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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().

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

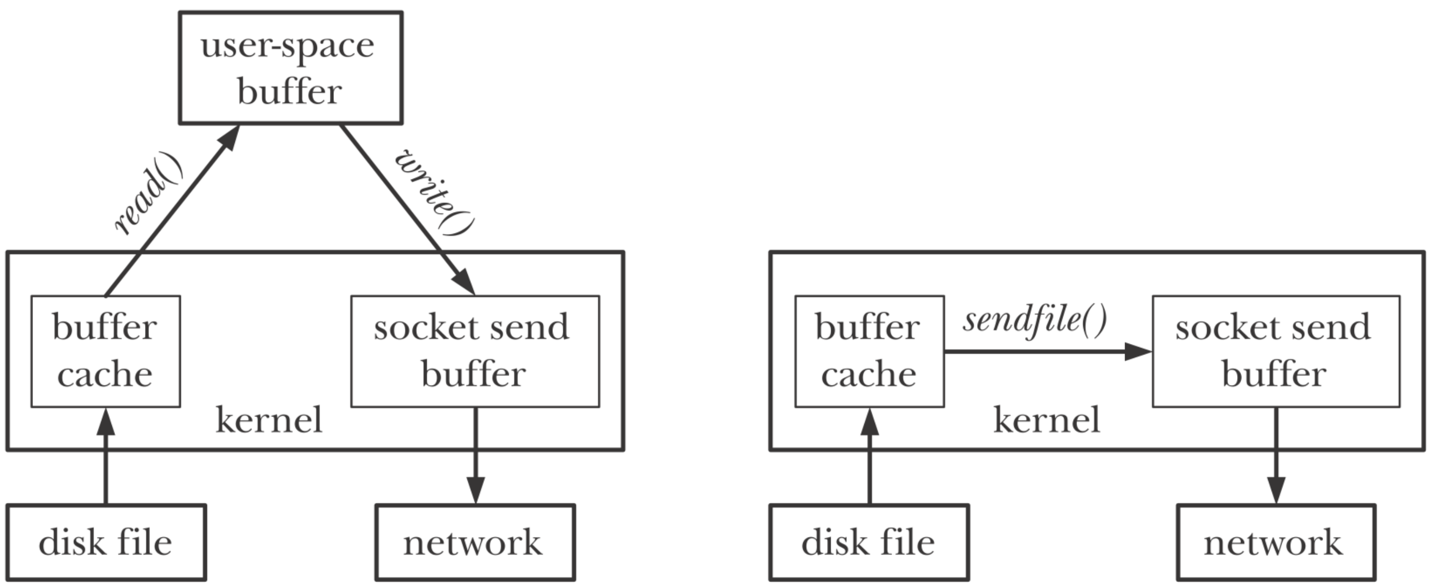
send() flags

- 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.

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



a) *read() + write()* b) *sendfile()*

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.*

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

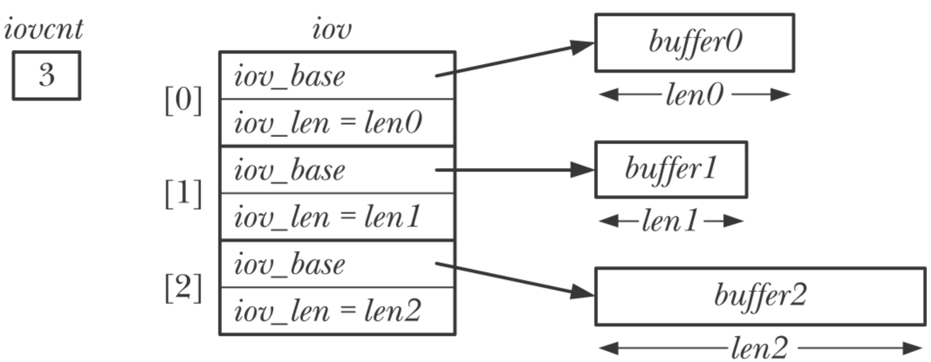
  - *out_fd:* is the socket fd.
  - *In_fd:* is regular file fd.
  - *off_t:* is the offset. This is a value-result argument.
  - *count* is the number of bytes to be transferred.
  - *sendfile* doesn't change the file offset for *in_fd*.

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.

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

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



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().

```c
#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
```

```c
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

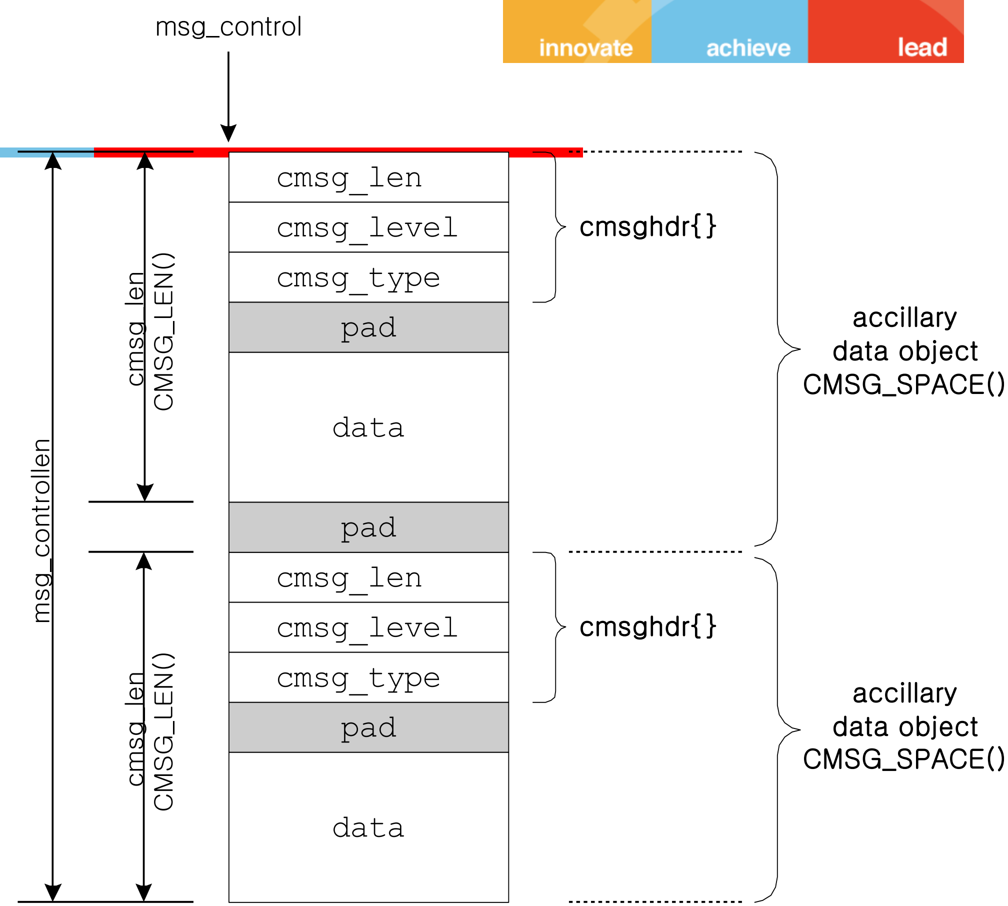
Flag	**Examined by:** Send flags Sendto flags Sendmsg flags	**Examined by:** recv flags recvfrom flags recvmsg flags	**Returned by:** Recvmsg msg_flags
MSG_DONTROUTE	•		
MSG_DONTWAIT	•	•	
MSG_PEEK		•	
MSG_WAITALL		•	
MSG_EOR	•		•
MSG_OOB	•	•	•
MSG_BCAST			•
MSG_MCAST			•
MSG_TRUNC			•
MSG_CTRUNC			•

Flags returned by rcvmsg()

- 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.




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

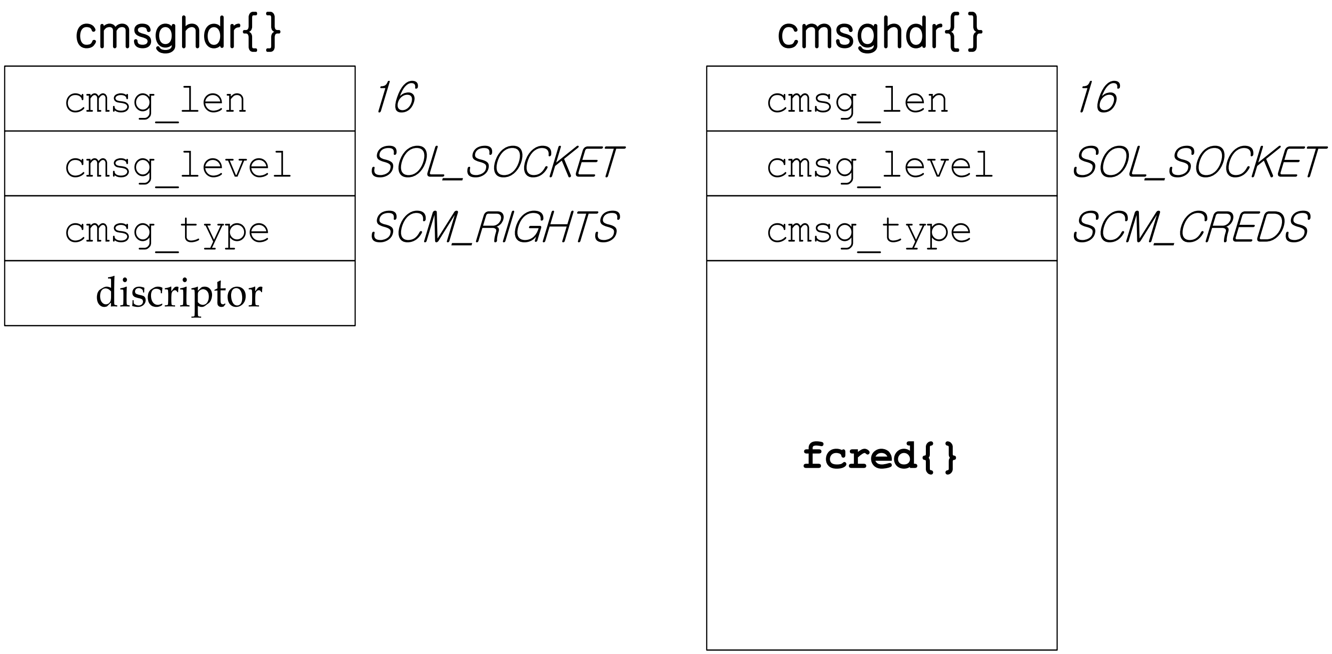
Ancillary Data

- Ancillary data is domain specific.

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

```
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.

```
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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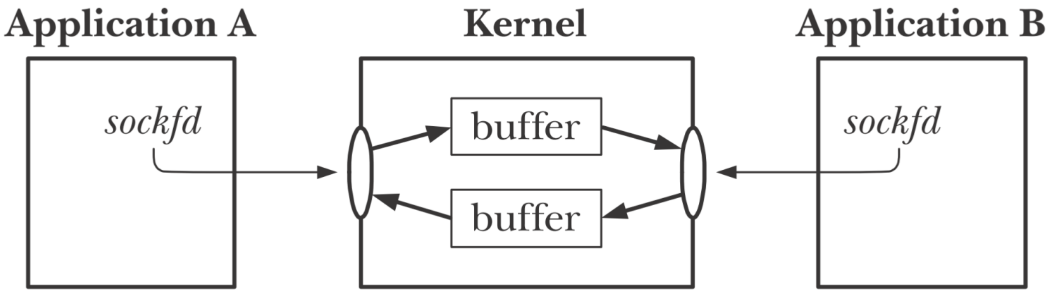
Unix Domain Sockets

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.

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

Binding End Point to a Socket

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

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

```
/*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

```
/*sockets/us_xfr_cl.c*/
main(int argc, char *argv[])
{    struct sockaddr_un addr;
     int sfd;
     ssize_t numRead;
     char buf[BUF_SIZE];
     sfd = socket(AF_UNIX, SOCK_STREAM, 0);  /* Create client socket */
     if (sfd == -1)  errExit("socket");
     /* Construct server address, and make the connection */
     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 (connect(sfd, (struct sockaddr *) &addr,
                    sizeof(struct sockaddr_un)) == -1)
         errExit("connect");
     /* Copy stdin to socket */
     while ((numRead = read(STDIN_FILENO, buf, BUF_SIZE)) > 0)
         if (write(sfd, buf, numRead) != numRead)
             fatal("partial/failed write");
     if (numRead == -1)
         errExit("read");
     exit(EXIT_SUCCESS);  /* Closes our socket; server sees EOF */
}
```

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

```
/*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

```
/* 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 */
}
```

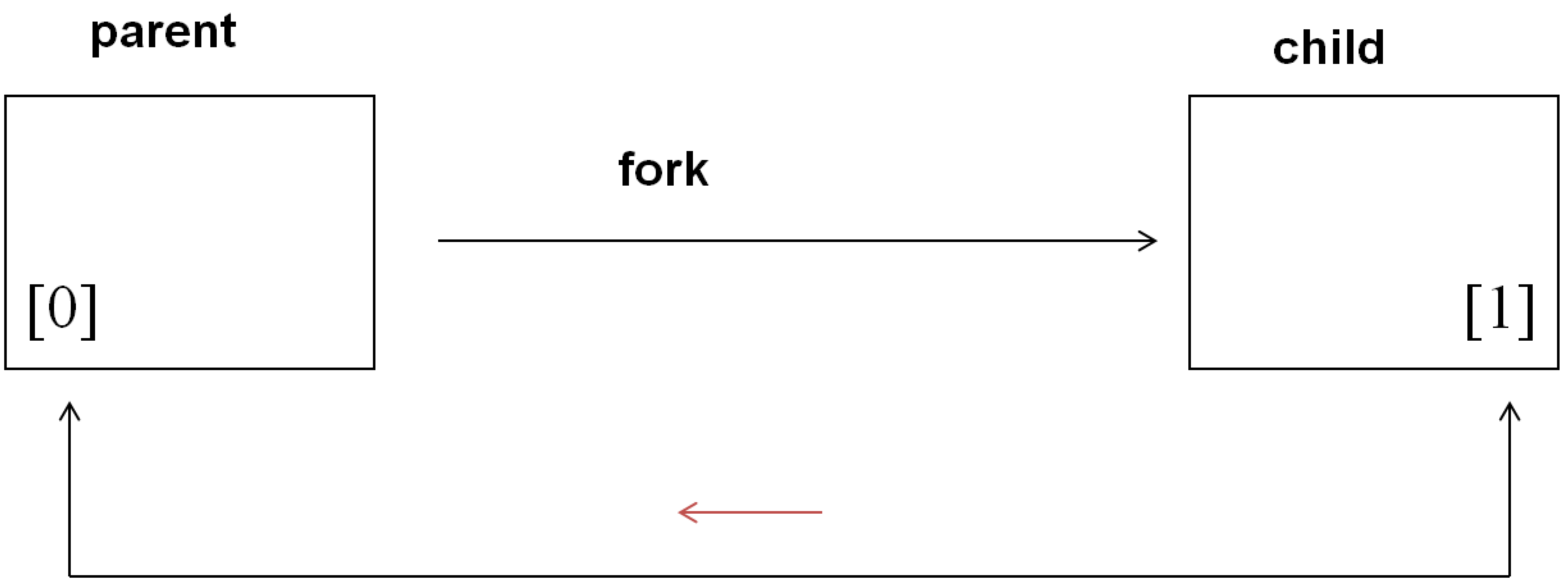
socketpair()

- creates a pair of sockets and connect them together.

```
#include <sys/socket.h>
int socketpair(int  domain, int  type ,int  protocol ,int  sockfd [2]);
//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()

```
#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

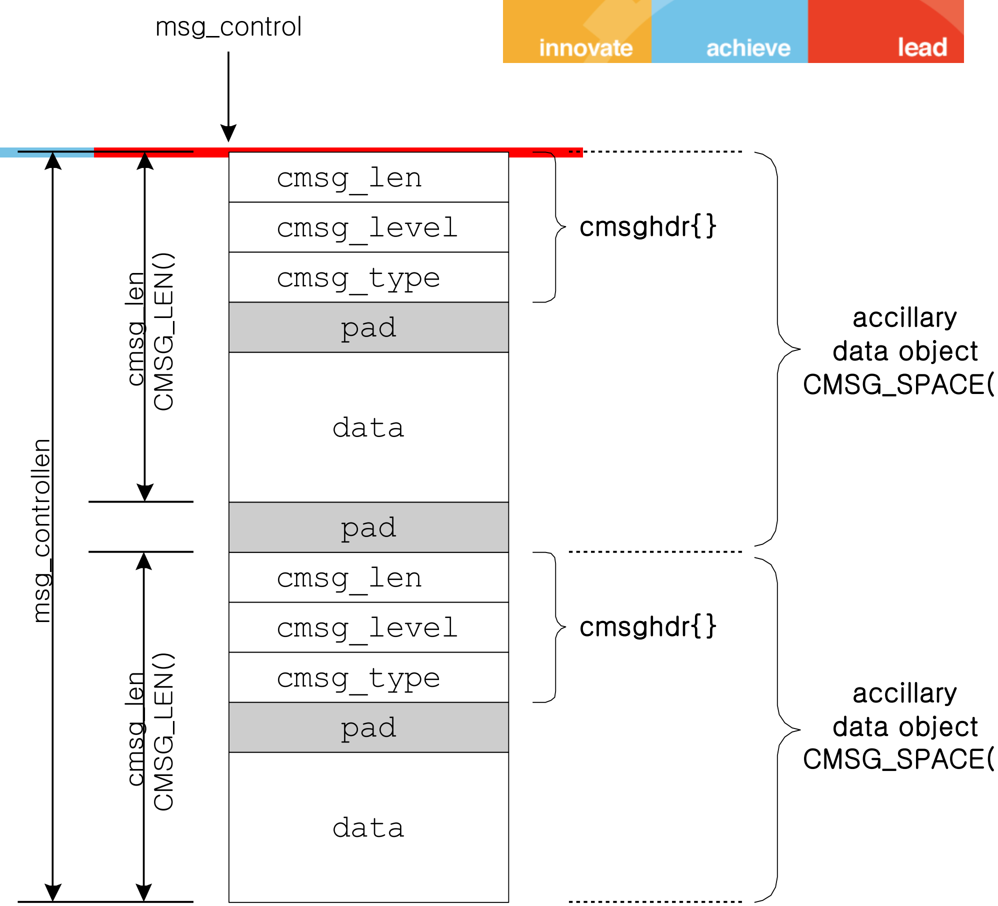
- Unix system provide a way to pass any open descriptor from one process to any other process.(using *sendmsg()*)
- It allows one process (typically a server) to do the privileged execution
  - dialing a modem, negotiating locks for the file or deal with database
  - simply pass back to the calling process 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.




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

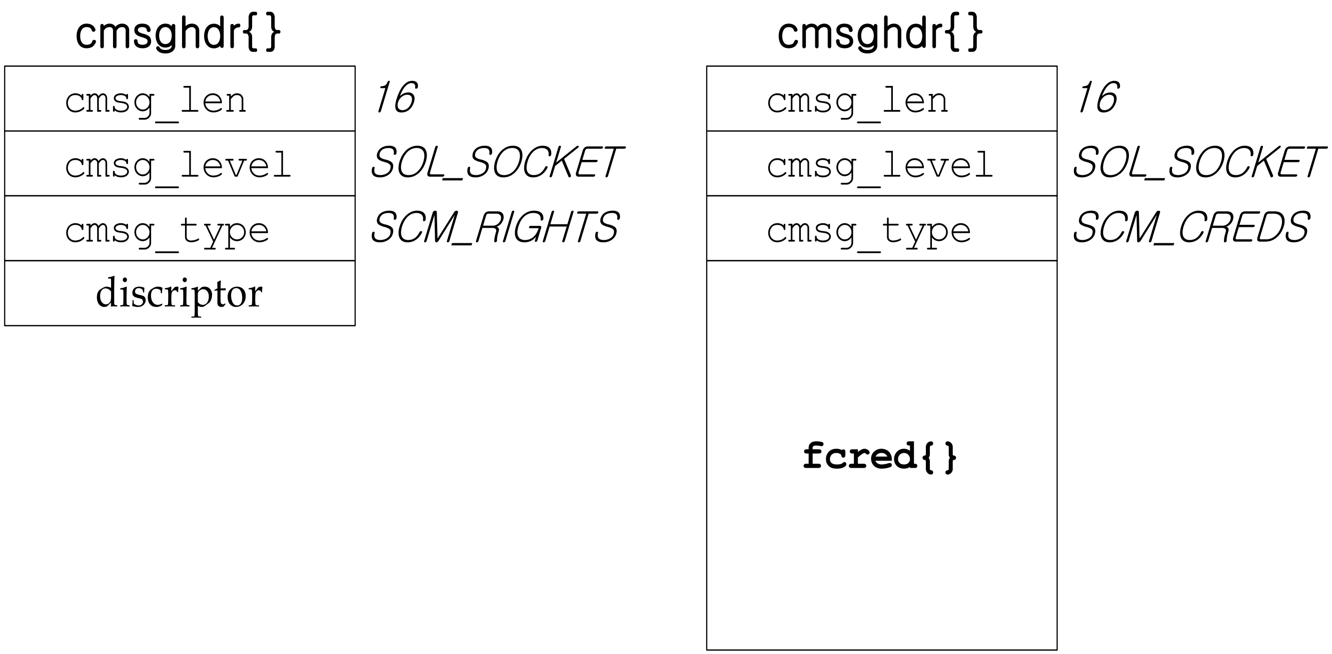
Ancillary Data

- Ancillary data is domain specific.

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

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- Macros associated with ancillary data

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

Send fd

```
#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

```
int recv_fd(int sockfd )
{
    #define CONTROLLEN  CMSG_LEN(sizeof(int))
    static struct cmsghdr   *cmptr = NULL;

    struct iovec    iov[1];
    struct msghdr   msg;
    char            buf[2]; /* send_fd()/recv_fd() 2-byte protocol */
    memset(&msg, 0, sizeof(msg));
    iov.iov_base   = buf;
    iov.iov_len    = sizeof(data)-1;
    msg.msg_iov    = &iov;
    msg.msg_iovlen = 1;
    if (cmptr == NULL && (cmptr = malloc(CONTROLLEN)) == NULL)
        return(-1);
    msg.msg_control = cmptr;
    msg.msg_controllen = CONTROLLEN;
    recvmsg(sockfd, &msg, 0)
        if (buf[1]<0)) {
                printf("failed to open %s: %s\n", name, data);
                return -1;
        }
        /* Loop over all control messages */
        cmsg = CMSG_FIRSTHDR(&msg);
        while (cmsg != NULL) {
                if (cmsg->cmsg_level == SOL_SOCKET
                 && cmsg->cmsg_type  == SCM_RIGHTS)
                        return *(int *) CMSG_DATA(cmsg);
                cmsg = CMSG_NXTHDR(&msg, cmsg);
        }
}
```

Passing Credentials

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

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

- 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

```
sockfd = socket(AF_LOCAL, SOCK_STREAM, 0);
bzero(&servaddr, sizeof(servaddr));
servaddr.sun_family = AF_LOCAL;
strcpy(servaddr.sun_path, "PATH");
connect(sockfd, (struct sockaddr *) &servaddr, sizeof(servaddr));
msgh.msg_iov = &iov;
msgh.msg_iovlen = 1;
/* Send Filename and Access Mode to server */
strcat(data, argv[1]);strcat(data, "#");
strcat(data, argv[2]);strcat(data, "#");
iov.iov_base = data;
iov.iov_len = MAX_DATA;
msgh.msg_name = NULL;
msgh.msg_namelen = 0;
msgh.msg_control = NULL;
msgh.msg_controllen = 0;

if(sendmsg(sockfd, &msgh, 0) < 0)
{
    perror("Error sending message");
    exit(1);
}
```

Receiver

```
optval = 1;
/* Set SO_PASSCRED socket option for receving credentials of other processes */
setsockopt(*(int *)arg, SOL_SOCKET, SO_PASSCRED, &optval, sizeof(optval));
/* Set 'control_un' to describe ancillary data that we want to receive */
control_un.cmh.cmsg_len = CMSG_LEN(sizeof(struct ucred));
control_un.cmh.cmsg_level = SOL_SOCKET;
control_un.cmh.cmsg_type = SCM_CREDENTIALS;
/* Set 'msgh' fields to describe 'control_un' */
msgh.msg_control = control_un.control;
msgh.msg_controllen = sizeof(control_un.control);
msgh.msg_iov = &iov;    msgh.msg_iovlen = 1;
iov.iov_base = data;
iov.iov_len = MAX_DATA;
msgh.msg_name = NULL;
msgh.msg_namelen = 0;
/* Receive real plus ancillary data */
nr = recvmsg(*(int *)arg, &msgh, 0);
/* Extract credentials information from received ancillary data */
cmhp = CMSG_FIRSTHDR(&msgh);
ucredp = (struct ucred *) CMSG_DATA(cmhp);
printf("Received Credentials pid: %ld, uid: %ld, gid: %ld\n",
(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

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

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Unix I/O Models

IO Models

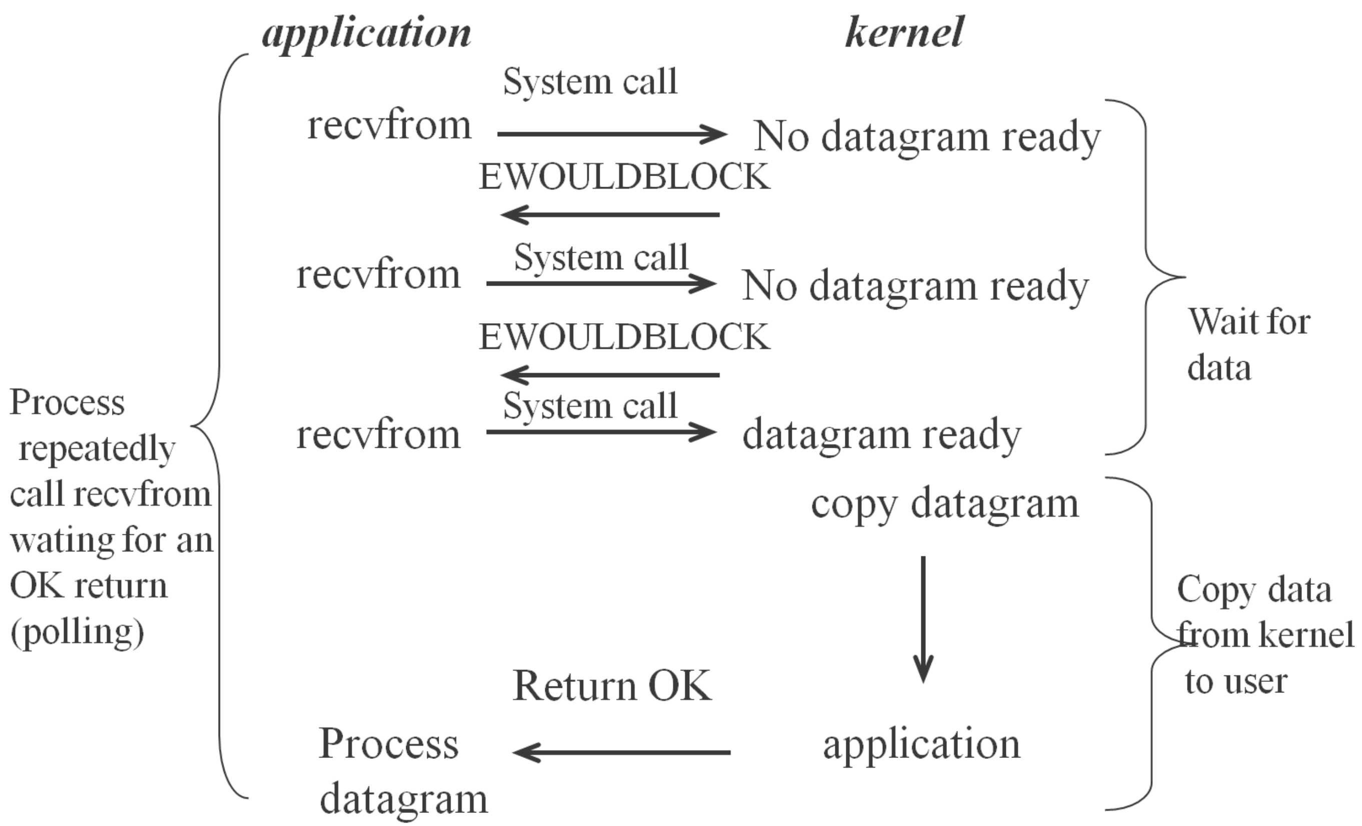
- While doing I/O there are two phases
  - Waiting for the data
  - Copying the data
- Each I/O model differs how it deals with these two phases.
- There are five I/O models
  - blocking I/O
  - nonblocking I/O
  - I/O multiplexing (select and poll)
  - signal driven I/O (SIGIO)
  - asynchronous I/O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

Blocking I/O Model

- Most prevalent model

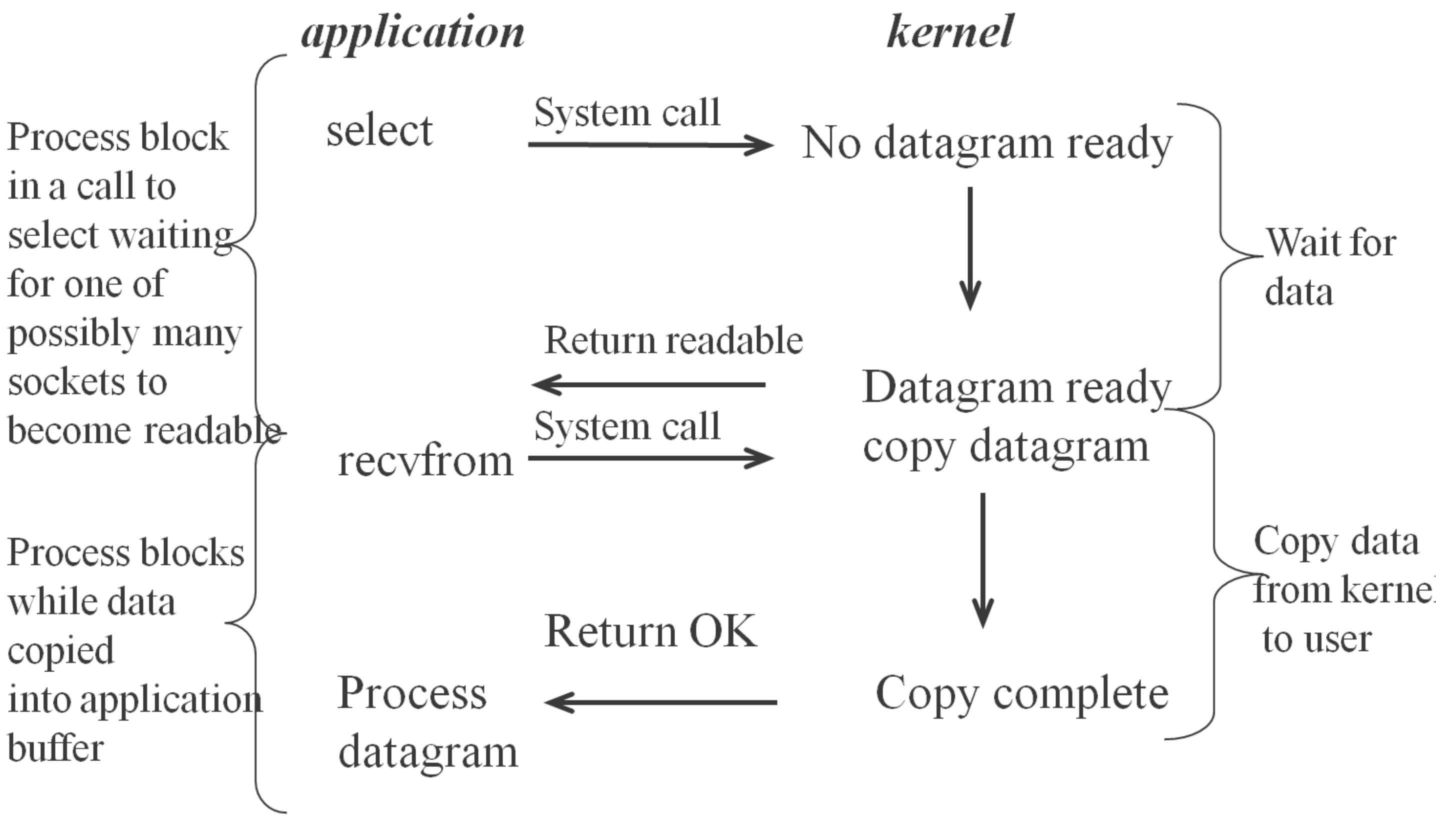
Nonblocking I/O Model

- 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.

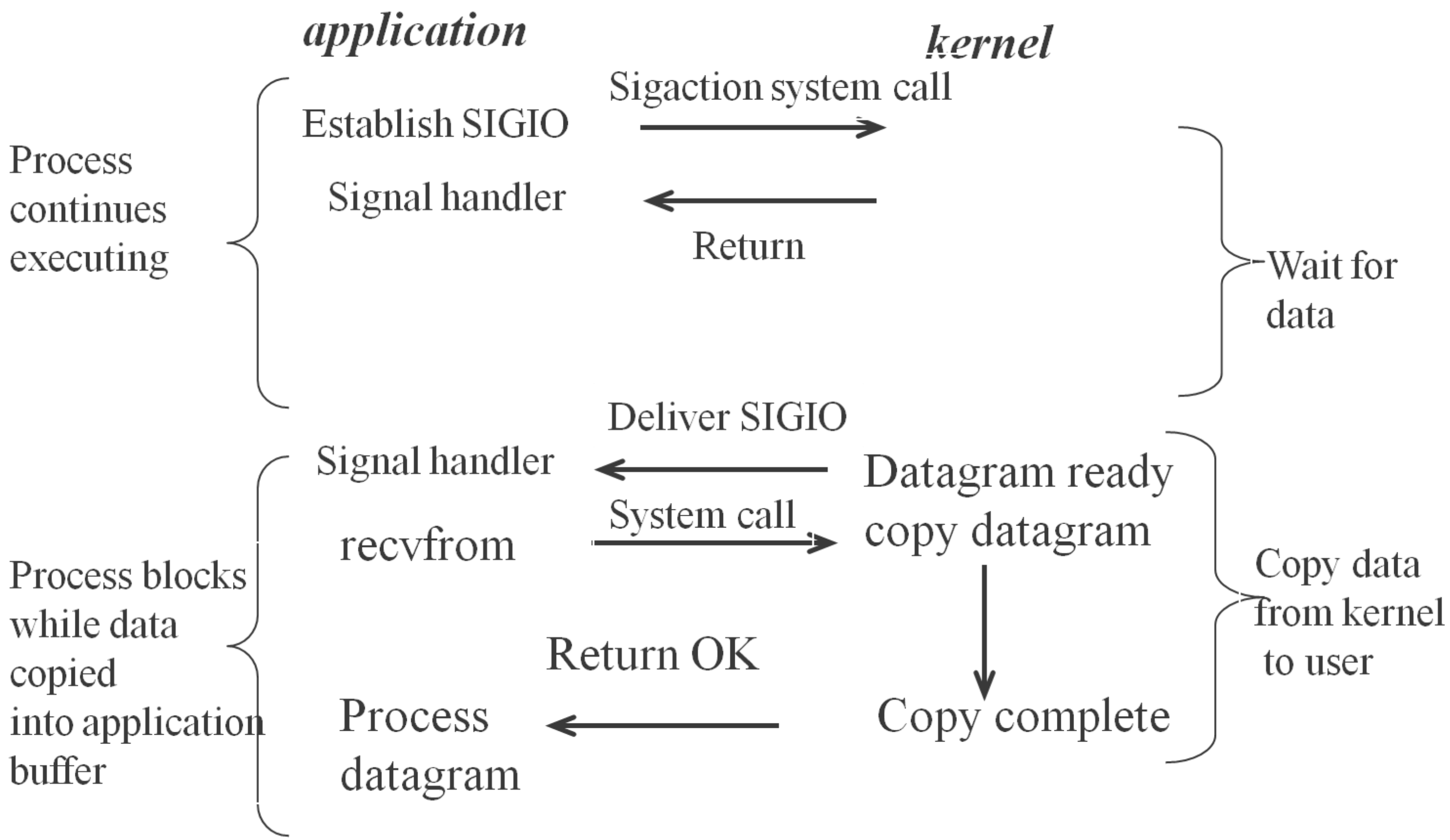


I/O Multiplexing Model

- 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.

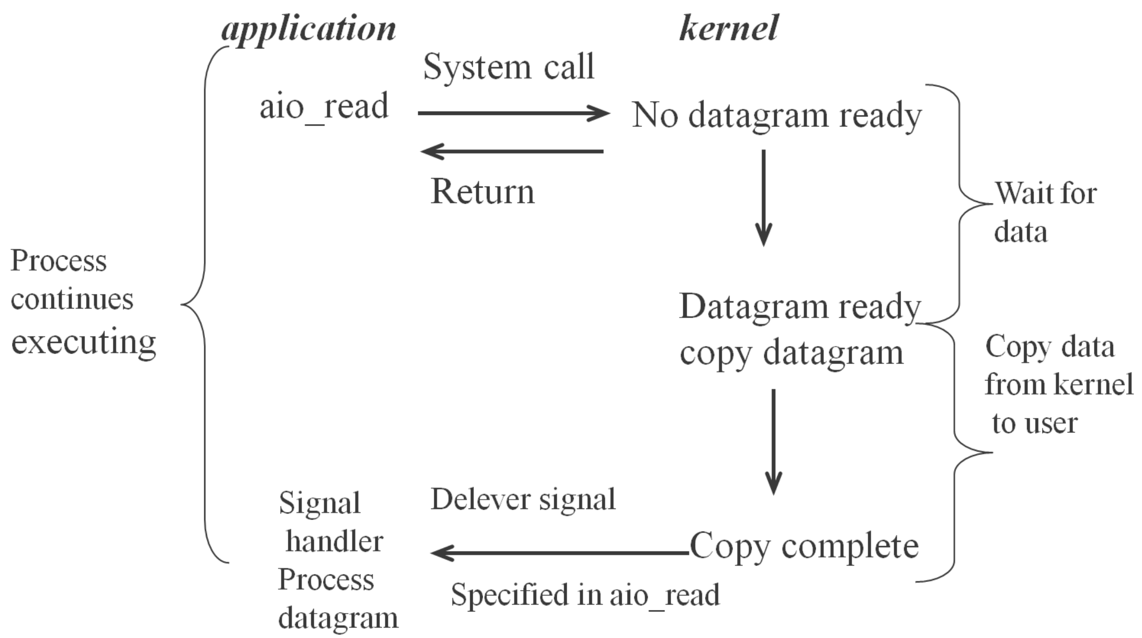


Signal-Driven I/O Model

- 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

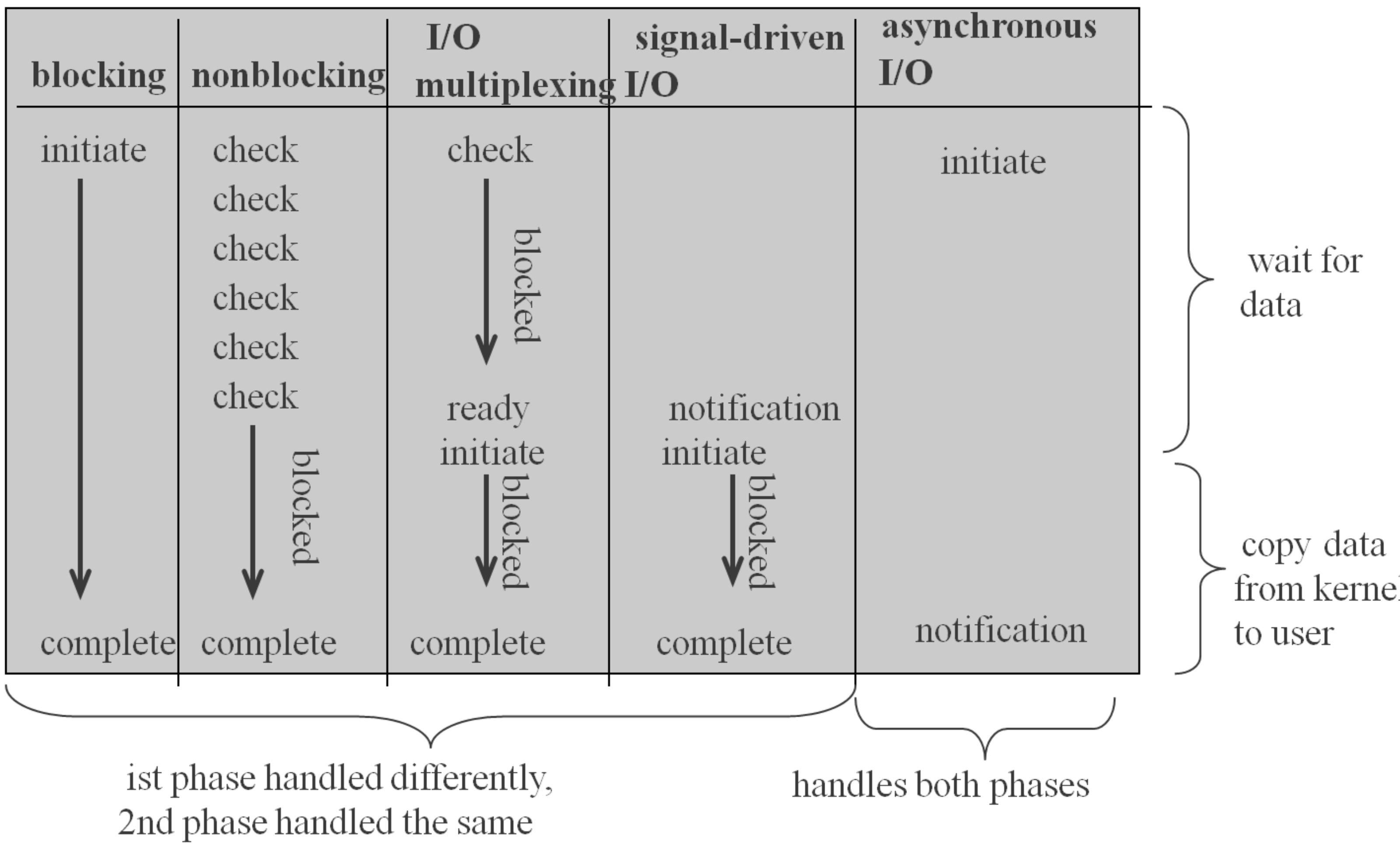
- POSIX API for asynchronous IO is implemented in a very few systems.
- *aiocb* structure

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

```
#include <aio.h>
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.

```
#include <sys/time.h>    /* For portability */
#include <sys/select.h>
int select(int  nfds , fd_set * readfds , fd_set * writefds,
          fd_set * exceptfds, struct timeval * timeout );
//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

```
struct timeval {
    long tv_usec;     /* seconds */
    long tv_usec;    /* microseconds */
}
```

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.

```c
#include <sys/select.h>
void FD_ZERO(fd_set *fdset);
 /* clear all bits in fdset */
void FD_SET(int fd, fd_set *fdset);
 /* turn on the bit for fd in fdset */
void FD_CLR(int fd, fd_set *fdset);
 /* turn off the bit for fd in fdset */
int FD_ISSET(int fd, fd_set *fdset);
 /* is the bit for fd on in fdset ? */
 //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?

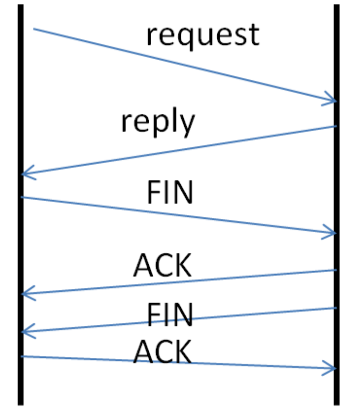
- The number of bytes of data in the socket receive buffer is greater than or equal to the current size of the low-water mark for the socket receive buffer. SO_RCVLOWAT socket option. It defaults to 1 for TCP and UDP sockets
- The read half of the connection is closed (i.e., a TCP connection that has 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*.

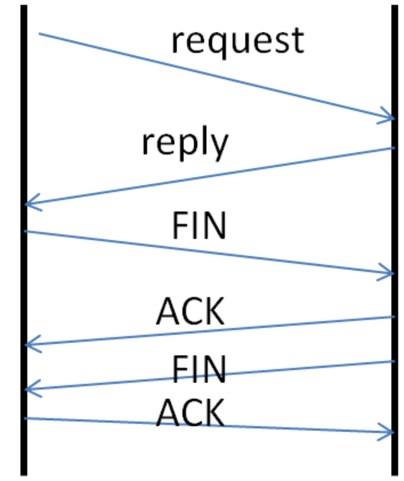


Normal course of actions

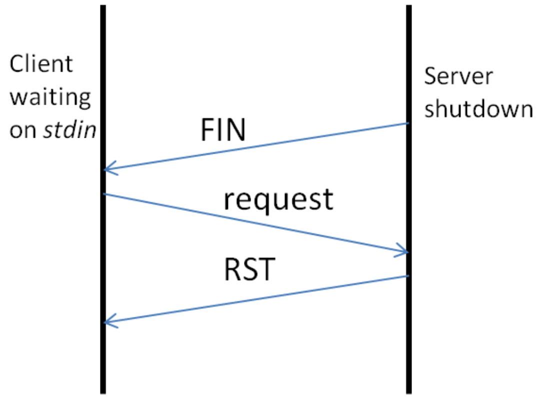
```
void str_cli(FILE *fp, int sockfd)
{
char sendline[MAXLINE], recvline[MAXLINE];
 while (Fgets(sendline, MAXLINE, fp) != NULL) {
     Writen(sockfd, sendline, strlen (sendline));
     if (Readline(sockfd, recvline, MAXLINE) == 0)
        err_quit("str_cli: server terminated prematurely");
     Fputs(recvline, stdout);
 }
}
```

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?



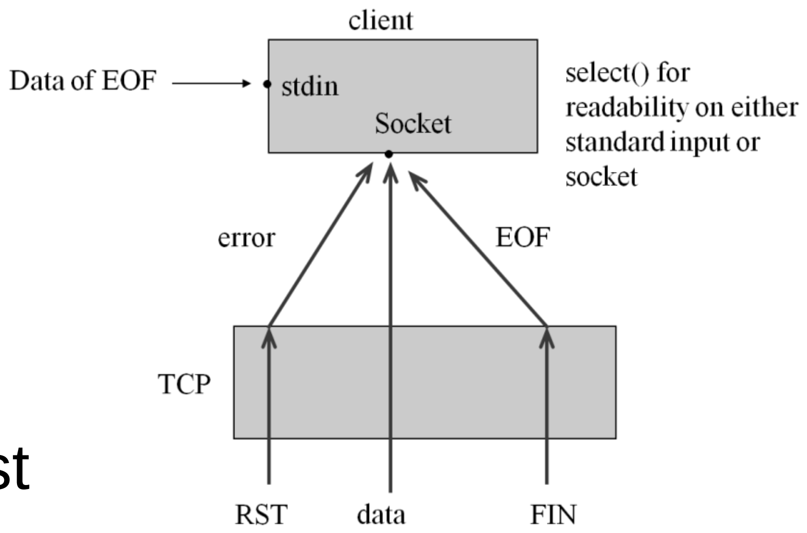
Normal course of actions



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

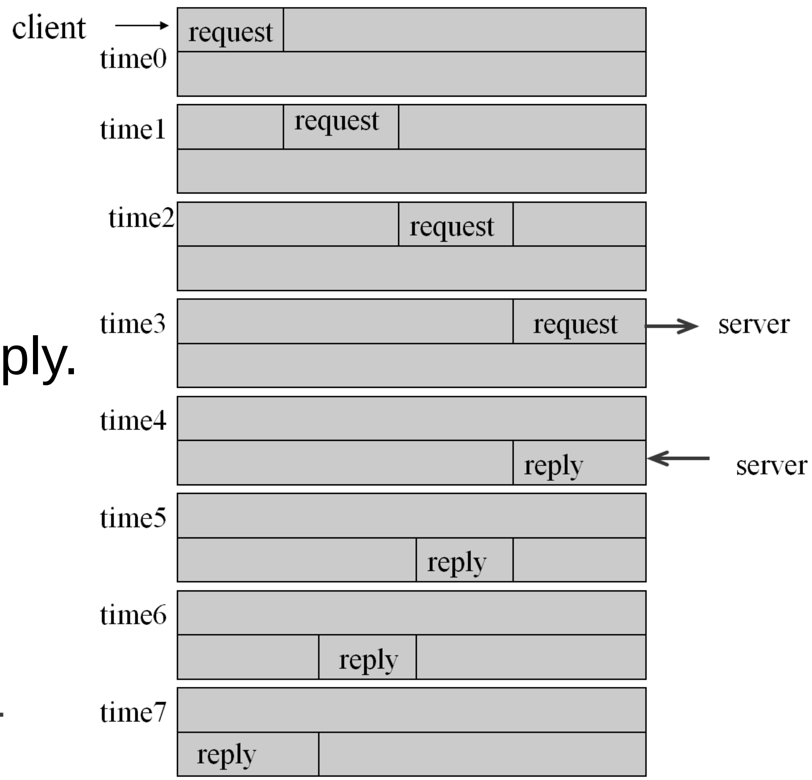
- To avoid a situation where data has arrived from socket but client is unable to take note of it, use I/O Multiplexing.
- Client can wait on select().
  - Add stdin, socket to fd_set.
  - Call select () with fd_set for readabliity
  - When select() returns, find out which descriptor is ready with data.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

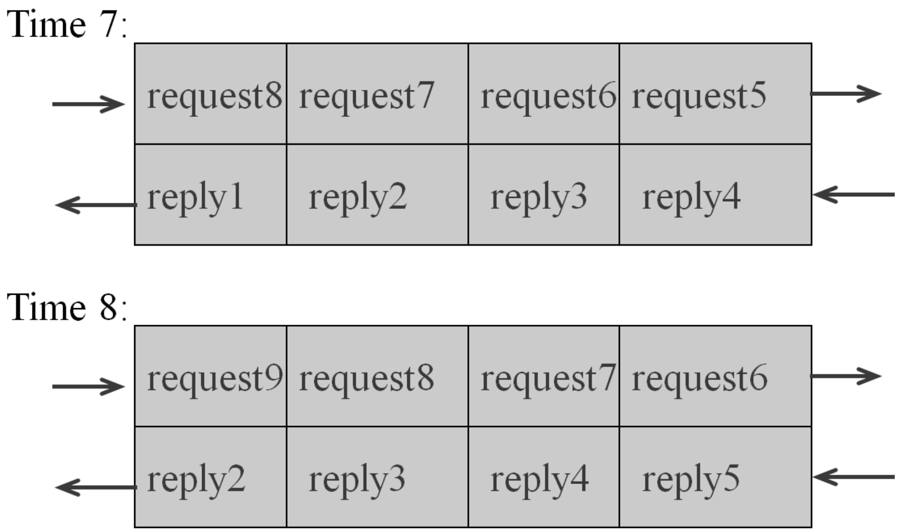
Client Handling Multiple Descriptors

```
void  str_cli(FILE *fp, int sockfd)
{
int    maxfdp1;
fd_set  rset;
char    sendline[MAXLINE], recvline[MAXLINE];
FD_ZERO(&rset);
for ( ; ; ) {
    FD_SET(fileno(fp), &rset);
    FD_SET(sockfd, &rset);
    maxfdp1 = max(fileno(fp), sockfd) + 1;
    select(maxfdp1, &rset, NULL, NULL, NULL);
    if (FD_ISSET(sockfd, &rset)) {    /* socket is readable */
    if (Readline(sockfd, recvline, MAXLINE) == 0)
    err_quit("str_cli: server terminated prematurely");
    Fputs(recvline, stdout);
    }
    if (FD_ISSET(fileno(fp), &rset)) {  /* input is readable */
    if (Fgets(sendline, MAXLINE, fp) == NULL)
    return;     /* all done */
    Writen(sockfd, sendline, strlen(sendline));
    }
}//for
}//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.





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

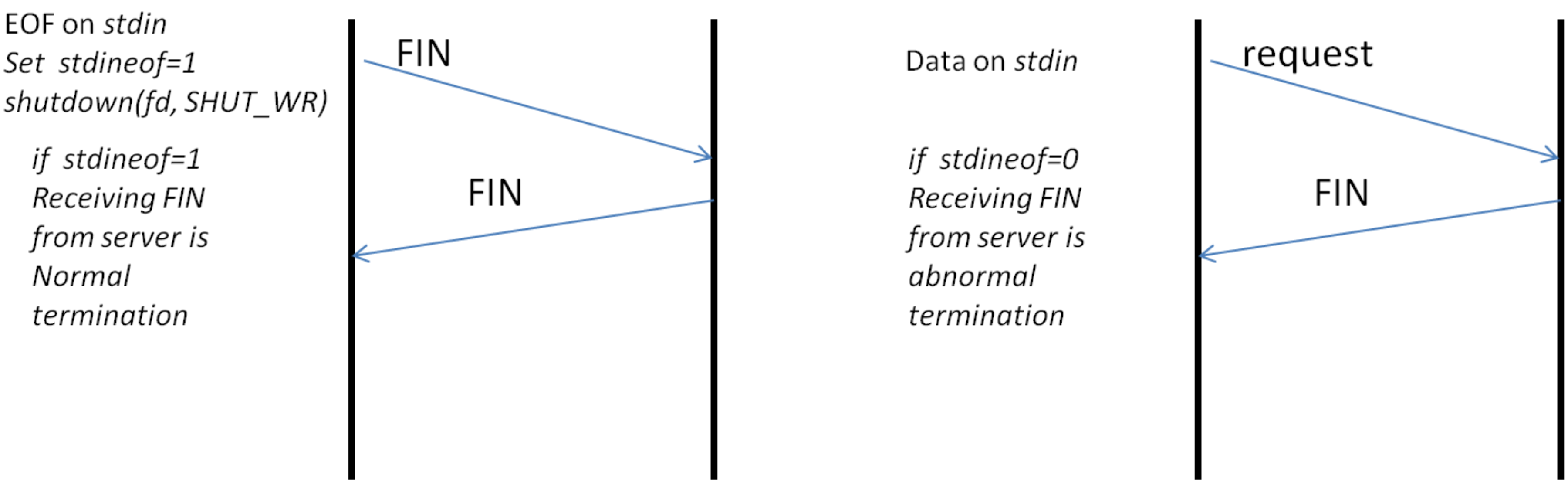
- Sometimes, it is useful to close one half of the connection, so that data can be transmitted in just one direction through the socket.

```
#include <sys/socket.h>
int shutdown(int  sockfd , int  how );
//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.



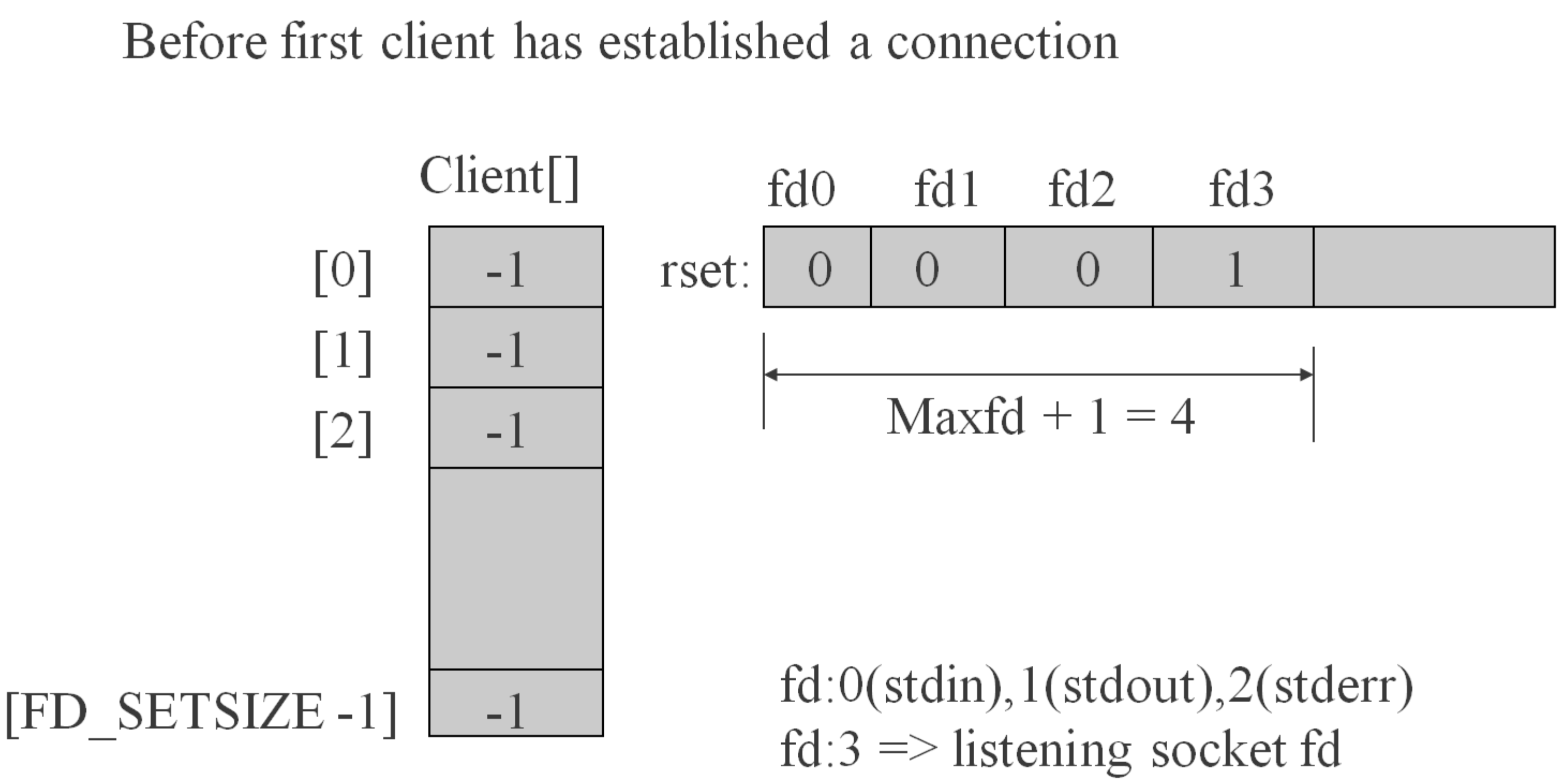
```c
str_cli(FILE *fp, int sockfd)
{
 int      maxfdp1, stdineof;
 fd_set   rset;
 stdineof = 0;
 FD_ZERO(&rset);
 for ( ; ; ) {
    if (stdineof == 0)
        FD_SET(fileno(fp), &rset);
    FD_SET(sockfd, &rset);
    maxfdp1 = max(fileno(fp), sockfd) + 1;
    select(maxfdp1, &rset, NULL, NULL, NULL);
     if (FD_ISSET(sockfd, &rset)) {  /* socket is readable */
     if ( (n = Read(sockfd, buf, MAXLINE)) == 0) {
         if (stdineof == 1)
             return;         /* normal termination */
         else
             err_quit("str_cli: server terminated prematurely");
             }
         Write(fileno(stdout), buf, n);
     }
     if (FD_ISSET(fileno(fp), &rset)) {  /* input is readable */
     if ( (n = Read(fileno(fp), buf, MAXLINE)) == 0) {
         stdineof = 1;
         shutdown(sockfd, SHUT_WR);  /* send FIN */
         FD_CLR(fileno(fp), &rset);
             continue;
             }
         Writen(sockfd, buf, n);
         }
     } }
```

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()

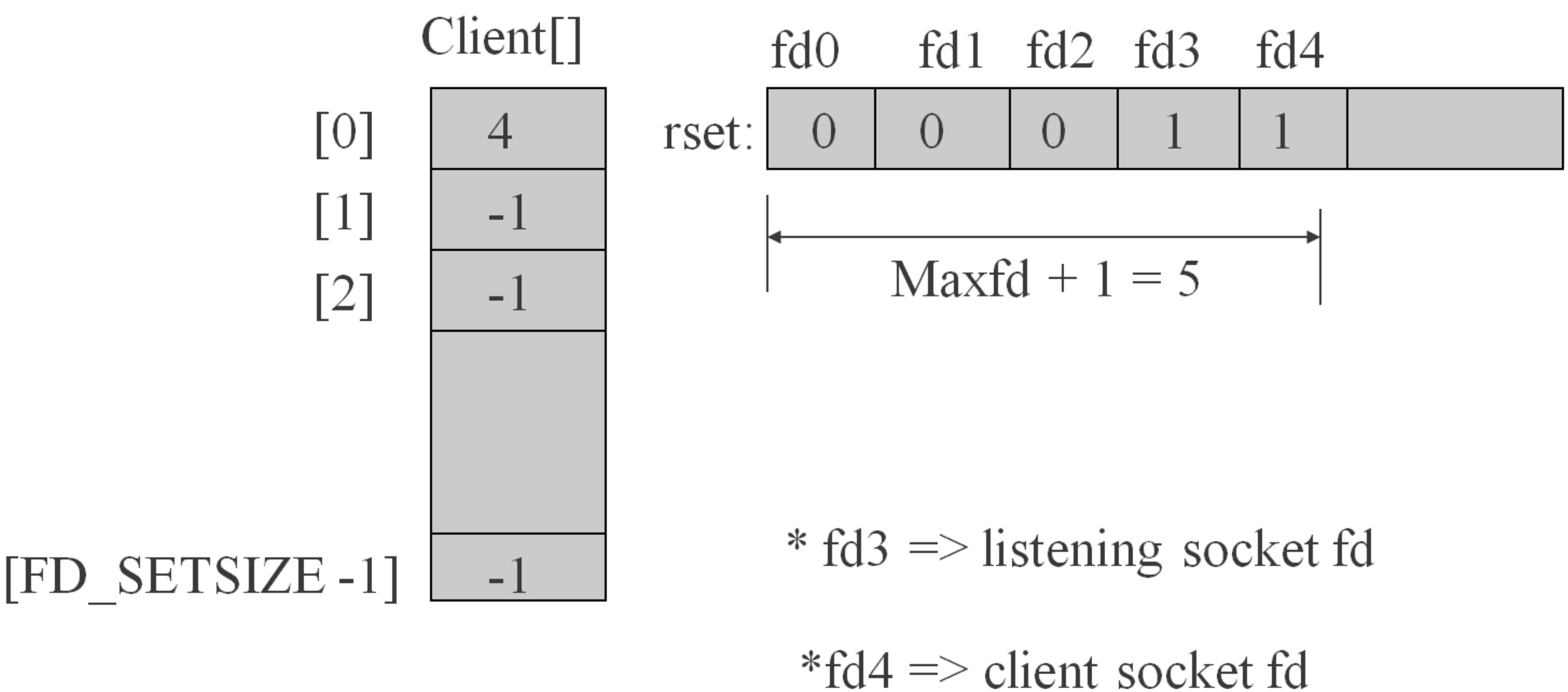
- There are three fds: 0,1,2
- One more fd after creating listening socket.



TCP Server Using select()

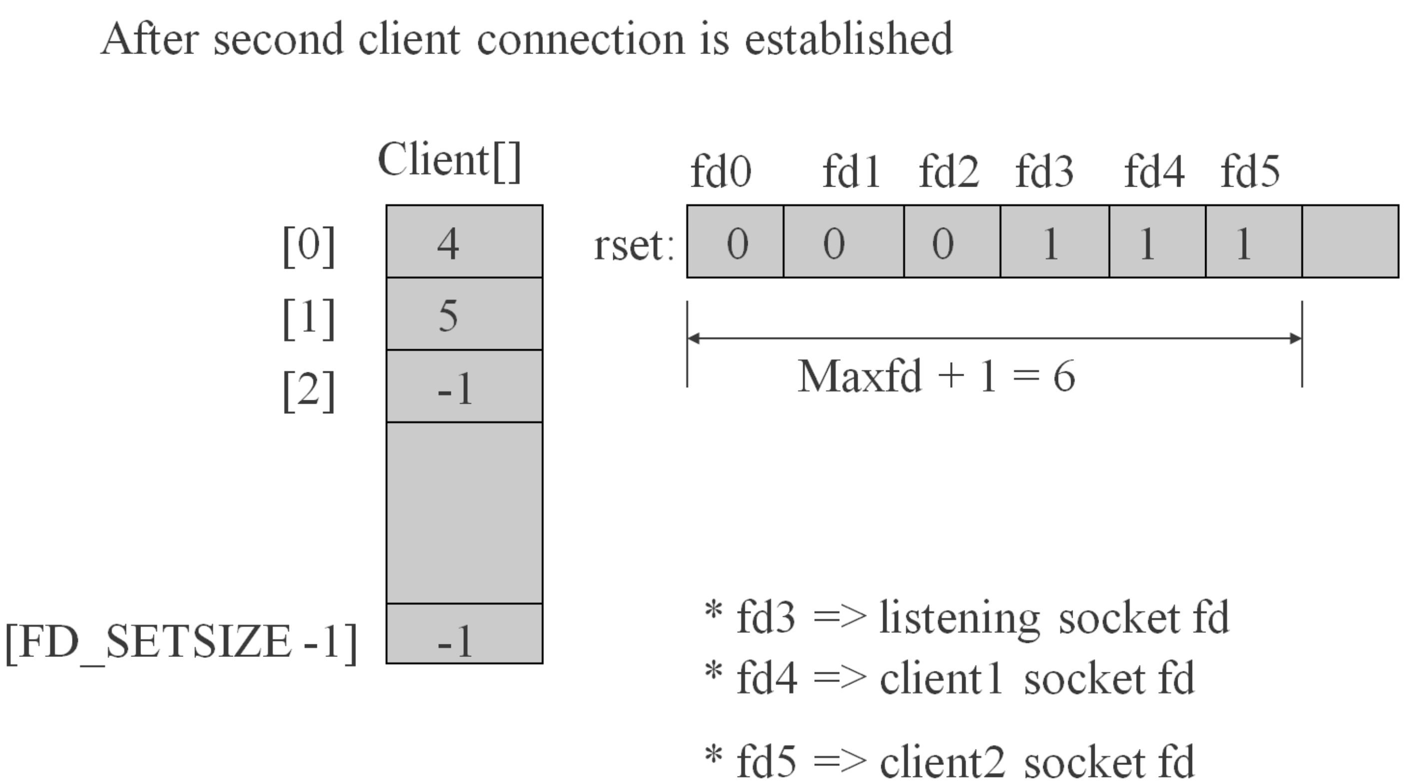
- When a new client is accepted through accept()
  - A connected socket is added

After first client connection is established



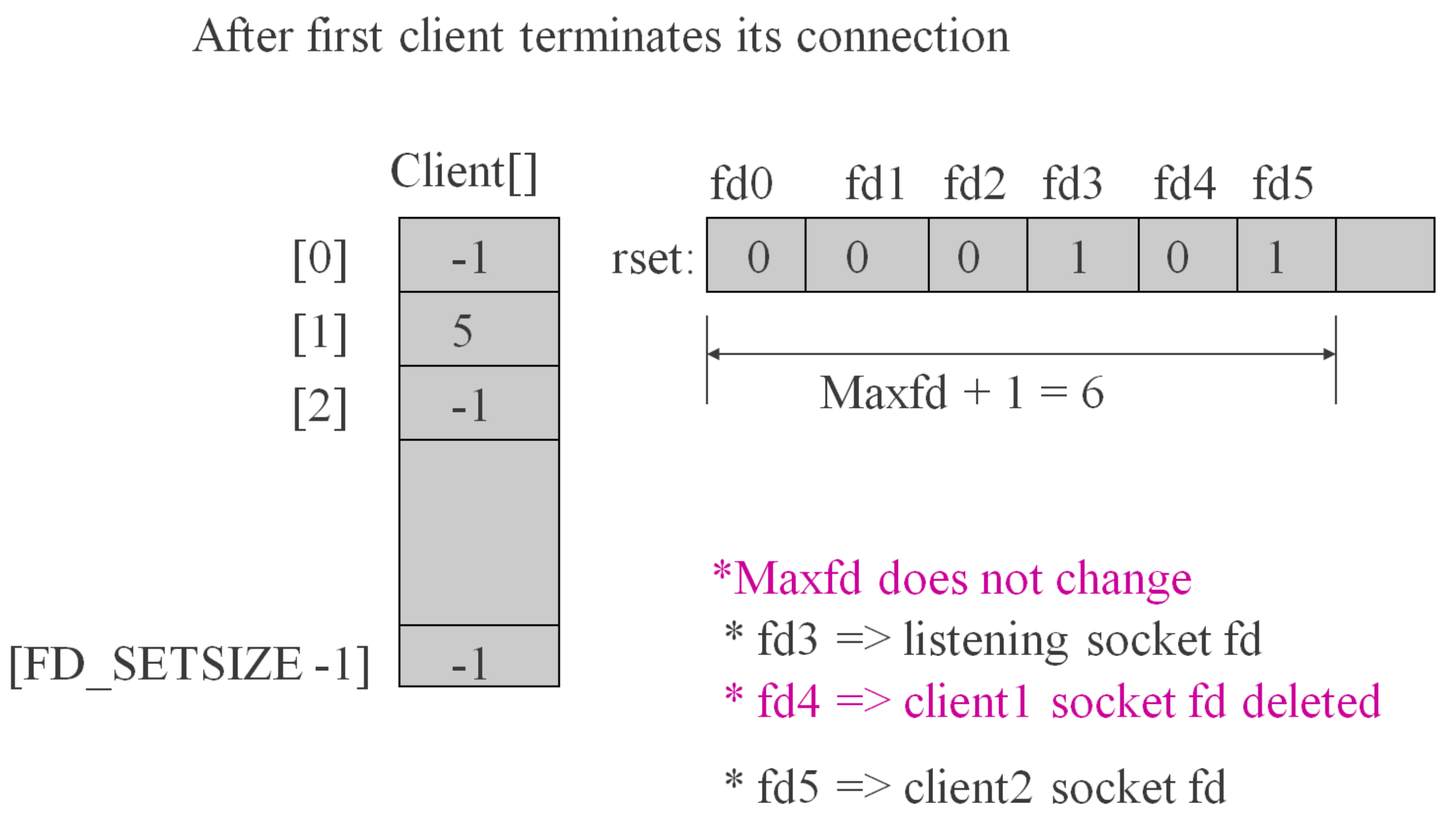
TCP Server Using select()

- 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.

```
int main(int argc, char **argv)
{
    int          i, maxi, maxfd, listenfd, connfd, sockfd;
    int          nready, client[FD_SETSIZE];
    fd_set              rset, allset;
    struct sockaddr_in  cliaddr, servaddr;
    listenfd = socket(AF_INET, SOCK_STREAM, 0);
    bzero(&servaddr, sizeof(servaddr));
    servaddr.sin_family      = AF_INET;
    servaddr.sin_addr.s_addr = htonl(INADDR_ANY);
    servaddr.sin_port        = htons(SERV_PORT);
    bind(listenfd, (SA *) &servaddr, sizeof(servaddr));
    listen(listenfd, LISTENQ);
```

TCP Server Using select()

- Handling when listening socket is readable

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

```
    if (FD_ISSET(listenfd, &rset)) {/* new client connection */
        clilen = sizeof(cliaddr);
        connfd = accept(listenfd, (SA *) &cliaddr, &clilen);
        for (i = 0; i < FD_SETSIZE; i++)
            if (client[i] < 0) {
                client[i] = connfd;    /* save descriptor */
            break;}
        if (i == FD_SETSIZE) err_quit("too many clients");
        FD_SET(connfd, &allset);    /* add new descriptor to set */
        if (connfd > maxfd)
            maxfd = connfd;         /* maxfd for select */
        if (i > maxi)
            maxi = i;    /* max index in client[] array */
        if (--nready <= 0)
            continue;    /* no more readable descriptors */
    }
```

TCP Server Using select()

- When a connected socket is readable

```
for (i = 0; i <= maxi; i++) {/* check all clients for data */
    if ((sockfd = client[i]) < 0)
        continue;
    if (FD_ISSET(sockfd, &rset)) {
        if ( (n = Readline(sockfd, line, MAXLINE)) == 0) {
            /*connection closed by client */
            close(sockfd);
            FD_CLR(sockfd, &allset);
            client[i] = -1;
        }
        else
            Writen(sockfd, line, n);
        if (--nready <= 0)
        break;  /* no more readable descriptors */
    }
}
```

- 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()

```
struct timespec{
	time_t  tv_sec;   /*seconds*/
	long     tv_nsec; /* nanoseconds */
};
```

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

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

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

  - This call is equivalent to

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

Problems with select() and poll()

- 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.

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Non-blocking I/O on Sockets

Socket Operations

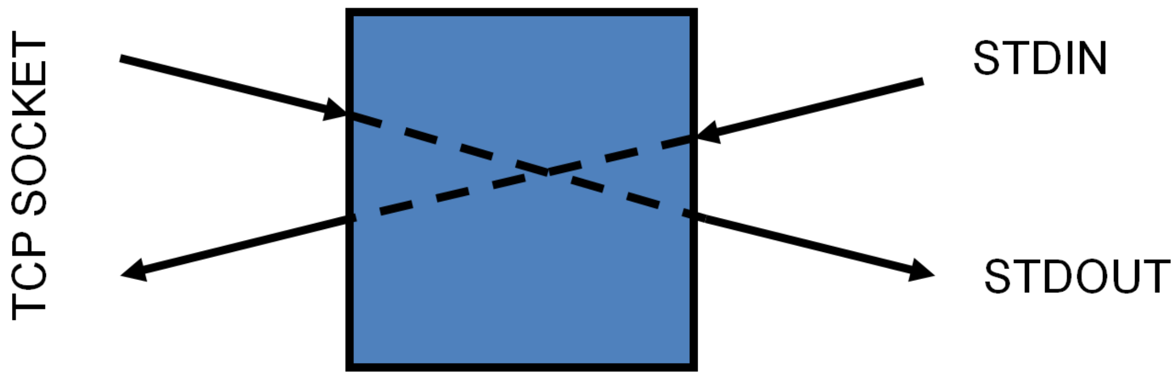
- Input operations: read, recv, readv, recvfrom, recvmsg
  - Blocking operations
  - TCP: until a byte arrives.
  - UDP: until a datagram arrives.
  - With non-blocking socket, if no data, return with EWOULDBLOCK error.
- Output Operations: write, send, writev, sendto, sendmsg
  - Blocks if there is 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.

```
str_cli(FILE *fp, int sockfd)
{
 int      maxfdp1, stdineof;
 fd_set   rset;
 stdineof = 0;
 FD_ZERO(&rset);
 for ( ; ; ) {
     if (stdineof == 0)
         FD_SET(fileno(fp), &rset);
     FD_SET(sockfd, &rset);
     maxfdp1 = max(fileno(fp), sockfd) + 1;
     select(maxfdp1, &rset, NULL, NULL, NULL);
     if (FD_ISSET(sockfd, &rset)) {  /* socket is readable */
     if ( (n = Read(sockfd, buf, MAXLINE)) == 0) {
         if (stdineof == 1)
             return;         /* normal termination */
         else
             err_quit("str_cli: server terminated prematurely");
             }
         Write(fileno(stdout), buf, n);
     }
     if (FD_ISSET(fileno(fp), &rset)) {  /* input is readable */
     if ( (n = Read(fileno(fp), buf, MAXLINE)) == 0) {
         stdineof = 1;
         shutdown(sockfd, SHUT_WR);  /* send FIN */
         FD_CLR(fileno(fp), &rset);
             continue;
             }
         Writen(sockfd, buf, n);
         }
     } }
```

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.

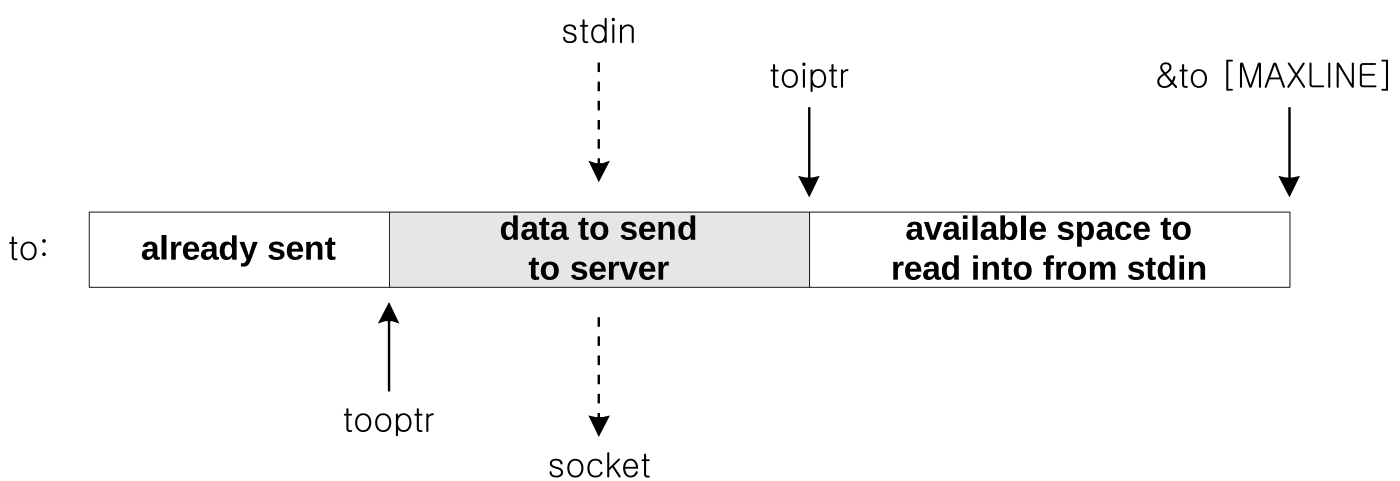


Figure 15.1 Buffer containing data from standard input going to the socket.

Select with Non-Blocking IO

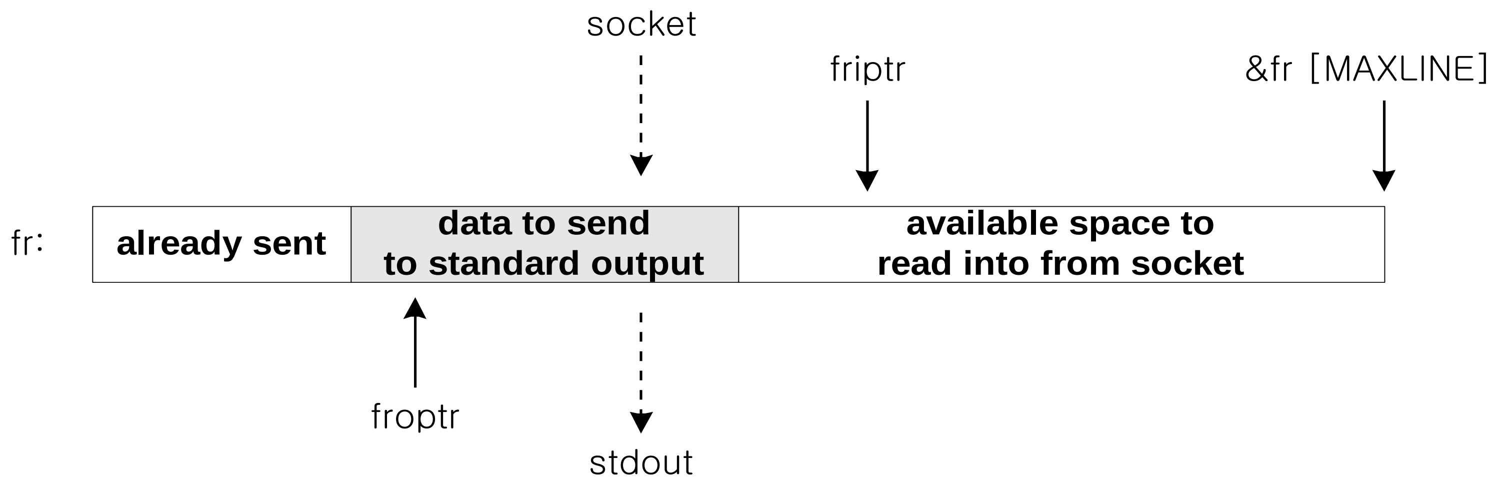


Figure 15.2 Buffer containing data from the socket going to standard output.

- *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

```c
void str_cli(FILE *fp, int sockfd)
 {
        int      maxfdp1, val, stdineof;
        ssize_t n, nwritten;
        fd_set  rset, wset;
        char    to[MAXLINE], fr[MAXLINE];
        char    *toiptr, *tooptr, *friptr, *froptr;
        val = fcntl(sockfd, F_GETFL, 0);
        fcntl(sockfd, F_SETFL, val | O_NONBLOCK);
        val = Fcntl(STDIN_FILENO, F_GETFL, 0);
        fcntl(STDIN_FILENO, F_SETFL, val | O_NONBLOCK);
        val = Fcntl(STDOUT_FILENO, F_GETFL, 0);
        fcntl(STDOUT_FILENO, F_SETFL, val | O_NONBLOCK);
        toiptr = tooptr = to;       /* initialize buffer pointers */
        friptr = froptr = fr;
        stdineof = 0;
```

```c
        maxfdp1 = max(max(STDIN_FILENO, STDOUT_FILENO), sockfd) + 1;
        for ( ; ; ) {
            FD_ZERO(&rset);
            FD_ZERO(&wset);
            if (stdineof == 0 && toiptr < &to[MAXLINE])
                FD_SET(STDIN_FILENO, &rset);     /* read from stdin */
            if (friptr < &fr[MAXLINE])
                FD_SET(sockfd, &rset);  /* read from socket */
            if (tooptr != toiptr)
                FD_SET(sockfd, &wset);  /* data to write to socket */
            if (froptr != friptr)
                FD_SET(STDOUT_FILENO, &wset);   /* data to write to stdout */
            select(maxfdp1, &rset, &wset, NULL, NULL);
```

reads from standard input

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

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

Amt of space available in from buffer

```
if (FD_ISSET(sockfd, &rset)) {
    if ( (n = read(sockfd, friptr, &fr[MAXLINE] - friptr)) < 0) {
        if (errno != EWOULDBLOCK)
            err_sys("read error on socket");
    } else if (n == 0) {
        fprintf(stderr, "%s: EOF on socket\n", gf_time());
        if (stdineof)
            return;     /* normal termination */
        else
            err_quit("str_cli: server terminated prematurely");
    } else {
        fprintf(stderr, "%s: read %d bytes from socket\n",
                gf_time(), n);
        friptr += n;     /* # just read */
        FD_SET(STDOUT_FILENO, &wset);     /* try and write below */
    }
}
```

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

writes to standard output

No of bytes to write >0

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

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

Writes to socket

No of bytes to write >0

```
    if (FD_ISSET(sockfd, &wset) && ((n = toiptr - tooptr) > 0)) {
        if ( (nwritten = write(sockfd, tooptr, n)) < 0) {
            if (errno != EWOULDBLOCK)
                err_sys("write error to socket");
        } else {
        fprintf(stderr, "%s: wrote %d bytes to socket\n",
                gf_time(), nwritten);
        tooptr += nwritten; /* # just written */
            if (tooptr == toiptr) {
                toiptr = tooptr = to;   /* back to beginning of buffer */
            if (stdineof)
                shutdown(sockfd, SHUT_WR);  /* send FIN */
            }
        }
    }
}
 }
```

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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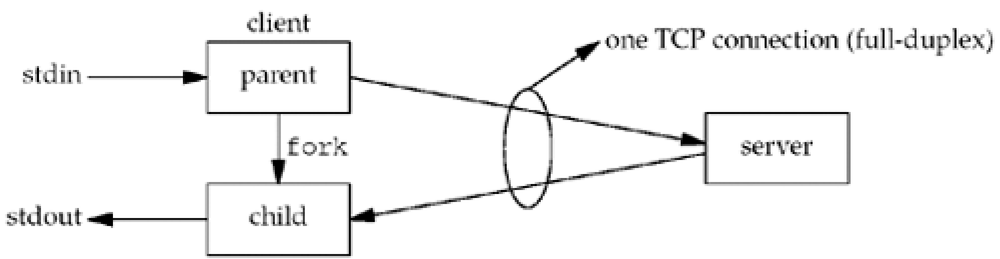
Client using Multiple Processes

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

```
void str_cli(FILE *fp, int sockfd)
{
    pid_t     pid;
    char      sendline[MAXLINE], recvline[MAXLINE];
    if ( (pid = fork()) == 0) {    /* child: server -> stdout */
       while (Readline(sockfd, recvline, MAXLINE) > 0)
           fputs(recvline, stdout);
       kill(getppid(), SIGTERM);    /* in case parent still running */
       exit(0);
    }
    /* parent: stdin -> server */
    while (fgets(sendline, MAXLINE, fp) != NULL)
        Writen(sockfd, sendline, strlen(sendline));
    shutdown(sockfd, SHUT_WR);  /* EOF on stdin, send FIN */
    pause();
    return;
}
```

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.

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Non-blocking Connect

Nonblocking connect()

- 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()

```c
int connect_nonb(int sockfd, const SA *saptr, socklen_t salen, int nsec)
 {
     int      flags, n, error;
     socklen_t len;
     fd_set rset, wset;
     struct timeval tval;
     flags = fcntl(sockfd, F_GETFL, 0);
     fcntl(sockfd, F_SETFL, flags | O_NONBLOCK);
     error = 0;
     if ( (n = connect(sockfd, saptr, salen)) < 0)
         if (errno != EINPROGRESS)
             return (-1);
     /* Do whatever we want while the connect is taking place. */
     if (n == 0)
         goto done;              /* connect completed immediately */
     FD_ZERO(&rset);
     FD_SET(sockfd, &rset);
     wset = rset;
     tval.tv_sec = nsec;
     tval.tv_usec = 0;
```

Nonblocking connect()

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```
    if ( (n = select(sockfd + 1, &rset, &wset, NULL,
                     nsec ? &tval : NULL)) == 0) {
        close(sockfd);          /* timeout */
        errno = ETIMEDOUT;
        return (-1);
    }
    if (FD_ISSET(sockfd, &rset) || FD_ISSET(sockfd, &wset)) {
        len = sizeof(error);
        if (getsockopt(sockfd, SOL_SOCKET, SO_ERROR, &error, &len) < 0)
            return (-1);     /* Solaris pending error */
    } else
        err_quit("select error: sockfd not set");
  done:
    Fcntl(sockfd, F_SETFL, flags);  /* restore file status flags */
    if (error) {
        close(sockfd);           /* just in case */
        errno = error;
        return (-1);
    }
    return (0);
}
```

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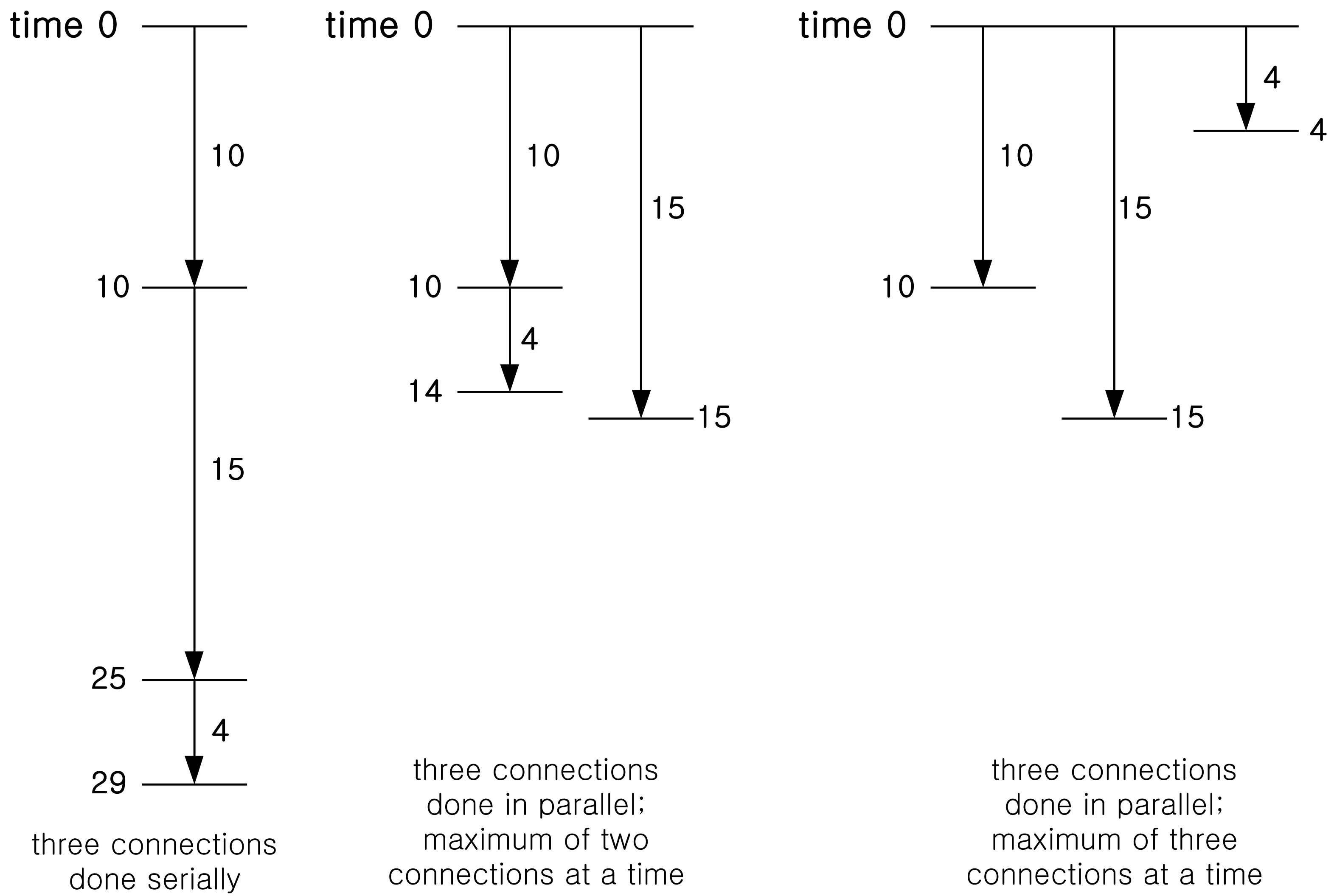
Web client: Non-blocking Connect

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.)



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

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

- Each file has a state and fd.

nonblock/web.c

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

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

nonblock/start_connect.c

```c
void start_connect(struct file *fptr)
 {
     int     fd, flags, n;
     ai = Host_serv(fptr->f_host, SERV, 0, SOCK_STREAM);
     fd = Socket(ai->ai_family, ai->ai_socktype, ai->ai_protocol);
     fptr->f_fd = fd;
     printf("start_connect for %s, fd %d\n", fptr->f_name, fd);
         /* Set socket nonblocking */
     flags = Fcntl(fd, F_GETFL, 0);
     Fcntl(fd, F_SETFL, flags | O_NONBLOCK);
         /* Initiate nonblocking connect to the server. */
     if ( (n = connect(fd, ai->ai_addr, ai->ai_addrlen)) < 0) {
         if (errno != EINPROGRESS)
             err_sys("nonblocking connect error");
         fptr->f_flags = F_CONNECTING;
         FD_SET(fd, &rset);     /* select for reading and writing */
         FD_SET(fd, &wset);
         if (fd > maxfd)
             maxfd = fd;
      } else if (n >= 0)            /* connect is already done */
          write_get_cmd(fptr);      /* write() the GET command */
 }
```

- 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

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

- Build command and send it
- Set flags

Main function: web.c

```
while (nlefttoread > 0) {
  while (nconn < maxnconn && nlefttoconn > 0) {
        /* find a file to read */
      for (i = 0; i < nfiles; i++)
         if (file[i].f_flags == 0)
             break;
      if  (i == nfiles)
          err_quit("nlefttoconn = %d but nothing found", nlefttoconn);
      start_connect(&file[i]);
      nconn++;
      nlefttoconn--;
  }
```

- Initiate another connection, if possible

Main function: web.c

```c
rs = rset;
ws = wset;
n = select(maxfd + 1, &rs, &ws, NULL, NULL);
for (i = 0; i < nfiles; i++) {
    flags = file[i].f_flags;
    if (flags == 0 || flags & F_DONE)
        continue;
    fd = file[i].f_fd;
    if (flags & F_CONNECTING &&
        (FD_ISSET(fd, &rs) || FD_ISSET(fd, &ws))) {
        n = sizeof(error);
        if (getsockopt(fd, SOL_SOCKET, SO_ERROR, &error, &n) < 0 ||
        error != 0) {
        err_ret("nonblocking connect failed for %s",
                file[i].f_name);
    }
        /* connection established */
    printf("connection established for %s\n", file[i].f_name);
    FD_CLR(fd, &wset); /* no more writeability test */
    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

```c
                /* connection established */
            printf("connection established for %s\n", file[i].f_name);
            FD_CLR(fd, &wset); /* no more writeability test */
            write_get_cmd(&file[i]);   /* write() the GET command */
        } else if (flags & F_READING && FD_ISSET(fd, &rs)) {
            if ( (n = Read(fd, buf, sizeof(buf))) == 0) {
                printf("end-of-file on %s\n", file[i].f_name);
                Close(fd);
                file[i].f_flags = F_DONE;    /* clears F_READING */
                FD_CLR(fd, &rset);
                nconn--;
                nlefttoread--;
            } else {
                printf("read %d bytes from %s\n", n, file[i].f_name);
            }
        }
    }
}
exit(0);
}
```

- 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