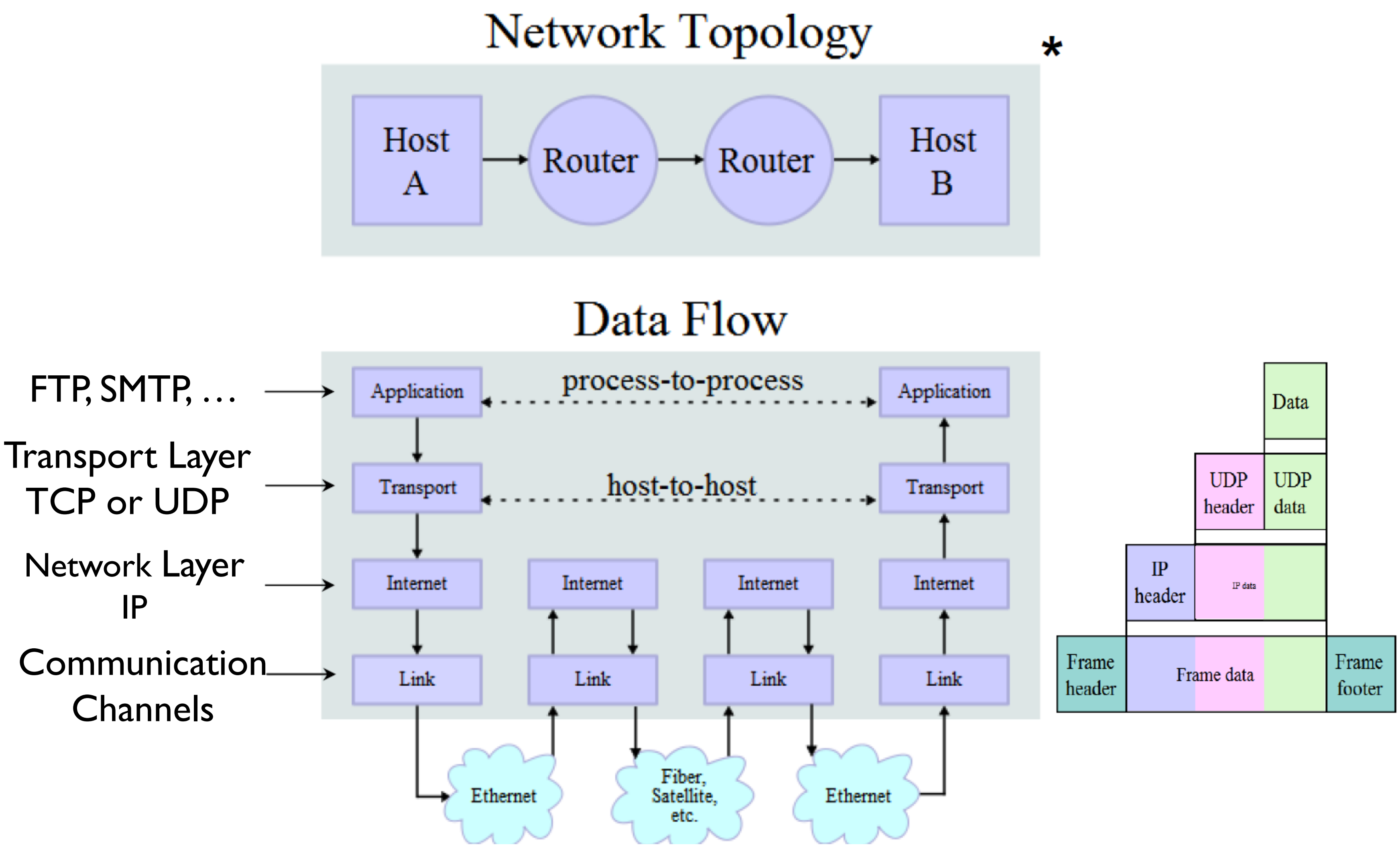


# Protocol Families-TCP/IP

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

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

# TCP/IP



Network Topology
*
Host A
Router
Router
Host B
Data Flow
FTP, SMTP, …
Transport Layer
TCP or UDP
Network Layer
IP
Communication Channels
Application
process-to-process
Application
Transport
host-to-host
Transport
Internet
Internet
Internet
Internet
Link
Link
Link
Link
Ethernet
Fiber, Satellite, etc.
Ethernet
Data
UDP header
UDP data
IP header
Frame header
Frame data
Frame footer

# Internet Protocol (IP)

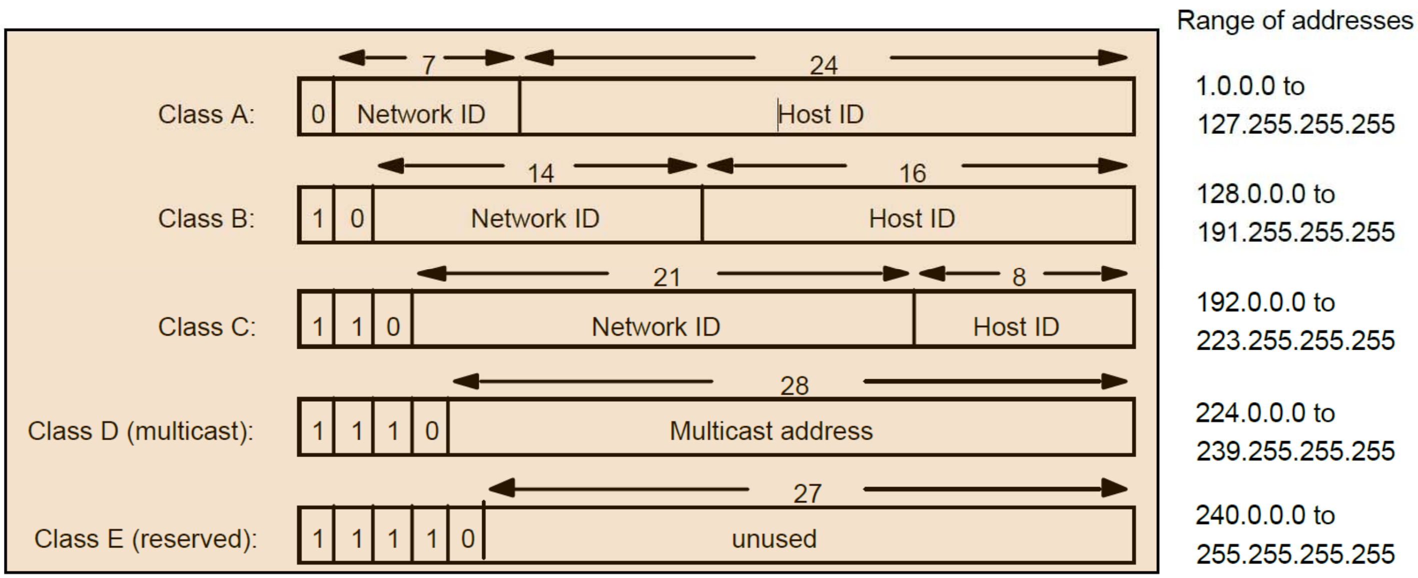
- Provides a datagram service
  - Packets are handled and delivered independently

- Best-effort protocol
  - may loose, reorder or duplicate packets

- Each packet must contain an IP address of its destination.

# Address –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



# TCP vs UDP

- Both use port numbers
  - application-specific construct serving as a communication endpoint
  - 16-bit signed integer, thus ranging from 0 to 65535
  - to provide end-to-end transport
- UDP: User Datagram Protocol
  - no acknowledgements
  - no retransmission
  - 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

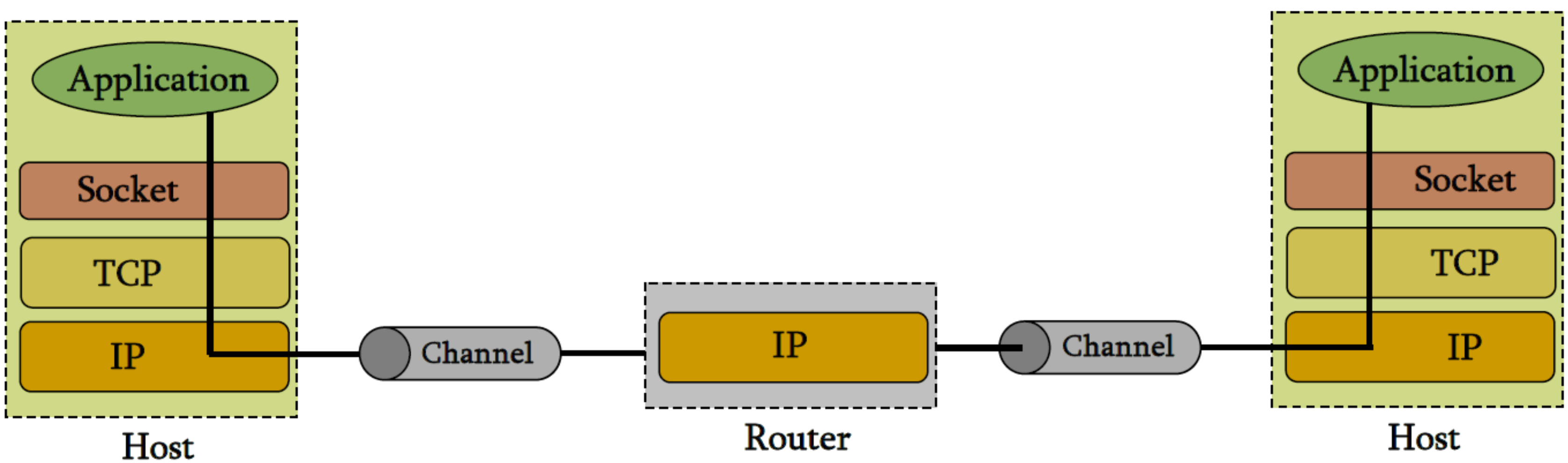
# TCP vs UDP

- 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 |

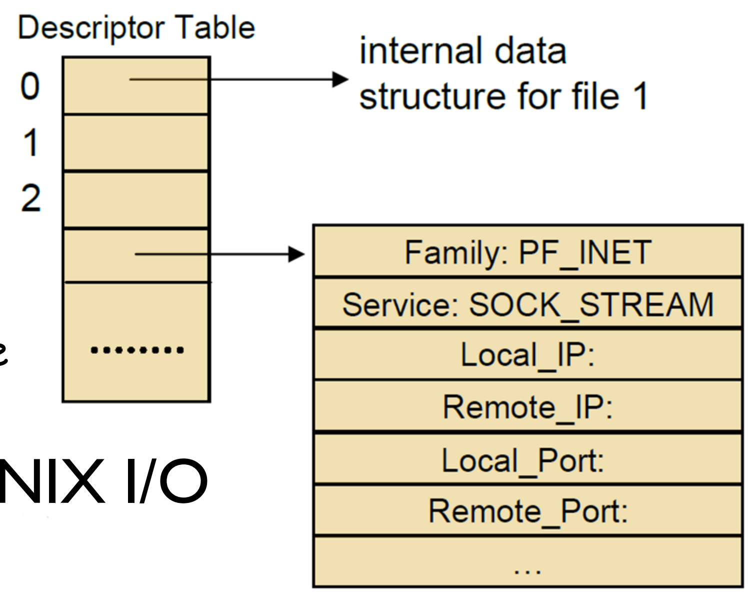
# Berkley Sockets

- 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

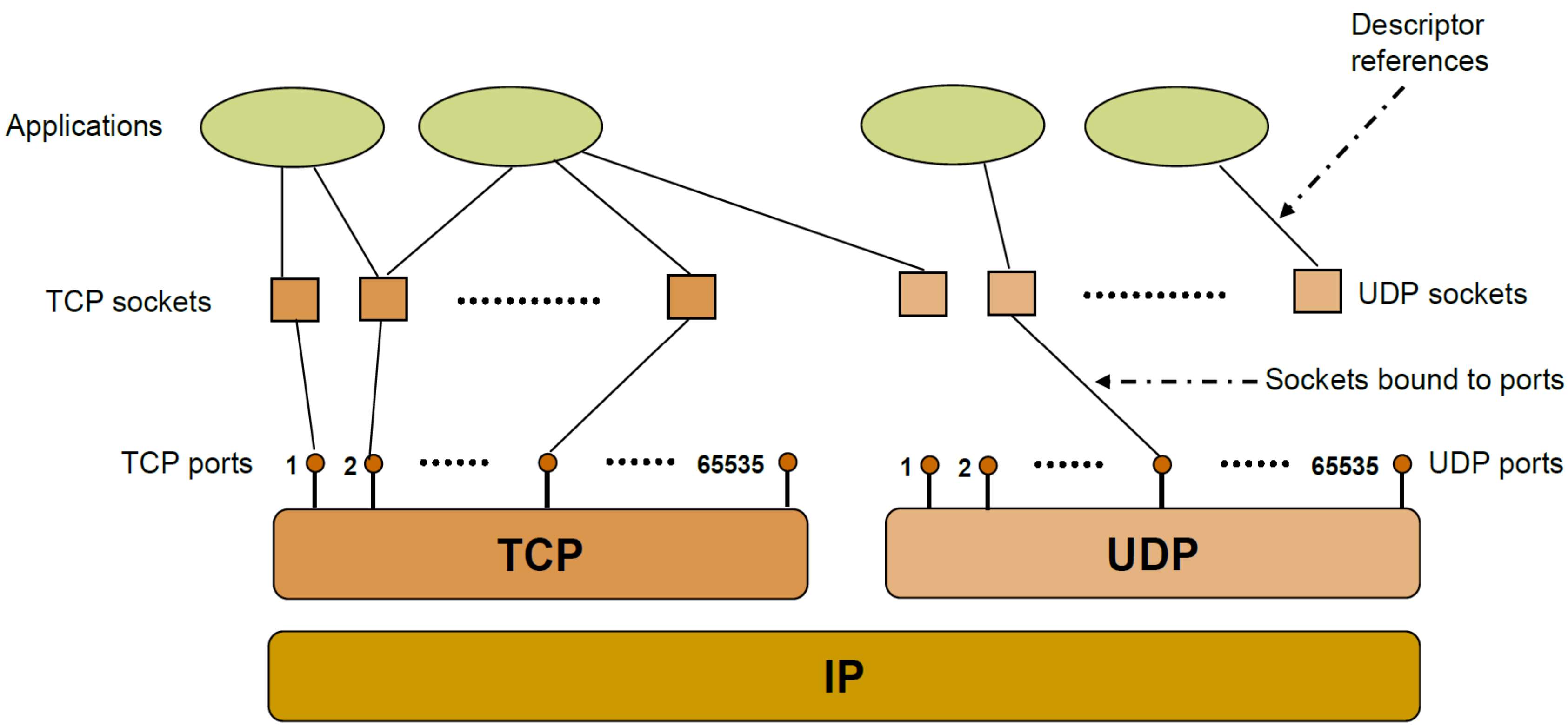


# Sockets

- 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 extends the convectional UNIX I/O facilities
  - file descriptors for network communication
  - extended the read and write system calls



# Sockets



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

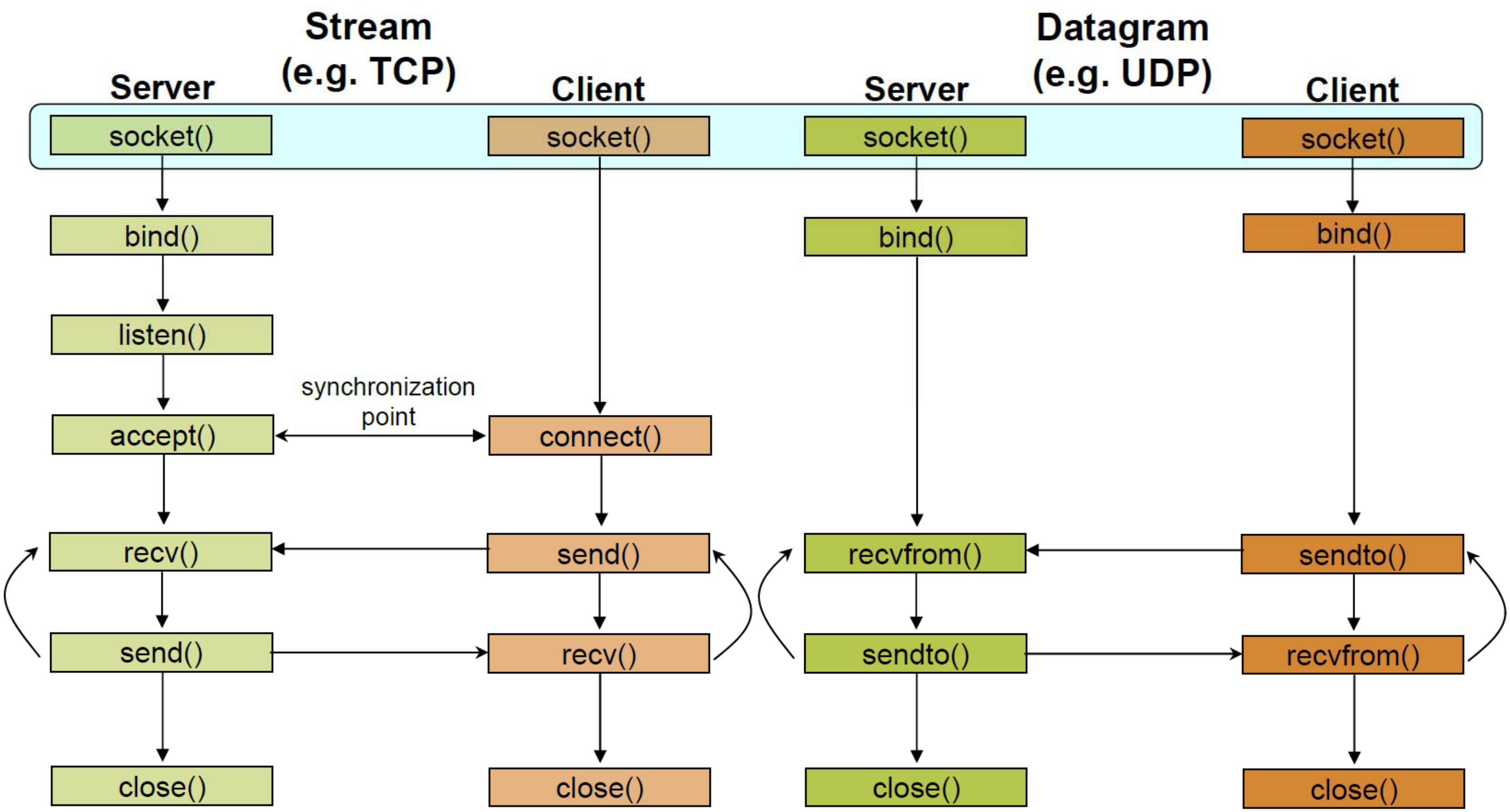
# Client-Server communication

- 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

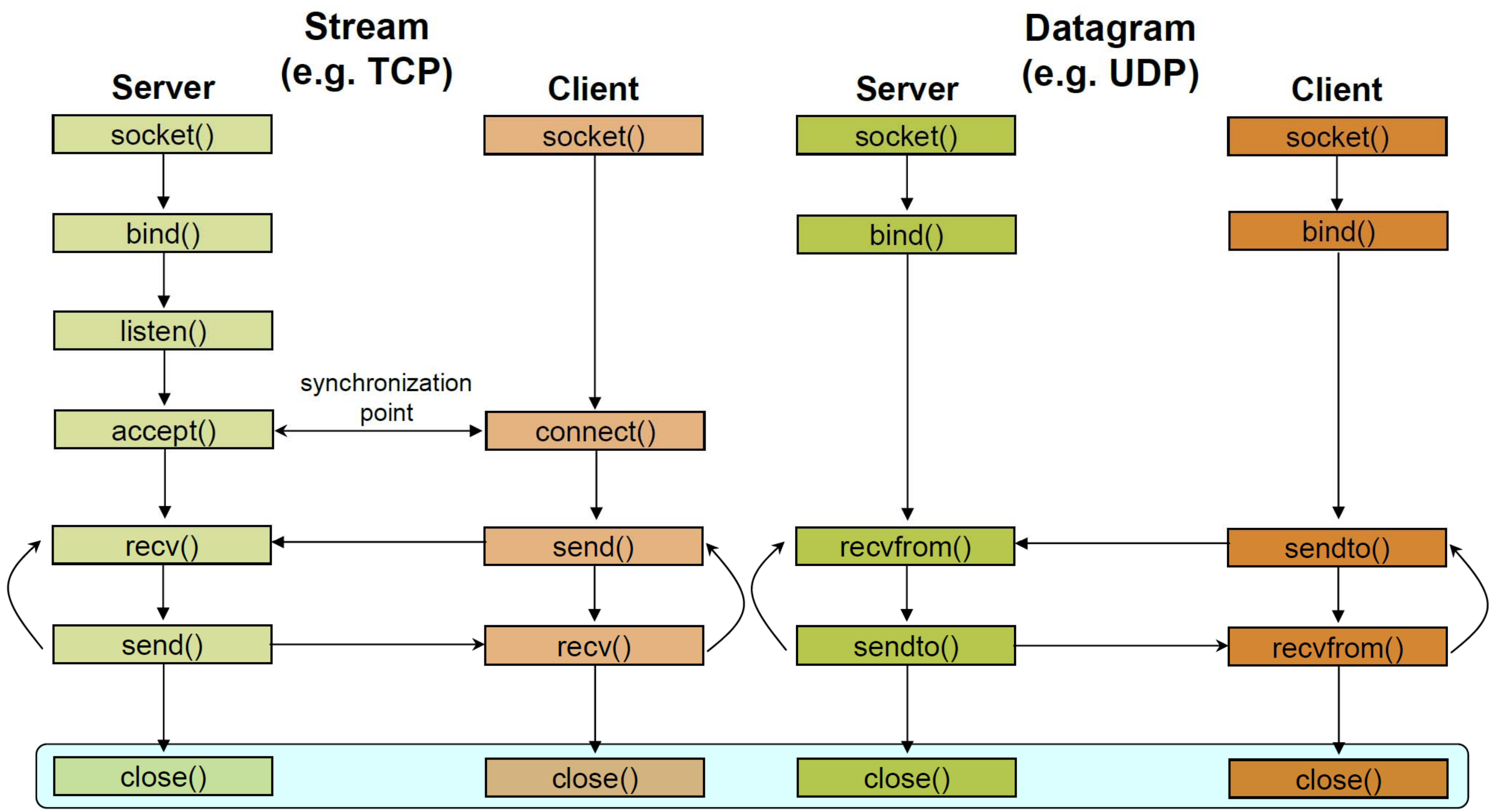


# Socket creation in C: socket()

- `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

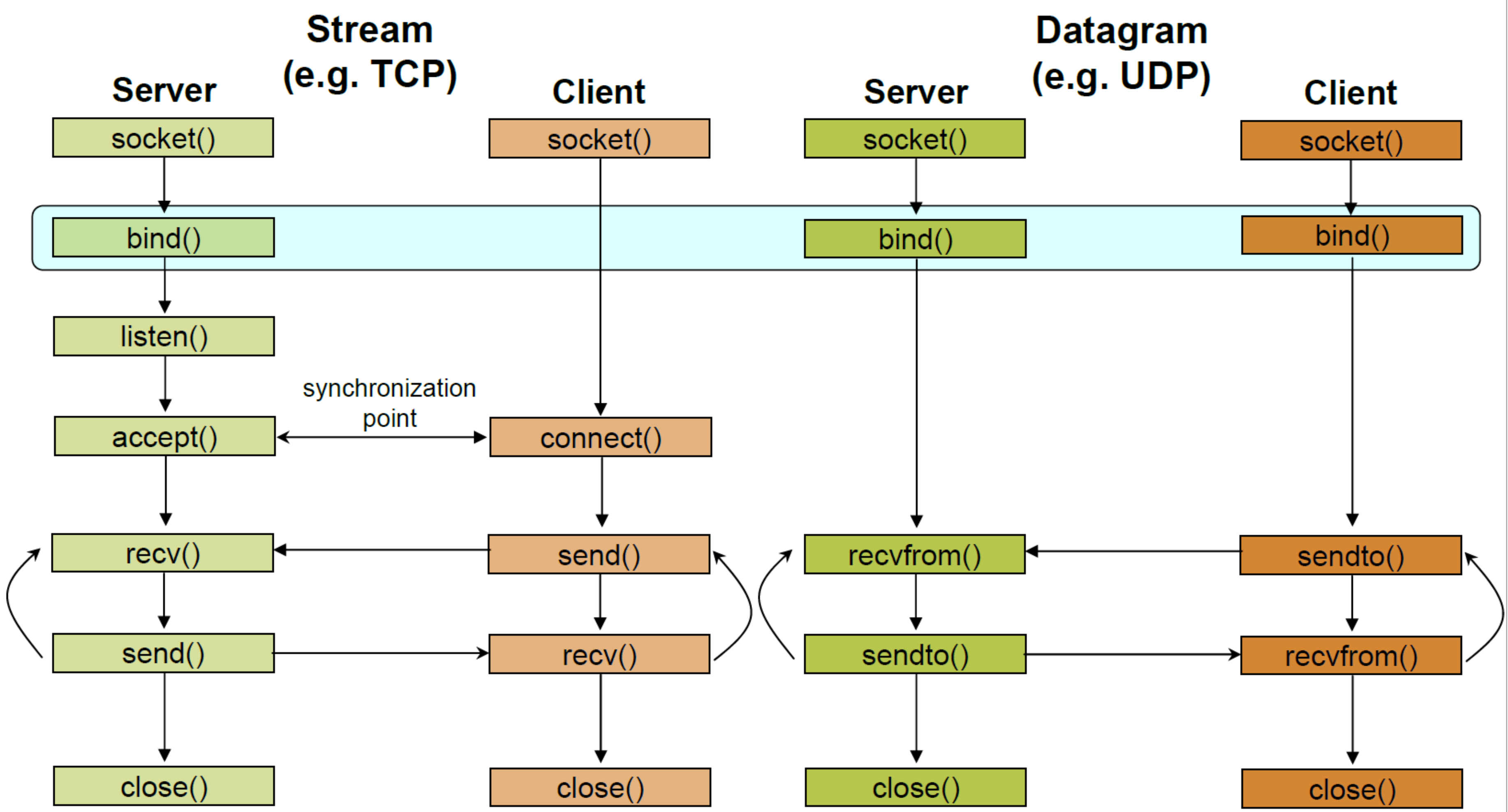
```
struct sockaddr {
    unsigned short sa_family;  /* Address family (e.g. AF_INET) */
    char sa_data[14];          /* Family-specific address information */
}
```

- 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

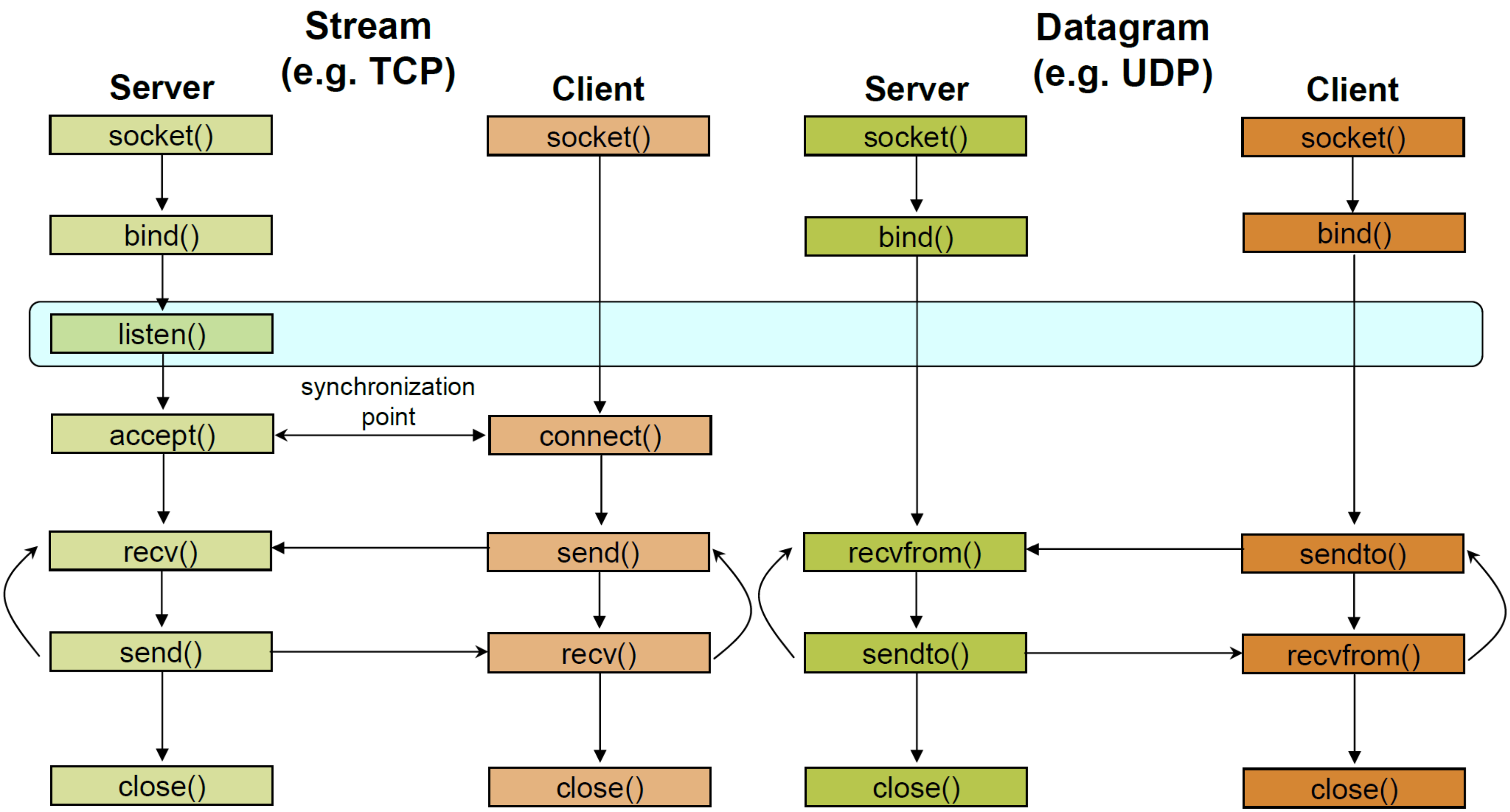
```
int sockid;
struct sockaddr_in addrport;
sockid = socket(PF_INET, SOCK_STREAM, 0);

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)

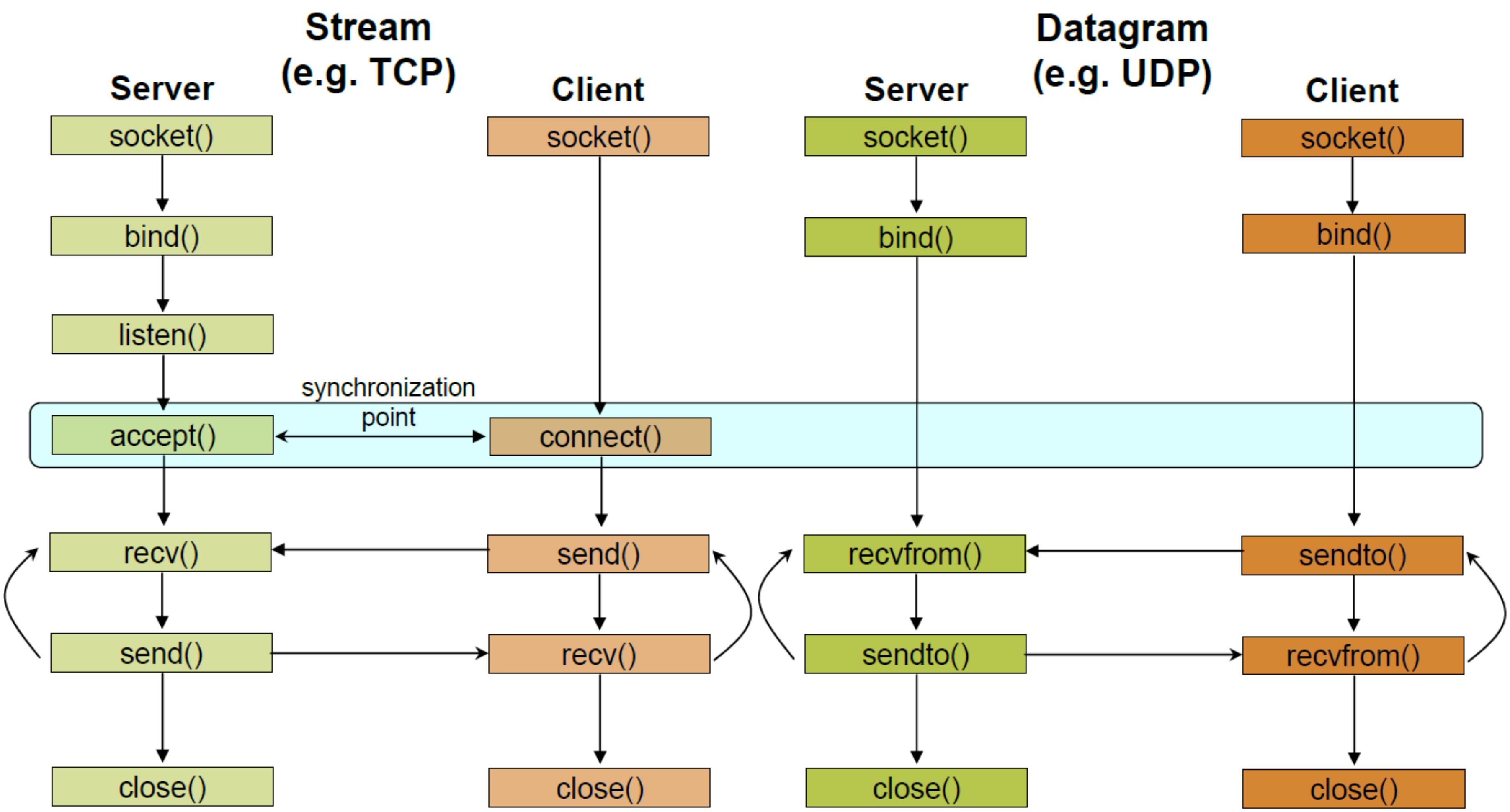
# Client-Server Communication - Unix



# 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



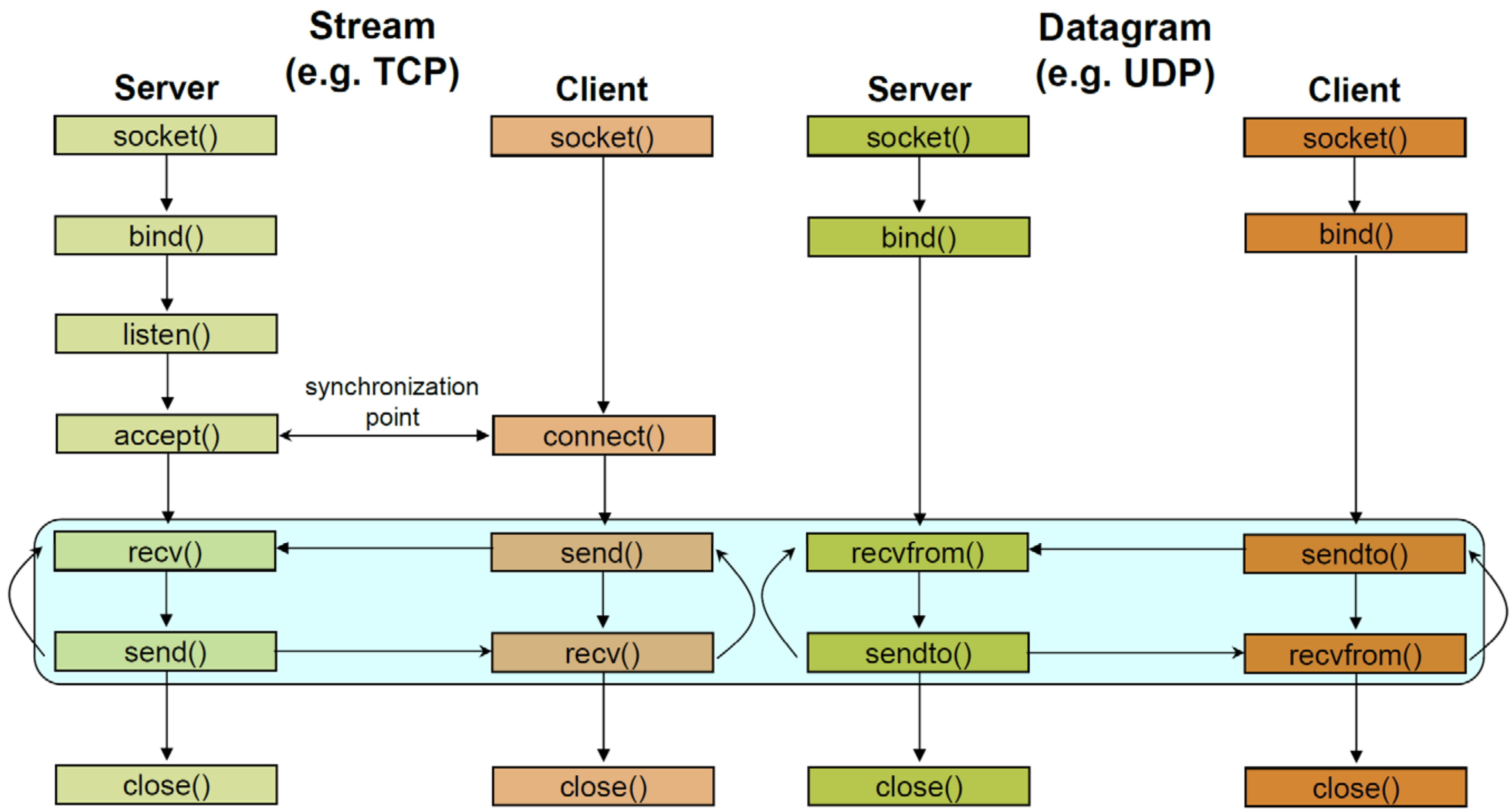
# Establish Connection: connect()

- 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: 0 # 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
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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

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

*Client:*

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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
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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

*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:*

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1. Create a TCP socket
2. Assign a port to socket
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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");
  ...
```

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   a. Accept new connection
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   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");
```

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1. Create a TCP socket
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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");
}
```

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# Example – Echo using stream socket

*Similarly, the client receives the data from the server*

*Client:*

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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:*

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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:
   a. 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:
   a. 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:
   a. 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
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3. Communicate
4. Close the socket

*Server:*

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

# Example – Echo using datagram socket

```
close(clientSock);
```

*Client:*

1. Create a UDP socket
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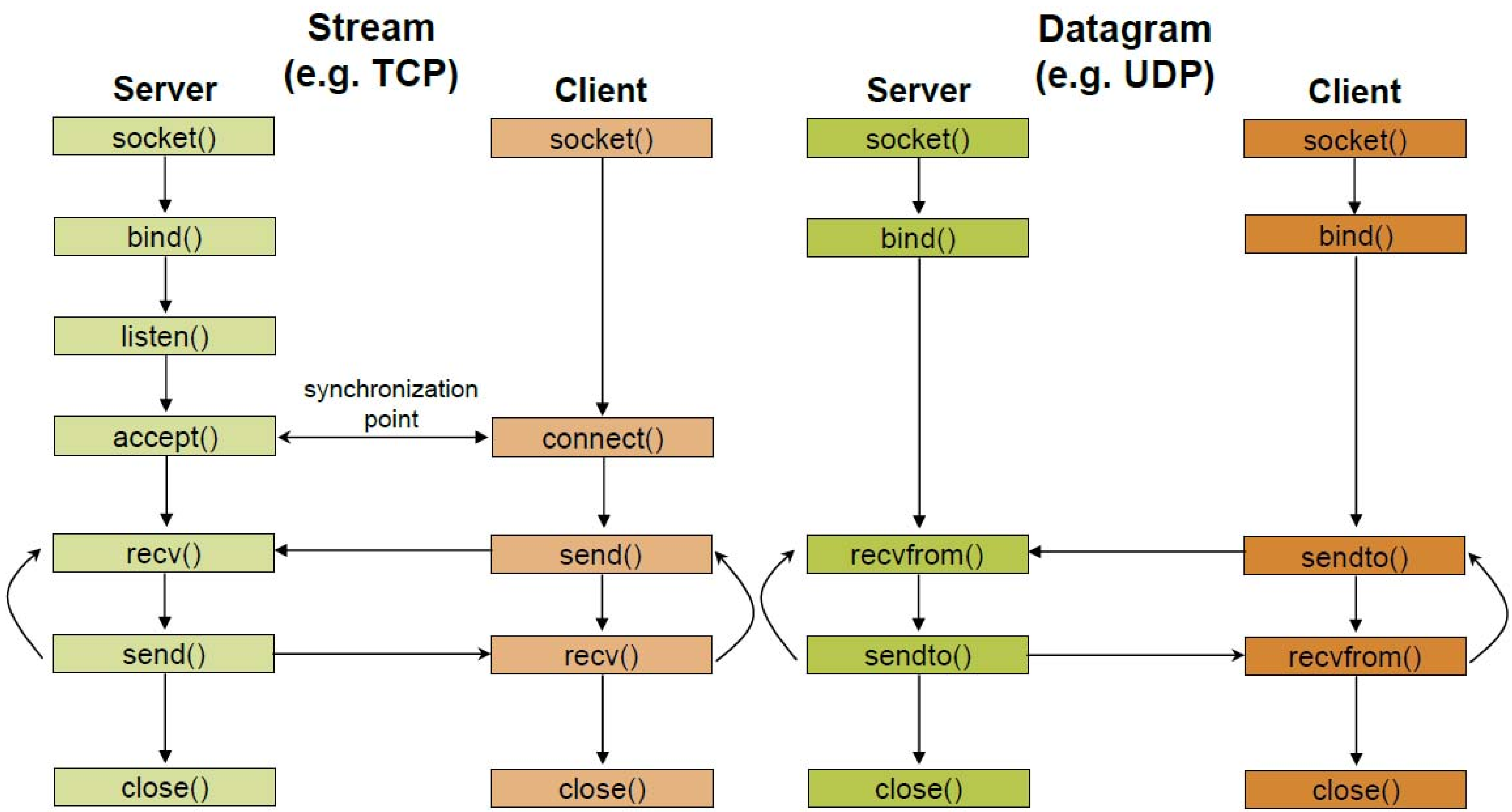
# Client-Server Communication - Unix



# 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

- Pitfall
  - 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);
```

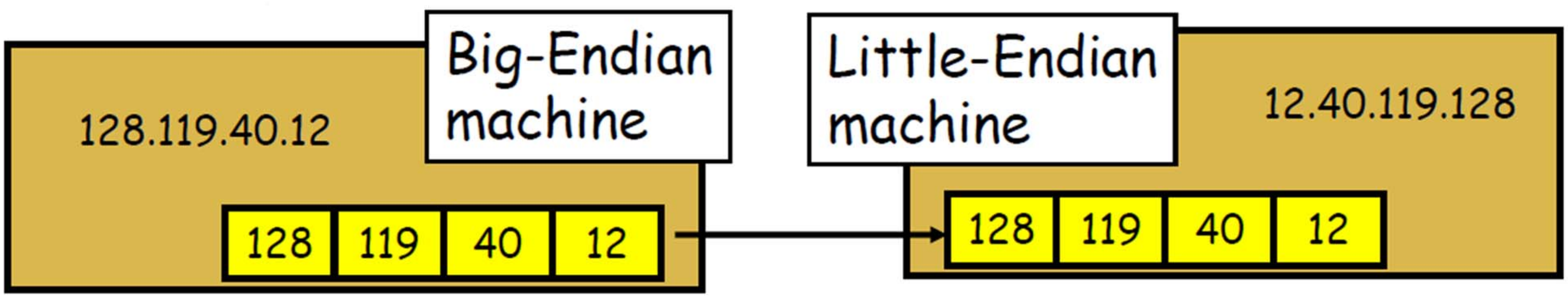
2nd Implementation

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

**2nd implementation works in any case?**

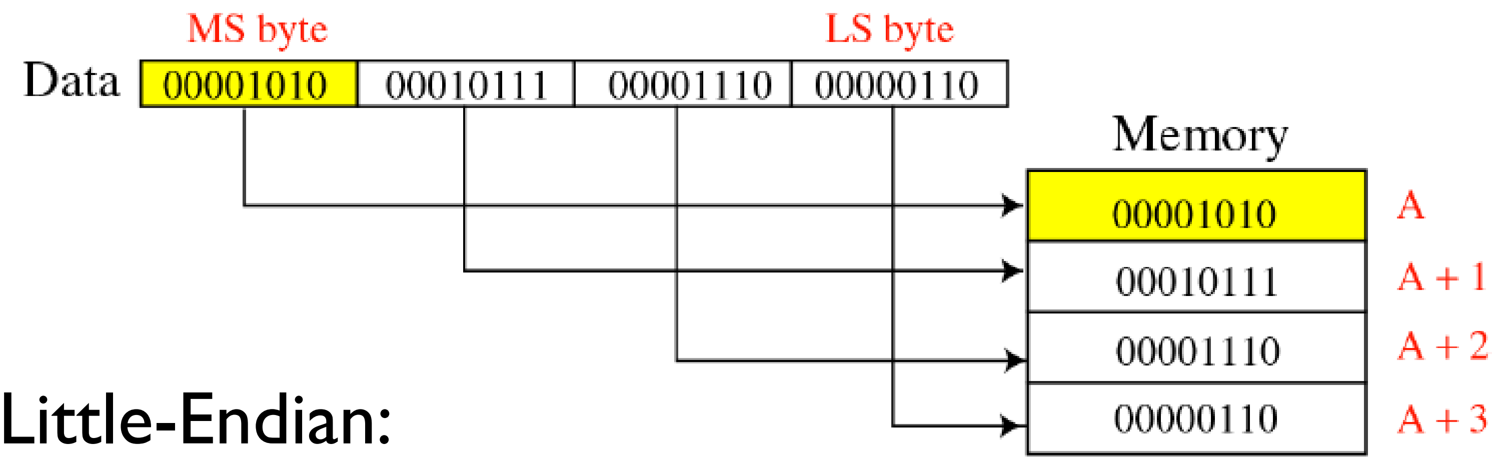
# Constructing Messages –Byte Ordering

- Address and port are stored as integers
  - u_short sin_port; (16 bit)
  - in_addr sin_addr; (32 bit)
- Problem
  - different machines / OS'suse different word orderings
    - little-endian: lower bytes first
    - big-endian: higher bytes first
  - these machines may communicate with one another over the network

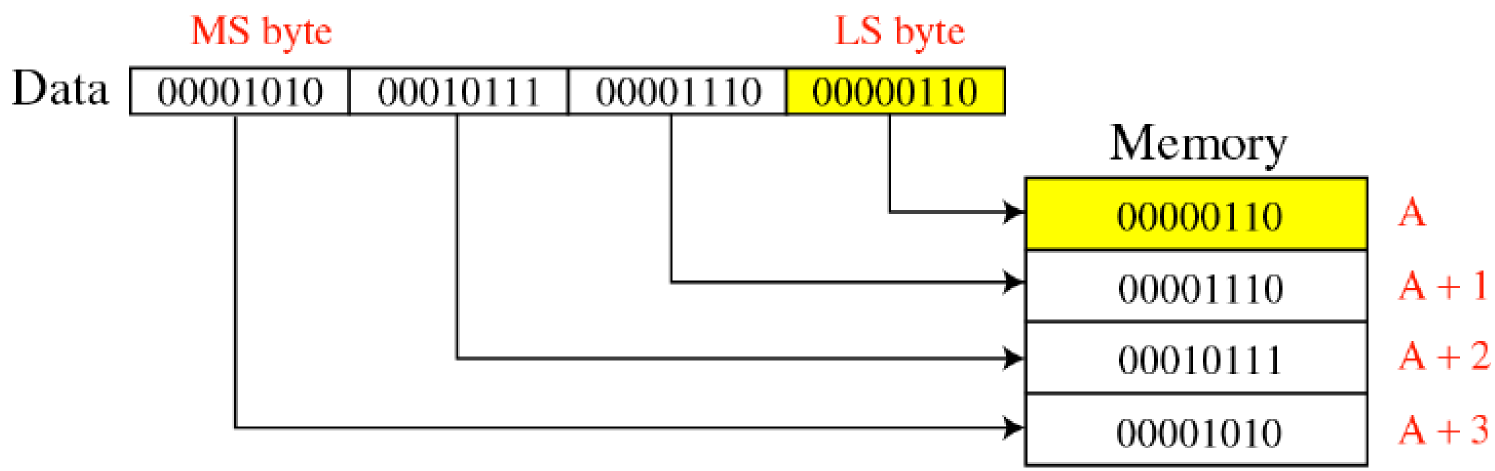


# Constructing Messages –Byte Ordering

- Big-Endian:

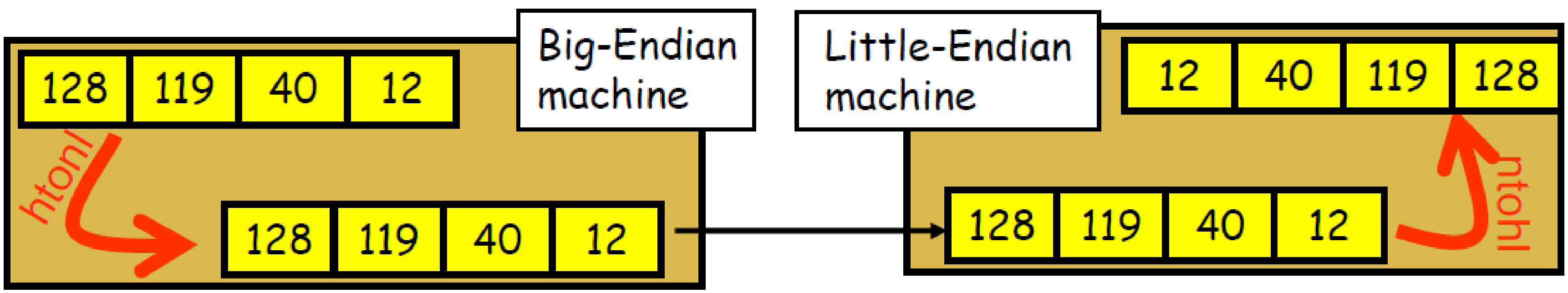



- Little-Endian:



# 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

| x | x2 | y | y2 |
|---|---|---|---|
| 4 bytes | 2 bytes | 4 bytes | 2 bytes |

→

| x | x2 | [pad] | y | y2 |
|---|---|---|---|---|
| 4 bytes | 2 bytes | 2 bytes | 4 bytes | 2 bytes |

- 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 Padding

- 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*

# Q&A