
Introduction to Sockets Programming in C using TCP/IP

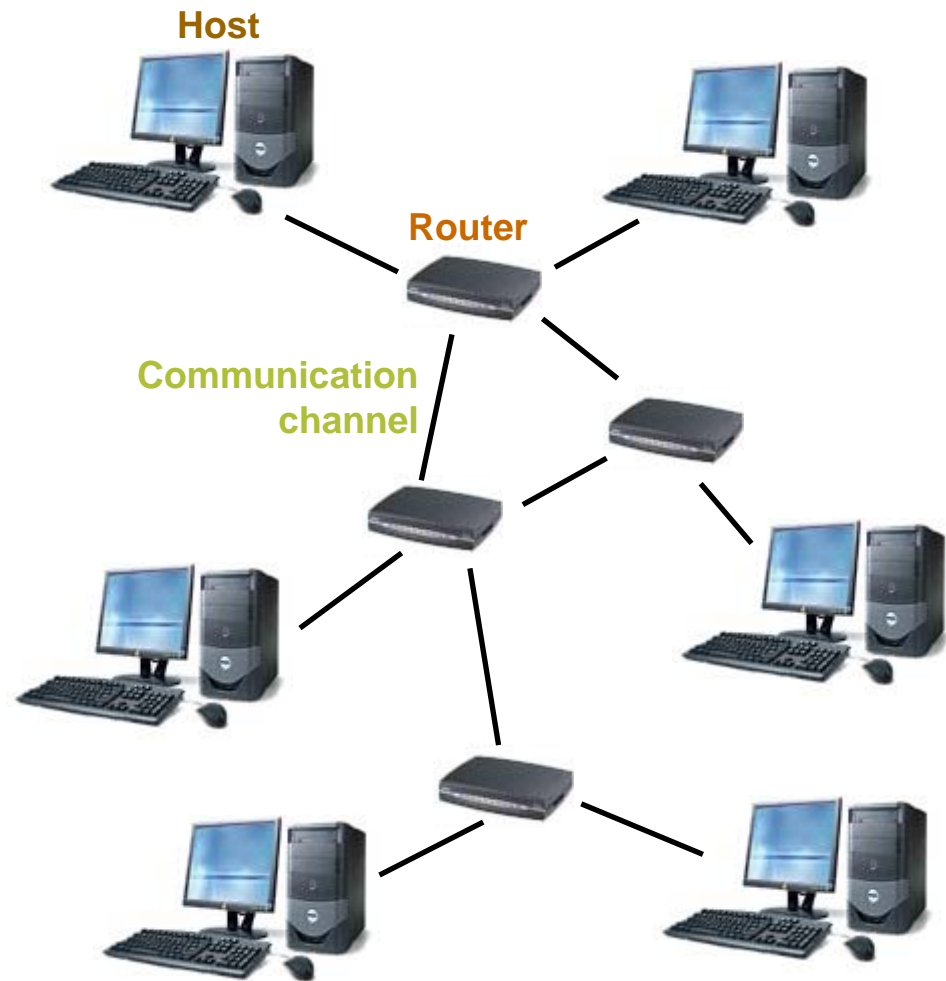
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Introduction

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



Protocol Families - TCP/IP

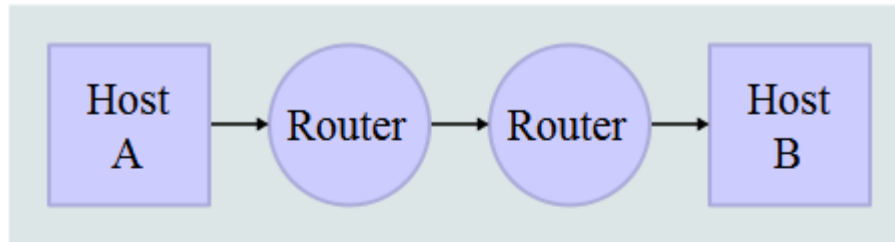
- Several protocols for different problems

☞ 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



*

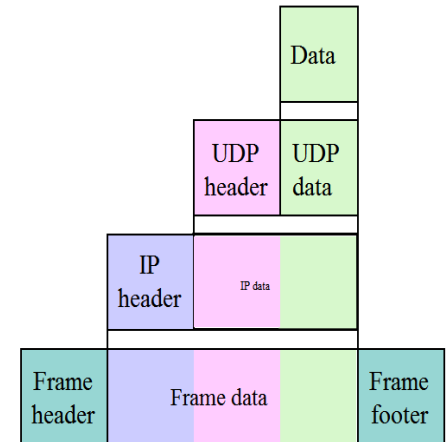
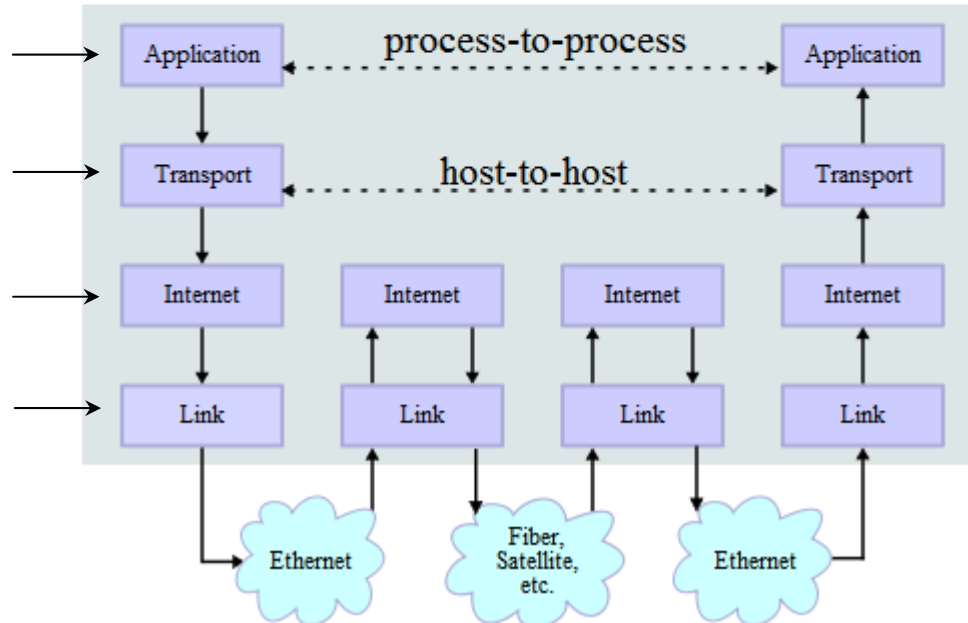
Data Flow

FTP, SMTP, ...

Transport Layer
TCP or UDP

Network Layer
IP

Communication
Channels



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

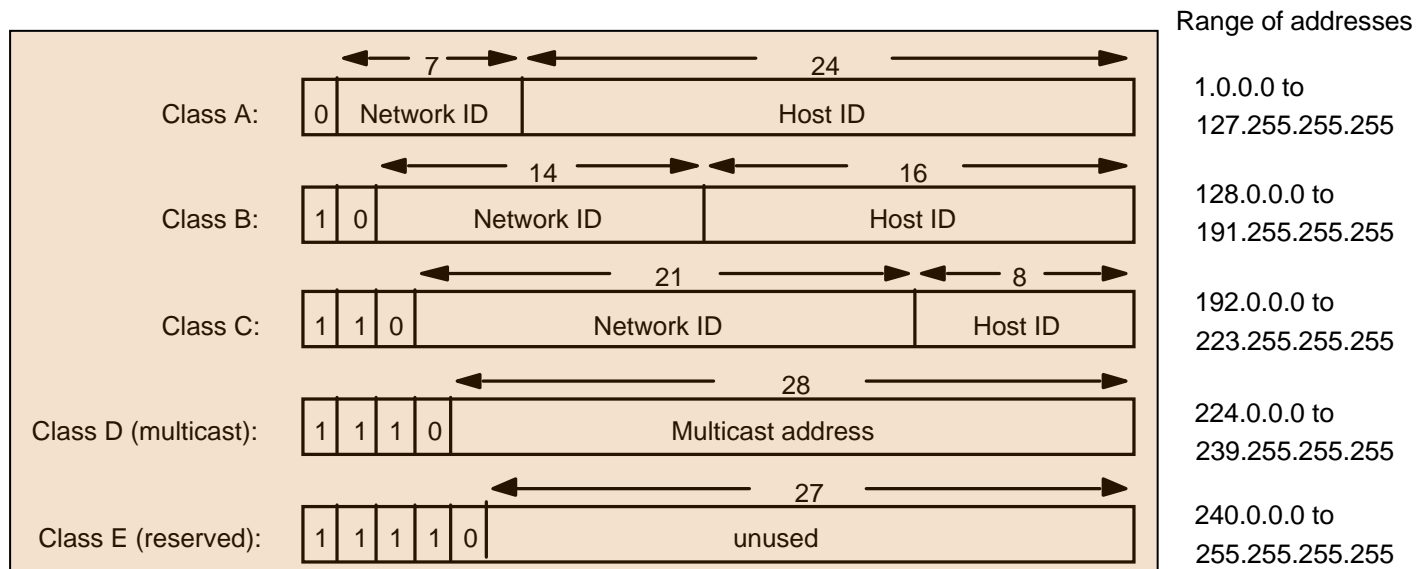
Internet Protocol (IP)

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

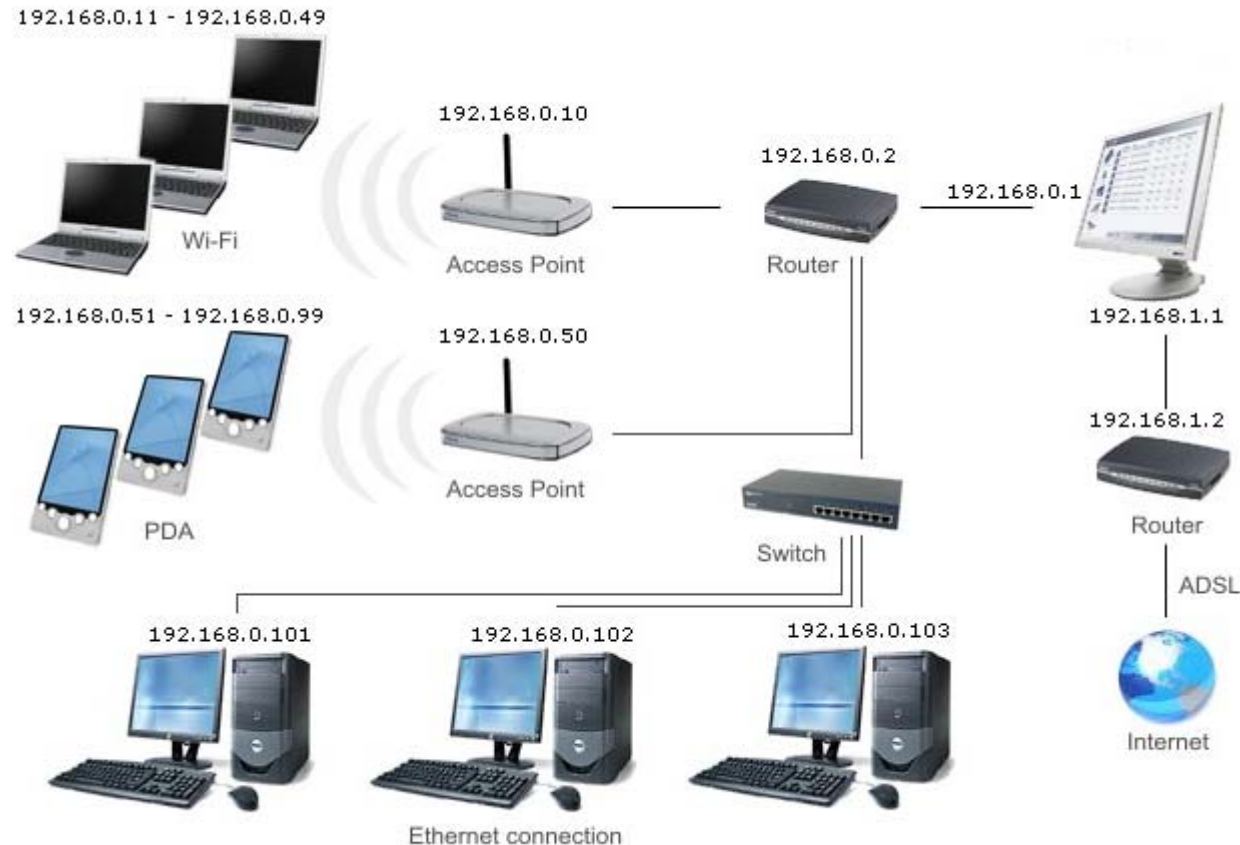


Addresses - IPv4

- 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

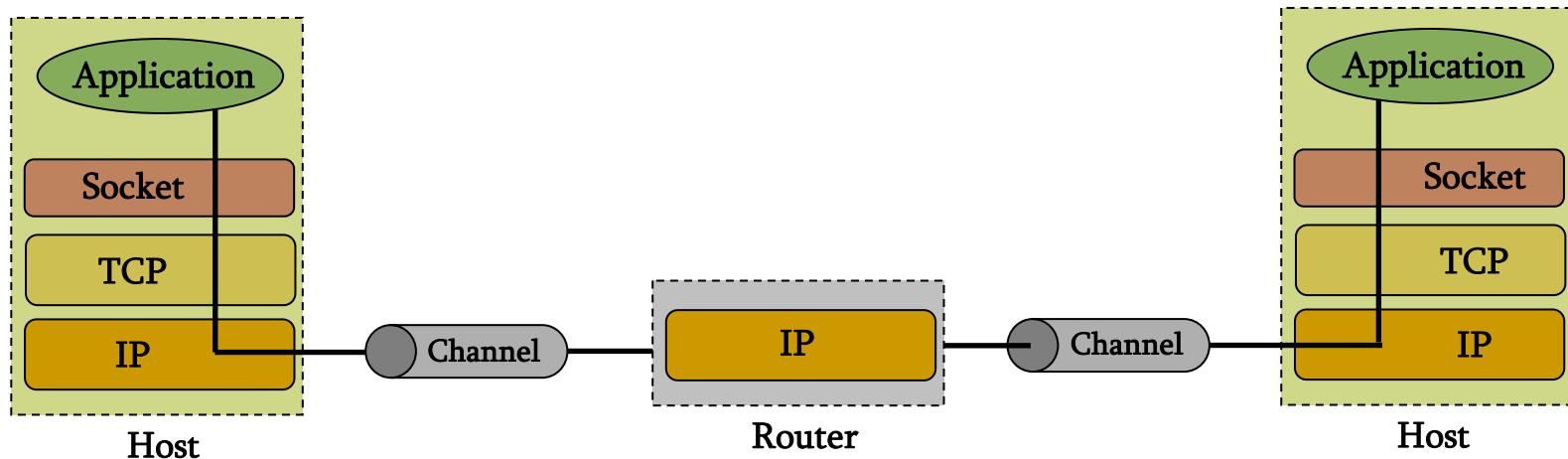
TCP vs UDP

- 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

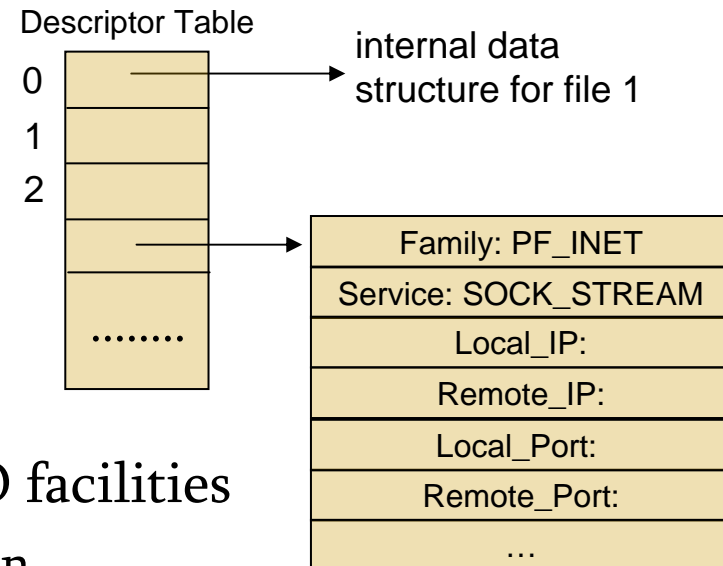
Berkley Sockets

- 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

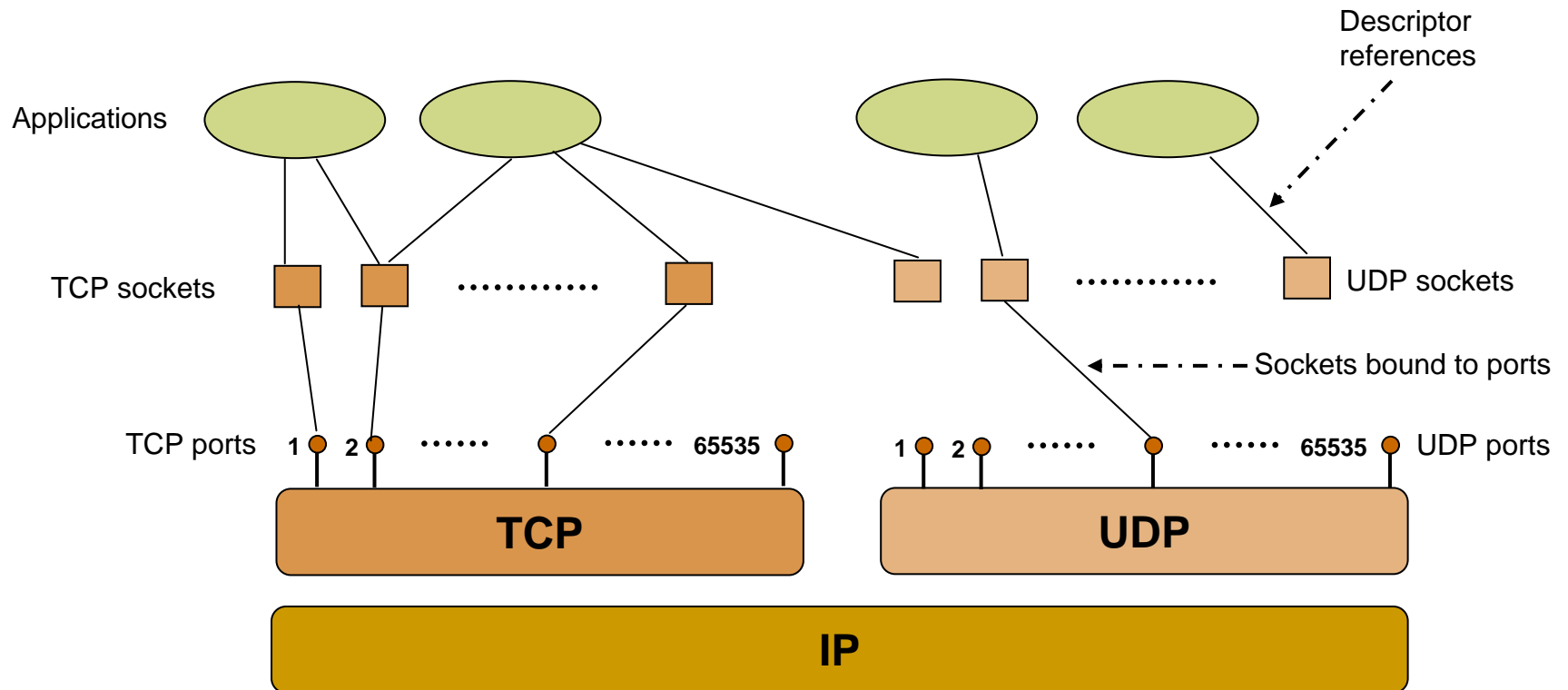


Sockets

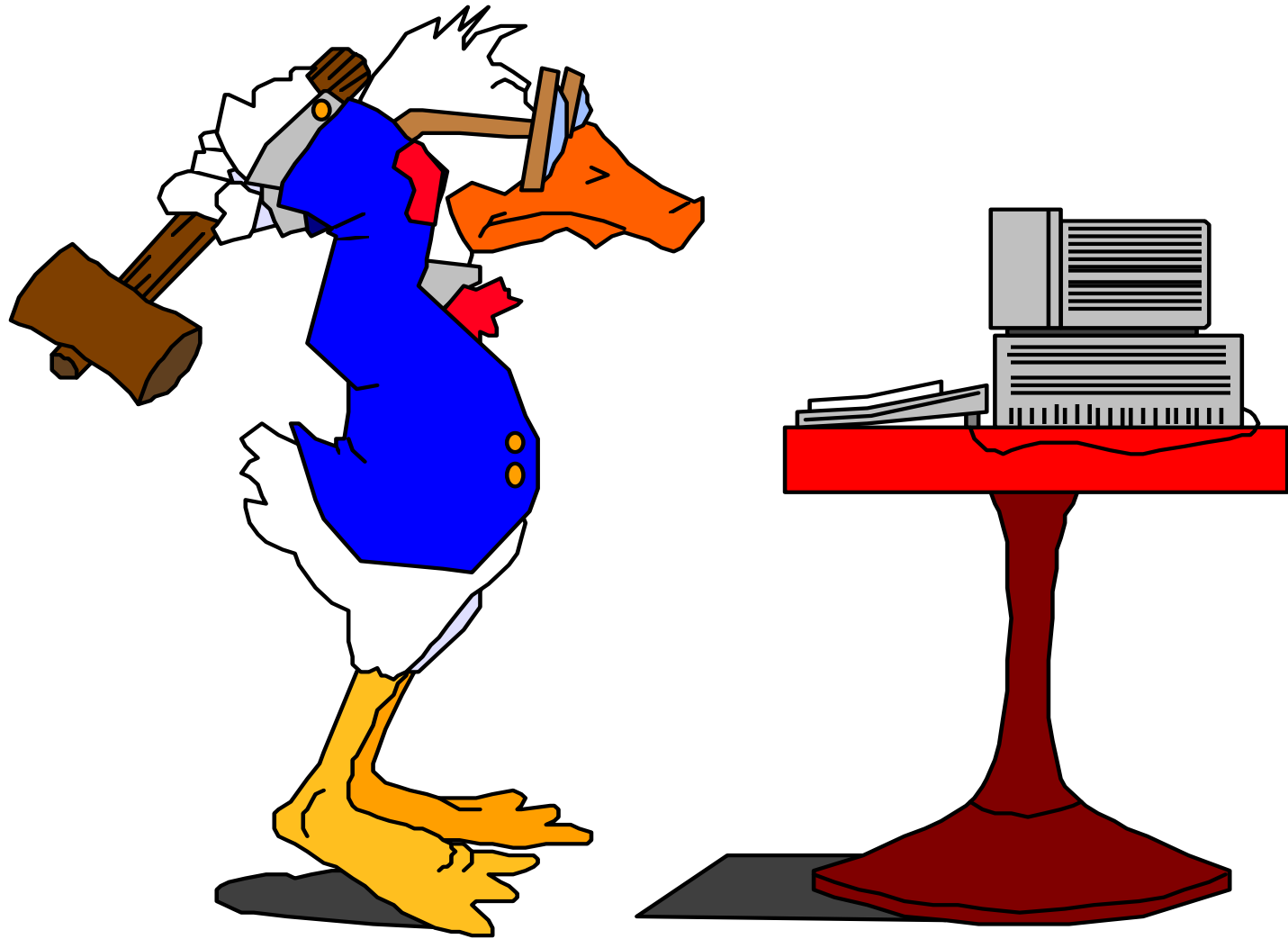
- Uniquely identified by
 - an internet address
 - an end-to-end protocol (e.g. TCP or UDP)
 - a port number
- Two types of (TCP/IP) sockets
 - **Stream** sockets (e.g. uses TCP)
 - provide reliable byte-stream service
 - **Datagram** sockets (e.g. uses UDP)
 - provide best-effort datagram service
 -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

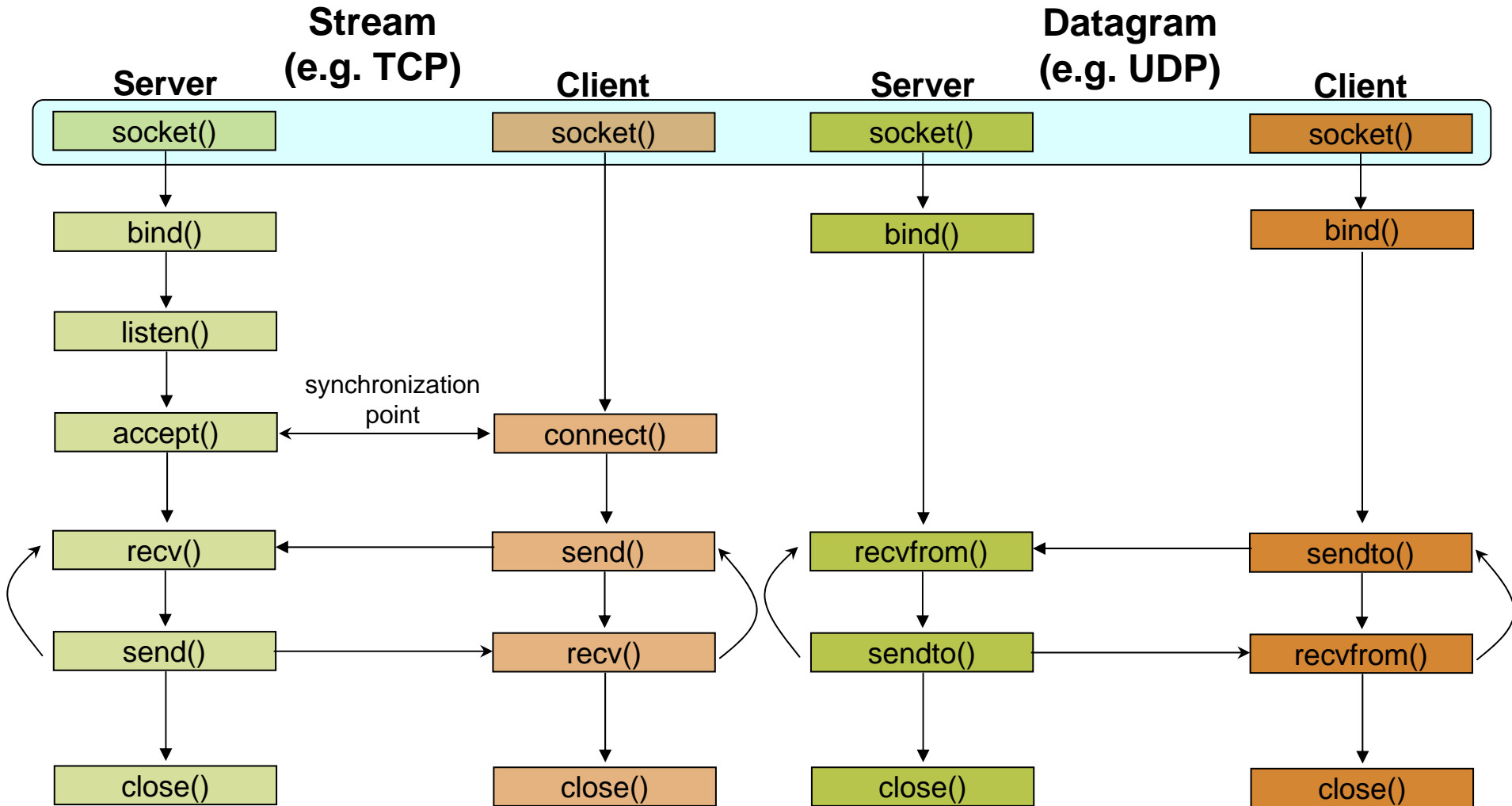
■ Client

- 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

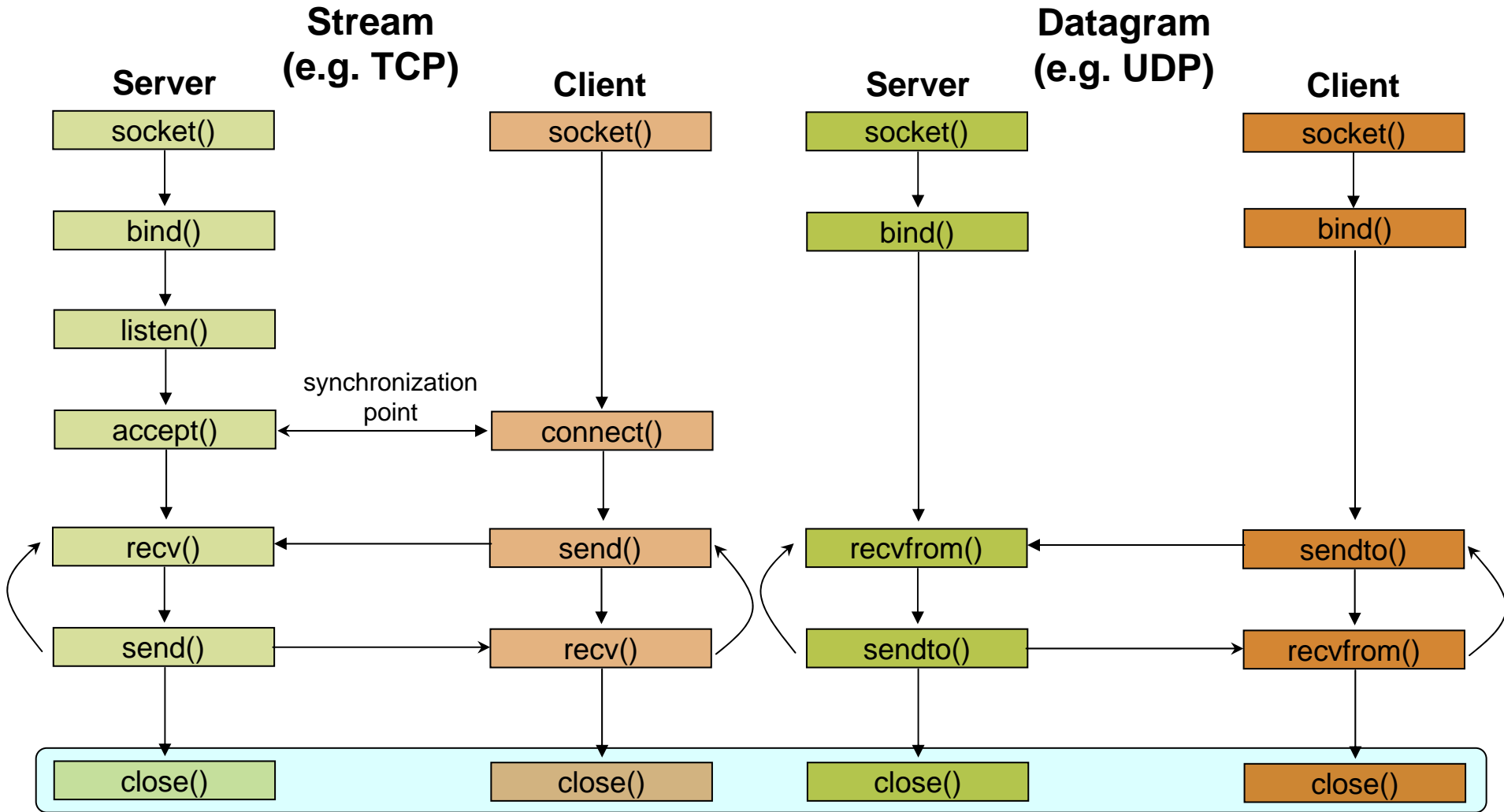
Client - Server Communication - Unix



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:

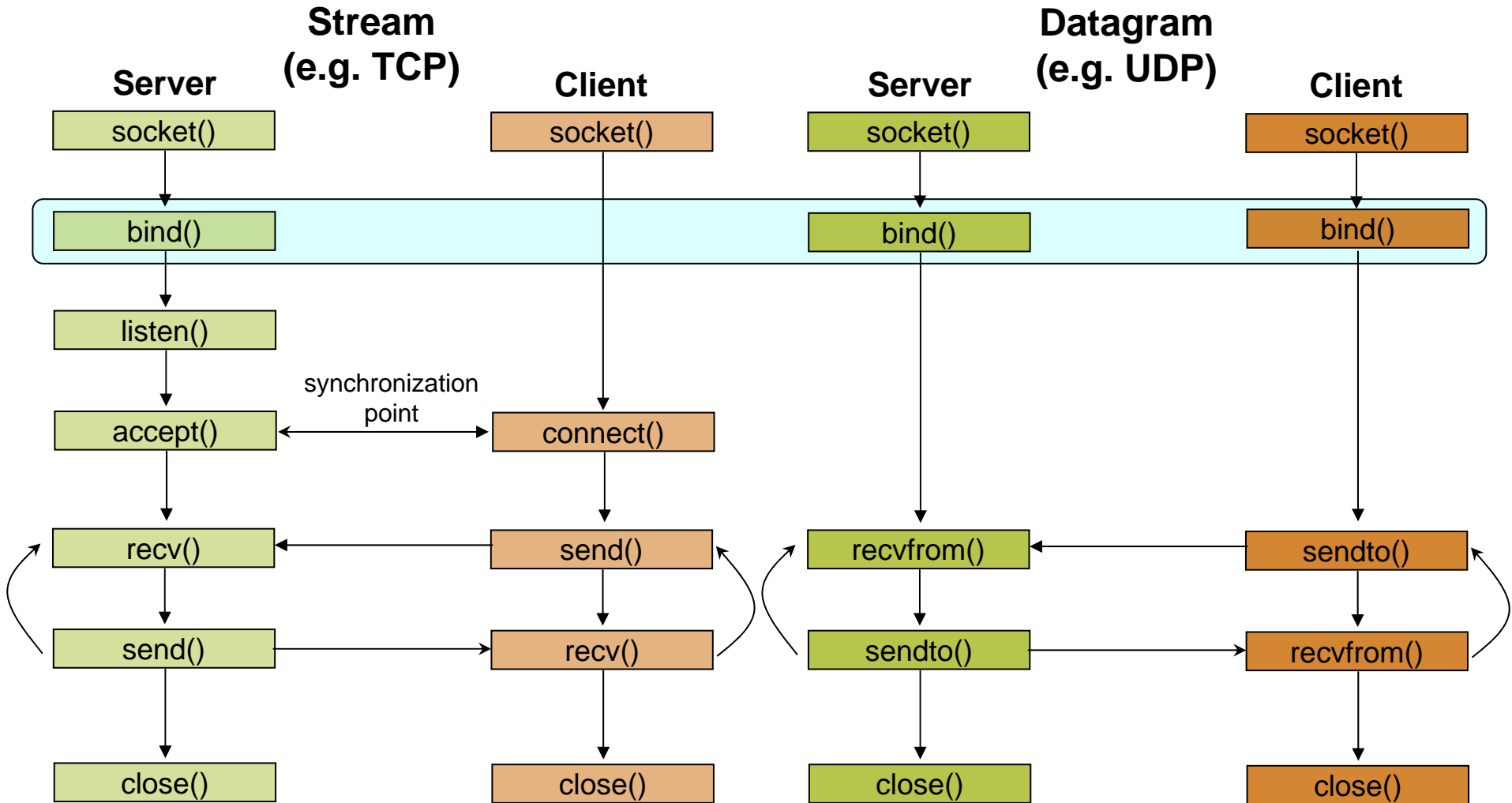
```
struct sockaddr {  
    unsigned short sa_family; /* Address family (e.g. AF_INET) */  
    char sa_data[14];         /* Family-specific address information */  
}
```

- 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

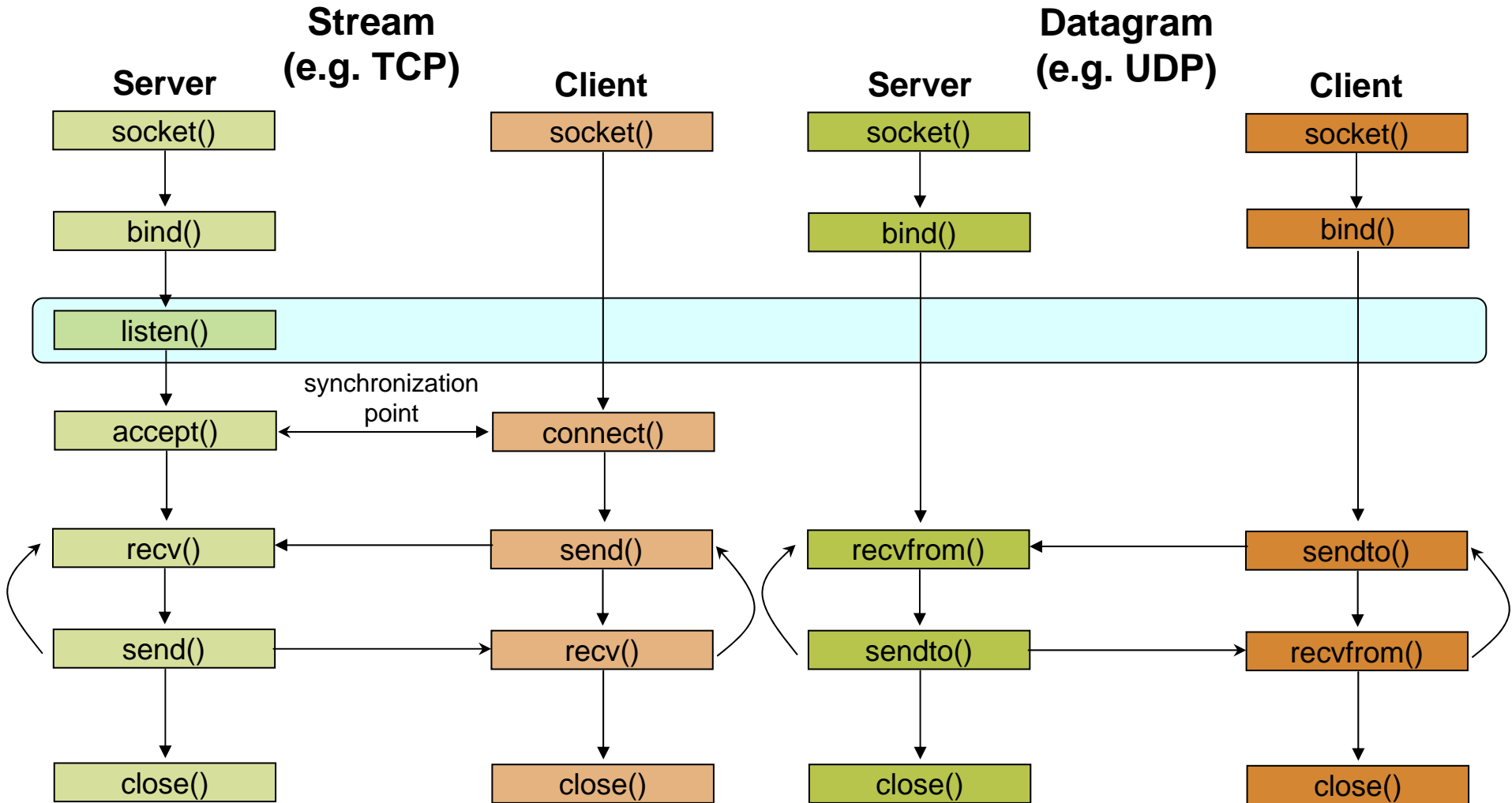
```
int sockid;
struct sockaddr_in addrport;
sockid = socket(PF_INET, SOCK_STREAM, 0);

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)

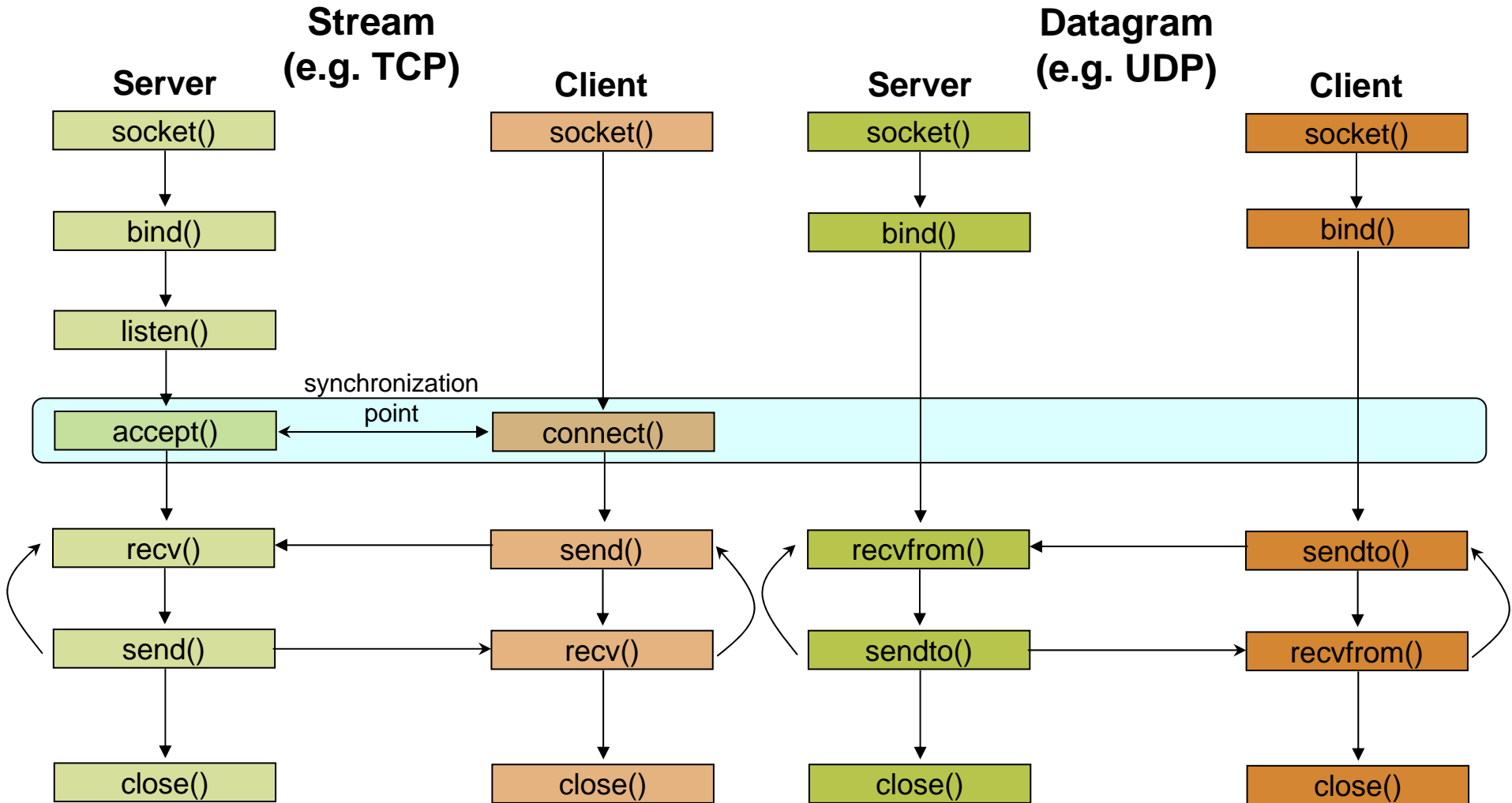
Client - Server Communication - Unix



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 ()`

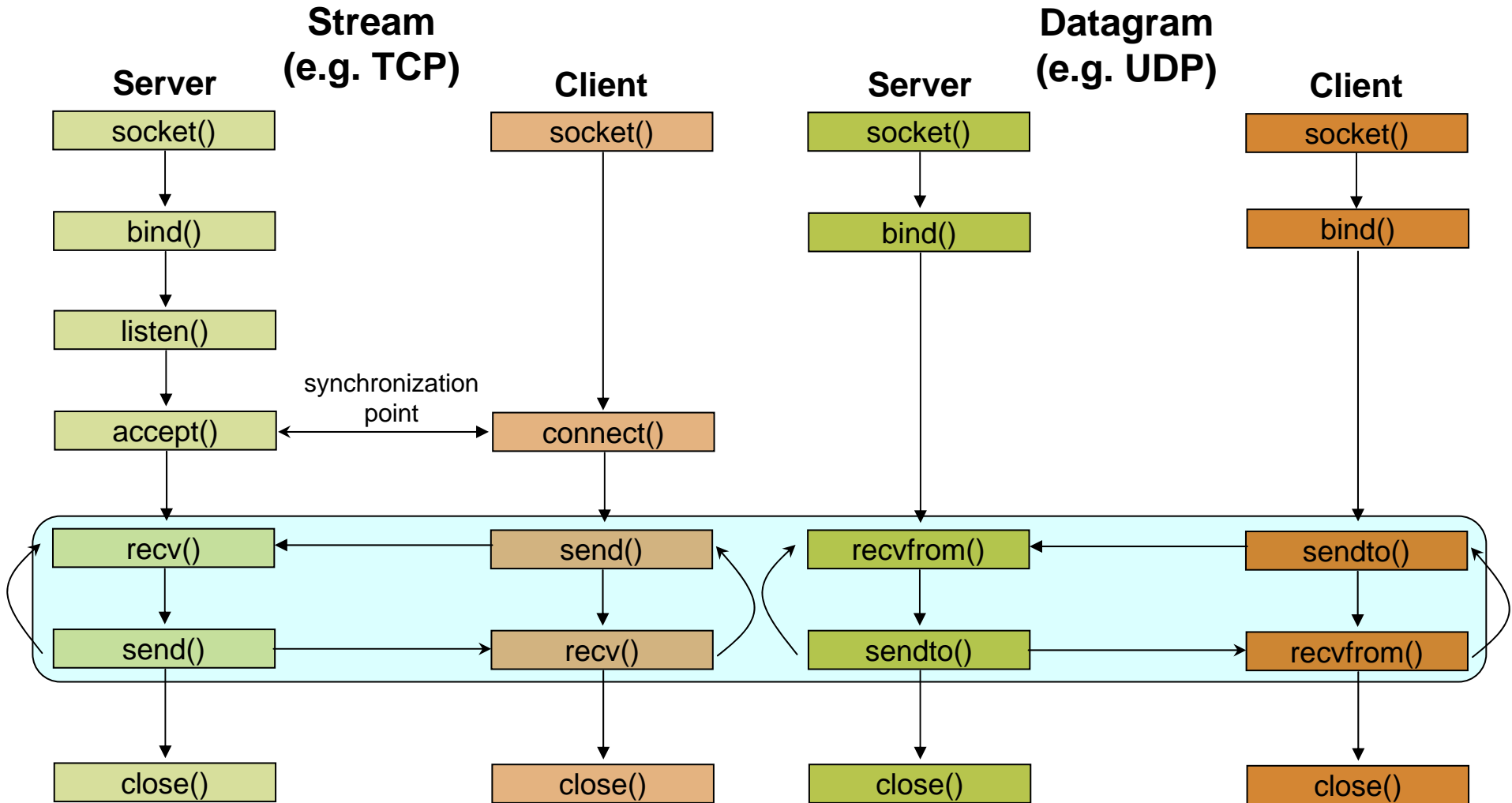
- ```
int status = connect(sockid, &foreignAddr, addrlen);
```

  - `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**
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  - 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
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4. Repeatedly:
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  - 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**
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  - a. **Accept new connection**
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# 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

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1. Create a TCP socket
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4. Repeatedly:
  - a. **Accept new connection**
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  - 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
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1. Create a TCP socket
2. Assign a port to socket
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  - c. Close the connection

# Example - Echo using stream socket

Similarly, the client receives the data from the server

## Client

1. Create a TCP socket
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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

```
close(clientSock);
```

## Client

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

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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

