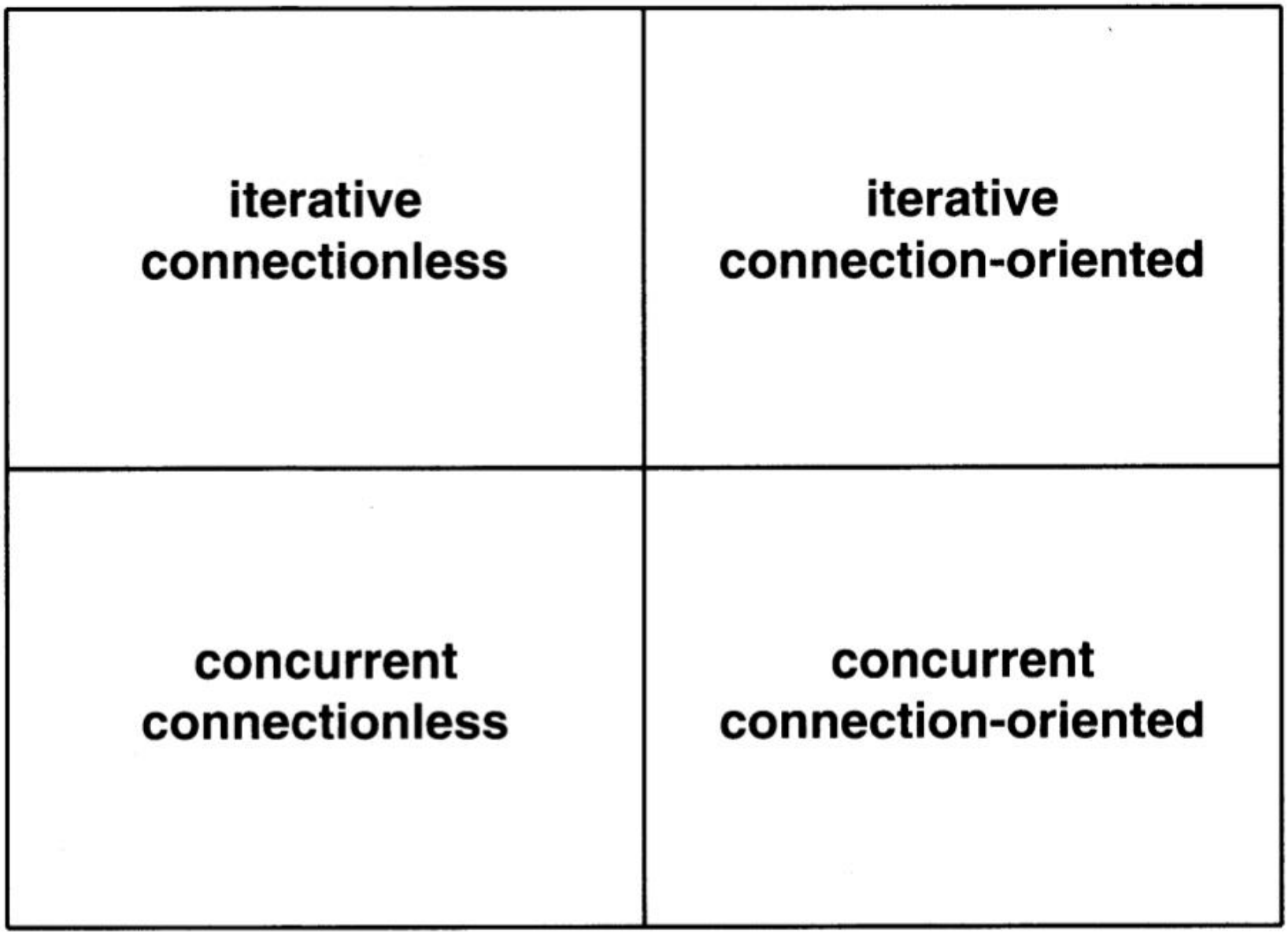
Client/Server Paradigms

- Basic functions
- Iterative, connectionless servers
- Iterative, connection-oriented servers
- Concurrent, connection-oriented servers
- Single-process, concurrent servers
- Multi-protocol servers
- Multi-service servers
- Concurrency in clients


iterative
connectionless
iterative
connection-oriented
concurrent
connectionless
concurrent
connection-oriented

connectTCP and connectUDP

```
int connectTCP( host, service )
char   *host;   /* name of host to which connection is desired */
char   *service;   /* service associated with the desired port */
{
    return connectsock( host, service, "tcp");
}

int connectUDP( host, service )
char        *host;                  /* name of host to which connection is desired        */
char        *service;  /* service associated with the desired port */
{
    return connectsock(host, service, "udp");
}
```

Connectsock -- (1)

```
int connectsock( host, service, protocol )
char   *host; /* name of host to which connection is desired */
char   *service; /* service associated with the desired port */
char   *protocol; /* name of protocol to use ("tcp" or "udp") */
{
    struct hostent   *phe; /* pointer to host information entry */
    struct servent   *pse; /* pointer to service information entry
                              */
    struct protoent *ppe; /* pointer to protocol information entry*/
    struct sockaddr_in sin; /* an Internet endpoint address */
    int      s, type; /* socket descriptor and socket type */

    bzero((char *)&sin, sizeof(sin));
    sin.sin_family = AF_INET;
```

Connectsock -- (2)

```
/* Map service name to port number */
 if ( pse = getservbyname(service, protocol) )
        sin.sin_port = pse->s_port;
 else if ( (sin.sin_port = htons((u_short)atoi(service))) == 0 )
        errexit("can't get \"%s\" service entry\n", service);

/* Map host name to IP address, allowing for dotted decimal */
 if ( phe = gethostbyname(host) )
        bcopy(phe->h_addr, (char *) &sin.sin_addr, phe->h_length);
 else if ( (sin.sin_addr.s_addr = inet_addr(host)) == INADDR_NONE )
        errexit("can't get \"%s\" host entry\n", host);
```

Services

Sample /etc/services file

```
# /etc/services
# This file associates official service names and aliases with the port
# number and protocol the services use. The form for each entry is:
# <official service name> <port number/protocol name> <aliases>
#
echo          7/tcp                     # Echo
echo          7/udp                     #
discard       9/tcp       sink null     # Discard
discard       9/udp       sink null     #
systat        11/tcp      users         # Active Users
qotd          17/tcp      quote         # Quote of the Day
ftp-data      20/tcp                    # File Transfer Protocol (Data)
ftp           21/tcp                    # File Transfer Protocol (Control)
telnet        23/tcp                    # Virtual Terminal Protocol
smtp          25/tcp                    # Simple Mail Transfer Protocol
domain        53/tcp      nameserver    # Domain Name Service
domain        53/udp      nameserver    #
bootps        67/udp                    # Bootstrap Protocol Service
bootpc        68/udp                    # Bootstrap Protocol Client
hostnames     101/tcp     hostname      # NIC Host Name Server
pop           109/tcp     postoffice    # Post Office Protocol - Version 2
portmap       111/tcp     sunrpc        # Sun Remote Procedure Protocol
portmap       111/udp     sunrpc        #
nntp          119/tcp     readnews      # Network News Transfer Protocol
ntp           123/udp                   # Network Time Protocol
snmp          161/udp     snmpd         # Simple Network Management Protocol
biff          512/udp     comsat        # mail notifiction
exec          512/tcp                   # remote execution, passwd required
login         513/tcp                   # remote login
who           513/udp     whod          # remote who and uptime
syslog        514/udp                   # remote system logging
printer       515/tcp     spooler       # remote print spooling
route         520/udp     router routed # routing information protocol
kerberos      750/udp     kdc           # Kerberos (server) udp -kfall
kerberos      750/tcp     kdc           # Kerberos (server) tcp -kfall
krbupdate     760/tcp     kreg          # Kerberos registration -kfall
nfsd          2049/udp                  # NFS remote file system
```

Hosts

Excerpt from `/etc/hosts` file

```
#/etc/hosts
# The form for each entry is:
# <internet address>  <official hostname> <aliases>
#
127.0.0.1         localhost     loopback
232.48.1.107      merlin
232.48.1.215      arthur
232.48.1.200      lancelot
232.48.2.35       guenevere
232.48.1.104      robin
232.48.1.183      sherlock
232.48.1.177      dracula
232.48.2.49       godzilla
```

Connectsock -- (3)

```
/* Map protocol name to protocol number */
 if ( (ppe = getprotobyname(protocol)) == 0)
        errexit("can't get \"%s\" protocol entry\n", protocol);

/* Use protocol to choose a socket type */
 if (strcmp(protocol, "udp") == 0)
        type = SOCK_DGRAM;
 else
        type = SOCK_STREAM;

/* Allocate a socket */
 s = socket(PF_INET, type, ppe->p_proto);
 if (s < 0)
        errexit("can't create socket: %s\n", sys_errlist[errno]);
```

Protocol List

Example `/etc/protocols` file

```
#/etc/protocols
# This file contains information regarding the known protocols
# used in the DARPA Internet
#
# The form for each entry is:
# <official protocol name>  <Protocol number>  <aliases>
#
# Internet (IP) protocols
#
ip              0       IP              # Internet protocol, pseudo protocol number
icmp            1       ICMP            # internet control message protocol
ggp             3       GGP             # gateway-gateway protocol
tcp             6       TCP             # transmission control protocol
egp             8       EGP             # exterior gateway protocol
pup             12      PUP             # PARC universal packet protocol
udp             17      UDP             # user datagram protocol
hmp             20      HMP             # host monitoring protocol
xns-idp         22      XNS-IDP         # Xerox NS IDP
rdp             27      RDP             # "reliable datagram" protocol
```

Connectsock -- (4)

```
    /* Connect the socket */
     if (connect(s, (struct sockaddr *)&sin, sizeof(sin)) < 0)
            errexit("can't connect to %s.%s: %s\n", host, service,
                    sys_errlist[errno]);
     return s;
}
```

TCPdaytime.c -- (1)

```
int
main(argc, argv)
int argc;
char        *argv[];
{
    char   *host = "localhost";             /* host to use if none supplied */
    char   *service = "daytime";  /* default service port */
```

TCPdaytime.c -- (2)

```
        switch (argc) {
        case 1:
                host = "localhost";
                break;
        case 3:
                service = argv[2];
                /* FALL THROUGH */
        case 2:
                host = argv[1];
                break;
        default:
                fprintf(stderr, "usage: TCPdaytime [host [port]]\n");
                exit(1);
        }
        TCPdaytime(host, service);
        exit(0);
}
```

TCPdaytime.c -- (2)

```
TCPdaytime(host, service)
char        *host;
char        *service;
{
    char    buf[LINELEN+1];    /* buffer for one line of text */
    int     s, n;              /* socket, read count */

    s = connectTCP(host, service);

    while( (n = read(s, buf, LINELEN)) > 0) {
            buf[n] = '\0';          /* insure null-terminated */
            (void) fputs( buf, stdout );
    }
}
```

UDPtime.c -- (1)

```
int main(argc, argv)
int  argc;
char        *argv[];
{
    char   *host = "localhost";            /* host to use if none supplied */
    char   *service = "time"; /* default service name */
    time_t              now;               /* 32-bit integer to hold time */
    int     s, n;                   /* socket descriptor, read count*/
    switch (argc) {
            ....
            See TCPdaytime.c -- (2)
            ....
    }
```

UDPtime.c -- (2)

```
        s = connectUDP(host, service);

        (void) write(s, MSG, strlen(MSG));

        /* Read the time */

        n = read(s, (char *)&now, sizeof(now));
        if (n < 0)
                errexit("read failed: %s\n", sys_errlist[errno]);
        now = ntohl((u_long)now); /* put in host byte order          */
        now -= UNIXEPOCH;                   /* convert UCT to UNIX epoch          */
        printf("%s", ctime(&now));
        exit(0);
}
```

passiveTCP and passiveUDP

```
int
passiveTCP( service, qlen )
char   *service; /* service associated with the desired port */
int  qlen;  /* maximum server request queue length  */
{
    return passivesock(service, "tcp", qlen);
}

int
passiveUDP( service )
char  *service; /* service associated with the desired port */
{
    return passivesock(service, "udp", 0);
}
```

Passivesock -- (1)

```
int passivesock( service, protocol, qlen )
char   *service;   /* service associated with the desired port */
char   *protocol;   /* name of protocol to use ("tcp" or "udp") */
int  qlen;     /* maximum length of the server request queue */
{
     struct servent    *pse;         /* pointer to service information                    entry */
     struct protoent *ppe;          /* pointer to protocol information entry*/
     struct sockaddr_in sin;        /* an Internet endpoint address */
     int      s, type;     /* socket descriptor and socket type          */

     bzero((char *)&sin, sizeof(sin));
     sin.sin_family = AF_INET;
     sin.sin_addr.s_addr = INADDR_ANY;
```

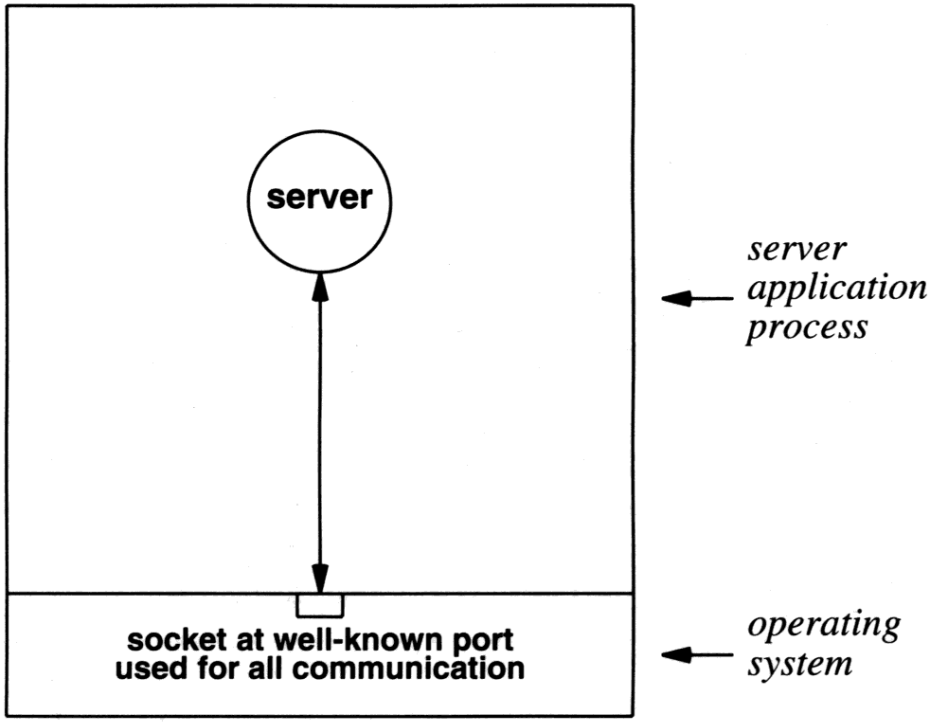
Passivesock -- (2)

```
/* Map service name to port number */
    if ( pse = getservbyname(service, protocol) )
            sin.sin_port = htons(ntohs((u_short)pse->s_port) + portbase);
    else if ( (sin.sin_port = htons((u_short)atoi(service))) == 0 )
            errexit("can't get \"%s\" service entry\n", service);

   /* Map protocol name to protocol number */
    if ( (ppe = getprotobyname(protocol)) == 0)
            errexit("can't get \"%s\" protocol entry\n", protocol);

   /* Use protocol to choose a socket type */
    if (strcmp(protocol, "udp") == 0)
            type = SOCK_DGRAM;
    else
            type = SOCK_STREAM;
```

Passivesock -- (3)

```
    /* Allocate a socket */
     s = socket(PF_INET, type, ppe->p_proto);
     if (s < 0)
            errexit("can't create socket: %s\n", sys_errlist[errno]);

    /* Bind the socket */
     if (bind(s, (struct sockaddr *)&sin, sizeof(sin)) < 0)
            errexit("can't bind to %s port: %s\n", service,
                    sys_errlist[errno]);
     if (type == SOCK_STREAM && listen(s, qlen) < 0)
            errexit("can't listen on %s port: %s\n", service,
                    sys_errlist[errno]);
     return s;
}
```

Iterative, Connectionless Servers



The process structure for an iterative, connectionless server. A single server process communicates with many clients using one socket.

- Example:UDPtimed.c (next slides)

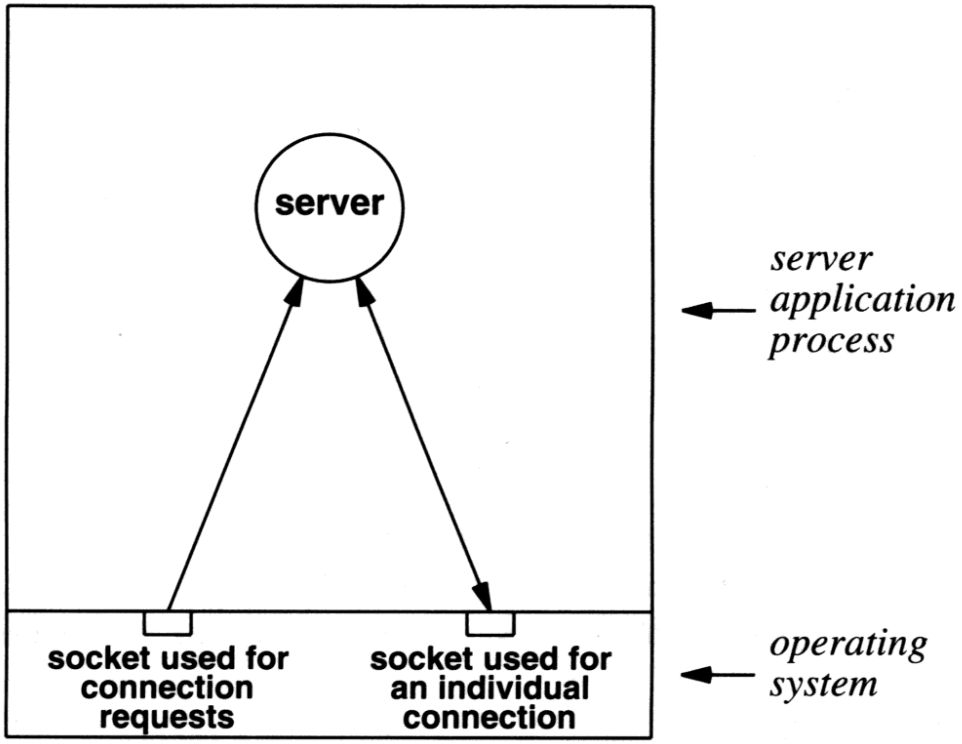
UDPtimed.c -- (1)

```
int main(argc, argv)
int   argc;
char*argv[];
{
        struct sockaddr_in fsin; /* the from address of a client */
        char    *service = "time"; /* service name or port number */
        char    buf[1];         /* "input" buffer; any size > 0         */
        int     sock;           /* server socket                        */
        time_t  now;            /* current time                         */
        int     alen;           /* from-address length  */

        switch (argc) {
        case    1:
                break;
        case    2:
                service = argv[1];
                break;
        default:
                errexit("usage: UDPtimed [port]\n");
        }
```

UDPtimed.c -- (2)

```
        sock = passiveUDP(service);

        while (1) {
                alen = sizeof(fsin);
                if (recvfrom(sock, buf, sizeof(buf), 0,
                        (struct sockaddr*)&fsin, &alen) < 0)
                    errexit("recvfrom: %s\n", sys_errlist[errno]);
                (void) time(&now);
                now = htonl((u_long)(now + UNIXEPOCH));
                (void) sendto(sock, (char *)&now,
                        sizeof(now), 0, (struct sockaddr *)
                        &fsin, sizeof(fsin));
        }
}
```

Iterative, Connection-Oriented Servers



The process structure of an iterative, connection-oriented server. The server waits at the well-known port for a connection, and then communicates with the client over that connection.

- Example: TCPtimed.c (next slides)

TCPdaytimed.c -- (1)

```
int main(argc, argv)
int   argc;
char*argv[];
{
      struct   sockaddr_in fsin;        /* the from address of a client       */
      char     *service = "daytime";    /* service name or port number        */
      int      msock, ssock;                    /* master & slave sockets              */
      int      alen;                            /* from-address length                 */

      switch (argc) {
      case     1:
               break;
      case     2:
               service = argv[1];
               break;
      default:
               errexit("usage: TCPdaytimed [port]\n");
      }
```

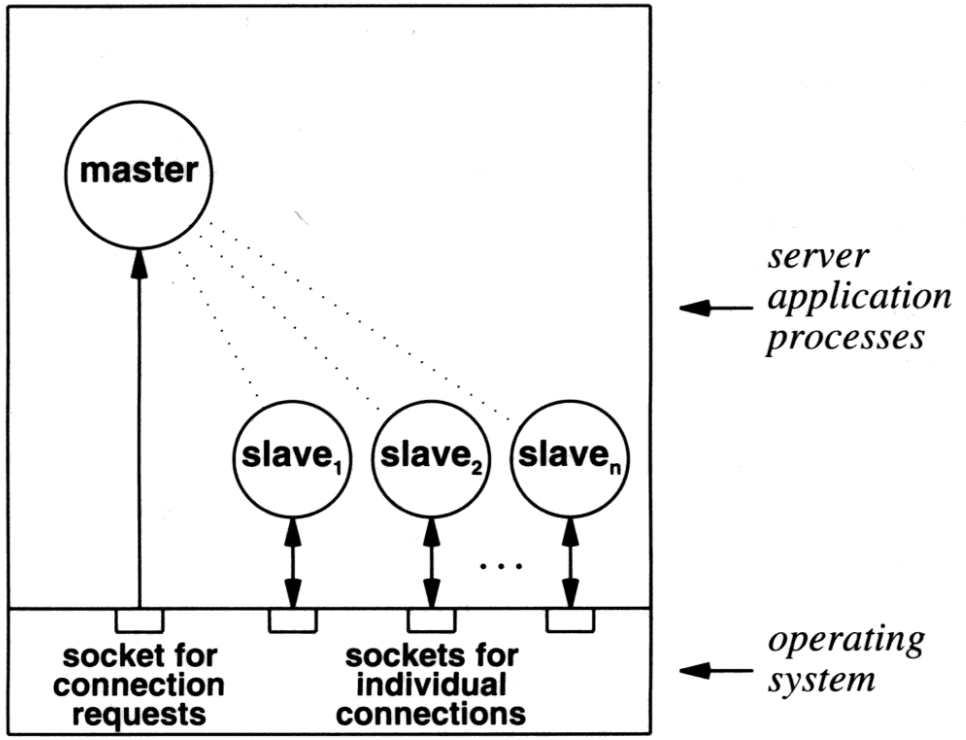
TCPdaytimed.c -- (2)

```
        msock = passiveTCP(service, QLEN);

        while (1) {
                ssock = accept(msock, (struct sockaddr *)
                        &fsin, &alen);

                if (ssock < 0)
                        errexit("acceptfailed:%s\n",sys_errlist[errno]);
                (void) TCPdaytimed(ssock);
                (void) close(ssock);
        }
}
```

TCPdaytimed.c -- (3)

```
/*------------------------------------------------------------------
 * TCPdaytimed - do TCP DAYTIME protocol
 *------------------------------------------------------------------
 */
int
TCPdaytimed(fd)
int   fd;
{
      char    *pts;                    /* pointer to time string*/
      time_t  now;                     /* current time                 */
      char    *ctime();

      (void) time(&now);
      pts = ctime(&now);
      (void) write(fd, pts, strlen(pts));
      return 0;
}
```

Concurrent, Connection-Oriented Servers



The process structure of a concurrent, connection-oriented server. A master server process accepts each incoming connection, and creates a slave process to handle it.

- Example: TCPechod.c (next slides)

TCPechod.c -- (1)

```
int main(argc, argv)
int  argc;
char        *argv[];
{
    char   *service = "echo";  /* service name or port number */
    struct sockaddr_in fsin;     /* the address of a client */
    int    alen;        /* length of client's address      */
    int    msock;       /* master server socket            */
    int    ssock;       /* slave server socket             */
    switch (argc) {
    case   1:
           break;
    case   2:
           service = argv[1];
           break;
    default:
           errexit("usage: TCPechod [port]\n");
    }
```

TCPechod.c -- (2)

msock = passiveTCP(service, QLEN);

(void) **signal(SIGCHLD, reaper);**

```
while (1) {
        alen = sizeof(fsin);
        ssock = accept(msock, (struct sockaddr *)
                        &fsin, &alen);
        if (ssock < 0) {
                if (errno == EINTR)
                        continue;
                errexit("accept: %s\n", sys_errlist[errno]);
        }
```

TCPechod.c -- (3)

```
            switch (fork()) {
            case 0:                 /* child */
                        (void) close(msock);
                        exit(TCPechod(ssock));
            default:    /* parent */
                        (void) close(ssock);
                        break;
            case -1:    errexit("fork: %s\n", sys_errlist[errno]);
            }
      }
}
```

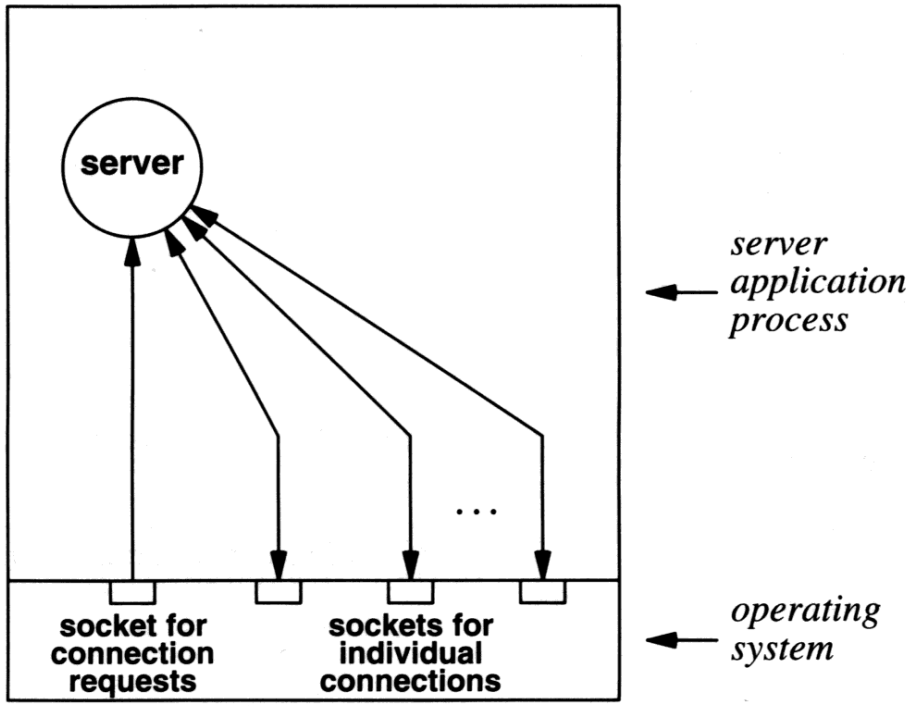
TCPechod.c -- (4)

```
int TCPechod(fd)
int  fd;
{
    char   buf[BUFSIZ];
    int    cc;

    while (cc = read(fd, buf, sizeof(buf))) {
        if (cc < 0)
            errexit("echo read: %s\n", sys_errlist[errno]);
        if (write(fd, buf, cc) < 0)
            errexit("echo write: %s\n", sys_errlist[errno]);
    }
    return 0;
}
```

TCPechod.c -- (5)

```
int reaper()
{
    union wait      status;

    while (wait3(&status, WNOHANG,
        (struct rusage *)0)>= 0)
        /* empty */;
}
```

Single-Process, Concurrent Servers (TCP)



The process structure of a connection-oriented server that achieves concurrency with a single process. The process manages multiple sockets.

- Example: TCPmechod.c (next slides)

TCPmechod.c (1)

```
/* TCPmechod.c - main, echo */

#include <sys/types.h>
#include <sys/socket.h>
#include <sys/time.h>
#include <netinet/in.h>

#include <unistd.h>
#include <string.h>
#include <stdio.h>

#define     QLEN        5       /* maximum connection queue length */
#define     BUFSIZE     4096

extern int  errno;
int         errexit(const char *format, ...);
int         passiveTCP(const char *service, int qlen);
int         echo(int fd);
```

TCPmechod.c (2)

```
/*------------------------------------------------------------------------
 * main - Concurrent TCP server for ECHO service
 *------------------------------------------------------------------------*/
int  main(int argc, char *argv[])
{    char   *service = "echo";  /* service name or port number          */
     struct sockaddr_in fsin;   /* the from address of a client*/
     int     msock;             /* master server socket         */
     fd_set          rfds;              /* read file descriptor set    */
     fd_set          afds;              /* active file descriptor set  */
     int     alen;              /* from-address length          */
     int     fd, nfds;
```

TCPmechod.c (2)

```
switch (argc) {
case   1:
       break;
case   2:
       service = argv[1];
       break;
default:
       errexit("usage: TCPmechod [port]\n");
}
```

TCPmechod.c (3)

```
msock = passiveTCP(service, QLEN);

nfds = getdtablesize();
FD_ZERO(&afds);
FD_SET(msock, &afds);

while (1) {
        memcpy(&rfds, &afds, sizeof(rfds));

        if (select(nfds, &rfds, (fd_set *)0, (fd_set *)0,
                                (struct timeval *)0) < 0)
                errexit("select: %s\n", strerror(errno));
```

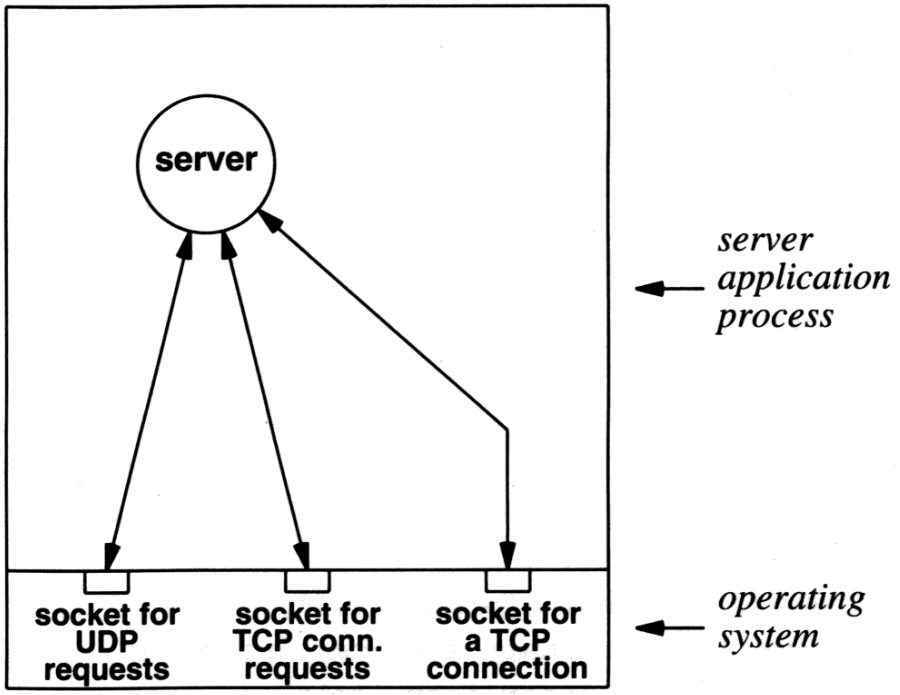
TCPmechod.c (4)

```
        if (FD_ISSET(msock, &rfds)) {
                int             ssock;
                alen = sizeof(fsin);
                ssock = accept(msock, (struct sockaddr *)&fsin,
                        &alen);
                if (ssock < 0)
                        errexit("accept: %s\n", strerror(errno));
                FD_SET(ssock, &afds);
        }
        for (fd=0; fd<nfds; ++fd)
                if (fd != msock && FD_ISSET(fd, &rfds))
                        if (echo(fd) == 0) {
                                (void) close(fd);
                                FD_CLR(fd, &afds);
                        }
    }
}
```

TCPmechod.c (5)

```
/*---------------------------------------------------------------------
 * echo - echo one buffer of data, returning byte count
 *---------------------------------------------------------------------
 */
int
echo(int fd)
{
        char    buf[BUFSIZE];
        int     cc;

        cc = read(fd, buf, sizeof buf);
        if (cc < 0)
                errexit("echo read: %s\n", strerror(errno));
        if (cc && write(fd, buf, cc) < 0)
                errexit("echo write: %s\n", strerror(errno));
        return cc;
}
```

Multiprotocol Servers



The process structure of an iterative, multiprotocol server. At any time, the server has at most three sockets open: one for UDP requests, one for TCP connection requests, and a temporary one for an individual TCP connection.

- Example: daytimed.c (next slides)

daytimed.c -- (1)

```
int
main(argc, argv)
int argc;
char       *argv[];
{
    char  *service = "daytime"; /* service name or port number */
    char  buf[LINELEN+1];/* buffer for one line of text */
    struct sockaddr_in fsin;  /* the request from address */
    int    alen;      /* from-address length        */
    int    tsock;     /* TCP master socket          */
    int    usock;     /* UDP socket                 */
    int    nfds;
    fd_set             rfds;      /* readable file descriptors   */
```

daytimed.c -- (2)

```
switch (argc) {
case   1:
        break;
case   2:
        service = argv[1];
        break;
default:
        errexit("usage: daytimed [port]\n");
}
```

daytimed.c -- (3)

```
tsock = passiveTCP(service, QLEN);
usock = passiveUDP(service);
nfds = MAX(tsock, usock) + 1;  /* bit number of max fd */

FD_ZERO(&rfds);

while (1) {
        FD_SET(tsock, &rfds);
        FD_SET(usock, &rfds);

        if (select(nfds, &rfds, (fd_set *)0,
          (fd_set *)0, (struct timeval *)0)<0)
                errexit("select error: %s\n", sys_errlist[errno]);
```

daytimed.c -- (4)

```
if (FD_ISSET(tsock, &rfds)) {
        int         ssock;  /* TCP slave socket */

        alen = sizeof(fsin);
        ssock = accept(tsock, (struct sockaddr *) &fsin,&alen);
        if (ssock < 0)
                errexit("accept failed: %s\n", sys_errlist[errno]);
        daytime(buf);

        write(ssock, buf, strlen(buf));
        close(ssock);
}
```

daytimed.c -- (5)

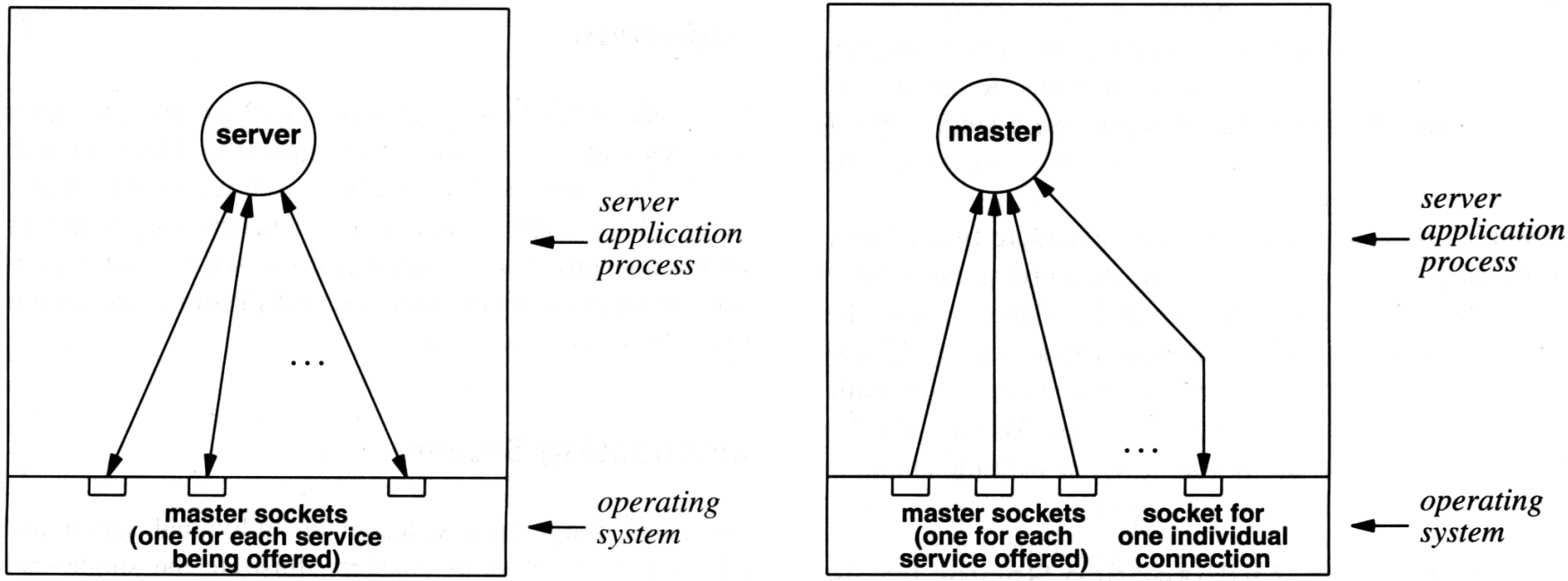
```
            if (FD_ISSET(usock, &rfds)) {
                    alen = sizeof(fsin);
                    if (recvfrom(usock, buf,
                        sizeof(buf), 0,  (struct
                        sockaddr *)&fsin, &alen) < 0)
                            errexit("recvfrom: %s\n",
                                    sys_errlist[errno]);
                    daytime(buf);
                    sendto(usock, buf, strlen(buf), 0,
                            (struct sockaddr *)&fsin,
                            sizeof(fsin));
            }
        }
    }
```

daytimed.c -- (6)

```
int daytime(buf)
char        buf[];
{
    time, now;
    (void) time(&now);
    sprintf(buf, "%s", ctime(&now));
}
```

Multiservice Servers

- Connectionless, Multiservice Server
- Connection-oriented, Multiservice Server



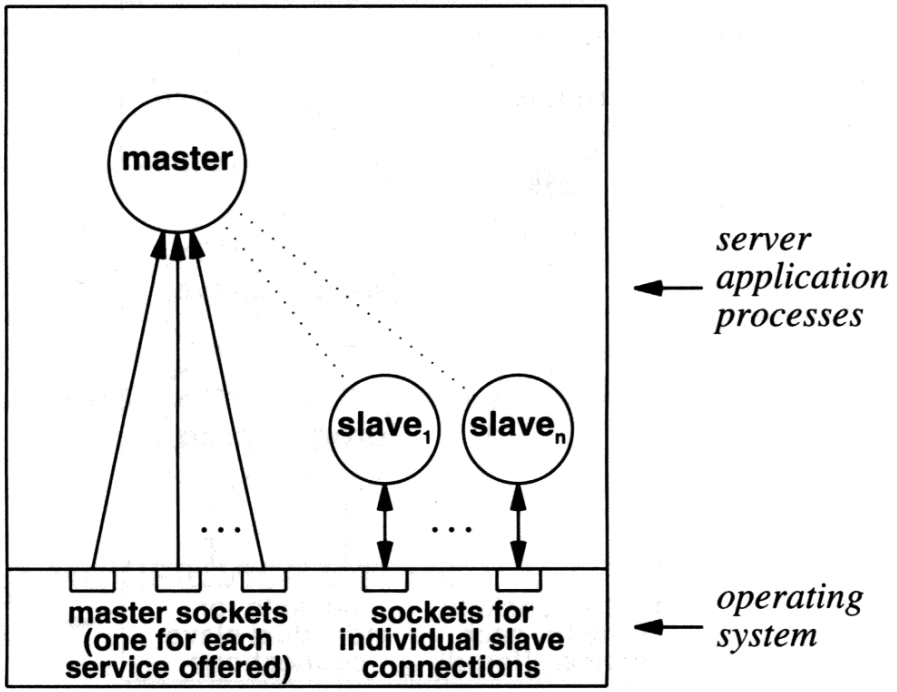
INETD

- `rc`:The initial process to invoke all servers.
- `/etc/inetd.conf`:table of all servers initially (invoked by `rc`) (see next slide)

Sample /etc/inet.conf **file**

```
#/etc/inetd.conf
#Inetd reads its configuration information from this file upon execution
#and at some later time if it is reconfigured.
#A line in the configuration file has the following fields:
#
#    service name              as in /etc/services
#    socket type               either ''stream'' or ''dgram''
#    protocol                  as in /etc/protocols
#    wait/nowait               only applies to datagram sockets, stream
#                              sockets should specify nowait
#    user                      name of user as whom the server should run
#    server program            absolute pathname for the server inetd will
#                              execute
#    server program args.      server program arguments where argv[0] is
#                              the name of the server
#
ftp      stream   tcp   nowait   root   /etc/ftpd  ftpd -l
telnet   stream   tcp   nowait   root   /etc/telnetd telnetd
tftp     dgram    udp   wait     root   /etc/tftpd tfpd
bootps   dgram    udp   wait     root   /etc/bootpd  bootpd
finger   stream   tcp   nowait   bin    /etc/fingerd  fingerd
login    stream   tcp   nowait   root   /etc/rlogind  rlogind
shell    stream   tcp   nowait   root   /etc/remshd  remshd
exec     stream   tcp   nowait   root   /etc/rexecd  rexecd
printer  stream   tcp   nowait   root   /usr/lib/rlpdaemon  rlpdaemon -i
daytime  stream   tcp   nowait   root   internal
daytime  dgram    udp   nowait   root   internal
time     stream   tcp   nowait   root   internal
time     dgram    udp   nowait   root   internal
echo     stream   tcp   nowait   root   internal
echo     dgram    udp   nowait   root   internal
discard  stream   tcp   nowait   root   internal
discard  dgram    udp   nowait   root   internal
chargen  stream   tcp   nowait   root   internal
chargen  dgram    udp   nowait   root   internal
#
#    rpc services, registered by inetd with portmap
#
rpc stream  tcp  nowait  root  /usr/etc/rpc.rexd    100017 1  rpc.rexd
rpc dgram   udp  wait    root  /usr/etc/rpc.rstatd  100001 1-3  rpc.rstatd
```

Concurrent, Connection-oriented, Multiservice Server



The process structure for a concurrent, connection-oriented, multiservice server. The master process handles incoming connection requests, while a slave process handles each connection.

- Example:superd.c (next slides)

superd.c -- (1)

```
struct service {
        char    *sv_name;
        char    sv_useTCP;
        int     sv_sock;
        int     (*sv_func)();
} svent[] = {
                { "echo", TCP_SERV, NOSOCK, TCPechod },
                { "chargen", TCP_SERV, NOSOCK, TCPchargend },
                { "daytime", TCP_SERV, NOSOCK, TCPdaytimed },
                { "time", TCP_SERV, NOSOCK, TCPtimed },
                { 0, 0, 0, 0 },
        };
```

superd.c -- (2)

```
int main(argc, argv)
int   argc;
char*argv[];
{
        struct service          *psv,           /* service table pointer */
                *fd2sv[NOFILE];         /* map fd to service pointer */
        int     fd, nfds;
        fd_set  afds, rfds;             /* readable file descriptors             */

        switch (argc) {
        case 1:
                break;
        case 2:
                portbase = (u_short) atoi(argv[1]);
                break;
        default:
                errexit("usage: superd [portbase]\n");
        }
```

superd.c -- (3)

```
nfds = 0;
FD_ZERO(&afds);
for (psv = &svent[0]; psv->sv_name; ++psv) {
        if (psv->sv_useTCP)
                psv->sv_sock = passiveTCP(psv->sv_name, QLEN);
        else
                psv->sv_sock = passiveUDP(psv->sv_name);
        fd2sv[psv->sv_sock] = psv;
        nfds = MAX(psv->sv_sock+1, nfds);
        FD_SET(psv->sv_sock, &afds);
}
(void) signal(SIGCHLD, reaper);
```

superd.c -- (4)

```
while (1) {
        bcopy((char *)&afds, (char *)&rfds, sizeof(rfds));
        if (select(nfds, &rfds, (fd_set *)0,
            (fd_set *)0, (struct timeval *)0)
            < 0) {
                if (errno == EINTR)
                        continue;
                errexit("select error: %s\n",
                        sys_errlist[errno]);
        }
        for (fd=0; fd<nfds; ++fd)
           if (FD_ISSET(fd, &rfds)) {
              psv = fd2sv[fd];
              if (psv->sv_useTCP)
                      doTCP(psv);
              else
                      psv->sv_func(psv->sv_sock);
           }
}
```

superd.c -- (5)

```
int doTCP(psv)
struct service        *psv;
{
    struct sockaddr_in fsin;  /* the request from address */
    int    alen       ;       /* from-address length */
    int    fd, ssock;
    alen = sizeof(fsin);
    ssock = accept(psv->sv_sock,(struct sockaddr *)
            &fsin, &alen);
    if (ssock < 0)
            errexit("accept: %s\n", sys_errlist[errno]);
```

superd.c -- (6)

```
    switch (fork()) {
    case 0:         break;
    case -1:        errexit("fork: %s\n", sys_errlist[errno]);
    default:        (void) close(ssock);
                    return;             /* parent */
    }
    /* child */
    for (fd = NOFILE; fd >= 0; --fd)
            if (fd != ssock)
                    (void) close(fd);
    exit(psv->sv_func(ssock));
}
```

sv_funcs.c -- (1)

```
int TCPechod(fd)
int  fd;
{
    char   buf[BUFSIZ];
    int    cc;

    while (cc = read(fd, buf, sizeof buf)) {
        if (cc < 0) errexit("echo read: %s\n", buf);

        if (write(fd, buf, cc) < 0)
            errexit("echo write: %s\n",
            sys_errlist[errno]);
    }
    return 0;
}
```

sv_funcs.c -- (2)

```
int TCPchargend(fd)
{
        char    c, buf[LINELEN+2];    /* print LINELEN chars + \r\n */
        c = ' ';
        buf[LINELEN] = '\r';
        buf[LINELEN+1] = '\n';
        while (1) {
                int             i;
                for (i=0; i<LINELEN; ++i) {
                        buf[i] = c++;
                        if (c > '~') c = ' ';
                }
                if (write(fd, buf, LINELEN+2) < 0)
                        break;
        }
        return 0;
}
```

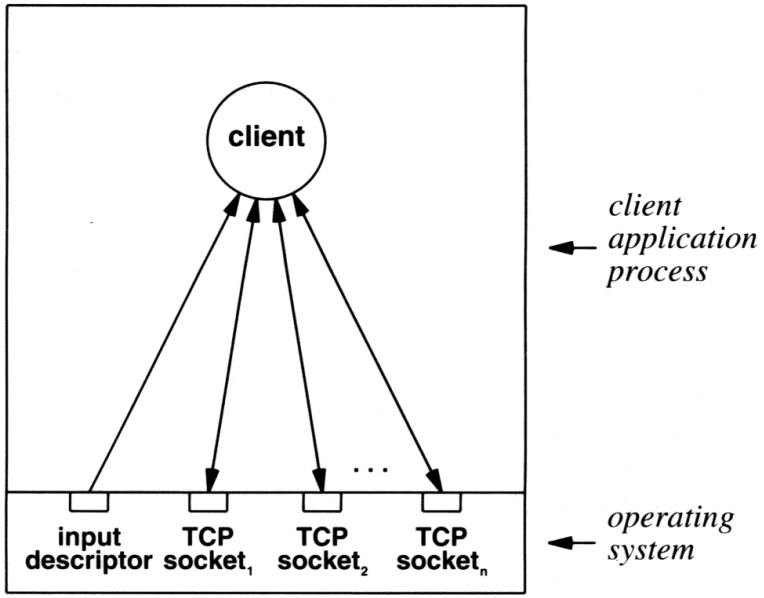
sv_funcs.c -- (3)

```
int TCPdaytimed(fd)
Int fd;
{
    char   buf[LINELEN], *ctime();
    time_t              time(), now;

    (void) time(&now);
    sprintf(buf, "%s", ctime(&now));
    (void) write(fd, buf, strlen(buf));
    return 0;
}
```

sv_funcs.c -- (4)

```
int TCPtimed(fd)
int fd;
{
    time_t          now, time();
    u_long          htonl();

    (void) time(&now);
    now = htonl((u_long)(now + UNIXEPOCH));
    (void) write(fd, (char *)&now, sizeof(now));
    return 0;
}
```

Concurrency in Clients



The process structure most often used with UNIX to provide apparent concurrency in a single-process, connection-oriented client. The client uses *select* to handle multiple connections concurrently.

- Example:TCPtecho.c (next slides)

TCPtecho.c -- (1)

```
/* TCPtecho.c - main, TCPtecho, reader, writer, mstime */
#include <sys/types.h>
#include <sys/param.h>
#include <sys/ioctl.h>
#include <sys/time.h>
#include <stdio.h>

extern int    errno;
extern char *sys_errlist[];

#define      BUFSIZE                4096        /* write buffer size */
#define      CCOUNT                 64*1024     /* default character count          */
#define      USAGE     "usage: TCPtecho [ -c count ] host1 host2...\n"

char*hname[NOFILE];  /* fd to host name mapping */
int   rc[NOFILE], wc[NOFILE]; /* read/write character counts */
charbuf[BUFSIZE];       /* read/write data buffer */
longmstime();
```

TCPtecho.c -- (2)

```
int
main(argc, argv)
int   argc;
char*argv[];
{
        int       ccount = CCOUNT;
        int       i, hcount, maxfd, fd;
        int       one = 1;
        fd_set  afds;

        hcount = 0;
        maxfd = -1;
        for (i=1; i<argc; ++i) {
                if (strcmp(argv[i], "-c") == 0) {
                                if (++i < argc && (ccount = atoi(argv[i])))
                                        continue;
                                errexit(USAGE);
                }
```

TCPtecho.c -- (3)

```
            /* else, a host */

            fd = connectTCP(argv[i], "echo");
            if (ioctl(fd, FIONBIO, (char *)&one))
                    errexit("can't mark socket nonblocking: %s\n", sys_errlist[errno]);
            if (fd > maxfd)
                    maxfd = fd;
            hname[fd] = argv[i];
            ++hcount;
            FD_SET(fd, &afds);
    }
    TCPtecho(&afds, maxfd+1, ccount, hcount);
    exit(0);
}
```

Note: ioctl(FIONBIO) and fcntl(O_NDELAY) is a little different and is inconsistent.
POSIX uses fcntl(O_NONBLOCK) for consistency.
See https://stackoverflow.com/questions/1150635/unix-nonblocking-i-o-o-nonblock-vs-fionbio

TCPtecho.c -- (4)

```
int
TCPtecho(pafds, nfds, ccount, hcount)
fd_set        *pafds;
int   nfds, ccount, hcount;
{
      fd_set  rfds, wfds;              /* read/write fd sets                    */
      fd_set  rcfds, wcfds;                        /* read/write fd sets (copy)          */
      int       fd, i;

      for (i=0; i<BUFSIZE; ++i)      /* echo data              */
            buf[i] = 'D';
      bcopy((char *)pafds, (char *)&rcfds, sizeof(rcfds));
      bcopy((char *)pafds, (char *)&wcfds, sizeof(wcfds));
      for (fd=0; fd<nfds; ++fd)
            rc[fd] = wc[fd] = ccount;

      (void) mstime((long *)0);        /* set the epoch */
```

TCPtecho.c -- (5)

```
        while (hcount) {
                bcopy((char *)&rcfds, (char *)&rfds, sizeof(rfds));
                bcopy((char *)&wcfds, (char *)&wfds, sizeof(wfds));

                if (select(nfds, &rfds, &wfds, (fd_set *)0, (struct timeval *)0) < 0)
                        errexit("select failed: %s\n",sys_errlist[errno]);
                for (fd=0; fd<nfds; ++fd) {
                        if (FD_ISSET(fd, &rfds))
                                if (reader(fd, &rcfds) == 0)
                                        hcount--;
                        if (FD_ISSET(fd, &wfds))
                                writer(fd, &wcfds);
                }
        }
}
```

TCPtecho.c -- (6)

```
int reader(fd, pfdset)
int  fd;
fd_set      *pfdset;
{
      long   now;
      int      cc;
      cc = read(fd, buf, sizeof(buf));
      if (cc < 0)
            errexit("read: %s\n", sys_errlist[errno]);
      if (cc == 0)
            errexit("read: premature end of file\n");
      rc[fd] -= cc;
      if (rc[fd])
            return 1;
```

TCPtecho.c -- (6)

```
        (void) mstime(&now);
        printf("%s: %d ms\n", hname[fd], now);
        (void) close(fd);
        FD_CLR(fd, pfdset);
        return 0;
    }
```

TCPtecho.c -- (7)

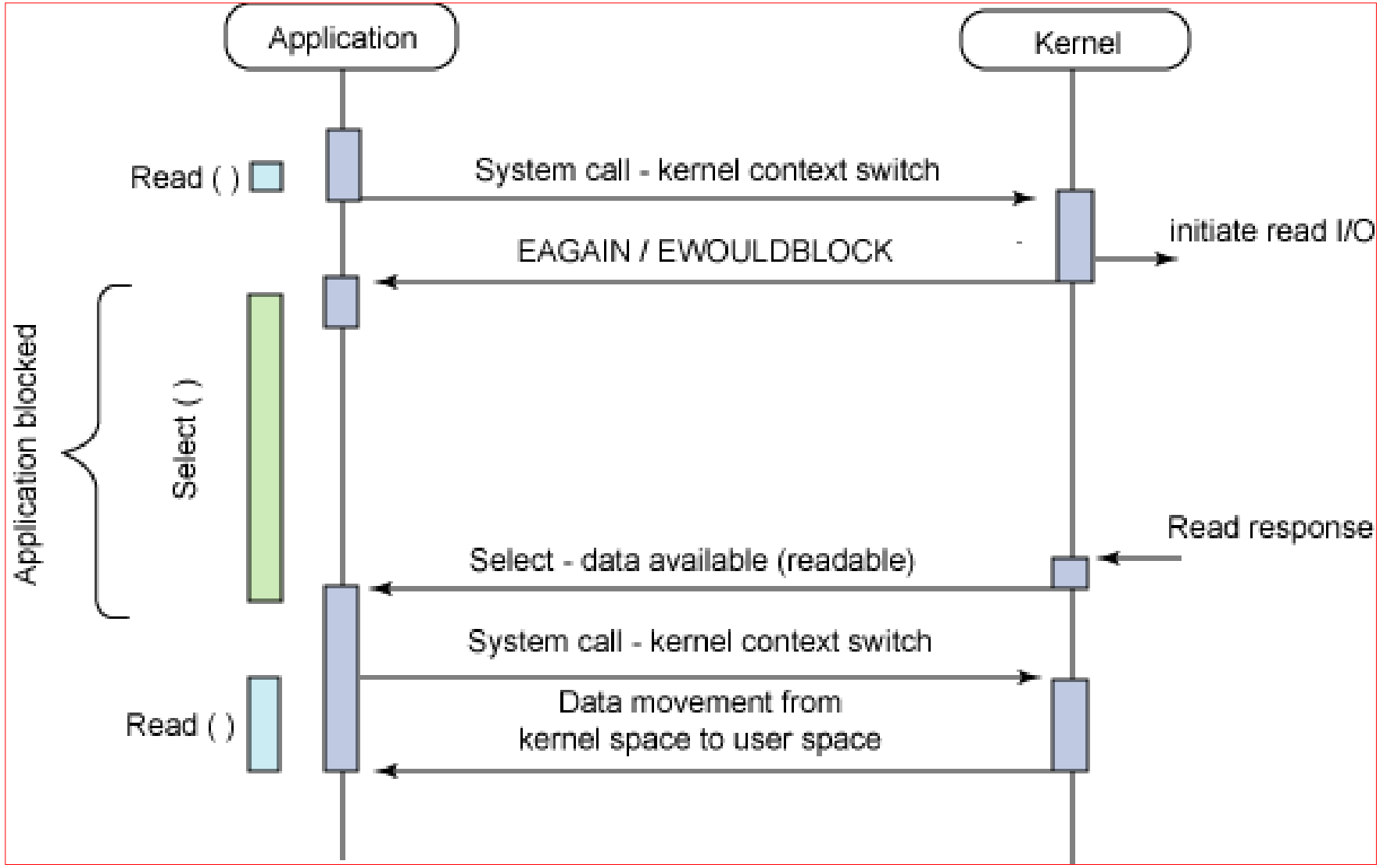
```
Int writer(fd, pfdset)
int  fd;
fd_set      *pfdset;
{
     int      cc;

     cc = write(fd, buf, MIN(sizeof(buf), wc[fd]));
     if (cc < 0)
          errexit("read: %s\n", sys_errlist[errno]);
     wc[fd] -= cc;
     if (wc[fd] == 0) {
          (void) shutdown(fd, 1);
          FD_CLR(fd, pfdset);
     }
}
```

TCPtecho.c -- (8)

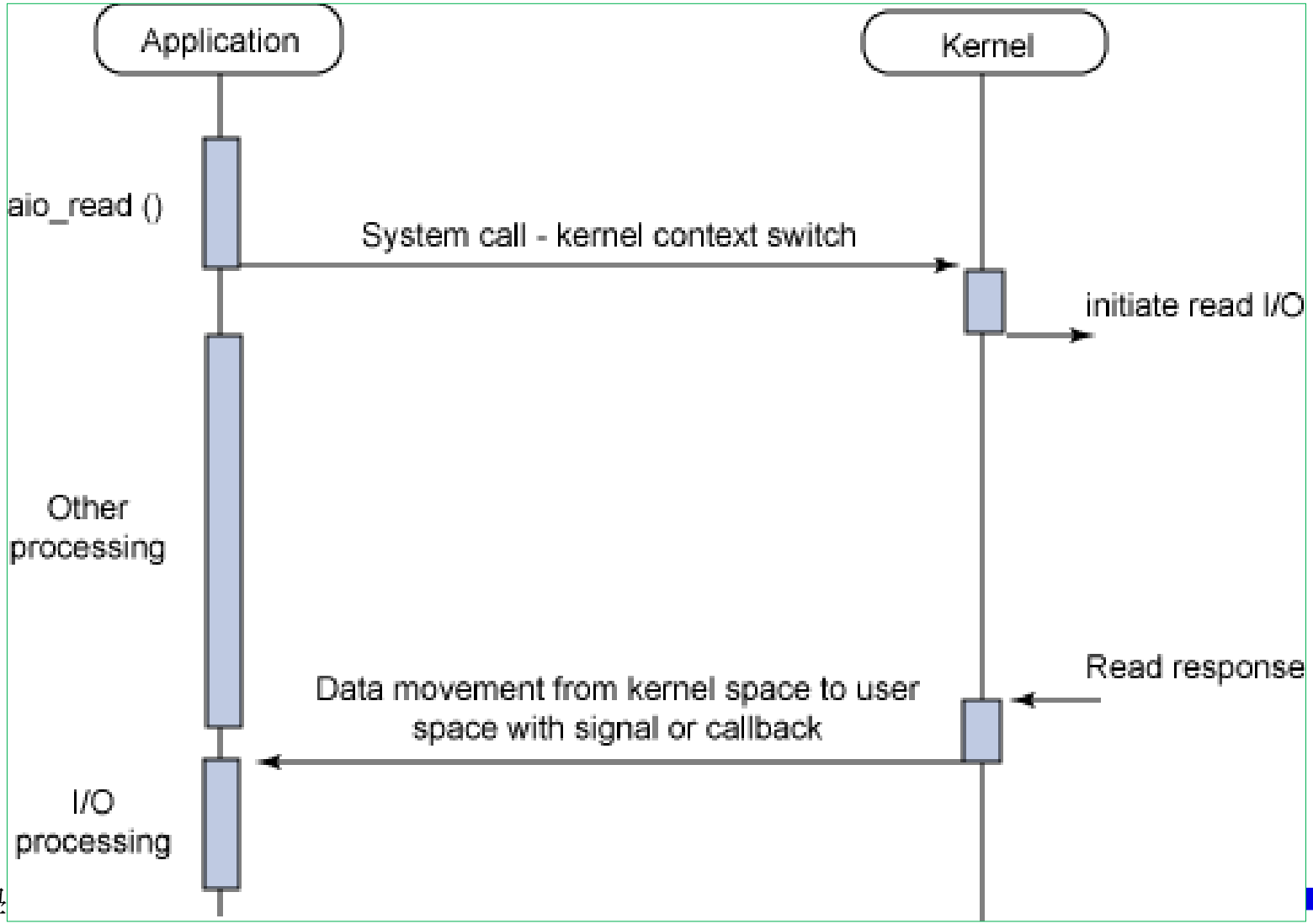
```
Long mstime(pms)
long        *pms;
{
    static struct timeval          epoch;
    struct timeval                 now;

    if (gettimeofday(&now, (struct timezone *)0))
            errexit("gettimeofday: %s\n", sys_errlist[errno]);
    if (!pms) {
            epoch = now;
            return 0;
    }
    *pms = (now.tv_sec - epoch.tv_sec) * 1000;
    *pms += (now.tv_usec - epoch.tv_usec + 500)/ 1000;
    return *pms;
}
```

Sample excerpt from sockets.h

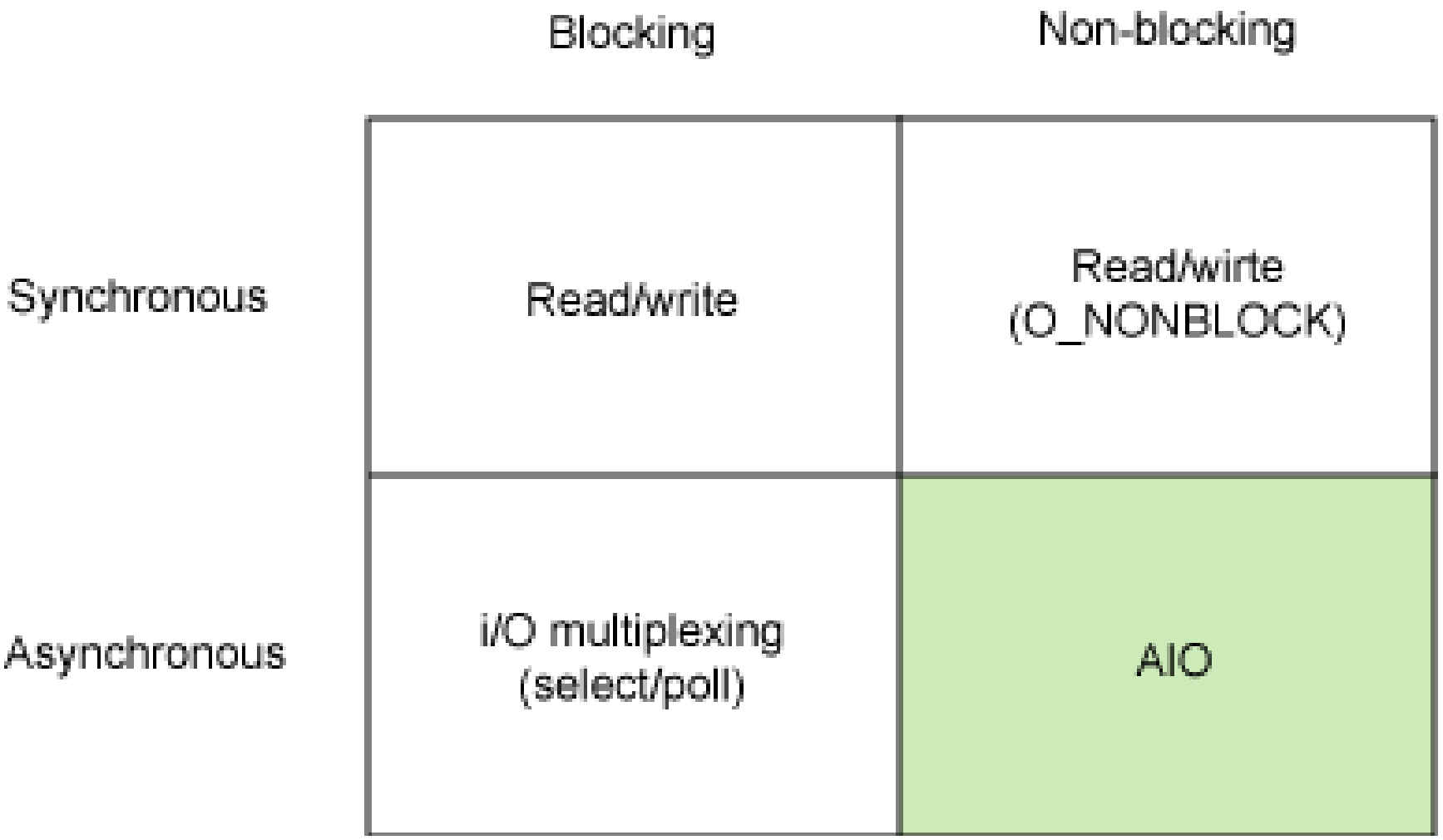
```
/* Copyright (c) 1982, 1985, 1986 Regents of the University of California.
All rights reserved.
Redistribution and use in source and binary forms are permitted provided
that the above copyright notice and this paragraph are duplicated in all
such forms and that any documentation, advertising materials, and other
materials related to such distribution and use acknowledge that the
software was developed by the University of California, Berkeley. The name
of the University may not be used to endorse or promote products derived
from this software without specific prior written permission.
THIS SOFTWARE IS PROVIDED "AS IS" AND WITHOUT
ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, WITHOUT LIMITATION, THE
IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR
PURPOSE
/*
 * Types of sockets
 */
#define SOCK_STREAM     1        /* stream socket */
#define SOCK_DGRAM      2        /* datagram socket */
#define SOCK_RAW        3        /* raw-protocol interface */
#define SOCK_RDM        4        /* reliably-delivered message */
#define SOCK_SEQPACKET  5        /* sequenced packet stream */
/*
 * Option flags per-socket
 */
#define SO_DEBUG        0x0001   /* turn on debugging info recording */
#define SO_ACCEPTCONN   0x0002   /* socket has had listen() */
#define SO_REUSEADDR    0x0004   /* allow local address reuse */
#define SO_KEEPALIVE    0x0008   /* keep connections alive */
#define SO_DONTROUTE    0x0010   /* just use interface addresses */
#define SO_BROADCAST    0x0020   /* permit sending of broadcast msgs */
#define SO_USELOOPBACK  0x0040   /* bypass hardware when possible */
#define SO_LINGER       0x0080   /* linger on close if data present */
#define SO_OOBINLINE    0x0100   /* leave received OOB data in line */
/*
 * Additional options, not kept in so_options.
 */
#define SO_SNDBUF       0x1001   /* send buffer size */
#define SO_RCVBUF       0x1002   /* receive buffer size */
#define SO_SNDLOWAT     0x1003   /* send low-water mark */
#define SO_RCVLOWAT     0x1004   /* receive low-water mark */
#define SO_SNDTIMEO     0x1005   /* send timeout */
#define SO_RCVTIMEO     0x1006   /* receive timeout */
#define SO_ERROR        0x1007   /* get error status and clear */
#define SO_TYPE         0x1008   /* get socket type */
```


Application
Kernel
Read ( )
System call - kernel context switch
initiate read I/O
EAGAIN / EWOULDBLOCK
Application blocked
Select ( )
Read response
Select - data available (readable)
System call - kernel context switch
Read ( )
Data movement from
kernel space to user space

Asynchronous I/O (AIO)



AIO in Linux


Blocking
Non-blocking
Synchronous
Asynchronous
Read/write
Read/wirte
(O_NONBLOCK)
i/O multiplexing
(select/poll)
AIO

AIO in Linux (cont.)

- Introduced in Linux kernel 2.6 (released at 2008) and also available in 2.4 if patched.
- The completion of I/O can be notified by two methods.
  - Signal.
  - Register a completion handler function to create a new thread.
- API:
  - aio_read
  - aio_error
  - aio_return
  - aio_write
  - aio_suspend
  - aio_cancel
  - lio_listio

Note: someone says the AIO in Linux is not as efficient as W

AIO in Windows

- Called Overlapped IO in Windows.
- After open I/O file with FILE_FLAG_OVERLAPPED, ReadFile and WriteFile (and more) can be used asynchronously.
- There are two method to notify the completion of I/O.
  - I/O completion port.
  - Use Event object to wait.