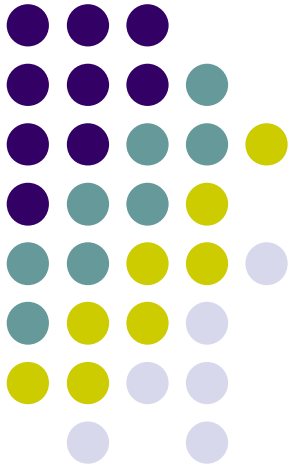
Network Programming

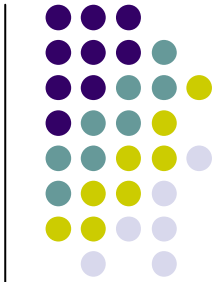
Kevin Bowers

15-213 Lecture

Thursday, April 20, 2006

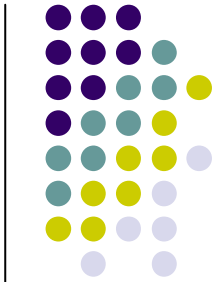


This Week



- No Quiz
- Tests handed back yesterday
  - See your TA to get your test
- No Class Thursday – Carnival
- Next Quiz
  - Network Programming

IP Addresses



- IPv4
  - 32-bit addresses
  - 128.2.134.11 (gs3082.sp.cs.cmu.edu)
- IPv6
  - 128-bit addresses
  - 3ffe:ffff:0100:f101:0210:a4ff:fee3:9566

- Lab only deals with IPv4

IP Address Struct

```
#include <netinet/in.h>

struct in_addr {
    unsigned int s_addr; /* network byte order (big-endian) */
};
```

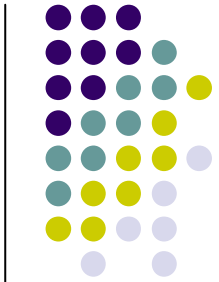
- Addresses are always stored in network byte order (big-endian)
- Machine you are working on may be little-endian
- Conversion functions

```
#include <netinet/in.h>

unsigned long int htonl(unsigned long int hostlong);
unsigned short int htons(unsigned short int hostshort);

unsigned long int ntohl(unsigned long int netlong);
unsighed short int ntohs(unsigned short int netshort);
```

Domain Naming System (DNS)

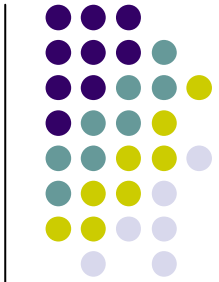


- Mapping from easy(er) to remember names to IP addresses
- gs3082.sp.cs.cmu.edu ⟷ 128.2.134.11

```
#include <netdb.h>

/* DNS host entry structure */
struct hostent {
  char   *h_name;       /* official domain name of host */
  char   **h_aliases;   /* null-terminated array of domain names */
  int    h_addrtype;    /* host address type (AF_INET) */
  int    h_length;      /* length of an address, in bytes */
  char   **h_addr_list; /* null-terminated array of in_addr structs */
};
```

DNS Queries



```
#include <netdb.h>

struct hostent *gethostbyname(const char *name);
```

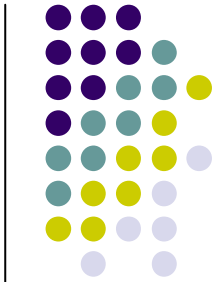
- gethostbyname(gs3082.sp.cs.cmu.edu)
  = 128.2.134.11

```
#include <netdb.h>

struct hostent *gethostbyaddr(const char *addr, int len, 0);
```

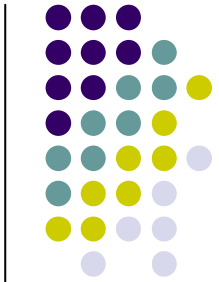
- gethostbyaddr(128.2.134.11, 4, 0)
  = gs3082.sp.cs.cmu.edu

Sockets



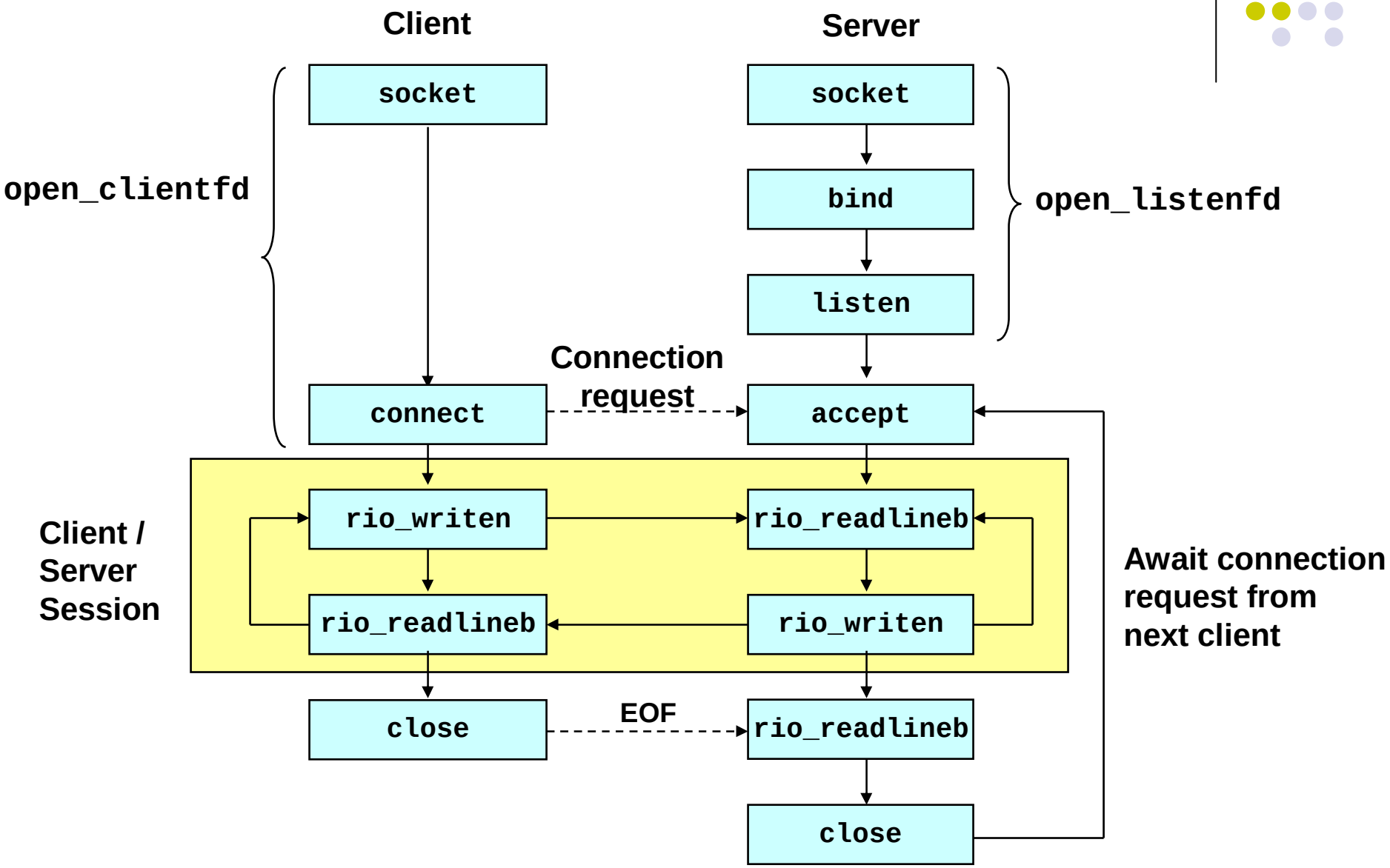
- Endpoints of connections between hosts
- Socket address
  - IP address (32 bits)
  - Port (16 bits)
  - **`address:port`**
- Connection identified by socket pairs
  - (**`clientAddr:clientPort, serverAddr:serverPort)`**

Ports

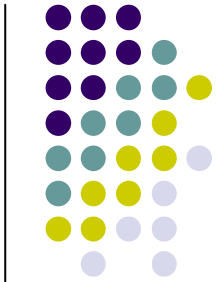


- Clients
  - Use any port given to them by the socket interface
- Servers
  - Host specific services on specific ports
    - Port 7: echo server
    - Port 23: telnet server
    - Port 25: mail server
    - Port 80: HTTP server

Sockets Interface



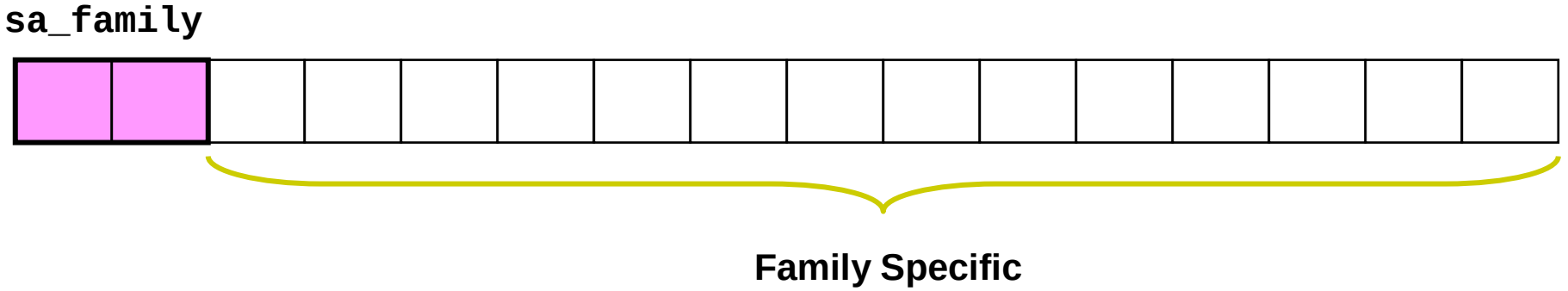
Socket Address Structs



- Generic socket address
  - Passed to **`connect`**, **`bind`**, and **`accept`**

```
#include <sys/socket.h>

struct sockaddr {
  unsigned short  sa_family;    /* protocol family */
  char            sa_data[14];  /* address data.  */
};
```

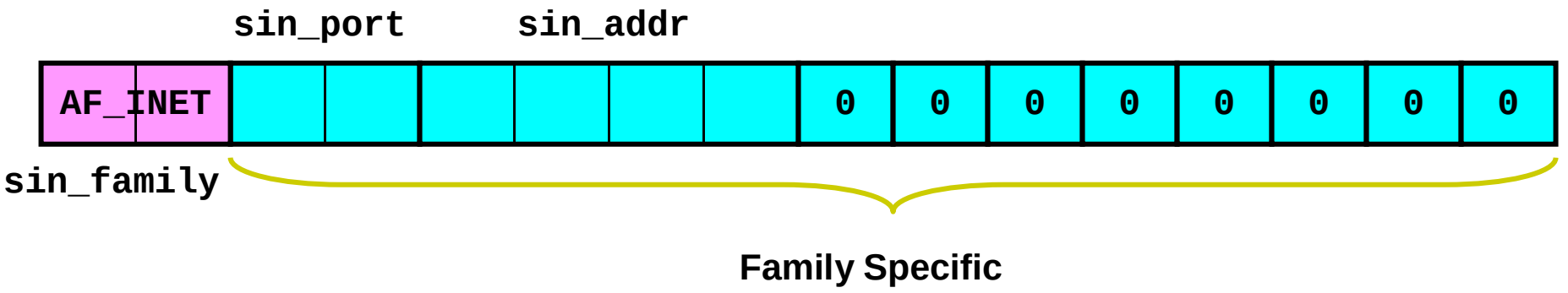


Socket Address Structs

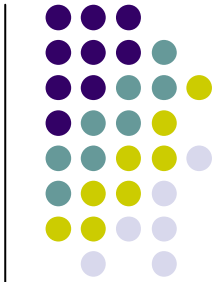
- Internet-specific socket address
- Must be cast to **`(sockaddr *)`** before passing to **`connect`**, **`bind`** or **`accept`**

```
#include <netinit/in.h>

struct sockaddr_in  {
  unsigned short  sin_family;  /* address family (always AF_INET) */
  unsigned short  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) */
};
```



The `socket` Function



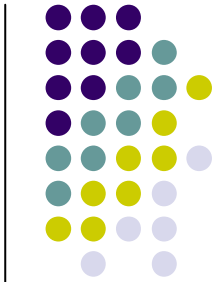
- Used to create a socket descriptor
  - Very similar to a standard file descriptor
  - Open procedure differs for clients or server

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

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

- For all applications in this class:
  - domain = AF_INET
  - type = SOCK_STREAM
  - protocol = 0

The `connect` Function



- Used by the ***client*** to create a connection to a server

```
#include <sys/socket.h>

int connect(int sockfd, struct sockaddr *srv_addr, int addrlen);
```

- **`srv_addr`** is the address of the server
- **`addrlen`** is the **`sizeof(sockaddr_in)`**
- If connect returns successfully, **`sockfd`** can be read and written just like any other file descriptor

The `bind` Function

- Used by the ***server*** to grab hold of a specific socket address on the server and tie it to the listed file descriptor

```
#include <sys/socket.h>

int bind(int sockfd, struck sockaddr *my_addr, int addrlen);
```

- **`sockfd`** is file descriptor to associate with socket address
- **`my_addr`** is local IP address and unused port
- **`addrlen = sizeof(sockaddr_in)`**

The `listen` Function

- By default, sockets are assumed active
- **`listen`** converts **`sockfd`** from an active socket to a listening socket, waiting for connections

```
#include <sys/socket.h>

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

- **`backlog`** is a hint to the kernel about how many requests should be queued before requests are refused

The `accept` Function

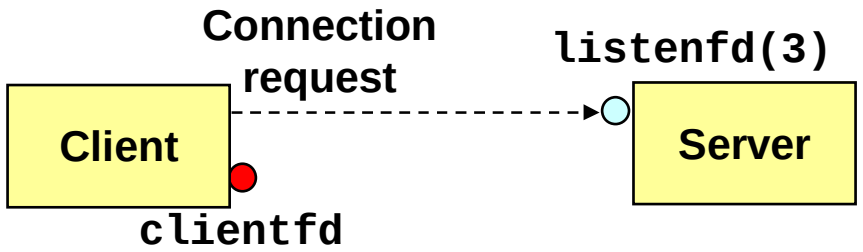
- **`accept`** waits for an incoming connection on the listed file descriptor
- Once connected, it fills in the client's socket address and returns a connected descriptor
  - Descriptor can then be used to communicate with the client

```
#include <sys/socket.h>

int accept(int lisenfd, struct sockaddr *addr, int *addrlen);
```

Illustration

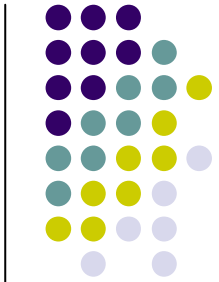
- Server blocks in **`accept`**, waiting for connection request on listening file descriptor **`listenfd`**



- Client makes connection request by calling and blocking in **`connect`**

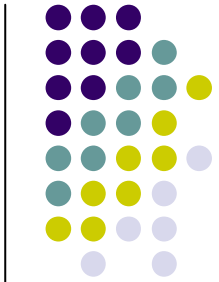
- Server returns **`connfd`** from **`accept`**. Client returns from **`connect`**. Connection is now established between **`clientfd`** and **`connfd`**

Listening vs. Connected



- 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.

`telnet`



- Great testing tool for servers that send ASCII over Internet connections

- Usage:
  - **`unix> telnet <host> <portnumber>`**
  - Creates a connection with a server running on **`<host>`** and listening on port **`<portnumber>`**

Echo client & server

On Server

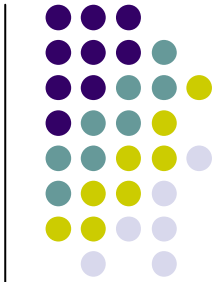
```
bass> echoserver 5000
server established connection with KITTYHAWK.CMCL (128.2.194.242)
server received 4 bytes: 123
server established connection with KITTYHAWK.CMCL (128.2.194.242)
server received 7 bytes: 456789
...
```

On Client

```
kittyhawk> echoclient bass 5000
Please enter msg: 123
Echo from server: 123

kittyhawk> echoclient bass 5000
Please enter msg: 456789
Echo from server: 456789
kittyhawk>
```

Echo Client Main Routine



```
#include "csapp.h"

/* usage: ./echoclient host port */
int main(int argc, char **argv)
{
    int clientfd, port;
    char *host, buf[MAXLINE];
    rio_t rio;
    host = argv[1];  port = atoi(argv[2]);
    clientfd = Open_clientfd(host, port);
    Rio_readinitb(&rio, clientfd);
    printf("type:"); fflush(stdout);
    while (Fgets(buf, MAXLINE, stdin) != NULL) {
        Rio_writen(clientfd, buf, strlen(buf));
        Rio_readlineb(&rio, buf, MAXLINE);
        printf("echo:");
        Fputs(buf, stdout);
        printf("type:"); fflush(stdout);
    }
    Close(clientfd);
    exit(0);
}
```

Echo Client: open_clientfd

```
int open_clientfd(char *hostname, int port)
{
  int clientfd;
  struct hostent *hp;
  struct sockaddr_in serveraddr;

  if ((clientfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
    return -1; /* check errno for cause of error */

  /* Fill in the server's IP address and port */
  if ((hp = gethostbyname(hostname)) == NULL)
    return -2; /* check h_errno for cause of error */
  bzero((char *) &serveraddr, sizeof(serveraddr));
  serveraddr.sin_family = AF_INET;
  bcopy((char *)hp->h_addr,
        (char *)&serveraddr.sin_addr.s_addr, hp->h_length);
  serveraddr.sin_port = htons(port);

  /* Establish a connection with the server */
  if (connect(clientfd, (SA *) &serveraddr, sizeof(serveraddr)) < 0)
    return -1;
  return clientfd;
}
```

bcopy Arguments

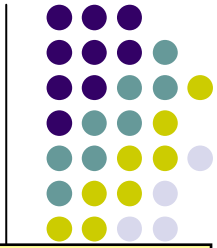
```
/* DNS host entry structure */
struct hostent {
   . . .
   int    h_length;      /* length of an address, in bytes */
   char   **h_addr_list; /* null-terminated array of in_addr structs */
};
```

```
struct sockaddr_in  {
  . . .
  struct in_addr  sin_addr;    /* IP addr in network byte order */
  . . .
};
```

```
/* Internet address structure */
struct in_addr {
    unsigned int s_addr; /* network byte order (big-endian) */
};
```

```
struct hostent *hp;             /* DNS host entry */
struct sockaddr_in serveraddr; /* server's IP address */
...
bcopy((char *)hp->h_addr_list[0], /* src, dest */
      (char *)&serveraddr.sin_addr.s_addr, hp->h_length);
```

Echo Server: Main Routine

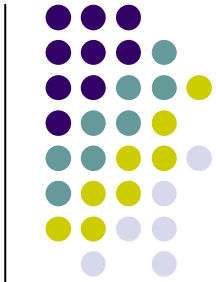


```
int main(int argc, char **argv) {
    int listenfd, connfd, port, clientlen;
    struct sockaddr_in clientaddr;
    struct hostent *hp;
    char *haddrp;

    port = atoi(argv[1]); /* the server listens on a port passed
                             on the command line */
    listenfd = open_listenfd(port);

    while (1) {
        clientlen = sizeof(clientaddr);
        connfd = Accept(listenfd, (SA *)&clientaddr, &clientlen);
        hp = Gethostbyaddr((const char *)&clientaddr.sin_addr.s_addr,
                           sizeof(clientaddr.sin_addr.s_addr), AF_INET);
        haddrp = inet_ntoa(clientaddr.sin_addr);
        printf("server connected to %s (%s)\n", hp->h_name, haddrp);
        echo(connfd);
        Close(connfd);
    }
}
```

Echo Server: open_listenfd



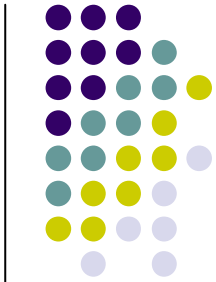
```
int open_listenfd(int port)
{
    int listenfd, optval=1;
    struct sockaddr_in serveraddr;

    /* Create a socket descriptor */
    if ((listenfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
        return -1;

    /* Eliminates "Address already in use" error from bind. */
    if (setsockopt(listenfd, SOL_SOCKET, SO_REUSEADDR,
                   (const void *)&optval , sizeof(int)) < 0)
        return -1;

... (more)
```

Echo Server: open_listenfd (cont)



```
...

  /* Listenfd will be an endpoint for all requests to port
       on any IP address for this host */
    bzero((char *) &serveraddr, sizeof(serveraddr));
    serveraddr.sin_family = AF_INET;
    serveraddr.sin_addr.s_addr = htonl(INADDR_ANY);
    serveraddr.sin_port = htons((unsigned short)port);
    if (bind(listenfd, (SA *)&serveraddr, sizeof(serveraddr)) < 0)
        return -1;

    /* Make it a listening socket ready to accept
       connection requests */
    if (listen(listenfd, LISTENQ) < 0)
        return -1;

   return listenfd;
}
```

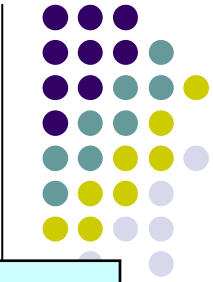
setsockopt

- The socket can be given some attributes.

```
...
/* Eliminates "Address already in use" error from bind(). */
if (setsockopt(listenfd, SOL_SOCKET, SO_REUSEADDR,
               (const void *)&optval , sizeof(int)) < 0)
    return -1;
```

- Handy trick that allows us to rerun the server immediately after we kill it.
  - Otherwise we would have to wait about 15 secs.
  - Eliminates “Address already in use” error from bind().
- Strongly suggest you do this for all your servers to simplify debugging.

Testing with `telnet`



```
bass> echoserver 5000
server established connection with KITTYHAWK.CMCL (128.2.194.242)
server received 5 bytes: 123
server established connection with KITTYHAWK.CMCL (128.2.194.242)
server received 8 bytes: 456789

kittyhawk> telnet bass 5000
Trying 128.2.222.85...
Connected to BASS.CMCL.CS.CMU.EDU.
Escape character is '^]'.
123
123
Connection closed by foreign host.
kittyhawk> telnet bass 5000
Trying 128.2.222.85...
Connected to BASS.CMCL.CS.CMU.EDU.
Escape character is '^]'.
456789
456789
Connection closed by foreign host.
kittyhawk>
```