

## LEC 06. I/O MULTIPLEXING SERVER

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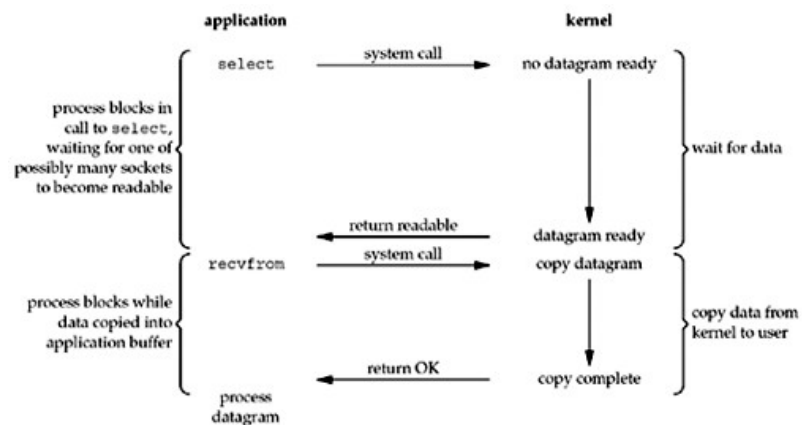
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### Content

- I/O Multiplexing Model
- `select()`
- `poll()`

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## I/O Multiplexing Model



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## select()

- The **select()** function asks kernel to simultaneously check multiple sockets to see if they have data waiting to be **recv()**, or if you can **send()** data to them without blocking, or if some exception has occurred.
- The kernel to wake up the process only when one or more of events occurs or when a specified amount of time has passed.
- Exp : kernel to return only when
  - {1, 4, 5} are ready for reading
  - {2, 7} are ready for writing
  - {1, 4} have an exception condition pending
  - 10.2 seconds have elapsed

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## select()

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

- [IN] **maxfd** SHOULD BE the highest-numbered file descriptor in any of the three sets, plus 1
- [IN] **readfds**, **writefds**, **exceptfds** : set of FD to test for reading/receiving, writing/sending, exception conditions. At least one of them SHOULD BE not **NULL**.
- [IN] **timeout** : how long to wait for one of the specified descriptors to become ready. There are three types of using timeout
  - **NULL**: Wait forever
  - Wait up to a fixed amount of time
  - Do not wait at all : **timeout** points to the a **timeval** structure having the value 0
- Return:
  - On success, returns the total number of bits that are set (that is the number of ready file descriptors)
  - On time-out, returns 0
  - On error, return -1

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## fd\_set

- Other **fd\_sets** use to specify the descriptors that we want the kernel to test for reading, writing, and exception conditions.
- To specify one or more descriptor values for each of these three arguments, select uses **descriptor sets**.
- All the implementation details are irrelevant to the application and are hidden in the **fd\_set** datatype and the following four macros:

```
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); /* Return true if fd is in the fdset */
```

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## select () - Conditions

- Ready for reading:
  - The socket receive buffer is not empty
  - The read half of the connection is closed
  - The listening socket receives a new connection request
  - A socket error is pending
- Ready for writing:
  - The size of the available space in the socket send buffer and either: (i) the socket is connected, or (ii) the socket does not require a connection (e.g., UDP).
  - The write half of the connection is closed
  - A socket using a non-blocking `connect` has completed the connection, or the `connect` has failed
  - A socket error is pending
- Exception: TCP out-of-band data

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## select () - How does kernel work?(Simplifying)

**Input:** maxfd, readfds, writefds, exceptfds, timeout

```
retval = 0;
is_timeout = false;
while(1){
    check_ready();
    is_timeout = check(timeout);
    if(retval || timeout ||
        interrupt()) break;
    if (check_error()){
        retval = err_num;
        break;
    }
}
wakeup_process();
return retval;
```

```
check_ready(){
    for(i = 0; i < maxfd, i++){
        in = readfds[i-th bit];
        out = writefds[i-th bit];
        ex = exceptfds[i-th bit];

        if(!(in | out | ex)) continue;

        res_in = check_ready_in(i);
        if(in & res_in){
            readfds[i-th bit] = in & res_in;
            retval++;
        }
        res_out = check_ready_out(i);
        if(out & res_out){
            writefds[i-th bit] = out & res_out;
            retval++;
        }
        res_ex = check_ready_ex(i);
        if(ex & res_ex){
            exceptfds[i-th bit] = out & res_ex;
            retval++;
        }
    }
}
```

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## Examples

```
int s1, s2, n;
fd_set readfds;
struct timeval tv;
char buf1[256], buf2[256];
//pretend we've connected both to a server at this point
//s1 = socket(...); s2 = socket(...);
//connect(s1, ...)... connect(s2, ...)...

// clear the set ahead of time
FD_ZERO(&readfds);

// add our descriptors to the set
FD_SET(s1, &readfds);
FD_SET(s2, &readfds);

// since we got s2 second, it's the "greater", so we use
that for
// the n param in select()
n = s2 + 1;
```

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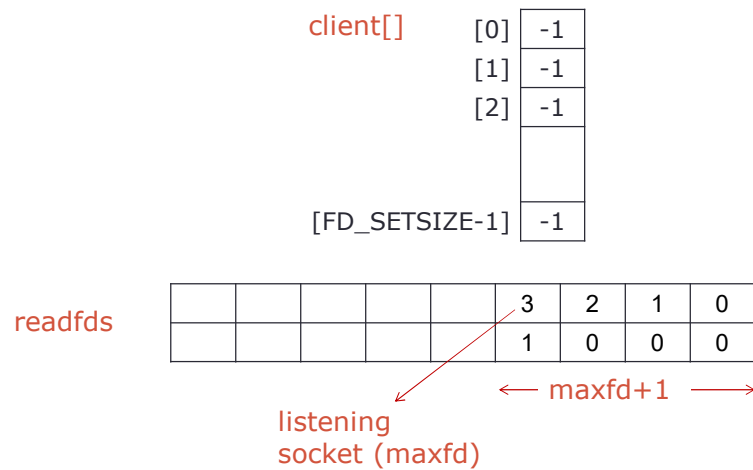
## Examples (2)

```
// wait until either socket has data ready to be recv()d
//(timeout 10.5 secs)
tv.tv_sec = 10;
tv.tv_usec = 500000;
rv = select(n, &readfds, NULL, NULL, &tv);
if (rv == -1) {
    perror("\Error: "); // error occurred in select() }
else if (rv == 0)
    printf("Timeout occurred! No data after 10.5s \n");
else {
    // one or both of the descriptors have data
    if (FD_ISSET(s1, &readfds))
        recv(s1, buf1, sizeof buf1, 0);
    if (FD_ISSET(s2, &readfds))
        recv(s2, buf2, sizeof buf2, 0);
}
```

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## How to use select() in TCP server

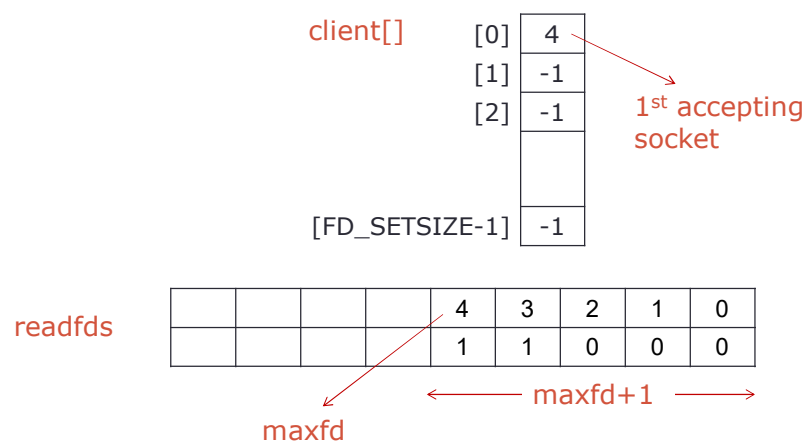
Data structures for TCP server with just a listening socket



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## How to use select() in TCP server

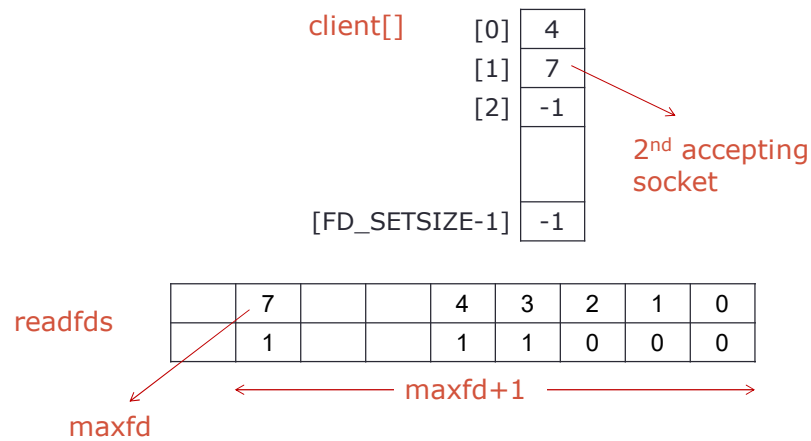
Data structures after the 1st client connection is established



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## How to use select() in TCP server

Data structures after the 2nd client connection is established

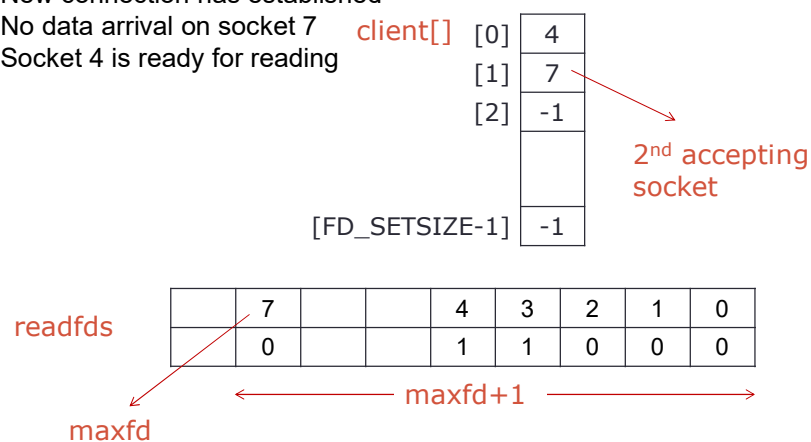


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## How to use select() in TCP server

After `select()` return. Example:

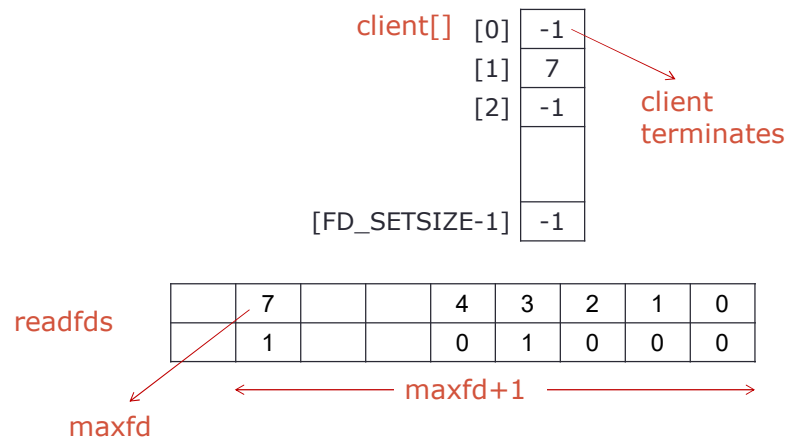
- New connection has established
- No data arrival on socket 7
- Socket 4 is ready for reading



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## How to use select() in TCP server

Data structures after a client terminates its connection



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## How to use select() in TCP server

```
//Step 1: Construct socket
//Step 2: Bind address to socket
//Step 3: Listen request from client

//Step 4: Initiate data structures
//Assign initial value for the array of connection socket
for(...) client[i] = -1;

//Assign initial value for the fd_set
//checkset: set of file descriptors that tested by kernel
fd_set checkfds, readfds, writefds, exceptfds;
FD_ZERO (&checkfds);

//Set bit for listenfd
FD_SET(listenfd, &checkfds)
maxfd = listenfd;
```

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## How to use select() in TCP server

```
//Step 5: Accept connection and communicate with clients
while(...) {
    readfds = writefds = exceptfds = checkfds;
    nEvents = select(...);
    //check the status of listenfd
    if(FD_ISSET(listenfd,...)) {
        connfd = accept(...);
        FD_SET(connfd, &checkfds);
        if(connfd > maxfd) maxfd = connfd;
        for(...)
            if (client[i] == -1) client[i] = connfd;
    }
    //check the status of connfd(s)
    for(...) {
        if(FD_ISSET(client[i],...)) {
            doSomething();
            close(connfd);
            FD_CLEAR(client[i],...);
            client[i] = -1;
        }
    }
}
```

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## TCP Echo Server(revisited - 1)

```
int client[FD_SETSIZE], connfd;
fd_set checkfds, readfds;
sockaddr_in clientAddr;
int ret, nEvents, clientAddrLen;
char rcvBuff[BUFF_SIZE], sendBuff[BUFF_SIZE];

//Step 4: Initiate data structures
for(int i = 0; i < FD_SETSIZE; i++)
    client[i] = -1;

FD_ZERO(&checkfds);

FD_SET(listenfd, &checkfds)
maxfd = listenfd;
```

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## TCP Echo Server(revisited - 2)

```
//Step 5: Accept connection and communicate with clients
while(1){
    readfds = checkfds;
    nEvents = select(maxfd + 1, &readfds, NULL, NULL, NULL);
    if(nEvents < 0){
        perror("\nError:");
        break;
    }

    if(FD_ISSET(listenfd, &readfds)){           //new client
        clientAddrLen = sizeof(clientAddr);
        connfd = accept(listenfd, (sockaddr *)
                        &clientAddr, &clientAddrLen);

        int i;
        for(i = 0; i < FD_SETSIZE; i++){
            if(client[i] < 0){
                client[i] = connfd;
                break;
            }
        }
    }
}
```

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## TCP Echo Server(revisited - 3)

```
if(i == FD_SETSIZE)
    printf("\nToo many clients.");
if(--nEvents <=0) continue; //no more event
}
//check the status of connfd(s)
for(int i = 0; i < FD_SETSIZE; i++){
    if(client[i] < 0) continue;
    if(FD_ISSET(client[i], &readfds)){
        ret = receiveData(client[i], rcvBuff, BUFF_SIZE, 0);
        if (ret <= 0){
            FD_CLR(client[i], &checkfds);
            closesocket(client[i]);
            client[i] = -1;
        }
        else if(ret > 0){
            processData(rcvBuff, sendBuff);
            sendData(client[i], sendBuff, ret, 0);
        }
        if(--nEvents <=0) continue; //no more event
    }
}
} //end while
```

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## TCP Echo Server(revisited - 4)

```
/* The processData function copies the input string to output*/
void processData(char *in, char *out){
    strcpy (out, in);
}
/* The recv() wrapper function*/
int receiveData(int s, char *buff, int size, int flags){
    int n;
    n = recv(s, buff, size, flags);
    if(n < 0)
        perror("Error: ");
    return n;
}
/* The send() wrapper function*/
int sendData(int s, char *buff, int size, int flags){
    int n;
    n = send(s, buff, size, flags);
    if(n < 0)
        perror("Error: ");
    return n;
}
```

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## poll()

```
#include <poll.h>
int poll (struct pollfd *fdarray, unsigned long nfds,
          int timeout);
```

- Similar to select()
- Provides additional information when dealing with STREAMS devices
- Parameter:
  - fdarray: point to the array of pollfd structures
  - nfds: number of elements in fdarray
  - timeout: INFTIM(wait forever), 0(return immediately) or >0(wait specified number of milliseconds)
- Return: number of elements have had event, 0 if timeout, -1 if error

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## pollfd structure

```
struct pollfd {
    int fd;           // the socket descriptor
    short events;     // bitmap of events we're interested in
    short revents;    // when poll() returns, bitmap of events
                    // that occurred
};
```

- `events` and `revents` are bitmasks constructed by OR'ing a combination of the following event flags

Constant	events	revents	Description
POLLIN	x	x	Normal or priority data can be read
POLRDNORM	x	x	Normal data can be read
POLLRDBAND	x	x	Priority (OOB) data may be read
POLLPRI	x	x	High-priority data may be read

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## poll() - Event flags(cont.)

Constant	events	revents	Description
POLLOUT	x	x	Normal data may be written
POLLWRNORM	x	x	Equivalent to POLLOUT
POLLWRBAND	x	x	Priority (OOB) data may be written
POLLERR		x	An error has occurred on socket
POLLHUP		x	The hangup state
POLLNVAL		x	Something was wrong with the socket descriptor <i>fd</i>

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## Example

```

struct pollfd ufds[2];
s1 = socket(AF_INET, SOCK_STREAM, 0);
s2 = socket(AF_INET, SOCK_STREAM, 0);
//connect to server...
ufds[0].fd = s1;
ufds[0].events = POLLIN;
ufds[1].fd = s2;
ufds[1].events = POLLOUT | POLLIN;
rv = poll(ufds, 2, 3500);
if (rv == -1) {
    perror("poll"); // error occurred in poll()
} else if (rv == 0) {
    printf("Timeout occurred! No data after 3.5 seconds.\n");
} else {
    // check for events on s1:
    if (ufds[0].revents & POLLIN)
        recv(s1, buf1, sizeof buf1, 0);

    // check for events on s2:
    if (ufds[1].revents & POLLOUT)
        send(s2, buf2, sizeof buf2, 0);
}

```

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## Polling TCP Server

```

struct pollfd sockets[1024], socknum = 0;
//initiate
for(int i = 0; i < 1024; i++)
    sockets[i].fd = -1;
listenfd = socket();
bind(listenfd);
listen(listenfd);
sockets[0].fd = listenfd;
sockets[0].events = POLLIN;
socknum = 1;

```

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```
while(1){
    ret = poll(sockets, socknumber, INFTIM);
    for(int i = 0; i < 1024; i++){
        if(sockets[0].revents & POLLIN) //new client
        {
            connfd = accept();
            if (socknum = 1024) printf("Too many");
            else{
                for(j = 0; j < 1024; j ++){
                    if(sockets[j].fd == -1){
                        sockets[j].fd = connfd;
                        sockets[j].events = POLLIN;
                        socknumber++;
                    }
                }
            }
            if(sockets[i].fd > -1 && sockets[i].revents & POLLIN)
                //do something
        }
    }
}
```