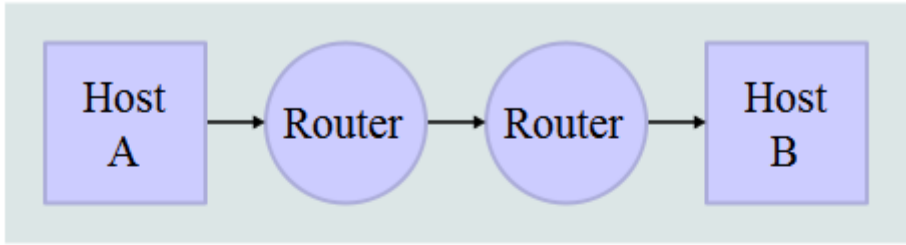
Introduction to Socket Programming

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 *



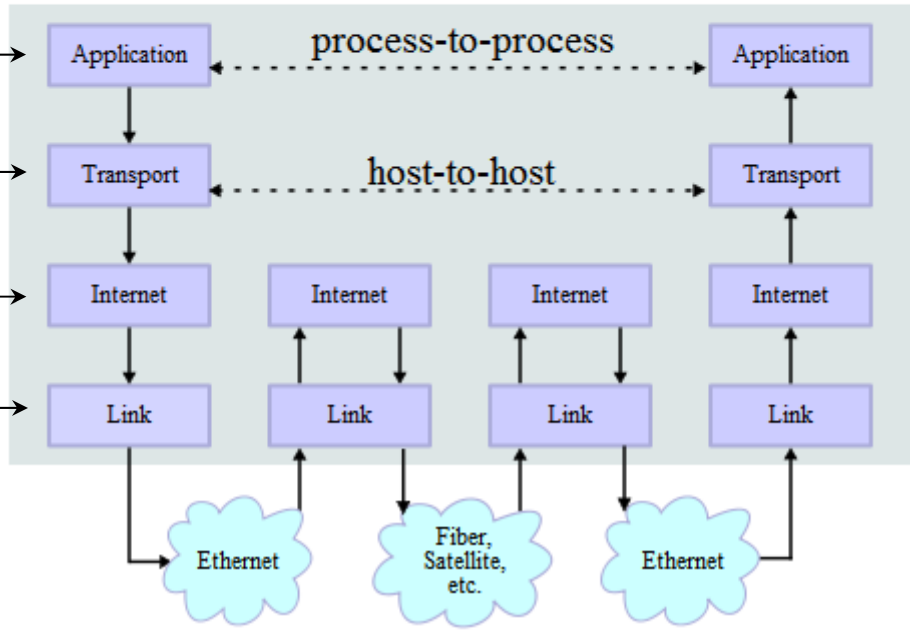
Data Flow

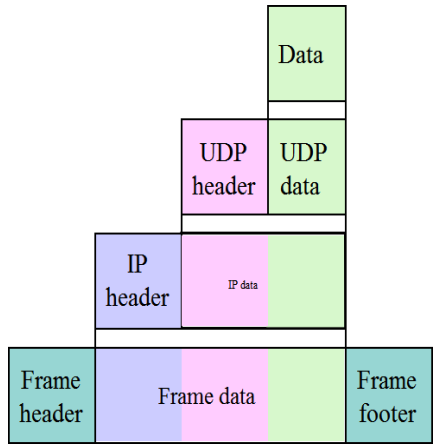
FTP, SMTP, …

Transport Layer TCP or UDP

Network Layer IP

Communication Channels





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

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 and 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

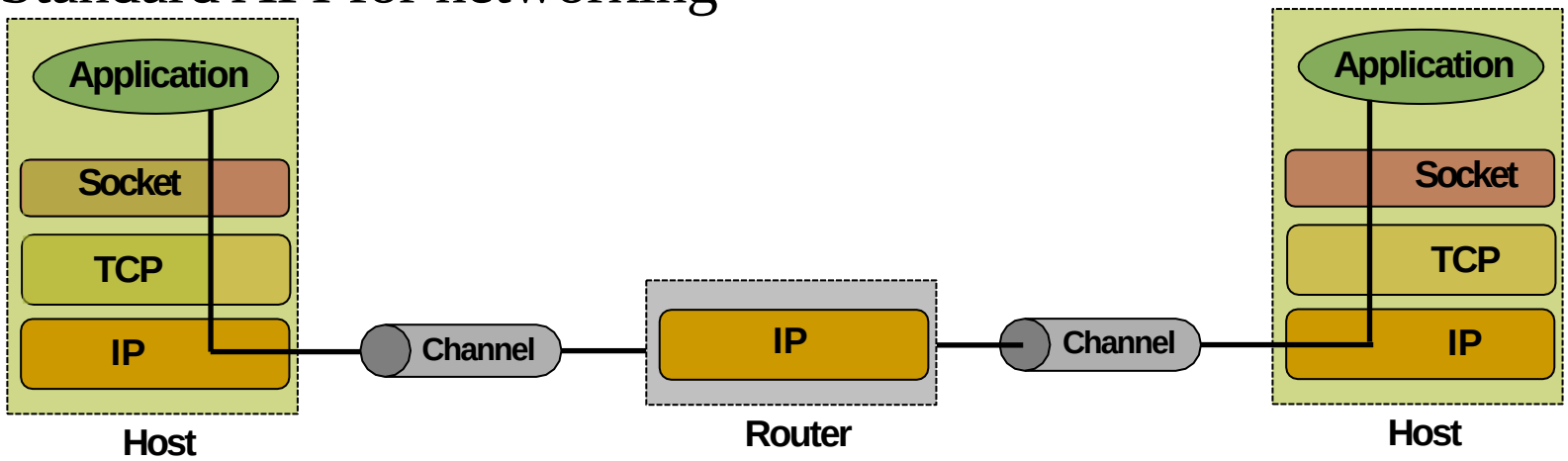
TCP vs UDP

- 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

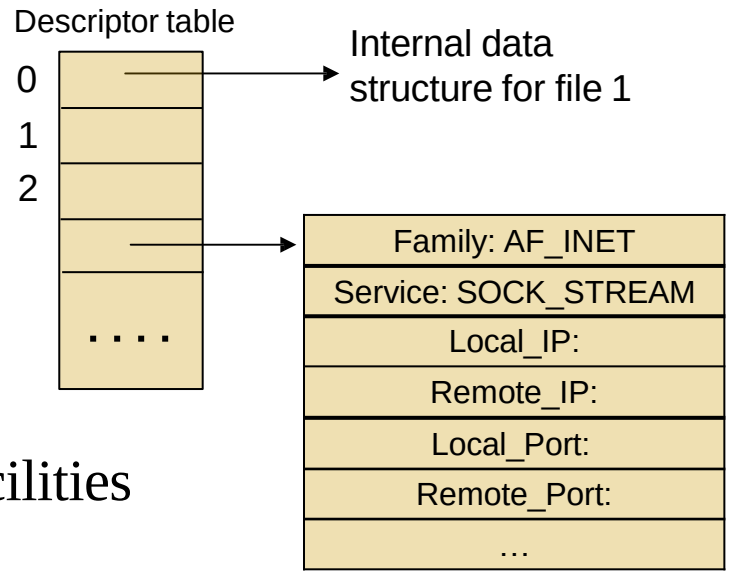
Berkley Sockets

- 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

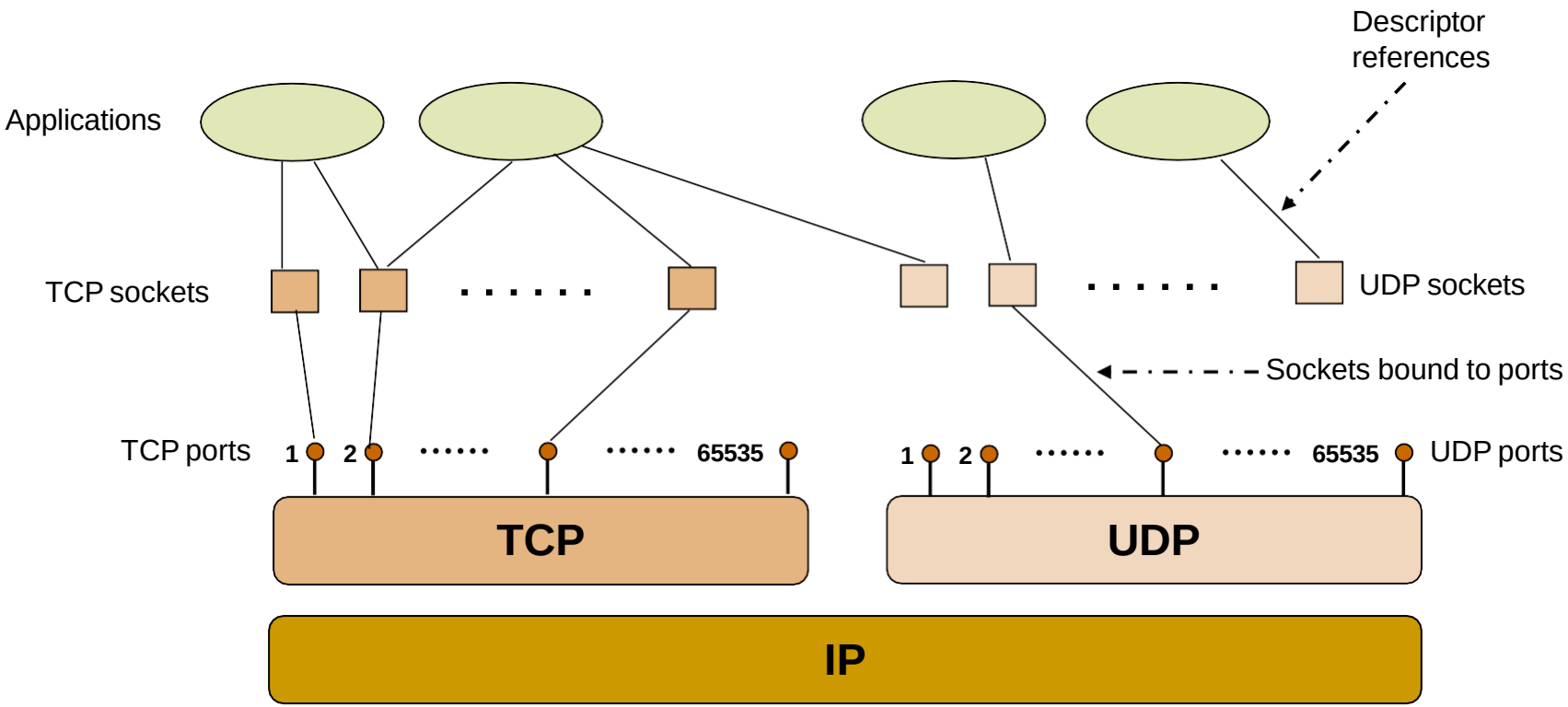


Sockets

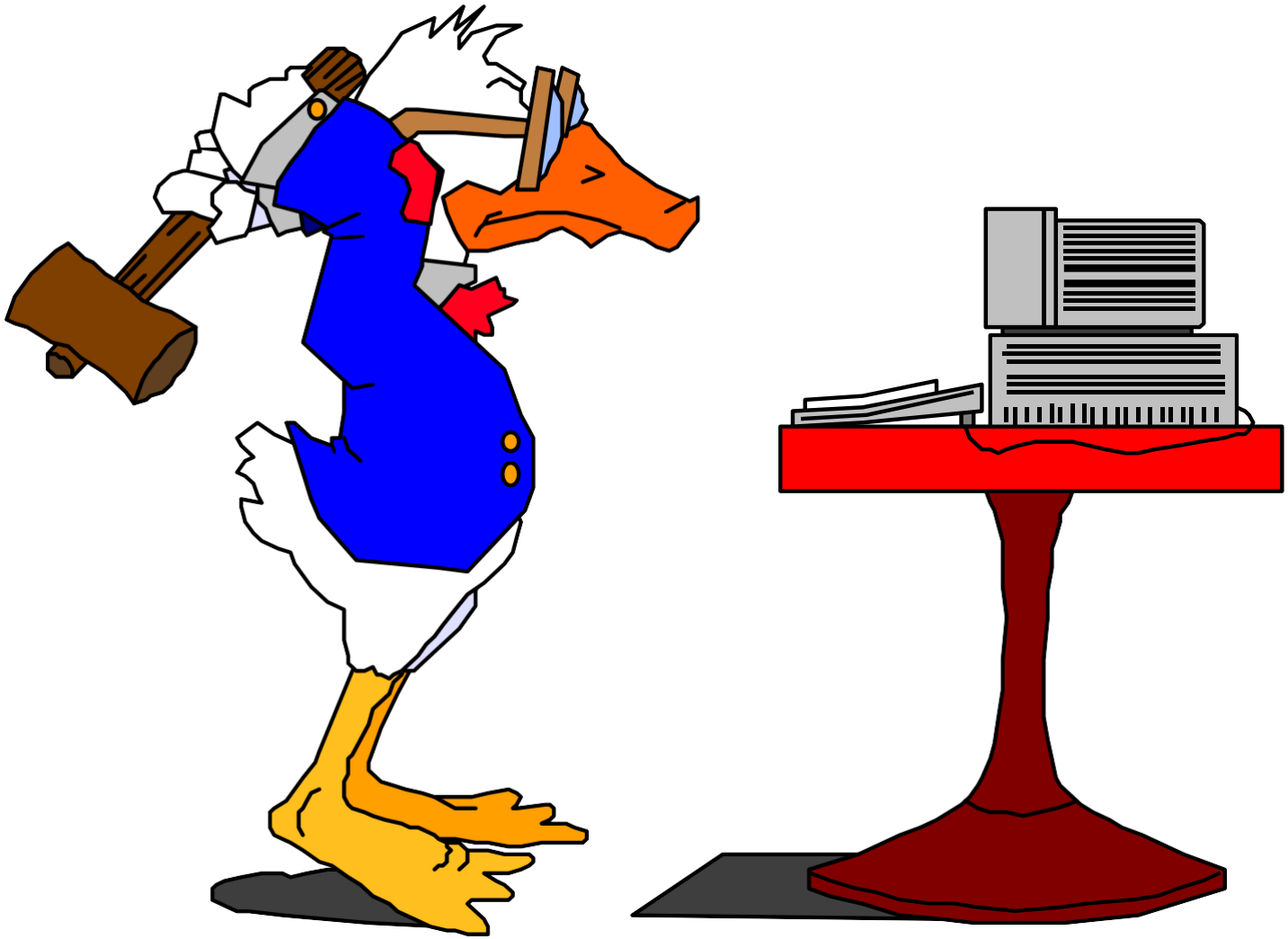
- Uniquely identified by
  - An internet address
  - An end-to-end protocol (e.G. TCP or UDP)
  - A port number
- **Two types of (TCP/IP) sockets**
- **Stream sockets (e.G. Uses TCP)**
  - Provide reliable byte-stream service
- **Datagram sockets (e.G. Uses UDP)**
  - Provide best-effort datagram service
  - Messages up to 65500 bytes
- Socket extend the convectional UNIX I/O facilities
  - File descriptors for network communication
  - Extended the read and write system calls



Sockets


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

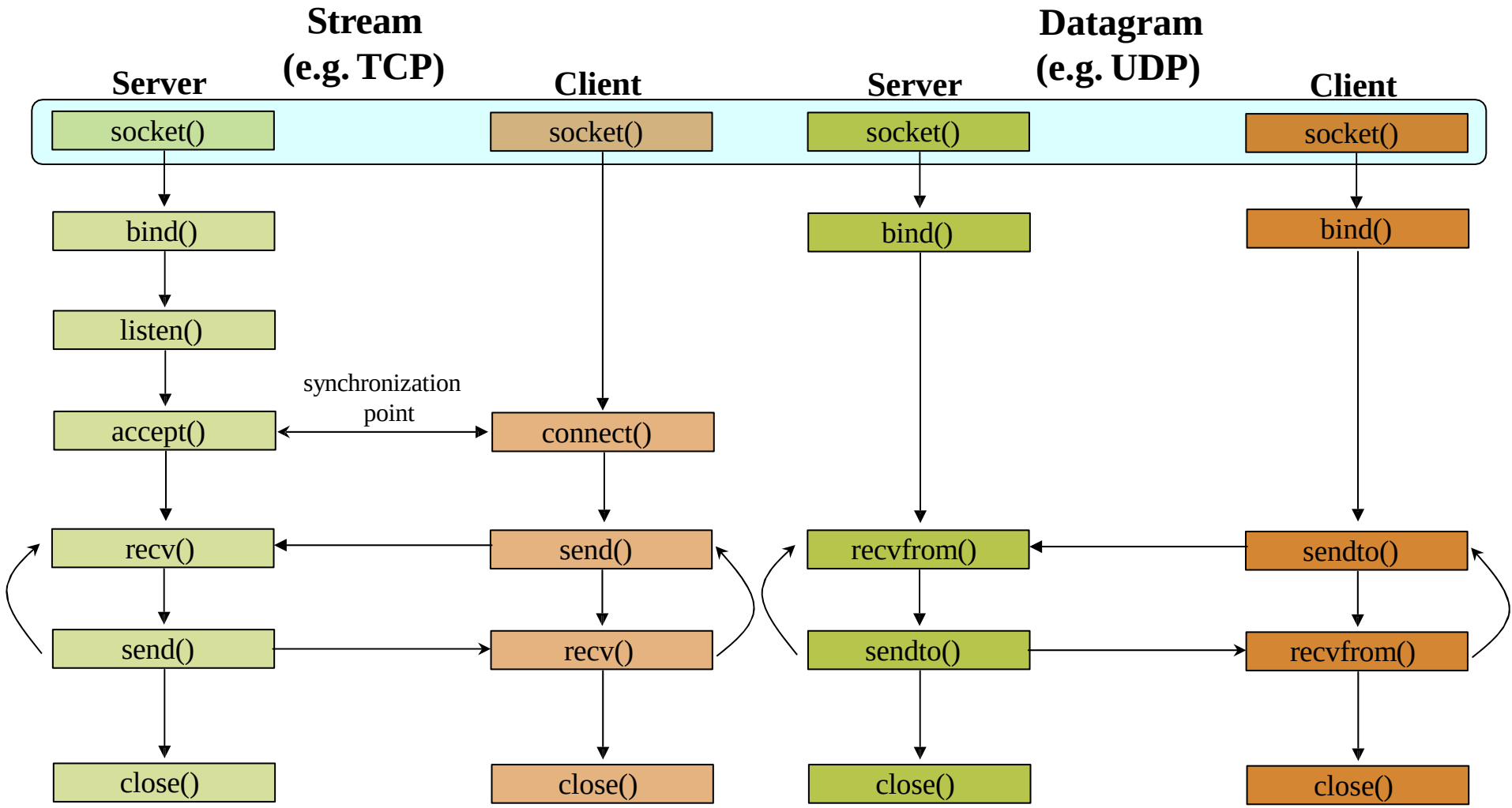
Socket Programming



Client-Server communication

- **Server**
  - Passively waits for and responds to clients
  - **Passive** socket
- **Client**
  - Initiates the communication
  - Must know the address and the port of the server
  - **Active** socket

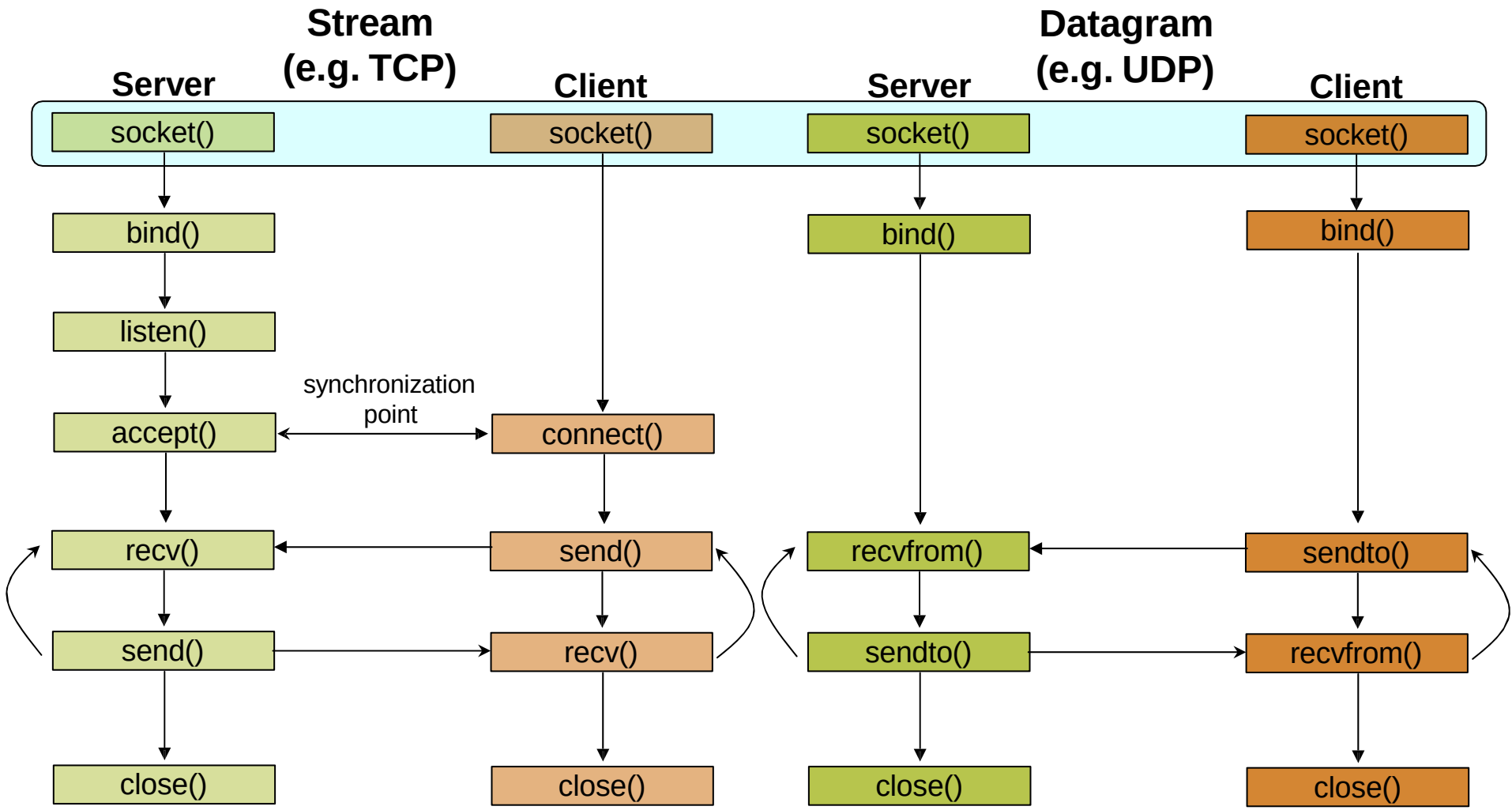
Client - Server Communication - Unix



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

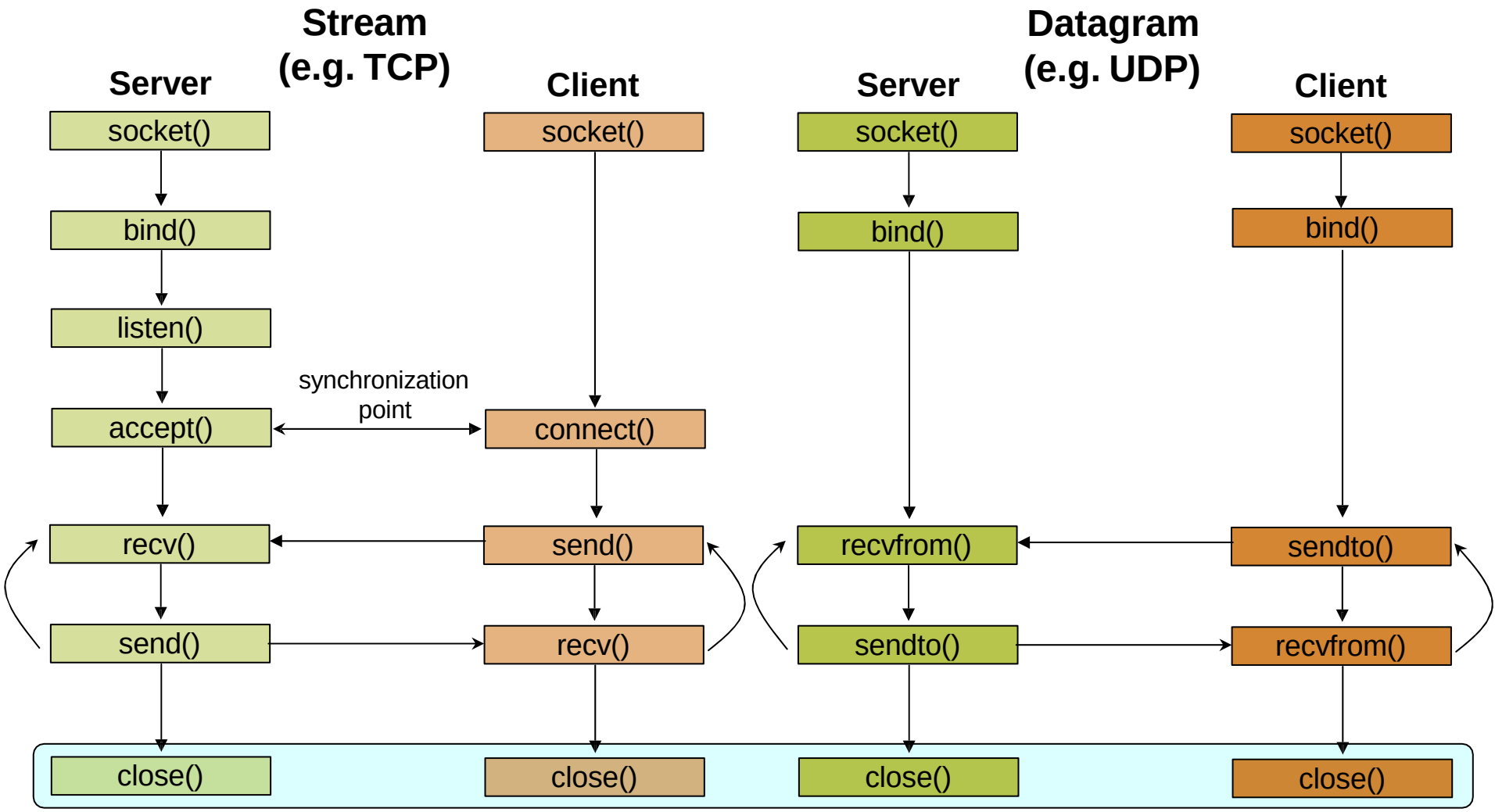
Client - Server Communication - Unix



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:

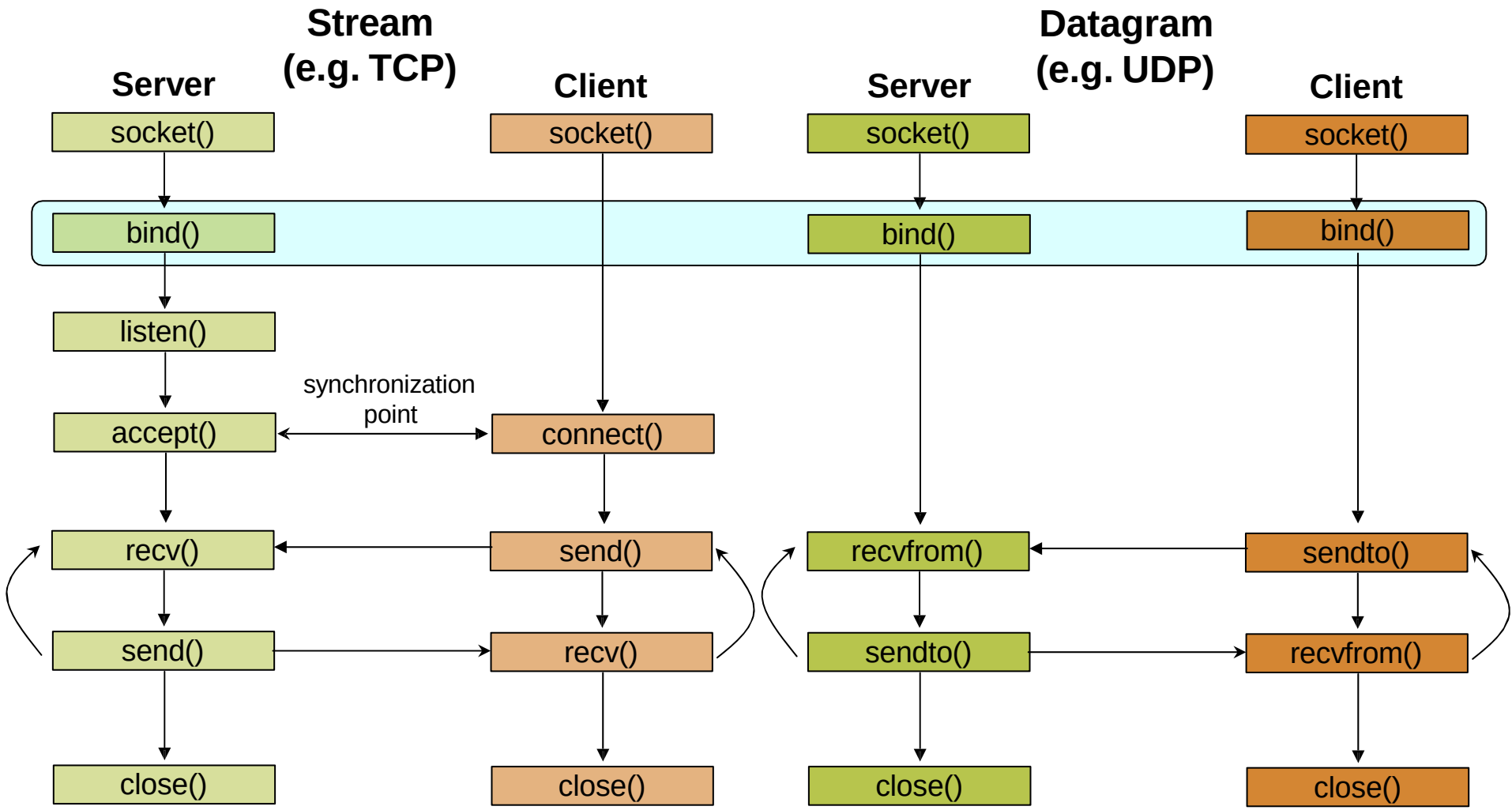
```
struct sockaddr {
    unsigned short sa_family;  /* Address family (e.g. AF_INET) */
    char sa_data[14];          /* Family-specific address information */
}
```

- 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

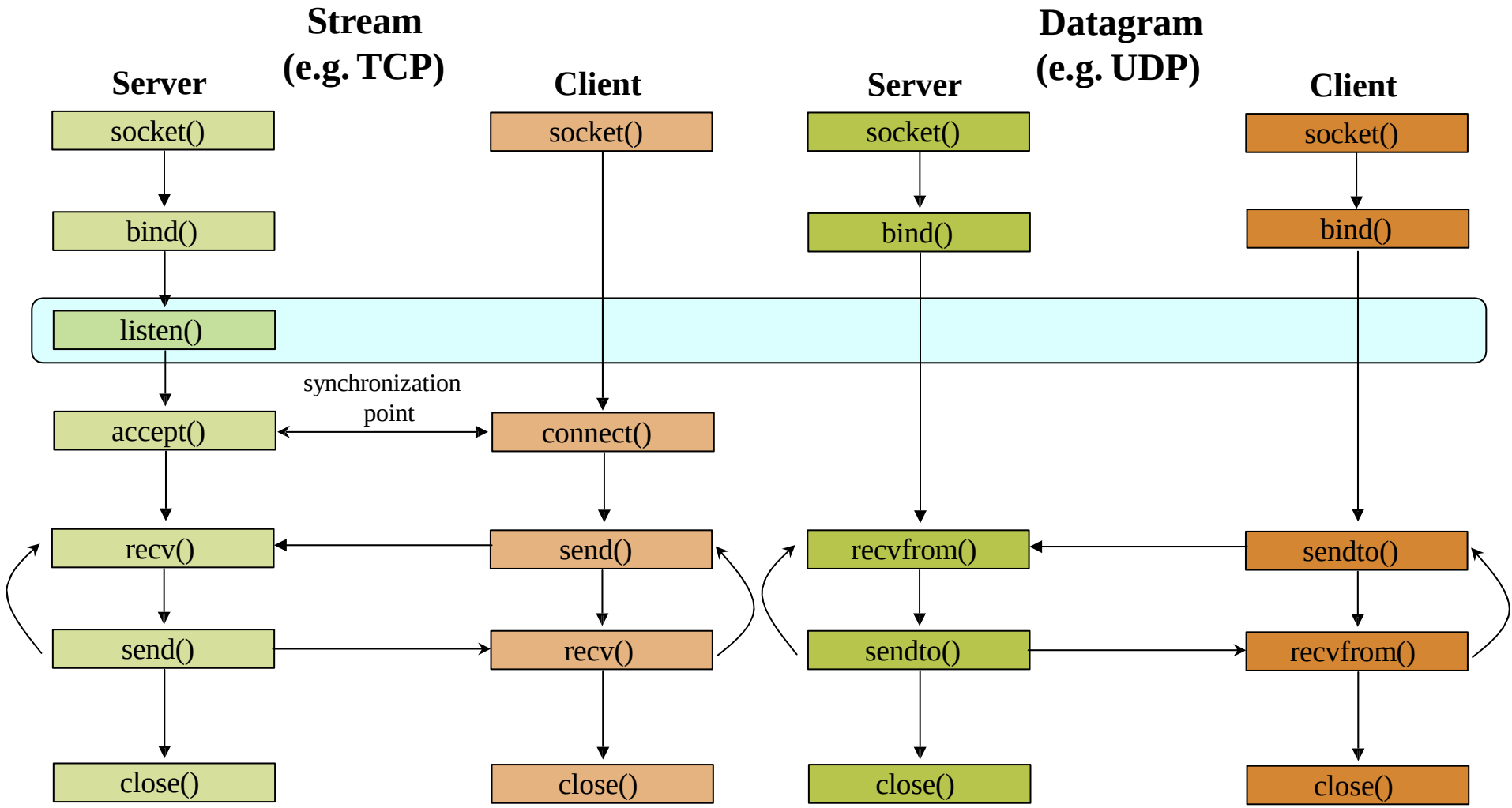
```
int sockid;
struct sockaddr_in addrport;
sockid = socket(PF_INET, SOCK_STREAM, 0);

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



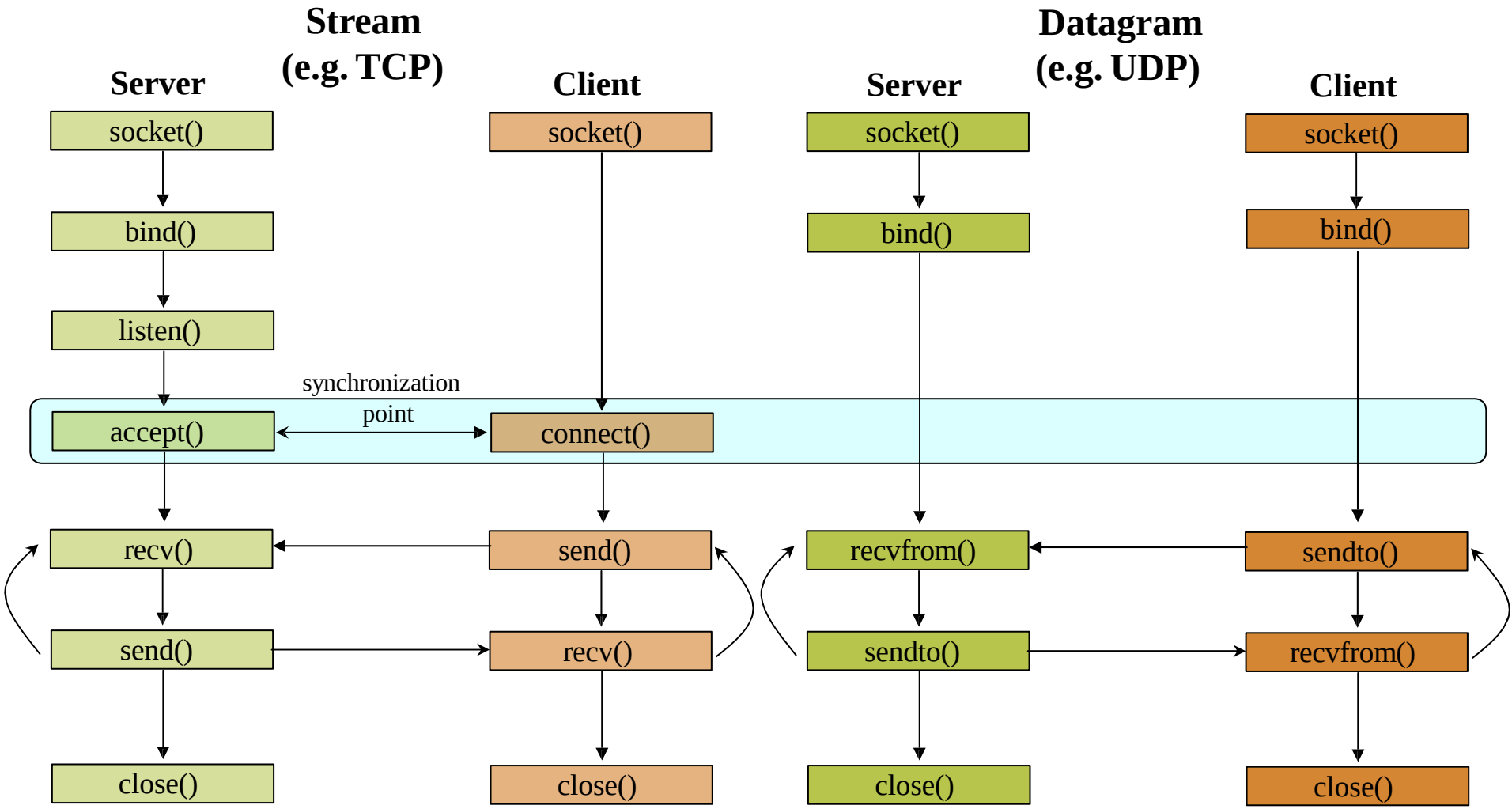
Assign address to socket: bind()

- Instructs TCP protocol implementation to listen for connections

- **int status = listen(sockid, queueLimit);**
  - **sockid**: integer, socket descriptor
  - **queueLimit**: 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()

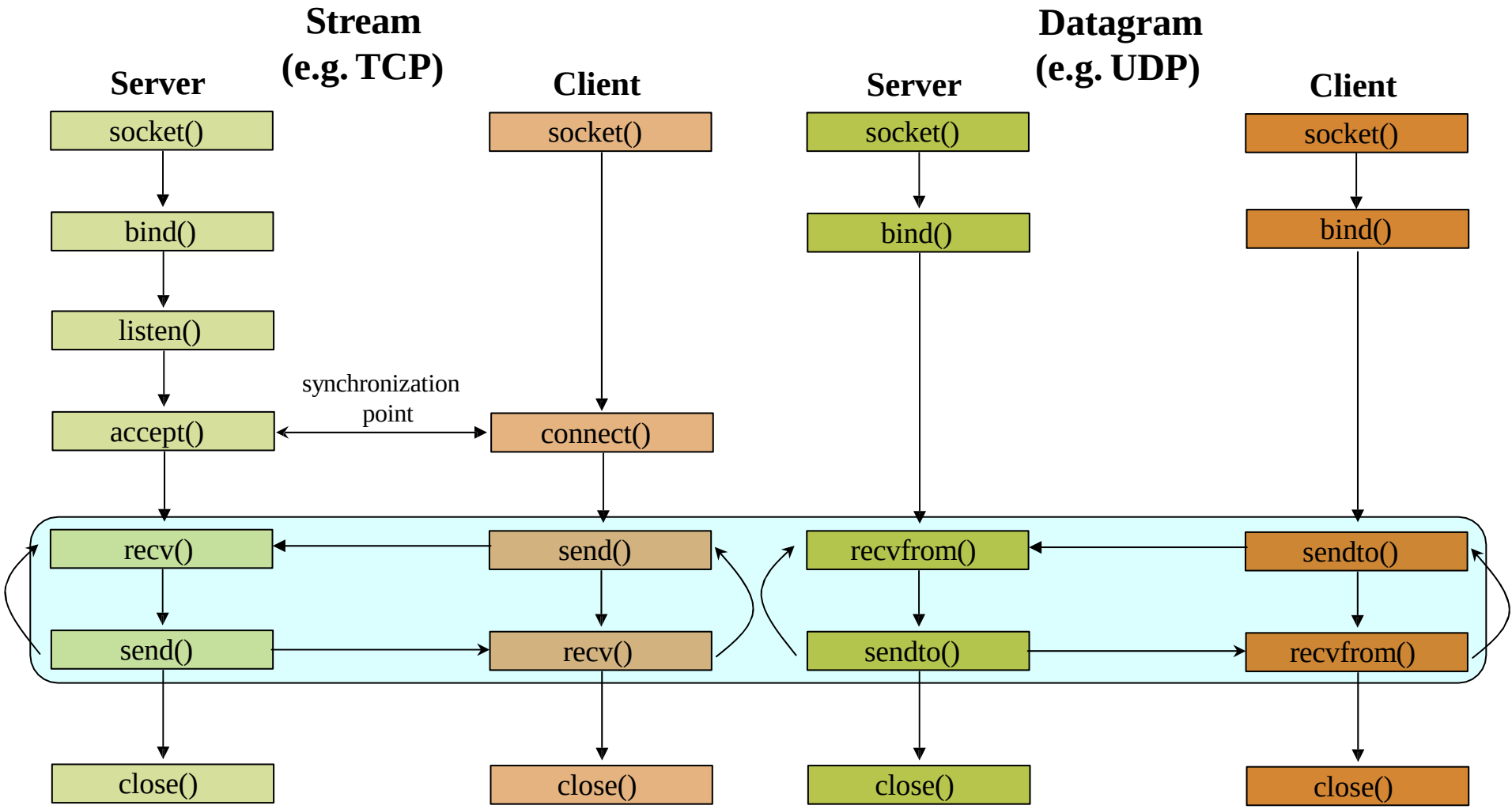
- **int status = connect(sockid, &foreignAddr, addrlen);**
  - **sockid**: integer, socket to be used in connection
  - **foreignAddr**: struct sockaddr: address of the passive participant
  - **addrlen**: integer, sizeof(name)
  - status: 0 if successful connect, -1 otherwise

- 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

Self Practice – Echo Server and Client

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