Linux IO

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Tools for Developers

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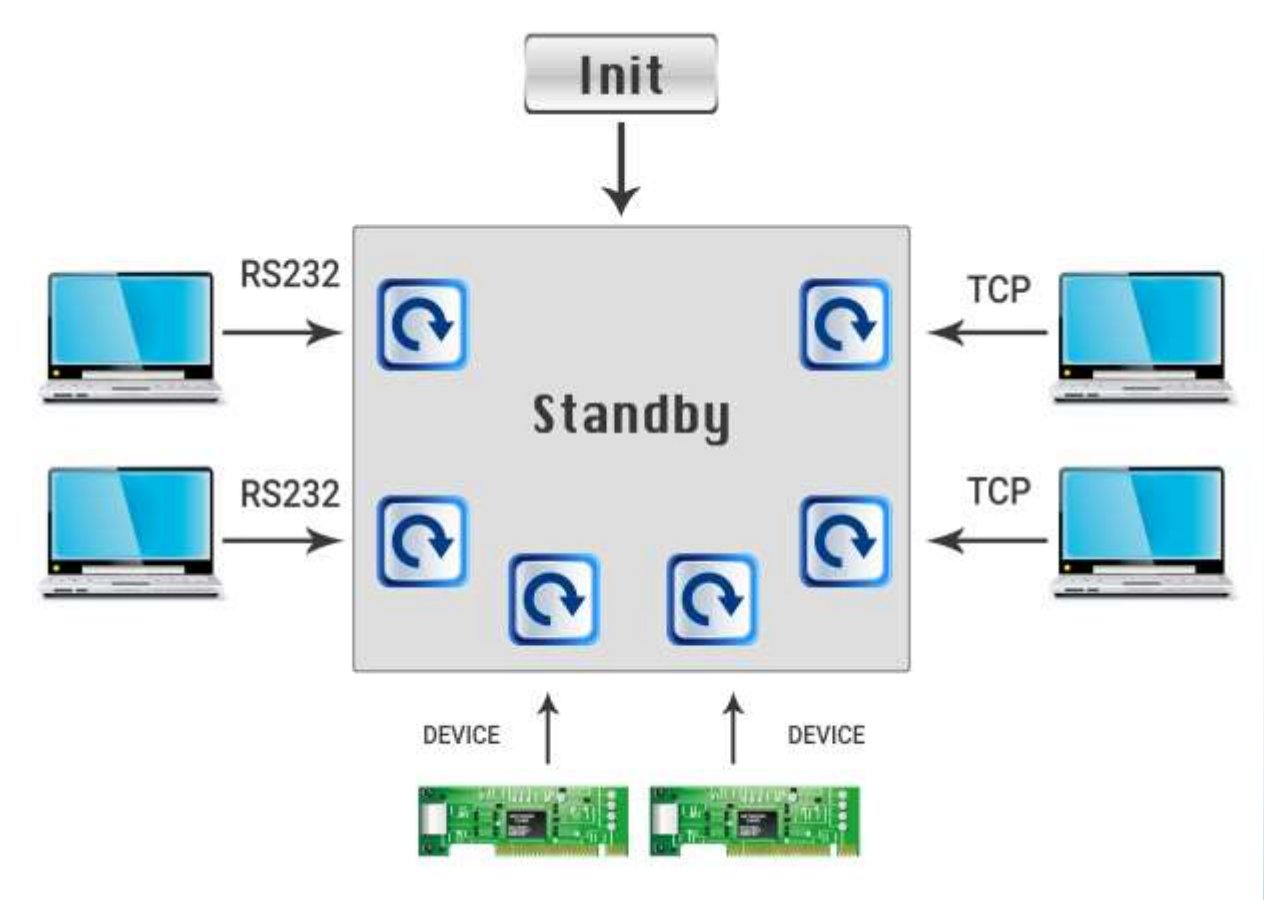
Typical System



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IO Models

- Blocking I/O
- Non-blocking I/O
- I/O multiplexing (select/poll/…)
- Signal driven I/O (SIGIO)
- Asynchronous I/O
  - aio_* functions
  - io_* functions

Blocking IO

- Default mode
- Makes the calling thread to block in the kernel in case no data is available
- Can block forever
  - To block with timeout, use select

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Non Blocking IO

- If there is no data, calling thread returns with EAGAIN or EWOULDBLOCK

flags = fcntl(fd, F_GETFL, 0);

fcntl(fd, F_SETFL, flags | O_NONBLOCK);

- To use in your own driver

```
if (filep->f_flags & O_NONBLOCK) {
        ret = -EWOULDBLOCK;
        break;
}
```

IO Multiplexing

- With **I/O multiplexing**, we call select/poll/epoll* and block in one of these system calls, instead of blocking in the actual I/O system call
- Disadvantage: using select requires at least two system calls (select and recvfrom) instead of one
- Advantage: we can wait for more than one descriptor to be ready

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Signal driven I/O

- The **signal-driven I/O model** uses signals, telling the kernel to notify us with the SIGIO signal when the descriptor is ready

```
fd=open("name", O_NONBLOCK);

fcntl(fd, F_SETSIG, SIGRTMIN + 1);
```

- Its better to use RT signals (queued)
- To use in your own driver
  - if (file->f_flags & O_NONBLOCK)
  - Send signal to file->f_owner (fown_struct)
    - signum
    - pid

Asynchronous IO

- The POSIX asynchronous I/O interface
  - Allows applications to initiate one or more I/O operations that are performed asynchronously.
  - The application can select to be notified of completion of the I/O operation in a variety of ways:
    - Delivery of a signal
    - Instantiation of a thread
    - No notification at all
  - User space asynchronous implementation
    - Call the driver read/write callbacks

Kernel Async Support

- file_operations callbacks
  - aio_read, aio_write
    - Initialize the data processing
    - Create workqueue item/completion/timer/…
  - On completion
    - aio_complete
- Kernel 3.16
  - read_iter
  - write_iter
- To use from user space call io_submit

I/O Multiplexing

- select, pselect
- poll, ppoll
- epoll
  - epoll_create, epoll_create1
  - epoll_ctl
  - epoll_wait, epoll_pwait

select(2) system call

- The select( ) system call provides a mechanism for implementing synchronous multiplexing I/O
- A call to select( ) will block until the given file descriptors are ready to perform I/O, or until an optionally specified timeout has elapsed
- The watched file descriptors are broken into three sets
  - File descriptors listed in the readfds set are watched to see if data is available for reading.
  - File descriptors listed in the writefds set are watched to see if a write operation will complete without blocking.
  - File descriptors in the exceptfds set are watched to see if an exception has occurred, or if out-of-band data is available (these states apply only to sockets).
- A given set may be NULL, in which case select( ) does not watch for that event.
- On successful return, each set is modified such that it contains only the file descriptors that are ready for I/O of the type delineated by that set

Blocking for events

- You can use select(2) to block for events
- int select(int nfds, fd_set *readfds, fd_set *writefds, fd_set *exceptfds, struct timeval *timeout);
  - **nfds**: number of highest file descriptor + 1
  - **fd_sets**: sets of file descriptors to block for events on, one for read, one for write, one for exceptions.
  - **timeout**: NULL or structure describing how long to block.
  - Linux updates the timeout structure according to how much time was left to the time out.

File Descriptor Sets

- fd_set is a group of file descriptor for actions or reports:

```
void FD_CLR(int fd, fd_set *set);
```

  - Remove fd from this set.

```
int  FD_ISSET(int fd, fd_set *set);
```

  - Is fd in the set?

```
void FD_SET(int fd, fd_set *set);
```

  - Add fd to this set.

```
void FD_ZERO(fd_set *set);
```

  - Zero the set.

Driver notification example

```
int fd1, fd2;

fd_set fds_set;

int ret;

fd1 = open(“/dev/drv_ctl0”, O_RDWR);

fd2 = open(“/dev/drv_ctl1”, O_RDWR);

FD_ZERO(&fds_set);

FD_SET(fd1, &fds_set);

FD_SET(fd2, &fds_set);

do {

ret = select(fd1 + fd2 + 1, &fds_set, NULL, NULL,
NULL);


} while(errno == EINTR);
```

- Open two file descriptors fd1 and fd2.
- Create an fd set that holds them.
- Block for events on them.
  - We try again if we interrupted by a signal.

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Driver notification example 2

```
if(ret == -1) {

perror("Select failed.");

exit(1);

}



if(FD_ISSET(fd1, &fds_set)) {

printf("event at FD 1... “);

ioctl(fd1, IOCTL_CLR, 1);

printf("clear\n);

}
```

- If we have an error bail out.
- Check if fd1 one has a pending read even.
- If so, use ioctl(2) to notify driver to clear status

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pselect

- POSIX implementation
- Does not modify the timeout parameter
- Can set signal mask before entering to sleep
- Uses the timespec structure (seconds, nanoseconds)

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Poll

- **int poll (struct pollfd *fds, unsigned int nfds, int timeout);**

- Unlike select(), with its inefficient three bitmask-based sets of file descriptors, poll( ) employs a single array of nfds pollfd structures

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

struct pollfd {
        int fd;
        short events;
        short revents;
};
```

- POSIX implementation – ppoll (with signal mask)

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```
// The structure for two events
struct pollfd fds[2];

// Monitor sock1 for input
fds[0].fd = sock1;
fds[0].events = POLLIN;

// Monitor sock2 for output
fds[1].fd = sock2;
fds[1].events = POLLOUT;

// Wait 10 seconds
int ret = poll( &fds, 2, 10000 );

     // Check if poll actually succeed
     if ( ret == -1 )
         // report error and abort
     else if ( ret == 0 )
         // timeout; no event detected
     else
     {
         // If we detect the event, zero it out so we can reuse the structure
         if ( pfd[0].revents & POLLIN )
             pfd[0].revents = 0;
             // input event on sock1

         if ( pfd[1].revents & POLLOUT )
             pfd[1].revents = 0;
             // output event on sock2
     }
```

https://www.ulduzsoft.com/2014/01/select-poll-epoll-practical-difference-for-system-architects/

Poll vs. Select

- poll( ) does not require that the user calculate the value of the highest-numbered file descriptor +1
- poll( ) is more efficient for large-valued file descriptors. Imagine watching a single file descriptor with the value 900 via select()—the kernel would have to check each bit of each passed-in set, up to the 900th bit.
- select( )'s file descriptor sets are statically sized.
- With select( ), the file descriptor sets are reconstructed on return, so each subsequent call must reinitialize them. The poll( ) system call separates the input (events field) from the output (revents field), allowing the array to be reused without change.
- The timeout parameter to select( ) is undefined on return. Portable code needs to reinitialize it. This is not an issue with pselect( )
- select( ) is more portable, as some Unix systems do not support poll( ).

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Event Poll

- Has state in the kernel
  - O(1) instead of O(n)
- epoll_create(2) – initializes epoll context
- epoll_ctl(2) – adds/removes file descriptors from the context
- epoll_wait(2) – performs the actual event wait
- Can behave as
  - Edge triggered
  - Level triggered

Example

```
int epfd = epoll_create(0);
int client_sock = socket(…..);
static struct epoll_event ev;
ev.events = EPOLLIN | EPOLLOUT | EPOLLERR;
ev.data.fd = client_sock;
int res = epoll_ctl(epfd, EPOLL_CTL_ADD, client_sock, &ev);
struct epoll_event *events = malloc(SIZE);
while (1) {
        int nfds = epoll_wait(epfd, events, MAX_EVENTS, TIMEOUT);
        for(int i = 0; i < nfds; i++) {
                int fd = events[i].data.fd;
                handle_io_on_socket(fd);
         }
}
```

Driver Implementation

- Implement poll callback on file_operations

```
unsigned int example_poll(struct file * file, poll_table * pt)
{
    unsigned int mask = 0;
    if (data_avail_to_read) mask |= POLLIN | POLLRDNORM;
    if (data_avail_to_write) mask |= POLLOUT | POLLWRNORM;
    poll_wait(file, &hr, pt);
    poll_wait(file, &hw, pt);
    return mask;
}
```

- The driver adds a wait queue to the poll_table structure by calling the function poll_wait

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Thank You

Code examples and more

http://www.discoversdk.com/blog