CSE 333
Section 8

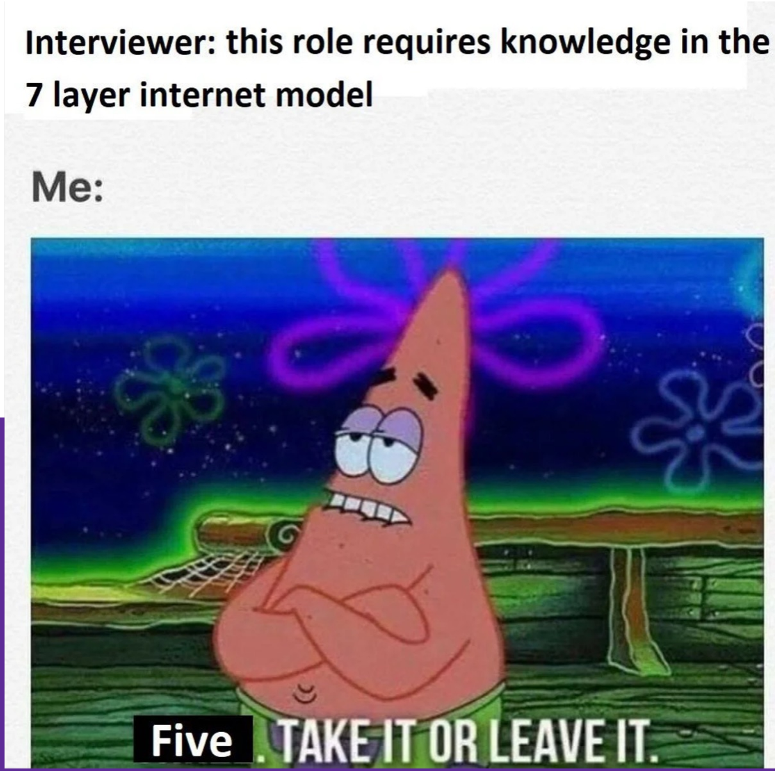
Client-side Networking
& demo

UNIVERSITY *of* WASHINGTON

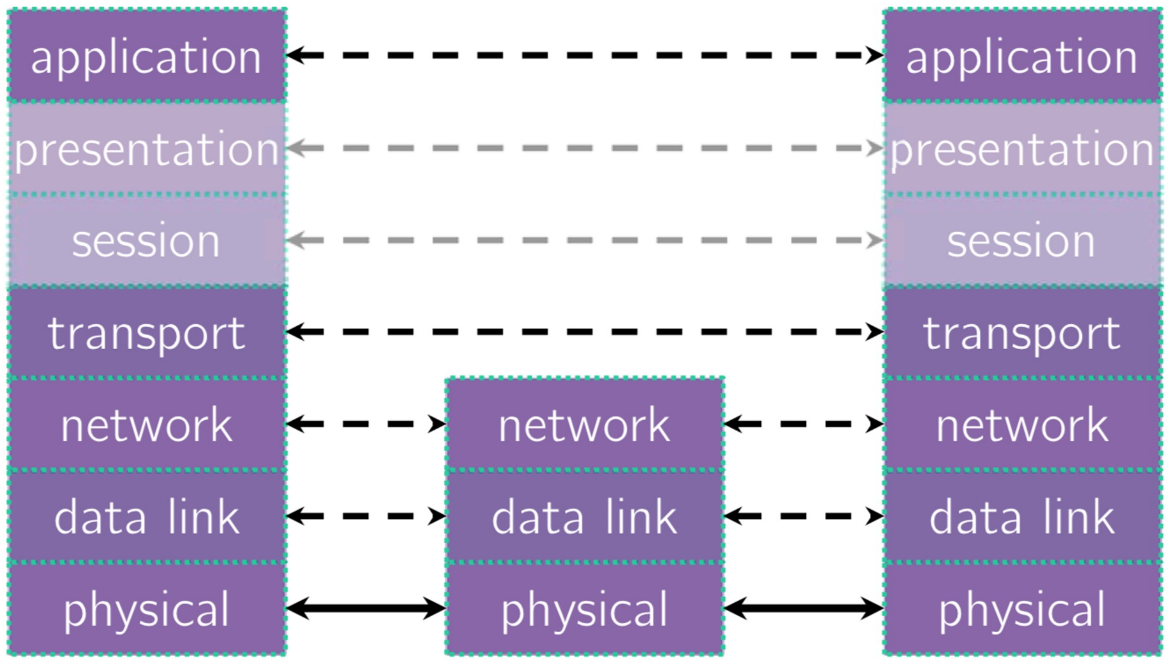
Logistics

- Homework 3:
  - Due **TONIGHT** (5/22) @ 11:59pm
- Exercise 15 – client-side networking:
  - Out after sections today
  - Due Wednesday morning, 10 AM
- Exercise 16 – server-side networking:
  - Out after lecture Friday
  - Due Wednesday morning, 10 AM
- For both you will want to (re-)use a lot of lecture/section demo code, rearranged as needed. Be sure you understand how the components work together!

Computer Networking - At a High Level



Computer Networks: A 7-ish Layer Cake



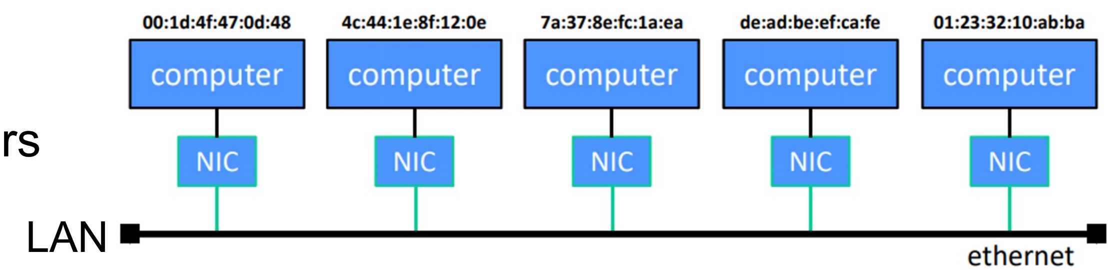
Computer Networks: A 7-ish Layer Cake

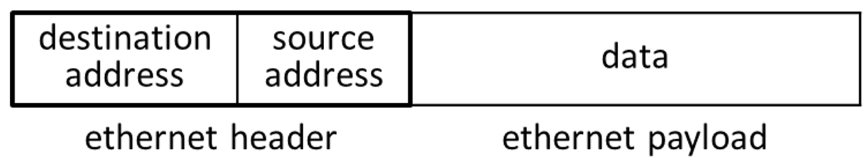
Wires, radio signals, fiber optics

bit encoding at signal level

Computer Networks: A 7-ish Layer Cake

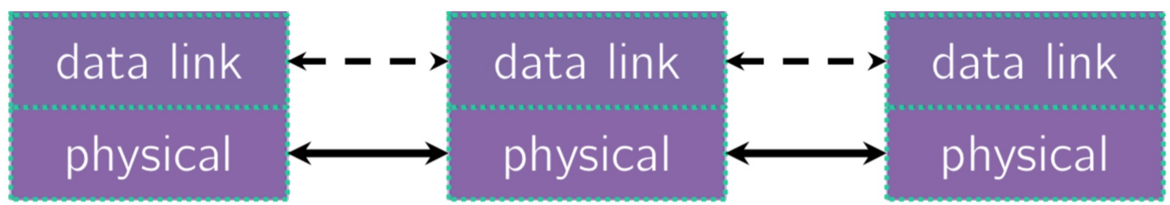
WiFi, ethernet.
Connecting multiple computers



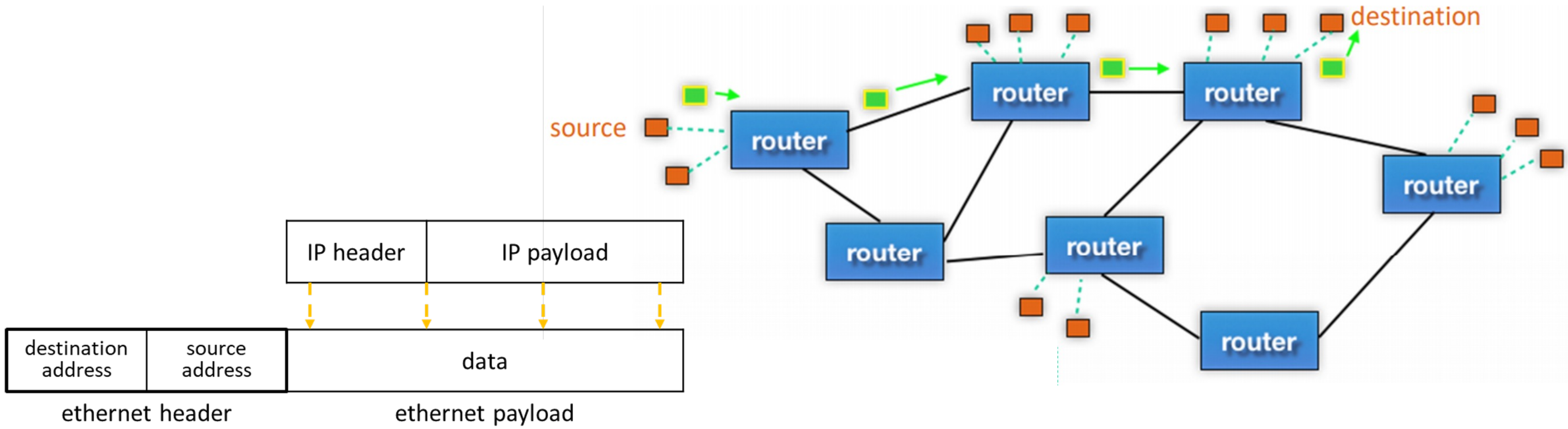


multiple computers on a local network

bit encoding at signal level



Computer Networks: A 7-ish Layer Cake

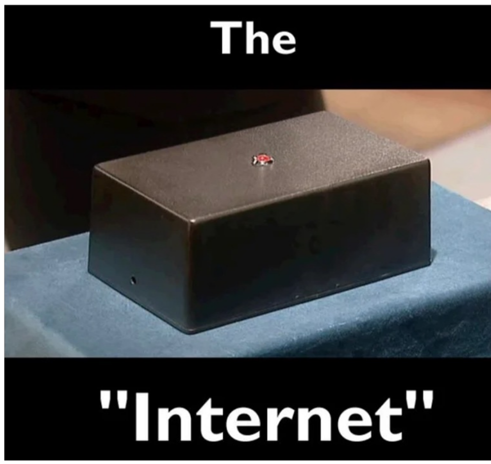


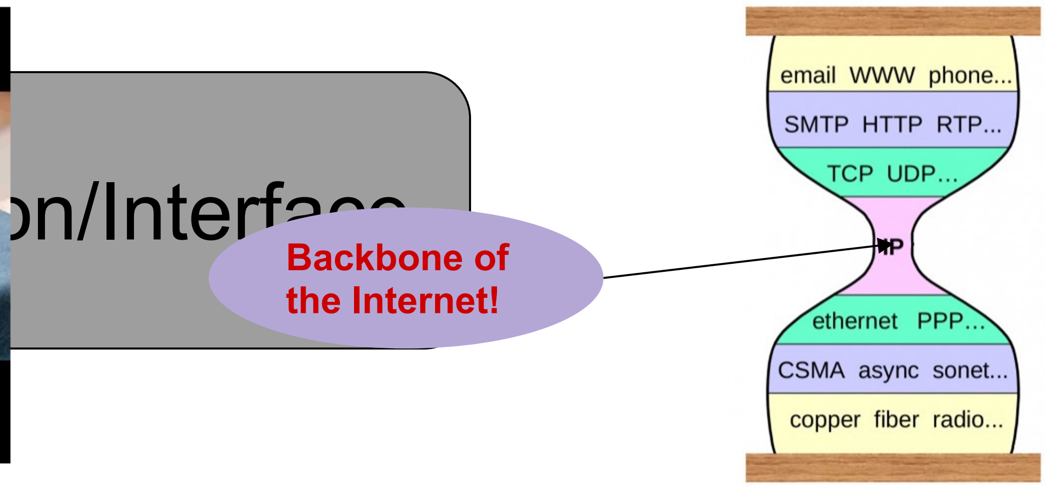
routing of packets across networks

multiple computers on a local network

bit encoding at signal level

Computer Networks: A 7-ish Layer Cake



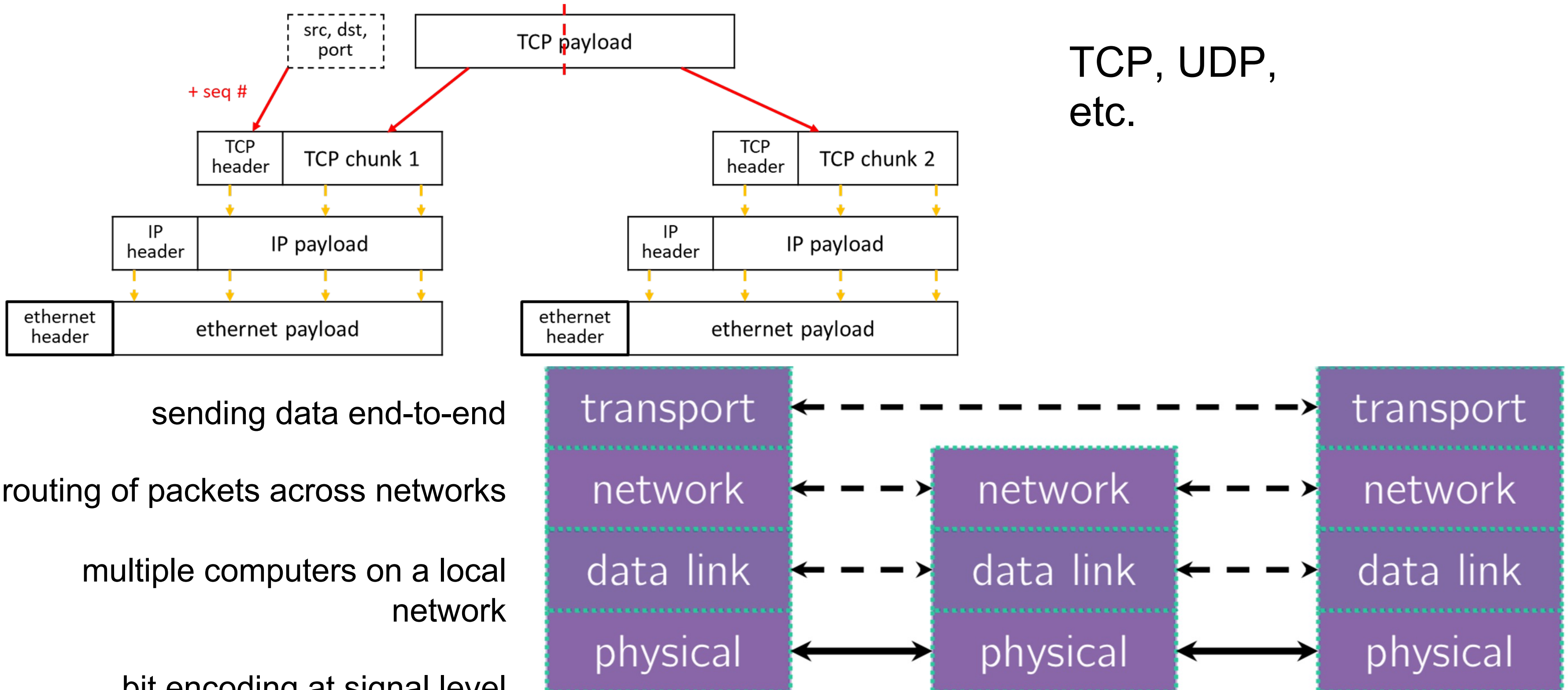


routing of packets across networks

multiple computers on a local network

bit encoding at signal level

Computer Networks: A 7-ish Layer Cake



TCP, UDP, etc.

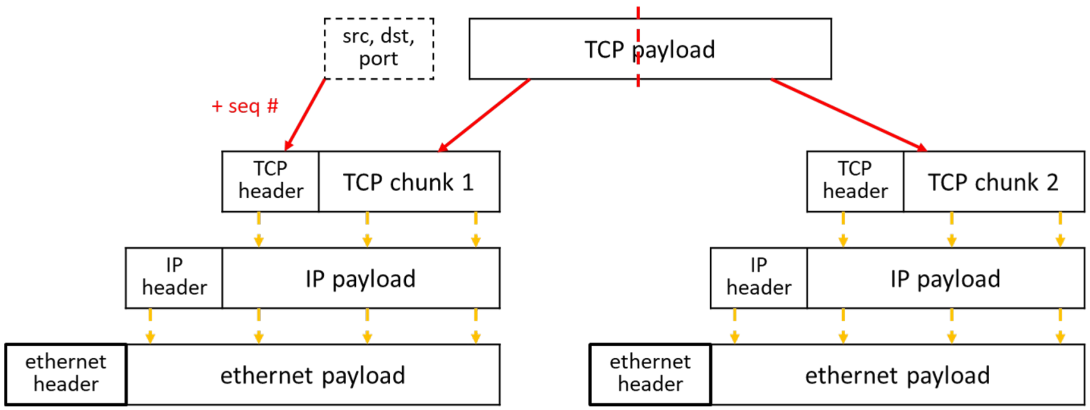
sending data end-to-end

routing of packets across networks

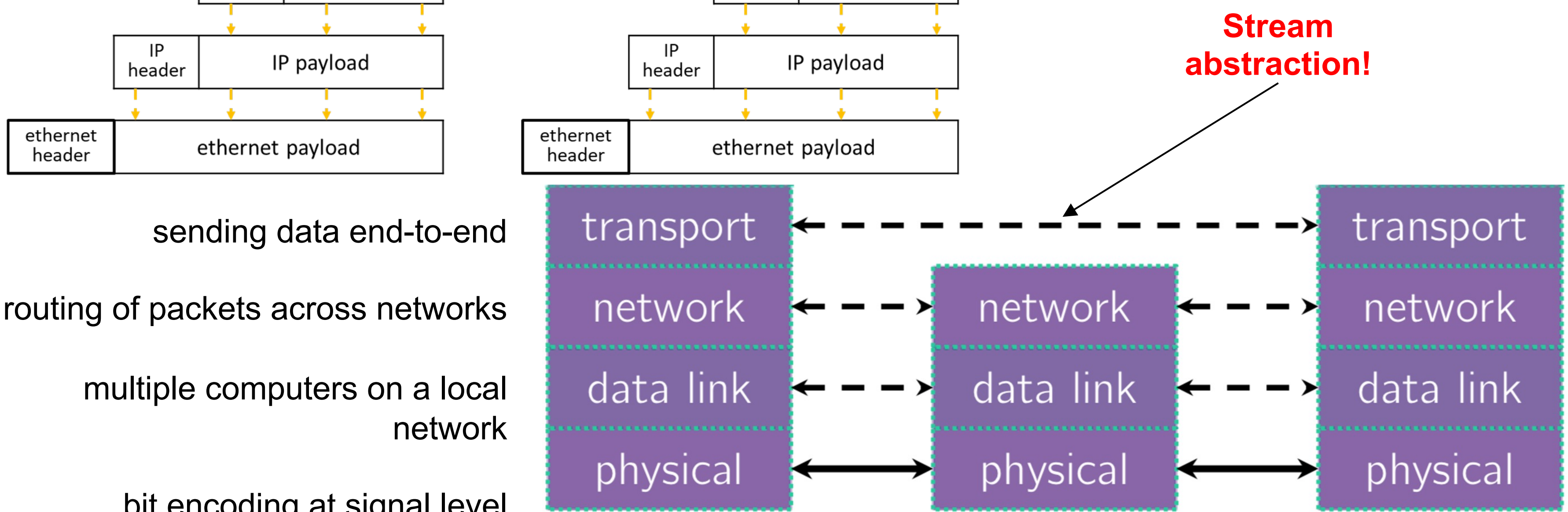
multiple computers on a local network

bit encoding at signal level

Computer Networks: A 7-ish Layer Cake



TCP, UDP, etc.



Computer Networks: A 7-ish Layer Cake

HTTP, DNS, much more

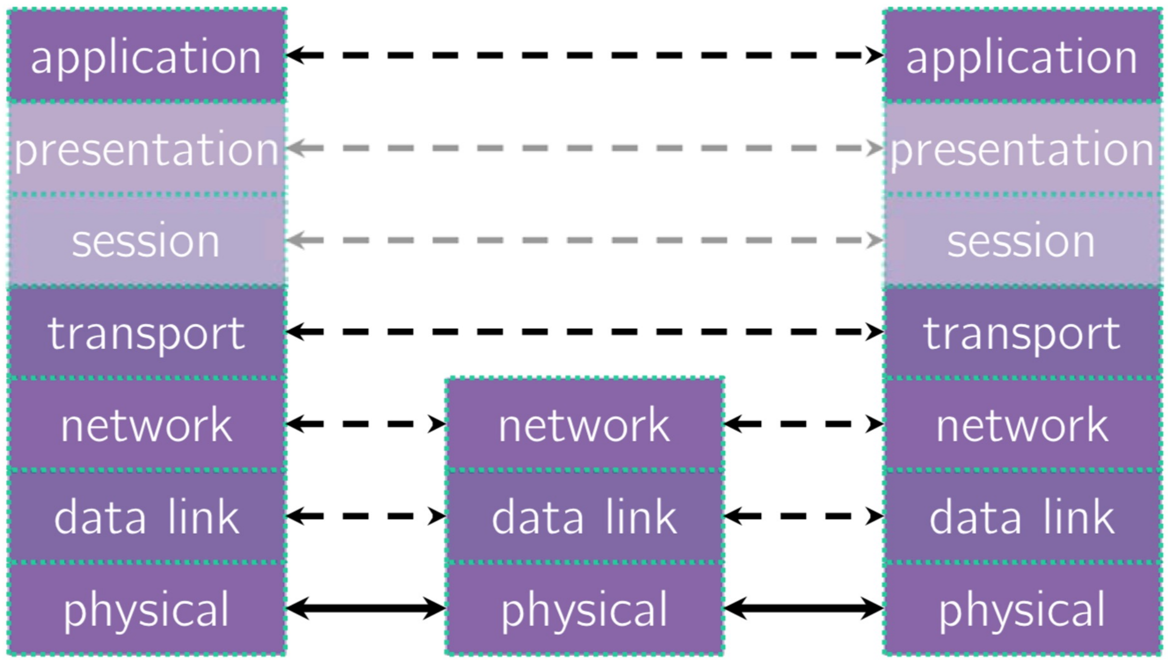
format/meaning of messages

sending data end-to-end

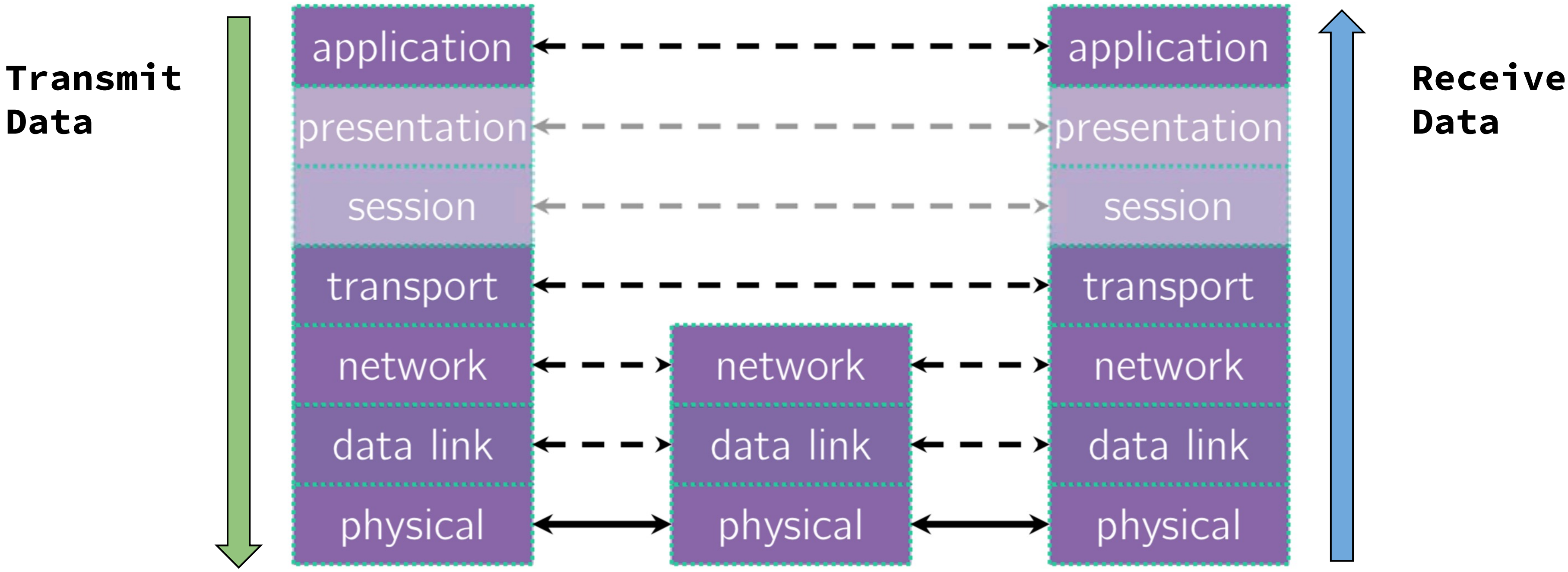
routing of packets across networks

multiple computers on a local network

bit encoding at signal level



Data Flow


Transmit
Data
application
presentation
session
transport
network
data link
physical
network
data link
physical
application
presentation
session
transport
network
data link
physical
Receive
Data

Exercise 1

Exercise 1

(Application Layer)
- DNS:

(Network Layer)
- IP:

(Transport Layer)
- ` TCP:

(Transport Layer)
- UDP:

(Application Layer)
- HTTP:

Reliable transport protocol on top of IP.

Translating between IP addresses and host names.

Sending websites and data over the Internet.

Unreliable transport protocol on top of IP.

Routing packets across the Internet.

TCP versus UDP

Transmission Control Protocol (TCP):

- Connection-oriented service
- Reliable and Ordered
- Flow control

User Datagram Protocol (UDP):

- “Connectionless” service
- Unreliable packet delivery
- High speed, no feedback

TCP guarantees reliability for things like messaging or data transfers. UDP has less overhead since it doesn’t make those guarantees, but is often fine for streaming applications (e.g., YouTube or Netflix) or other applications that manage packets on their own or do not want occasional pauses for packet retransmission or recovery.

Client-Side Networking

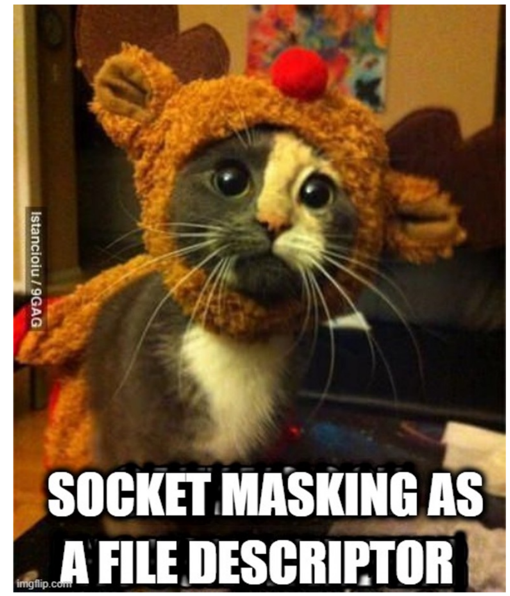
Client-Side Networking in 5 Easy* Steps!

1. Figure out what IP address and port to talk to
2. Build a socket from the client
3. Connect to the server using the client socket and server socket
4. Read and/or write using the socket
5. Close the socket connection

Remember these are POSIX operations called using glibc C functions, though we are using them in our C++ programs

*difficulty is subjective

Sockets (Berkeley Sockets)



- Just a file descriptor for network communication
  - Defines a local endpoint for network communication
  - Built on various operating system calls

- Types of Sockets
  - Stream sockets (TCP)
  - Datagram sockets (UDP)
  - There are other types, which we will not discuss

- Each TCP socket is associated with **a TCP port number (`uint16_t`)** and **an IP address**
  - These are in network order (not host order) in TCP/IP data structures! (https://www.gnu.org/software/libc/manual/html_node/Byte-Order.html)
  - `ai_family` will help you to determine what is stored for your socket!

Understanding Socket Addresses

struct sockaddr (pointer to this struct is used as parameter type in system calls)

fam	????

....

struct sockaddr_in (IPv4)

fam	**port**	**addr**	zero

16

struct sockaddr_in6 (IPv6)

fam	**port**	flow	**addr**	scope

28

struct sockaddr_storage

fam	????

Big enough to hold either

Understanding `struct sockaddr*`

- It’s just a pointer. To use it, we’re going to have to dereference it and cast it to the right type (Very strange C “inheritance”)
  - It is the endpoint your connection refers to

- Convert to a `struct sockaddr_storage`
  - Read the `sa_family` to determine whether it is IPv4 or IPv6
  - IPv4: `AF_INET` (macro) → cast to `struct sockaddr_in`
  - IPv6: `AF_INET6` (macro) → cast to `struct sockaddr_in6`

Step 1: Figuring out the port and IP

- Performs a **DNS Lookup** for a hostname
- Use "hints" to specify constraints (`struct addrinfo*`)
- Get back a linked list of `struct addrinfo` results

Name of host whose IP we want

```
int getaddrinfo(const char* hostname,
                const char* service,
                const struct addrinfo* hints,
                struct addrinfo** res);
```

We will set this to `nullptr` to get the default; otherwise you can specify service/port

Output parameter; `*res` is set to the first result in LL

Hints for the lookup server/refine results

Step 1: Obtaining your server's socket address

```
struct addrinfo {
    int ai_flags;                   // additional flags
    int ai_family;                  // AF_INET, AF_INET6, AF_UNSPEC
    int ai_socktype;                // SOCK_STREAM, SOCK_DGRAM, 0
    int ai_protocol;                // IPPROTO_TCP, IPPROTO_UDP, 0
    size_t ai_addrlen;              // length of socket addr in bytes
    struct sockaddr* ai_addr;       // pointer to socket addr
    char* ai_canonname;             // canonical name
    struct addrinfo* ai_next;       // can have linked list of records
}
```

- `ai_addr` points to a `struct sockaddr` describing a socket address, can be IPv4 or IPv6

Steps 2 and 3: Building a Connection

2. Create a client socket to manage (returns an integer file descriptor, just like POSIX open)

```
// returns file descriptor on success, -1 on failure (errno set)
int socket(int domain,           // AF_INET, AF_INET6, etc.
           int type,             // SOCK_STREAM, SOCK_DGRAM, etc.
           int protocol);        // just put 0 (network abstraction)
```

3. Use that created client socket to connect to the server socket

```
// Connects to the server
// returns 0 on success, -1 on failure (errno set)
int connect(int sockfd,                      // socket file descriptor
            struct sockaddr* serv_addr,      // socket addr of server
            socklen_t addrlen);              // size of serv_addr
```

Usually from `getaddrinfo`! (→ struct sockaddr* serv_addr)

Steps 4 and 5: Using your Connection

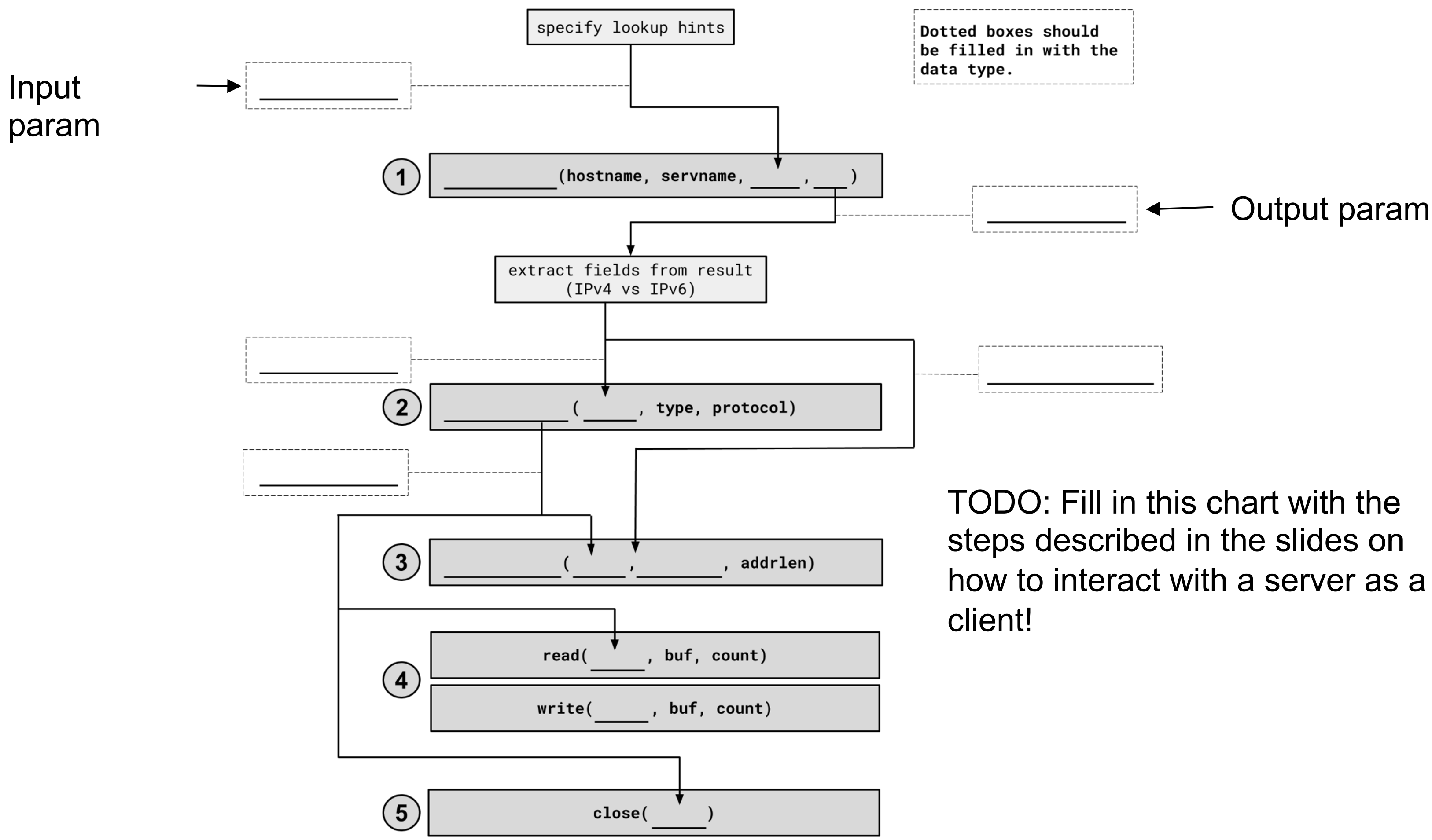
```
// returns amount read, 0 for EOF, -1 on failure (errno set)
ssize_t read(int fd, void* buf, size_t count);

// returns amount written, -1 on failure (errno set)
ssize_t write(int fd, void* buf, size_t count);

// returns 0 for success, -1 on failure (errno set)
int close(int fd);
```

- Same POSIX methods we used for file I/O!
  (so they require the same error checking...)

Helpful References

1. Figure out what IP address and port to talk to
   - dnsresolve.cc
2. Build a socket from the client
   - connect.cc
3. Connect to the server using the client socket and server socket
   - sendreceive.cc
4. Read and/or write using the socket
   - sendreceive.cc (same as above)
5. Close the socket connection

Exercise 2

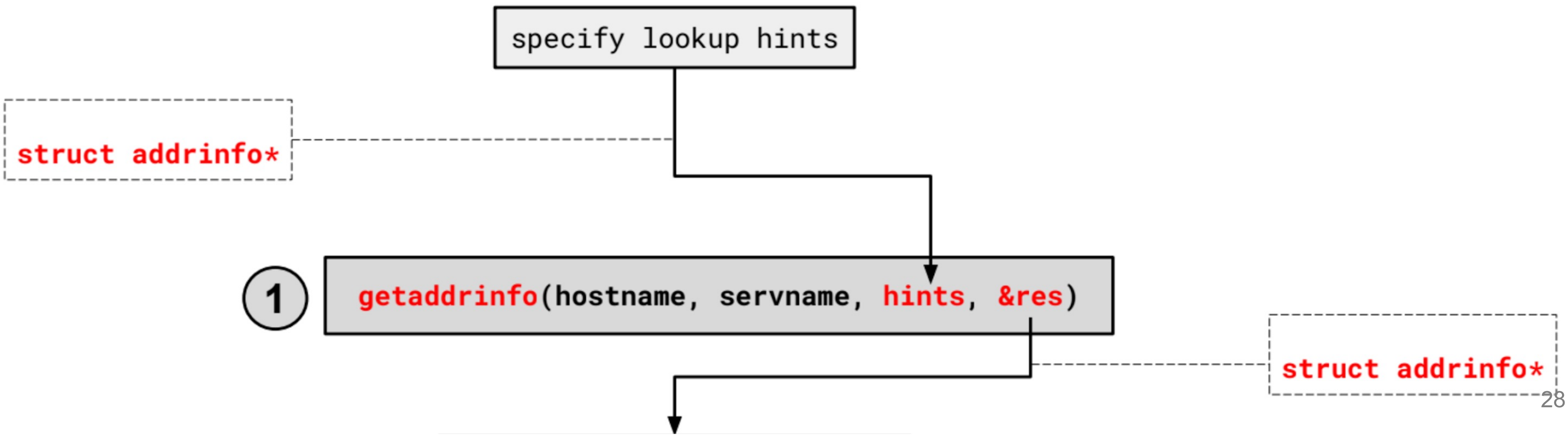


TODO: Fill in this chart with the steps described in the slides on how to interact with a server as a client!

1. getaddrinfo()

```
int getaddrinfo(const char* hostname,
                const char* service,
                const struct addrinfo* hints,
                struct addrinfo** res);
```

- Performs a **DNS Lookup** for a hostname
- Use “hints” to specify constraints (`struct addrinfo*`)
- Get back a linked list of `struct addrinfo` results



1. getaddrinfo() - Interpreting Results

```
struct addrinfo {
    int ai_flags; // additional flags
    int ai_family; // AF_INET, AF_INET6, AF_UNSPEC
    int ai_socktype; // SOCK_STREAM, SOCK_DGRAM, 0
    int ai_protocol; // IPPROTO_TCP, IPPROTO_UDP, 0
    size_t ai_addrlen; // length of socket addr in bytes
    struct sockaddr* ai_addr; // pointer to sockaddr for address
    char* ai_canonname; // canonical name
    struct addrinfo* ai_next; // can form a linked list
};
```

*Note that we get a linked list of results

1. getaddrinfo() - Interpreting Results

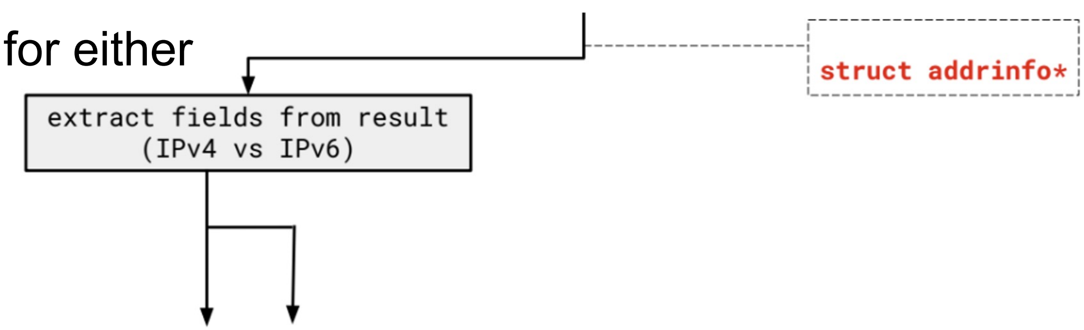
```
struct addrinfo {
    int ai_family; // AF_INET, AF_INET6, AF_UNSPEC
    struct sockaddr* ai_addr; // pointer to socket addr
    ...
};
```

- These records are dynamically allocated; you should pass the head of the linked list to `freeaddrinfo()`
- The field `ai_family` describes if it is IPv4 or IPv6
- `ai_addr` points to a `struct sockaddr` describing the socket address

1. getaddrinfo() - Interpreting Results

With a `struct sockaddr*`:

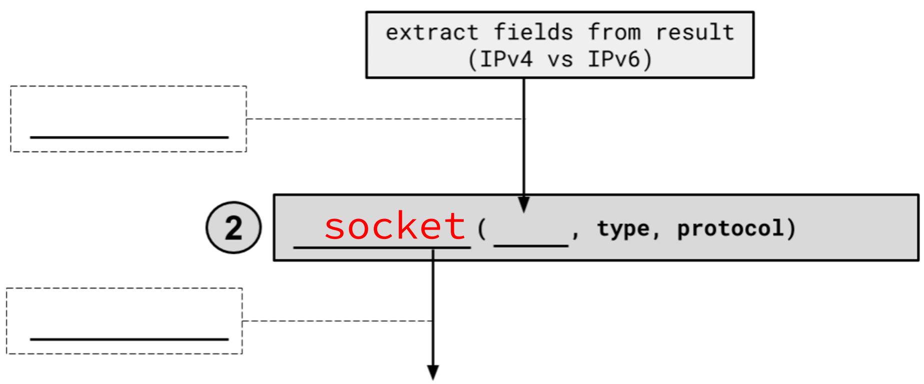
- The field `sa_family` describes if it is IPv4 or IPv6
- Cast to `struct sockaddr_in*` `(v4)`or `struct sockaddr_in6*` `(v6)` to access/modify specific fields (i.e. ports)
- Store results in a `struct sockaddr_storage` to have a space big enough for either



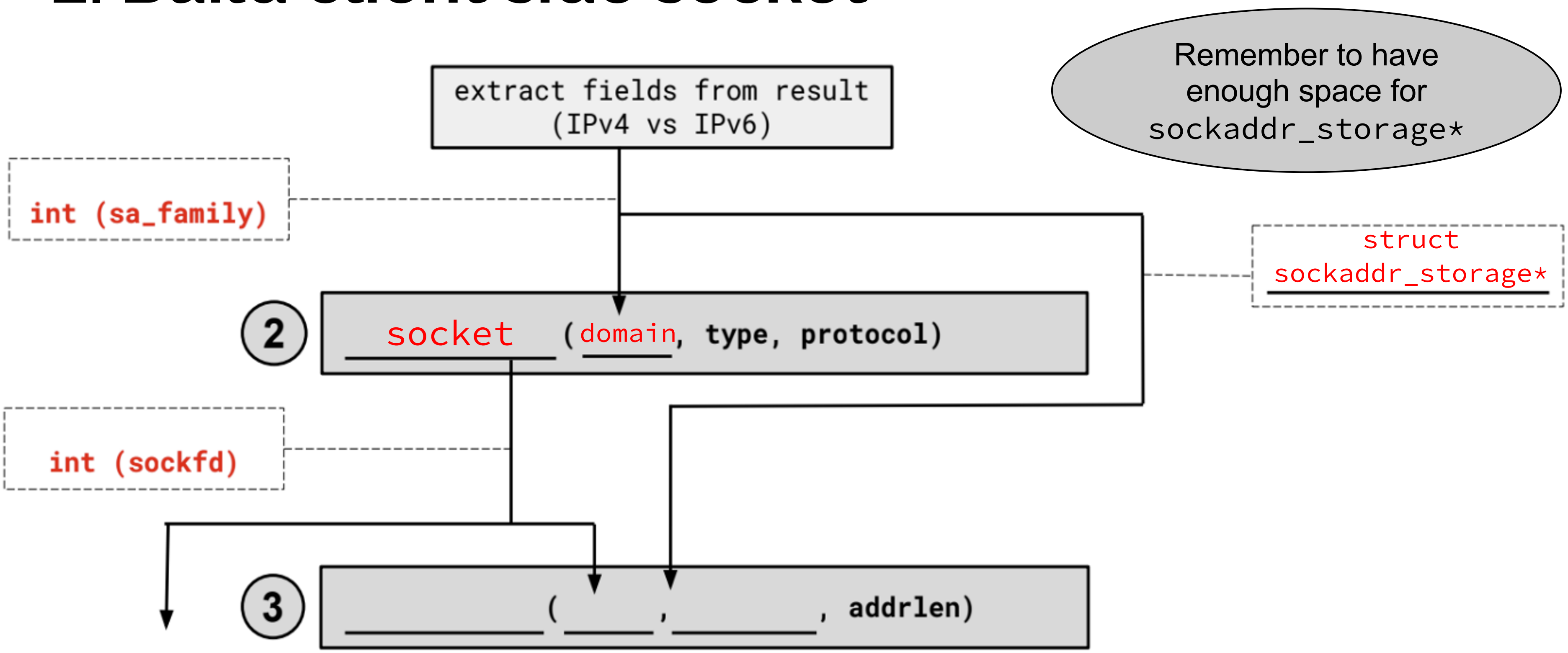
2. Build client side socket

```
int socket(int domain,      // AF_INET, AF_INET6
           int type,        // SOCK_STREAM (for TCP)
           int protocol);   // 0 for the default
```

- This gives us an unbound socket that's not connected to anywhere in particular
- Returns a socket file descriptor (we can use it everywhere we can use any other file descriptor as well as in socket specific system calls)



2. Build client side socket



3. connect()

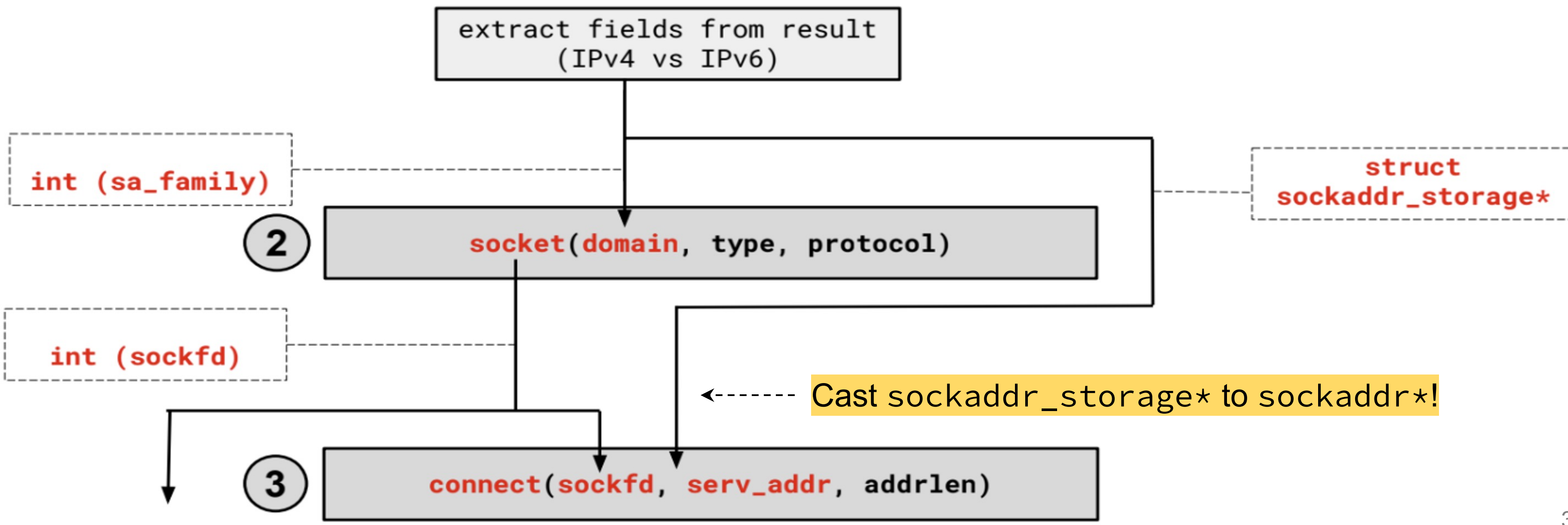
```
int connect(int socket,                    // socket fd
            const struct sockaddr *addr, // address to connect to
            socklen_t addr_len);         // length of *addr
```

- This takes our unbound socket and connects it to the host at `addr`
- Returns 0 on success, -1 on error with `errno` set appropriately
- After this call completes, we can actually use our socket for communication!

3. connect()

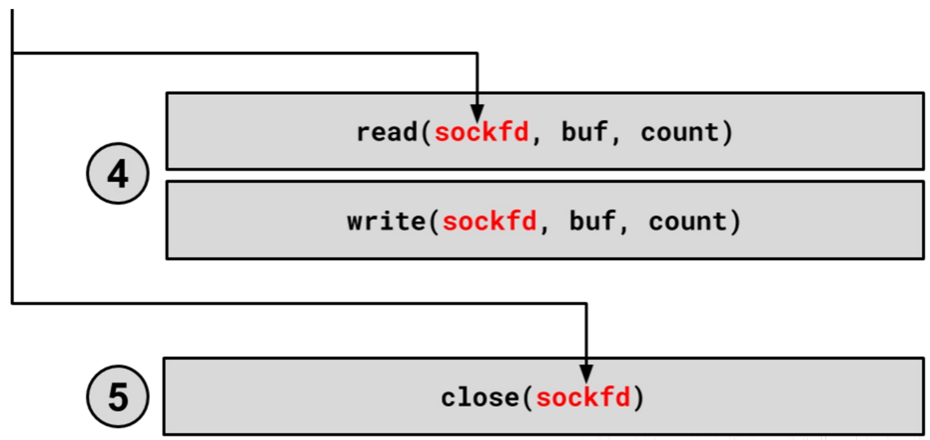
```
int connect(int socket,                          // from 1
            const struct sockaddr *addr,  // from 2
            socklen_t addr_len); // size of serv_addr
```

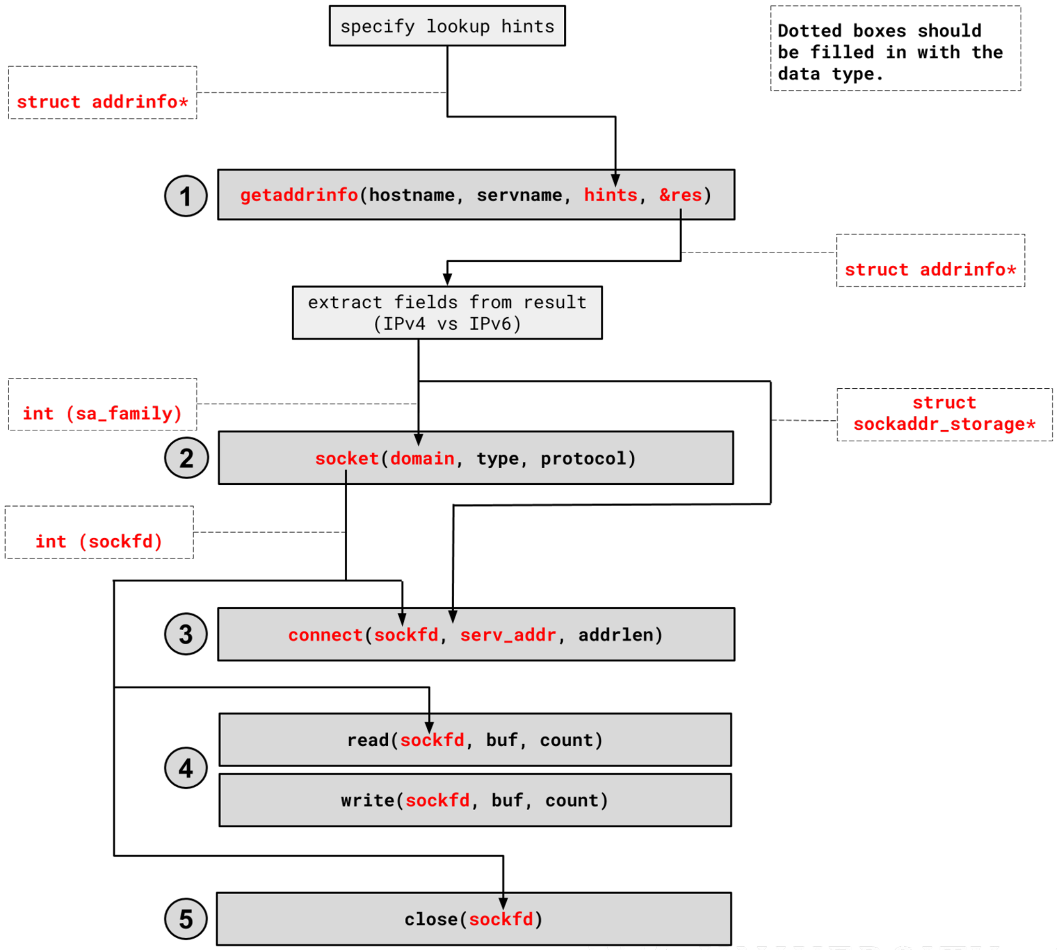
- Connects an available socket to a specified address
- Returns 0 on success, -1 on failure



4. read/write and 5. close

- Thanks to the file descriptor abstraction, use as normal!
- `read` from and `write` to a buffer, the OS will take care of sending/receiving data across the network
- Make sure to `close` the fd afterward




specify lookup hints
Dotted boxes should be filled in with the data type.
struct addrinfo*
1
getaddrinfo(hostname, servname, hints, &res)
struct addrinfo*
extract fields from result (IPv4 vs IPv6)
int (sa_family)
struct sockaddr_storage*
2
socket(domain, type, protocol)
int (sockfd)
3
connect(sockfd, serv_addr, addrlen)
4
read(sockfd, buf, count)
write(sockfd, buf, count)
5
close(sockfd)

Netcat and Exercise demo

netcat

- Command-line utility to setup a TCP/UDP connection to read/write data
  - Man page: https://www.commandlinux.com/man-page/man1/nc.1.html
- To start a server:
  - `nc -l <hostname> <port>`
- To connect to that server (as a client):
  - `nc <hostname> <port>`
- `<hostname>` can be:
  - `localhost`
  - `attu#.cs.washington.edu`