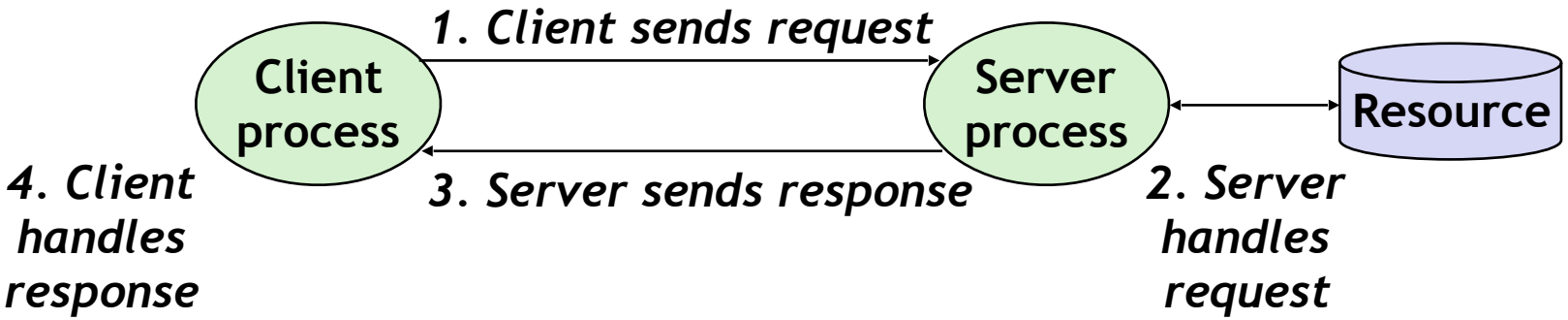
+

Network Programming

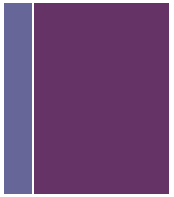
A Client-Server Transaction

- **Many network applications are based on the client-server model:**
  - A server *process* and one or more client processes
  - Server manages some *resource*
  - Server provides service by manipulating resource for clients
  - Server activated by *request* from client



Note: clients and servers are processes running on hosts (can be the same or different hosts)

Computer Networks



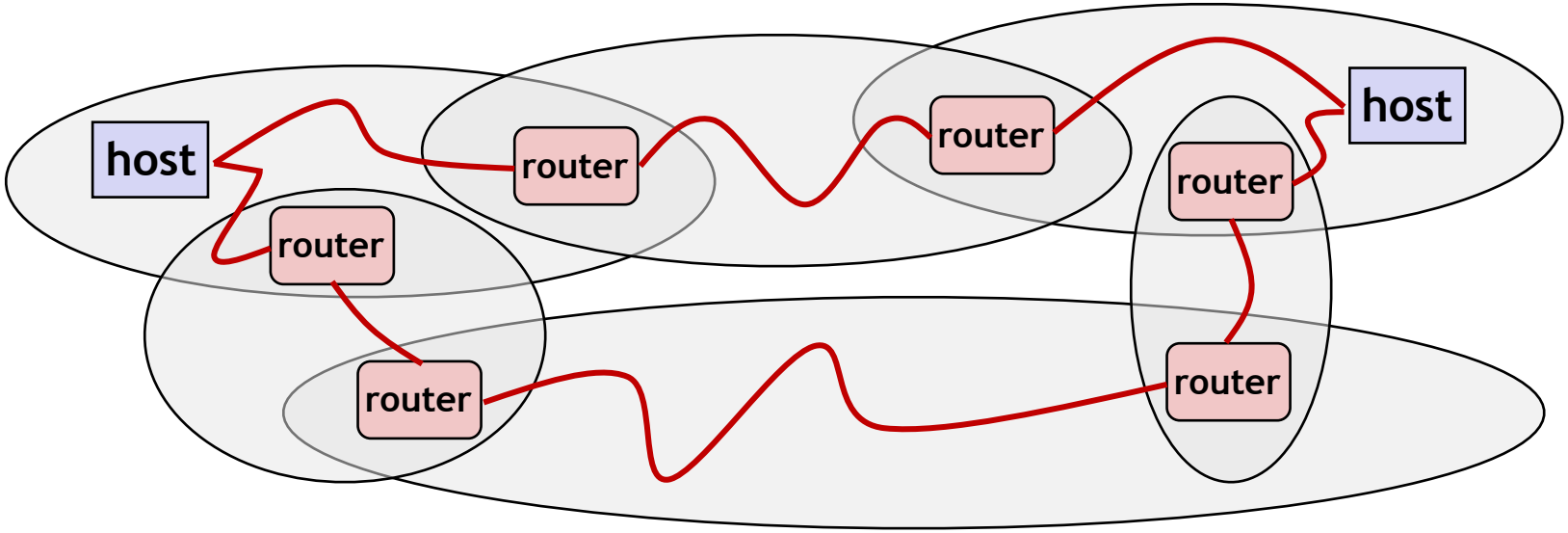
- **A network is a group of connected systems that are able to communicate in order to exchange data.**
- **There are many kinds of networks, some examples..**
  - *LAN* (Local Area Network) spans a building or campus
    - *Ethernet* is most prominent example
  - *WAN* (Wide Area Network) spans country or world
    - Typically high-speed *point-to-point telecom lines*
- **An internetwork (internet) is an interconnected set of networks**
  - The Global IP Internet (uppercase "I") is the most famous example of an internet (lowercase "i")

Computer Networks *con't*

- **Network devices that originate, route and terminate data are called '*nodes*'.**
  - Nodes or '*hosts*' can be personal computers, phones, servers as well as special networking hardware.
- **Two such devices can be said to be '*networked*' together when one device is able to exchange information with the other device.**
- **A '*router*' is an networking device that forwards data between networks in an internet.**
- **A '*link*' is the means of connecting one location to another for the purpose of transmitting and receiving data across networks.**
  - phone lines, fiberoptic cables, bluetooth, ethernet, wireless, etc...

Logical Structure of an internet

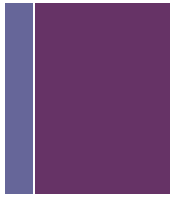
- **Ad hoc interconnection of networks**
  - No particular topology
  - Vastly different router & link capacities
- **Send packets from source to destination by hopping through networks**
  - Router forms bridge from one network to another
  - Different *packets* may take different routes



The Notion of an internet Protocol

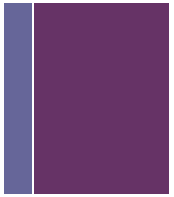
- **How is it possible to send bits across incompatible LANs and WANs?**
- **Solution: *protocol* software running on each host and router**
  - *A* protocol is a set of rules that governs how hosts and routers should cooperate when they transfer data from network to network.
  - The rules define the syntax, semantics and synchronization of communication and possible error recovery methods.
  - Protocols may be implemented by hardware, software, or a combination of both.

What Does an internet Protocol Do?



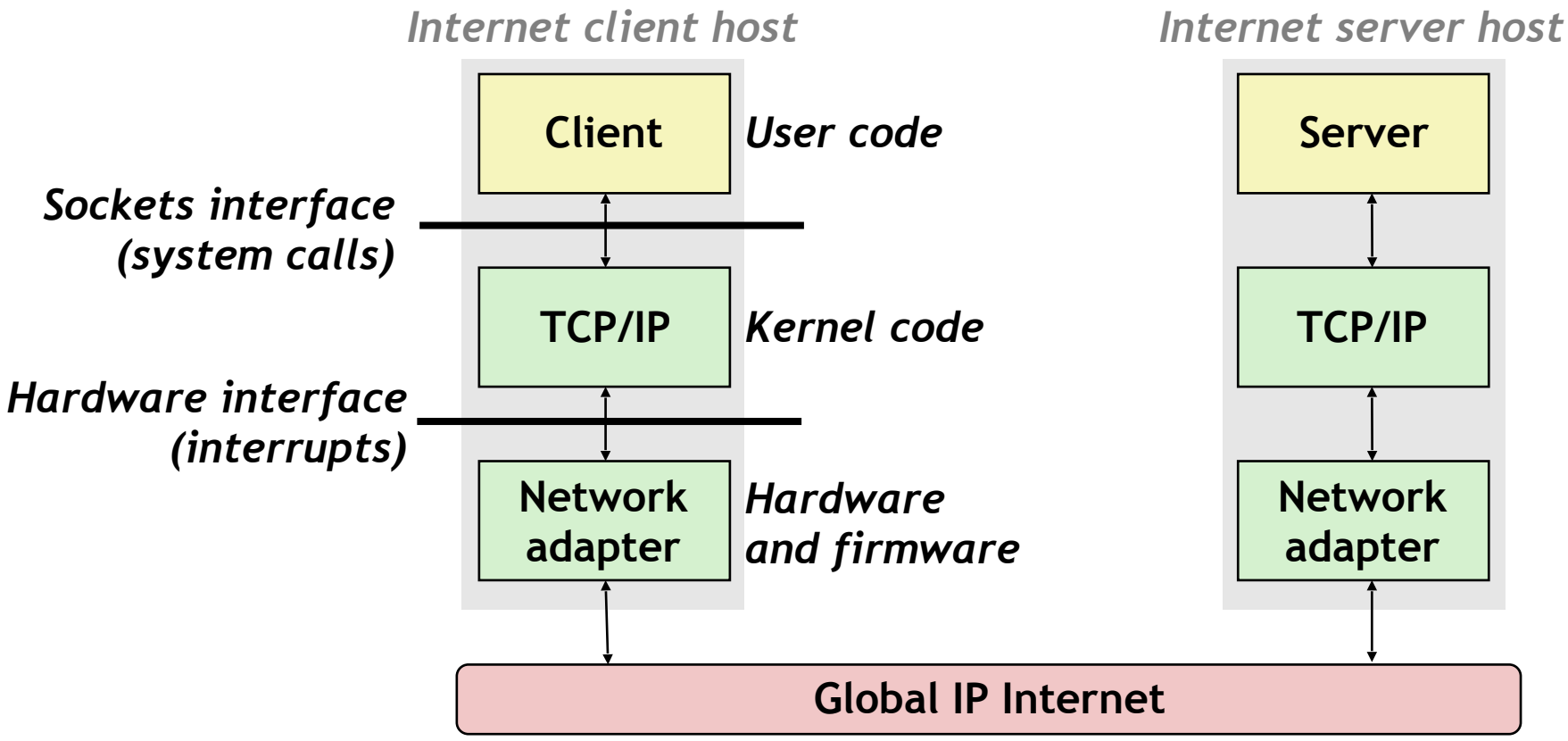
- **Provides a naming scheme**
  - An internet protocol defines a uniform format for *host addresses*
  - Each host (and router) is assigned at least one of these internet addresses that uniquely identifies it
- **Provides a delivery mechanism**
  - An internet protocol defines a standard transfer unit (*packet*)
  - Packet consists of *header* and *payload*
    - *Header*: contains info such as packet size, source and destination addresses
    - *Payload*: contains data bits sent from source host
- **Lots of other things…**
  - Example, what order do the bytes go on the wire? Little-endian or Big-endian?

Global IP Internet (upper case)

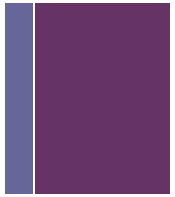


- **Most famous example of an internet**
- **Based on the TCP/IP protocol family**
  - *IP (Internet Protocol) :*
    - Provides basic *naming scheme* and unreliable *delivery capability* of packets (*datagrams*) from *host-to-host*
  - *UDP (Unreliable Datagram Protocol)*
    - Uses IP to provide *unreliable* datagram delivery from *process-to-process*
  - *TCP (Transmission Control Protocol)*
    - Uses IP to provide *reliable* byte streams from *process-to-process*
- **Accessed via a mix of Unix file I/O and functions from the *sockets interface***

Organization of an Internet Application

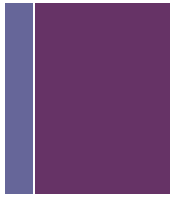


A Programmer's View of the Internet



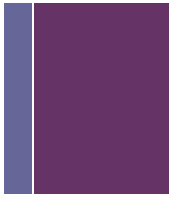
- **Hosts are mapped to a set of 32-bit *IP addresses***
  - 128.122.49.30
- **The set of IP addresses is mapped to a set of identifiers called Internet *domain names***
  - 128.122.49.30 is mapped to `cs.nyu.edu`
- **A process on one Internet host can communicate with a process on another Internet host over a *connection***

Domain Naming System (DNS)



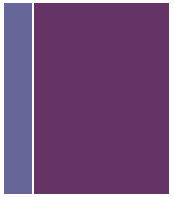
- **The Internet maintains a mapping between IP addresses and domain names in a huge worldwide distributed database called DNS**
- **Conceptually, programmers can view the DNS database as a collection of millions of host entries.**
  - Each host entry defines the mapping between a set of domain names and IP addresses.
- **These names can be resolved on the command line using `nslookup` command.**
- **Many names can be mapped to the same IP or multiple IPs mapped to same name.**
  - Why? Geolocation.

Internet Connections



- **Clients and servers communicate by sending streams of bytes over *connections*. Each connection is:**
  - *Point-to-point*: connects a pair of processes.
  - *Full-duplex*: data can flow in both directions at the same time,
  - *Reliable*: stream of bytes sent by the source is eventually received by the destination in the same order it was sent.
- **A *port* is a 16-bit integer that identifies a *process*:**
  - *Ephemeral port:* Assigned automatically by client kernel when client makes a connection request. (Also used by server in some cases)
  - *Well-known port:* Associated with some service provided by a server (e.g., port 80 is associated with Web servers)
- **A *socket* is an endpoint of a connection**
  - Socket address is an `IPaddress:port` pair

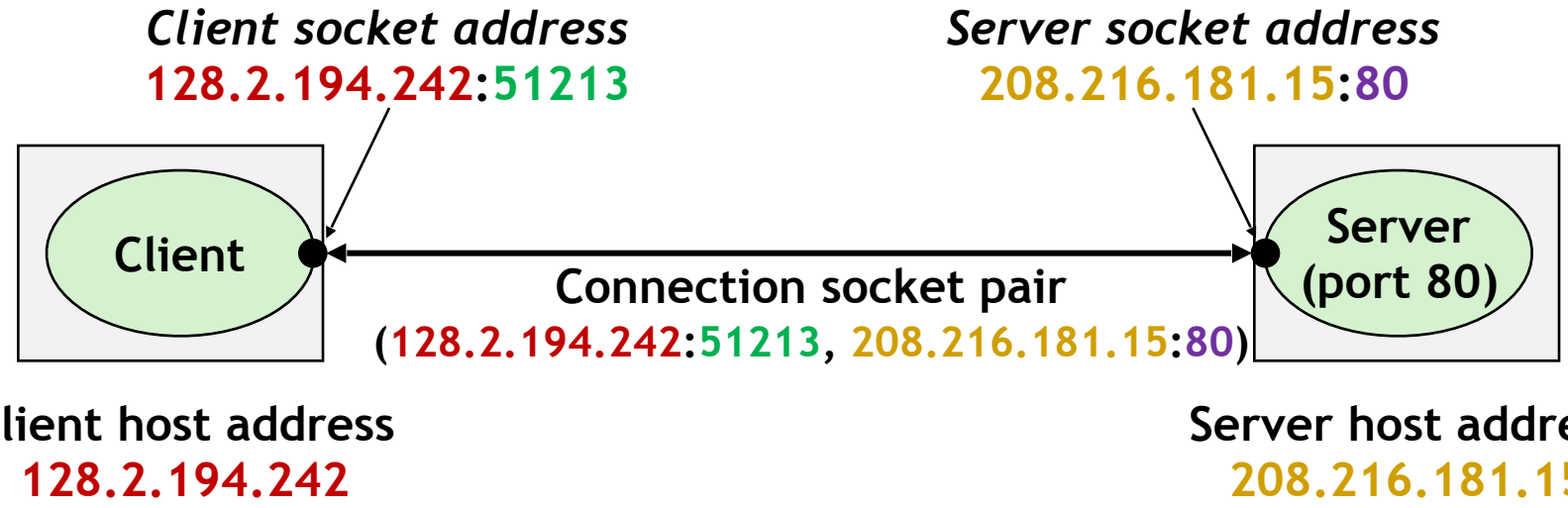
Well-known Ports and Service Names



- **Popular services have permanently assigned well-known ports and corresponding well-known service names:**
  - Examples
    - echo server: `7/echo`
    - ssh servers: `22/ssh`
    - email server: `25/smtp`
    - web servers: `80/http`
  - *0-1023* have special semantics
    - https://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers
- **Mappings between well-known ports and service names is contained in the file /etc/services on each Linux machine.**

Anatomy of a Connection

- **A connection is uniquely identified by the socket addresses of its endpoints (socket pair)**
  - `(cliaddr:cliport, servaddr:servport)`



51213 is an ephemeral port allocated by the kernel

80 is a well-known port associated with Web servers

Sockets

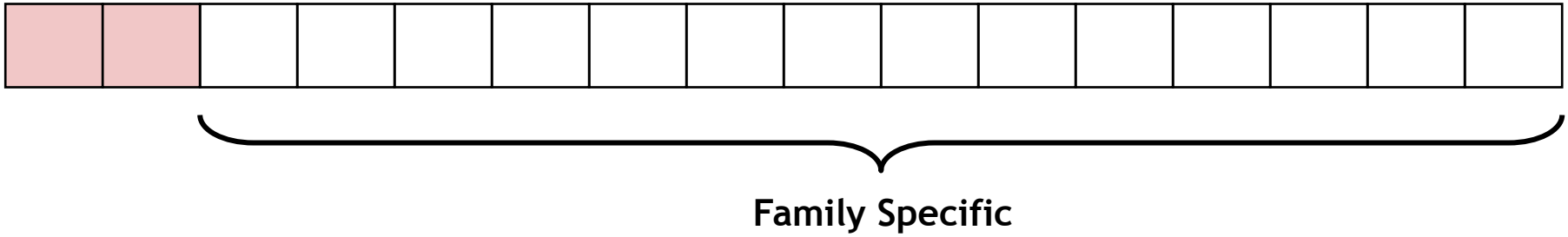
- **What is a socket?**
  - To the kernel, a socket is an endpoint of communication
  - To an application, a socket is a file descriptor that lets the application read/write from/to the network
    - All Unix I/O devices, including networks, are modeled as files
- **Clients and servers communicate with each other by reading from and writing to socket descriptors**

- **The main distinction between regular file I/O and socket I/O is how the application "opens" the socket descriptors**

Socket Address Structures

- **Generic socket address:**
  - For address arguments to `connect`, `bind`, and `accept`
  - Necessary only because C did not have generic (void*) pointers when the sockets interface was designed

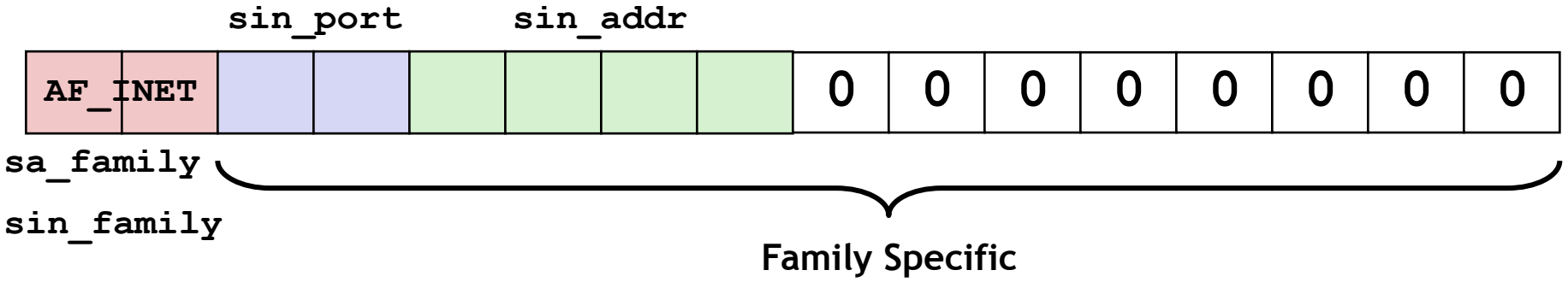
```
struct sockaddr {
  uint16_t  sa_family;    /* Protocol family */
  char      sa_data[14];  /* Address data.  */
};
```



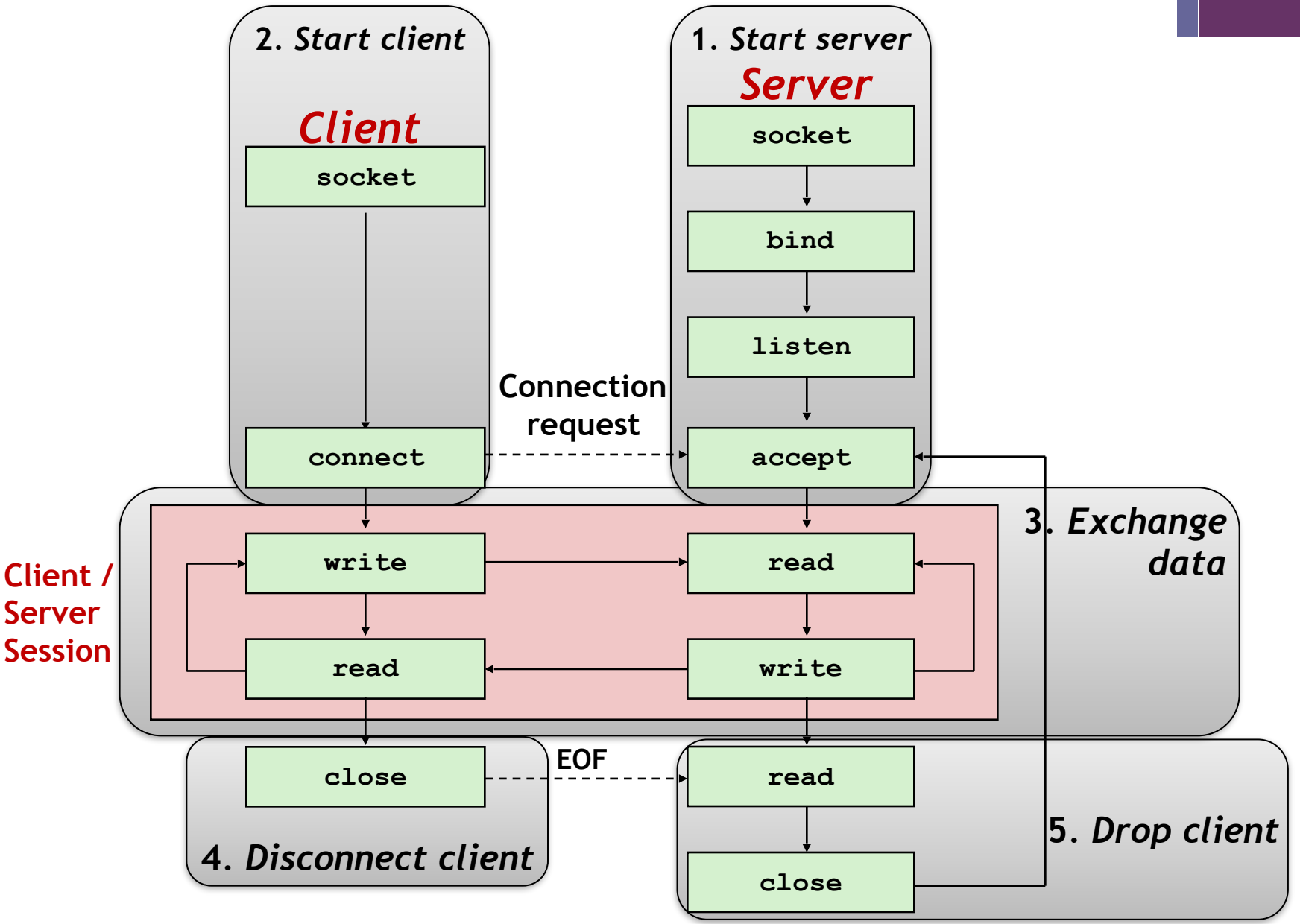
Socket Address Structures *con't*

- **Internet-specific socket address:**
  - Must cast `struct sockaddr_in*` to `struct sockaddr*` for functions that take socket address arguments.

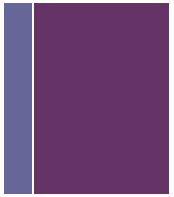
```
struct sockaddr_in  {
  uint16_t        sin_family;  /* Protocol family (always AF_INET) */
  uint16_t        sin_port;    /* Port num in network byte order */
  struct in_addr  sin_addr;    /* IP addr in network byte order */
  unsigned char   sin_zero[8]; /* Pad to sizeof(struct sockaddr) */
};
```



Client/Server



Sockets Interface: `socket`



- **Clients and servers use the socket function to create a socket descriptor:**

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

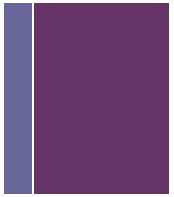
- **Example:**

```
int clientfd = Socket(AF_INET, SOCK_STREAM, 0);
```

Indicates that we are using 32-bit IPV4 addresses

Indicates that the socket will be the end point of a TCP connection

Sockets Interface: `bind`

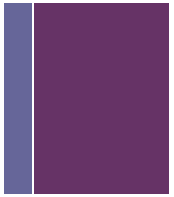


- A server uses **`bind`** to ask the kernel to associate the server's socket address with a socket descriptor:

```
int bind(int sockfd, sockaddr* addr, socklen_t addrlen);
```

- The process can read bytes that arrive on the connection whose endpoint is **`addr`** by reading from descriptor **`sockfd`**.
- Similarly, writes to **`sockfd`** are transferred along connection whose endpoint is **`addr`**.

Sockets Interface: `listen`

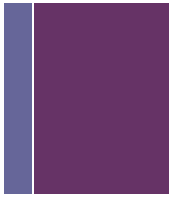


- By default, kernel assumes that descriptor from socket function is an active socket that will be on the client end of a connection.
- A server calls `listen` to tell the kernel that a descriptor will be used by a server rather than a client:

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

- Converts `sockfd` from an active socket to a *listening* socket that can accept connection requests from clients.
- `backlog` is a hint about the number of outstanding connection requests that the kernel should queue up before starting to refuse requests.

Sockets Interface: `accept`



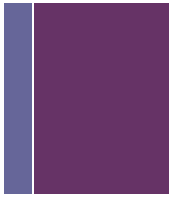
- **Servers wait for connection requests from clients by calling accept:**

```
int accept(int listenfd, sockaddr* addr, int* addrlen);
```

- **Waits for connection request to arrive on the connection bound to `listenfd`, then fills in client's socket address in `addr` and size of the socket address in `addrlen`.**

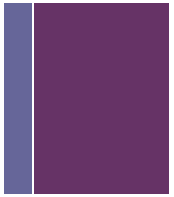
- **Returns a connected descriptor that can be used to communicate with the client via Unix I/O routines.**

Connected vs. Listening Descriptors



- **Listening descriptor**
  - End point for client connection requests
  - Created once and exists for lifetime of the server
- **Connected descriptor**
  - End point of the connection between client and server
  - A new descriptor is created each time the server accepts a connection request from a client
  - Exists only as long as it takes to service client
- **Why the distinction?**
  - Allows for concurrent servers that can communicate over many client connections simultaneously
    - E.g., Each time we receive a new request, we fork a child to handle the request

Sockets Interface: `connect`



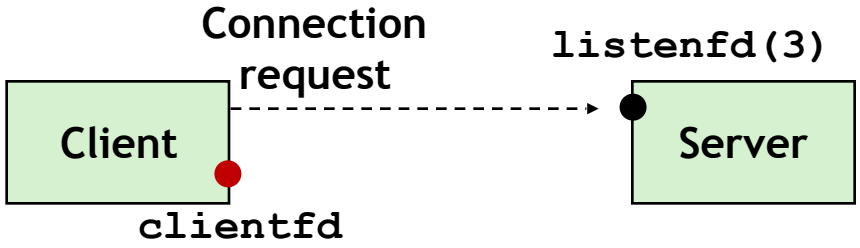
- **A client establishes a connection with a server by calling connect:**

```
int connect(int clientfd, sockaddr* addr, socklen_t addrlen);
```

- **Attempts to establish a connection with server at socket address `addr`**
  - If successful, then `clientfd` is now ready for reading and writing.
  - `addrlen` is `sizeof(sockaddr_in)`

accept & connect Illustrated

1. Server blocks in `accept`, waiting for connection request on listening descriptor `listenfd`



2. Client makes connection request by calling and blocking in `connect`

3. Server returns `connfd` from `accept`. Client returns from `connect`. Connection is now established between `clientfd` and `connfd`

Socket Client & Server

- **Lets take a look at some code…**
- **See lecture24/client.c and lecture24/server.c**