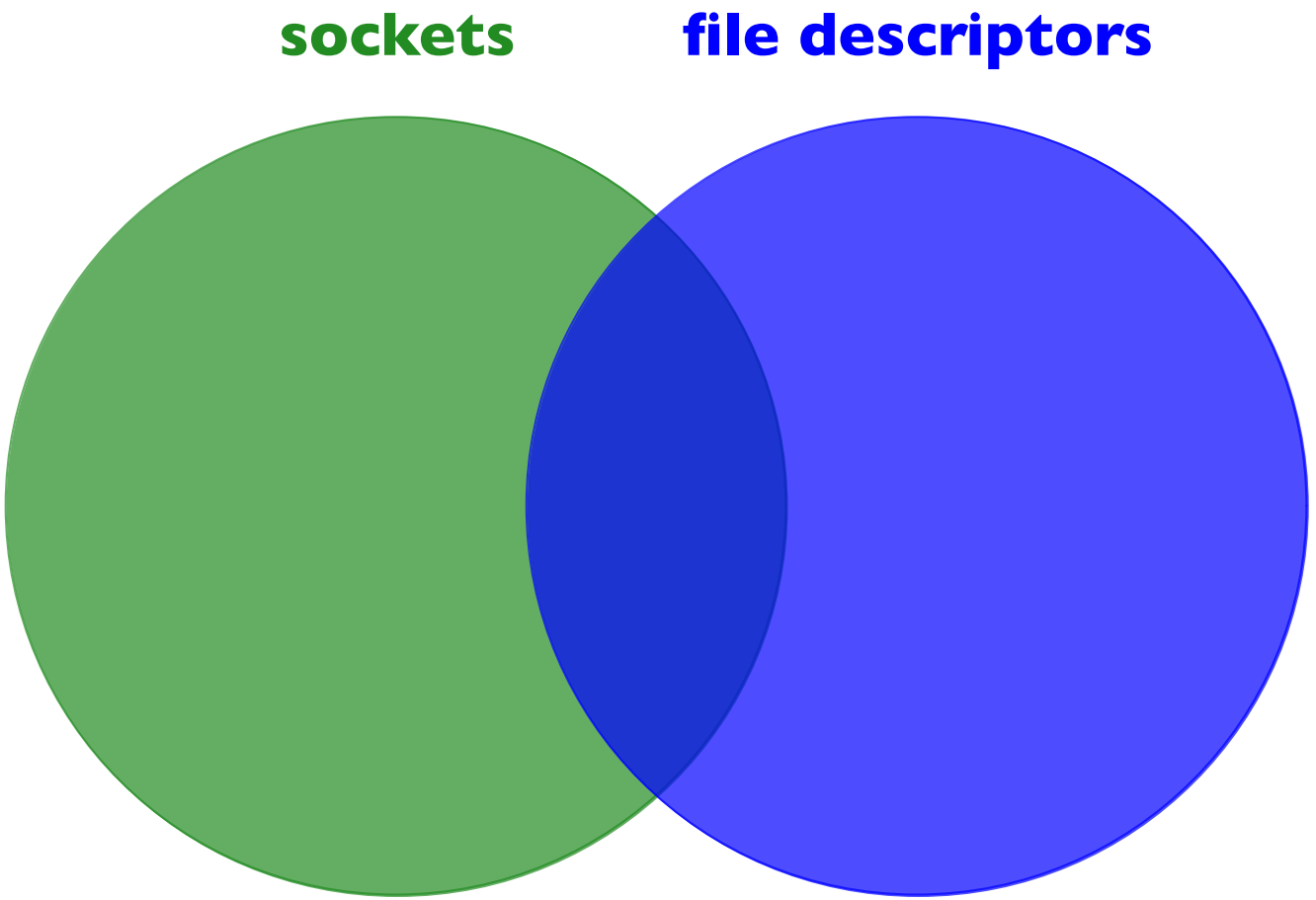
sockets
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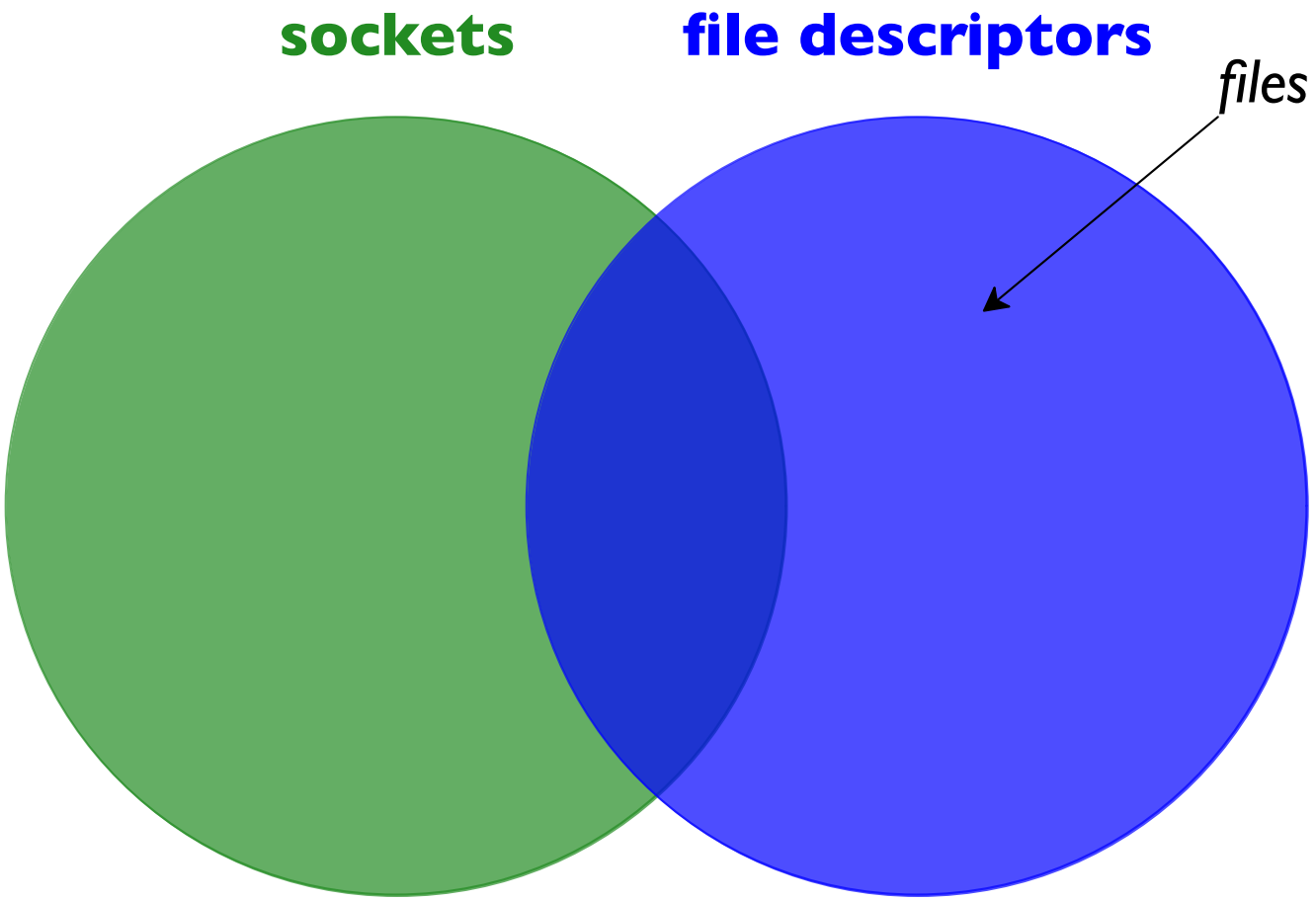
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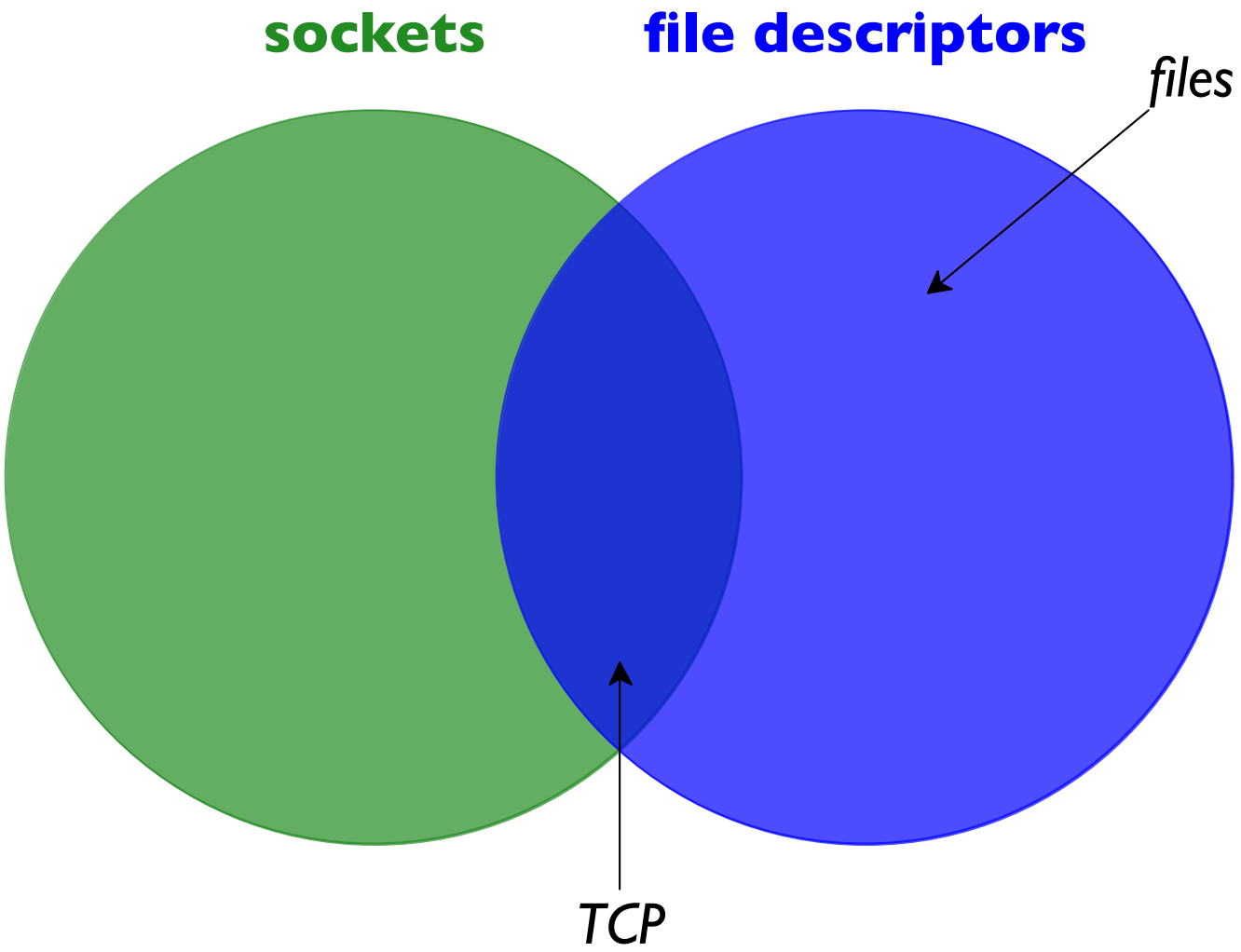
sockets
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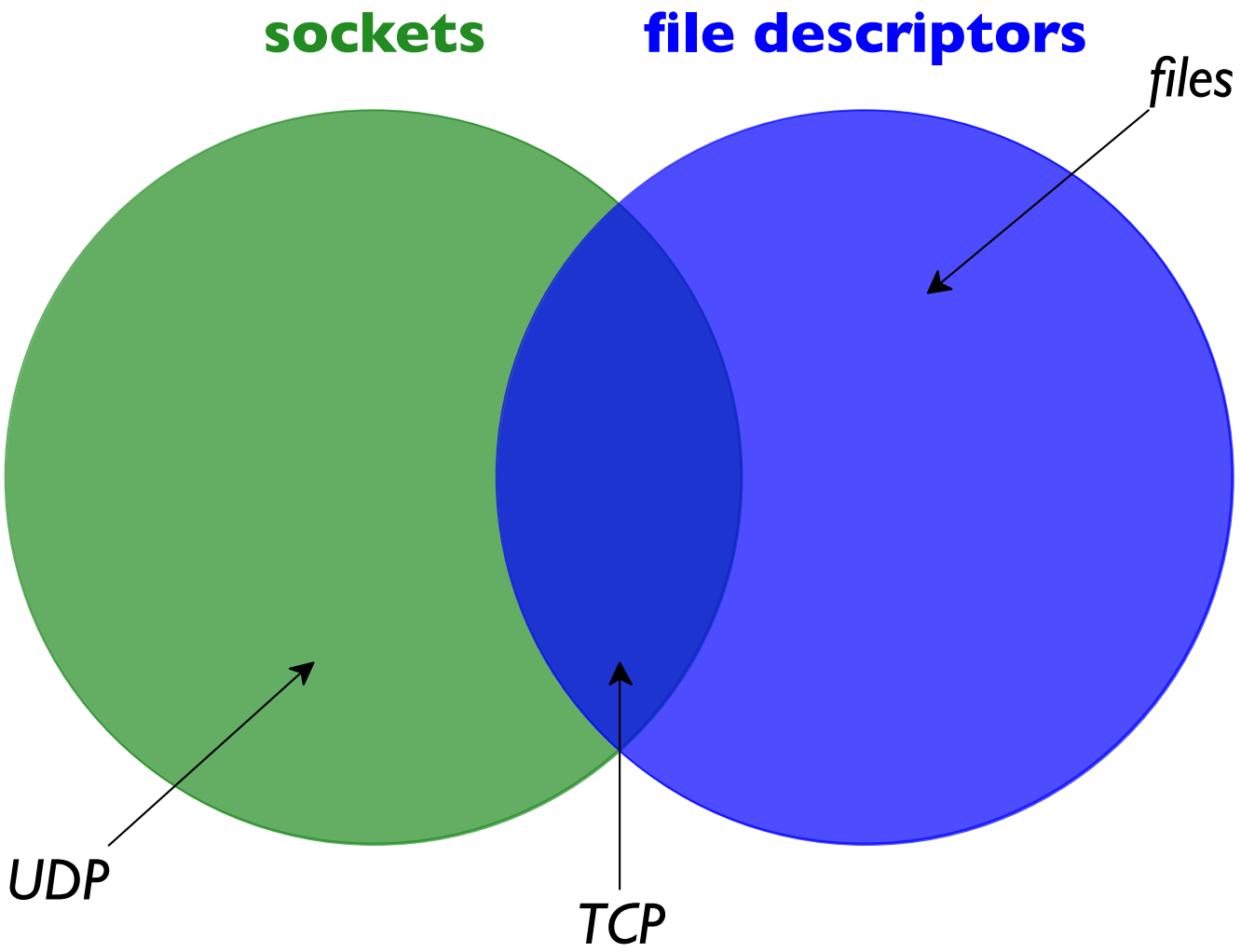
TCP


sockets
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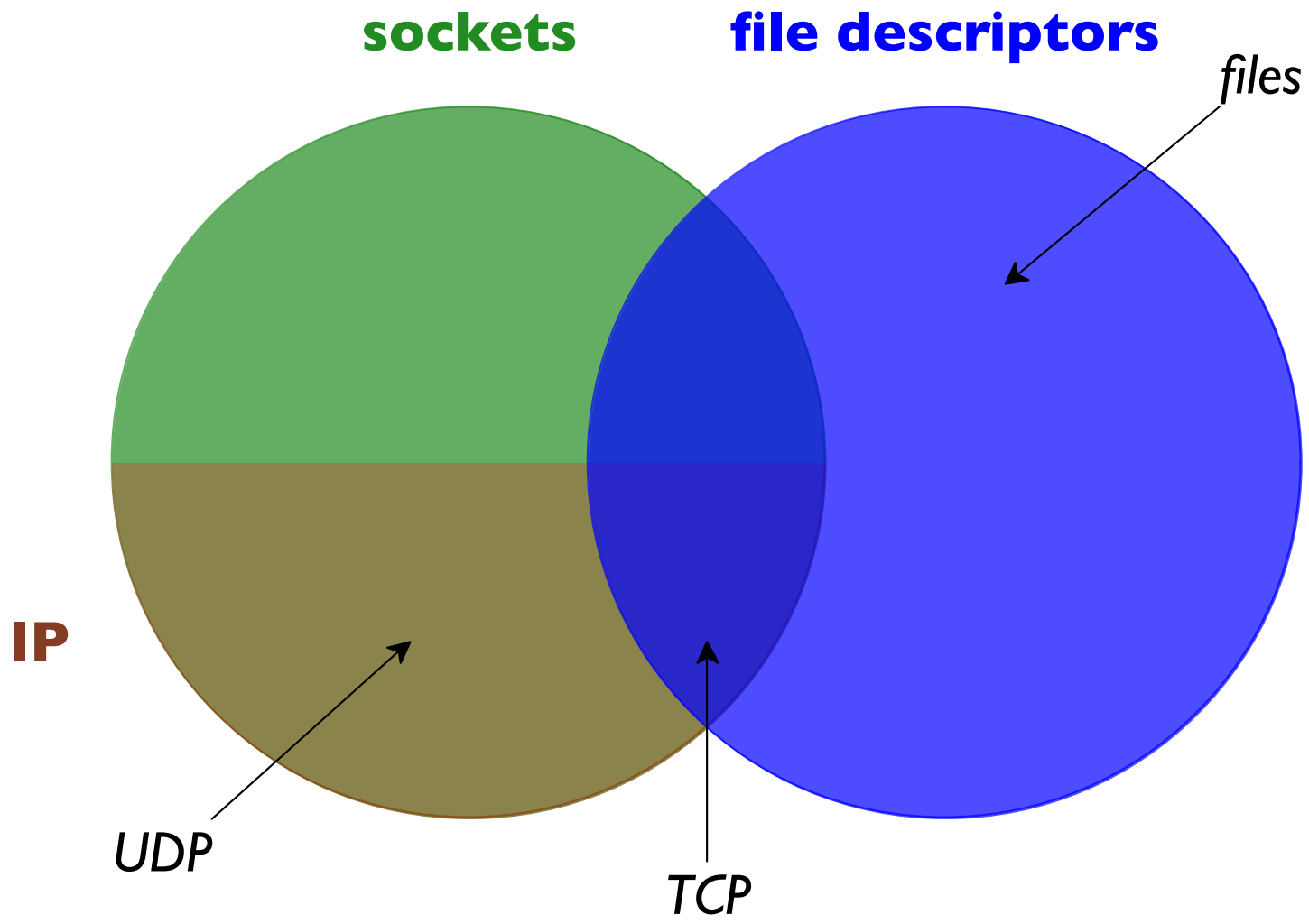
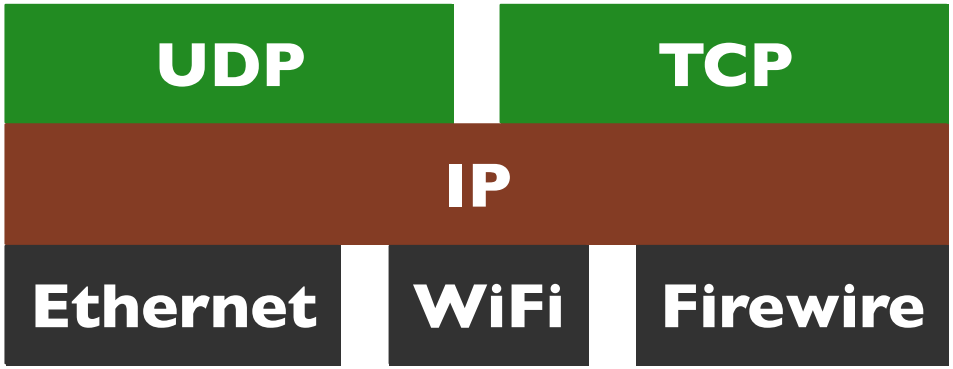
UDP
TCP


sockets
file descriptors
files
IP
UDP
TCP

IP

IP is an addressing scheme and packet format



IP

- Each node has a 32-bit address written in four parts, e.g.

  `192.168.1.100`

- "Directly" connected to other addresses that match within the ***netmask***

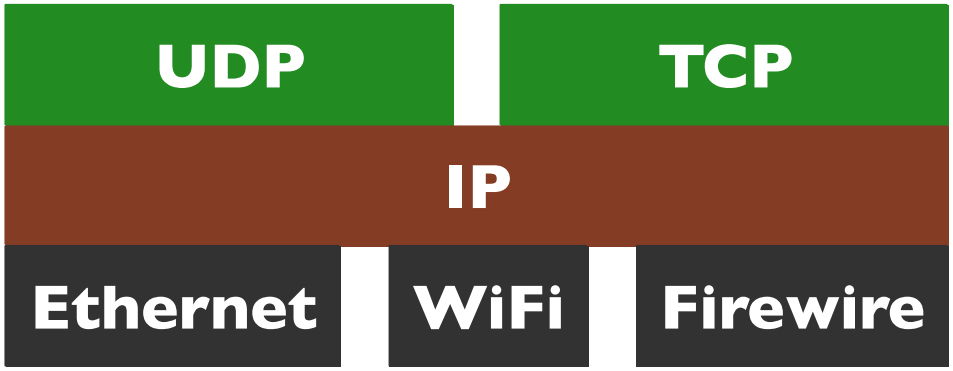
  netmask **`255.255.255.0`**:

  ⇒ **`192.168.1.100`** on subnet of **`192.168.1.28`**

  ⇒ **`192.168.1.100`** not on subnet of **`192.168.2.100`**

Interfaces

A machine may have multiple IP ***interfaces***



Try running `ifconfig` or `ipconfig`

Getting an Address

- Static addressing: user/administrator tells the OS to use a particular address and netmask
- ***DHCP***: machine gets address from a server to which it is "directly" connected
  - Exploits IP netmask-constrained broadcast without knowing the subnet address
- ***NAT*** makes multiple nodes look like one

UDP and TCP

Applications practically never create raw IP packets

- An exception: **`ping`**

Primarily two choices for layers over IP:

- ***UDP*** packet-based, not reliable
- ***TCP*** stream-based, reliable

IP Message

The destination of an IP message is

- a host address
- a protocol (e.g., TCP or UDP)
- a port number

Port numbers range from 1 to 65535

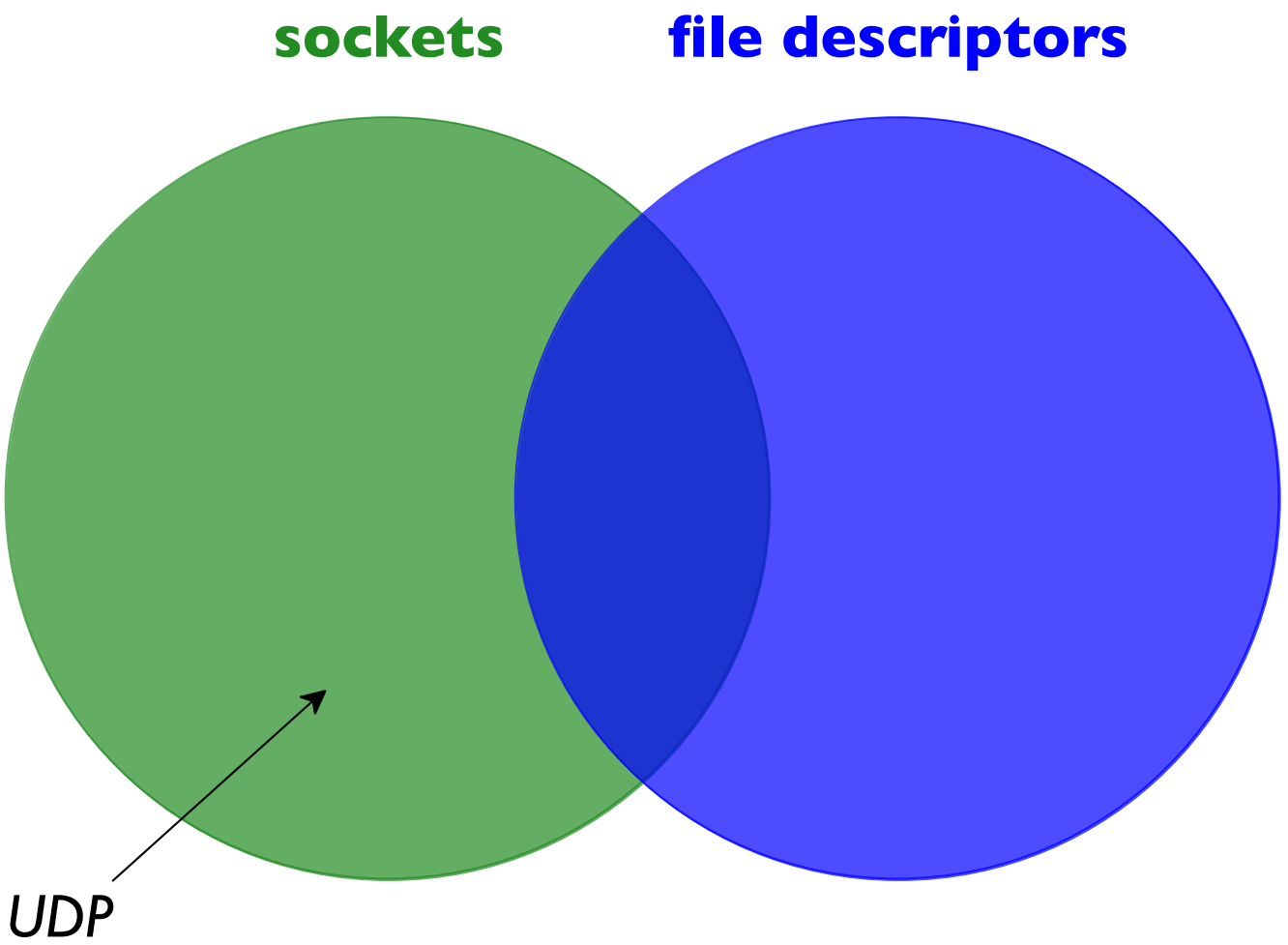
Port numbers below 1024 require special privilege

Creating a Socket

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

- domains: **`PF_INET`**, **`PF_UNIX`**, ...
- types: **`SOCK_STREAM`**, **`SOCK_DGRAM`**, ...
- protocols: **`"tcp"`**, **`"udp"`**, ...
  convert string to a number with **`getprotoent()`**

UDP



Sending a UDP Message

```
ssize_t sendto(int socket,
               void *buffer, size_t length,
               int flags,
               struct sockaddr *dest_addr,
               socklen_t dest_len);
```

Need to build an address...

Binding a Socket

```
int bind(int socket,
         struct sockaddr *address,
         socklen_t address_len);
```

Need to build an address...

Receiving a UDP Message

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

Computing an IP Address

```
struct sockaddr_in addr;
```

- set **`serv_addr.sin_family`** to **`AF_INET`**
- set **`serv_addr.sin_port`** to a port number
- set **`serv_addr.sin_addr.s_addr`** to a numerical IP address

Getting a numerical address:

- Convert a hostname string with **`gethostbyname()`**
- Use **`INADDR_ANY`** with **`bind()`**

See **udp_recv.c**, **udp_send.c**, **udp_recvfrom.c**, **udp_lh_recv.c**, **udp_sendfrom.c**

Binding to a Destination

```
int connect(int socket,
            struct sockaddr *address,
            socklen_t address_len);

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

For UDP, **`connect()`** is just a convenience

See **`udp_many_send.c`**

UDP Summary

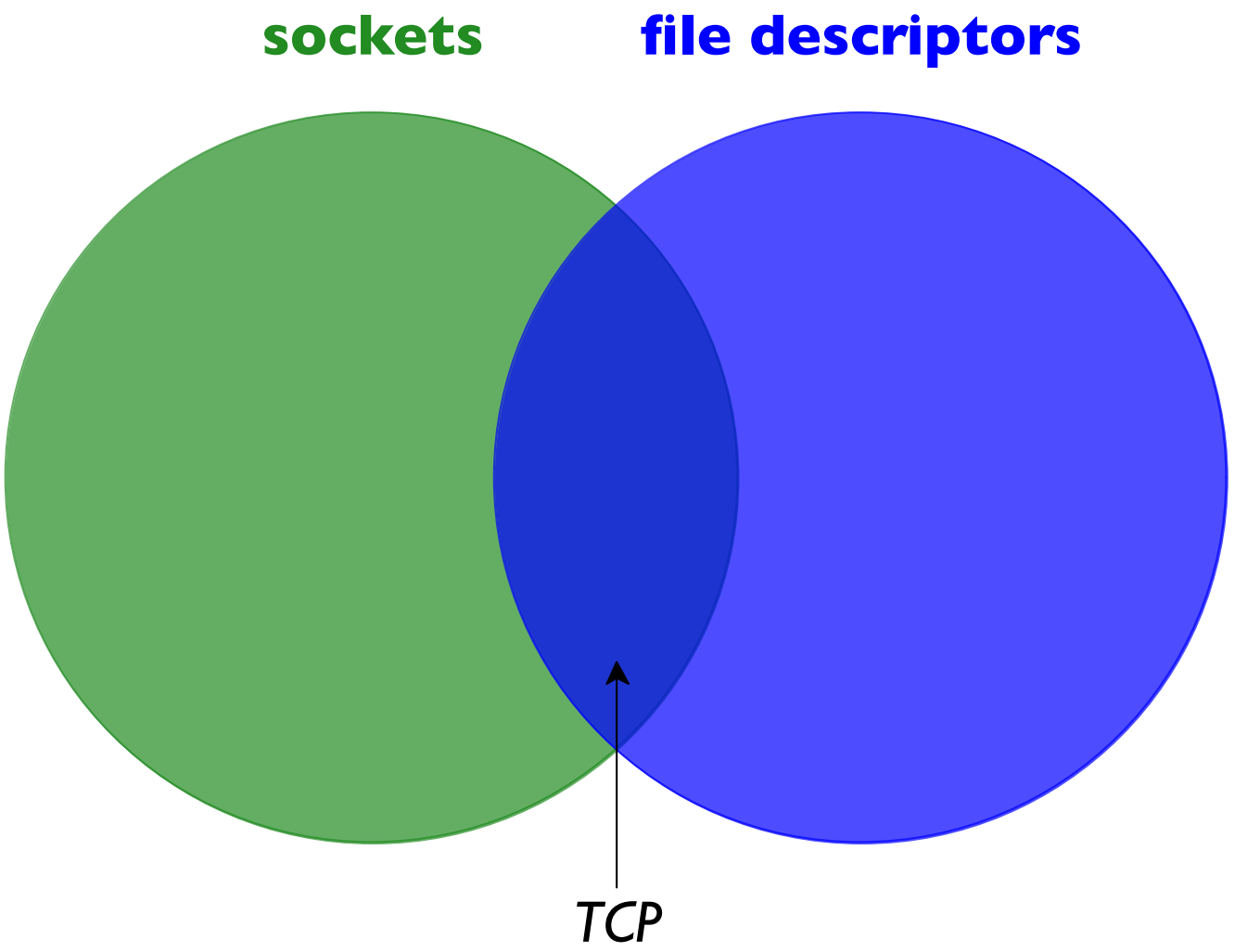
- About as simple as possible
- No guarantees about delivery
- No guarantees on order of messages

UDP in the OS

OS needs to maintain

- A mapping from port numbers to process+socket
  - Handle incoming messages
  - Disallow multiple uses of port numbers
- Little buffering for messages going our or coming in

TCP



Creating a TCP Connection

Client:

- **`socket()`** and **`connect()`** *N* times

  socket works with **`send()`**, **`recv()`**, **`read()`**, and **`write()`**

Server:

- **`socket()`**, **`bind()`**, and **`listen()`** once

  socket works only with **`accept()`**

- **`accept()`** [implicitly creates new socket] *N* times

  socket works with **`send()`**, etc.

Listening and Accepting TCP Connections

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

int accept(int socket,
           struct sockaddr *address,
           socklen_t *address_len);
```

See **tcp_server.c**, **tcp_client.c**

TCP Streams

A TCP connection allows both read and write

- **`close()`** ends both directions
- **`shutdown()`** ends one direction
  - shutdown output ⇒ other end recieves EOS
  - shutdown input ⇒ no message

See **`tcp_server2.c`**, **`tcp_client2.c`**

Reliable Data Delivery

When an IP packet is lost for a TCP connection, TCP re-sends the data

- Requires an ACK from other end
- Messages have IDs for ACKs and ordering

Resending uses ***exponential backoff***:

- Send message, wait *N* msecs for reply...
- Re-send message, wait 2*N* msecs for reply...
- Re-re-send message, wait 4*N* msecs for reply...

An ACK is needed even for a shutdown EOS

TCP in the OS

A program could make a TCP connection, send data, **`close()`** the connection, and exit

- OS typically allows the close and exit immediately
- Some TCP work work may survive the process, such as EOS ACKs

Absent an EOS, how does the OS know that no more data will arrive on a TCP connection?

- OS hedges with connection in **`TIME_WAIT`** state
- **`SO_REUSEADDR`** truncates **`TIME_WAIT`** state on listeners

See **`server.c`**