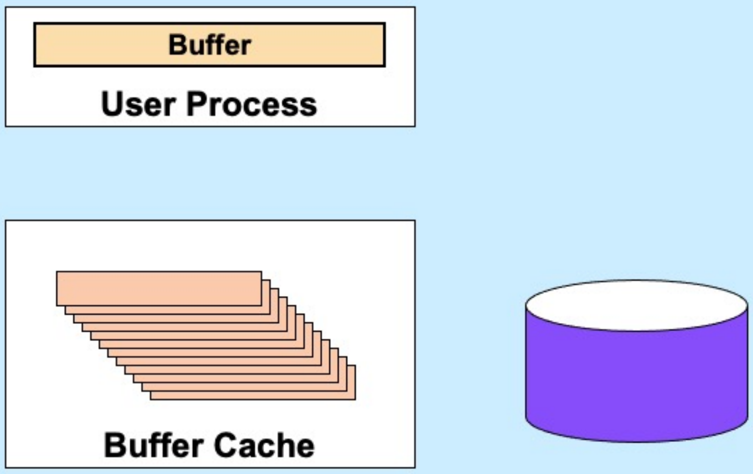
CS 33

Virtual Memory (2)

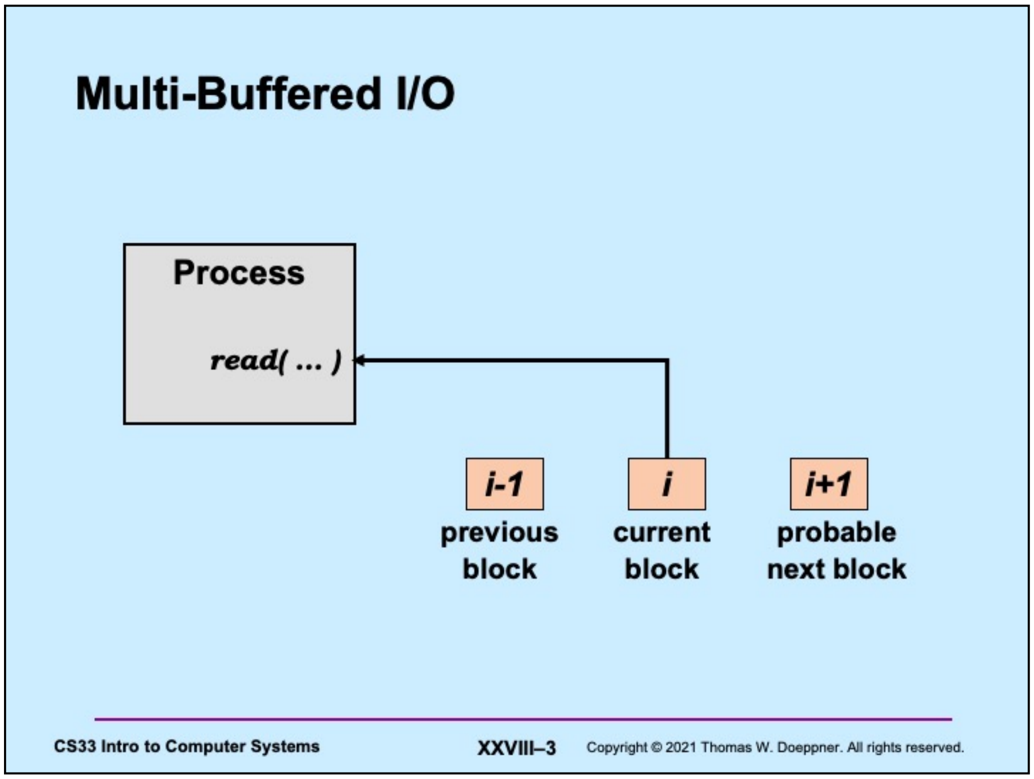
File I/O



File I/O in Unix, and in most operating systems, is not done directly to the disk drive, but through intermediary buffers, known as the buffer cache, in the operating system's address space. This cache has two primary functions. The first, and most important, is to make possible concurrent I/O and computation within a Unix process. The second is to insulate the user from physical disk-block boundaries.

From a user process's point of view, I/O is **synchronous**. By this we mean that when the I/O system call returns, the system no longer needs the user-supplied buffer. For example, after a write system call, the data in the user buffer has either been transmitted to the device or copied to a kernel buffer — the user can now scribble over the buffer without affecting the data transfer. Because of this synchronization, from a user process's point of view, no more than one I/O operation can be in progress at a time.

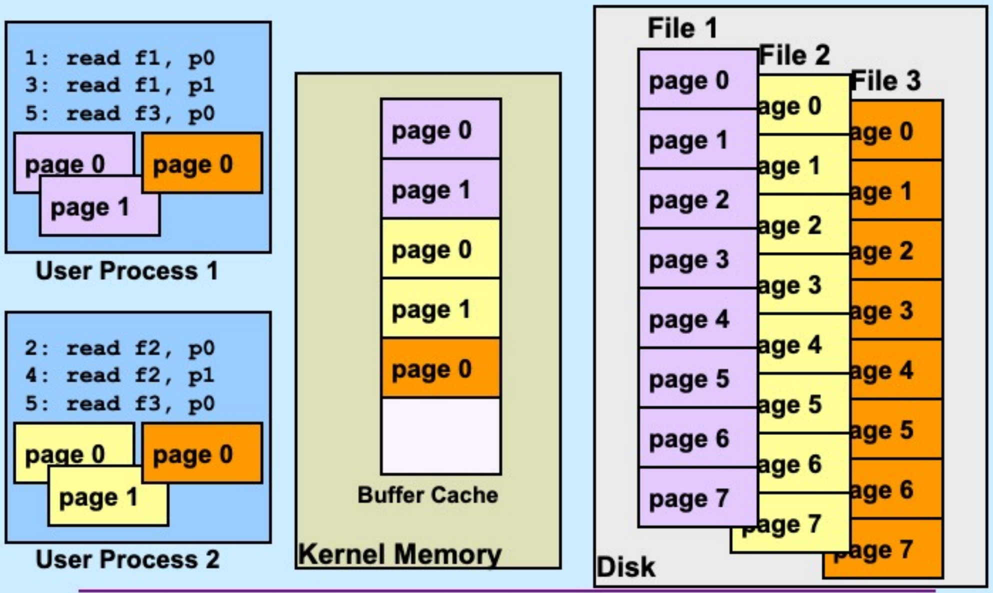
The buffer cache provides a kernel implementation of multibuffered I/O, and thus concurrent I/O and computation are made possible.

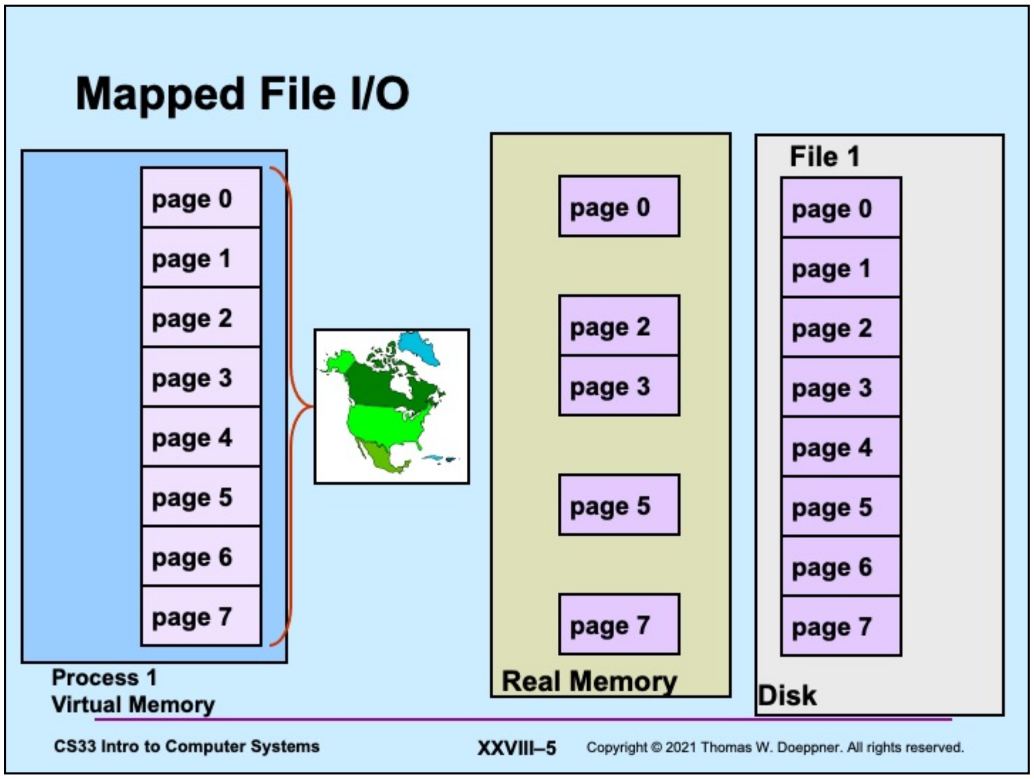


Multi-Buffered I/O

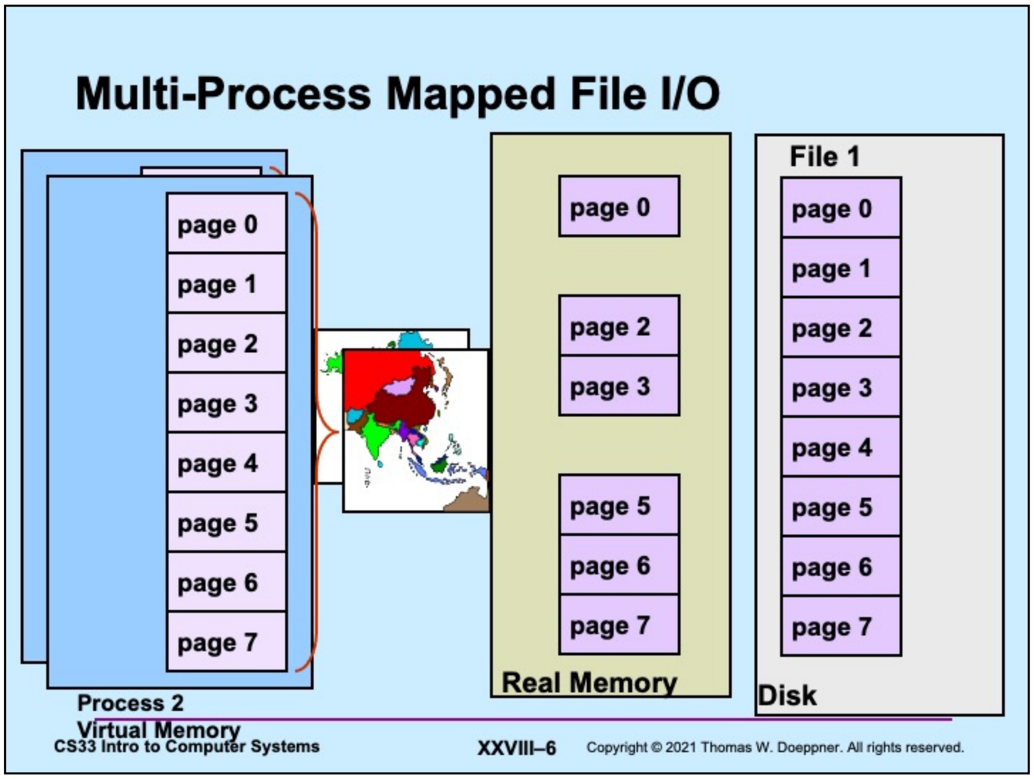
The use of **read-aheads** and **write-behinds** makes possible concurrent I/O and computation: if the block currently being fetched is block *i* and the previous block fetched was block *i-1*, then block *i+1* is also fetched. Modified blocks are normally written out not synchronously but instead sometime after they were modified, asynchronously.

Traditional I/O

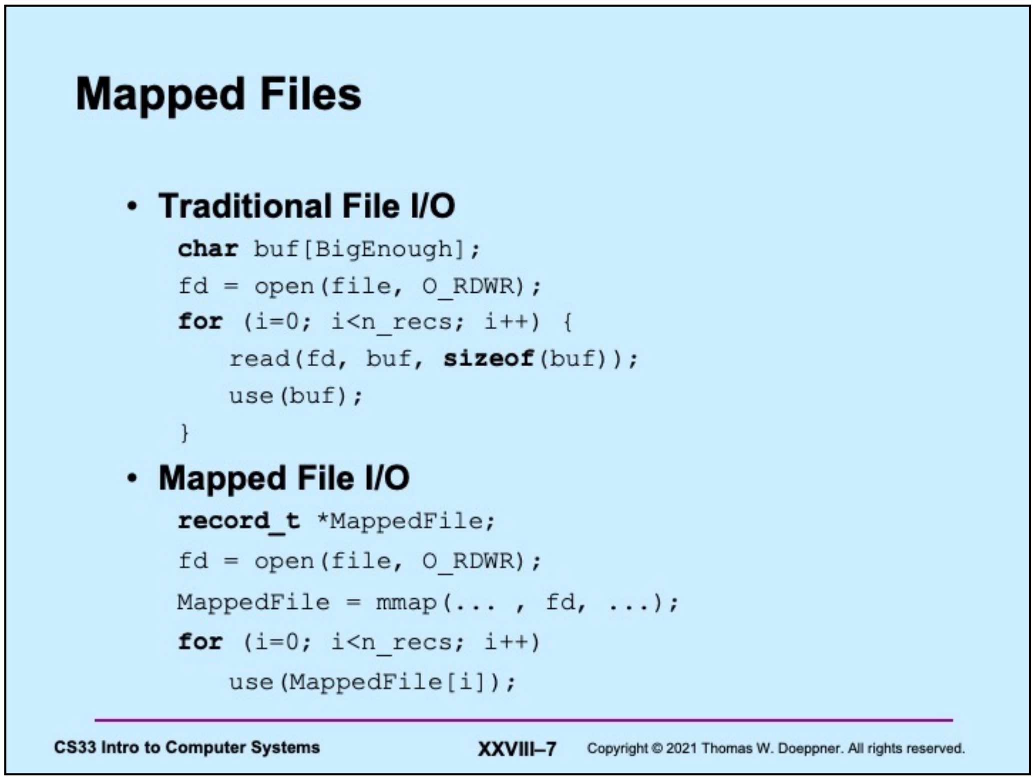




Mapped File I/O



Multi-Process Mapped File I/O



Mapped Files

- **Traditional File I/O**

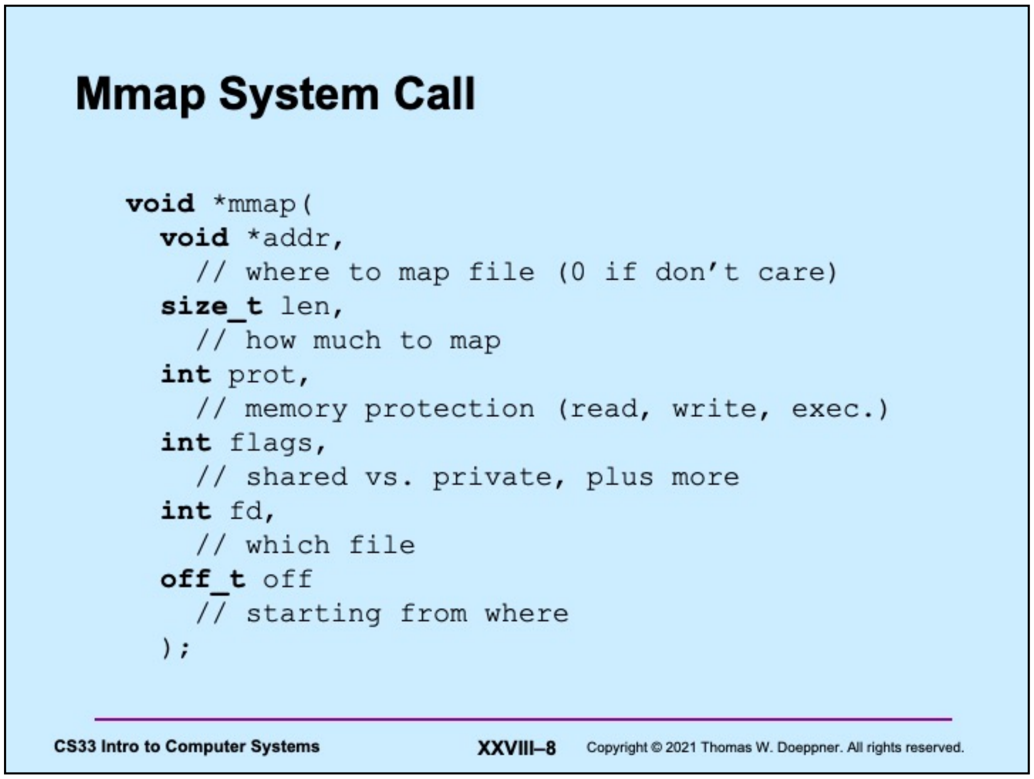
```
char buf[BigEnough];
fd = open(file, O_RDWR);
for (i=0; i<n_recs; i++) {
    read(fd, buf, sizeof(buf));
    use(buf);
}
```

- **Mapped File I/O**

```
record_t *MappedFile;
fd = open(file, O_RDWR);
MappedFile = mmap(... , fd, ...);
for (i=0; i<n_recs; i++)
    use(MappedFile[i]);
```

Traditional I/O involves explicit calls to read and write, which in turn means that data is accessed via a buffer; in fact, two buffers are usually employed: data is transferred between a user buffer and a kernel buffer, and between the kernel buffer and the I/O device.

An alternative approach is to *map* a file into a process's address space: the file provides the data for a portion of the address space and the kernel's virtual-memory system is responsible for the I/O. A major benefit of this approach is that data is transferred directly from the device to where the user needs it; there is no need for an extra system buffer.



Mmap System Call

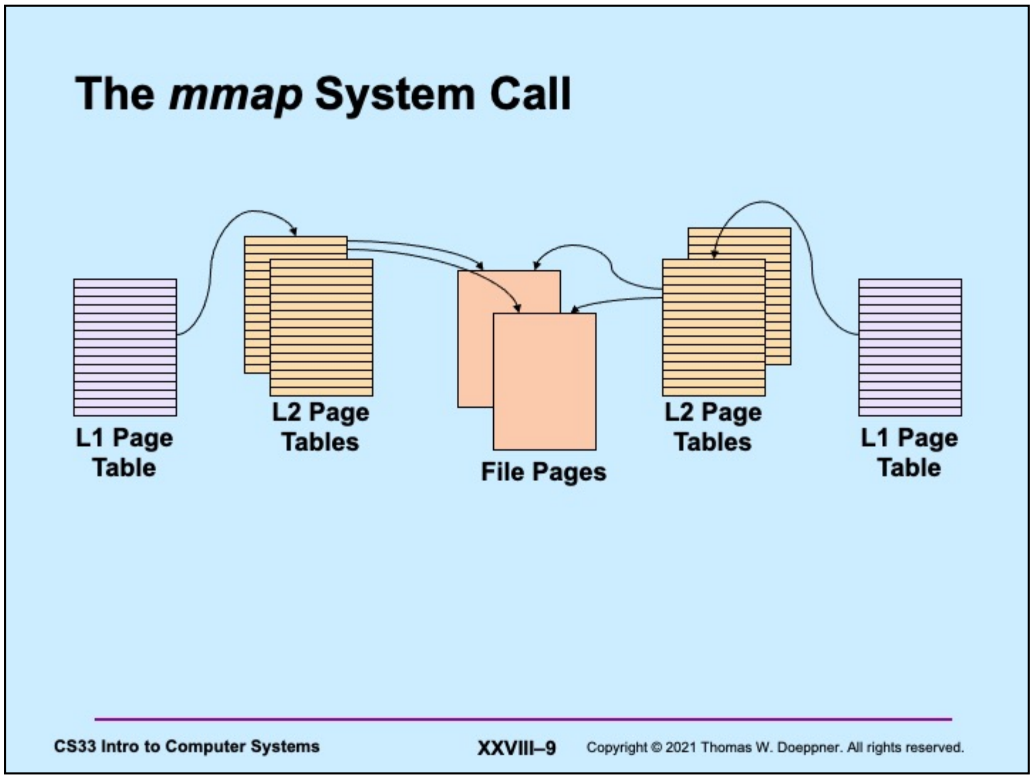
```
void *mmap(
  void *addr,
    // where to map file (0 if don't care)
  size_t len,
    // how much to map
  int prot,
    // memory protection (read, write, exec.)
  int flags,
    // shared vs. private, plus more
  int fd,
    // which file
  off_t off
    // starting from where
  );
```

Mmap maps the file given by **fd**, starting at position **off**, for **len** bytes, into the caller's address space starting at location **addr**

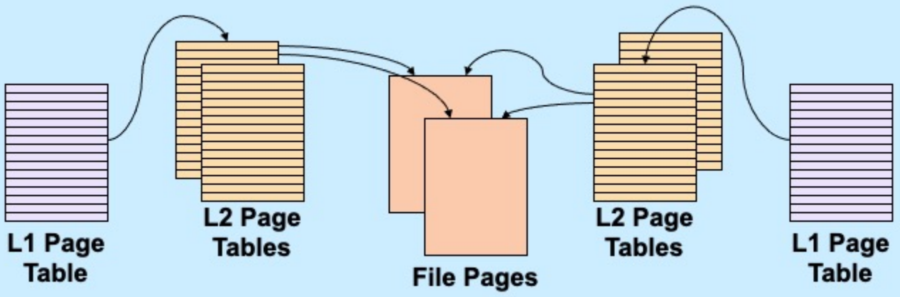
- **len** is rounded up to a multiple of the page size
- **off** must be page-aligned
- if **addr** is zero, the kernel assigns an address
- if **addr** is positive, it is a suggestion to the kernel as to where the mapped file should be located (it usually will be aligned to a page). However, if *flags* includes MAP_FIXED, then **addr** is not modified by the kernel (and if its value is not reasonable, the call fails)
- the call returns the address of the beginning of the mapped file

The flags argument must include either MAP_SHARED or MAP_PRIVATE (but not both). If it's MAP_SHARED, then the mapped portion of the caller's address space contains the current contents of the file; when the mapped portion of the address space is modified by the process, the corresponding portion of the file is modified.

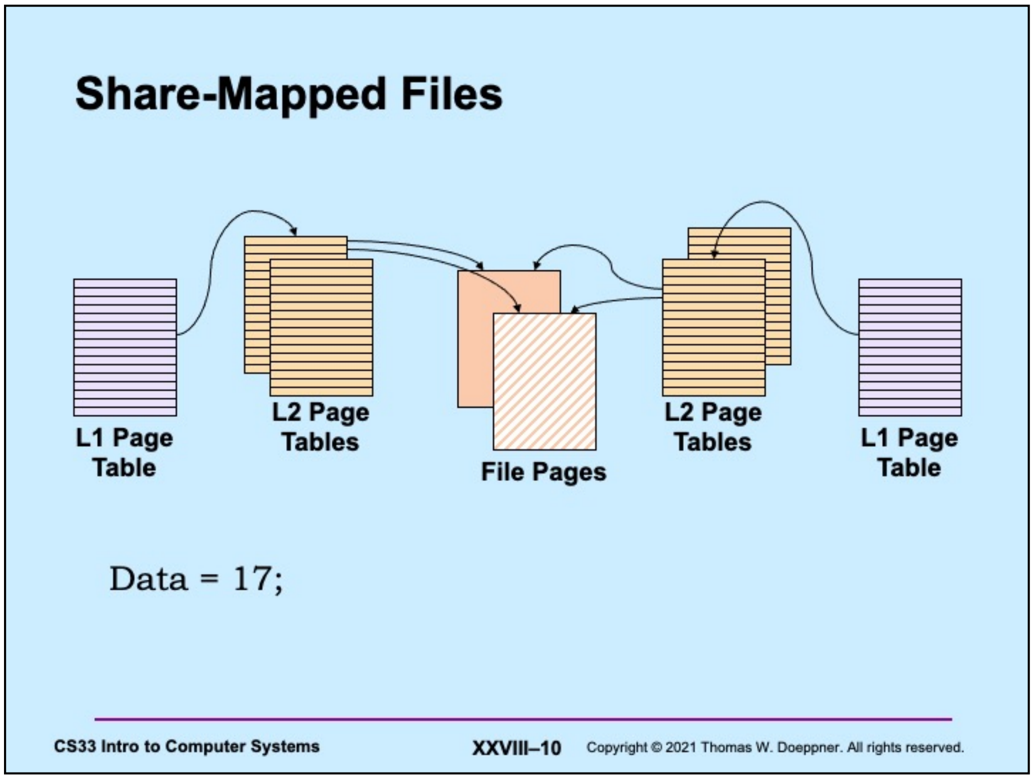
However, if *flags* includes MAP_PRIVATE, then the idea is that the mapped portion of the address space is initialized with the contents of the file, but that changes made to the mapped portion of the address space by the process are private and not written back to the file. The details are a bit complicated: as long as the mapping process does not modify any of the mapped portion of the address space, the pages contained in it contain the current contents of the corresponding pages of the file. However, if the process modifies a page, then that particular page no longer contains the current contents of the corresponding file page, but contains whatever modifications are made to it by the process. These changes are not written back to the file and not shared with any other process that has mapped the file. It's unspecified what the situation is for other pages in the mapped region after one of them is modified. Depending on the implementation, they might continue to contain the current contents of the corresponding pages of the file until they, themselves, are modified. Or they might also be treated as if they'd just been written to and thus no longer be shared with others.



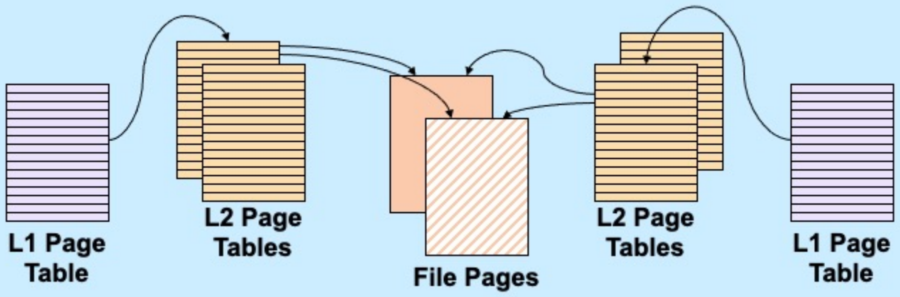
The *mmap* System Call



The **mmap** system call maps a file into a process's address space. All processes mapping the same file can share the pages of the file.



Share-Mapped Files

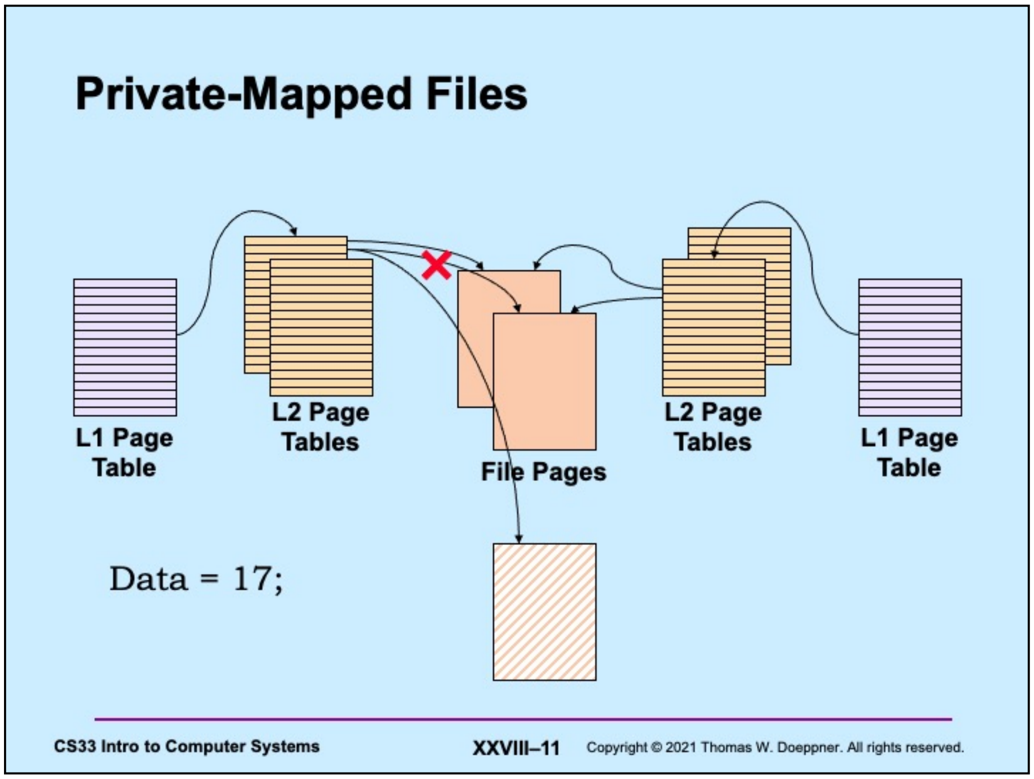


Data = 17;

Here, **Data** is a variable located in the highlighted file page.

There are a couple options for how modifications to mmapped files are dealt with. The most straightforward is the **share** option in which changes to mmapped file pages modify the file and hence the changes are seen by the other processes who have share-mapped the file.

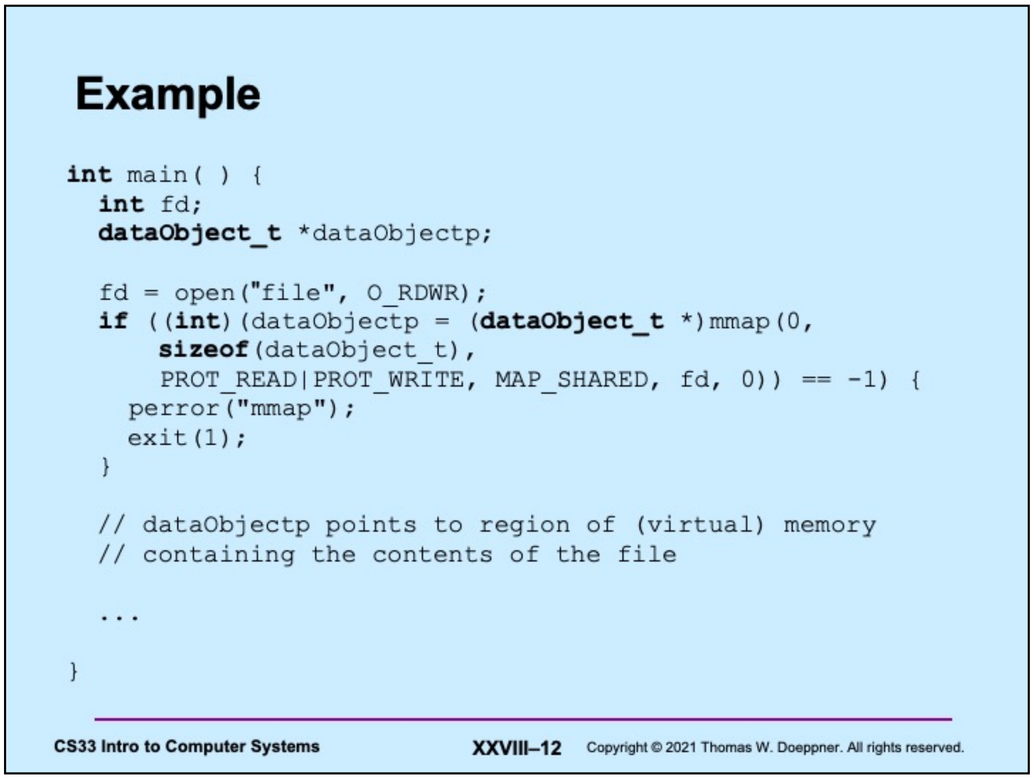
Hence, the change to **Data** is seen by both processes mapping the file.



Private-Mapped Files

The other option is to **private**-map the file: changes made to mmapped file pages do not modify the file. Instead, when a page of a file is first modified via a private mapping, a copy of just that page is made for the modifying process, but this copy is not seen by other processes, nor does it appear in the file.

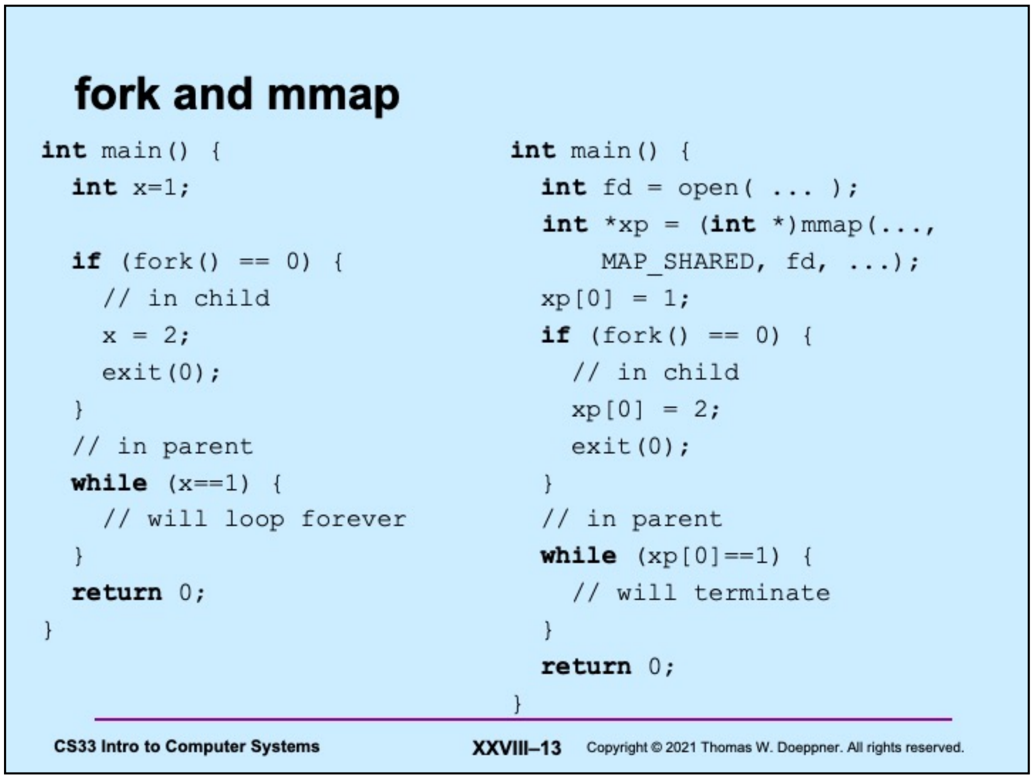
In the slide, the process on the left has private-mapped the file. Thus, its changes to **Data** (in the private-mapped portion of the address space) are made to a copy of the page containing Data. Thus, the other process will continue to see the original Data.



Example

```
int main( ) {
  int fd;
  dataObject_t *dataObjectp;

  fd = open("file", O_RDWR);
  if ((int)(dataObjectp = (dataObject_t *)mmap(0,
      sizeof(dataObject_t),
      PROT_READ|PROT_WRITE, MAP_SHARED, fd, 0)) == -1) {
    perror("mmap");
    exit(1);
  }

  // dataObjectp points to region of (virtual) memory
  // containing the contents of the file

  ...

}
```

Here we map the contents of a file containing a dataObject_t into the caller's address space, allowing it both read and write access. Note mapping the file into memory does not cause any immediate I/O to take place. The operating system will perform the I/O when necessary, according to its own rules.

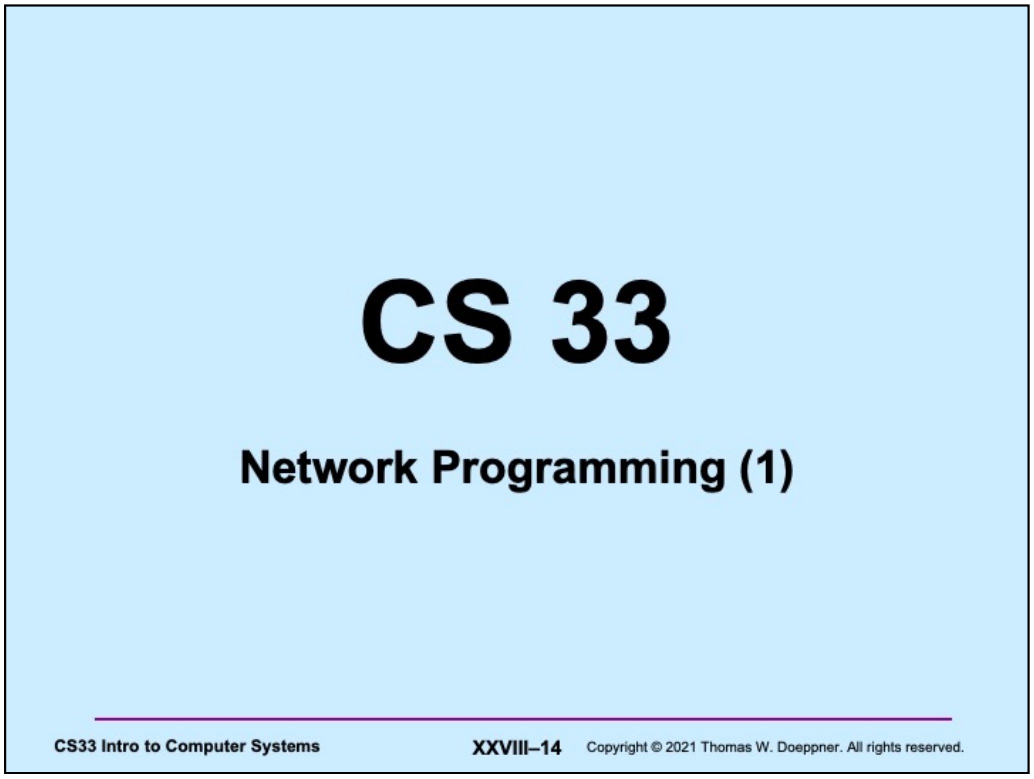


fork and mmap

```
int main() {
  int x=1;

  if (fork() == 0) {
    // in child
    x = 2;
    exit(0);
  }
  // in parent
  while (x==1) {
    // will loop forever
  }
  return 0;
}
```

```
int main() {
  int fd = open( ... );
  int *xp = (int *)mmap(...,
      MAP_SHARED, fd, ...);
  xp[0] = 1;
  if (fork() == 0) {
    // in child
    xp[0] = 2;
    exit(0);
  }
  // in parent
  while (xp[0]==1) {
    // will terminate
  }
  return 0;
}
```

When a process calls fork and creates a child, the child's address space is normally a copy of the parent's. Thus changes made by the child to its address space will not be seen in the parent's address space (as shown in the left-hand column). However, if there is a region in the parent's address space that has been mmapped using the MAP_SHARED flag, and subsequently the parent calls fork and creates a child, the mmapped region is not copied but is shared by parent and child. Thus changes to the region made by the child will be seen by the parent (and vice versa).

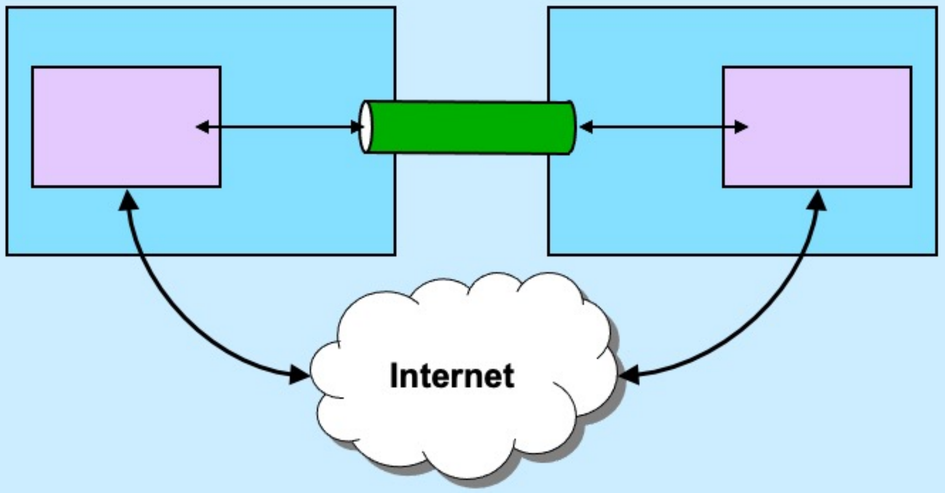


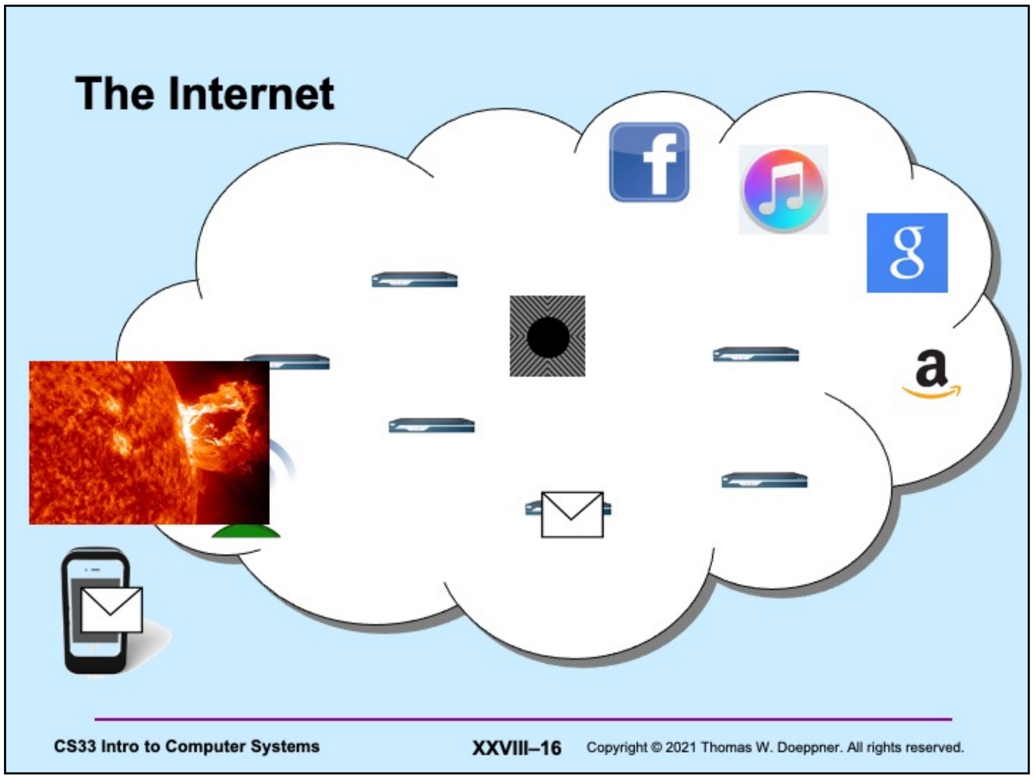
CS 33

Network Programming (1)

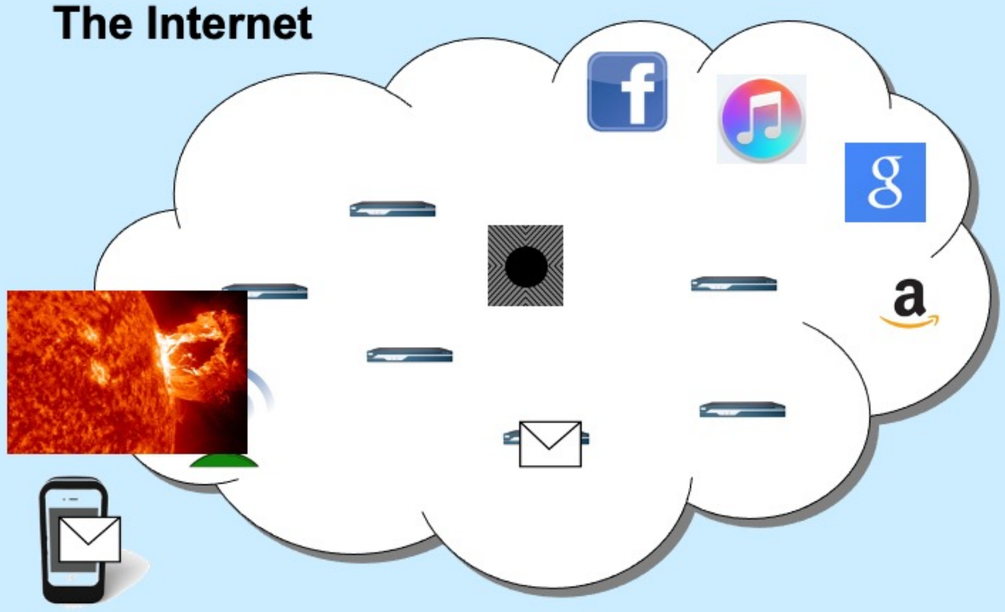
The source code used in this lecture, as well as some additional related source code, is on the course web page.

Communicating Over the Internet





The Internet



Names and Addresses

- cslab1c.cs.brown.edu
  - the name of a computer on the internet
  - mapped to an internet address
- nytimes.com
  - the name of a website
  - mapped to a number of internet addresses

- How are names mapped to addresses?
  - domain name service (DNS): a distributed database
- How are the machines corresponding to internet addresses found?
  - with the aid of various routing protocols

Internet Addresses

- IP (internet protocol) address
  - one per network interface
  - 32 bits (IPv4)
    - » 5527 per acre of RI
    - » 25 per acre of Texas
  - 128 bits (IPv6)
    - » 1.6 billion per cubic mile of a sphere whose radius is the mean distance from the Sun to the (former) planet Pluto
- Port number
  - one per service instance per machine
  - 16 bits
    - » port numbers less than 1024 are reserved for privileged applications

Notation

- Addresses (assume IPv4: 32-bit addresses)
  - written using dot notation
    - 128.48.37.1
      - dots separate bytes
  - address plus port (1426):
    - 128.48.37.1:1426

Reliability

- Two possibilities
  - don't worry about it
    - » just send it
      - if it arrives at its destination, that's good!
        - no verification
  - worry about it
    - » keep track of what's been successfully communicated
      - receiver "acks"
    - » retransmit until
      - data is received

      or
      - it appears that "the network is down"

Reliability vs. Unreliability

- Reliable communication
  - good for
    - » email
    - » texting
    - » distributed file systems
    - » web pages
  - bad for
    - » streaming audio
    - » streaming video

$\left.\begin{array}{l}\text{streaming audio}\\ \text{streaming video}\end{array}\right\}$ a little noise is better than a long pause

The Data Abstraction

- Byte stream
  - sequence of bytes
    - » as in pipes
  - any notion of a larger data aggregate is the responsibility of the programmer
- Discrete records
  - sequence of variable-size “records”
  - boundaries between records maintained
  - receiver receives discrete records, as sent by sender

What's Supported

- Stream
  - byte-stream data abstraction
  - reliable transmission
- Datagram
  - discrete-record data abstraction
  - unreliable transmission

Quiz 1

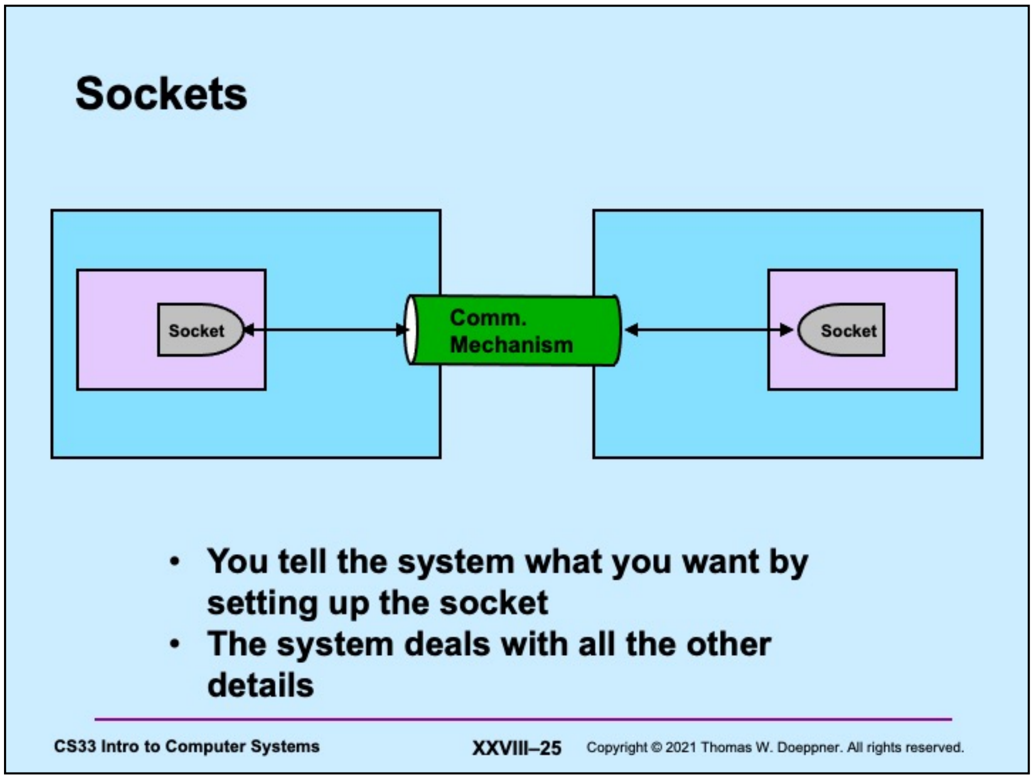
The following code is used to transmit data over a reliable byte-stream communication channel. Assume sizeof(data) is large.

```
// sender
record_t data=getData();
write(fd, &data,
  sizeof(data));
```

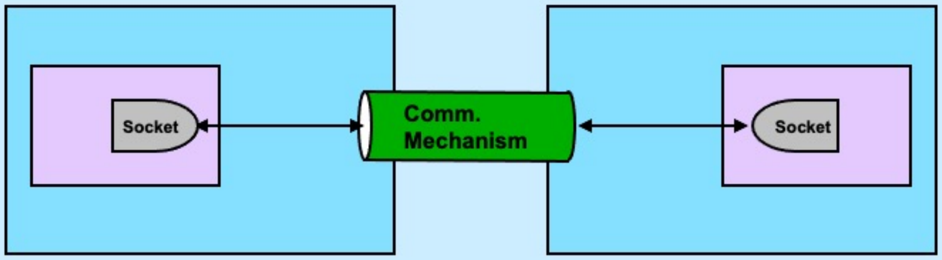
```
// receiver
read(fd, &data,
  sizeof(data));
useData(data);
```

Does it work?

- **a) always**
- **b) always, assuming no network problems**
- **c) sometimes**
- **d) never**

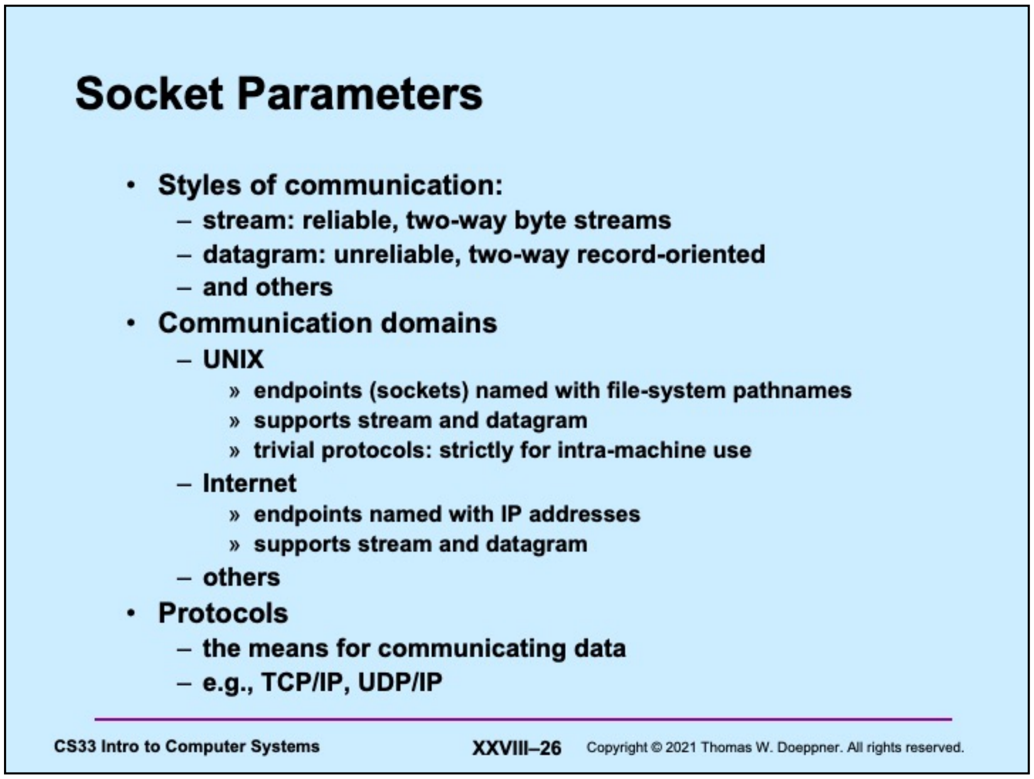


Sockets



- You tell the system what you want by setting up the socket
- The system deals with all the other details

Sockets are the abstraction of the communication path. An application sets up a socket as the basis for communication. It refers to it via a file descriptor.



Socket Parameters

- Styles of communication:
  - stream: reliable, two-way byte streams
  - datagram: unreliable, two-way record-oriented
  - and others
- Communication domains
  - UNIX
    - » endpoints (sockets) named with file-system pathnames
    - » supports stream and datagram
    - » trivial protocols: strictly for intra-machine use
  - Internet
    - » endpoints named with IP addresses
    - » supports stream and datagram
  - others
- Protocols
  - the means for communicating data
  - e.g., TCP/IP, UDP/IP

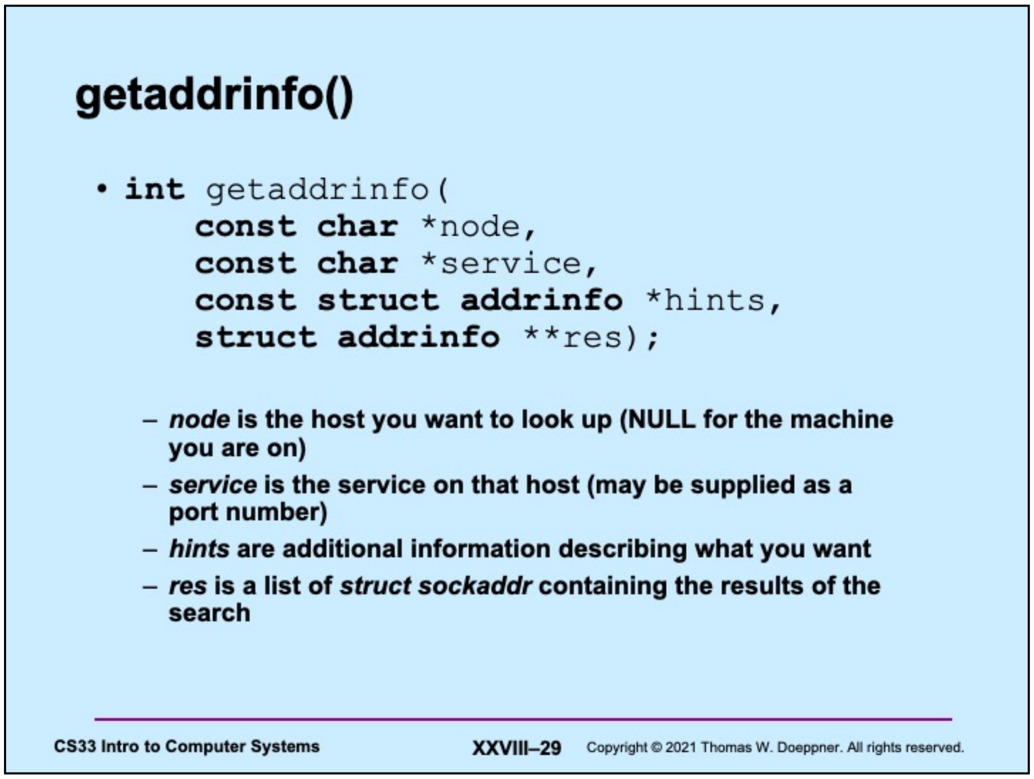
We focus strictly on the internet domain.

Setting Things Up

- Socket (communication endpoint) is set up
- Datagram communication
  - use *sendto* system call to send data to named recipient
  - use *recvfrom* system call to receive data and name of sender
- Stream communication
  - client connects to server
    - » server uses *listen* and *accept* system calls to receive connections
    - » client uses *connect* system call to make connections
  - data transmitted using *send* or *write* system calls
  - data received using *recv* or *read* system calls

Socket Addresses

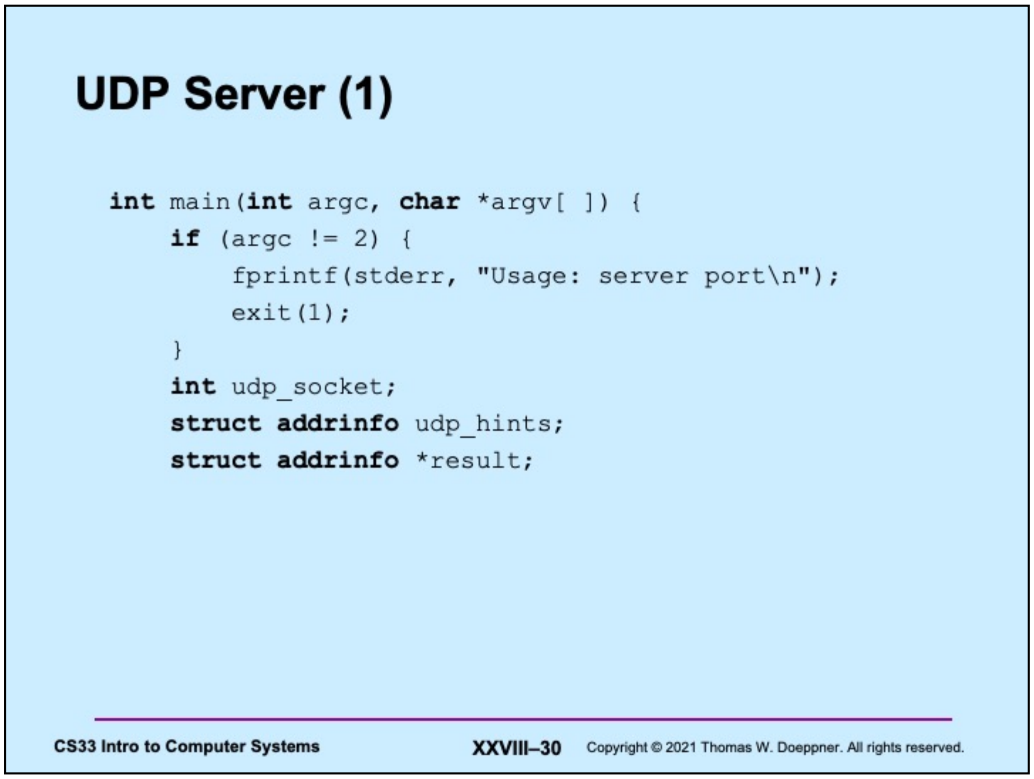
- `struct sockaddr`
  - represents a network address
  - many sorts
    - » we use struct *sockaddr_in*
  - we can ignore the details
    - » embedded in layers of software
- getaddrinfo()
  - function used to obtain `struct sockaddr`'s



getaddrinfo()

-
  ```
  int getaddrinfo(
      const char *node,
      const char *service,
      const struct addrinfo *hints,
      struct addrinfo **res);
  ```
  - *node* is the host you want to look up (NULL for the machine you are on)
  - *service* is the service on that host (may be supplied as a port number)
  - *hints* are additional information describing what you want
  - *res* is a list of *struct sockaddr* containing the results of the search

The general idea of using **getaddrinfo** is that you supply the name of the host you'd like to contact (*node*), which service on that host (*service*), and a description of how you'd like to communicate (**hints**). It returns a list of possible means for contacting the server in the form of a list of addrinfo structures (**res**). If the node argument is neither NULL nor the name of the local machine, getaddrinfo looks up what it needs in the domain name service (DNS) – the internet-wide distributed name service.

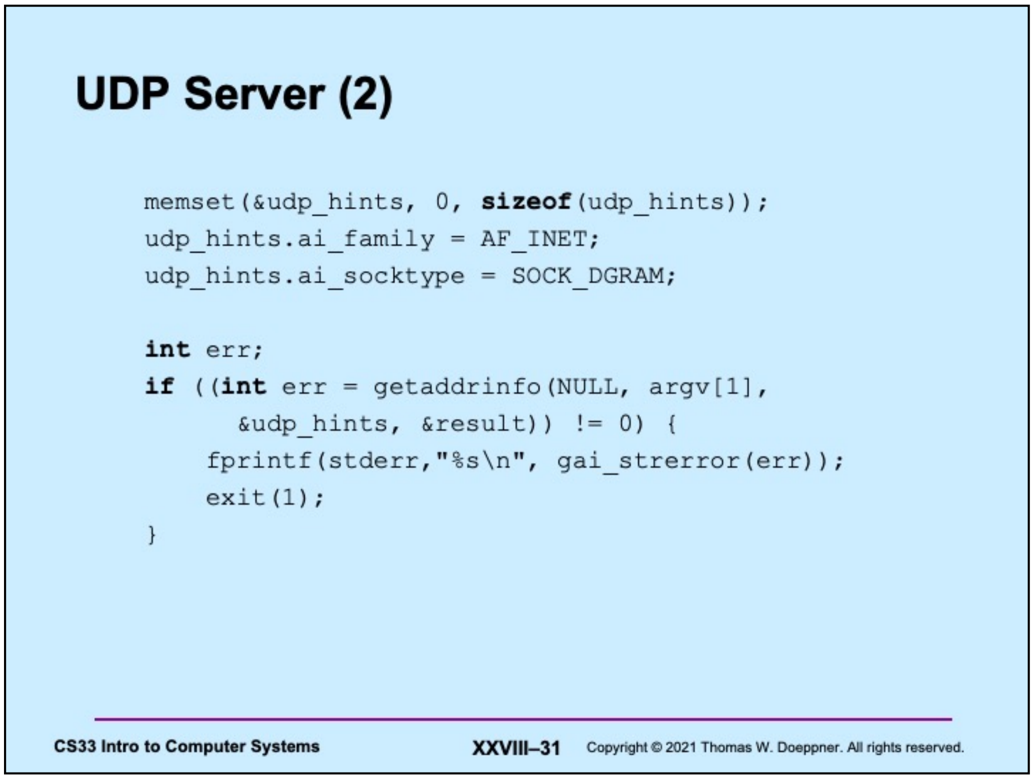


UDP Server (1)

```
int main(int argc, char *argv[ ]) {
    if (argc != 2) {
        fprintf(stderr, "Usage: server port\n");
        exit(1);
    }
    int udp_socket;
    struct addrinfo udp_hints;
    struct addrinfo *result;
```

Here we begin an example of a simple UDP server that receives messages from clients, prints them along with an indication of who sent the message, and politely responds.

In this first slide we check that we're invoked correctly (the command line should include the port number we're expecting to receive messages on) and have some initial declarations.

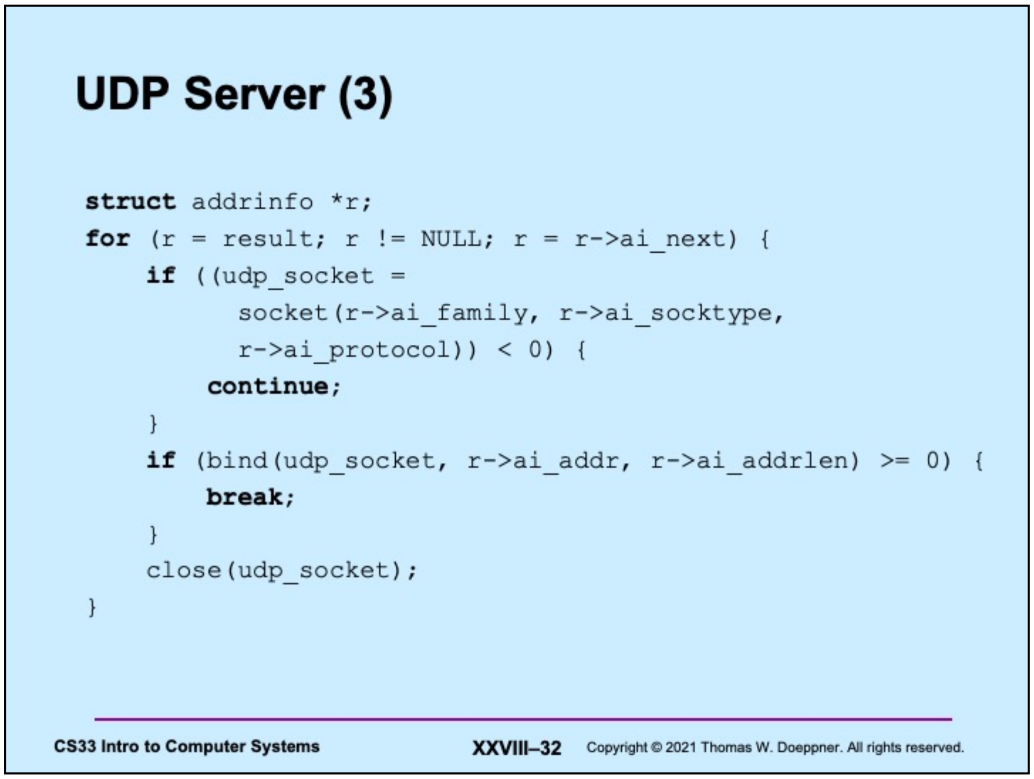


UDP Server (2)

```
memset(&udp_hints, 0, sizeof(udp_hints));
udp_hints.ai_family = AF_INET;
udp_hints.ai_socktype = SOCK_DGRAM;

int err;
if ((int err = getaddrinfo(NULL, argv[1],
      &udp_hints, &result)) != 0) {
    fprintf(stderr,"%s\n", gai_strerror(err));
    exit(1);
}
```

The next step is to set up an address for our socket so that clients can contact us. In the *hints* structure, which we initialize to zeroes so that components we don't set are zero, we specify that we're using IPv4 (AF_INET), that we are using datagrams (which, over IPv4, means UDP).

We call **getaddrinfo** to get an appropriate address to bind to our socket (next slide). Note the use of **gai_strerror** to produce an error message given an error return from **getaddrinfo**. Note that its first (name) argument is NULL, which means that we want the address of the machine we're on.

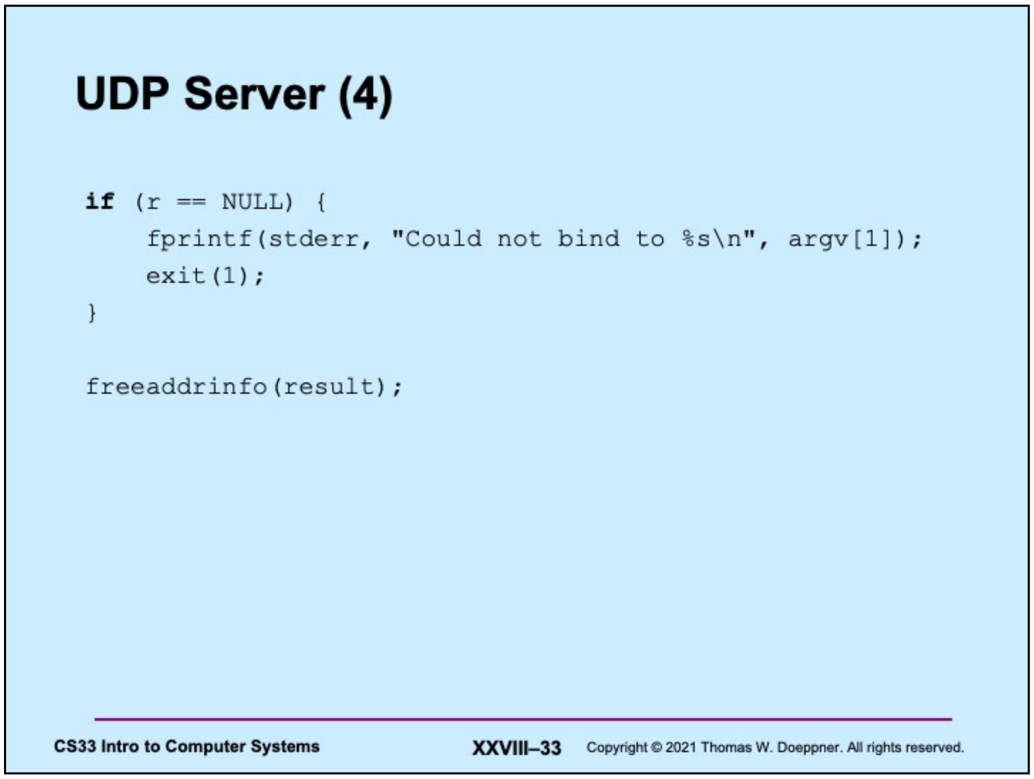


UDP Server (3)

```
struct addrinfo *r;
for (r = result; r != NULL; r = r->ai_next) {
    if ((udp_socket =
          socket(r->ai_family, r->ai_socktype,
          r->ai_protocol)) < 0) {
        continue;
    }
    if (bind(udp_socket, r->ai_addr, r->ai_addrlen) >= 0) {
        break;
    }
    close(udp_socket);
}
```

Next we iterate over the output of **getaddrinfo** (the list pointed to by its *result* argument). Though the length of this list is normally exactly one, it could be greater than one if our computer has multiple network interfaces. (The length could also be zero if it has no network interfaces, or none of the right sort.)

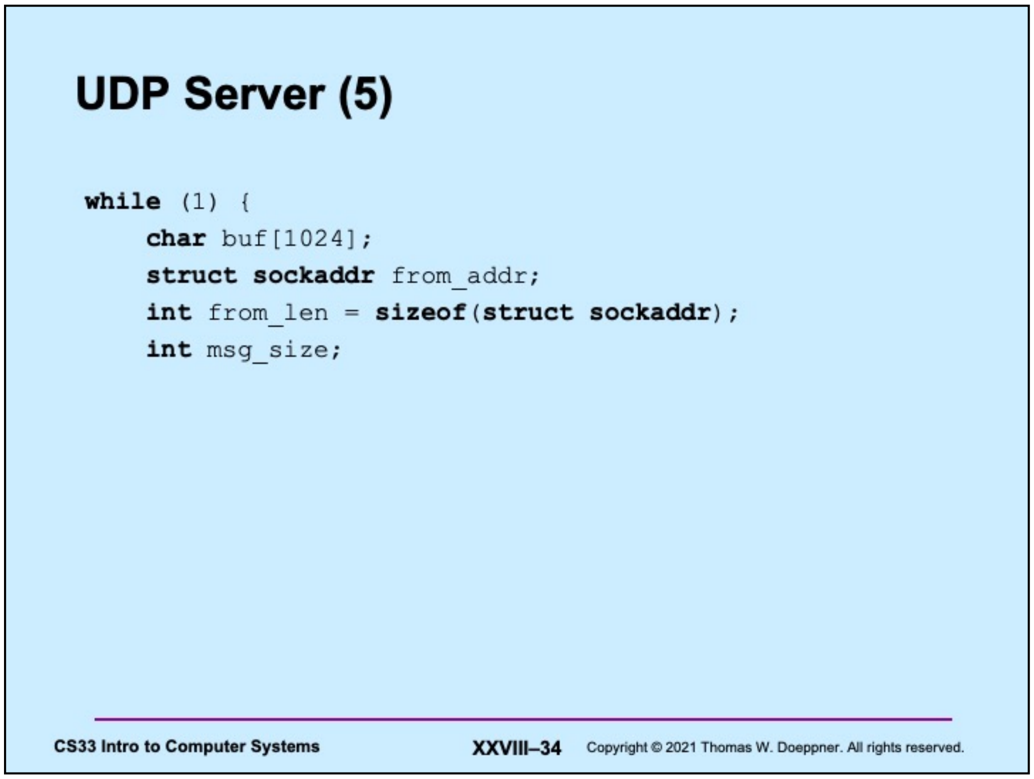
We try to create a socket that matches our desired socket type. Assuming we get the socket (which is referred to by the file descriptor **udp_socket**), we then try to bind it to the address returned by **getaddrinfo**. If all this works, we assume we're good to go. Otherwise, we try the next address in the list, if there are any more.



UDP Server (4)

```
if (r == NULL) {
    fprintf(stderr, "Could not bind to %s\n", argv[1]);
    exit(1);
}

freeaddrinfo(result);
```

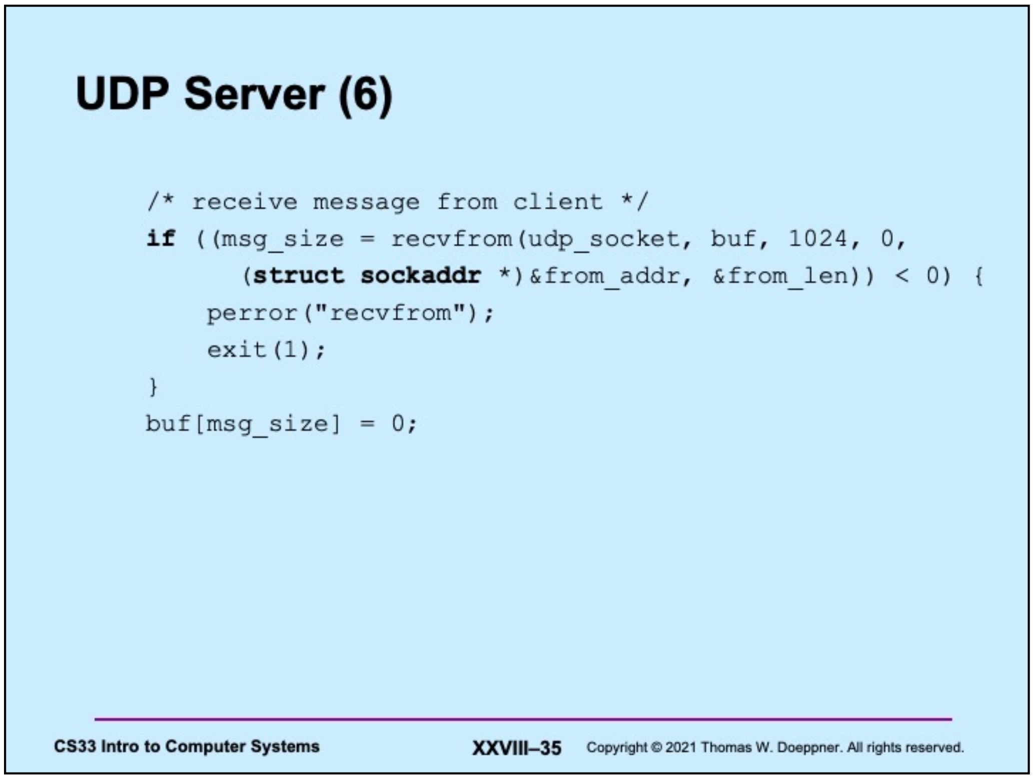
If we couldn't find anything that worked, we terminate the program. Otherwise we free up the list of addresses, since we don't need them anymore. Note the use of **freeaddrinfo** for this purpose.



UDP Server (5)

```
while (1) {
    char buf[1024];
    struct sockaddr from_addr;
    int from_len = sizeof(struct sockaddr);
    int msg_size;
```

Now that we've set up a socket and bound it to an address that clients can send messages to, we enter a loop to deal with all the incoming messages.

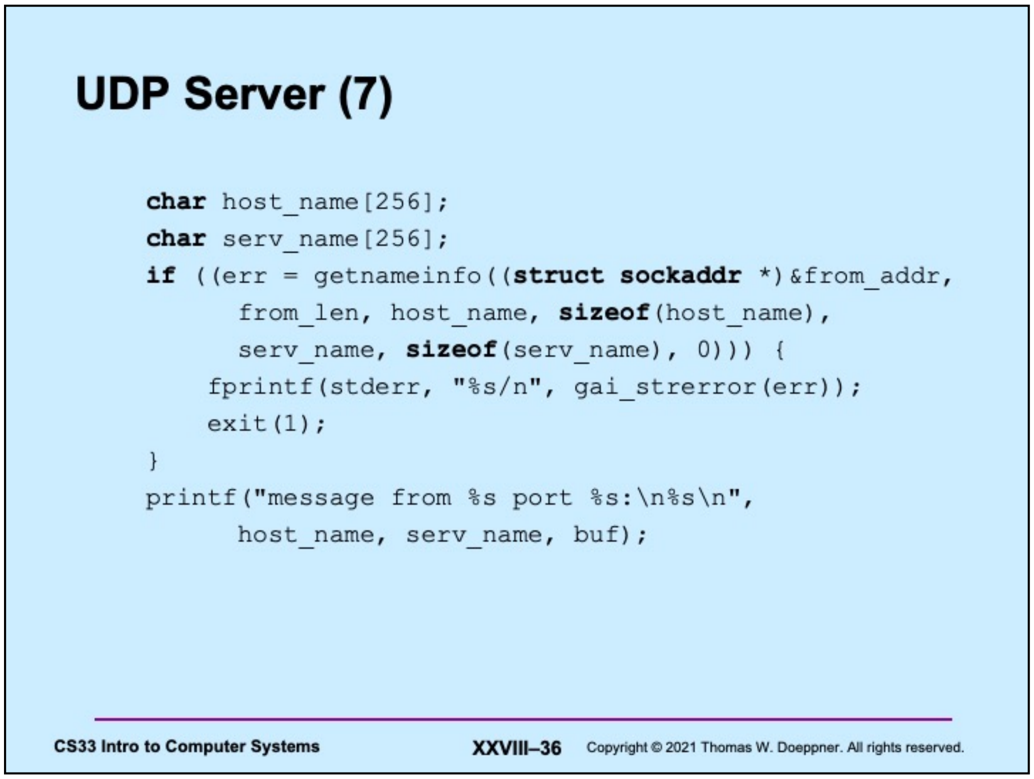


UDP Server (6)

```
/* receive message from client */
if ((msg_size = recvfrom(udp_socket, buf, 1024, 0,
      (struct sockaddr *)&from_addr, &from_len)) < 0) {
    perror("recvfrom");
    exit(1);
}
buf[msg_size] = 0;
```

We call **recfrom** (which is just like read, but with extra arguments) to get the next message from a client. The fourth argument could specify some flags, but we don't need any here (or in the networking lab). The fourth and fifth arguments, if not zeroes, give an address of memory to receive the network name of the caller, as well as its length. The length argument serves two purposes: on entry to the function it indicates how much memory we have to receive the network address. On return from the function it tells us how many bytes were actually used.

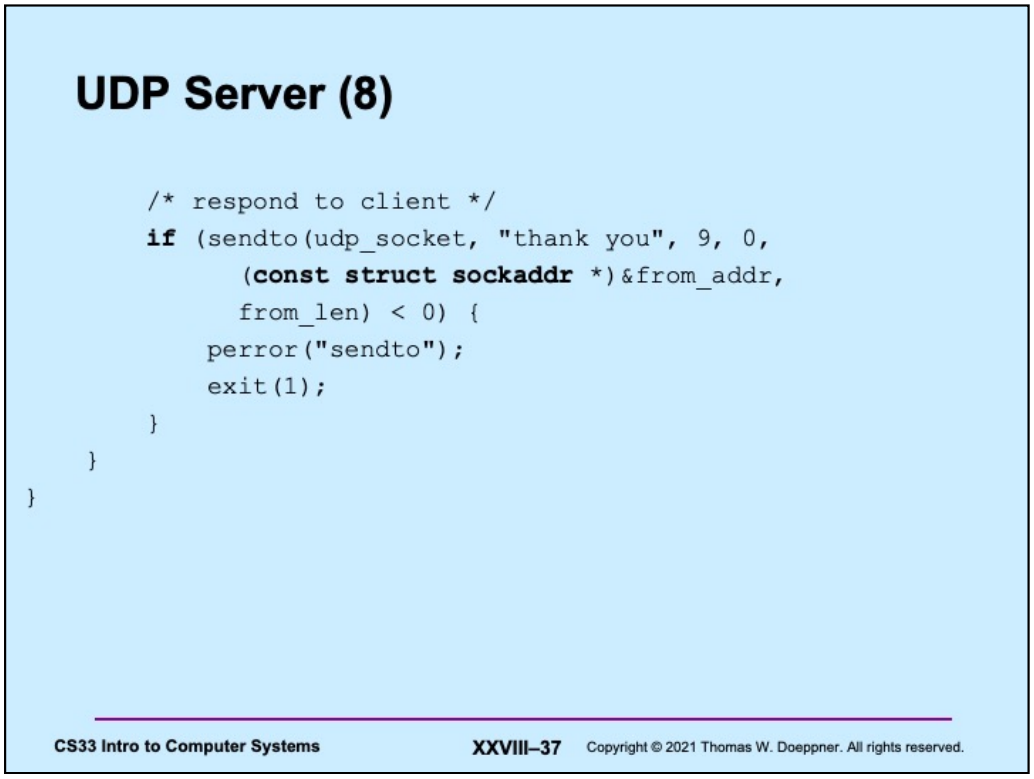
Note that we put a zero at the end of buf, so we can safely print it (next slide).



UDP Server (7)

```
char host_name[256];
char serv_name[256];
if ((err = getnameinfo((struct sockaddr *)&from_addr,
      from_len, host_name, sizeof(host_name),
      serv_name, sizeof(serv_name), 0))) {
    fprintf(stderr, "%s/n", gai_strerror(err));
    exit(1);
}
printf("message from %s port %s:\n%s\n",
      host_name, serv_name, buf);
```

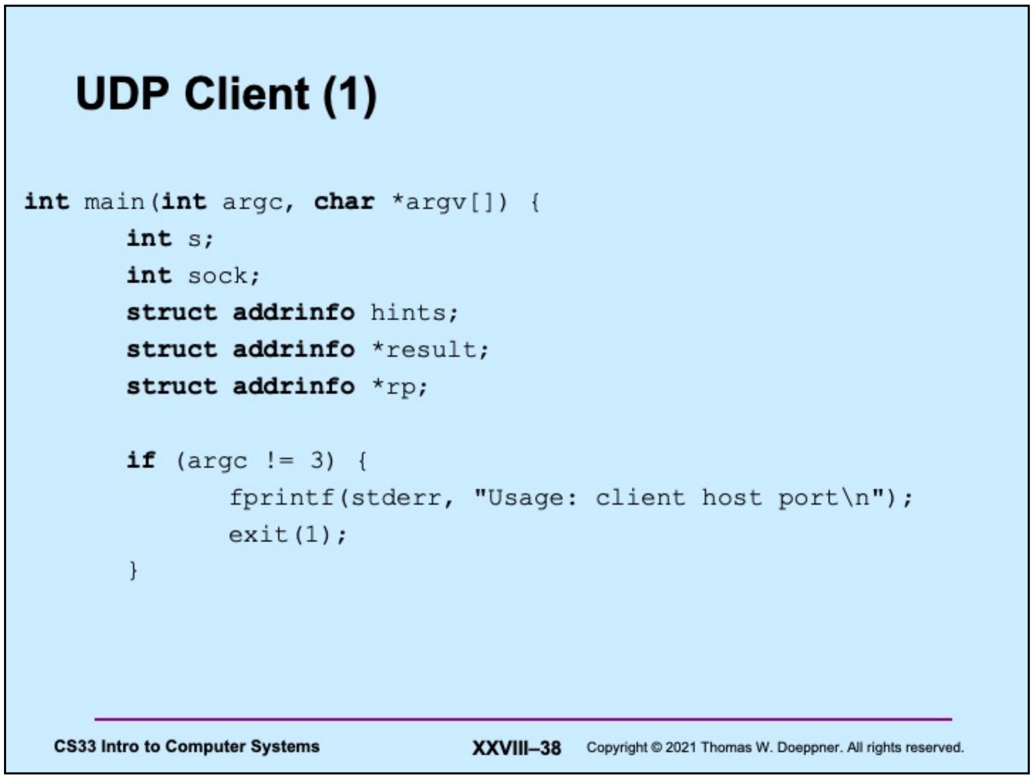
Next we print out who the client was and what its message was. The function **getnameinfo** is sort of the inverse of **getaddrinfo**: given a struct sockaddr (as produced by **recvfrom**), it tells us the name of the machine and the service requested (or port number). We then print the name of the machine, the service name (or port number), and the message itself. Note the use of **gai_strerror** for interpreting an error return from **getnameinfo**.



UDP Server (8)

```
        /* respond to client */
        if (sendto(udp_socket, "thank you", 9, 0,
              (const struct sockaddr *)&from_addr,
              from_len) < 0) {
            perror("sendto");
            exit(1);
        }
    }
}
```

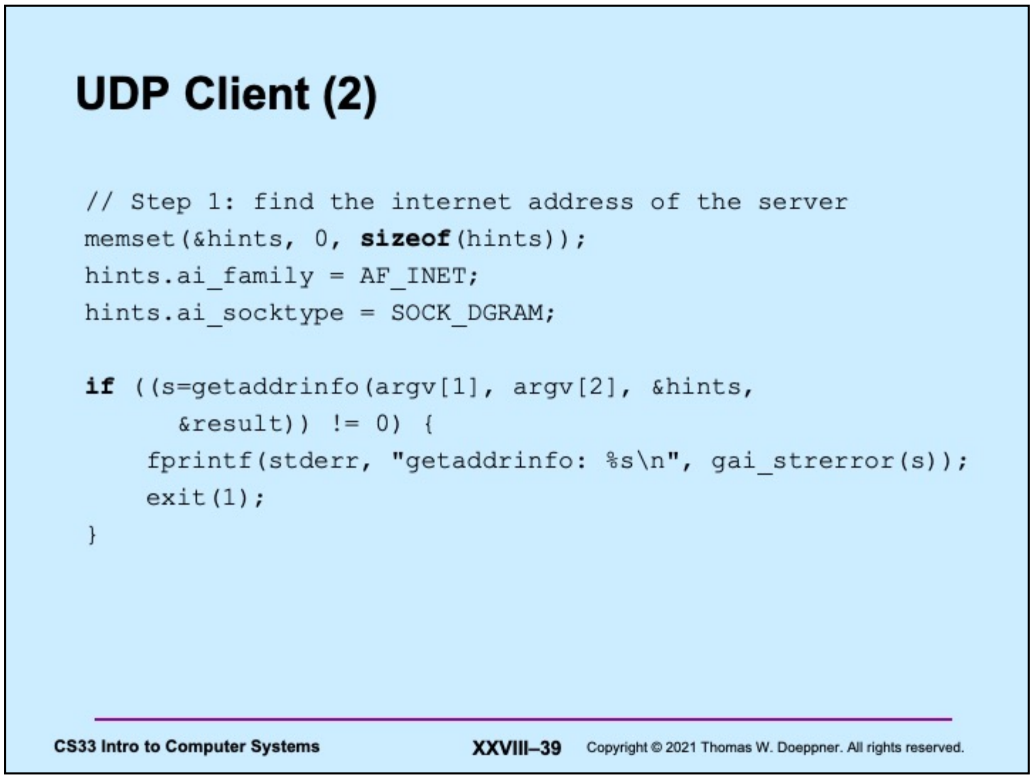
Finally, to be polite, we send a response to the client, thanking it for its message. The function **sendto** is like write, but with extra arguments. As with **recvfrom**, we set the flags argument (4th) to zero, but the next two arguments indicate whom we're sending the message to (the client, in this case).



UDP Client (1)

```
int main(int argc, char *argv[]) {
        int s;
        int sock;
        struct addrinfo hints;
        struct addrinfo *result;
        struct addrinfo *rp;

        if (argc != 3) {
                fprintf(stderr, "Usage: client host port\n");
                exit(1);
        }
```

Now we look at the code for a client that communicates with our UDP server. Note that the command line of the client specifies both the host the server is on, as well as the port number. If the server is on the same host as the client, host may be specified as "localhost".

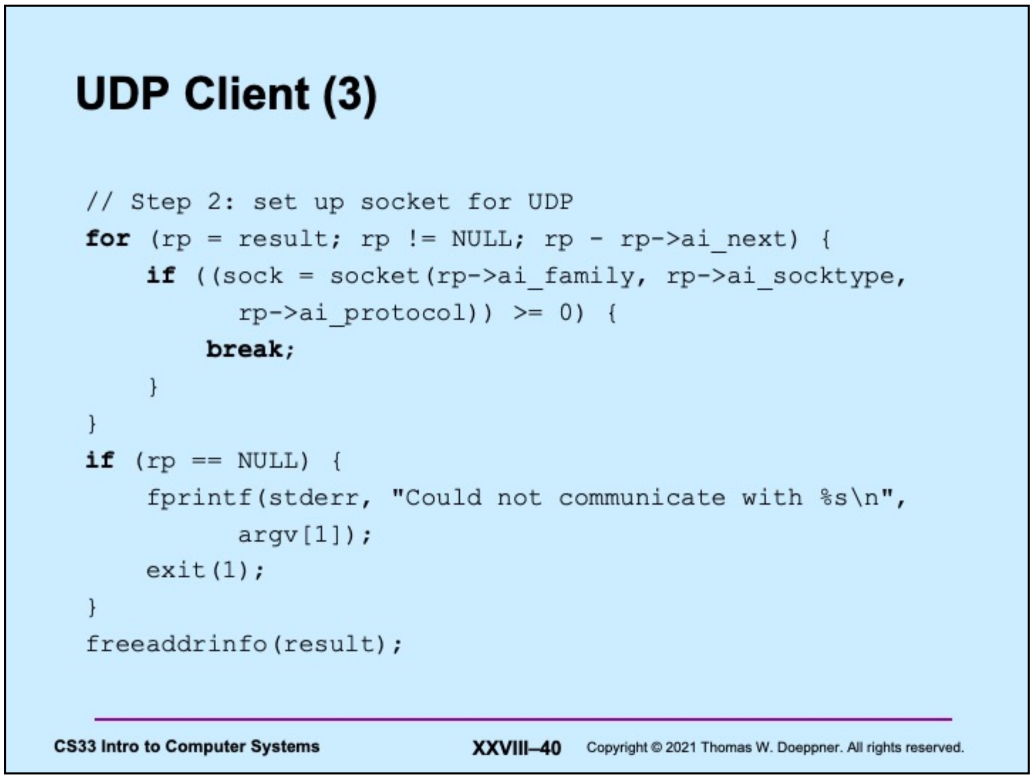


UDP Client (2)

```
// Step 1: find the internet address of the server
memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET;
hints.ai_socktype = SOCK_DGRAM;

if ((s=getaddrinfo(argv[1], argv[2], &hints,
      &result)) != 0) {
    fprintf(stderr, "getaddrinfo: %s\n", gai_strerror(s));
    exit(1);
}
```

We start by looking up the internet address of the server. To do this, we first fill in the hints structure to make it clear that we want a server with an internet (IPv4) interface and that we want UDP (datagrams). We call **getaddrinfo** to get a list of addresses. Again, note the use of **gai_strerror** to give us an error message.

Unlike what we did for the server code, we supply a non-null first argument to **getaddrinfo**, indicating which server we want to communicate with.

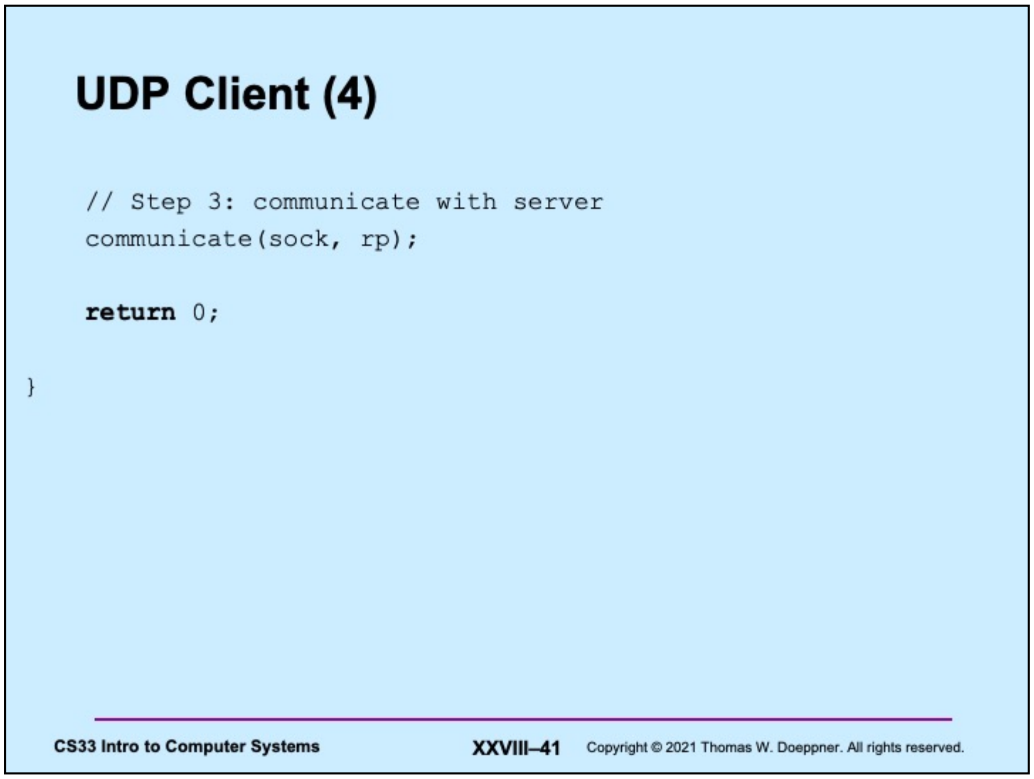


UDP Client (3)

```
// Step 2: set up socket for UDP
for (rp = result; rp != NULL; rp - rp->ai_next) {
    if ((sock = socket(rp->ai_family, rp->ai_socktype,
          rp->ai_protocol)) >= 0) {
        break;
    }
}
if (rp == NULL) {
    fprintf(stderr, "Could not communicate with %s\n",
          argv[1]);
    exit(1);
}
freeaddrinfo(result);
```

Next we go through the addresses returned by **getaddrinfo** and use the first one for which we can successfully set up a socket. The list's length is usually one, and that one usually works.

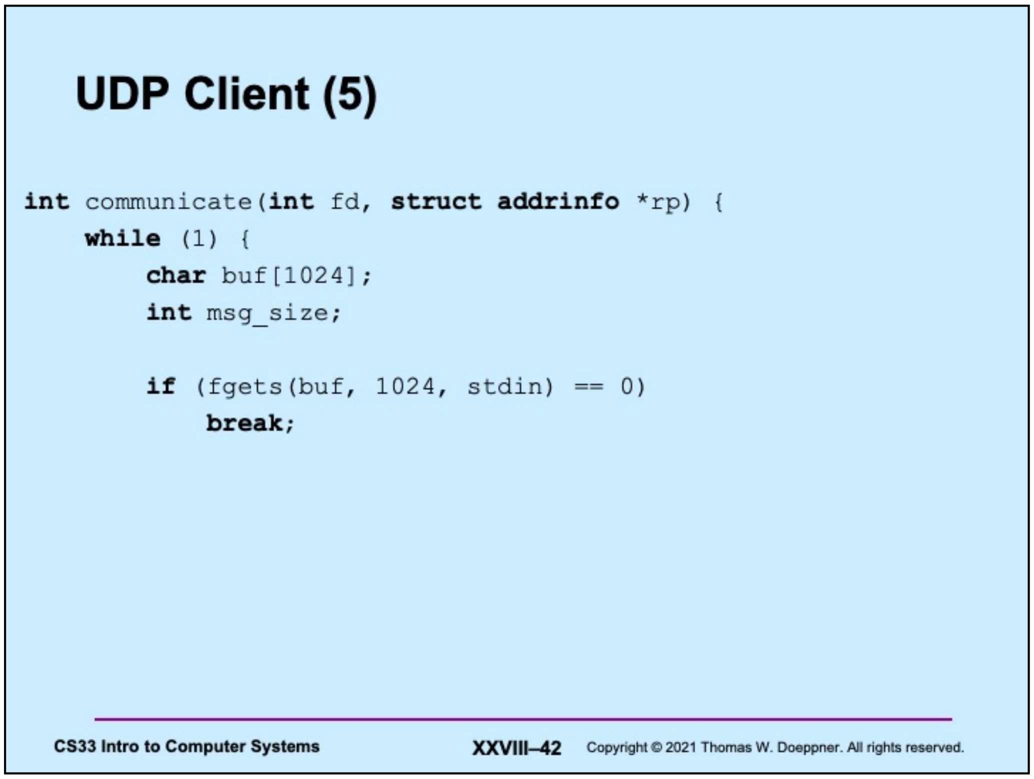
We free up list (by calling **freeaddrinfo**) since we no longer need it.



UDP Client (4)

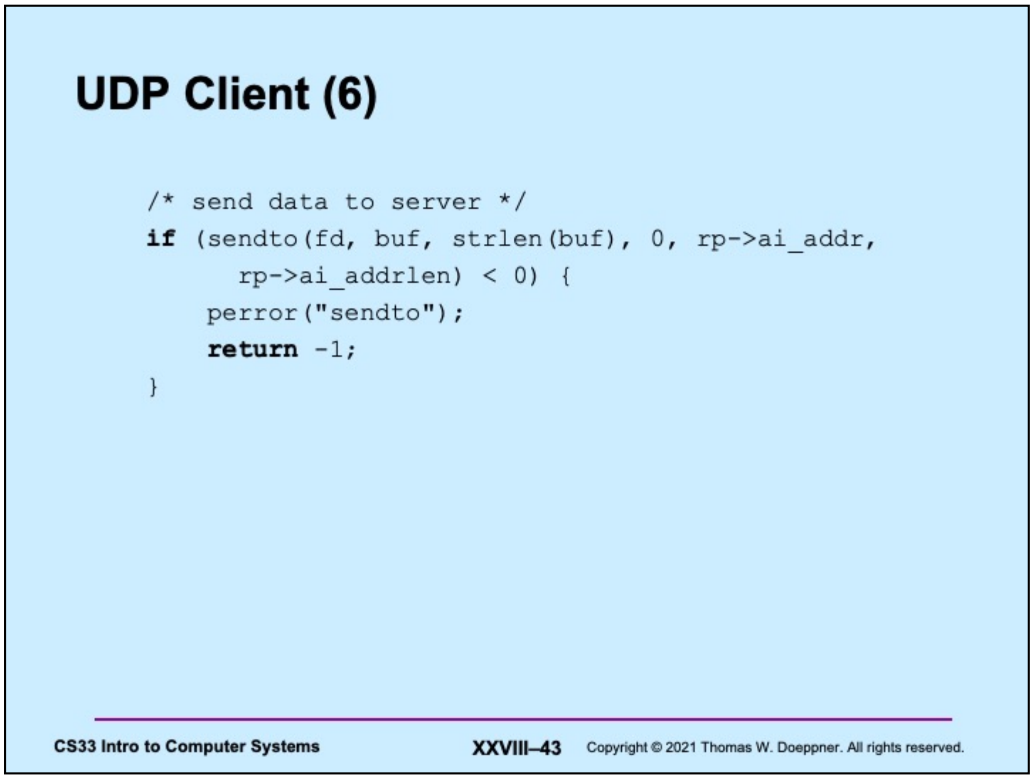
```
    // Step 3: communicate with server
    communicate(sock, rp);

    return 0;

}
```

Next we call our communicate function that will exchange messages with the server (although we don't know yet whether the server is up and running).


UDP Client (5)

```
int communicate(int fd, struct addrinfo *rp) {
    while (1) {
        char buf[1024];
        int msg_size;

        if (fgets(buf, 1024, stdin) == 0)
            break;
```

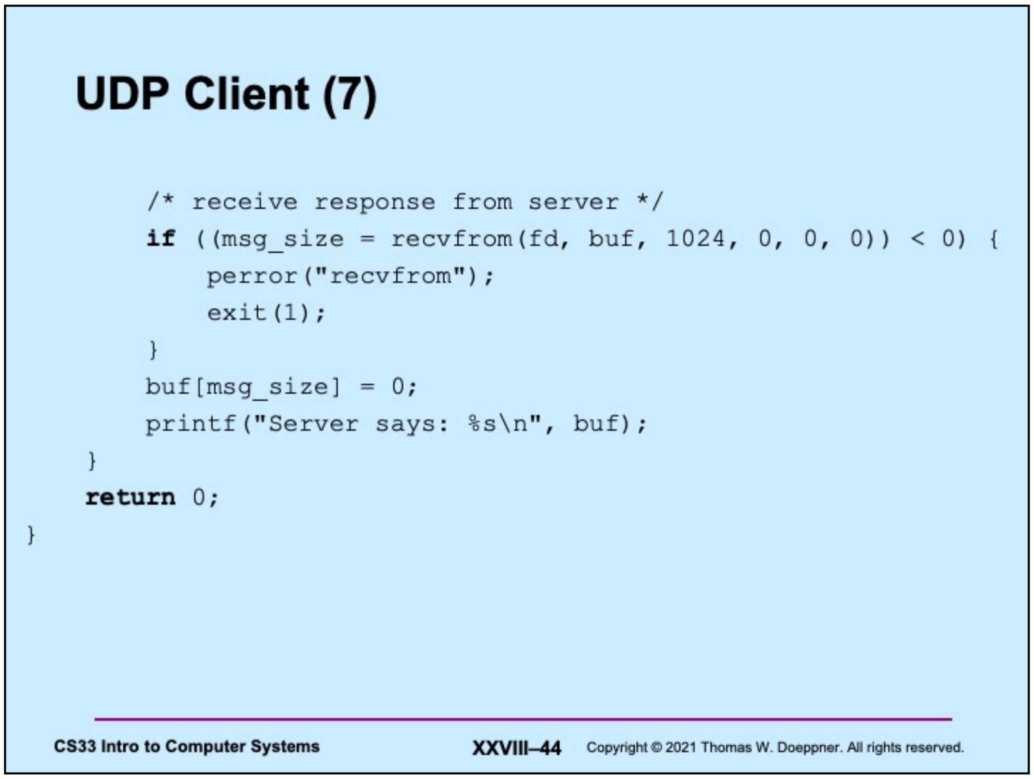
In our *communicate* function, we first read a line from stdin (which will be sent to the server).



UDP Client (6)

```
/* send data to server */
if (sendto(fd, buf, strlen(buf), 0, rp->ai_addr,
      rp->ai_addrlen) < 0) {
    perror("sendto");
    return -1;
}
```

The client sends to the server what was just read from stdin.



UDP Client (7)

```
        /* receive response from server */
        if ((msg_size = recvfrom(fd, buf, 1024, 0, 0, 0)) < 0) {
            perror("recvfrom");
            exit(1);
        }
        buf[msg_size] = 0;
        printf("Server says: %s\n", buf);
    }
    return 0;
}
```

The client receives the server's response, makes sure it's null-terminated, and prints it out.

Quiz 2

Suppose a process on one machine sends a datagram to a process on another machine. The sender uses *sendto* and the receiver uses *recvfrom*. There's a momentary problem with the network and the datagram doesn't make it to the receiving process. Its call to *recvfrom*

- **a) returns –1 (indicating an error)**
- **b) returns 0**
- **c) returns some other value**
- **d) doesn't return**

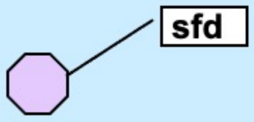
Reliable Communication

- The promise …
  - what is sent is received
  - order is preserved
- Set-up is required
  - two parties agree to communicate
  - within the implementation of the protocol:
    - » each side keeps track of what is sent, what is received
    - » received data is acknowledged
    - » unack'd data is re-sent
- The standard scenario
  - server receives connection requests
  - client makes connection requests

Streams in the Inet Domain (1)

- **Server steps**
  1) create socket

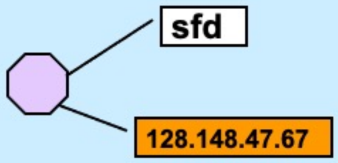
```
sfd = socket(AF_INET, SOCK_STREAM, 0);
```

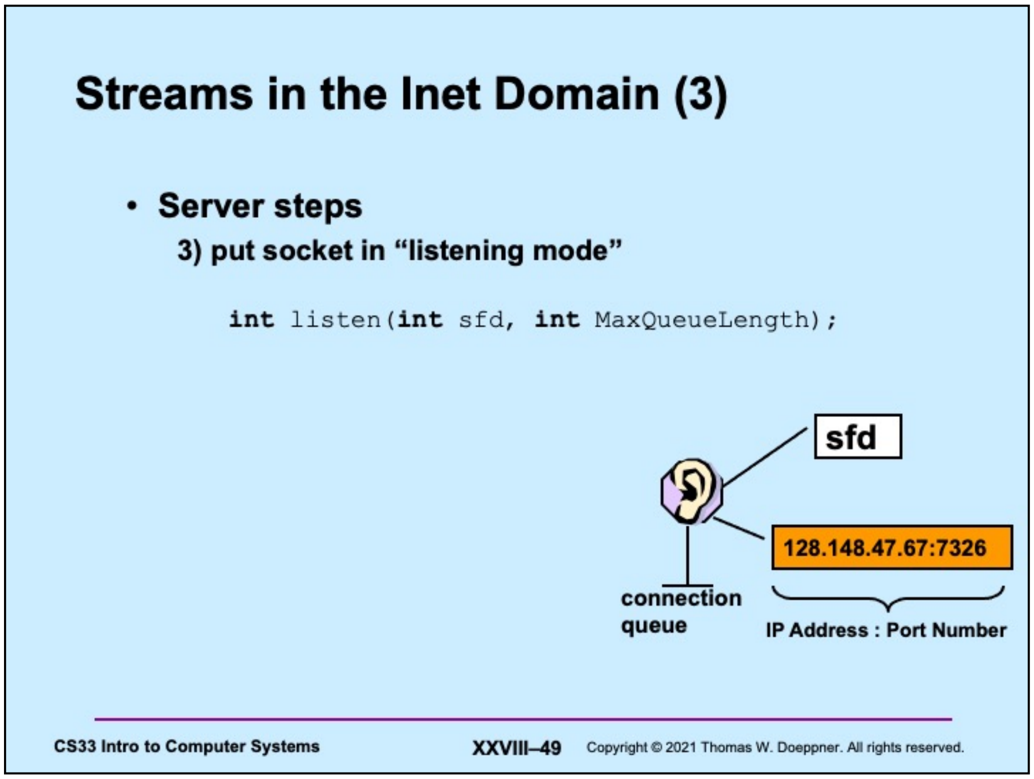


Streams in the Inet Domain (2)

- **Server steps**
  2) bind name to socket

```
bind(sfd,
  (struct sockaddr *)&my_addr, sizeof(my_addr));
```

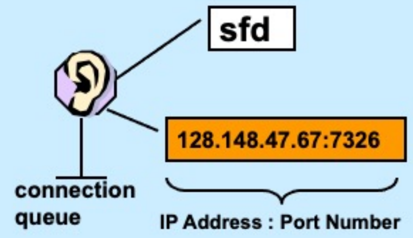




Streams in the Inet Domain (3)

- **Server steps**
  - 3) put socket in "listening mode"

```
int listen(int sfd, int MaxQueueLength);
```

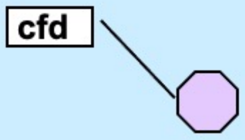


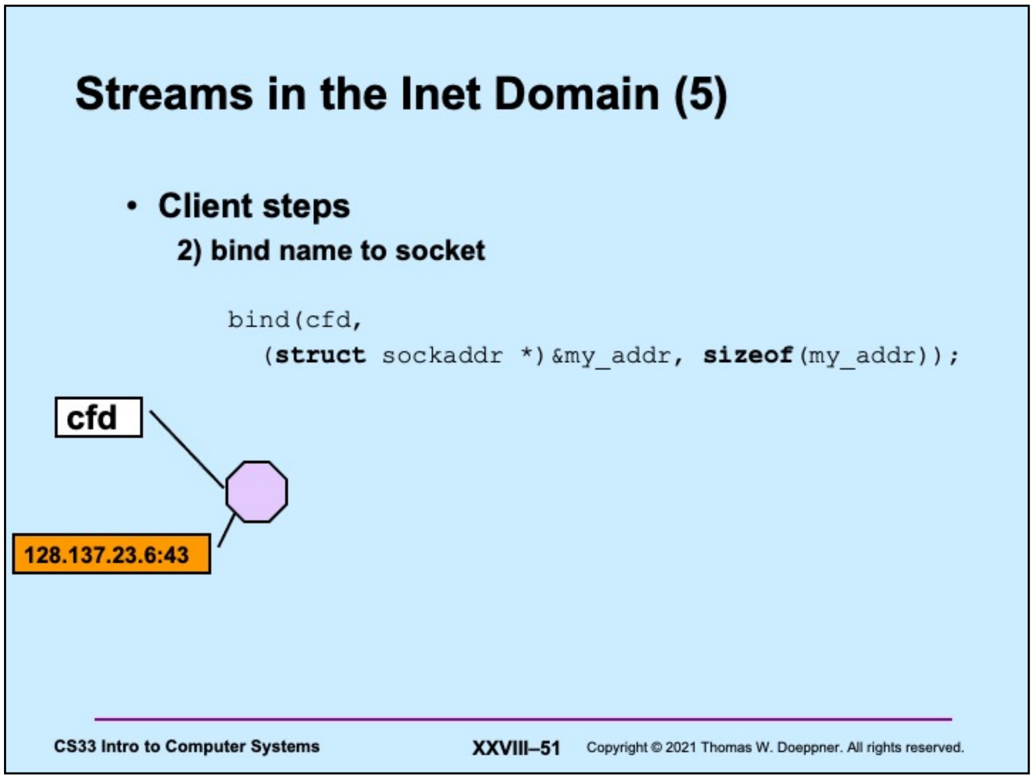
The **listen** system call tells the OS that the process would like to receive connections from clients via the indicated socket. The **MaxQueueLength** argument is the maximum number of connections that may be queued up, waiting to be accepted. Its maximum value is in /proc/sys/net/core/somaxconn (and is currently 128).

Streams in the Inet Domain (4)

- **Client steps**
  1) create socket

```
cfd = socket(AF_INET, SOCK_STREAM, 0);
```

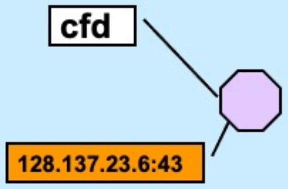




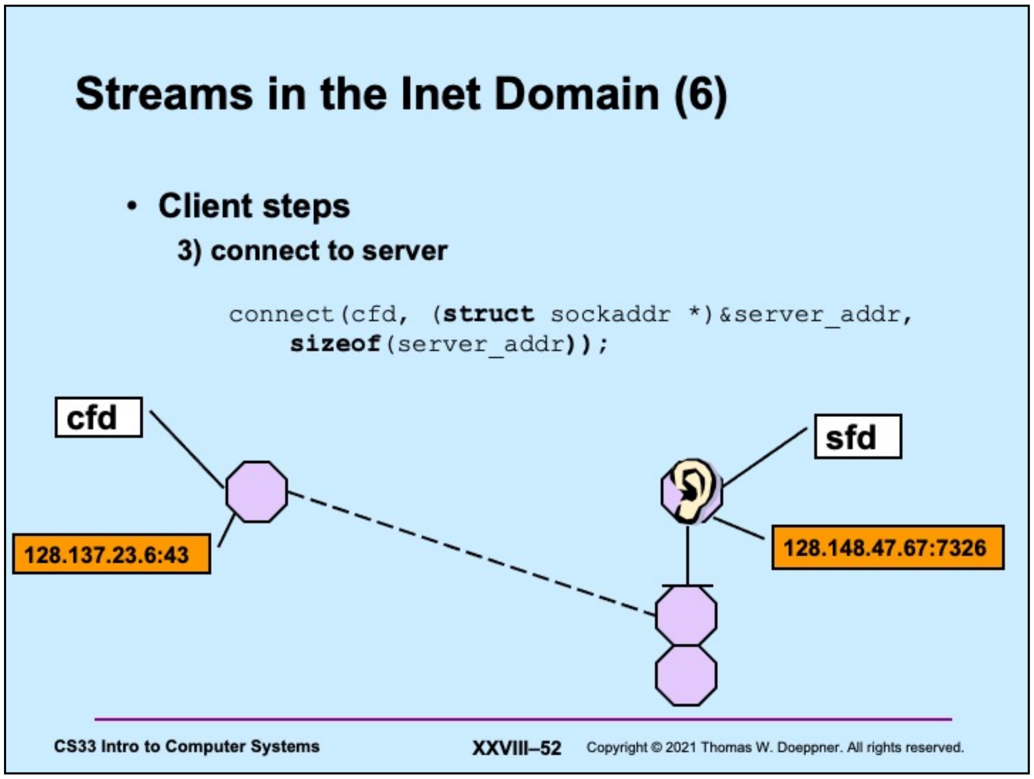
Streams in the Inet Domain (5)

- **Client steps**
  - **2) bind name to socket**

```
bind(cfd,
  (struct sockaddr *)&my_addr, sizeof(my_addr));
```



This step is optional – if not done, the OS does it automatically, supplying some available port number.



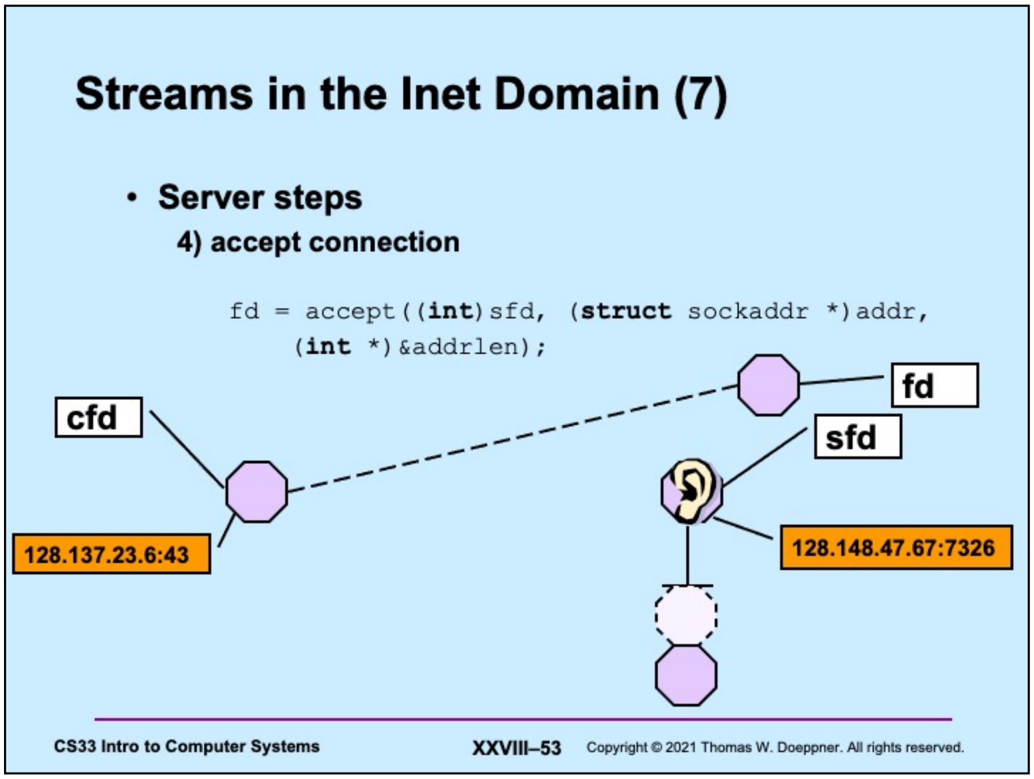
Streams in the Inet Domain (6)

- **Client steps**
  - **3) connect to server**

```
connect(cfd, (struct sockaddr *)&server_addr,
    sizeof(server_addr));
```

cfd
128.137.23.6:43
sfd
128.148.47.67:7326

The client issues the **connect** system call to initiate a connection with the server. The first argument is a file descriptor referring to the client's socket. Ultimately this socket will be connected to a socket on the server. Behind the scenes the client OS communicates with the server OS via a protocol-specific exchange of messages. Eventually a connection is established and a new socket is created on the server to represent its end of the connection. This socket is queued on the server's listening socket, where it stays until the server process accepts the connection (as shown in the next slide).



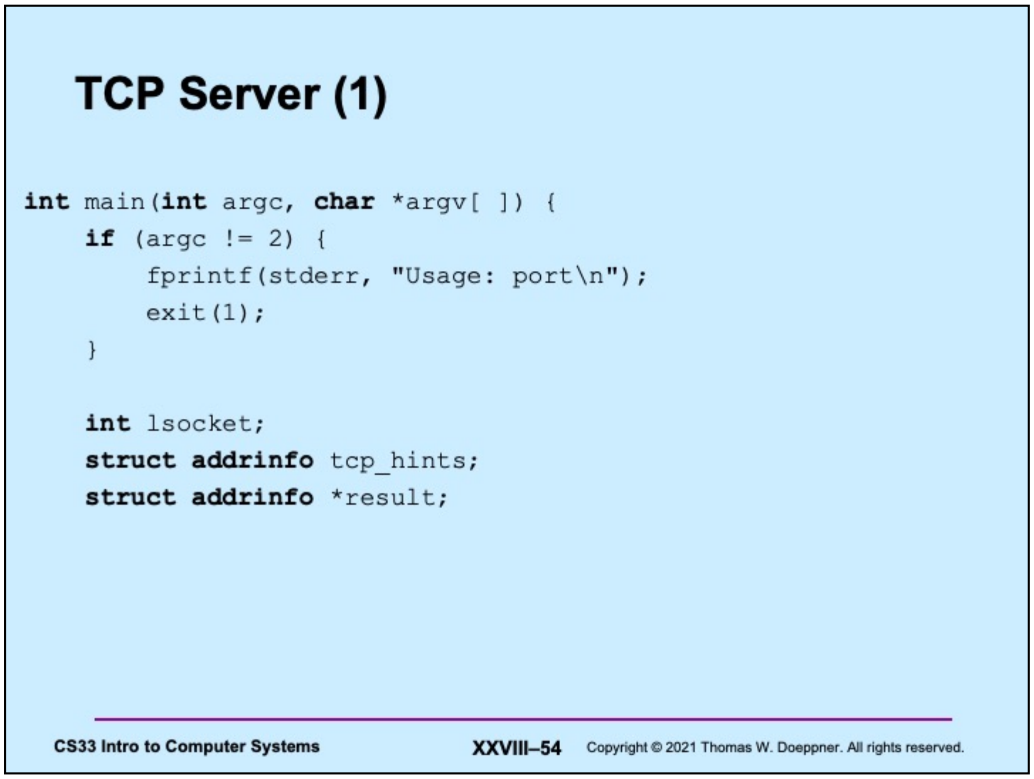
Streams in the Inet Domain (7)

- **Server steps**
  - **4) accept connection**

```
fd = accept((int)sfd, (struct sockaddr *)addr,
    (int *)&addrlen);
```

cfd
fd
sfd
128.137.23.6:43
128.148.47.67:7326

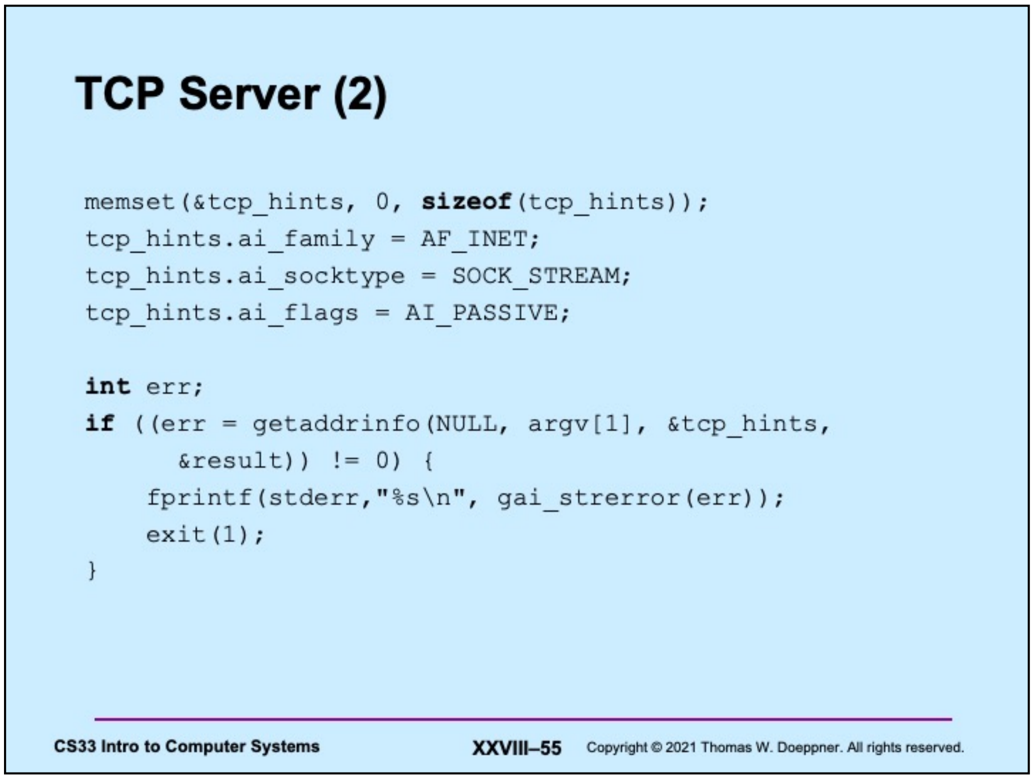
The server process issues an **accept** system which waits if necessary for a connected socked to appear on the listening socket's queue, then pulls the first such socket from the queue. This socket is the server end of a connection from a client. A file descriptor is returned that refers to that socket, allowing the process to now communicate with the client.



TCP Server (1)

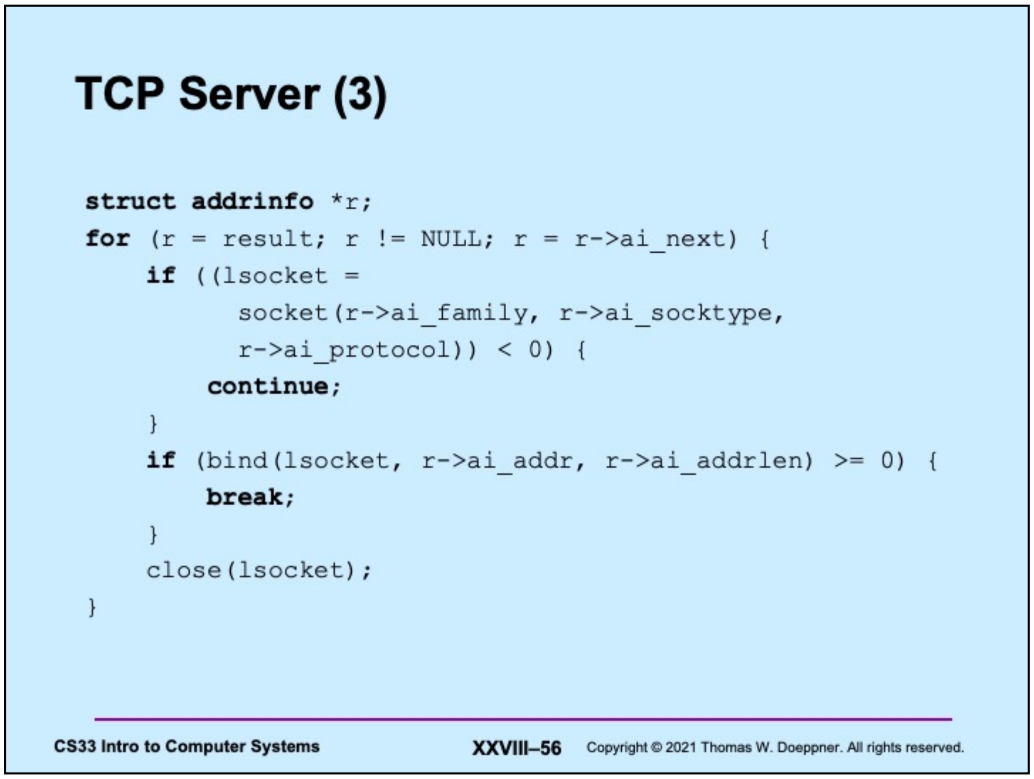
```
int main(int argc, char *argv[ ]) {
    if (argc != 2) {
        fprintf(stderr, "Usage: port\n");
        exit(1);
    }

    int lsocket;
    struct addrinfo tcp_hints;
    struct addrinfo *result;
```

We begin looking at a TCP example similar to our UDP example. Clients will contact our server, which prints everything its clients send to it.


TCP Server (2)

```
memset(&tcp_hints, 0, sizeof(tcp_hints));
tcp_hints.ai_family = AF_INET;
tcp_hints.ai_socktype = SOCK_STREAM;
tcp_hints.ai_flags = AI_PASSIVE;

int err;
if ((err = getaddrinfo(NULL, argv[1], &tcp_hints,
      &result)) != 0) {
    fprintf(stderr,"%s\n", gai_strerror(err));
    exit(1);
}
```

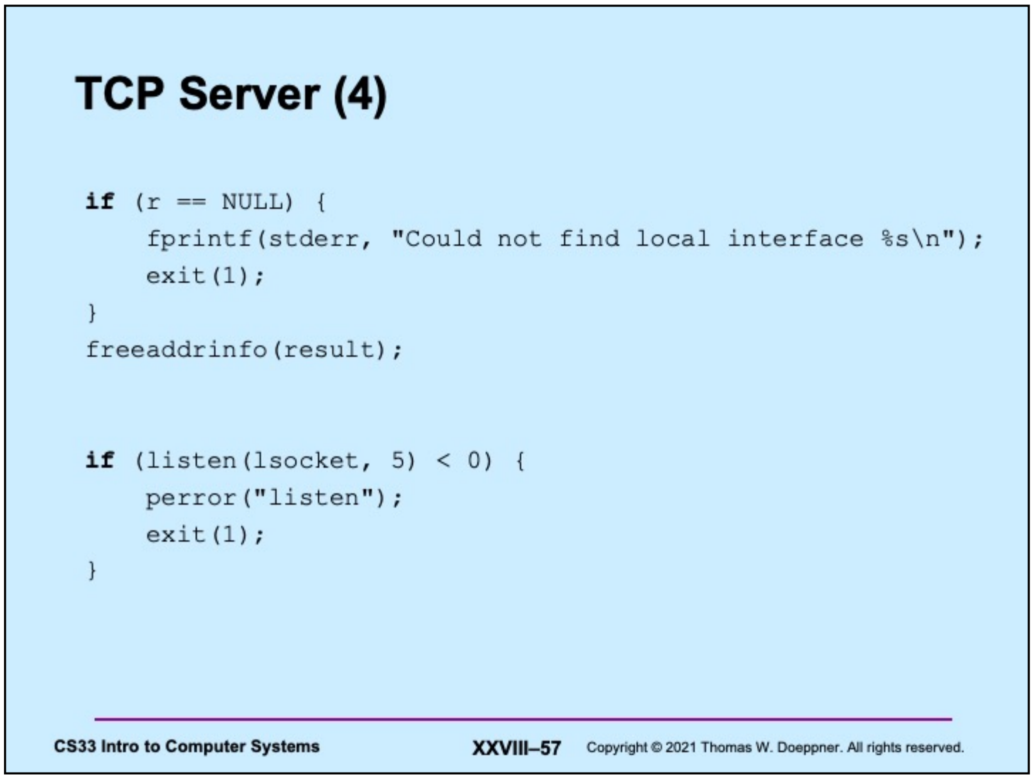
The server starts by using **getaddrinfo** to obtain information about its interfaces. Via **tcp_hints**, we request information about IPv4 (AF_INET) interfaces supporting TCP (SOCK_STREAM). The value to which **ai_flags** is set (AI_PASSIVE) indicates that our socket will be put into listening mode and its address will be set to the "wildcard address", as shown earlier.



TCP Server (3)

```
struct addrinfo *r;
for (r = result; r != NULL; r = r->ai_next) {
    if ((lsocket =
          socket(r->ai_family, r->ai_socktype,
          r->ai_protocol)) < 0) {
        continue;
    }
    if (bind(lsocket, r->ai_addr, r->ai_addrlen) >= 0) {
        break;
    }
    close(lsocket);
}
```

Here we look at the list of **addrinfo** structures returned by **getaddrinfo** and use the first for which we can create a socket and bind to (as usual with this, it will probably be the first and only item in the list).

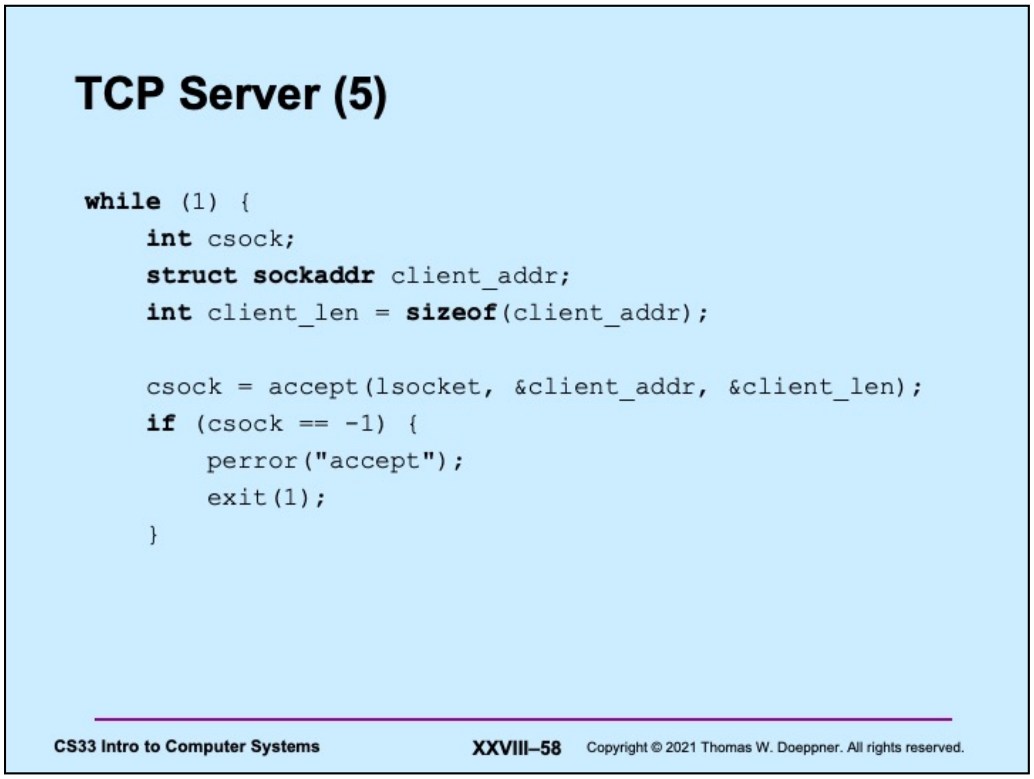


TCP Server (4)

```
if (r == NULL) {
    fprintf(stderr, "Could not find local interface %s\n");
    exit(1);
}
freeaddrinfo(result);


if (listen(lsocket, 5) < 0) {
    perror("listen");
    exit(1);
}
```

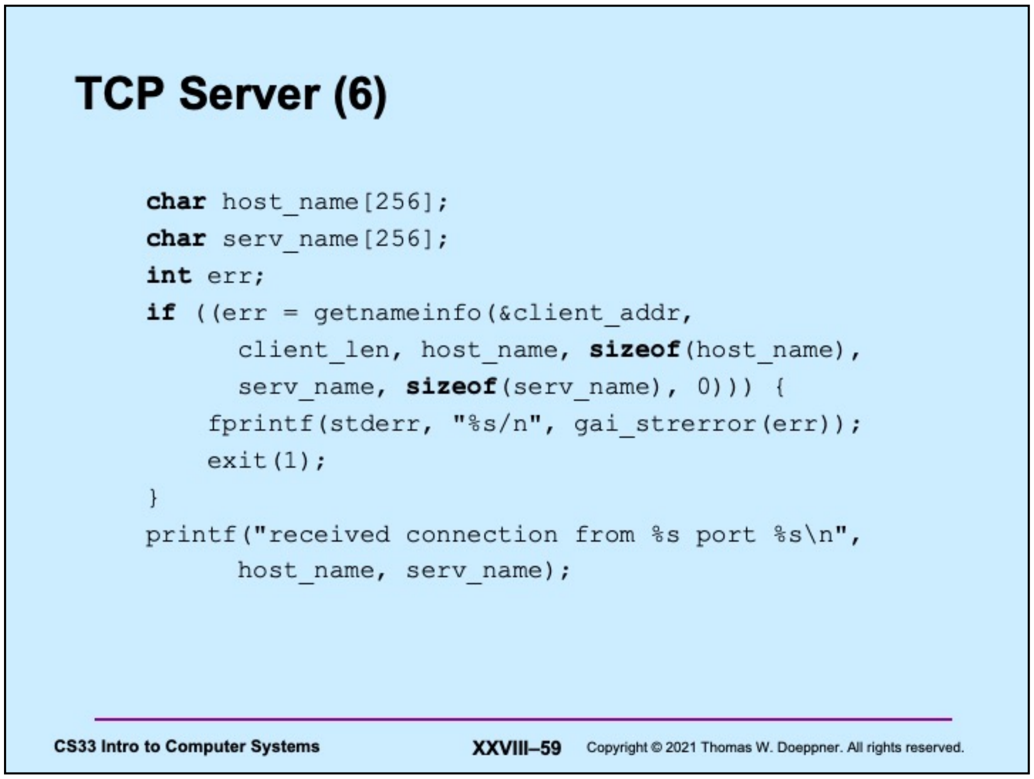
We check to make sure we found a suitable local address. Assuming we did, we free list of addresses, since we don't need them anymore.

Now that we have a socket, we put it in listening mode, indicating a maximum queue length of 5 (an arbitrarily chosen value).


TCP Server (5)

```
while (1) {
    int csock;
    struct sockaddr client_addr;
    int client_len = sizeof(client_addr);

    csock = accept(lsocket, &client_addr, &client_len);
    if (csock == -1) {
        perror("accept");
        exit(1);
    }
```

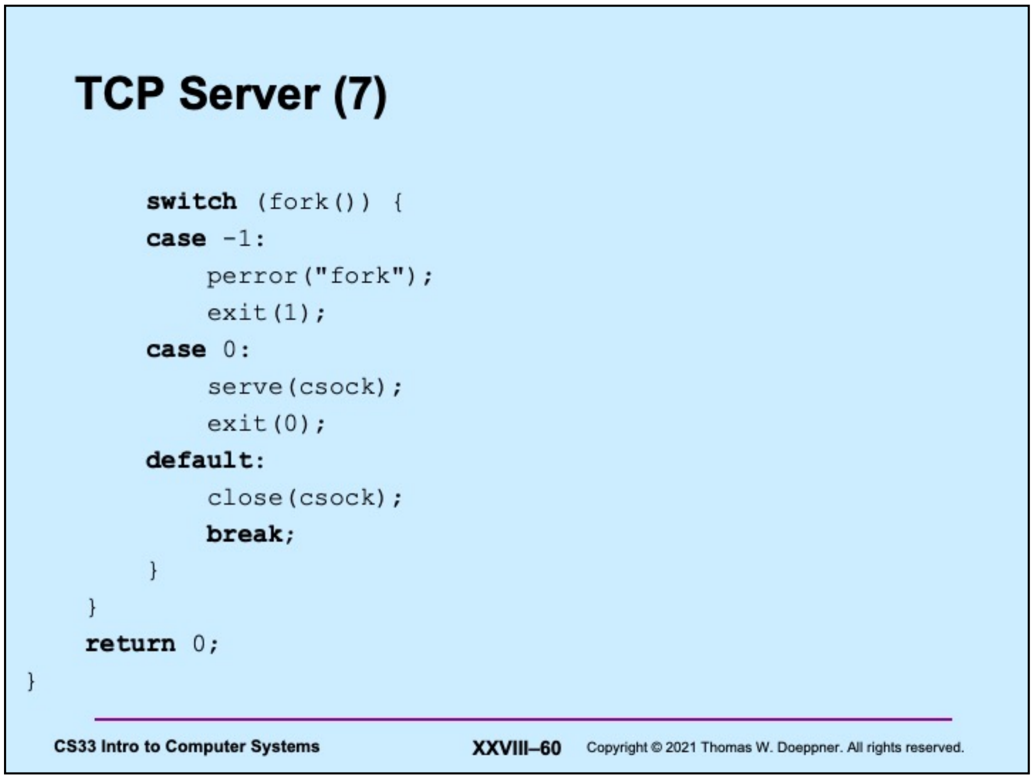
The server now begins a loop, accepting incoming connection requests from clients. Each time *accept* returns (assuming no errors), we have a file descriptor (**csock**) for the new client connection.



TCP Server (6)

```
char host_name[256];
char serv_name[256];
int err;
if ((err = getnameinfo(&client_addr,
      client_len, host_name, sizeof(host_name),
      serv_name, sizeof(serv_name), 0))) {
    fprintf(stderr, "%s/n", gai_strerror(err));
    exit(1);
}
printf("received connection from %s port %s\n",
      host_name, serv_name);
```

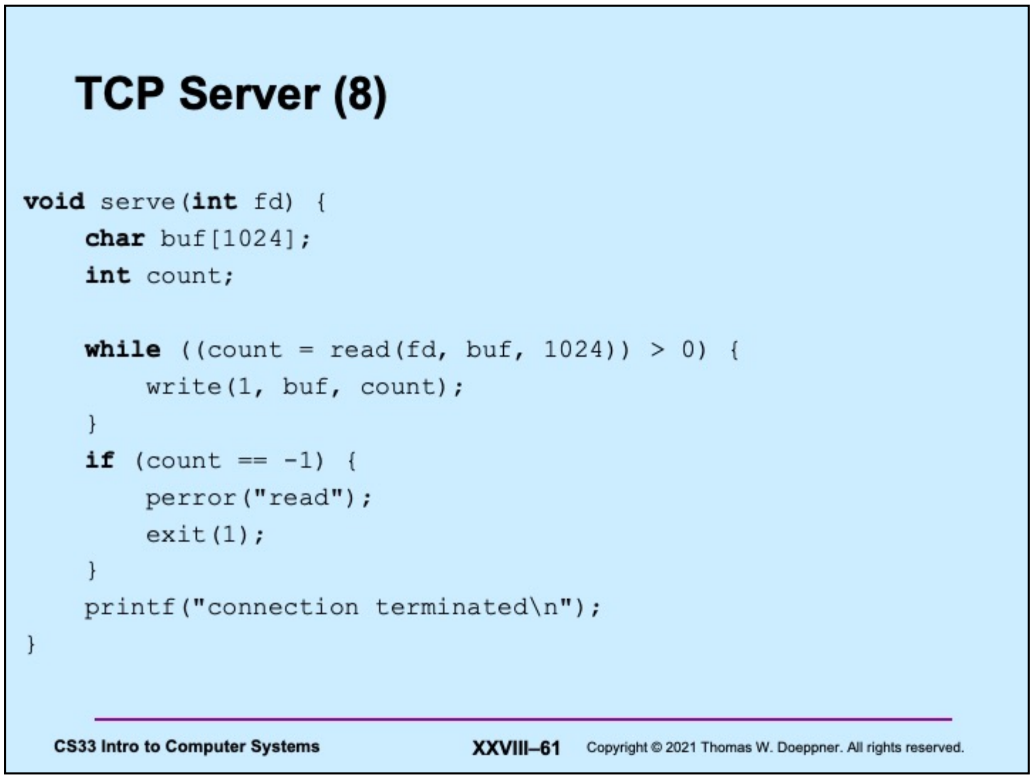
We figure how who the client is, based on the information returned by accept. We use **getnameinfo** to decode the host name and the service name (port number). Note the use of **gai_strerror** to deal with errors.



TCP Server (7)

```
        switch (fork()) {
        case -1:
            perror("fork");
            exit(1);
        case 0:
            serve(csock);
            exit(0);
        default:
            close(csock);
            break;
        }
    }
    return 0;
}
```

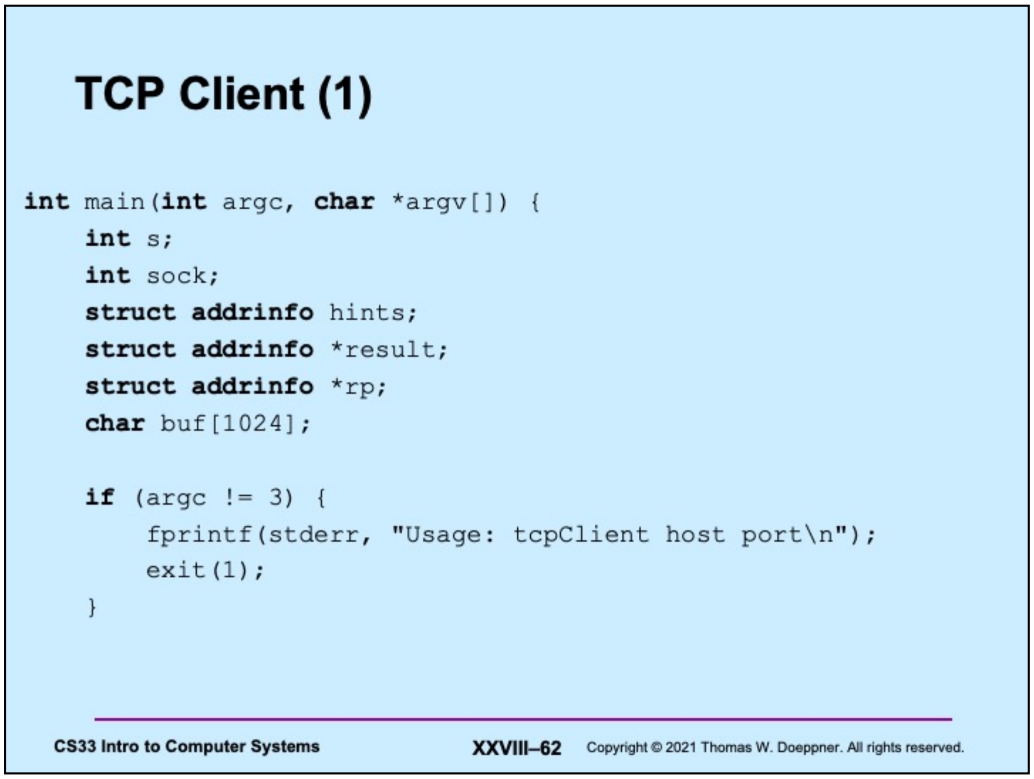
The server, having just received a connection from the client, creates a new process to handle that client's connection. The new (child) process calls serve, passing it the file descriptor for the connected socket. The parent has no further use for that file descriptor, so it closes it.



TCP Server (8)

```
void serve(int fd) {
    char buf[1024];
    int count;

    while ((count = read(fd, buf, 1024)) > 0) {
        write(1, buf, count);
    }
    if (count == -1) {
        perror("read");
        exit(1);
    }
    printf("connection terminated\n");
}
```

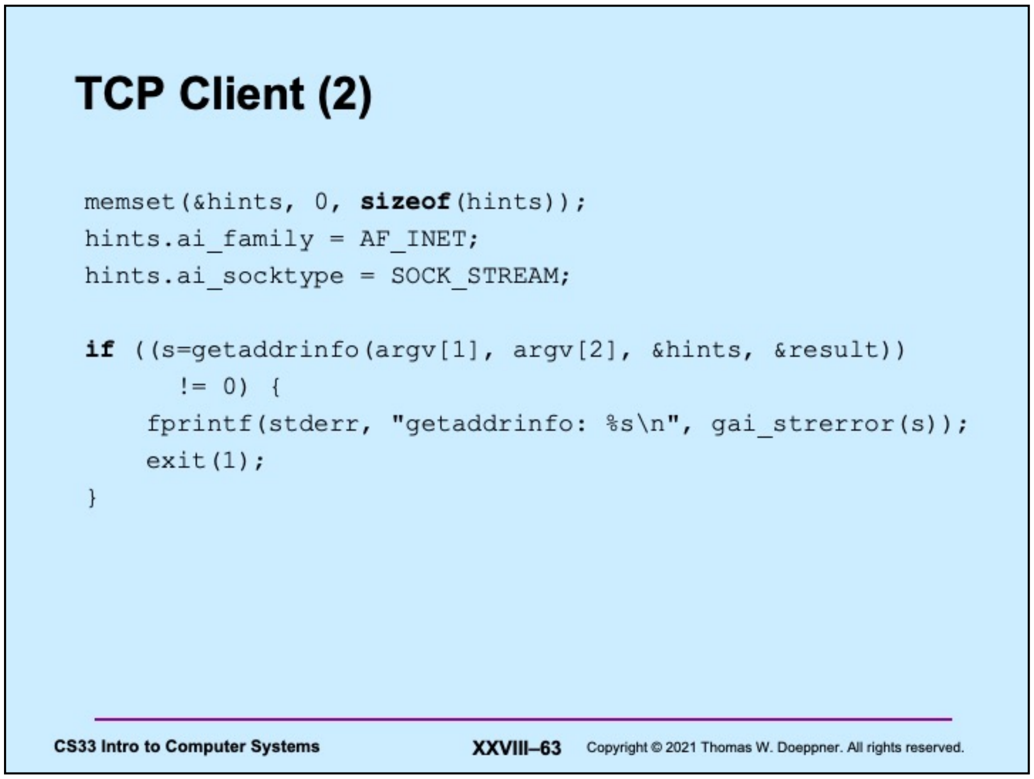
Finally, we have the *serve* function, which reads incoming data from the client and write it to file descriptor 1.



TCP Client (1)

```
int main(int argc, char *argv[]) {
    int s;
    int sock;
    struct addrinfo hints;
    struct addrinfo *result;
    struct addrinfo *rp;
    char buf[1024];

    if (argc != 3) {
        fprintf(stderr, "Usage: tcpClient host port\n");
        exit(1);
    }
```

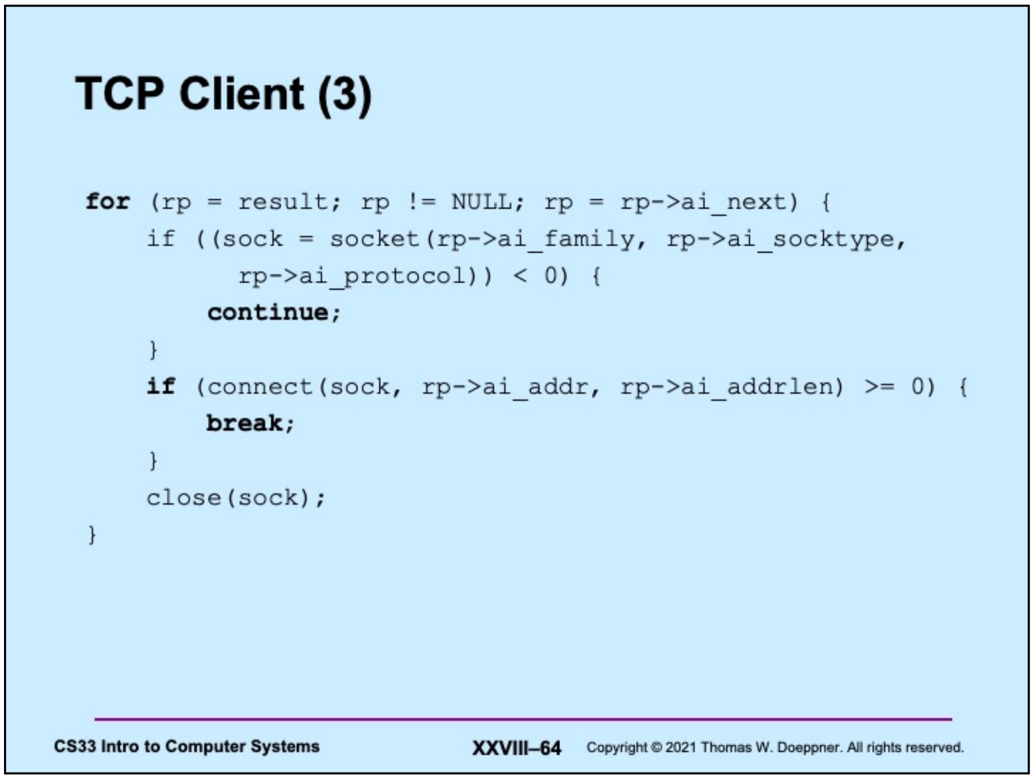
And lastly we have the code for our TCP client.



TCP Client (2)

```
memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET;
hints.ai_socktype = SOCK_STREAM;

if ((s=getaddrinfo(argv[1], argv[2], &hints, &result))
      != 0) {
    fprintf(stderr, "getaddrinfo: %s\n", gai_strerror(s));
    exit(1);
}
```

The client begins by looking up, via **getaddrinfo**, possible addresses for the server.

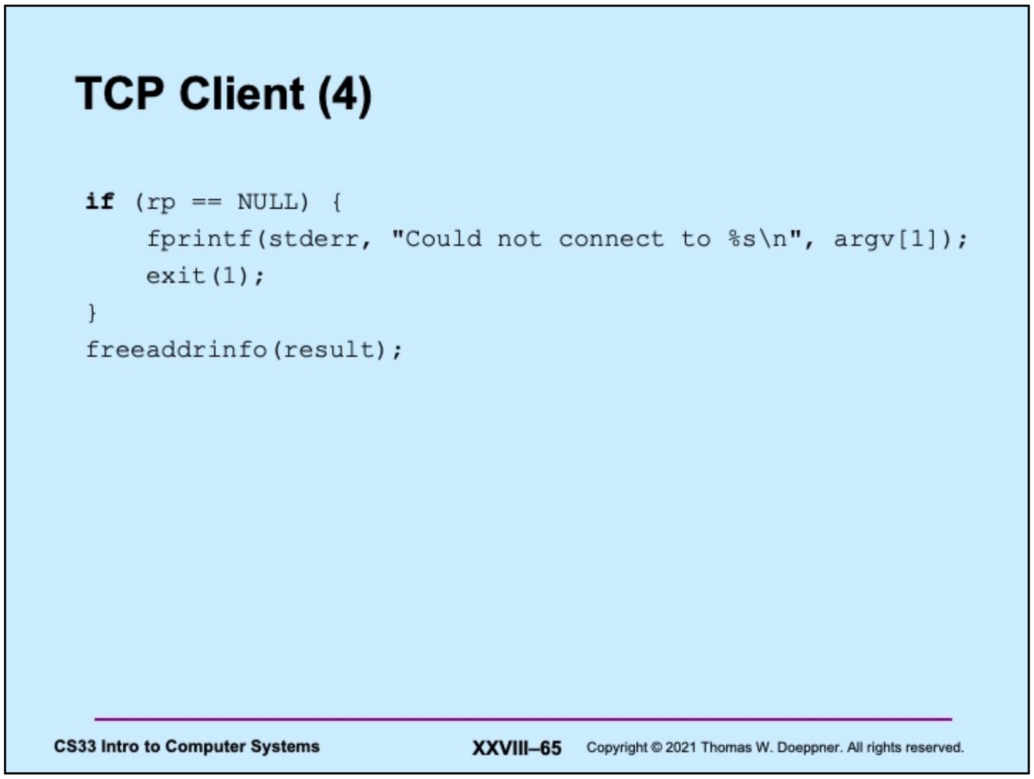


TCP Client (3)

```
for (rp = result; rp != NULL; rp = rp->ai_next) {
    if ((sock = socket(rp->ai_family, rp->ai_socktype,
          rp->ai_protocol)) < 0) {
        continue;
    }
    if (connect(sock, rp->ai_addr, rp->ai_addrlen) >= 0) {
        break;
    }
    close(sock);
}
```

The client chooses an address for which it can create a socket and connect to. Thus, if this code completes successfully, the client is now connected to the server via *sock*.

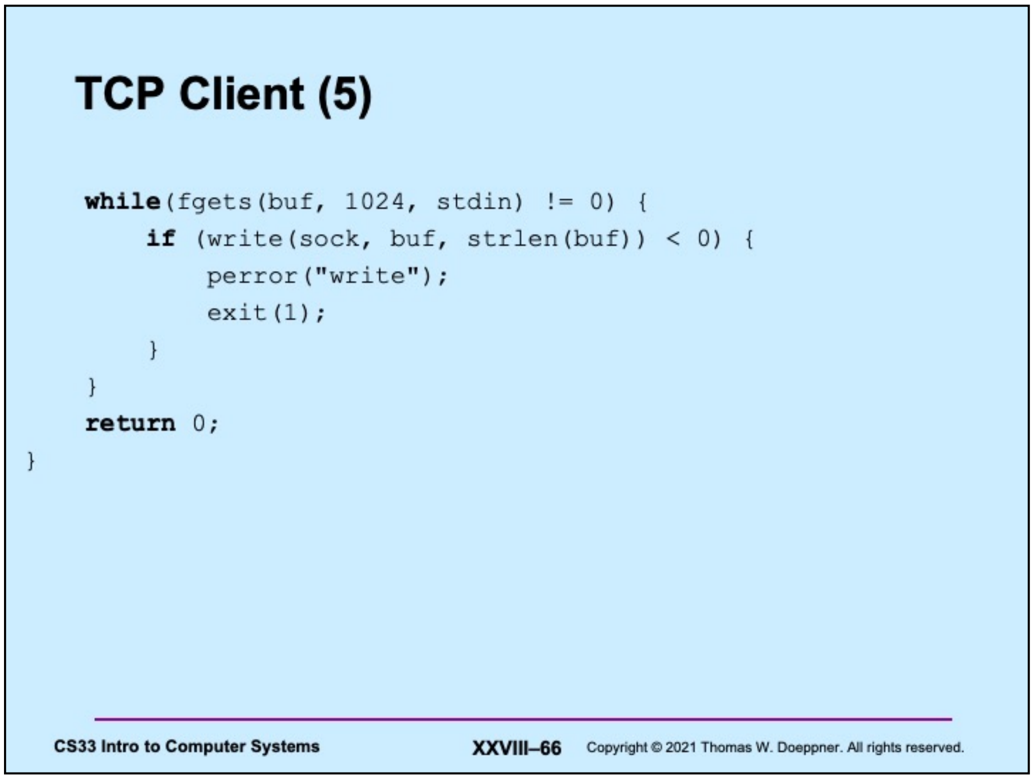
Note that no port number (or service) is associated with the client's socket. Usually what port the client is using is unimportant and one is assigned arbitrarily when the client calls connect. If it's important that the client's socket have a particularly port associated with it, **bind** can be called on the socket before its used for communication.



TCP Client (4)

```
if (rp == NULL) {
    fprintf(stderr, "Could not connect to %s\n", argv[1]);
    exit(1);
}
freeaddrinfo(result);
```

If no satisfactory address was found, the client terminates. Otherwise it frees up the no-longer-needed list of addresses.



TCP Client (5)

```
    while(fgets(buf, 1024, stdin) != 0) {
        if (write(sock, buf, strlen(buf)) < 0) {
            perror("write");
            exit(1);
        }
    }
    return 0;
}
```

Finally, the clients reads from stdin and sends whatever it reads to the server.

Quiz 3

The previous slide contains

`write(sock, buf, strlen(buf))`

If data is lost and must be retransmitted

a) write returns an error so the caller can retransmit the data.

b) nothing happens as far as the application code is concerned, the data is retransmitted automatically.

Quiz 4

A previous slide contains

```
write(sock, buf, strlen(buf))
```

We lose the connection to the other party (perhaps a network cable is cut).

a) write returns an error so the caller can reconnect, if desired.

b) nothing happens as far as the application code is concerned, the connection is reestablished automatically.