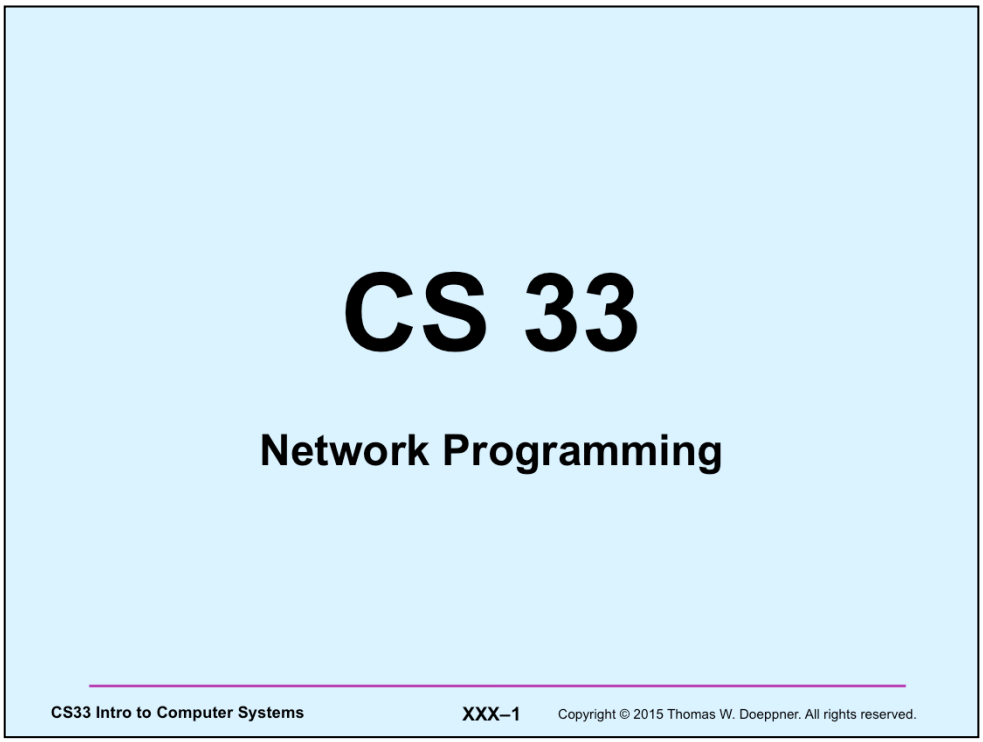
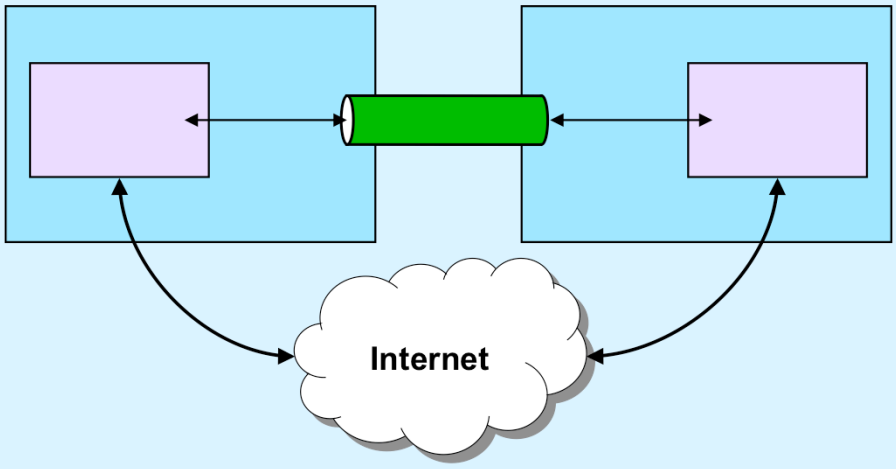
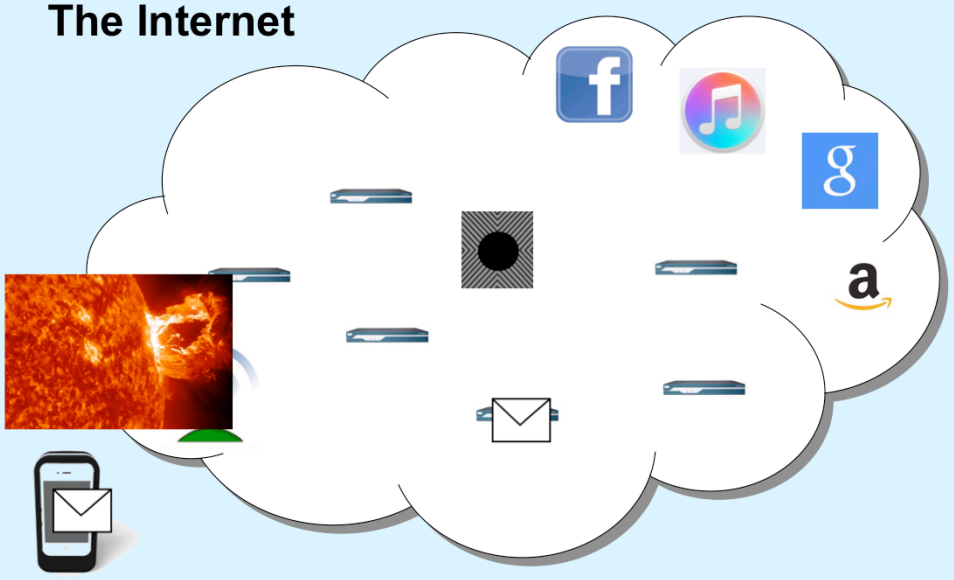


The source code used in this lecture, as well as some additional related source code, is on the course web page.

Communicating Over the Internet



The Internet



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
    - » retransmit until
      - data is received

      or
      - it appears that "the network is down"

Reliability vs. Unreliability

- Good vs. evil
  - (but which is which?)
- Reliable communication
  - good for
    - » email
    - » texting
    - » distributed file systems
    - » web pages
  - bad for
    - » streaming audio
    - » streaming video

} 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
- Record stream
  - 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
  - record-stream data abstraction
  - unreliable transmission

Quiz 1

The following code is used to transmit data over a reliable byte-stream communication channel. Assume sizeof(record_t) 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, assuming no network problems
b) sometimes
c) never

What We'd Like ...

```
int fd = open("remote party", stream|O_RDWR);
write(fd, request, request_size);
read(fd, response, sizeof(response));
```

- But ...
  - remote party is an active participant
    - must agree to participate
  - must support multiple styles of communication
  - must handle various sorts of errors

Client-Server Interaction

- Client sends requests to server
- Server responds
- Server may deal with multiple clients at once
- Client may contact multiple servers

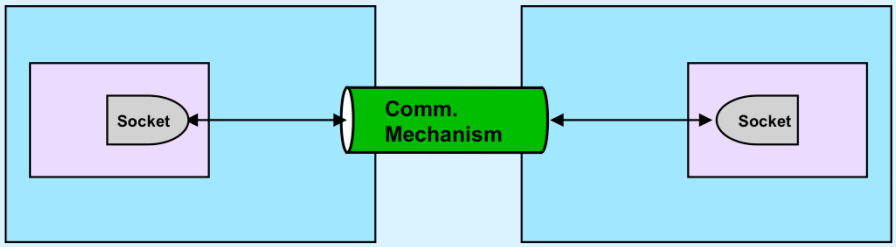
Sockets

Communication abstraction

endpoint of communication path

referenced via file descriptor

Sockets



Socket Parameters

- Styles of communication:
  - stream: reliable, two-way byte streams
  - datagram: unreliable, two-way record-oriented
  - and others, if needed
- 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

Setting Things Up

- Socket (communication endpoint) is given a name
  - *bind* system call
- 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

Datagrams in the UNIX Domain (1)

- **Steps**
  1) **create socket**

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

fd = socket(AF_UNIX, SOCK_DGRAM, 0);
```


The first step is to create a socket. We request a datagram socket in the Unix domain. The third argument specifies the protocol, but since in this and pretty much all examples the protocol is determined by the first two arguments, a zero may be used.

Datagrams in the UNIX Domain (2)

2) set up name

```
struct sockaddr_un {
  short sun_family;      /* AF_UNIX */
  char sun_path[108];    /* path name */
} name;

name.sun_family = AF_UNIX;
memcpy(name.sun_path, path, strlen(path));
```


The next step is to put the name for the socket into the unix-domain-specific version of the *sockaddr* structure, called the *sockaddr_un* structure.

Datagrams in the UNIX Domain (3)

3) bind name to socket

```
name_len = sizeof(name.sun_family) +
    strlen(name.sun_path);
bind(fd, (struct sockaddr *)&name,
    name_len);
```


The bind system call is used to pass this name to the kernel and use it to name the socket. Bind takes a generic *struct sockaddr* argument and is given the combined length of the first part of the structure and that portion of the second part that is used. Note that we have to cast the *struct sockaddr_un* * that's actually used to a *struct sockaddr* *.

Datagrams in the UNIX Domain (4)

4) send data

```
ssize_t sendto(int fd, const void *buf,
    ssize_t len, int flags,
    const struct sockaddr *to,
    socklen_t to_len);

struct sockaddr_un to_name;
socklen_t to_len = sizeof(to_name);

sendto(fd, buf, sizeof(buf), 0,
    (struct sockaddr *)&to_name,
    to_len);
```


Use the *sendto* system call to send data to a particular destination socket.

Datagrams in the UNIX Domain (5)

5) receive data

```
ssize_t recvfrom(int s, void *buf,
    ssize_t len,
    int flags, struct sockaddr *from,
    socklen_t *from_len);

struct sockaddr_un from_name;
int from_len = sizeof(from_name);

recvfrom(fd, buf, sizeof(buf), 0,
    (struct sockaddr *)&from_name,
    &from_len);
```


Use the *recvfrom* system call not only to receive data, but also to obtain the sender's address. The from_len parameter is both an input and an output parameter. On input, it gives the size of the area of memory pointed to by *from*. On output, it gives the size of the portion of that memory that was actually used.

UNIX Datagram Example (1)

- **Server side**

```
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/un.h>
#define NAME  "/home/twd/server"

main( ) {
  struct sockaddr_un        sock_name;
  int fd, len;
  /* Step 1: create socket in UNIX domain for datagram
     communication.  The third argument specifies the
     protocol, but since there's only one such protocol in
     this domain, it's set to zero */
  if ((fd = socket(AF_UNIX, SOCK_DGRAM, 0)) < 0) {
    perror("socket");
    exit(1);
  }
```


UNIX Datagram Example (2)

```
/* Step 2: set up a sockaddr structure to contain the
   name we want to assign to the socket */
sock_name.sun_family = AF_UNIX;
strcpy(sock_name.sun_path, NAME);
len = strlen(NAME) + sizeof(sock_name.sun_family);


/* Step 3: bind the name to the socket */
if (bind(fd, (struct sockaddr *)&sock_name, len) < 0) {
  perror("bind");
  exit(1);
}
```


UNIX Datagram Example (3)

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

  /* Step 4: receive message from client */
  if ((msg_size = recvfrom(fd, buf, 1024, 0,
      (struct sockaddr *)&from_addr, &from_len)) < 0) {
    perror("recvfrom");
    exit(1);
  }
  buf[msg_size] = 0;
  printf("message from %s:\n%s\n", from_addr.sun_path,
      buf);
```


UNIX Datagram Example (4)

```
    /* Step 5: respond to client */
    if (sendto(fd, "thank you", 9, 0,
        (const struct sockaddr *)&from_addr,
        from_len) < 0) {
      perror("sendto");
      exit(1);
    }
  }
}
```


UNIX Datagram Example (5)

- **Client Side**

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/un.h>

#define SNAME "/home/twd/server"
#define CNAME "/home/twd/client"

int main( ) {
  struct sockaddr_un server_name;
  struct sockaddr_un client_name;
  int fd, server_len, client_len;
```


UNIX Datagram Example (6)

```
/* Step 1: create socket in UNIX domain for datagram
   communication.  The third argument specifies the
   protocol, but since there's only one such protocol
   in this domain, it's set to zero */
if ((fd = socket(AF_UNIX, SOCK_DGRAM, 0)) < 0) {
  perror("socket");
  exit(1);
}

/* Step 2: set up a sockaddr structure to contain the
   name we want to       assign to the socket */
client_name.sun_family = AF_UNIX;
strcpy(client_name.sun_path, CNAME);
client_len = strlen(CNAME) +
    sizeof(client_name.sun_family);
```


UNIX Datagram Example (7)

```
/* Step 3: bind the name to the socket */
if (bind(fd, (struct sockaddr *)&client_name,
    client_len) < 0) {
  perror("bind");
  exit(1);
}
```


It's not necessary to bind a name to the client socket — doing so is important only if required by the server (who might, for example, deal with requests only from certain clients). It's needed here so the server will know whom to send a response to.

UNIX Datagram Example (8)

```
/* Step 4: set up server's name */
server_name.sun_family = AF_UNIX;
strcpy(server_name.sun_path, SNAME);
server_len = strlen(SNAME) +
    sizeof(server_name.sun_family);

while (1) {
  char buf[1024];
  int msg_size;

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

UNIX Datagram Example (9)

```
/* Step 5: send data to server */
if (sendto(fd, buf, strlen(buf), 0,
    (const struct sockaddr *)&server_name,
    server_len) < 0) {
  perror("sendto");
  exit(1);
}
```


UNIX Datagram Example (10)

```
    /* Step 6: 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);
}
```


Quiz 2

In the previous slide was

```
recvfrom(fd, buf, 1024, 0, 0, 0));
```

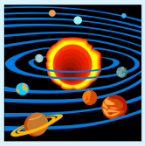
The 0's indicate the caller is not interested in who sent the datagram.

a) This makes sense: having sent a datagram to the server, we now have a connection to the server and anything coming back must be from that server.

b) This doesn't make sense: anyone could be sending the pathname the socket is bound to, and thus the response could be coming from some other sender.

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 application 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

Host Names

- Hosts are referred to by "DNS names"
  - e.g. nfs.cs.brown.edu
- DNS (Domain Name Service) is a distributed database
  - translates names to addresses
  - nfs.cs.brown.edu
    - » 10.116.110.153
    - » 10.116.110.154
    - » 10.116.110.155
- The library routine *getaddrinfo* performs DNS lookups

Note that in the particular case of nfs.cs.brown.edu, the name actually refers to a number of co-equal machines, each with its separate network interface and IP address.

Some Details …

```
struct sockaddr_in {
  sa_family_t    sin_family; /* address family: AF_INET */
  in_port_t      sin_port;   /* port in network byte order */
  struct in_addr sin_addr;   /* internet address */
};

struct in_addr {
  uint32_t       s_addr;     /* address in network byte order */
};

my_addr.sin_family = AF_INET;
inet_pton(AF_INET, "10.116.72.109", &my_addr.sin_addr.s_addr);
my_addr.sin_port = htons(port);
```


Setting the network address is surprisingly complicated.

One issue has to do with the byte order of integers on the local computer. Since different computers might have different byte orders, this could be a problem. One byte order is chosen as the standard; for network use, all must convert to that order if necessary. The macros “htonl()” (“host to network long”) and “htons()” (“host to network short”) do the conversions if necessary. Note that the port number is converted to a short int in network byte order. Network byte order is defined to be big-endian (and thus conversion is required on IA-32 and x86-64 machines).

The other issue is translating an internet address in dot notation into a 32-bit integer (or 128-bit integer for IPv6) in network byte order. This is accomplished with the library routine inet_pton. Its first argument is either AF_INET (for IPv4) or AF_INET6 (for IPv6). Its second argument is the string to be converted, and its third argument is a pointer to where the result should go.

getaddrinfo()

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

  struct addrinfo {
      int                ai_flags;
      int                ai_family;
      int                ai_socktype;
      int                ai_protocol;
      socklen_t         *ai_addrlen;
      struct sockaddr   *ai_addr;
      char              *ai_canonname;
      struct addrinfo   *ai_next;
  };
```


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*).

Using *getaddrinfo* (1)

```
struct addrinfo hints, **res, *rp;
// zero out hints
memset(&hints, 0, sizeof(hints));
hints.ai_family = AF_INET;
  // want IPv4
hints.ai_socktype = SOCK_STREAM;
  // want stream communication

getaddrinfo("cslab1a.cs.brown.edu", "3333",
    &hints, &res);
```


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*). Here we've specified the service as a port number (in ASCII). It could also be specified as a standard service name — such names are listed in the file /etc/services.

Note that much of the hints structure is not specified. Thus we first initialize the whole thing to zeroes, then fill in the part we want to specify.

Using *getaddrinfo* (2)

```
for (rp = res; rp != NULL; rp = rp->ai_next) {
  // try each interface till we find one that works
  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);
}
if (rp == NULL) {
  fprintf(stderr, "Could not connect to %s\n", argv[1]);
  exit(1);
}
freeaddrinfo(result); // free up storage allocated for list
```


getaddrinfo returns, via its *res* output argument, a list of interfaces. We try each in turn until we find one that works.

Note that the list was *malloc*'d within *getaddrinfo* and must be freed by calling *freeaddrinfo*.

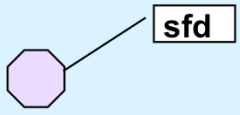
Reliable Communication

- The promise …
  - what is sent is received
  - order is preserved
- Set-up is required
  - two parties agree to communicate
    - » 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**

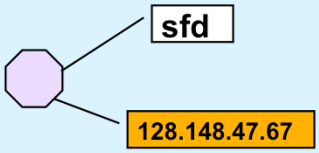
```
sfd = socket(AF_INET, SOCK_STREAM, 0);
```



Streams in the Inet Domain (2)

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

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



Some Details …

- **Server may have multiple interfaces; we want to be able to receive on all of them**

```
struct sockaddr_in {
  short sin_family;
  u_short sin_port;
  struct in_addr sin_addr;
  char sin_zero[8];        /* padding */
} my_addr;

my_addr.sin_family = AF_INET;
my_addr.sin_addr.s_addr = htonl(INADDR_ANY);
my_addr.sin_port = htons(port);
```

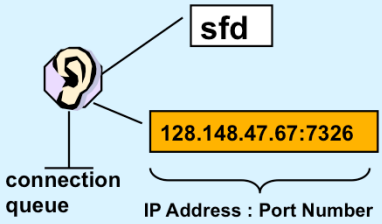
"Wildcard" address

A machine might have multiple addresses — this is often the case for servers. Rather than having to specify all of them, one simply gives the "wildcard" address, meaning all the addresses on the machine. This is useful even on a machine with just one network interface, since the wildcard address in that case refers to just the one interface.

Streams in the Inet Domain (3)

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

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

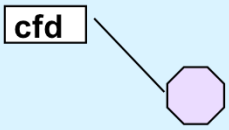


The MaxQueueLength argument is the maximum number of connections that may be queued up, waiting to be accepted. Its maximum value is in /proc/sys/net/core/somaxconn (and is currently 128).

Streams in the Inet Domain (4)

- **Cient steps**
  - **1) create socket**

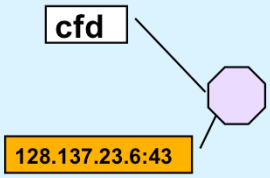
```
cfd = socket(AF_INET, SOCK_STREAM, 0);
```



Streams in the Inet Domain (5)

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

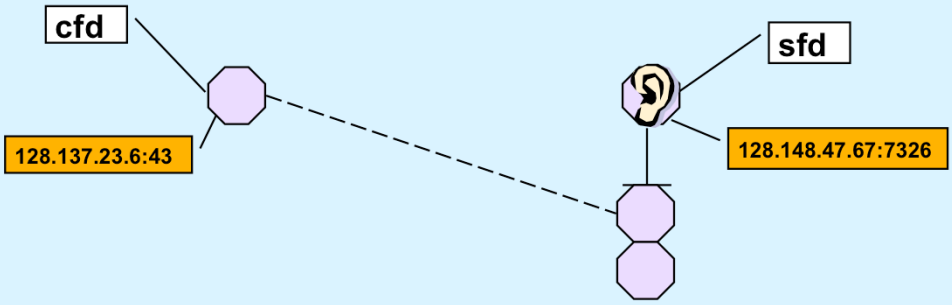
```
bind(cfd,
  (struct sockaddr *)&my_addr, sizeof(my_addr));
```



Streams in the Inet Domain (6)

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

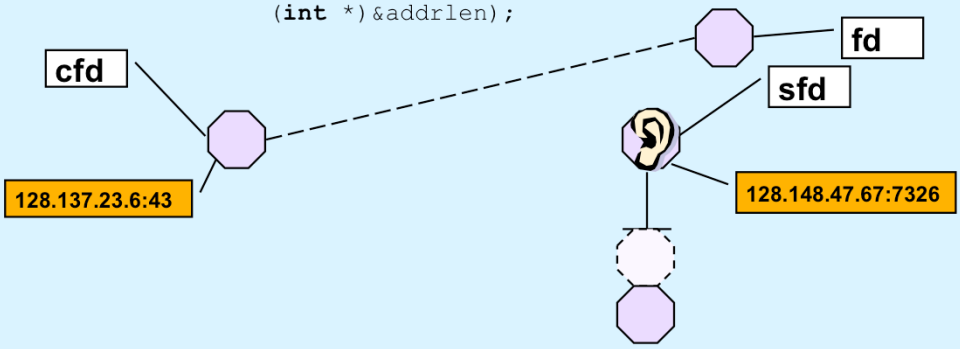
```
connect(cfd, (struct sockaddr *)&server_addr,
    sizeof(server_addr));
```



Streams in the Inet Domain (6)

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

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



Inet Stream Example (1)

- **Server side**

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>

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


Inet Stream Example (2)

```
// Step 1: establish a socket for TCP
if ((lsock = socket(AF_INET, SOCK_STREAM, 0)) < 0) {
  perror("socket");
  exit(1);
}
```


Inet Stream Example (3)

```
/* Step 2: set up our address */
memset(&my_addr, 0, sizeof(my_addr));
my_addr.sin_family = AF_INET;
my_addr.sin_addr.s_addr = htonl(INADDR_ANY);
my_addr.sin_port = htons(atoi(argv[1]));

/* Step 3: bind the address to our socket */
if (bind(lsock, (struct sockaddr *)&my_addr,
    sizeof(my_addr)) < 0) {
  perror("bind");
  exit(1);
}
```


The *memset* command copies some number of instances of its second argument into what its first argument points to. The number of instances is given by its third argument. As used here it is setting *my_addr* to all zeroes.

Inet Stream Example (4)

```
/* Step 4: put socket into "listening mode" */
if (listen(lsock, 100) < 0) {
  perror("listen");
  exit(1);
}
while (1) {
  int csock;
  struct sockaddr_in client_addr;
  int client_len = sizeof(client_addr);

  /* Step 5: receive a connection */
  csock = accept(lsock,
      (struct sockaddr *)&client_addr, &client_len);
  printf("Received connection from %s#%hu\n",
      inet_ntoa(client_addr.sin_addr), client_addr.sin_port);
```


The library routine "inet_ntoa" converts a 32-bit network address into an ASCII string in "dot notation" (bytes are separated by dots).

Inet Stream Example (5)

```
    switch (fork( )) {
    case -1:
      perror("fork");
      exit(1);
    case 0:
      // Step 6: create a new process to handle connection
      serve(csock);
      exit(0);
    default:
      close(csock);
      break;
    }
  }
}
```


Inet Stream Example (6)

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

  // Step 7: read incoming data from connection
  while ((count = read(fd, buf, 1024)) > 0) {
    write(1, buf, count);
  }
  if (count == -1) {
    perror("read");
    exit(1);
  }
  printf("connection terminated\n");
}
```


Inet Stream Example (7)

- **Client side**

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <string.h>
// + more includes ...

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

  char buf[1024];
  if (argc != 3) {
       fprintf(stderr, "Usage: tcpClient host port\n");
       exit(1);
  }
```


Inet Stream Example (8)

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


We specify AF_UNSPEC for the address family, which allows us to connect to hosts supporting either IPv4 or IPv6.

Inet Stream Example (9)

```
// Step 2: set up socket for TCP and connect to server
for (rp = result; rp != NULL; rp = rp->ai_next) {
     // try each interface till we find one that works
     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);
}
if (rp == NULL) {
     fprintf(stderr, "Could not connect to %s\n", argv[1]);
     exit(1);
}
freeaddrinfo(result);
```


Inet Stream Example (10)

```
    // Step 3: send data to the server
    while(fgets(buf, 1024, stdin) != 0) {
        if (write(sock, buf, strlen(buf)) < 0) {
                perror("write");
                exit(1);
        }
    }
    return 0;
}
```


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

The 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.

