UNIX I/O

- Files and File Representation
- Basic operations: Reading / Writing
- Caching: File Open / Close
- Multiplexing: Select / Poll
- File Descriptors

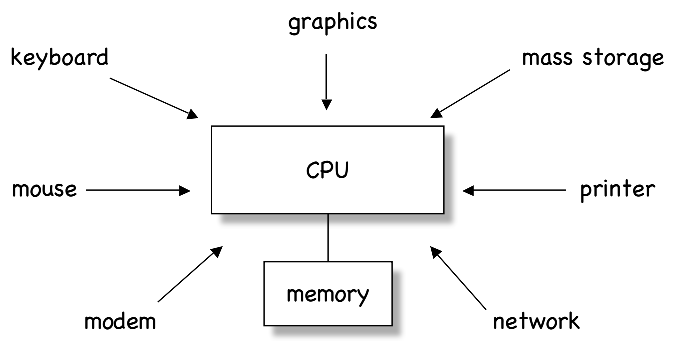
- Reading: R&R, Ch 4

Note: Some material in this set of slides comes from Solomon&Russinovich, "Inside Windows 2000," Microsoft Programming Series.

What is a File?

- A **file** is a collection of data elements, grouped together for purpose of access control, retrieval, and modification
- Often, files are mapped onto physical storage devices, usually nonvolatile.
- Some modern systems define a file simply as a sequence, or stream of data units.
  ==> Files don't need to be persistent. (We can call any stream of data units a file!)

Files are not always "Files": I/O Devices



File Operations: Read/Write: `read`

```
#include <unistd.h>

ssize_t read(int fildes, void & buf, size_t n_byte);
```

`ECONNRESET:`	`read` attempted on a socket and connection was forcibly closed by peer
`EAGAIN:`	`O_NONBLOCK` is set for file descriptor and thread would be delayed
`EBADF:`	fildes is not a valid file descriptor open for reading
`EINTR:`	`read` was terminated due to receipt of a signal and no data was transferred
`EIO:`	<paraphrased: process has problems reading from controlling terminal>
`ENOTCONN:`	read socket is not connected
`EOVERFLOW:`	<for regular files> starting position exceeds offset maximum
`ETIMEDOUT:`	`read` on socket, and transmission timeout occurred
`EWOULDBLOCK:`	file descriptor is for socket marked `O_NONBLOCK` and no data is waiting to be received.

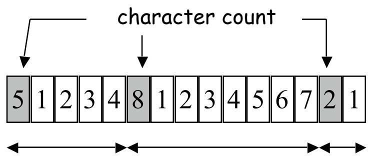
`read` Example

```
#include <errno.h>
#include <unistd.h>

ssize_t rf_read(int fd, void * buf, size_t size) {
    size_t  to_read;
    ssize_t retval;

    for (to_read = size, ret_val = 0;
         to_read > 0;
         buf += ret_val, to_read -= ret_val) {
      ret_val = read(fd, buf, to_read);
      if ((ret_val < 0) && (errno != EINTR))   return -1;
      if (ret_val < 0) ret_val = 0;
      to_read -= ret_val;
    }
    return size;
}
```

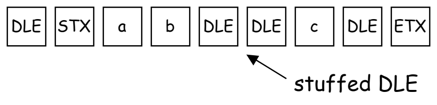
`rf_read` similar to `read` except that it restarts if interrupted and reads the full amount

Framing

- Character count



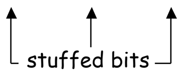
- Starting and ending chars, with character stuffing



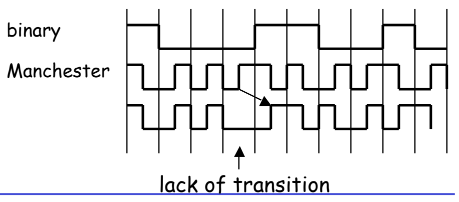
- Starting and ending flags, with bit stuffing

framing pattern: 01111110

011011111**0**11111**0**11111**0**10010



- Physical layer coding violations



File Operations: Read/Write

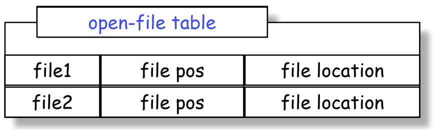
```
#include <unistd.h>

ssize_t write(int fildes, const void & buf, size_t n_byte);
```

ECONNRESET:	write attempted on a socket and connection was forcibly closed by peer
EAGAIN:	O_NONBLOCK is set for file descriptor and thread would be delayed
EBADF:	fildes is not a valid file descriptor open for writing
EINTR:	write was terminated due to receipt of a signal and no data was transferred
EIO:	<paraphrased: process has problems writing to controlling terminal>
ENOSPC:	no free space remaining on device containing the file
EPIPE:	attempt to write to a closed pipe or closed connection
EWOULDBLOCK:	file descriptor is for socket marked O_NONBLOCK and write would block

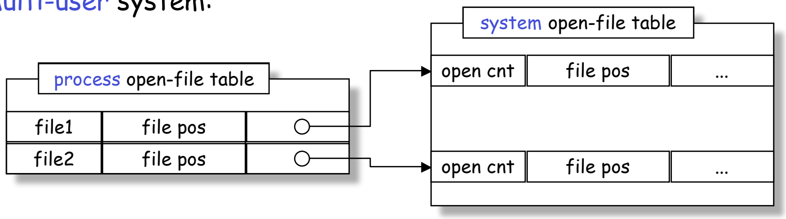
Bookkeeping

(for details on file descriptors, see later)

- **Open file** system call: cache information about file in kernel memory:
  - location of file on disk
  - file pointer for read/write
  - blocking information
  - etc.
- Single-user system:



- Multi-user system:



Example: W2k File Objects

Filename	Identifies the physical file that the file object refers to
Current byte offset	Identifies the current location of the file (valid only for synchronous I/O)
Share modes	Indicate whether other callers can access the file while the current caller is using it.
Open mode flags	Indicate whether I/O will be synchronous or asynchronous, cached or non-cached, sequential or random, etc.
Pointer to device object	
Pointer to volume parameter block	Indicates the volume, or partition, that the file resides on.
Pointer to section object pointers	Indicates a root structure that describes a mapped file.
Pointer to private cache map	Identifies which part of the file are cached by the cache manager

Opening a File Object (W2k)

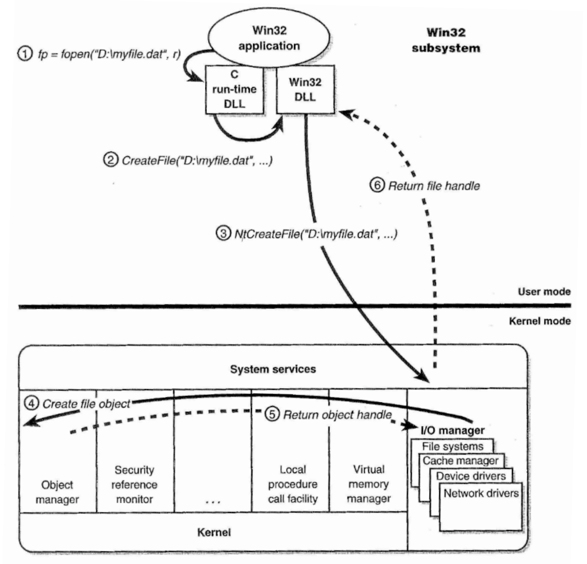


Figure from Solomon&Russinovich, "Inside Windows 2000," Microsoft Programming Series

Opening/Closing Files

```
#include <fcntl.h>
#include <sys/stat.h>

int open(const char * path, int oflag, …);
/* returns open file descriptor */
```

Flags:

```
O_RDONLY, O_WRONLY, O_RDWR
O_APPEND, O_CREAT, O_EXCL, O_NOCCTY
O_NONBLOCK, O_TRUNC
```

Errors:

`EACCESS:`	<various forms of access denied>
`EEXIST`	`O_CREAT` and `O_EXCL` set, and file exists already.
`EINTR:`	signal caught during `open`
`EISDIR:`	file is a directory and `O_WRONLY` or `O_RDWR` in flags
`ELOOP:`	there is a loop in the path
`EMFILE:`	to many files open in calling process
`ENAMETOOLONG:` …	
`ENFILE:`	to many files open in system
…	

Opening/Closing Files

```
#include <unistd.h>

int close(int fildes);
```

Errors:

`EBADF:`	`fildes` is not valid file descriptor
`EINTR:`	signal caught during `close`

Example:

```
int r_close(int fd) {
    int retval;

    while (retval = close(fd), ((retval == -1) && (errno == EINTR)));
    return retval;
}
```

Multiplexing: select()

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

int select(int                nfds,
           fd_set           * readfds,
           fd_set           * writefds,
           fd_set           * errorfds,
           struct timeval     timeout);
           /* timeout is relative */

void FD_CLR  (int fd, fd_set * fdset);
int  FD_ISSET(int fd, fd_set * fdset);
void FD_SET  (int fd, fd_set * fdset);
void FD_ZERO (fd_set * fdset);
```

Errors:

EBADF:	fildes is not valid for one or more file descriptors
EINVAL:	<some error in parameters>
EINTR:	signal caught during select before timeout or selected event

select() Example: Reading from multiple fd's

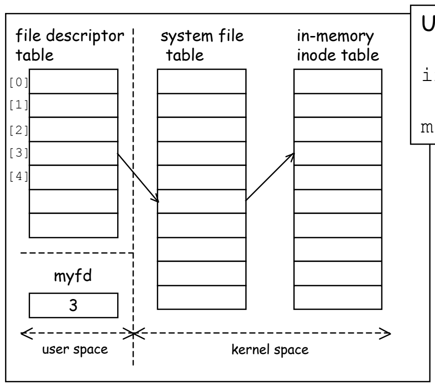
```
FD_ZERO(&readset);
maxfd = 0;
for (int i = 0; i < numfds; i++) {
  /* we skip all the necessary error checking */
  FD_SET(fd[i], &readset);
  maxfd = MAX(fd[i], maxfd);
}
```

```
while (!done) {
  numready = select(maxfd, &readset, NULL, NULL, NULL);
  if ((numready == -1) && (errno == EINTR))
    /* interrupted by signal; continue monitoring */
    continue;
  else if (numready == -1)
    /* a real error happened; abort monitoring */
    break;

  for (int i = 0; i < numfds) {
    if (FD_ISSET(fd[i], &readset) { /* this descriptor is ready*/
      bytesread = read(fd[i], buf, BUFSIZE);
      done = TRUE;
    }
}
```

select() Example: Timed Waiting on I/O

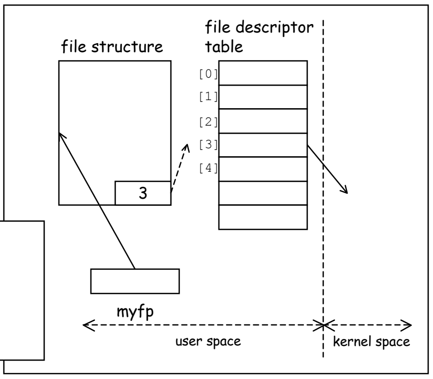
```
int waitfdtimed(int fd, struct timeval end) {
  fd_set          readset;
  int             retval;
  struct timeval timeout;

  FD_ZERO(&readset);
  FDSET(fd, &readset);
  if (abs2reltime(end, &timeout) == -1) return -1;
  while (((retval = select(fd+1,&readset,NULL,NULL,&timeout)) == -1)
           && (errno == EINTR)) {
      if (abs2reltime(end, &timeout) == -1) return -1;
      FD_ZERO(&readset);
      FDSET(fd, &readset);
  }
  if (retval == 0) {errno = ETIME; return -1;}
  if (retval == -1) {return -1;}
  return 0;
}
```

File Representation to User



UNIX File Descriptors:

```
int myfd;

myfd = open("myfile.txt", O_RDONLY));
```

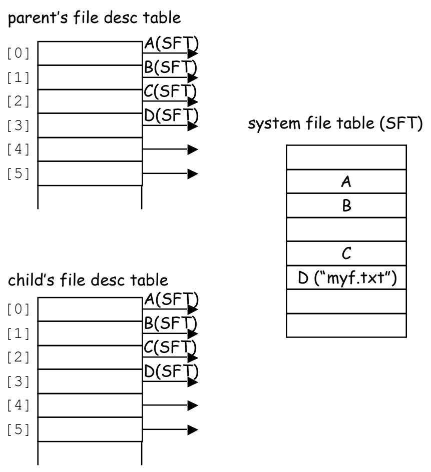


ISO C File Pointers:

```
FILE *myfp;

myfp = fopen("myfile.txt", "w");
```

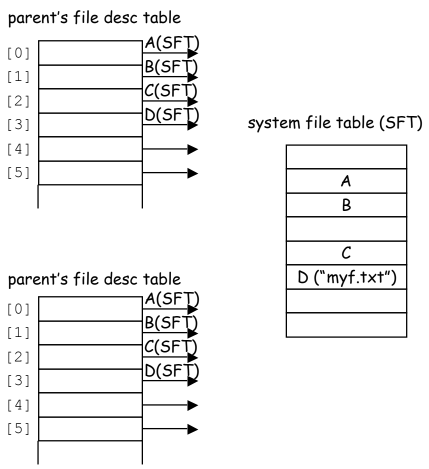
File Descriptors and `fork()`

- With `fork()`, child inherits content of parent's address space, including most of parent's state:
  - scheduling parameters
  - file descriptor table
  - signal state
  - environment
  - etc.



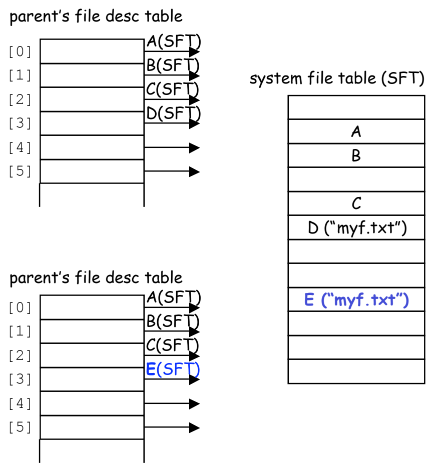
File Descriptors and `fork()` (II)

```
int main(void) {
  char c = '!';
  int myfd;

  myfd = open('myf.txt', O_RDONLY);

  fork();

  read(myfd, &c, 1);

  printf('Process %ld got %c\n',
            (long)getpid(), c);

  return 0;
}
```



File Descriptors and `fork()` (III)

```
int main(void) {
  char c = '!';
  int myfd;

  fork();

  myfd = open('myf.txt', O_RDONLY);

  read(myfd, &c, 1);

  printf('Process %ld got %c\n',
             (long)getpid(), c);

  return 0;
}
```



Duplicating File Descriptors: `dup2()`

- Want to redirect I/O from well-known file descriptor to descriptor associated with some other file?
  - e.g. `stdout` to file?

Errors:
`EBADF`: `fildes` or `fildes2` is not valid
`EINTR`: `dup2` interrupted by signal

```
#include <unistd.h>

int dup2(int fildes, int fildes2);
```

Example: redirect standard output to file.

```
int main(void) {
  int fd = open('my.file', <some_flags>, <some_mode>);

  dup2(fd, STDOUT_FILENO);

  close(fd);

  write(STDOUT_FILENO, 'OK', 2);
}
```