Socket Programming

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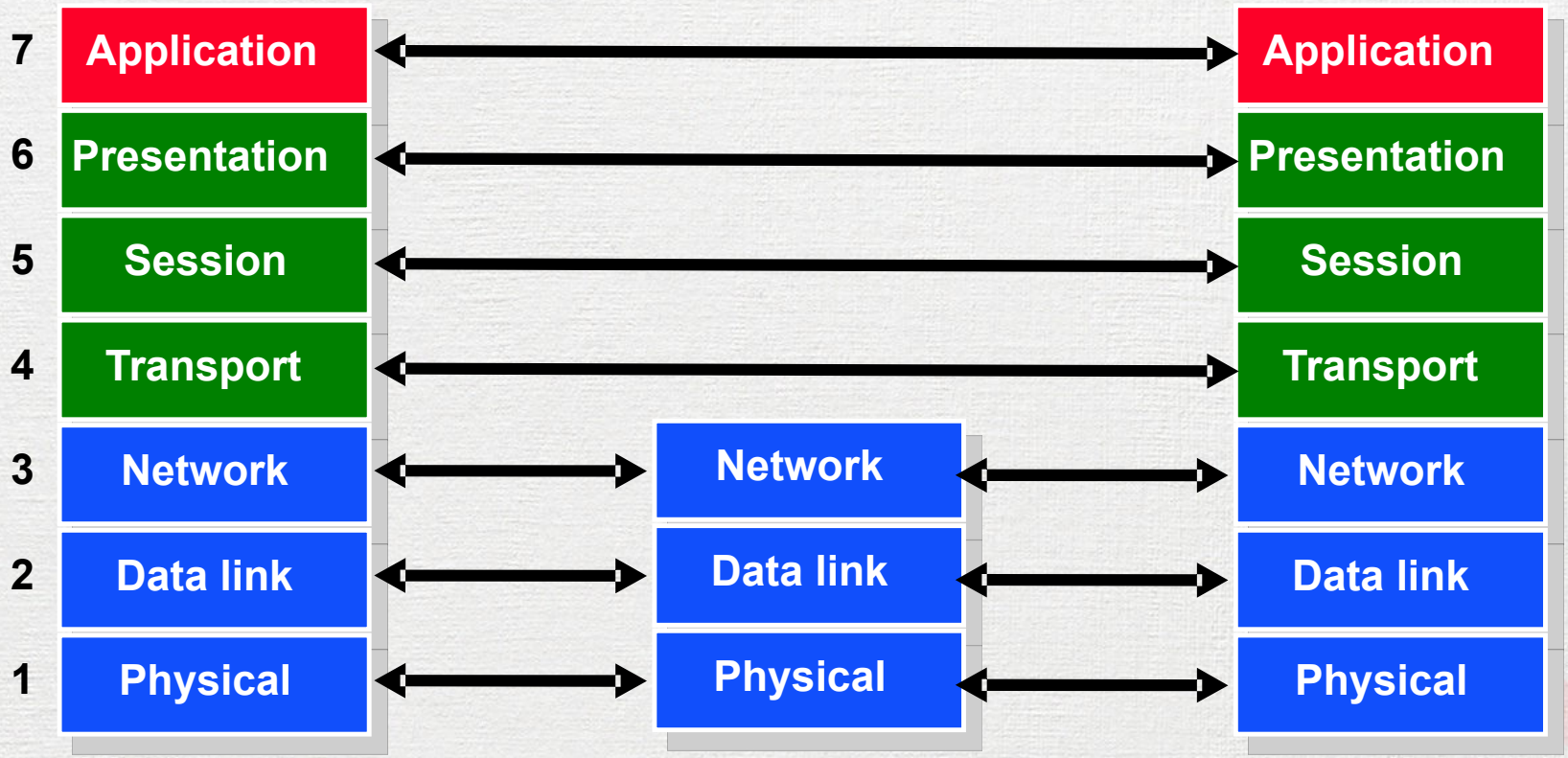
Contents

- What's a socket?
- Why socket?
- What's in a socket?
- How to use sockets?

What & Why?

Layers


7
Application
Application
6
Presentation
Presentation
5
Session
Session
4
Transport
Transport
3
Network
Network
Network
2
Data link
Data link
Data link
1
Physical
Physical
Physical

Why layering?

- Similar to application layering
- Application programmer
  - Doesn't care about routing
  - Doesn't care about Ethernet frame
  - Doesn't care about WiFi WPA2 encryption
  - Doesn't care about reliability implementations

Why layering?

- Application programmer
  - Passes the data down
  - Focus on the application

Why layering?

Lower layers:

- What does they need to know?

Why layering?

Lower layers:

- What does they need to know?
- Destination
  - Where to?
    - Hostname («resolved» with gethostbyname())
    - IP address
  - Which service?
    - Indicated by port number

Socket: What?

- Endpoint of a two-way communication link between two networked programs
- Represented by a file descriptor after creation
  - Unix philosophy: Everything is a file
- *De facto* standard for TCP/UDP, replaced
  - NetBIOS / NetBEUI
  - IPX / SPX

Socket: Applications

Most network applications use sockets

- Send messages
- Share data: image, music, video, "cast''
- Interprocess Communication (IPC)

Socket: Which types?

- Stream sockets: connection-oriented with TCP
  - Make a connection
  - Transfer data
  - Close connection
  - Ensure sequence, error checking, etc. . .
  - Example: youtube video

Socket: Which types?

- Stream sockets: connection-oriented with TCP
  - Make a connection
  - Transfer data
  - Close connection
  - Ensure sequence, error checking, etc. . .
  - Example: youtube video
- Datagram sockets: connectionless with UDP
  - Transfer data without explicitly making a connection
  - Example: DNS

Socket: Why?

- The **standard** API for connecting processes
  - Local
  - Networked

Socket: Why?

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- Compatibility: widely supported
  - Linux / UNIX
  - Windows
  - macOS

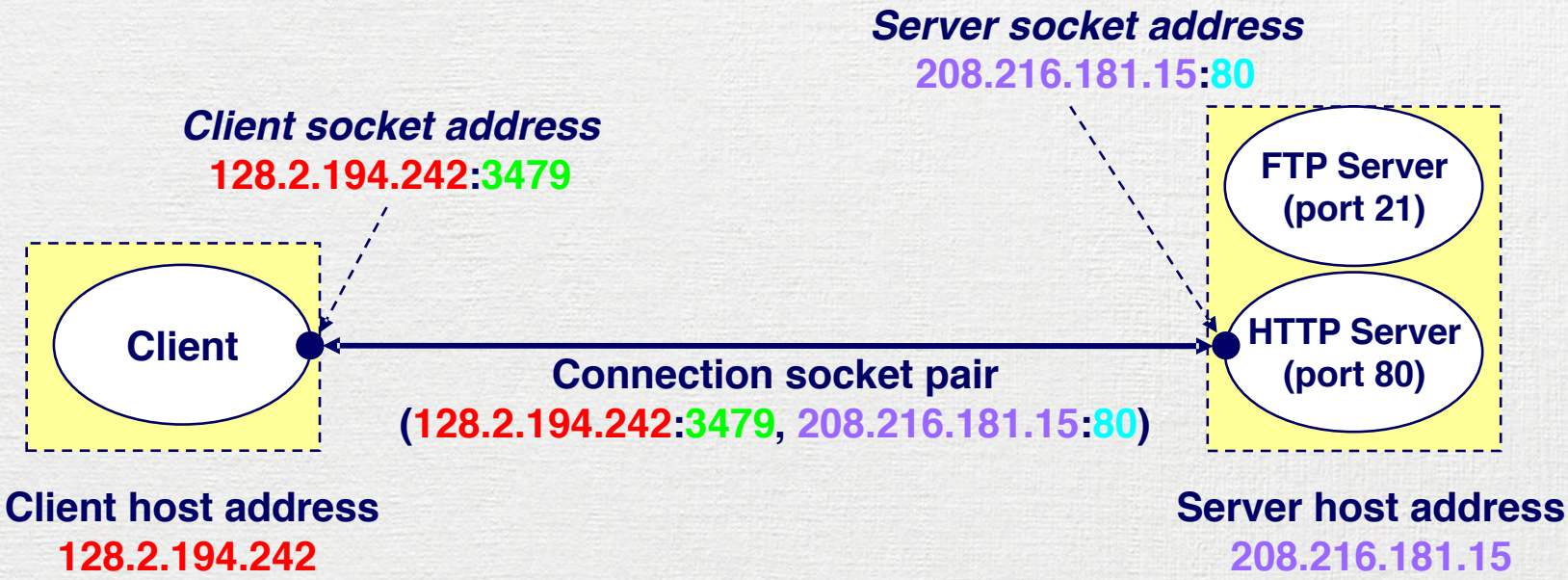
Socket: Why?

- The **standard** API for connecting processes
  - Local
  - Networked
- Compatibility: widely supported
  - Linux / UNIX
  - Windows
  - macOS
- Low level
  - Minimize amount of data transfer
  - Fast, very little overhead
  - Customizable, flexible, self-defined protocol

Why NOT socket over higher level libraries?

- Low level: more efforts
  - Define protocol
  - Message boundaries
  - Data representation
  - Security
- Session control
  - Authentication, etc.

What's in a socket?



Overview & Setup

Overview

Server

- Passively waits
- Passive socket

Client

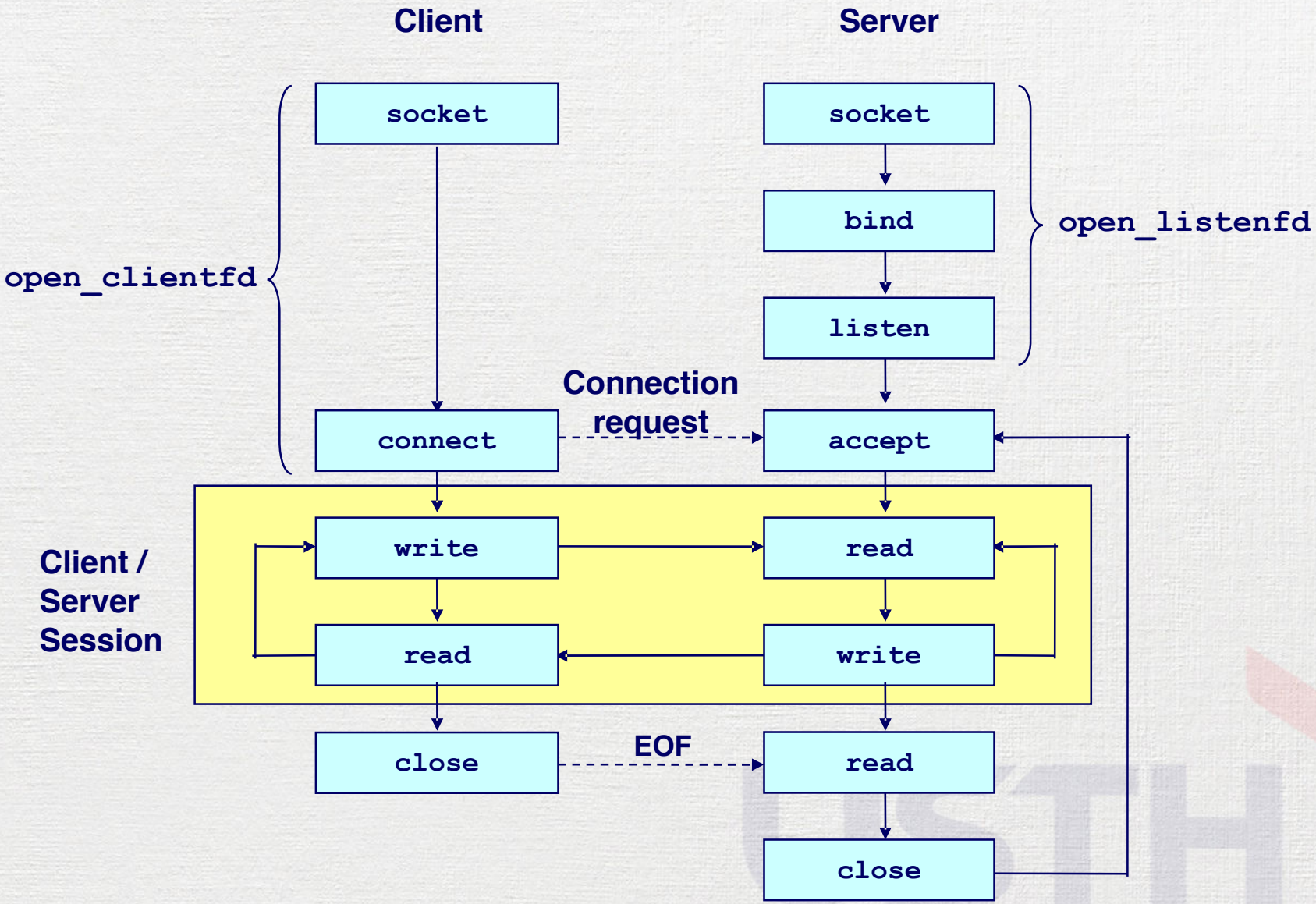
- Initiates the connection
- Active socket

Overview

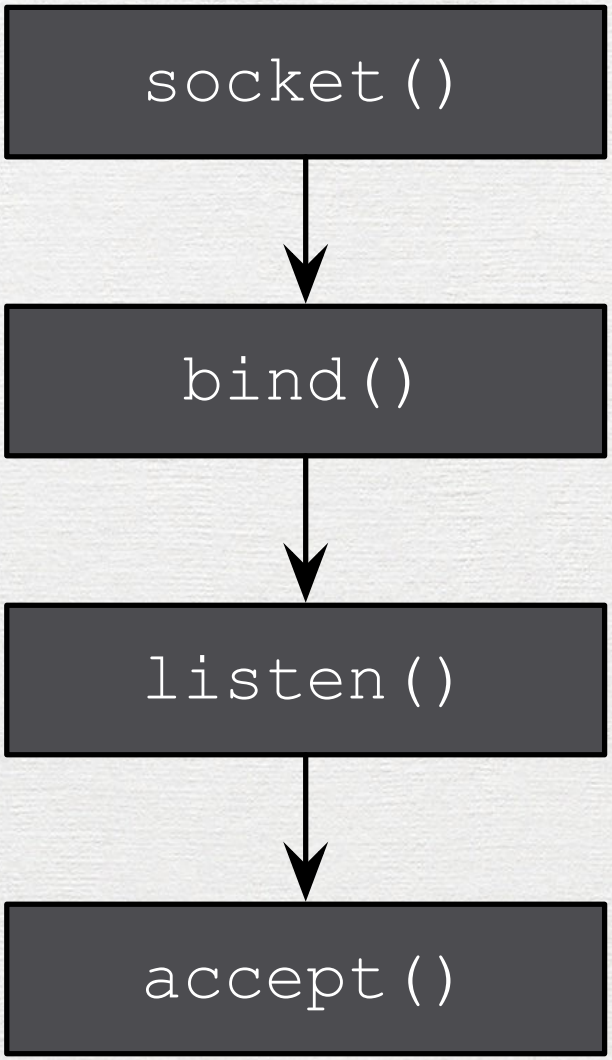
Steps

- Setup
  - Where is the remote host?
  - What service?
- Transfer Data
  - Send/Receive ~ write() / read()
- Close

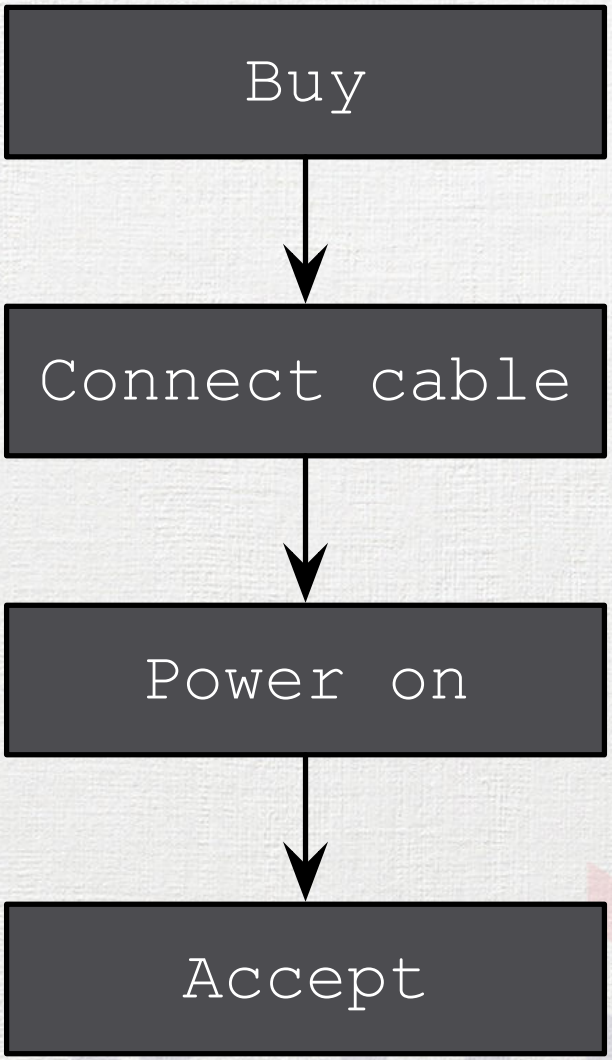
Socket Overview



Server: Overview



Server socket



Landline phone

Socket: Important `struct`

```
struct sockaddr_in {
    short           sin_family;   // e.g. AF_INET
    unsigned short  sin_port;     // e.g. htons(3490)
    struct in_addr  sin_addr;     // see struct in_addr, below
    char            sin_zero[8];  // zero this if you want to
};

struct in_addr {
    unsigned long s_addr;  // load with inet_aton()
};
```

Server: Setup `socket()`

```
int socket(int domain, int type, int protocol);
```

- `domain`: `AF_INET` (IPv4) or `AF_INET6` (IPv6)
- `type`: `SOCK_STREAM` (TCP) or `SOCK_DGRAM` (UDP)
- `protocol`: 0

For example:

```
int sockfd = socket(AF_INET, SOCK_STREAM, 0);
```

Server: Binding `bind()`

```
int bind(int sockfd,
    const struct sockaddr *bind_addr,
    socklen_t addrlen);
```

- `sockfd`: file descriptor that `socket()` returned
- `bind_addr`: a «struct sockaddr_in» for IPv4
- `addrlen`: size of the struct pointed by bind_addr

Server: Example for `socket()` and `bind()`

```
struct sockaddr_in saddr;
int sockfd;
unsigned short port = 80;
if ((sockfd = socket(AF_INET, SOCK_STREAM, 0)) < 0) {
    printf("Error creating socket\n");
    ...
}

memset(&saddr, 0, sizeof(saddr));
saddr.sin_family = AF_INET;
saddr.sin_addr.s_addr = htonl(INADDR_ANY);
saddr.sin_port = htons(port);
if (bind(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) {
    printf("Error binding\n"); ...
}
```

Server: Listen to incoming connections `listen()`

```
int listen(int sockfd, int backlog);
```

- `sockfd`: file descriptor that `socket()` returned
- `backlog`: number of pending connections to queue

For example:

```
listen(sockfd, 10);
```

Server: Accept an incoming connection `accept()`

- Server must explicitly accept incoming connections

```
int accept(int sockfd,
    struct sockaddr *addr,
    socklen_t *addrlen)
```

- `sockfd`: file descriptor that `socket()` returned
- `addr`: pointer to store client address
- `addrlen`: size of addr
- Returns a file descriptor for the connected socket

For example:

```
int client = accept(sockfd,
    (struct sockaddr_in *) &caddr, &clen);
```

Server: Example for `listen()` and `accept()`

```
if (listen(sockfd, 5) < 0) {
    printf("Error listening\n");
    ...
}

clen=sizeof(caddr);
if ((clientfd=accept(sockfd,
    (struct sockaddr *) &caddr, &clen)) < 0) {
    printf("Error accepting connection\n");
    ...
}
```

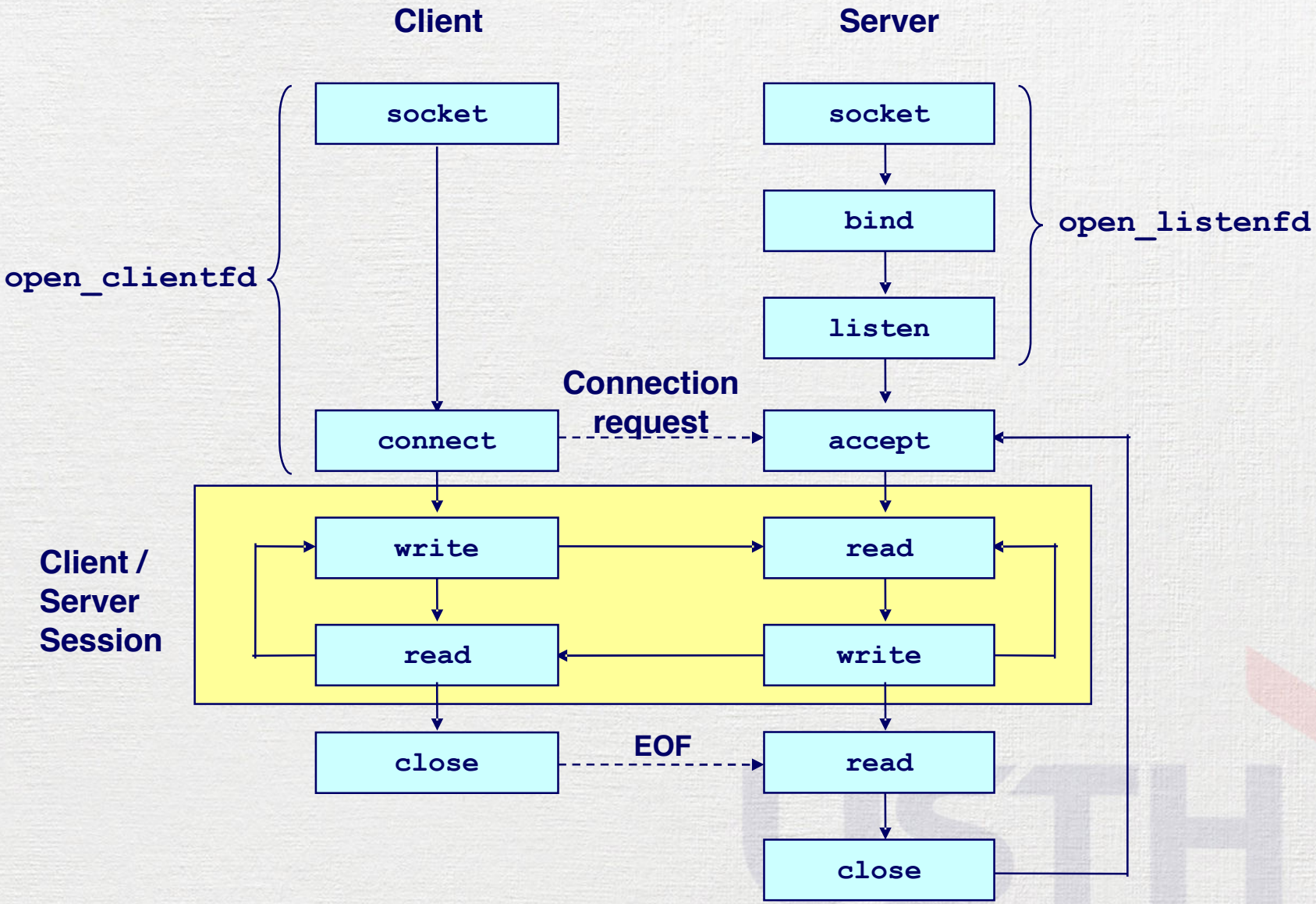
Server: Complete Example

```
int sockfd, clen, clientfd;
struct sockaddr_in saddr, caddr;
unsigned short port = 80;
if ((sockfd=socket(AF_INET, SOCK_STREAM, 0)) < 0) {
    printf("Error creating socket\n");
    ...
}

memset(&saddr, 0, sizeof(saddr));
saddr.sin_family = AF_INET;
saddr.sin_addr.s_addr = htonl(INADDR_ANY);
saddr.sin_port = htons(port);

if ((bind(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) {
    printf("Error binding\n");
    ...
}

if (listen(sockfd, 5) < 0) {
    printf("Error listening\n");
    ...
}

clen=sizeof(caddr);
if ((clientfd=accept(sockfd, (struct sockaddr *) &caddr, &clen)) < 0) {
    printf("Error accepting connection\n");
    ...
}
```

Practical Work 3: Server setup

- Write a new program in C
  - Name it « 03.practical.work.server.setup.c »
  - Write a server that:
    - listens to **TCP** port **8784** [USTH in a T9 dial pad!]
    - binds to all possible interfaces
    - prints a message when a client connects to it
- Deploy to your shiny VPS
- Test the connection
  - Use «telnet» or «nc»
- Push your C program to corresponding forked Github repository

Remind: Socket Overview



Client: Setup socket()

- Similar to server's

```
int socket(int domain, int type, int protocol);
```

- `domain`: `AF_INET` (IPv4) or `AF_INET6` (IPv6)
- `type`: `SOCK_STREAM` (TCP) or `SOCK_DGRAM` (UDP)
- `protocol`: 0

For example:

```
int sockfd = socket(AF_INET, SOCK_STREAM, 0);
```

Client: Connect to server `connect()`

```
int connect(int sockfd,
    const struct sockaddr *saddr,
    socklen_t addrlen);
```

- `sockfd`: file descriptor that `socket()` returned
- `addr`: pointer to store **server** address
- `addrlen`: size of addr

Example:

```
connect(sockfd, (struct sockaddr *) &saddr, sizeof(saddr));
```

Client: Complete Example

```
struct sockaddr_in saddr;
struct hostent *h;
int sockfd;
unsigned short port = 80;
if ((sockfd=socket(AF_INET, SOCK_STREAM, 0)) < 0) {
    printf("Error creating socket\n");
    ...
}
if ((h=gethostbyname("ict.usth.edu.vn")) == NULL) {
    printf("Unknown host\n");
    ...
}
memset(&saddr, 0, sizeof(saddr));
saddr.sin_family = AF_INET;
memcpy((char *) &saddr.sin_addr.s_addr, h->h_addr_list[0], h->h_length)
saddr.sin_port = htons(port);
if (connect(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) {
    printf("Cannot connect\n");
    ...
}
```

Practical Work 4: Client setup

- Write a new program in C
  - Name it « 04.practical.work.client.setup.c »
  - Write a client that:
    - gets server hostname from program arguments
    - in case no argument, asks hostname from STDIN
    - resolves its IP address, print to STDOUT
    - connects to that server, **TCP** port **8784** [It's **USTH**]
    - prints a message if it connects to server successfully
- Test the connection from your client to your server on VPS
- Push your C program to corresponding forked Github repository

Data Transfer

Data Transfer: Overview

- Two common ways for data transfer
  - `send()` / `recv()`
    - Original socket functions
    - Specific to sockets with «flags»
  - `read()` / `write()`
    - Consider socket as a file
    - Generic functions
- Use either of the two pairs

Data Transfer: `recv()` and `send()`

```
ssize_t recv(int socket, void *buffer, size_t length, int flags);
ssize_t send(int socket, const void *buffer, size_t length, int flags);
```

- `socket`: use socket file descriptor returned by `socket()` or `accept()`
- `buffer`: buffer to read from / write to
- `length`: size of the allocated buffer (`recv()`) and length of the content (`send()`)
- `flags`: specific "settings" for the request

Example

```
recv(sockfd, buffer, sizeof(buffer), 0);
send(sockfd, "hello world!\n", 13, 0);
```

Data Transfer: `read()` and `write()`

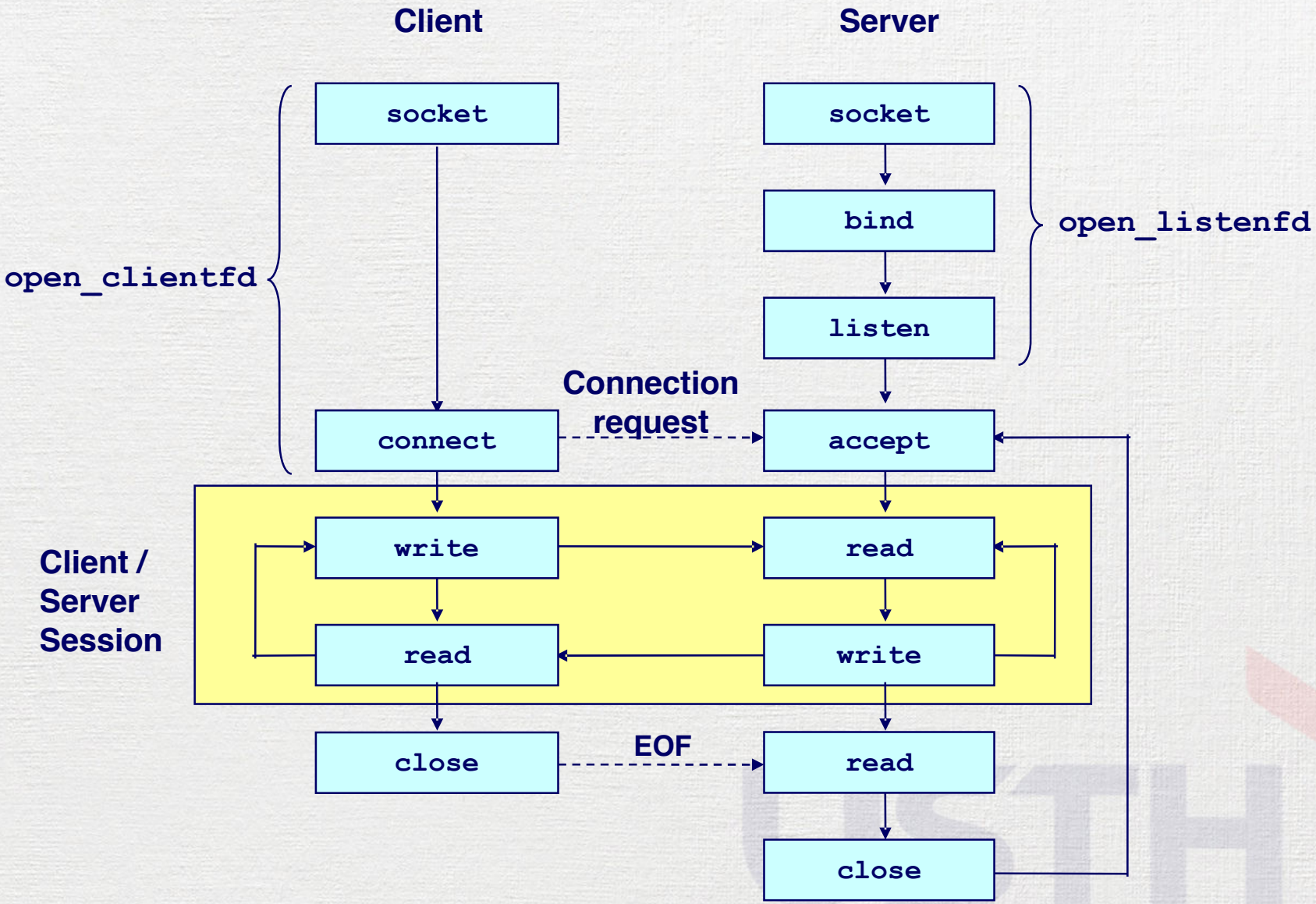
```
ssize_t read(int fd, void *buf, size_t len);
ssize_t write(int fd, const void *buf, size_t len);
```

- `fd`: file descriptor, use socket file descriptor returned by `socket()` or `accept()`
- `buf`: buffer to read from / write to
- `len`: size of the allocated buffer (`read()`) and length of the content (`write()`)

Example

```
read(sockfd, buffer, sizeof(buffer));
write(sockfd, "hello world!\n", 13);
```

Data Transfer: Taking Turn



Data Transfer: Taking Turn

- Client

```
while (condition) {
    scanf() from STDIN;
    send() to server;
    recv() from server;
    printf() to STDOUT;
}
```

- Server

```
while (condition) {
    recv() from client;
    printf() to STDOUT;
    scanf() from STDIN;
    send() to client;
}
```

Practical Work 5: Data Transfer, Taking Turn

- Copy your client and server code from 4^{th} practical work to
  - « 05.practical.work.server.turn.c »
  - « 05.practical.work.client.turn.c »
  - Improve the client and server to build a chat system
    - input from STDIN
    - send to other side
    - output received data to STDOUT
    - client and server take turn
- Test the system between your laptop and VPS
- Push your C programs to corresponding forked Github repository

Message Framing

Problem

- Problem: Message boundaries are not preserved
  - One «send» may result in many «receive»s
  - Many «send»s may result in one «receive»
  - Usually not considered by developers
    - Especially when testing on `127.0.0.1`
- For example:
  - sends: “hell”, “o wo”, “rld!\n”
  - receive: “hello world!\n”

Problem

- Why?
  - Applications work with messages
  - TCP sockets work with streams
  - Network is unstable and unpredictable
  - ACK is not delivered

Solution

- Use a buffer
- Make your own protocol

«Protocolization»

KEEP
CALM
&
FOLLOW
THE RULES

Message Framing

- Possible approaches
  - Delimiter character (\n, \0)
  - Structured data
    - Define your own with headers...
    - Reuse predefined representations & validations

Delimiter character

- Define a rare (or unused) character to indicate a termination of message
  - Usually \0 or \n

- If `recv()` does not have the delimiter character, wait for more data

Delimiter character

Pros

- Easy to implement
- Flexible

Cons

- Easy to mess up
- Escaping / unescaping delimiters
- How much to allocate buffer?

Delimiter character

```
while (condition) {
    // read messages until we have delimiter
    while (no_delimit_char) {
        read();
        append_to_buffer();
    }
    // process the message
    // and write back
    write();
}
```

Structured Data

- Use several bytes for length
- The rest for message
- [Optional] Validation: hash, checksum, etc..

- If `recv()` does not return the total amount of bytes, wait for more data

Structured Data

Pros

- Flexible, can handle large or small message frames

Cons

- Manage allocating buffers based on the length-prefix
- Waste memory

Structured Data

```
while (condition) {
    // read the message until we have termination
    while (not_enough) {
        read();
        append_to_buffer();
    }
    // process the message
    // and write
    write();
}
```

Practical Work 6: Delimiter character

- Copy your client and server code from 5^{th} practical work to
  - « 06.practical.work.server.turn.delim.c »
  - « 06.practical.work.client.turn.delim.c »
  - Improve the client and server to integrate delimiter character
    - Can use existing null termination scheme ☺
- Test the system between your laptop and VPS
- Push your C program to corresponding forked Github repository