

CS 118 Discussion Week 3: The Application Layer and BSD Sockets

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Slides by Eric Newberry

January 22, 2021

Application

HTTP

SMTP

DNS

Transport

TCP

UDP

Network

Link

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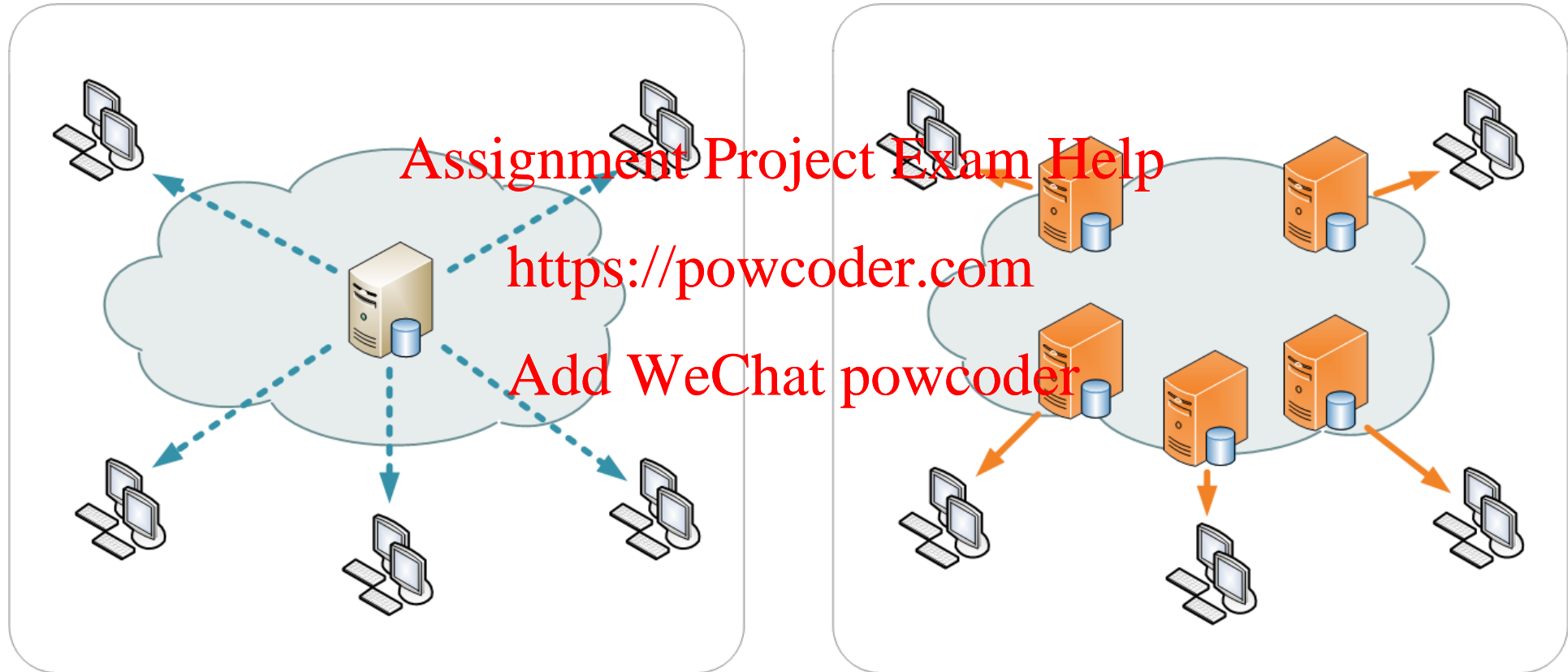
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Content Distribution Networks

- Store content at geographically distributed locations
- Through the magic of DNS, clients will find the geographically closest location
- Idea is to reduce both latency and load on a small set of servers
 - By using closer content and more servers
- Content providers pay CDN companies to serve their data

Content Distribution Networks



https://commons.wikimedia.org/wiki/File:NCDN_-_CDN.png

Video Streaming with DASH

- Split video file into chunks and encode at different bit rates
 - Smaller bit rates → less bandwidth required to transfer
- Replicate various bit rate chunks on CDN
- Client will use a manifest file to identify different chunks at different bit rates
- Client will periodically estimate available bandwidth to reach server
 - In this case CDN nodes are the server
- Retrieve video at maximum bit rate that estimate says have enough bandwidth for
 - Can also change which CDN node retrieving from based upon geographical and available bandwidth considerations

UDP

- User Datagram Protocol
- The simpler of the two, provides less “features” than TCP
- Provides the bare minimum needed to get packets to the receiver
- Packets *not* guaranteed to be received by remote app in order
- Packets *not* guaranteed to get to remote host at all
- No connection → just send data

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TCP

- Transmission Control Protocol
- Data guaranteed to be delivered and delivered *in order*
- Provides “congestion control” to allow it to “play nice” with other communication streams on the network
- Need to establish connection with a specific remote host

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Should I use TCP or UDP?

- Still no guarantee of delay or throughput in either TCP or UDP
- Discuss: What types of applications would benefit the most from using each transport protocol?

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Which applications use which protocols?

- TCP

- HTTP (current versions)
- SMTP, IMAP
- FTP (file transfer)
- SSH (remote shell)

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- UDP

- DNS (can also use TCP), DHCP (network configuration)
- Streaming audio and video (including voice-over-IP/“VoIP”)
- HTTP/3 and QUIC
 - Use congestion control and reliability at application layer (if needed)!

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Socket Programming in C

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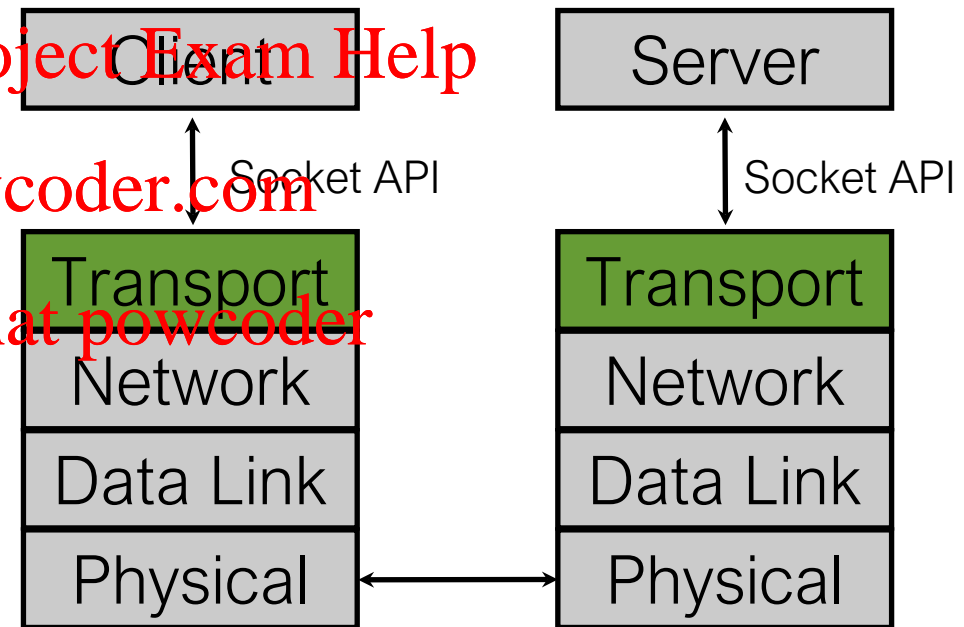
“Where” are we programming?

- “Clients” and “servers” are programs at the **application layer**
- The **transport layer** is responsible for providing communication services for the application layer
- Basic transport protocols
 - TCP
 - UDP

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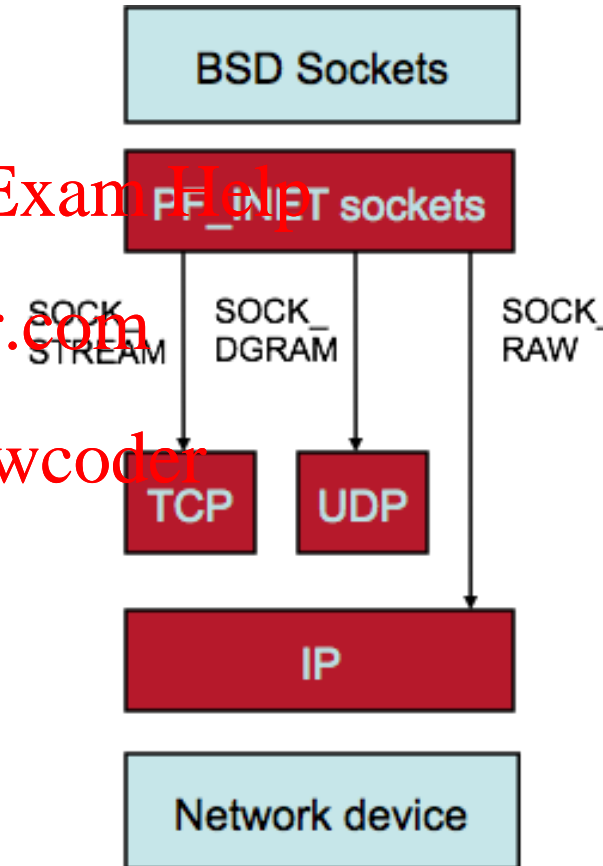
What is socket programming?

- From Wikipedia: “A network socket is an endpoint of an inter-process communication flow across a computer network”
- In other words, sockets are APIs between applications and transport/network services

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TCP Socket Programming

- Create service
- Establish a TCP connection
- Send and receive data
- Close TCP connection

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TCP Socket: Service Setup

TCP Client

TCP Server

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TCP Socket: Service Setup

TCP Client

TCP Server

socket()

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TCP Socket: Service Setup

TCP Client

TCP Server

socket()



bind()

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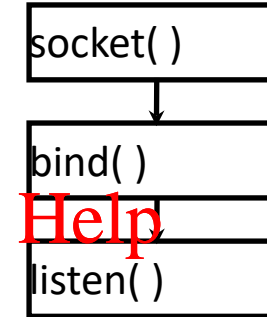
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TCP Socket: Service Setup

TCP Client

TCP Server



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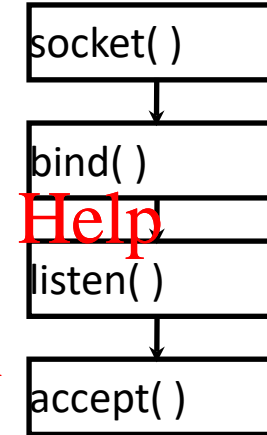
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TCP Socket: Service Setup

TCP Client

TCP Server



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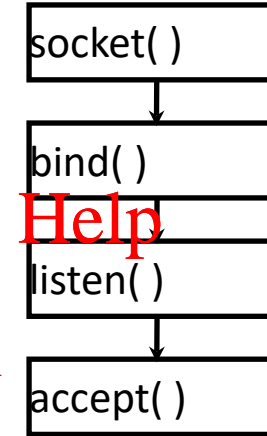
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TCP Socket: Service Setup

TCP Client

TCP Server



blocked until
connection from client

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TCP Socket: Establish Connection

TCP Client

socket()

TCP Server

socket()

bind()

listen()

accept()

blocked until
connection from client

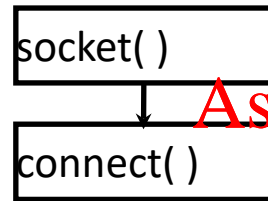
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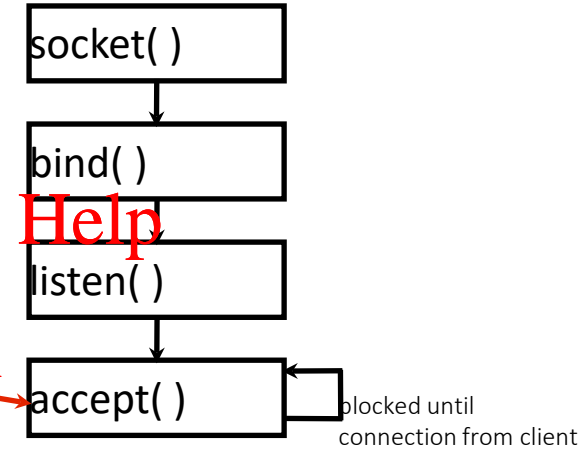
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TCP Socket: Establish Connection

TCP Client



TCP Server



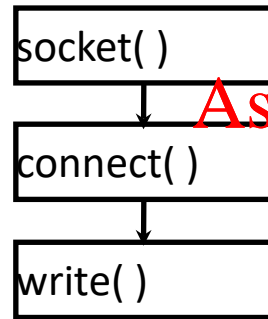
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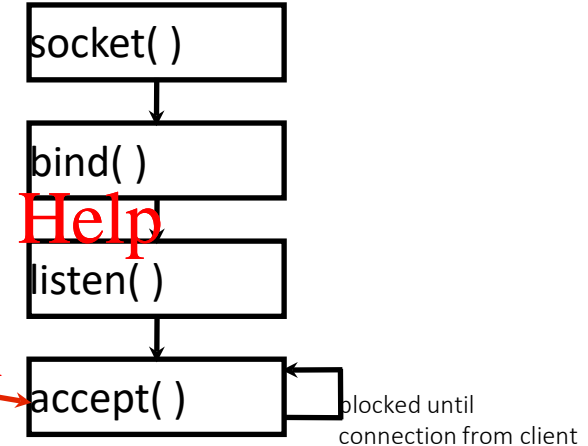
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TCP Socket: Send/Receive Data

TCP Client



TCP Server



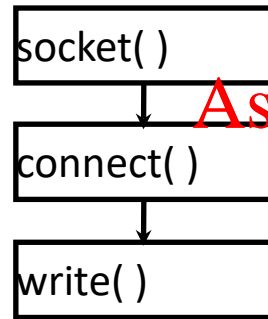
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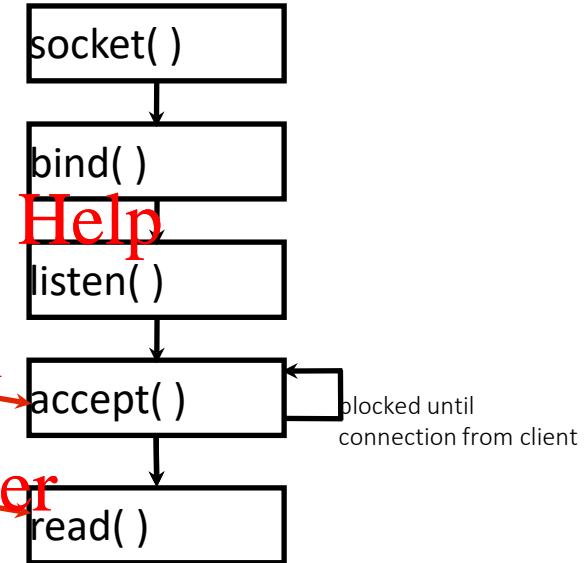
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TCP Socket: Send/Receive Data

TCP Client



TCP Server



Data

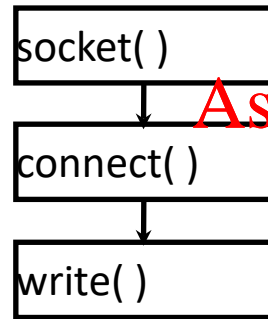
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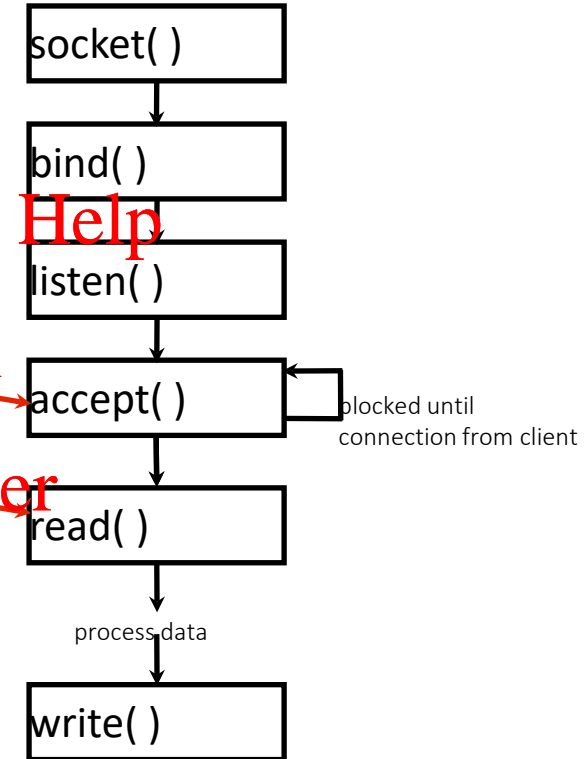
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TCP Socket: Send/Receive Data

TCP Client



TCP Server



Data

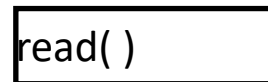
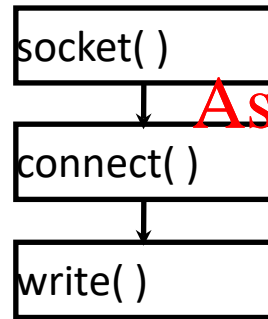
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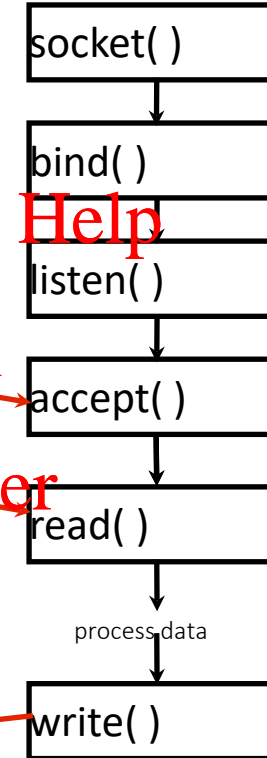
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TCP Socket: Send/Receive Data

TCP Client



TCP Server



blocked until
connection from client

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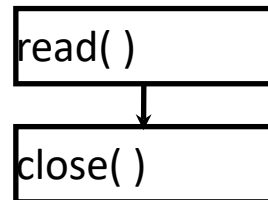
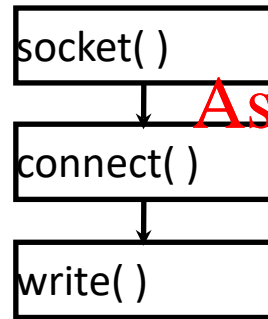
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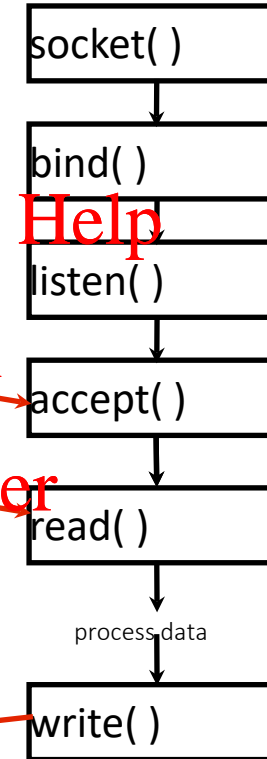
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TCP Socket: Close Connection

TCP Client



TCP Server



blocked until
connection from client

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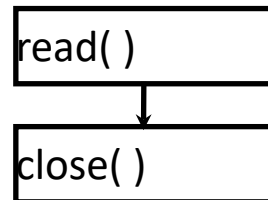
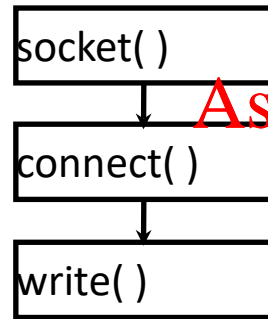
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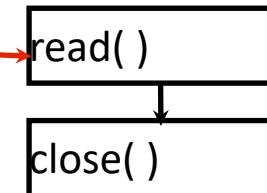
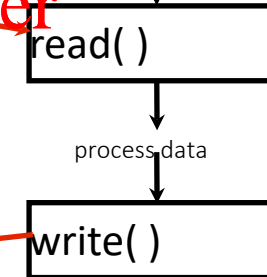
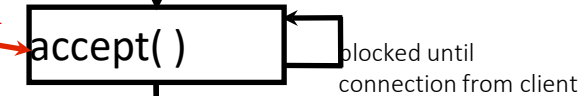
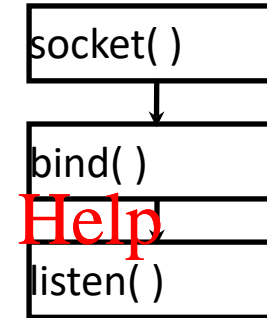
Data

TCP Socket: Close Connection

TCP Client



TCP Server



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Data

Data

Functions

- **int socket(int domain, int type, int protocol);**

- Creates a socket

- Returns the socket descriptor or -1 (failure). Also sets errno on failure

- **domain**: protocol family

- **PF_INET** for IPv4, **PF_INET6** for IPv6, **PF_UNIX** or **PF_LOCAL** for Unix socket, **PF_ROUTE** for routing

- **type**: communication paradigm

- **SOCK_STREAM** for TCP (with **PF_INET** or **PF_INET6**)

- **SOCK_DGRAM** for UDP (with **PF_INET** or **PF_INET6**)

- **protocol**: protocol within family, which is typically set to 0

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Functions

(struct sockaddr*) ...

- **int bind(int sockfd, struct sockaddr* myaddr, int addrlen);**

- Bind a socket to a local IP address and port number

- Returns 0 on success, returns -1 and sets errno on failure

- **sockfd**: socket file descriptor returned by socket ()

- **myaddr**: includes IP address and port number

- **NOTE**: sockaddr and sockaddr_in are of the same size, use sockaddr_in and convert it to sockaddr

- **sin_family**: protocol family, e.g. AF_INET

- **sin_port**: port number assigned by caller

- **sin_addr**: IP address (0.0.0.0 binds to all)

- **sin_zero**: used for keeping same size as sockaddr

- **addrlen**: sizeof(struct sockaddr_in)

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```
struct sockaddr {
    short sa_family;
    char sa_data[14];
};

struct sockaddr_in {
    short sin_family;
    ushort sin_port;
    struct in_addr sin_addr;
    unsigned char sin_zero[8];
};
```

Functions

- **int listen(int sockfd, int backlog);**
 - Put socket into passive state (wait for connections rather than initiating a connection)
 - Returns 0 on success, returns -1 and sets errno on failure
 - **sockfd**: socket file descriptor returned by socket()
 - **backlog**: the maximum number of connections this program can serve simultaneously

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Functions

- **int accept(int sockfd, struct sockaddr* client_addr, int* addrlen);**
 - Accepts a new connection
 - Returns client socket file descriptor, returns -1 and sets errno on failure
 - **sockfd**: socket file descriptor for server, returned by socket()
 - **client_addr**: IP address and port number of a client (returned from call)
 - **addrlen**: length of address structure, pointer to it set to size of struct sockaddr_in)
 - **NOTE: client_addr and addrlen are result arguments**
 - i.e. The program passes empty client_addr and addrlen into the function, and the kernel will fill in these arguments with client's information

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More Information about accept()

- A new socket is cloned from the listening socket
- If there are no incoming connections to accept:
 - **Blocking mode (default):** accept() call will block until a client connects

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Functions

- **int connect (int sockfd, struct sockaddr* server_addr, int addrlen);**
 - Connects to another socket (server)
 - Returns 0 on success, returns -1 and sets errno on failure
 - **sockfd**: socket file descriptor returned from socket()
 - **server_addr**: IP address and port number of server
 - Server's IP address and port number should be known in advance
 - **addrlen**: sizeof(struct sockaddr_in)

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Functions

- **int write(int sockfd, char* buf, size_t nbytes);**
 - Writes data to a socket
 - Return the number of sent bytes or -1 on failure
 - **sockfd**: socket file descriptor from `socket()`
 - **buf**: data buffer to send
 - **nbytes**: the number of bytes that caller wants to send from buf

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Functions

- **int read(int sockfd, char* buf, size_t nbytes);**
 - Reads data from a socket
 - Returns the number of bytes read or -1 on failure
 - Returns 0 if socket is closed
 - **sockfd**: socket file descriptor returned from socket()
 - **buf**: data buffer to store read data in
 - **nbytes**: the number of bytes that caller can read (usually set to buffer size)

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Functions

- **int close(int sockfd);**

- Closes a socket
- Returns 0 on success, returns -1 on failure
- After being closed, sockfd is no longer valid

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