# Network Programming


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# Outline

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- Advanced I/O
  - recv(), send()
  - readv(), writev()
  - recvmsg(), sendmsg()

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# Advanced I/O Functions (T1: ch 14)

# recv() and send()



- The recv() and send() system calls perform I/O on connected sockets (TCP or connected UDP sockets).
- Socket-Specific I/O System Calls:
  - They provide socket-specific functionality not available with read(0 and write().

```
1  #include <sys/socket.h>
2  ssize_t recv(int  sockfd , void * buffer , size_t  length , int  flags );
3  //Returns number of bytes received, 0 on EOF, or -1 on error
4  ssize_t send(int  sockfd , const void * buffer , size_t  length , int  flags );
5  //Returns number of bytes sent, or -1 on error
```

  - Same as read() and write() except for *flags*.
  - Return values are same as read() and write().

# recv() flags



- MSG_DONTWAIT:
  - perform a non-blocking recv().
  - can be done using fcntl() call but that will make sock fd non-blocking. Here only this operation is non-blocking.
- MSG_OOB:
  - receive out-of-band data on the socket.
- MSG_PEEK:
  - retrieve a copy of the requested bytes from the socket buffer.
  - Data is not removed from the socket buffer.
  - Used for knowing the no of bytes available on the buffer.
- MSG_WAITALL
  - Blocks until *length* bytes are read from socket buffer.
  - May get interrupted by signals.

# send() flags

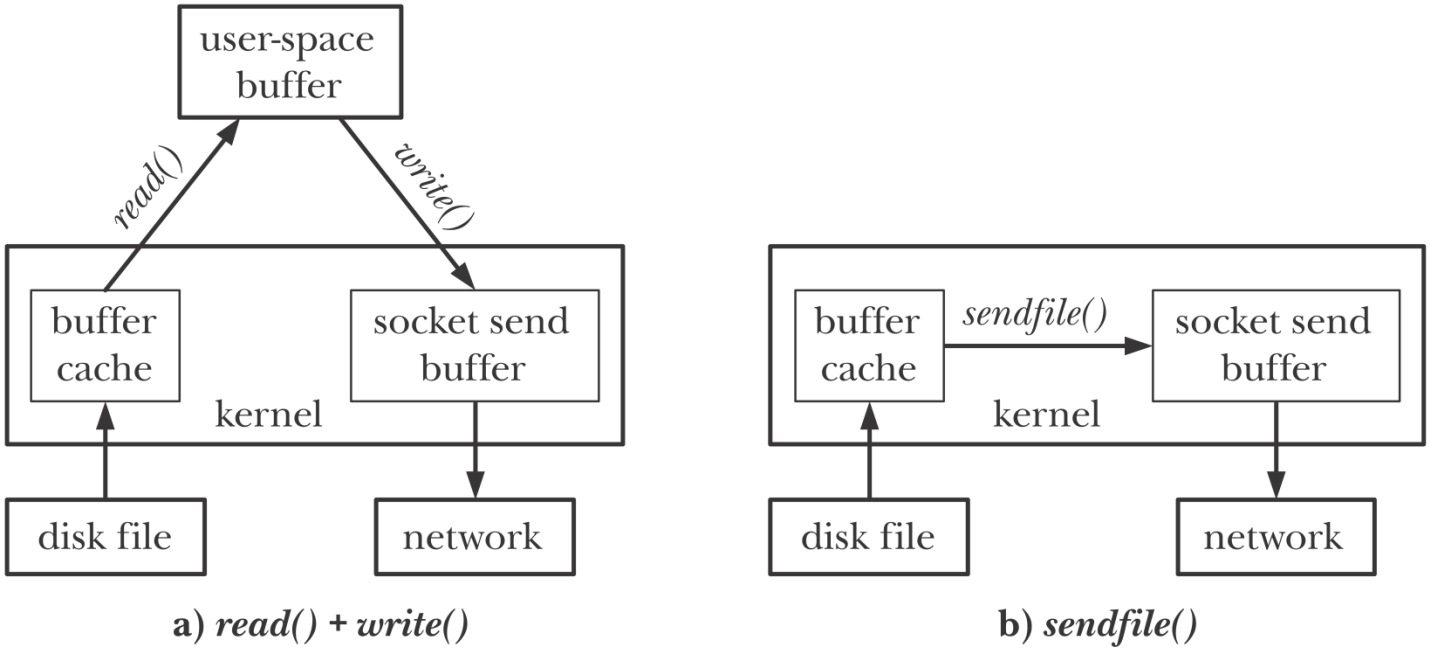


- MSG_DONTWAIT
  - Perform a  non-blocking send.
- MSG_MORE
  - Data written using send() or sendto() calls with this flag is packaged into a single datagram until a send() without this flag.
- MSG_NOSIGNAL
  - Do not generate SIGPIPE signal. Return only EPIPE error.
- MSG_OOB
  - Write out of band data on TCP.

# sendfile() sys call (R1: 61.4)

- Transferring large file in web servers requires repeated calls to read() and write().
  - This is inefficient.

```
1   while ((n = read(diskfilefd, buf, BUZ_SIZE)) > 0)
2       write(sockfd, buf, n);
```



# sendfile() sys call (R1: 61.4)



- The sendfile() sys call is designed to eliminate copying file data into user space.
  - File contents are directly transferred to the socket without going through user space.
  - This is referred as a *zero-copy transfer.*

```
1  #include <sys/sendfile.h>
2  ssize_t sendfile(int out_fd, int  in_fd, off_t * offset, size_t count );
3  //Returns number of bytes transferred, or -1 on error
```

  - *out_fd:* is the socket fd.
  - *In_fd:* is regular file fd.
  - *off_t:* is the offset. This is a value-result argument.
  - *count* is the number of bytes to be transferred.
  - *sendfile* doesn't change the file offset for *in_fd*.

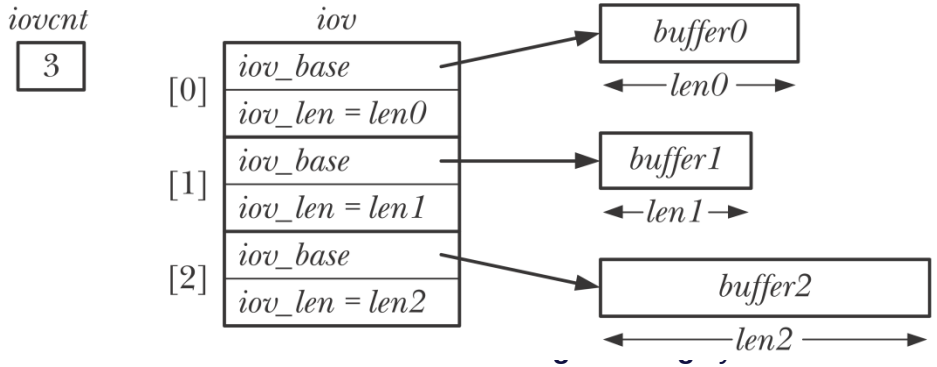
# readv() and writev()



- The readv() and writev() system calls perform scatter-gather I/O.
- *iov* points to an array of buffers, each in *iovec* structure.

```
1  #include <sys/uio.h>
2  ssize_t readv(int  fd , const struct iovec * iov , int  iovcnt );
3  //Returns number of bytes read, 0 on EOF, or -1 on error
4  ssize_t writev(int  fd , const struct iovec * iov , int  iovcnt );
5  //Returns number of bytes written, or -1 on error
```

```
 8  struct iovec {
 9      void  *iov_base; /* Start address of buffer */
10      size_t iov_len;  /* Number of bytes to transfer to/from buffer */
11  };
```



# readv() and writev()



- The readv() system call performs scatter input:
  - Reads from the file and puts the data into the buffer starting at iov[0]. Once the first buffer is full, it goes to another.
- readv() completes atomically:
  - Kernel performs a single data transfer.
  - Assured that all the bytes read are contiguous in the file. File offset can't be changed by other process.
- The writev() call performs gather output:
  - Starting from the first buffer, writes the data contiguously into the file.
  - Partial write is possible.
- writev() completes atomically.
- readv() and writev() are used for convenience and speed.
  - Reduce number of sys calls.

# sendmsg() & recvmsg() sys calls



- The sendmsg() and recvmsg() system calls are the most general purpose of the socket I/O system calls.
  - The sendmsg() system call can do everything that is done by write(), send(), and sendto();
  - the recvmsg() system call can do everything that is done by read(), recv(), and recvfrom().

```
#include <sys/socket.h>
 ssize_t recvmsg(int sockfd, struct msghdr *msg, int flags);
 ssize_t sendmsg(int sockfd, struct msghdr *msg, int flags);
 //Both return: number of bytes read or written if OK, -1 on error
```

```
struct msghdr {
  void         *msg_name;       /* protocol address */
  socklen_t     msg_namelen;    /* size of protocol address */
  struct iovec *msg_iov;        /* scatter/gather array */
  int           msg_iovlen;     /* # elements in msg_iov */
  void         *msg_control;    /* ancillary data (cmsghdr struct) */
  socklen_t     msg_controllen; /* length of ancillary data */
  int           msg_flags;      /* flags returned by recvmsg() */
};
```

# sendmsg() & recvmsg() sys calls



- Can be used to send or receive ancillary data (control information).
- Flags are

| Flag | **Examined by:** Send flags Sendto flags Sendmsg flags | **Examined by:** recv flags recvfrom flags recvmsg flags | **Returned by:** Recvmsg msg_flags |
|---|---|---|---|
| MSG_DONTROUTE | • | | |
| MSG_DONTWAIT | • | • | |
| MSG_PEEK | | • | |
| MSG_WAITALL | | • | |
| MSG_EOR | • | | • |
| MSG_OOB | • | • | • |
| MSG_BCAST | | | • |
| MSG_MCAST | | | • |
| MSG_TRUNC | | | • |
| MSG_CTRUNC | | | • |

# Flags returned by rcvmsg()

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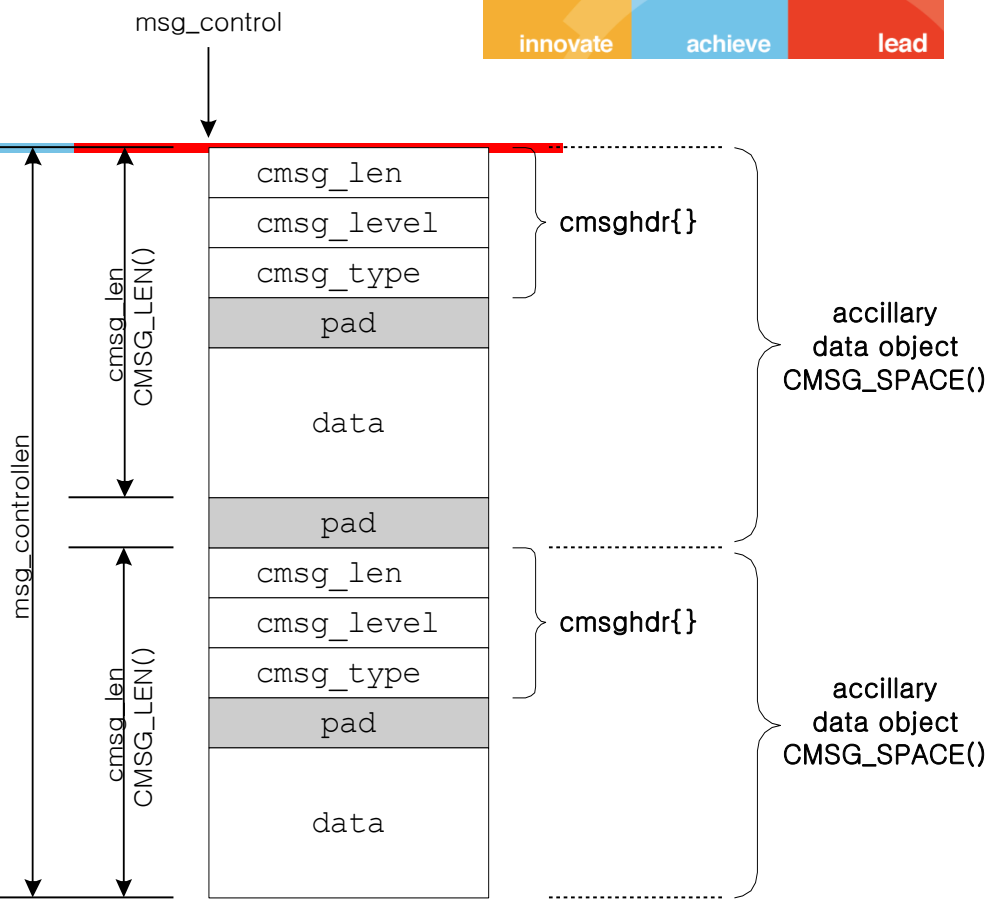
- MSG_BCAST
  - is returned if the datagram was received as as a broadcast.
- MSG_MCAST
  - is returned if the datagram was received as a link-layer multicast.
- MSG_TRUNC
  - is returned if the datagram was truncated
- MSG_CTRUNC
  - is returned if the ancillary data was truncated
- MSG_EOR
  - is turned on if the returned data ends a logical record.
- MSG_OOB
  - This flag is never returned for TCP out-of-band data. This flag is returned by other protocol suites (e.g., the OSI protocols).
- MSG_NOTIFICATON
  - This flag is returned for SCTP receivers to indicate that the message read is an event notification, not a data message.

# Ancillary Data

- Ancillary data can be sent and received using the msg_control and msg_controllen members of the msghdr structure.
  - Another term for ancillary data is control information.




```
1  struct cmsghdr {
2    socklen_t  cmsg_len;   /* length in bytes, including this structure */
3    int        cmsg_level; /* originating protocol */
4    int        cmsg_type;  /* protocol-specific type */
5      /* followed by unsigned char cmsg_data[] */
6  };
```

# Ancillary Data

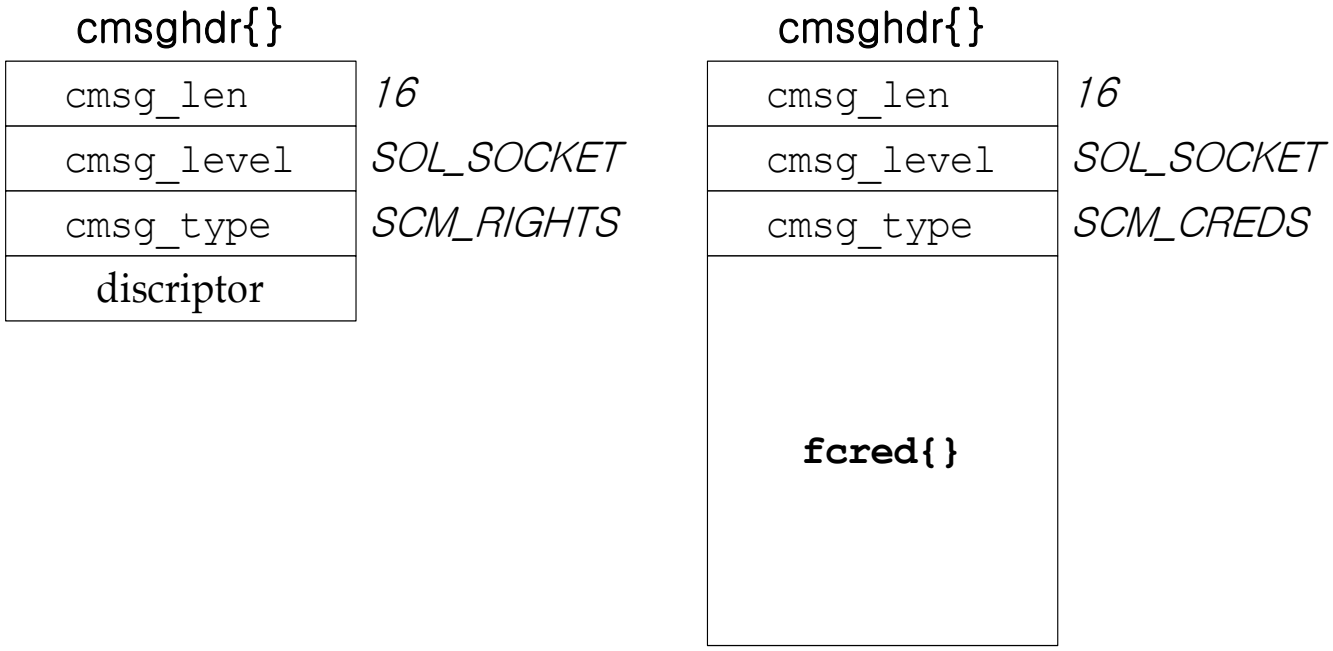


- Ancillary data is domain specific.

| Protocol | cmsg_level | Cmsg_type | Description |
|---|---|---|---|
| IPv4 | IPPROTO_IP | IP_RECVDSTADDR<br>IP_RECVIF | receive destination address with UDP datagram<br>receive interface index with UDP datagram |
| IPv6 | IPPROTO_IPV6 | IPV6_DSTOPTS<br>IPV6_HOPLIMIT<br>IPV6_HOPOPTS<br>IPV6_NEXTHOP<br>IPV6_PKTINFO<br>IPV6_RTHDR | specify / receive destination options<br>specify / receive hop limit<br>specify / receive hop-by-hop options<br>specify next-hop address<br>specify / receive packet information<br>specify / receive routing header |
| Unix domain | SOL_SOCKET | SCM_RIGHTS<br>SCM_CREDS | send / receive descriptors<br>send / receive user credentials |

# Ancillary Data

- File descriptors and process credentials can be passed between unrelated processes using ancillary data.



# How much data is Queued?



- Use *recv*() with MSG_PEEK flag.

```
2    int numbytes = recv(fd, buf, bufsize, MSG_PEEK);
```

  - For TCP, this will give the number of bytes available in socket recv buffer.
    - This value could change in between two reads.
  - For a connected UDP socket, this return the number of bytes in the next available datagram.
    - Between two reads this value remains same.
- Use *ioctl*() call with FIONREAD command.

```
2    ioctl(fd, FIONREAD, &numbytes)
```

- In UDP case, the size of datagram can be zero. This makes it difficult to distinguish between nodata or data.
  - Safer to use *select*() first and then call I/O.

# Sockets and Standard I/O



- TCP and UDP sockets are full duplex. File streams can also be full duplex.
- We can open a file stream on a socket using *fdopen()*.
- If we open with mode r+, then
  - An input function can't be followed by output function without calling fseek().
  - An output function can't followed by input function without calling fseek().
  - But we can't call lseek() on sockets.
- So open two separate streams on a socket: one for reading, one for writing.

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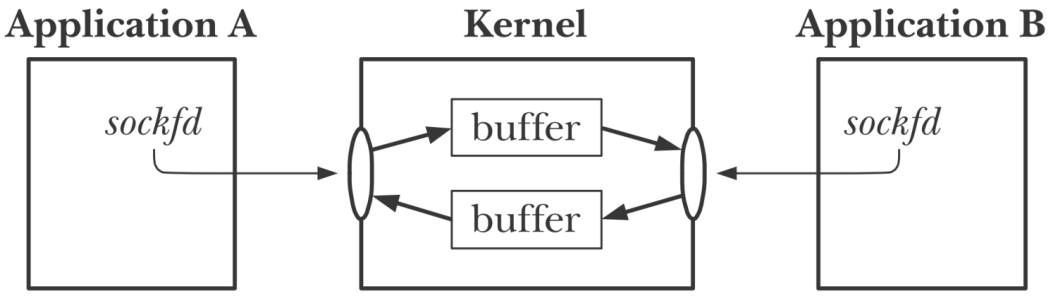
# Unix Domain Sockets

# Internet Domain vs Unix Domain



- Internet Domain: *AF_INET or AF_INET6*
  - Used in network communication.
  - Can be used between two processes in the same host also.
- Unix Domain: *AF_UNIX or AF_LOCAL*
  - Used for communication between processes on the same host. Same API as sockets API.
  - No TCP/IP protocol stack. A socket is made of two buffers in the kernel.
  - No  header processing, no checksums. Reliable communication. Unix domain sockets are twice faster.



# Unix Domain Sockets - Usage



- Unix domain sockets are used for three reasons:
  - Unix domain sockets are often twice as fast as a TCP socket when both peers are on the same host.
    - X Windows
  - used when passing file descriptors between processes on the same host.
  - unix domain sockets provide the client's process credentials (user ID and group IDs) to the server, which can provide additional security checking

# Unix Domain Sockets



- Two types of sockets are provided.
  - Stream sockets
    - Similar to TCP
  - Datagram Sockets
    - Similar to UDP sockets.
    - Message boundaries are preserved.
    - Communication is reliable unlike UDP.

# Unix Domain Socket Address



- End Point Address
  - pathnames within the normal file system
  - The pathname associated with a Unix domain socket should be an absolute pathname.

```
1  struct sockaddr_un {
2      sa_family_t sun_family;/* Always AF_UNIX */
3      char sun_path[108]; /* Null-terminated socket pathname */
4  };
```

# Binding End Point to a Socket



- When used to bind a UNIX domain socket, bind() creates an entry in the file system.

```
1   const char *SOCKNAME = "/tmp/mysock";
2   int sfd;
3   struct sockaddr_un addr;
4   sfd = socket(AF_UNIX, SOCK_STREAM, 0);   /* Create socket */
5   if (sfd == -1)
6       errExit("socket");
7   memset(&addr, 0, sizeof(struct sockaddr_un)); /* Clear structure */
8   addr.sun_family = AF_UNIX;   /* UNIX domain address */
9   strncpy(addr.sun_path, SOCKNAME, sizeof(addr.sun_path) - 1);
10  if (bind(sfd, (struct sockaddr *) &addr, sizeof(struct sockaddr_un)) == -1)
11      errExit("bind");
```

  - We can't bind a socket to an existing pathname (bind() fails with the error EADDRINUSE ).
  - A socket may be bound to only one pathname; conversely, a pathname can be bound to only one socket.
    - When the socket is no longer required, its pathname entry should be removed using unlink().

# Unix Domain Stream Sockets



- Server
  - Absolute pathname is required.
  - Pathname specified in connect() should be existing, and bound to a socket
  - If the listening socket's queue is full, ECONREFUSED is immediately returned.
- Client
  - Create socket
  - Connect to the server.

# Unix Domain Stream Server



```c
/*sockets/us_xfr_sv.c*/
main(int argc, char *argv[])
{   struct sockaddr_un addr;
    int sfd, cfd;
    ssize_t numRead;
    char buf[BUF_SIZE];
    sfd = socket(AF_UNIX, SOCK_STREAM, 0);
    if (sfd == -1)  errExit("socket");
    if (remove(SV_SOCK_PATH) == -1 && errno != ENOENT)
        errExit("remove-%s", SV_SOCK_PATH);
    memset(&addr, 0, sizeof(struct sockaddr_un));
    addr.sun_family = AF_UNIX;
    strncpy(addr.sun_path, SV_SOCK_PATH, sizeof(addr.sun_path) - 1);
    if (bind(sfd, (struct sockaddr *) &addr, sizeof(struct sockaddr_un)) == -1)
        errExit("bind");
    if (listen(sfd, BACKLOG) == -1)  errExit("listen");
    for (;;) {
        cfd = accept(sfd, NULL, NULL);
        if (cfd == -1)    errExit("accept");
        while ((numRead = read(cfd, buf, BUF_SIZE)) > 0)
            if (write(STDOUT_FILENO, buf, numRead) != numRead)
                fatal("partial/failed write");
        if (numRead == -1) errExit("read");
        if (close(cfd) == -1) errMsg("close");
    }}
```

# Unix Domain Stream Client

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```
1  /*sockets/us_xfr_cl.c*/
2  main(int argc, char *argv[])
3  {    struct sockaddr_un addr;
4       int sfd;
5       ssize_t numRead;
6       char buf[BUF_SIZE];
7       sfd = socket(AF_UNIX, SOCK_STREAM, 0);  /* Create client socket */
8       if (sfd == -1)  errExit("socket");
9       /* Construct server address, and make the connection */
10      memset(&addr, 0, sizeof(struct sockaddr_un));
11      addr.sun_family = AF_UNIX;
12      strncpy(addr.sun_path, SV_SOCK_PATH, sizeof(addr.sun_path) - 1);
13      if (connect(sfd, (struct sockaddr *) &addr,
14                  sizeof(struct sockaddr_un)) == -1)
15          errExit("connect");
16      /* Copy stdin to socket */
17      while ((numRead = read(STDIN_FILENO, buf, BUF_SIZE)) > 0)
18          if (write(sfd, buf, numRead) != numRead)
19              fatal("partial/failed write");
20      if (numRead == -1)
21          errExit("read");
22      exit(EXIT_SUCCESS);  /* Closes our socket; server sees EOF */
23  }
```

# Unix Domain Datagram Sockets



- Datagram sockets are reliable unlike UDP sockets.
  - Datagrams are not lost.
  - Datagrams are delivered in order and without duplicates.
- Server
  - Creates a socket
  - binds to well-known path.
- Client
  - Creates a socket
  - **binds the socket to an address, so that the server can send its reply.**
  - The client address is made unique by including the client's process ID in the pathname.

# Unix Domain Datagram Server

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```
/*sockets/ud_ucase_sv.c*/
main(int argc, char *argv[])
{   struct sockaddr_un svaddr, claddr;
    sfd = socket(AF_UNIX, SOCK_DGRAM, 0);       /* Create server socket */
    if (remove(SV_SOCK_PATH) == -1 && errno != ENOENT)
        errExit("remove-%s", SV_SOCK_PATH);
    memset(&svaddr, 0, sizeof(struct sockaddr_un));
    svaddr.sun_family = AF_UNIX;
    strncpy(svaddr.sun_path, SV_SOCK_PATH, sizeof(svaddr.sun_path) - 1);
    if (bind(sfd, (struct sockaddr *) &svaddr, sizeof(struct sockaddr_un)) == -1)
        errExit("bind");
    for (;;) {
        len = sizeof(struct sockaddr_un);
        numBytes = recvfrom(sfd, buf, BUF_SIZE, 0,
                            (struct sockaddr *) &claddr, &len);
        if (numBytes == -1)  errExit("recvfrom");
        printf("Server received %ld bytes from %s\n", (long) numBytes,
                claddr.sun_path);
        for (j = 0; j < numBytes; j++)
            buf[j] = toupper((unsigned char) buf[j]);
        if (sendto(sfd, buf, numBytes, 0, (struct sockaddr *) &claddr, len) !=
                numBytes)
            fatal("sendto");
    }}
```

# Unix Domain Datagram Client

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```c
/* sockets/ud_ucase_cl.c*/
main(int argc, char *argv[])
{   struct sockaddr_un svaddr, claddr;
     sfd = socket(AF_UNIX, SOCK_DGRAM, 0);
    memset(&claddr, 0, sizeof(struct sockaddr_un));
    claddr.sun_family = AF_UNIX;
    snprintf(claddr.sun_path, sizeof(claddr.sun_path),
            "/tmp/ud_ucase_cl.%ld", (long) getpid());
if (bind(sfd, (struct sockaddr *) &claddr, sizeof(struct sockaddr_un)) == -1)
        errExit("bind");
    /* Construct address of server */
    memset(&svaddr, 0, sizeof(struct sockaddr_un));
    svaddr.sun_family = AF_UNIX;
    strncpy(svaddr.sun_path, SV_SOCK_PATH, sizeof(svaddr.sun_path) - 1);
    /* Send messages to server; echo responses on stdout */
    for (j = 1; j < argc; j++) {
        msgLen = strlen(argv[j]);       /* May be longer than BUF_SIZE */
        if (sendto(sfd, argv[j], msgLen, 0, (struct sockaddr *) &svaddr,
                sizeof(struct sockaddr_un)) != msgLen)
            fatal("sendto");
        numBytes = recvfrom(sfd, resp, BUF_SIZE, 0, NULL, NULL);
        if (numBytes == -1)   errExit("recvfrom");
        printf("Response %d: %.*s\n", j, (int) numBytes, resp); }
    remove(claddr.sun_path);/* Remove client socket pathname */
}
```

# socketpair()

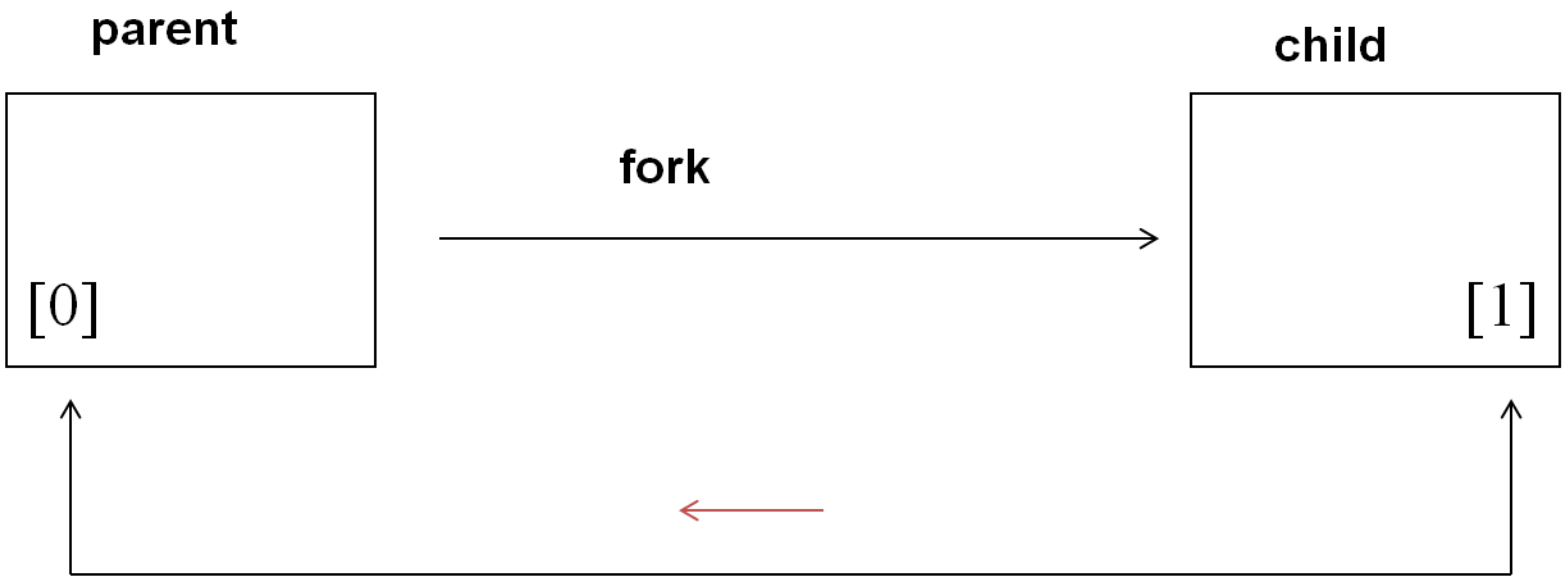


- creates a pair of sockets and connect them together.

```
1  #include <sys/socket.h>
2  int socketpair(int  domain, int  type ,int  protocol ,int  sockfd [2]);
3  //Returns 0 on success, or -1 on error
```

  - Returns two socket fds.
  - No path names bound for sockets. Not visible outside the process.
  - Type SOCK_STREAM  creates the equivalent of a bidirectional pipe (also known as a stream pipe).
  - Each socket can be used for both reading and writing.
  - Just like in pipe, after creating calling socketpair(), fork() is called.
  - Parent and child can communicate using sockets.

# socketpair()



# socketpair()

```c
#include <sys/types.h>
#include <unistd.h>
#include <sys/socket.h>
main ()
{
  int i;
  int p[2];
  pid_t ret;
    socketpair(AF_UNIX, SOCK_STREAM, 0, p);
  ret = fork ();
  if (ret == 0)
    {
      close (1);
      dup (p[1]);
      close (p[0]);
      execlp ("ls", "ls", "-l", (char *) 0);
    }
  if (ret > 0)
    {
      close (0);
      dup (p[0]);
      close (p[1]);
  execlp ("wc", "wc", "-l", (char *) 0);
    }
}
```

# Passing File Descriptors



- Unix system provide a way to pass any open descriptor from one process to any other process.(using *sendmsg()*)
- It allows one process (typically a server) to do the privileged execution
  - dialing a modem, negotiating locks for the file or deal with database
  - simply pass back to the calling process a descriptor that can be used with all the I/O functions.
- All the details involved in opening the file or device are hidden from the client.

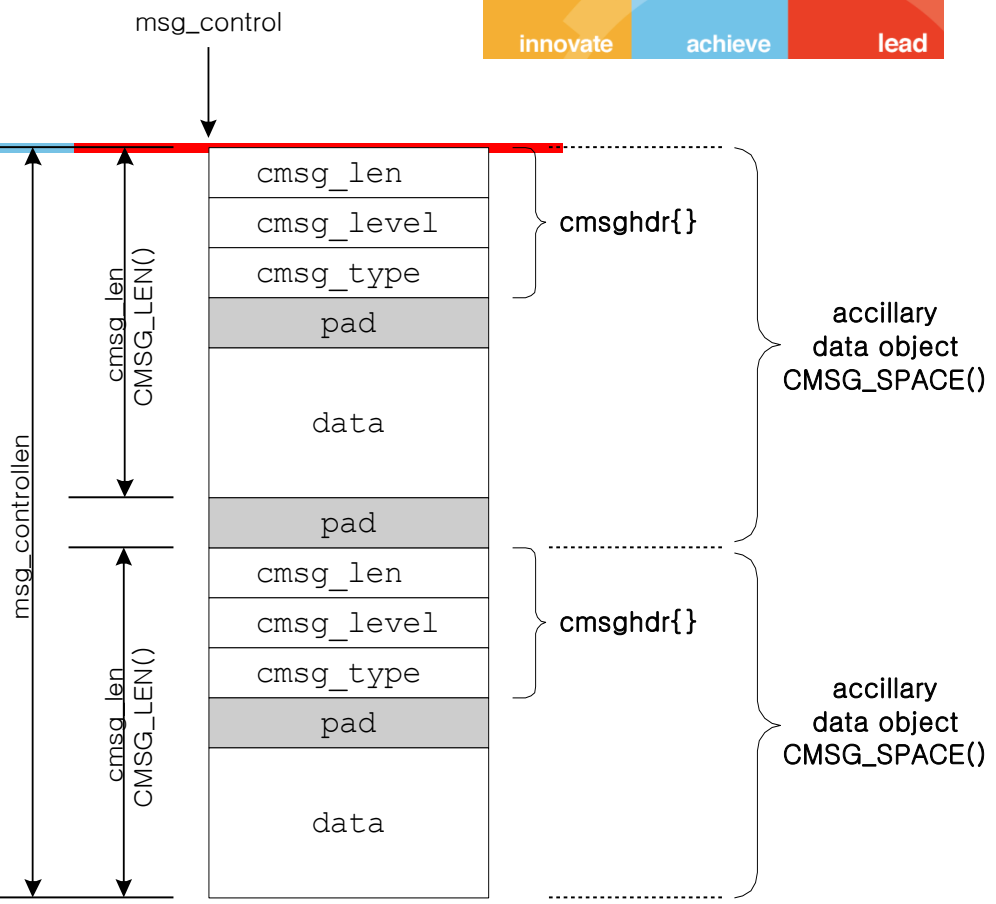
# Passing File Descriptors



- Steps involved
  - Create a unix domain socket(stream or datagram)
  - one process opens a descriptor by calling any of the unix function that returns a descriptor
  - the sending process build a ***msghdr*** structure containing the descriptor to be passed
  - Sending process sends ancillary data using ***sendmsg()*** with SCM_RIGHTS
  - the receiving process calls ***recvmsg()*** to receive the descriptor on the unix domain socket
- Passing a descriptor is not same as passing descriptor number
  - involves creating a new descriptor in the receiving process that refers to the same file table entry within the kernel.

# Ancillary Data

- Ancillary data can be sent and received using the msg_control and msg_controllen members of the msghdr structure.
  - Another term for ancillary data is control information.




```
1  struct cmsghdr {
2    socklen_t  cmsg_len;   /* length in bytes, including this structure */
3    int        cmsg_level; /* originating protocol */
4    int        cmsg_type;  /* protocol-specific type */
5      /* followed by unsigned char cmsg_data[] */
6  };
```

# Ancillary Data

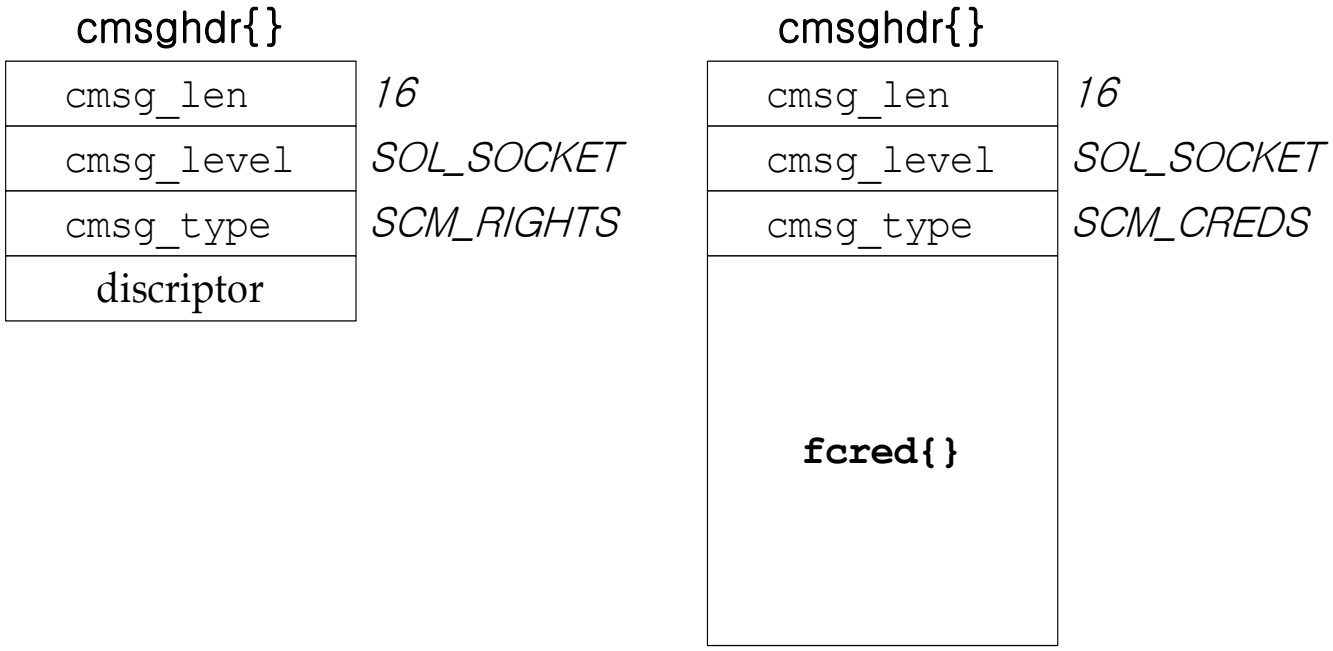


- Ancillary data is domain specific.

| Protocol | cmsg_level | Cmsg_type | Description |
|---|---|---|---|
| IPv4 | IPPROTO_IP | IP_RECVDSTADDR<br>IP_RECVIF | receive destination address with UDP datagram<br>receive interface index with UDP datagram |
| IPv6 | IPPROTO_IPV6 | IPV6_DSTOPTS<br>IPV6_HOPLIMIT<br>IPV6_HOPOPTS<br>IPV6_NEXTHOP<br>IPV6_PKTINFO<br>IPV6_RTHDR | specify / receive destination options<br>specify / receive hop limit<br>specify / receive hop-by-hop options<br>specify next-hop address<br>specify / receive packet information<br>specify / receive routing header |
| Unix domain | SOL_SOCKET | SCM_RIGHTS<br>SCM_CREDS | send / receive descriptors<br>send / receive user credentials |

# Ancillary Data

- File descriptors and process credentials can be passed between unrelated processes using ancillary data.



# Passing File Descriptors Example



- Protocol
  - If buf[1]<0 then there is error.
  - If buf[1]=0 then it is success.
- Receiver
  - Create unix domain stream socket
  - Send file name
  - Call recv_fd
- Sender
  - Create unix domain stream socket
  - Open the file descriptor
  - Call send_fd

# Macros



- Macros associated with ancillary data

```
1  #include <sys/socket.h>
2  #include <sys/param.h> /* for ALIGN macro on many implementations */
3  struct cmsghdr *CMSG_FIRSTHDR(struct msghdr *mhdrptr) ;
4  //Returns: pointer to first cmsghdr structure or NULL if no ancillary data
5  struct cmsghdr *CMSG_NXTHDR(struct msghdr *mhdrptr, struct cmsghdr *cmsgptr) ;
6  //Returns: pointer to next cmsghdr structure or NULL if no more ancillary data
7  unsigned char *CMSG_DATA(struct cmsghdr *cmsgptr) ;
8  //Returns: pointer to first byte of data associated with cmsghdr structure
9  unsigned int CMSG_LEN(unsigned int length) ;
10 //Returns: value to store in cmsg_len given the amount of data
11 unsigned int CMSG_SPACE(unsigned int length) ;
12 //Returns: total size of an ancillary data object given the amount of data
```

# Send fd

```c
#include <sys/socket.h>
#define CONTROLLEN  CMSG_LEN(sizeof(int))
static struct cmsghdr   *cmptr = NULL;
int send_fd(int fd, int fd_to_send)
{   struct iovec    iov[1];
    struct msghdr   msg;
    char            buf[2]; /* send_fd()/recv_fd() 2-byte protocol */
    iov[0].iov_base = buf; iov[0].iov_len  = 2;
    msg.msg_iov     = iov; msg.msg_iovlen  = 1;
    msg.msg_name    = NULL; msg.msg_namelen = 0;
if (fd_to_send < 0) {
        msg.msg_control    = NULL;
        msg.msg_controllen = 0;
        buf[1] = -fd_to_send;   /* nonzero status means error */
}
else { if (cmptr == NULL && (cmptr = malloc(CONTROLLEN)) == NULL)
            return(-1);
        cmptr->cmsg_level  = SOL_SOCKET;
        cmptr->cmsg_type   = SCM_RIGHTS;
        cmptr->cmsg_len    = CONTROLLEN;
        msg.msg_control    = cmptr;
        msg.msg_controllen = CONTROLLEN;
        *(int *)CMSG_DATA(cmptr) = fd_to_send;     /* the fd to pass */
        buf[1] = 0;          /* zero status means OK */
    }
    buf[0] = 0;              /* null byte flag to recv_fd() */
    if (sendmsg(fd, &msg, 0) != 2)
        return(-1);
    return(0);
}
```

# Receive fd

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```
1  int recv_fd(int sockfd )
2  {
3      #define CONTROLLEN  CMSG_LEN(sizeof(int))
4      static struct cmsghdr   *cmptr = NULL;
5
6      struct iovec    iov[1];
7      struct msghdr   msg;
8      char            buf[2]; /* send_fd()/recv_fd() 2-byte protocol */
9      memset(&msg, 0, sizeof(msg));
10     iov.iov_base   = buf;
11     iov.iov_len    = sizeof(data)-1;
12     msg.msg_iov    = &iov;
13     msg.msg_iovlen = 1;
14     if (cmptr == NULL && (cmptr = malloc(CONTROLLEN)) == NULL)
15        return(-1);
16     msg.msg_control = cmptr;
17     msg.msg_controllen = CONTROLLEN;
18     recvmsg(sockfd, &msg, 0)
19         if (buf[1]<0)) {
20                 printf("failed to open %s: %s\n", name, data);
21                 return -1;
22         }
23         /* Loop over all control messages */
24         cmsg = CMSG_FIRSTHDR(&msg);
25         while (cmsg != NULL) {
26                 if (cmsg->cmsg_level == SOL_SOCKET
27                  && cmsg->cmsg_type  == SCM_RIGHTS)
28                         return *(int *) CMSG_DATA(cmsg);
29                 cmsg = CMSG_NXTHDR(&msg, cmsg);
30         }
31 }
```

# Passing Credentials



- A process can pass its credentials as ancillary data using SCM_CREDS option.
- The structure for credentials

```
1  struct ucred {
2      pid_t pid;    /* process ID of the sending process */
3      uid_t uid;    /* user ID of the sending process */
4      gid_t gid;    /* group ID of the sending process */
5  };
```

- This structure is filled by the kernel and passed onto the receiver process.
- Example:
  - Sender process sends file name and access mode.
  - Server verifies the credentials and passes on the fd.

# Sender

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```
1  sockfd = socket(AF_LOCAL, SOCK_STREAM, 0);
2  bzero(&servaddr, sizeof(servaddr));
3  servaddr.sun_family = AF_LOCAL;
4  strcpy(servaddr.sun_path, "PATH");
5  connect(sockfd, (struct sockaddr *) &servaddr, sizeof(servaddr));
6  msgh.msg_iov = &iov;
7  msgh.msg_iovlen = 1;
8  /* Send Filename and Access Mode to server */
9  strcat(data, argv[1]);strcat(data, "#");
10 strcat(data, argv[2]);strcat(data, "#");
11 iov.iov_base = data;
12 iov.iov_len = MAX_DATA;
13 msgh.msg_name = NULL;
14 msgh.msg_namelen = 0;
15 msgh.msg_control = NULL;
16 msgh.msg_controllen = 0;
17
18 if(sendmsg(sockfd, &msgh, 0) < 0)
19 {
20     perror("Error sending message");
21     exit(1);
22 }
```

# Receiver

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```
1   optval = 1;
2   /* Set SO_PASSCRED socket option for receving credentials of other processes */
3   setsockopt(*(int *)arg, SOL_SOCKET, SO_PASSCRED, &optval, sizeof(optval));
4   /* Set 'control_un' to describe ancillary data that we want to receive */
5   control_un.cmh.cmsg_len = CMSG_LEN(sizeof(struct ucred));
6   control_un.cmh.cmsg_level = SOL_SOCKET;
7   control_un.cmh.cmsg_type = SCM_CREDENTIALS;
8   /* Set 'msgh' fields to describe 'control_un' */
9   msgh.msg_control = control_un.control;
10  msgh.msg_controllen = sizeof(control_un.control);
11  msgh.msg_iov = &iov;    msgh.msg_iovlen = 1;
12  iov.iov_base = data;
13  iov.iov_len = MAX_DATA;
14  msgh.msg_name = NULL;
15  msgh.msg_namelen = 0;
16  /* Receive real plus ancillary data */
17  nr = recvmsg(*(int *)arg, &msgh, 0);
18  /* Extract credentials information from received ancillary data */
19  cmhp = CMSG_FIRSTHDR(&msgh);
20  ucredp = (struct ucred *) CMSG_DATA(cmhp);
21  printf("Received Credentials pid: %ld, uid: %ld, gid: %ld\n",
22  (long) ucredp->pid, (long) ucredp->uid, (long) ucredp->gid);
```

# The Linux Abstract Socket Namespace



- Is a Linux-specific feature that allows us to bind a UNIX domain socket to a name without that name being created in the file system.
- It is not necessary to unlink the socket pathname when we have finished using the socket. The abstract name is automatically removed when the socket is closed.
  - To create an abstract binding, we specify the first byte of the sun_path field as a null byte ( \0 ).
  - The remaining bytes of the sun_path field then define the abstract name for the socket. These bytes are interpreted in their entirety, rather than as a null-terminated string.

# The Linux Abstract Socket Namespace Example

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```
1   struct sockaddr_un addr;
2   memset(&addr, 0, sizeof(struct sockaddr_un));  /* Clear address structure */
3   addr.sun_family = AF_UNIX;                     /* UNIX domain address */
4   /* addr.sun_path[0] has already been set to 0 by memset() */
5   strncpy(&addr.sun_path[1], "xyz", sizeof(addr.sun_path) - 2);
6               /* Abstract name is "xyz" followed by null bytes */
7   sockfd = socket(AF_UNIX, SOCK_STREAM, 0);
8   if (sockfd == -1)
9       errExit("socket");
10  if (bind(sockfd, (struct sockaddr *) &addr,
11           sizeof(struct sockaddr_un)) == -1)
12      errExit("bind");
```

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# Unix I/O Models

# IO Models



- While doing I/O there are two phases
  - Waiting for the data
  - Copying the data
- Each I/O model differs how it deals with these two phases.
- There are five I/O models
  - blocking I/O
  - nonblocking I/O
  - I/O multiplexing (select and poll)
  - signal driven I/O (SIGIO)
  - asynchronous I/O (the POSIX aio_functions)

# Blocking I/O Model

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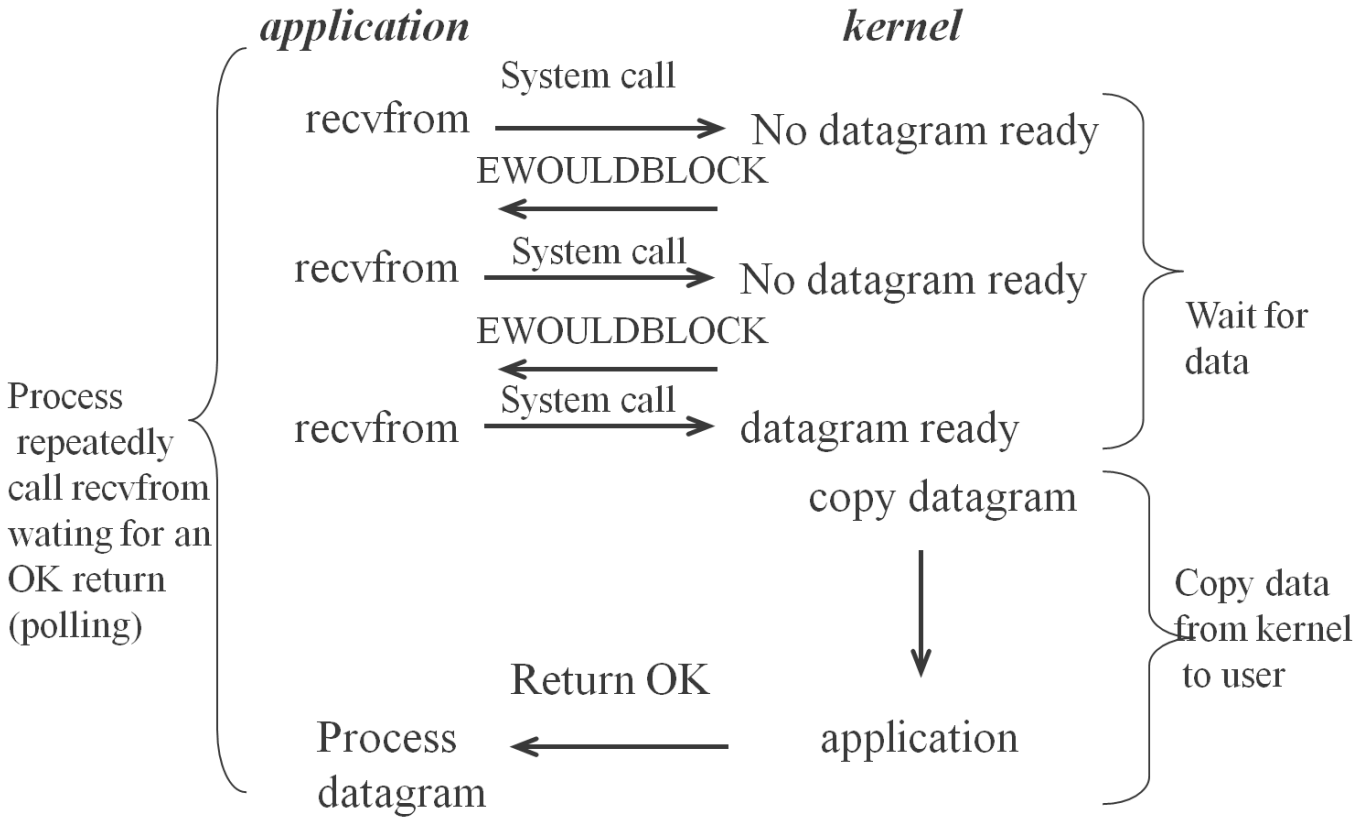
- Most prevalent model

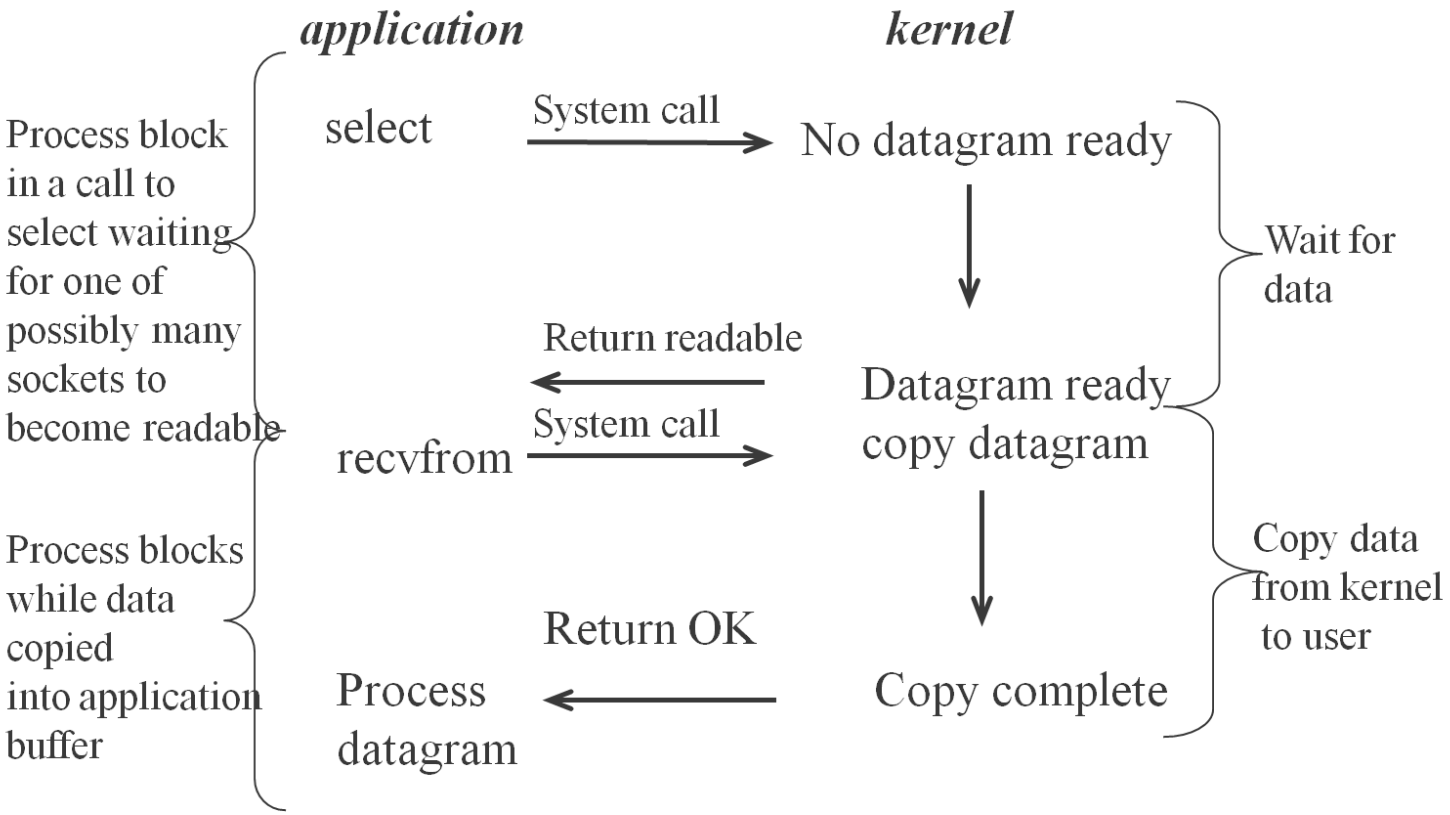
# Nonblocking I/O Model

- When the socket is set to be non-blocking,
  - We tell the kernel that do not put the process to sleep if IO can't be completed.



# I/O Multiplexing Model

- Block in select() or poll() instead of blocking in actual I/O system call.



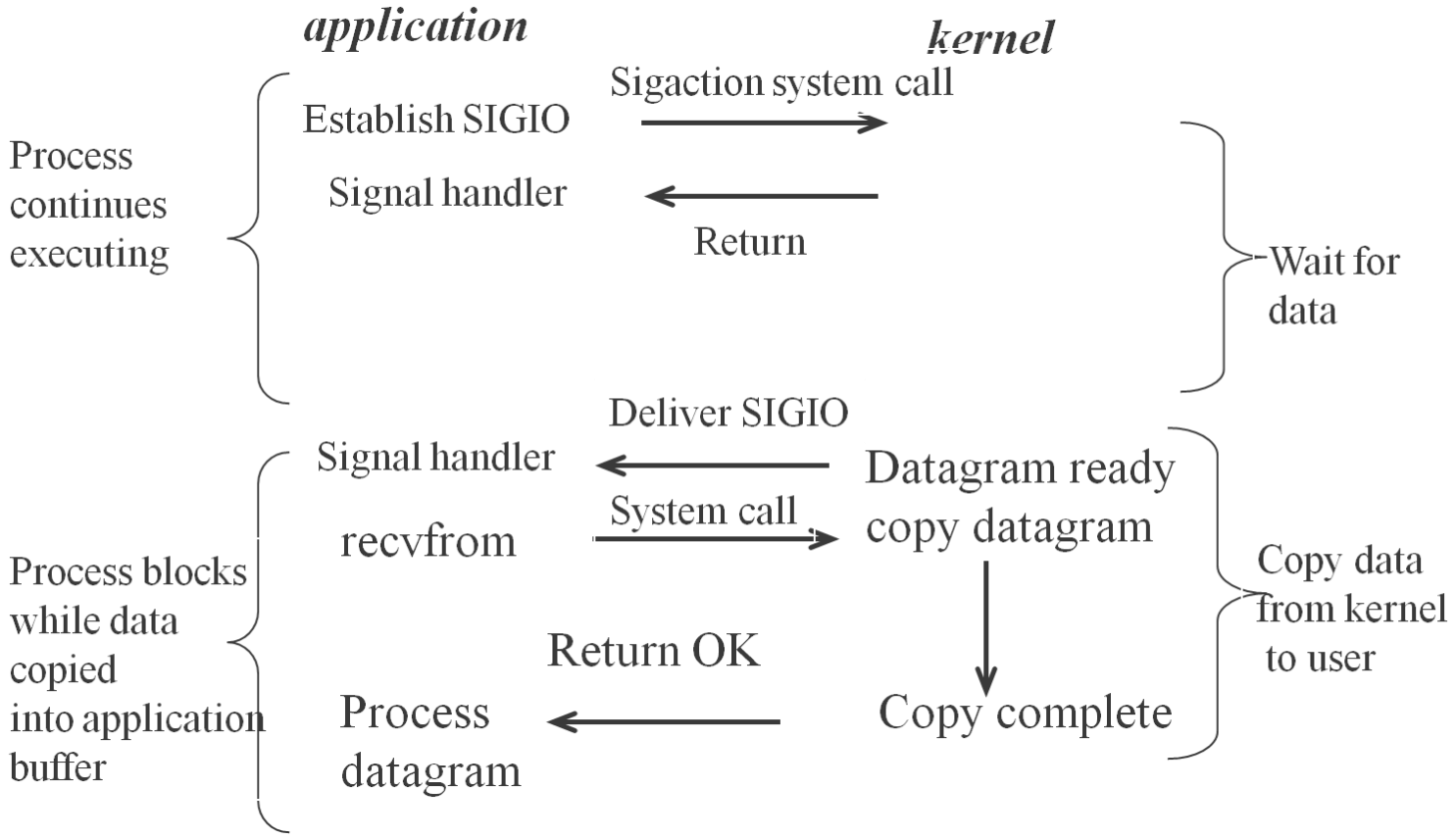
# I/O Multiplexing Model



- Blocking and I/O multiplexing seem to be non-different and actually calling two sys calls in I/O multiplexing.
- Advantage with I/O multiplexing is that it can wait for I/O on multiple fds.

# Signal-Driven I/O Model

- Tell the kernel to notify us with the SIGIO signal when the descriptor is ready.



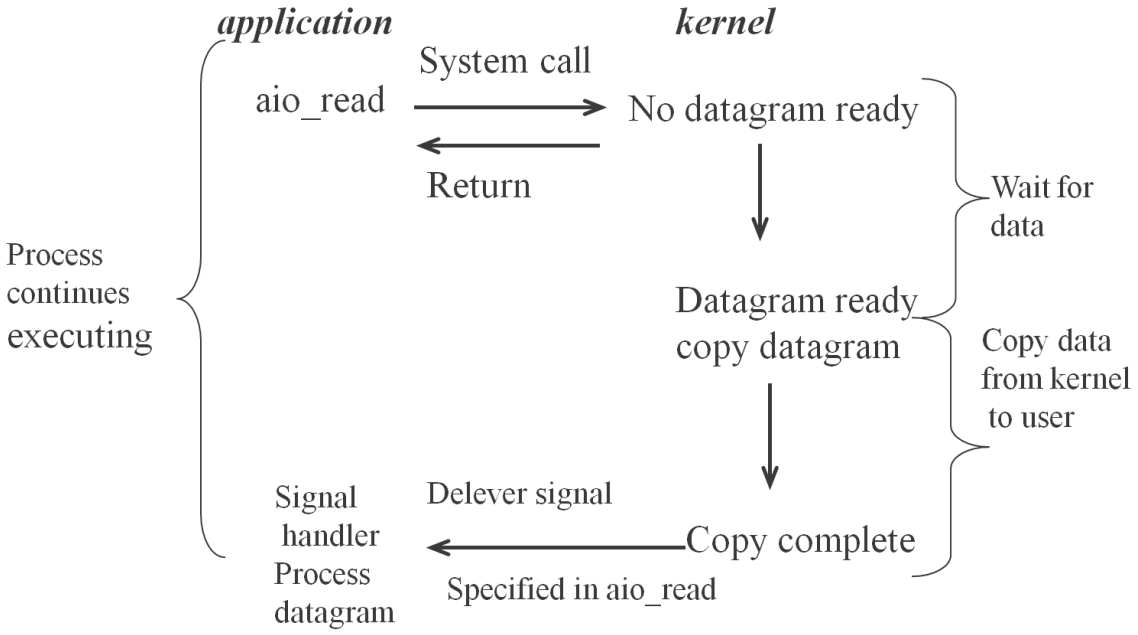
# Signal-Driven I/O Model



- To use signal-driven I/O with a socket (SIGIO) requires the process to perform the following three steps:
  - A signal handler must be established for the SIGIO signal.
  - The socket owner must be set, normally with the F_SETOWN command of fcntl.
  - Signal-driven I/O must be enabled for the socket, normally with the F_SETFL command of fcntl to turn on the O_ASYNC flag.

# Asynchronous I/O Model

- The main difference between this model and the signal-driven I/O models that
  - with signal-driven I/O, the kernel tells us when an I/O operation can be initiated,
  - but with asynchronous I/O, the kernel tells us when an I/O operation is complete.



# Asynchronous I/O Model



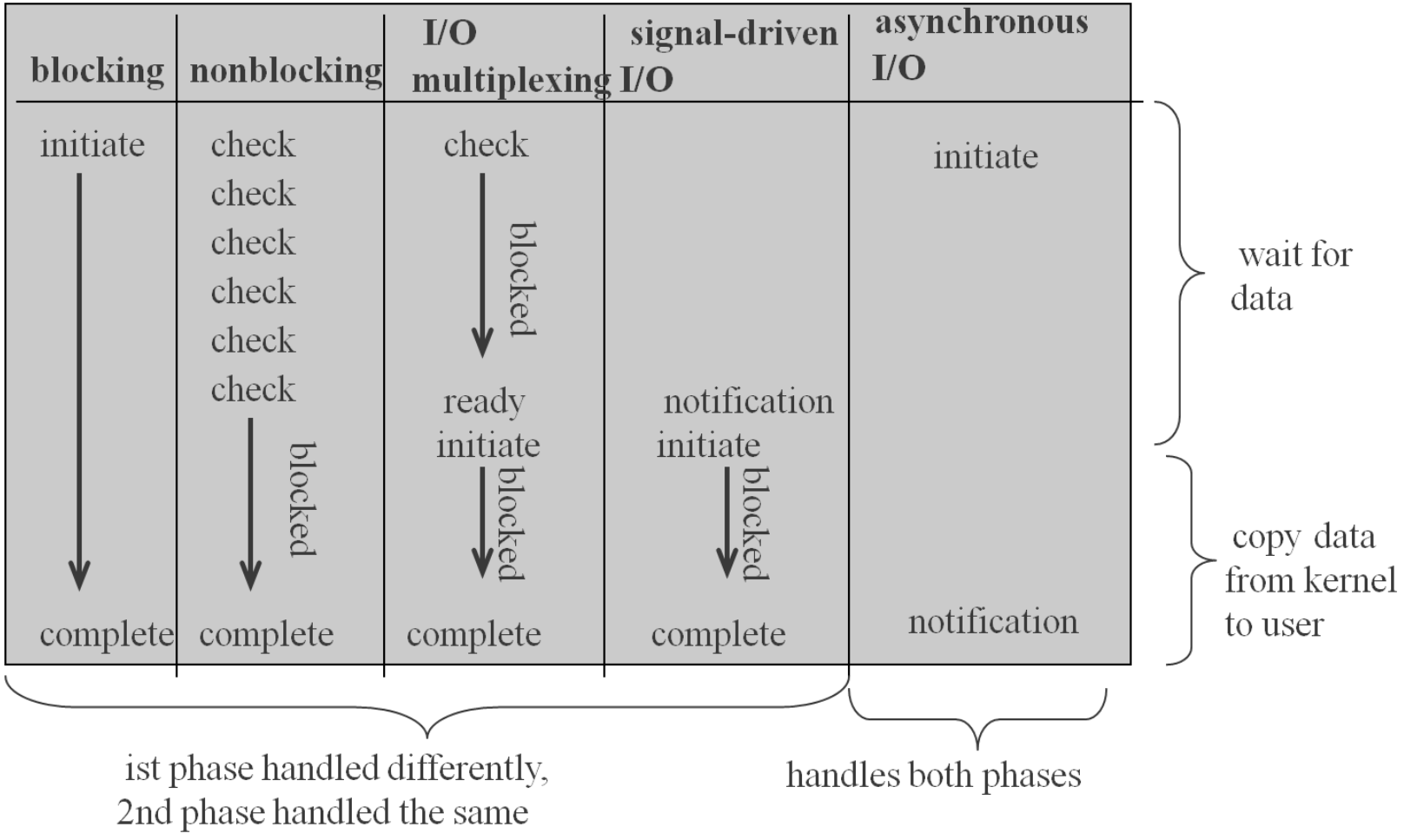
- POSIX API for asynchronous IO is implemented in a very few systems.
- *aiocb* structure

```
1  struct aiocb{
2  int             aio_fildes //    file descriptor
3  off_t           aio_offset //    file offset
4  volatile void*  aio_buf //       location of buffer
5  size_t          aio_nbytes //    length of transfer
6  int             aio_reqprio //   request priority offset
7  struct sigevent aio_sigevent  // signal number and value
8  int             aio_lio_opcode //operation to be performed
9  };
```

```
1  #include <aio.h>
2  int aio_read(struct aiocb *aiocbp);
```

# Comparison of I/O Models

- First four models differ only in first phase.



# Synchronous I/O vs Asynchronous I/O



- POSIX defines these two terms as follows:
  - A synchronous I/O operation causes the requesting process to be blocked until that I/O operation completes.
  - An asynchronous I/O operation does not cause the requesting process to be blocked.
- Using these definitions,
  - the first four I/O models
    - blocking,
    - nonblocking,
    - I/O multiplexing,
    - and signal-driven I/O
  - are all synchronous because the actual I/O operation (recvfrom) blocks the process.
  - Only the asynchronous I/O model matches the asynchronous I/O definition.

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# I/O Multiplexing

T1: Ch6

# I/O Multiplexing



- I/O multiplexing allows us to simultaneously monitor multiple file descriptors to see if I/O is possible on any of them.
- select(), appeared along with the sockets API in BSD. This was historically the more widespread of the two system calls. The other system call, poll(), appeared in System V.
- We can use select() and poll() to monitor file descriptors for regular files, terminals, pseudoterminals, pipes, FIFOs, sockets, and some types of character devices.
- Both system calls allow a process either to block indefinitely waiting for file descriptors to become ready or to specify a timeout on the call.

# select()



- The select() system call blocks until one or more of a set of file descriptors becomes ready.

```
1  #include <sys/time.h>   /* For portability */
2  #include <sys/select.h>
3  int select(int  nfds , fd_set * readfds , fd_set * writefds,
4             fd_set * exceptfds, struct timeval * timeout );
5  //Returns number of ready file descriptors, 0 on timeout, or -1 on error
```

  - *nfds*: highest number assigned to a descriptor +1.
  - *readfds*: set of descriptors we want to read from.
  - *writefds*: set of descriptors we want to write to.
  - *exceptfds*: set of descriptors to watch for  exceptions.
  - *timeout*: maximum time select should wait

```
7  struct timeval {
8      long tv_usec;    /* seconds */
9      long tv_usec;    /* microseconds */
10 }
```

# select()



- timeval==NULL
  - Wait forever : return only when descriptor is ready
- timeval != NULL: wait up to a fixed amount of time
  - timeval = 0
    - Do not wait at all : return immediately after checking the descriptors
  - Timeval>0
    - Return only if descriptor is ready or timeval expires.

# File descriptor sets



- The readfds, writefds, and exceptfds arguments are pointers to file descriptor sets, represented using the data type *fd_set*.
- the fd_set data type is implemented as a bit mask.

```
1  #include <sys/select.h>
2  void FD_ZERO(fd_set *fdset);
3   /* clear all bits in fdset */
4  void FD_SET(int fd, fd_set *fdset);
5   /* turn on the bit for fd in fdset */
6  void FD_CLR(int fd, fd_set *fdset);
7   /* turn off the bit for fd in fdset */
8  int FD_ISSET(int fd, fd_set *fdset);
9   /* is the bit for fd on in fdset ? */
10  //Returns true (1) if fd is in fdset, or false (0) otherwise
```

- A file descriptor set has a maximum size, defined by the constant FD_SETSIZE . On Linux, this constant has the value 1024.

# select()



- *nfds*
  - Its value is the maximum descriptor to be tested, plus one
    - example: fds 1,2,5 => nfds: 6
- *readset*
  - descriptor set for checking readable
- *writeset*
  - descriptor set for checking writable
- *exceptset*
  - descriptor set for checking two exception conditions
    - arrival of out of band data for a socket
    - he presence of control status information to be read from the master side of a pseudo terminal
- When select returns value>1, these sets have been modified by kernel. Now they contain the fds which are ready.

# When is the descriptor ready for reading?



- The number of bytes of data in the socket receive buffer is greater than or equal to the current size of the low-water mark for the socket receive buffer. SO_RCVLOWAT socket option. It defaults to 1 for TCP and UDP sockets
- The read half of the connection is closed (i.e., a TCP connection that has received a FIN)
- The socket is a listening socket and the number of completed connections is nonzero.
- A socket error is pending. A read operation on the socket will not block and will return an error (–1) with errno set to the specific error condition.

# When the socket is ready for writing?

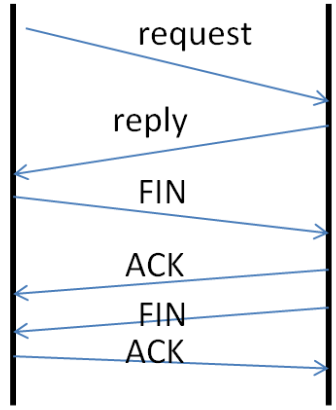


- The number of bytes of available space in the socket send buffer is greater than or equal to the current size of the low-water mark for the socket send buffer. 2048 bytes.
- The write half of the connection is closed. A write operation on the socket will generate SIGPIPE.
- A socket using a non-blocking connect has completed the connection, or the connect has failed
- A socket error is pending. A write operation on the socket will not block and will return an error (–1) with errno set to the specific error condition.
- These pending errors can also be fetched and cleared by calling getsockopt with the SO_ERROR socket option.

# Client Handling Multiple Descriptors



- A client is handling two descriptors.
  - *stdin*
  - *socket*
- Sequential handling:
  - First wait on *stdin.*
  - Write to *socket*
  - Read from *socket*.
  - Write to *stdout*.



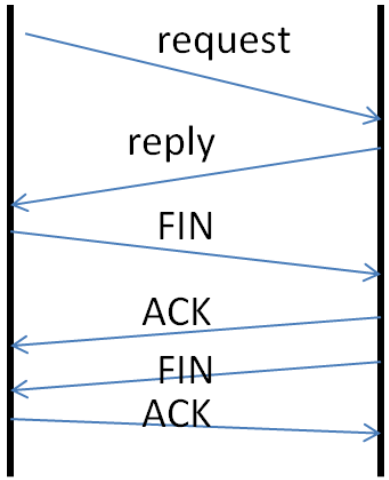
Normal course of actions

```
1  void str_cli(FILE *fp, int sockfd)
2  {
3  char sendline[MAXLINE], recvline[MAXLINE];
4   while (Fgets(sendline, MAXLINE, fp) != NULL) {
5       Writen(sockfd, sendline, strlen (sendline));
6       if (Readline(sockfd, recvline, MAXLINE) == 0)
7          err_quit("str_cli: server terminated prematurely");
8       Fputs(recvline, stdout);
9   }
10 }
```

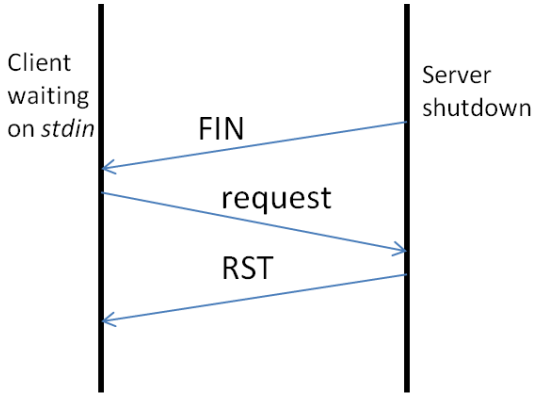
# Client Handling Multiple Descriptors



- read() call on both stdin and socket will block until data is available.
- Consider a case:
  - If client is blocked in waiting for user to enter data, meanwhile TCP receives FIN from server.
    - Server is down. So sending request is meaningless.
- How to handle uncertainty of availability of data on descriptors?



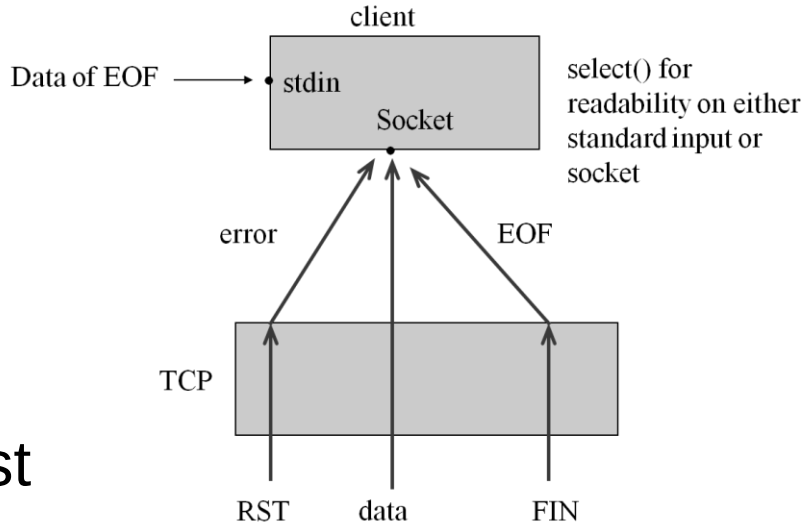

Normal course of actions




Unexpected Server shutdown

# read() on socket

- Peer TCP sends data, the socket becomes readable and *read* returns greater than 0.
- Peer TCP send a FIN(peer process terminates), the socket become readable and *read* returns 0(end-of-file)
- Peer TCP send a RST(peer host has crashed and rebooted), the socket become readable and returns -1 and *errno* contains the specific error code



# Client Handling Multiple Descriptors



- To avoid a situation where data has arrived from socket but client is unable to take note of it, use I/O Multiplexing.
- Client can wait on select().
  - Add stdin, socket to fd_set.
  - Call select () with fd_set for readabliity
  - When select() returns, find out which descriptor is ready with data.
  - Call read() on that fd.
- This will enable client to give timely response and avoid error situations.

# Client Handling Multiple Descriptors

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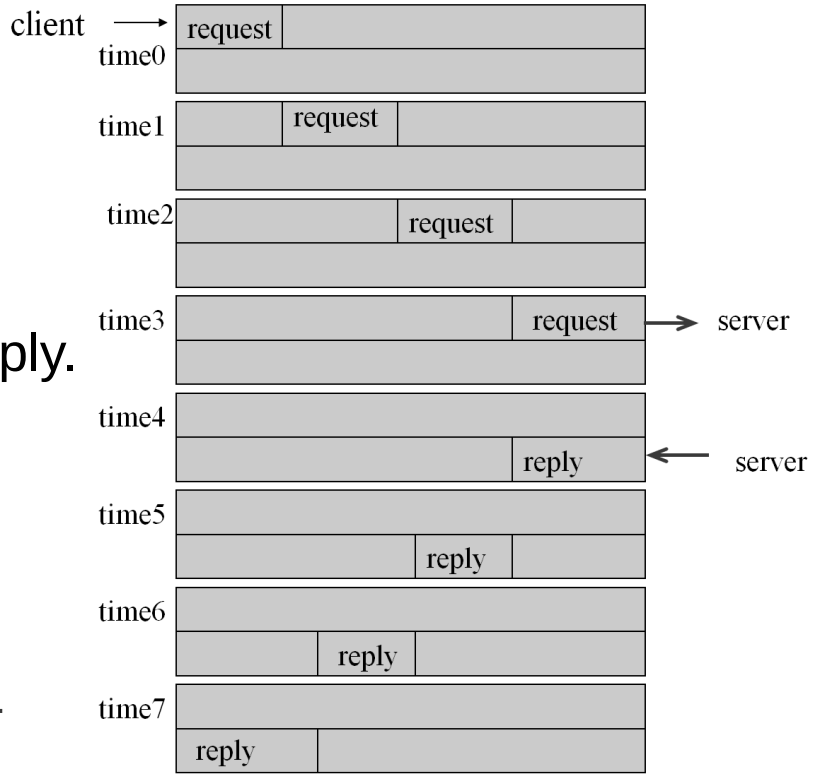
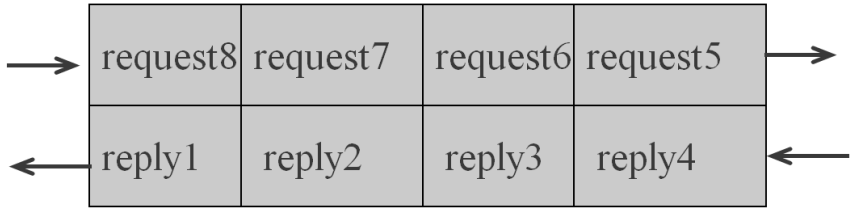
```
1   void  str_cli(FILE *fp, int sockfd)
2   {
3   int    maxfdp1;
4   fd_set  rset;
5   char    sendline[MAXLINE], recvline[MAXLINE];
6   FD_ZERO(&rset);
7   for ( ; ; ) {
8       FD_SET(fileno(fp), &rset);
9       FD_SET(sockfd, &rset);
10      maxfdp1 = max(fileno(fp), sockfd) + 1;
11      select(maxfdp1, &rset, NULL, NULL, NULL);
12      if (FD_ISSET(sockfd, &rset)) {    /* socket is readable */
13      if (Readline(sockfd, recvline, MAXLINE) == 0)
14      err_quit("str_cli: server terminated prematurely");
15      Fputs(recvline, stdout);
16      }
17      if (FD_ISSET(fileno(fp), &rset)) {  /* input is readable */
18      if (Fgets(sendline, MAXLINE, fp) == NULL)
19      return;      /* all done */
20      Writen(sockfd, sendline, strlen(sendline));
21      }
22  }//for
23  }//str_cli
```

# Batch Mode Client

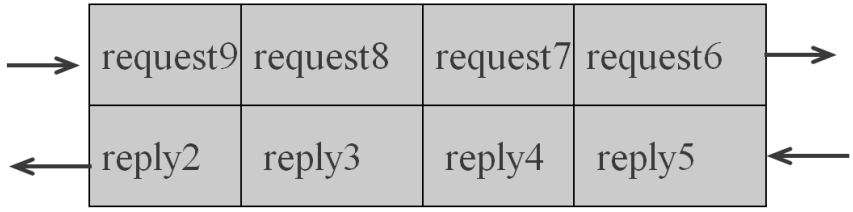
- Stop and Wait client
  - Send one request and wait for reply.
  - Usual in interactive mode.
- Batch Mode clients
  - Send requests without waiting for reply.
  - Better bandwidth utilization.




Time 7:




Time 8:



# Batch Mode Client



- Need for closing a socket partially:
  - We tell server that we have sent all requests by closing socket.
    - It will send FIN to server.
  - But in batch mode, by closing socket, we send FIN but we can't read replies which are yet to reach the client.
- close() vs shutdown() sys calls
  - closes the socket partially (either read end or write end) unlike close() sys call.
    - close() closes completely.
  - Irrespective of reference count it closes the socket.
    - close() will initiate FIN only if reference count for the fd reaches 0.

# shutdown() sys call



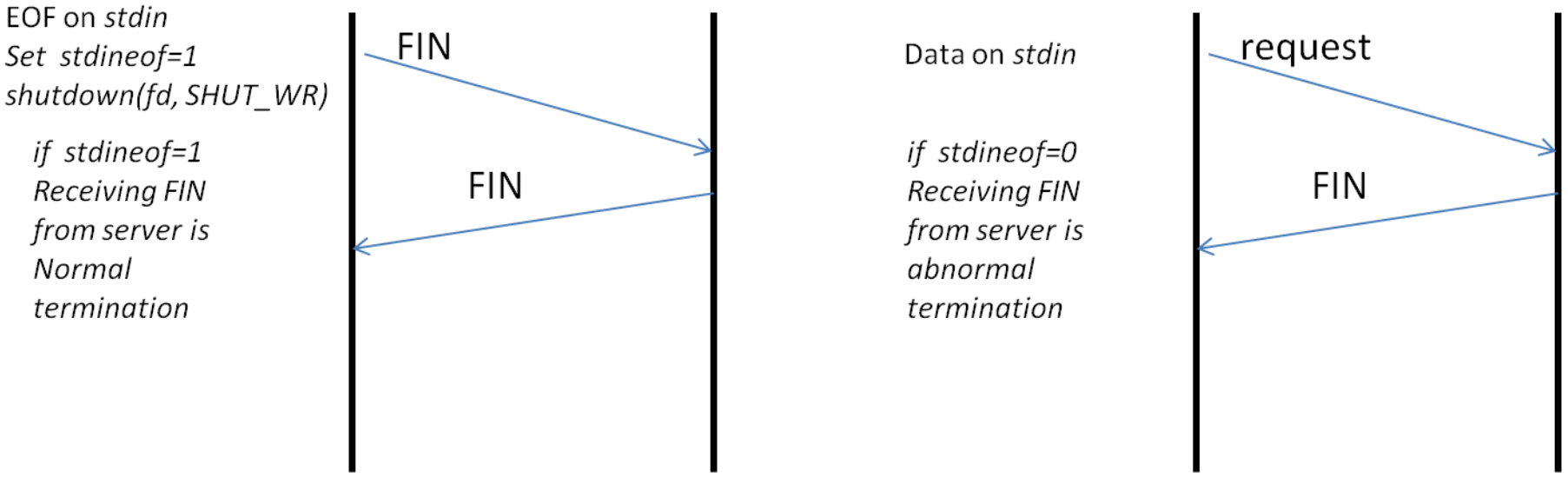
- Sometimes, it is useful to close one half of the connection, so that data can be transmitted in just one direction through the socket.

```
1  #include <sys/socket.h>
2  int shutdown(int  sockfd , int  how );
3  //Returns 0 on success, or -1 on error
```

  - SHUT_RD : read-half of the connection closed. Subsequent reads will return end-of-file (0).
    - SHUT_RD can't be used meaningfully for TCP sockets.
  - SHUT_WR : write-half of the connection closed. Also called *socket half-close*. Buffered data will be sent followed by termination sequence.
    - Common use of shutdown()
    - Subsequent writes to the local socket yield the SIGPIPE signal and an EPIPE error.
  - SHUT_RDWR : both closed
    - Note that shutdown() doesn't close the file descriptor, even if how is specified as SHUT_RDWR . To close the file descriptor, we must additionally call close().

# Batch Mode Client

- After user presses, Ctrl-D (EOF), close write half of the socket.
- Also set *stdineof* variable to 1.
  - This will help in inferring the FIN received from server as normal or abnormal termination.
  - In case of normal termination, we received all the replies.



```
1  str_cli(FILE *fp, int sockfd)
2  {
3   int     maxfdp1, stdineof;
4   fd_set  rset;
5   stdineof = 0;
6   FD_ZERO(&rset);
7   for ( ; ; ) {
8      if (stdineof == 0)
9          FD_SET(fileno(fp), &rset);
10     FD_SET(sockfd, &rset);
11     maxfdp1 = max(fileno(fp), sockfd) + 1;
12     select(maxfdp1, &rset, NULL, NULL, NULL);
13     if (FD_ISSET(sockfd, &rset)) {  /* socket is readable */
14     if ( (n = Read(sockfd, buf, MAXLINE)) == 0) {
15         if (stdineof == 1)
16             return;         /* normal termination */
17         else
18             err_quit("str_cli: server terminated prematurely");
19             }
20         Write(fileno(stdout), buf, n);
21     }
22     if (FD_ISSET(fileno(fp), &rset)) {  /* input is readable */
23     if ( (n = Read(fileno(fp), buf, MAXLINE)) == 0) {
24         stdineof = 1;
25         shutdown(sockfd, SHUT_WR);  /* send FIN */
26         FD_CLR(fileno(fp), &rset);
27             continue;
28             }
29         Writen(sockfd, buf, n);
30         }
31     } }
```

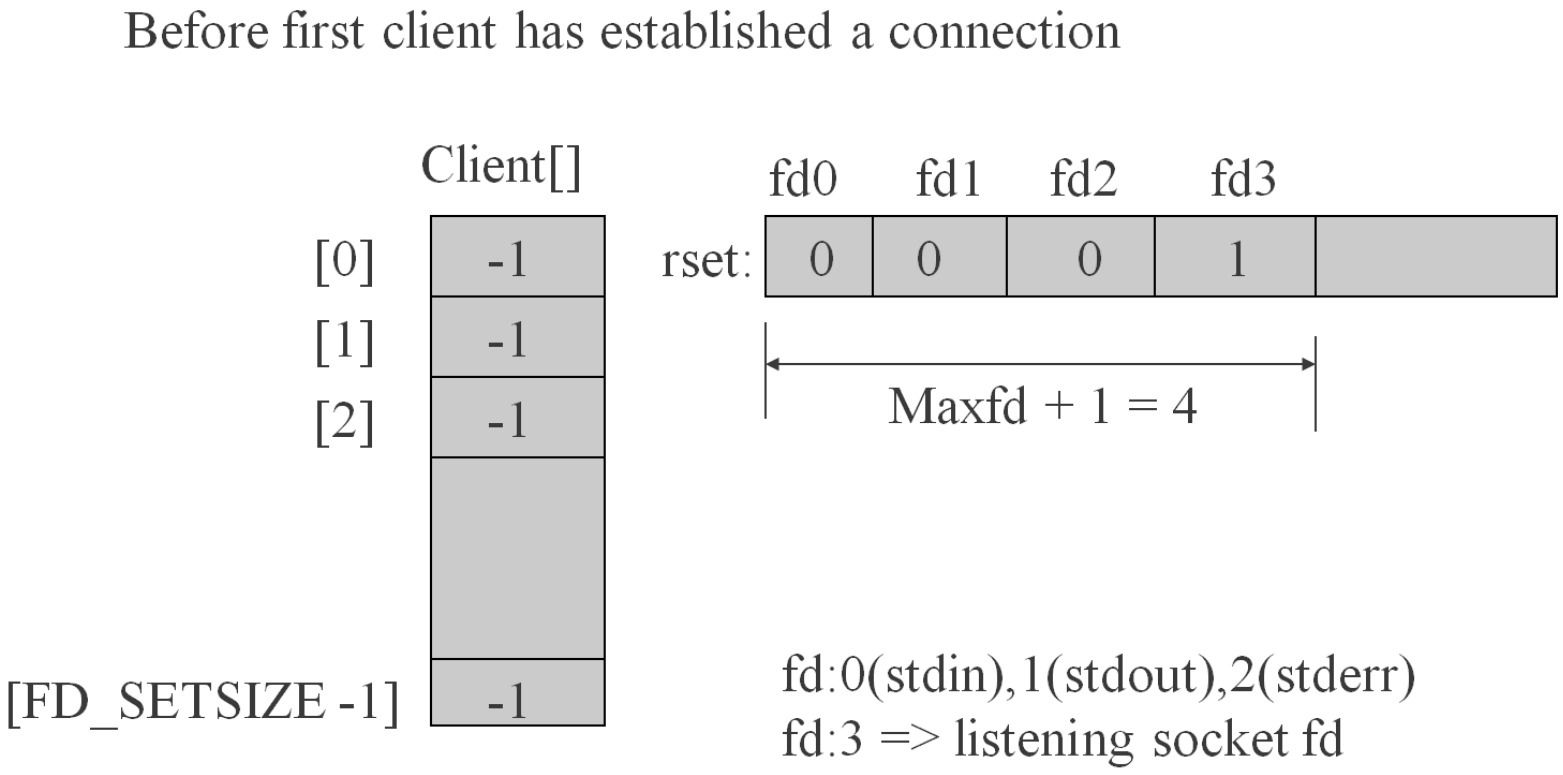
# TCP Server Using select()



- Single process server that uses select to handle any number of clients, instead of forking one child per client.
- Protocol: echo
- Two data structures:
  - Client array
    - Keeps list of client sockets connected currently
  - fd_set *allset*
    - Keeps list of fds for checking against readability.

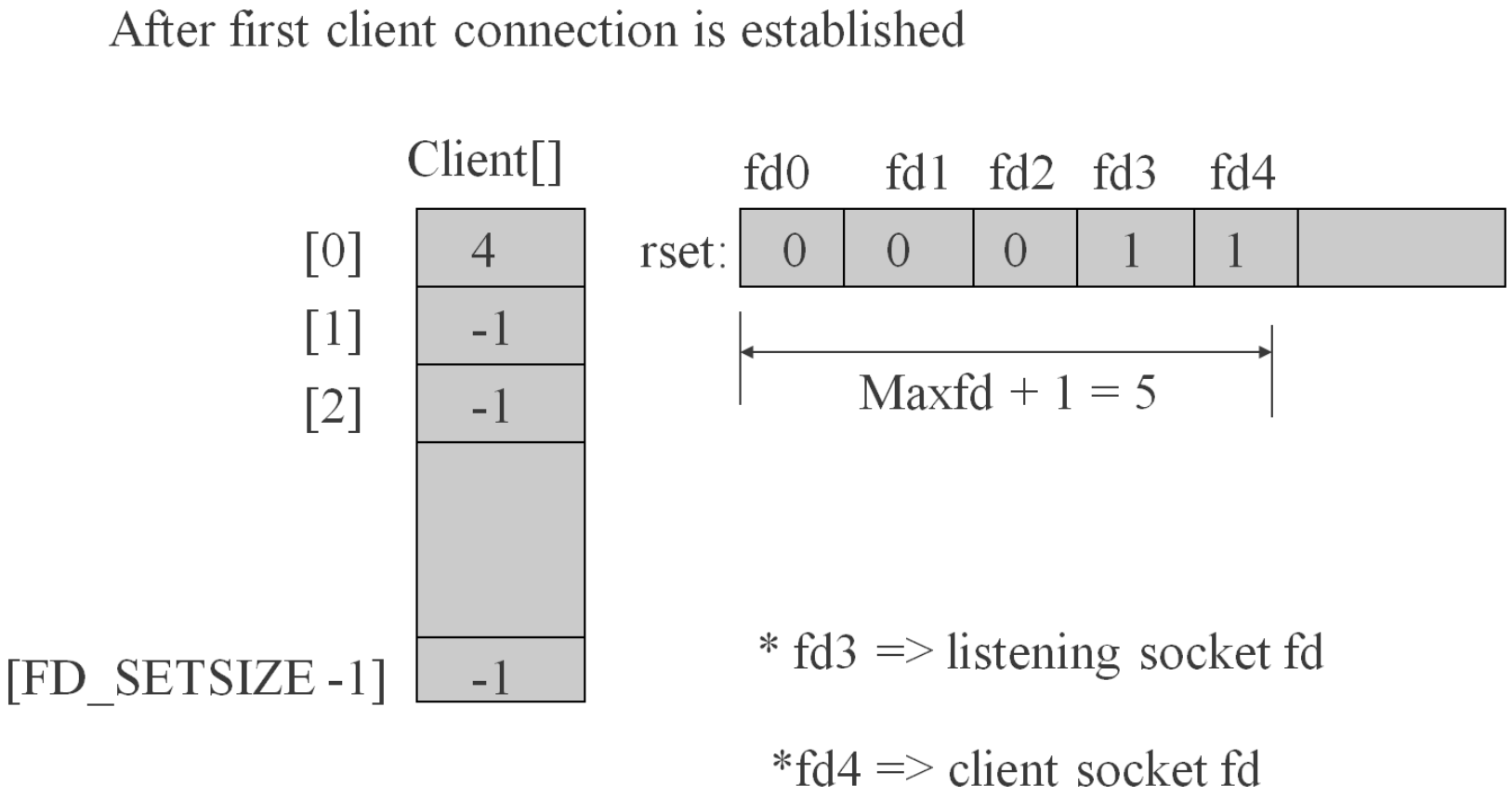
# TCP Server Using select()

- There are three fds: 0,1,2
- One more fd after creating listening socket.



# TCP Server Using select()

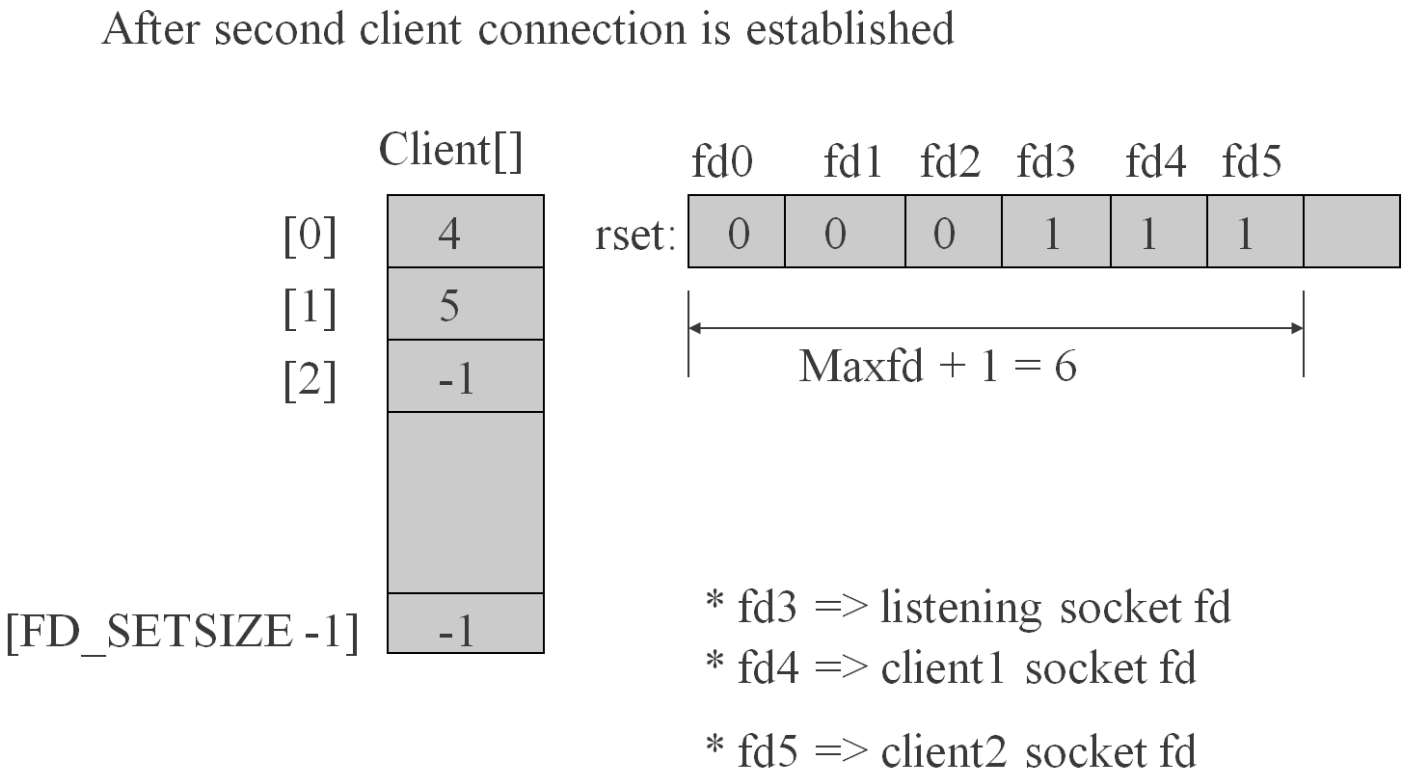
- When a new client is accepted through accept()
  - A connected socket is added



# TCP Server Using select()

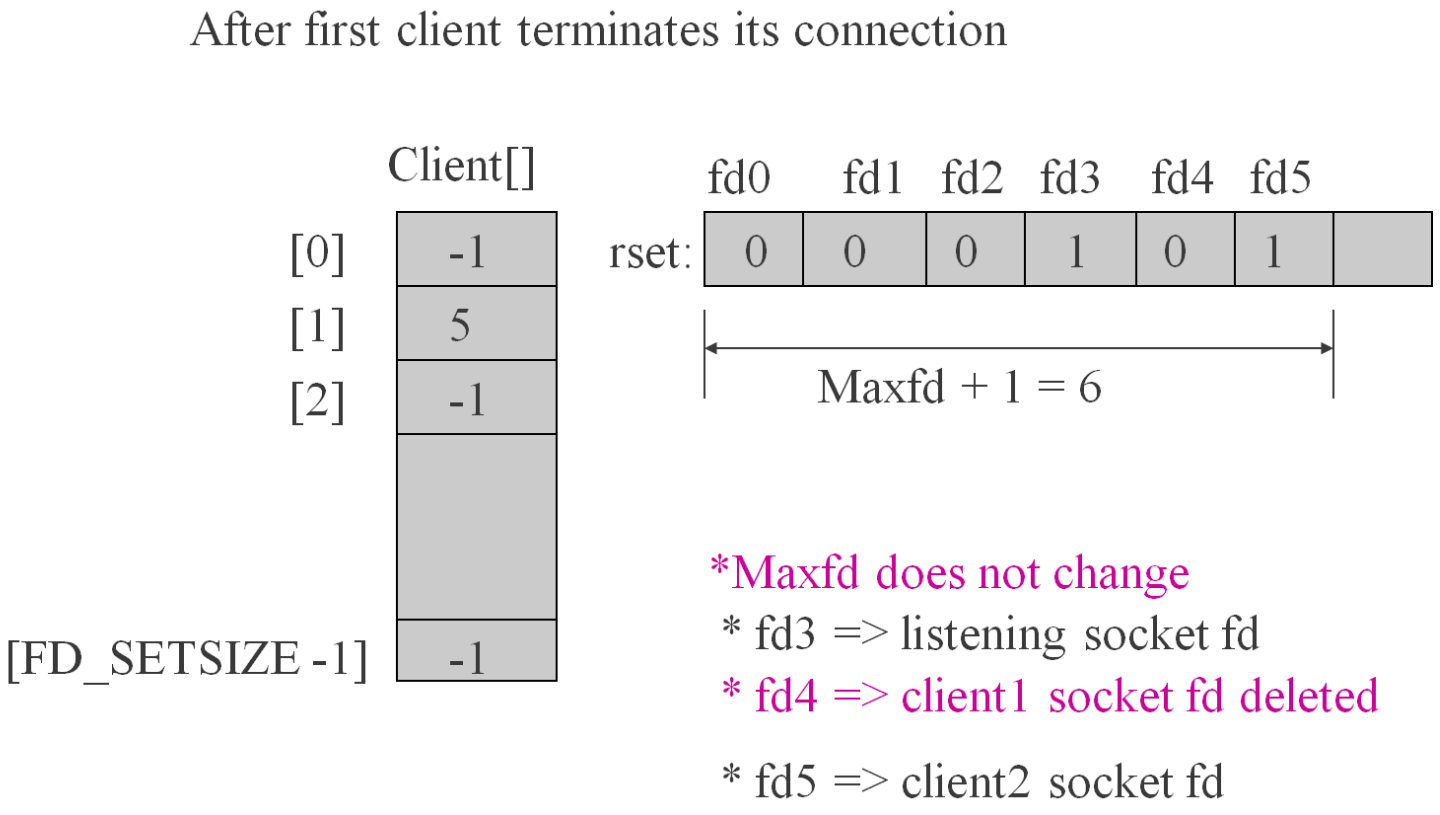


- When second client is accepted



# TCP Server Using select()

- When the first client terminates connection
  - This is known when read() returns zero.



# TCP Server Using select()



- Create a passive socket.

```
 1  int main(int argc, char **argv)
 2  {
 3      int         i, maxi, maxfd, listenfd, connfd, sockfd;
 4      int         nready, client[FD_SETSIZE];
 5      fd_set          rset, allset;
 6      struct sockaddr_in  cliaddr, servaddr;
 7      listenfd = socket(AF_INET, SOCK_STREAM, 0);
 8      bzero(&servaddr, sizeof(servaddr));
 9      servaddr.sin_family      = AF_INET;
10      servaddr.sin_addr.s_addr = htonl(INADDR_ANY);
11      servaddr.sin_port        = htons(SERV_PORT);
12      bind(listenfd, (SA *) &servaddr, sizeof(servaddr));
13      listen(listenfd, LISTENQ);
```

# TCP Server Using select()



- Handling when listening socket is readable

```
1   maxfd = listenfd;           /* initialize */
2   maxi = -1;                  /* index into client[] array */
3   for (i = 0; i < FD_SETSIZE; i++)
4   client[i] = -1;             /* -1 indicates available entry */
5   FD_ZERO(&allset);
6   FD_SET(listenfd, &allset);
7   for ( ; ; ) {
8       rset = allset;          /* structure assignment */
9       nready = select(maxfd+1, &rset, NULL, NULL, NULL);
```

```
10      if (FD_ISSET(listenfd, &rset)) {/* new client connection */
11          clilen = sizeof(cliaddr);
12          connfd = accept(listenfd, (SA *) &cliaddr, &clilen);
13          for (i = 0; i < FD_SETSIZE; i++)
14              if (client[i] < 0) {
15                  client[i] = connfd;     /* save descriptor */
16              break;}
17          if (i == FD_SETSIZE) err_quit("too many clients");
18          FD_SET(connfd, &allset);    /* add new descriptor to set */
19          if (connfd > maxfd)
20              maxfd = connfd;         /* maxfd for select */
21          if (i > maxi)
22              maxi = i;   /* max index in client[] array */
23          if (--nready <= 0)
24              continue;   /* no more readable descriptors */
25      }
```

# TCP Server Using select()



- When a connected socket is readable

```
1  for (i = 0; i <= maxi; i++) {/* check all clients for data */
2      if ((sockfd = client[i]) < 0)
3          continue;
4      if (FD_ISSET(sockfd, &rset)) {
5          if ( (n = Readline(sockfd, line, MAXLINE)) == 0) {
6              /*connection closed by client */
7              close(sockfd);
8              FD_CLR(sockfd, &allset);
9              client[i] = -1;
10         }
11         else
12             Writen(sockfd, line, n);
13         if (--nready <= 0)
14         break;  /* no more readable descriptors */
15     }
16 }
```

- This code looks complicated when compared to fork-per-client model. But this design avoids overhead of fork().

# Denial-of-Service Attacks



- If malicious client connect to the server, send 1 byte of data (other than a newline), and then goes to sleep.
  - in readline(), server is blocked.
- Solution
  - use nonblocking I/O
  - have each client serviced by a separate thread of control (spawn a process or a thread to service each client)
  - place a timeout on the I/O operation

# pselect()

```
1 struct timespec{
2       time_t  tv_sec;   /*seconds*/
3       long     tv_nsec; /* nanoseconds */
4 };
```



- pselect contains two changes from the normal select function:
  - pselect uses the timespec structure instead of the timeval structure.
  - Accepts signal mask.

```
1  #define _XOPEN_SOURCE 600
2  #include <sys/select.h>
3  int pselect(int  nfds , fd_set * readfds , fd_set * writefds ,
4      fd_set * exceptfds,struct timespec * timeout , const sigset_t * sigmask );
5  //Returns number of ready file descriptors, 0 on timeout, or -1 on error
```

```
2  ready = pselect(nfds, &readfds, &writefds, &exceptfds, timeout, &sigmask);
```

  - This call is equivalent to

```
1  sigset_t origmask;
2  sigprocmask(SIG_SETMASK, &sigmask, &origmask);
3  ready = select(nfds, &readfds, &writefds, &exceptfds, timeout);
4  sigprocmask(SIG_SETMASK, &origmask, NULL);        /* Restore signal mask */
```

# Problems with select() and poll()

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- The select() and poll() system calls are the portable, long-standing, and widely used methods of monitoring multiple file descriptors for readiness.
- Suffer from some probems
  - Kernel must check all the fds to check if they are ready.
  - Each time select() passes data structures which kernel modifies and returns.
  - Once select() returns, the program must inspect the data structure to see which fds are ready.
- Select() scales poorly with the increase of *fds*.
- Signal driven I/O or *epoll* (event poll) provide a scalable solution.


# Non-blocking I/O on Sockets

# Socket Operations



- Input operations: read, recv, readv, recvfrom, recvmsg
  - Blocking operations
  - TCP: until a byte arrives.
  - UDP: until a datagram arrives.
  - With non-blocking socket, if no data, return with EWOULDBLOCK error.
- Output Operations: write, send, writev, sendto, sendmsg
  - Blocks if there is no room in socket send buffer.
  - TCP: until all the data is written.
  - UDP: no send buffer present.
  - With non-blocking socket, TCP write will write whatever it can and returns no. of bytes written. If no room at all, it returns with error EWOULDBLOCK.

# Socket Operations

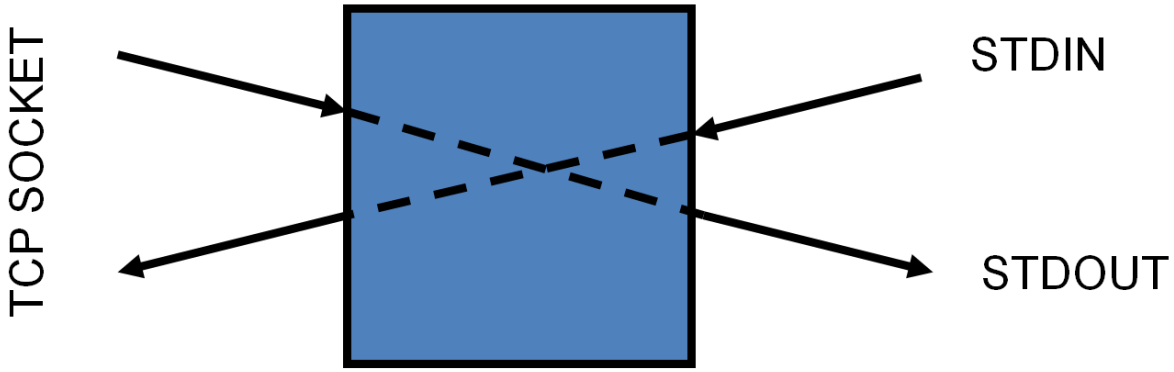


- Accepting incoming connections: accept
  - Blocks if no incoming connection.
  - With non-blocking socket, it would return with an error.
- Initiating Connections: connect
  - Blocks until client TCP receives ACK.
  - With non-blocking socket, it returns *errno* EINPROGRESS, and continues to establish connection.

# Client Handling a socket, stdin, stdout



- A client usually deals with
  - Stdin
  - Stdout
  - Socket



# Client Handling a socket, stdin, stdout



- We looked at
  - Stop and wait client
  - Batch mode client - select with blocking I/O
    - Once select() returns, and if socket is readable, read() is called on socket.
    - readline() call gets blocked on socket till it gets required data.
    - During this time, other clients have to wait.
- Now we look at select with non-blocking I/O
  - In this, read() will be a non-blocking operation. It will read whatever data available on socket. It returns.
  - When this fd is readable next time, further data is read.
    - This requires that we track the number of bytes read and the pointers in the buffer.

```
1  str_cli(FILE *fp, int sockfd)
2  {
3   int     maxfdp1, stdineof;
4   fd_set  rset;
5   stdineof = 0;
6   FD_ZERO(&rset);
7   for ( ; ; ) {
8      if (stdineof == 0)
9          FD_SET(fileno(fp), &rset);
10     FD_SET(sockfd, &rset);
11     maxfdp1 = max(fileno(fp), sockfd) + 1;
12     select(maxfdp1, &rset, NULL, NULL, NULL);
13     if (FD_ISSET(sockfd, &rset)) {  /* socket is readable */
14     if ( (n = Read(sockfd, buf, MAXLINE)) == 0) {
15         if (stdineof == 1)
16             return;         /* normal termination */
17         else
18             err_quit("str_cli: server terminated prematurely");
19             }
20         Write(fileno(stdout), buf, n);
21     }
22     if (FD_ISSET(fileno(fp), &rset)) {  /* input is readable */
23     if ( (n = Read(fileno(fp), buf, MAXLINE)) == 0) {
24         stdineof = 1;
25         shutdown(sockfd, SHUT_WR);  /* send FIN */
26         FD_CLR(fileno(fp), &rset);
27             continue;
28             }
29         Writen(sockfd, buf, n);
30         }
31     } }
```

# Select with Non-Blocking IO



- Non-blocking IO complicates buffer management.
  - We have to keep track of how much is read and how much is written.
- Two buffers:
  - *to*: reading from standard input and write to socket.
  - *from*: read from socket and write to stdout.

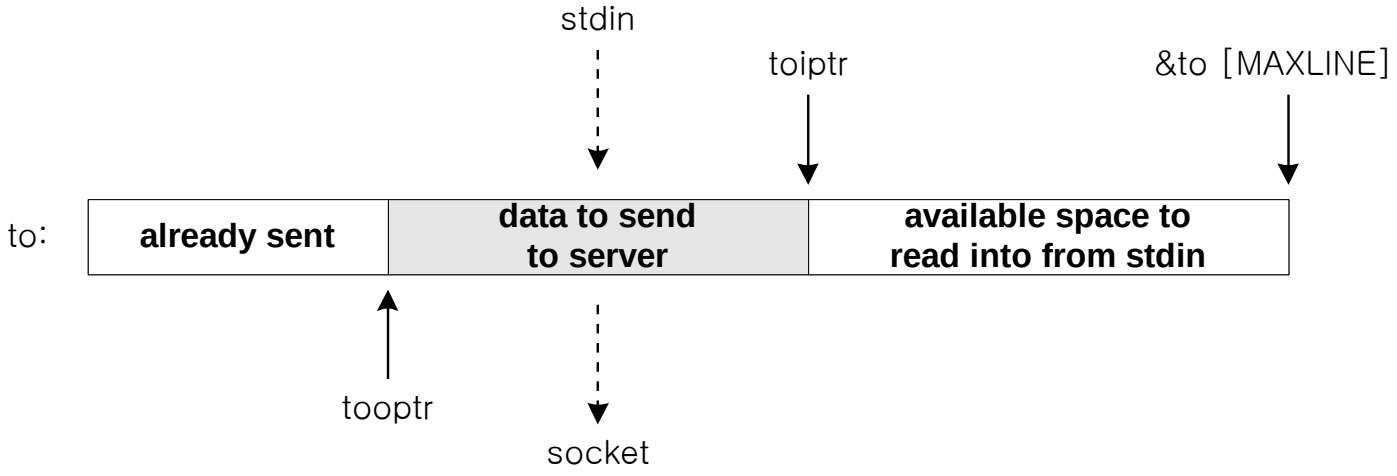



Figure 15.1 Buffer containing data from standard input going to the socket.

# Select with Non-Blocking IO

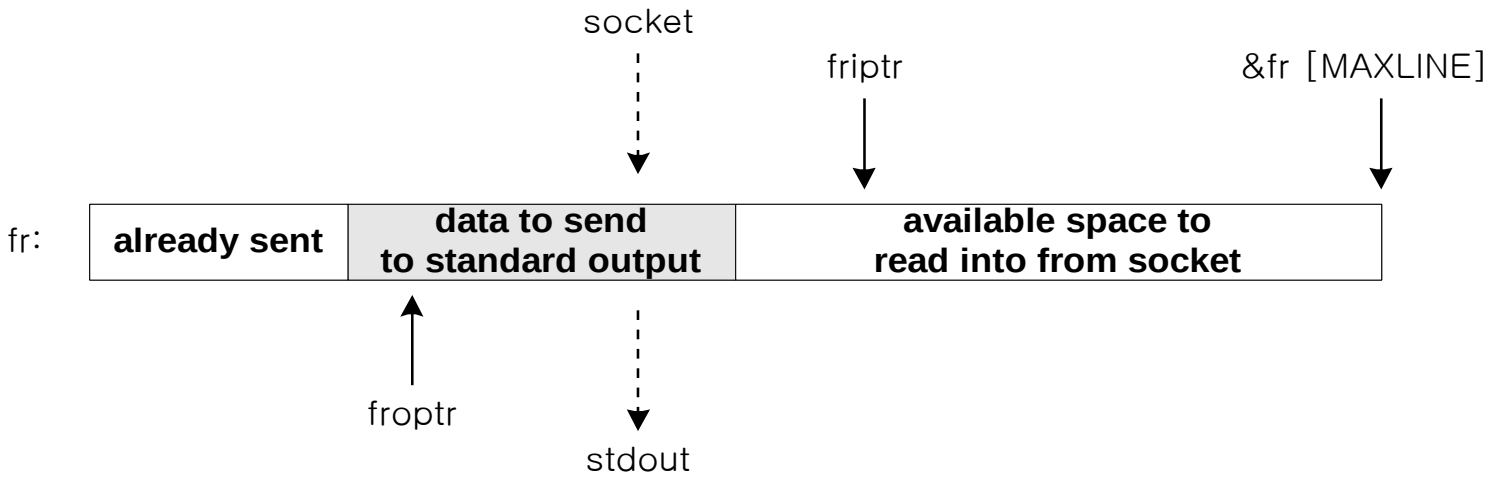



Figure 15.2 Buffer containing data from the socket going to standard output.

- *froptr*: points to the next byte to be sent to stdout.
- *froiptr*: points to the next byte into which next byte can be read..

# Select with Non-Blocking IO

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```
1  void str_cli(FILE *fp, int sockfd)
2   {
3       int     maxfdp1, val, stdineof;
4       ssize_t n, nwritten;
5       fd_set  rset, wset;
6       char    to[MAXLINE], fr[MAXLINE];
7       char    *toiptr, *tooptr, *friptr, *froptr;
8       val = fcntl(sockfd, F_GETFL, 0);
9       fcntl(sockfd, F_SETFL, val | O_NONBLOCK);
10      val = Fcntl(STDIN_FILENO, F_GETFL, 0);
11      fcntl(STDIN_FILENO, F_SETFL, val | O_NONBLOCK);
12      val = Fcntl(STDOUT_FILENO, F_GETFL, 0);
13      fcntl(STDOUT_FILENO, F_SETFL, val | O_NONBLOCK);
14      toiptr = tooptr = to;       /* initialize buffer pointers */
15      friptr = froptr = fr;
16      stdineof = 0;
```

```
18      maxfdp1 = max(max(STDIN_FILENO, STDOUT_FILENO), sockfd) + 1;
19      for ( ; ; ) {
20          FD_ZERO(&rset);
21          FD_ZERO(&wset);
22          if (stdineof == 0 && toiptr < &to[MAXLINE])
23              FD_SET(STDIN_FILENO, &rset);     /* read from stdin */
24          if (friptr < &fr[MAXLINE])
25              FD_SET(sockfd, &rset);  /* read from socket */
26          if (tooptr != toiptr)
27              FD_SET(sockfd, &wset);  /* data to write to socket */
28          if (froptr != friptr)
29              FD_SET(STDOUT_FILENO, &wset);   /* data to write to stdout */
30          select(maxfdp1, &rset, &wset, NULL, NULL);
```

# reads from standard input



```
30      select(maxfdp1, &rset, &wset, NULL, NULL);
31       if (FD_ISSET(STDIN_FILENO, &rset)) {
32          if((n = read(STDIN_FILENO, toiptr, &to[MAXLINE] - toiptr)) < 0) {
33              if (errno != EWOULDBLOCK)
34                  err_sys("read error on stdin");
35          }else if (n == 0) {
36              fprintf(stderr, "%s: EOF on stdin\n", gf_time());
37              stdineof = 1;   /* all done with stdin */
38              if (tooptr == toiptr)
39                  shutdown(sockfd, SHUT_WR);   /* send FIN */
40          } else {
41          fprintf(stderr, "%s: read %d bytes from stdin\n", gf_time(),
42                          n);
43              toiptr += n;     /* # just read */
44              FD_SET(sockfd, &wset); /* try and write to socket below */
45          }
46       }
```

Amt of space available in to buffer

If user has pressed Ctrl-D, set stdineof=1
If no outstanding data on buffer, close the write end.

Increment to pointer
set socket in wset for writability

# reads from socket



```
47  if (FD_ISSET(sockfd, &rset)) {
48      if ( (n = read(sockfd, friptr, &fr[MAXLINE] - friptr)) < 0) {
49          if (errno != EWOULDBLOCK)
50              err_sys("read error on socket");
51      } else if (n == 0) {
52          fprintf(stderr, "%s: EOF on socket\n", gf_time());
53          if (stdineof)
54              return;     /* normal termination */
55          else
56              err_quit("str_cli: server terminated prematurely");
57      } else {
58          fprintf(stderr, "%s: read %d bytes from socket\n",
59                  gf_time(), n);
60          friptr += n;     /* # just read */
61          FD_SET(STDOUT_FILENO, &wset);     /* try and write below */
62      }
63  }
```

Amt of space available in from buffer

Increment friptr.
Add stdout to wset to test for writability.

# writes to standard output



No of bytes to write >0

```
65  if (FD_ISSET(STDOUT_FILENO, &wset) && ((n = friptr - froptr) > 0)) {
66      if ( (nwritten = write(STDOUT_FILENO, froptr, n)) < 0) {
67          if (errno != EWOULDBLOCK)
68              err_sys("write error to stdout");
69      } else {
70          fprintf(stderr, "%s: wrote %d bytes to stdout\n",
71                  gf_time(), nwritten);
72          froptr += nwritten; /* # just written */
73          if (froptr == friptr)
74              froptr = friptr = fr;   /* back to beginning of buffer */
75      }
76  }
```

If the write is successful, froptr is incremented by the number of bytes written

# Writes to socket



No of bytes to write >0

```
78    if (FD_ISSET(sockfd, &wset) && ((n = toiptr - tooptr) > 0)) {
79        if ( (nwritten = write(sockfd, tooptr, n)) < 0) {
80            if (errno != EWOULDBLOCK)
81                err_sys("write error to socket");
82        } else {
83        fprintf(stderr, "%s: wrote %d bytes to socket\n",
84                gf_time(), nwritten);
85        tooptr += nwritten; /* # just written */
86            if (tooptr == toiptr) {
87                toiptr = tooptr = to;   /* back to beginning of buffer */
88            if (stdineof)
89                shutdown(sockfd, SHUT_WR);  /* send FIN */
90            }
91        }
92    }
93  }
94  }
```

If the write is successful, tooptr is incremented by the number of bytes written

if we encountered an EOF on standard input, the FIN can be sent to the server

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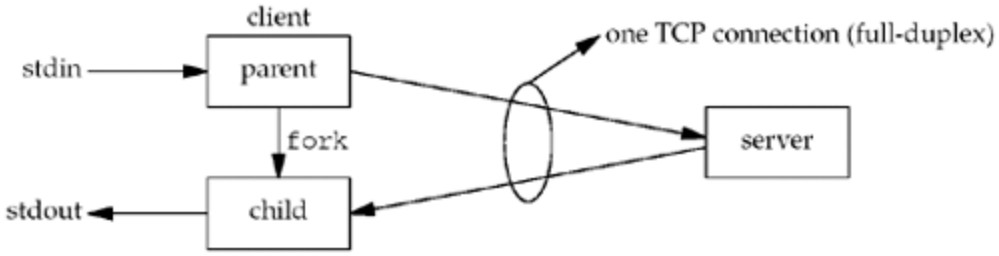
# Client using Multiple Processes

# Client using Multiple Processes



- Whenever we find the need to use nonblocking I/O, it will usually be simpler to split the application into either processes (using fork) or threads.
  - Parent reads from stdin and writes to socket
  - Child reads from socket and writes to stdout.




  - Normal termination occurs when the EOF on standard input is encountered. The parent reads this EOF and calls shutdown to send a FIN.
  - If abnormal occurs, the child will read an EOF on the socket. If this happens, the child must tell the parent to stop copying from the standard input to the socket
    - the child sends a signal (e.g. SIGTERM) to the parent.

# Client using Multiple Processes

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```
1  void str_cli(FILE *fp, int sockfd)
2   {
3       pid_t     pid;
4       char      sendline[MAXLINE], recvline[MAXLINE];
5       if ( (pid = fork()) == 0) {   /* child: server -> stdout */
6          while (Readline(sockfd, recvline, MAXLINE) > 0)
7              fputs(recvline, stdout);
8          kill(getppid(), SIGTERM);    /* in case parent still running */
9          exit(0);
10      }
11      /* parent: stdin -> server */
12      while (fgets(sendline, MAXLINE, fp) != NULL)
13          Writen(sockfd, sendline, strlen(sendline));
14      shutdown(sockfd, SHUT_WR);  /* EOF on stdin, send FIN */
15      pause();
16      return;
17  }
```

# Comparing Cleint Designs



- when copying 2,000 lines from a client to a server with an RTT of 175 ms:

| Client | Time taken for sending and receiving |
|---|---|
| stop-and-wait | 354.0 sec |
| select and blocking I/O | 12.3 sec |
| nonblocking I/O | 6.9 sec |
| fork | 8.7 sec |
| threaded version | 8.5 sec |

  - nonblocking I/O version is almost twice as fast as version using blocking I/O with select.
  - Version using fork is slower than nonblocking I/O version.
  - Nevertheless, given the complexity of the nonblocking I/O code versus the fork code, fork version is simple approach.


# Non-blocking Connect

# Nonblocking connect()

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- TCP socket nonblocking connect
  - return: an error of EINPROGRESS
  - TCP three-way handshake continues
  - check the connection establishment using select
- There are three uses for a nonblocking connect.
  - We can overlap other processing with the three-way handshake.
  - We can establish multiple connections at the same time using this technique.
    - popular with Web browsers
  - Since we wait for the connection establishment to complete using select, we can specify time limit for select, allowing us to shorten the timeout for the connect.

# Nonblocking connect()



- Set the socket to non-blocking.
- Call connect(). It will return immediately with error EINPROGRESS.
- We use *select*() to check what has happened to connect().
- If the descriptor is readable or writable, we call getsockopt() to fetch the socket's pending error (SO_ERROR). If the connection completed successfully, this value will be 0.

# Nonblocking connect()

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```
1  int connect_nonb(int sockfd, const SA *saptr, socklen_t salen, int nsec)
2  {
3      int     flags, n, error;
4      socklen_t len;
5      fd_set rset, wset;
6      struct timeval tval;
7      flags = fcntl(sockfd, F_GETFL, 0);
8      fcntl(sockfd, F_SETFL, flags | O_NONBLOCK);
9      error = 0;
10     if ( (n = connect(sockfd, saptr, salen)) < 0)
11         if (errno != EINPROGRESS)
12             return (-1);
13     /* Do whatever we want while the connect is taking place. */
14     if (n == 0)
15         goto done;              /* connect completed immediately */
16     FD_ZERO(&rset);
17     FD_SET(sockfd, &rset);
18     wset = rset;
19     tval.tv_sec = nsec;
20     tval.tv_usec = 0;
```

# Nonblocking connect()

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```
22          if ( (n = select(sockfd + 1, &rset, &wset, NULL,
23                           nsec ? &tval : NULL)) == 0) {
24              close(sockfd);          /* timeout */
25              errno = ETIMEDOUT;
26              return (-1);
27          }
28          if (FD_ISSET(sockfd, &rset) || FD_ISSET(sockfd, &wset)) {
29              len = sizeof(error);
30              if (getsockopt(sockfd, SOL_SOCKET, SO_ERROR, &error, &len) < 0)
31                  return (-1);     /* Solaris pending error */
32          } else
33              err_quit("select error: sockfd not set");
34      done:
35          Fcntl(sockfd, F_SETFL, flags);  /* restore file status flags */
36          if (error) {
37              close(sockfd);          /* just in case */
38              errno = error;
39              return (-1);
40          }
41          return (0);
42      }
```

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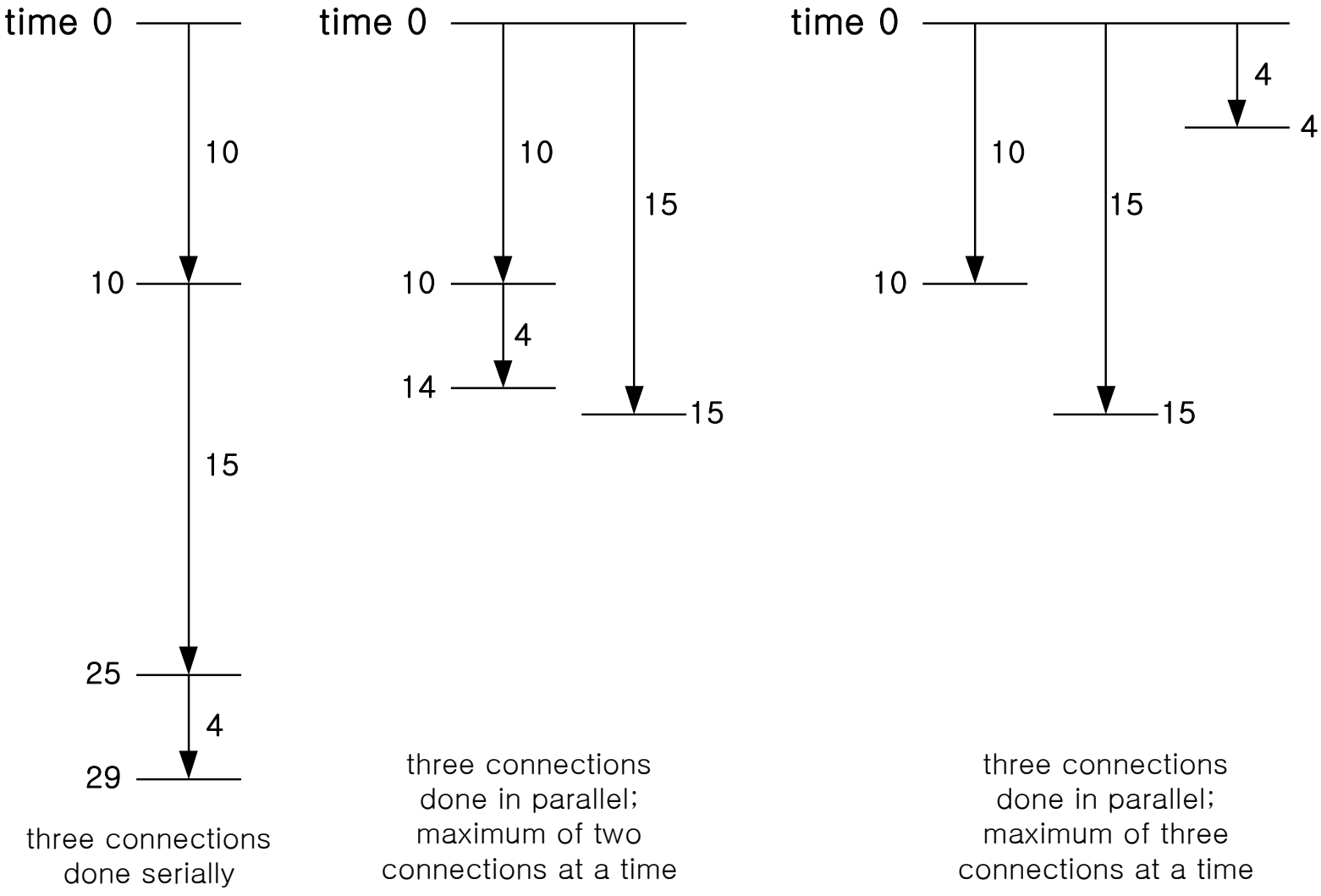
# Web client: Non-blocking Connect

# nonblocking `connect`: web client



- A real-world example of nonblocking connects started with Netscape Web Client
- The client establishes an HTTP connection with a Web server and fetches a home page.
- On that page are often numerous references to other Web pages.
- Instead of fetching these other pages serially, one at a time, the client can fetch more than one at the same time, using nonblocking connects.

# nonblocking connect: web client (cont.)




three connections done serially

three connections done in parallel; maximum of two connections at a time

three connections done in parallel; maximum of three connections at a time

# Non-blocking Connect



- This program will read up to 20 files from a Web server.
- We specify as command-line arguments
  - the maximum number of parallel connections,
  - the server's hostname, and
  - each of the filenames to fetch from the server.

```
bash$ web 3 www.foobar.com image1.gif image2.gif image3.gif image4.gif
    image5.gif image6.gif image7.gif
```

  - It means
    - three simultaneous connection
    - server’s hostname
    - filename for the home page
    - the files to be read

# nonblock/web.h

```
1  #define MAXFILES     20
2  #define SERV         "80"         /* port number or service name */
3  struct file {
4   char   *f_name;               /* filename */
5   char   *f_host;               /* hostname or IPv4/IPv6 address */
6   int     f_fd;                 /* descriptor */
7   int     f_flags;              /* F_xxx below */
8  } file[MAXFILES];
9  #define F_CONNECTING     1        /* connect() in progress */
10 #define F_READING        2        /* connect() complete; now reading */
11 #define F_DONE           4        /* all done */
12 #define GET_CMD      "GET %s HTTP/1.0\r\n\r\n"
13       /* globals */
14 int     nconn,  nfiles, nlefttoconn, nlefttoread, maxfd;
15 fd_set  rset, wset;
16       /* function prototypes */
17 void   home_page(const char *, const char *);
18 void   start_connect(struct file *);
19 void   write_get_cmd(struct file *);
```

- Each file has a state and fd.

# nonblock/web.c

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```
1  main(int argc, char **argv)
2  {
3   int     i, fd, n, maxnconn, flags, error;
4   char    buf[MAXLINE];
5   fd_set  rs, ws;
6   if (argc < 5)
7       err_quit("usage: web <#conns> <hostname> <homepage> <file1> ...");
8   maxnconn = atoi(argv[1]);
9   nfiles = min(argc - 4, MAXFILES);
10  for (i = 0; i < nfiles; i++) {
11      file[i].f_name = argv[i + 4];
12      file[i].f_host = argv[2];
13      file[i].f_flags = 0;
14  }
15  printf("nfiles = %d\n", nfiles);
16  home_page(argv[2], argv[3]);
17  FD_ZERO(&rset);
18  FD_ZERO(&wset);
19  maxfd = -1;
20  nlefttoread = nlefttoconn = nfiles;
21  nconn = 0;
```

- Process command-line arguments
- Read home page
- Initialize globals
  - Fd sets, nconn is current number of connections.

# nonblock/start_connect.c

```
1  void start_connect(struct file *fptr)
2   {
3       int     fd, flags, n;
4       ai = Host_serv(fptr->f_host, SERV, 0, SOCK_STREAM);
5       fd = Socket(ai->ai_family, ai->ai_socktype, ai->ai_protocol);
6       fptr->f_fd = fd;
7       printf("start_connect for %s, fd %d\n", fptr->f_name, fd);
8           /* Set socket nonblocking */
9       flags = Fcntl(fd, F_GETFL, 0);
10      Fcntl(fd, F_SETFL, flags | O_NONBLOCK);
11          /* Initiate nonblocking connect to the server. */
12      if ( (n = connect(fd, ai->ai_addr, ai->ai_addrlen)) < 0) {
13          if (errno != EINPROGRESS)
14              err_sys("nonblocking connect error");
15          fptr->f_flags = F_CONNECTING;
16          FD_SET(fd, &rset);      /* select for reading and writing */
17          FD_SET(fd, &wset);
18          if (fd > maxfd)
19              maxfd = fd;
20       } else if (n >= 0)             /* connect is already done */
21           write_get_cmd(fptr);      /* write() the GET command */
22  }
```

- Initiate nonblocking connect
- Handle connection complete
- If connect returns successfully, the connection is already complete and the function write_get_cmd ends a command to the server.

# nonblock/write_get_cmd.c

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```
1  #include     "web.h"
2   void write_get_cmd(struct file *fptr)
3   {
4       int      n;
5       char     line[MAXLINE];
6       n = snprintf(line, sizeof(line), GET_CMD, fptr->f_name);
7       Writen(fptr->f_fd, line, n);
8       printf("wrote %d bytes for %s\n", n, fptr->f_name);
9       fptr->f_flags = F_READING;  /* clears F_CONNECTING */
10      FD_SET(fptr->f_fd, &rset);  /* will read server's reply */
11      if (fptr->f_fd > maxfd)
12          maxfd = fptr->f_fd;
13  }
```

- Build command and send it
- Set flags

# Main function: web.c

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```
1  while (nlefttoread > 0) {
2    while (nconn < maxnconn && nlefttoconn > 0) {
3            /* find a file to read */
4        for (i = 0; i < nfiles; i++)
5            if (file[i].f_flags == 0)
6                break;
7        if  (i == nfiles)
8            err_quit("nlefttoconn = %d but nothing found", nlefttoconn);
9        start_connect(&file[i]);
10       nconn++;
11       nlefttoconn--;
12   }
```

- Initiate another connection, if possible

# Main function: web.c



```
13    rs = rset;
14    ws = wset;
15    n = select(maxfd + 1, &rs, &ws, NULL, NULL);
16    for (i = 0; i < nfiles; i++) {
17        flags = file[i].f_flags;
18        if (flags == 0 || flags & F_DONE)
19            continue;
20        fd = file[i].f_fd;
21        if (flags & F_CONNECTING &&
22            (FD_ISSET(fd, &rs) || FD_ISSET(fd, &ws))) {
23            n = sizeof(error);
24            if (getsockopt(fd, SOL_SOCKET, SO_ERROR, &error, &n) < 0 ||
25            error != 0) {
26            err_ret("nonblocking connect failed for %s",
27                    file[i].f_name);
28        }
29            /* connection established */
30        printf("connection established for %s\n", file[i].f_name);
31        FD_CLR(fd, &wset); /* no more writeability test */
32        write_get_cmd(&file[i]);    /* write() the GET command */
```

- select waits for either readability or writability.
  - Descriptors that have a nonblocking connect in progress will be enabled in both sets, while descriptors with a completed connection that are waiting for data from the server will be enabled in just the read set.

# Main function: web.c

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```
29          /* connection established */
30        printf("connection established for %s\n", file[i].f_name);
31        FD_CLR(fd, &wset); /* no more writeability test */
32        write_get_cmd(&file[i]);   /* write() the GET command */
33  } else if (flags & F_READING && FD_ISSET(fd, &rs)) {
34      if ( (n = Read(fd, buf, sizeof(buf))) == 0) {
35          printf("end-of-file on %s\n", file[i].f_name);
36          Close(fd);
37          file[i].f_flags = F_DONE;     /* clears F_READING */
38          FD_CLR(fd, &rset);
39          nconn--;
40          nlefttoread--;
41      } else {
42          printf("read %d bytes from %s\n", n, file[i].f_name);
43      }
44   }
45  }
46  }
47  exit(0);
48  }
```

- If the F_READING flag is set and the descriptor is ready for reading, we call read.

# Performance of Nonblocking Connect



- Table shows the clock time required to fetch a Web server's home page, followed by nine image files from that server.
  - The RTT to the server is about 150 ms.
  - The home page size was 4,017 bytes and the average size of the 9 image files was 1,621 bytes.
  - TCP's segment size was 512 bytes.
- Most of the improvement is obtained with three simultaneous connections.

| # simultaneous connections | Clock time (seconds), non blocking | Clock time(secs) Threads |
|---|---|---|
| 1 | 6.0 | 6.3 |
| 2 | 4.1 | 4.2 |
| 3 | 3.0 | 3.1 |
| 4 | 2.8 | 3.0 |
| 5 | 2.5 | 2.7 |
| 6 | 2.4 | 2.5 |
| 7 | 2.3 | 2.3 |
| 8 | 2.2 | 2.3 |
| 9 | 2.0 | 2.2 |

# Q&A

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# Thank You