

CMSC 216: UNIX File Input/Output

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Logistics

Reading: Bryant/O'Hallaron

Ch	Read?	Topic
8	Finish	See specific section guide from previous slides
10	READ Except	UNIX File structure, File System structure, I/O functions
10.5	Opt	Optional: "Robust" I/O library built on top of primitive ops

Assignments

- ▶ Grading has commenced for P3 / Exam 2, likely to complete late this week
- ▶ Lab09 on `fork()` / `wait()` + HW09 on `fork()`
- ▶ P4 goes up later today

Goals

- File Descriptors, `open()` / `close()` / `read()` `write()`
- I/O Redirection with `dup2()` / `dup()`
- C Standard I/O library vs UNIX I/O
- File Attributes / Permissions `stat()` / `chmod()`
- (Optional) Directory Traversal `opendir()` / `readdir()`
- Next: Memory Systems (Ch. 6 & Ch 9)

Announcements

Office Hours Relocation Thu to Mon

See <https://piazza.com/class/meuaquvb4xy46i/post/551>

Exercise: C Standard I/O Functions

Recall basic I/O functions from the C Standard Library header
`stdio.h`

1. Printing things to the screen?
2. Opening a file?
3. Closing a file?
4. Printing to a file?
5. Scanning from terminal or file?
6. Get whole lines of text?
7. Names for standard input, output, error

Give samples of function calls

Answers: C Standard I/O Functions

Recall basic I/O functions from the C Standard Library header stdio.h

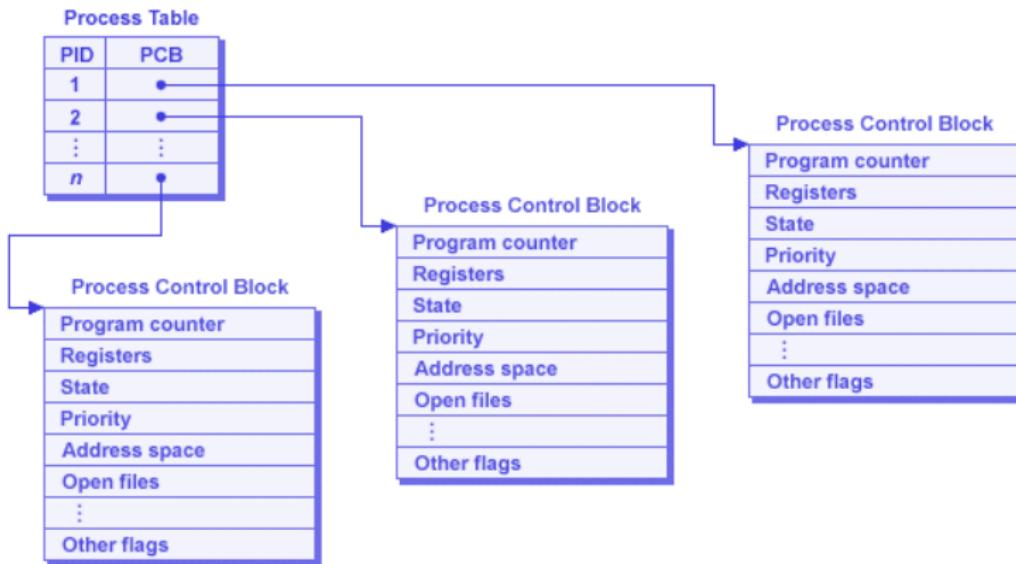
1	printf("%d is a number",5);	Printing things to the screen?
2	FILE *file = fopen("myfile.txt","r");	Opening a file?
3	fclose(file);	Close a file?
4	fprintf(file,"%d is a number",5);	Printing to a file?
5	scanf("%d %f",&myint,&mydouble); fscanf(file2,"%d %f",&myint,&mydouble);	Scanning from terminal or file?
6	result = fgets(charbuf, 1024, file);	Get whole lines of text?
7	FILE *stdin, *stdout, *stderr;	Names for standard input, etc

The standard I/O library was written by Dennis Ritchie around 1975.

–Stevens and Rago, Advanced Programming for the Unix Environment

- ▶ Assuming you are familiar with these and could look up others like fgetc() (single char) and fread() (read binary)
- ▶ Library Functions: available with any compliant C compiler
- ▶ On Unix systems, fscanf(), FILE*, and the like are backed by lower level System Calls and Kernel Data Structures

The Process Table

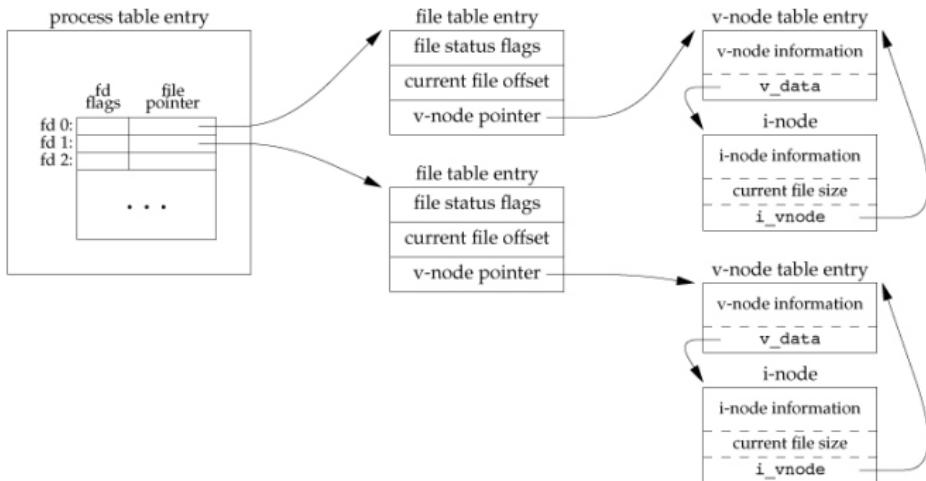


Source:

SO What is the Linux Process Table?

- ▶ OS maintains data on all processes in a Process Table
- ▶ Process Table Entry ≈ Process Control Block
- ▶ Contains info like PID, instruction that process is executing*, Virtual Memory Address Space and **Files in Use**

File Descriptors



- ▶ Each Process Table entry contains a table of open files
- ▶ A user program refers to these via **File Descriptors**
- ▶ File Descriptor is an integer index into Kernel's table

```
int fd = open("some_file.txt", O_RDONLY);
```
- ▶ FD Table entry refers to other Kernel/OS data structures

File Descriptors (FDs) are Multi-Purpose

- ▶ Unix tries to provide most things via files/file descriptor
- ▶ Many Unix system actions are handled via `read()`-from or `write()`-to file descriptors
- ▶ FDs allow interaction with “normal” files like `myfile.txt` or `commando.c` to read/change them
- ▶ FDs also allow interaction with many other things
 - ▶ Pipes for interprocess communication
 - ▶ Sockets for network communication
 - ▶ Special files to manipulate terminal, audio, graphics, etc.
 - ▶ Raw blocks of memory for Shared Memory communication
 - ▶ Even processes themselves have special files in the file system:
`ProcFS` in `/proc/PID#`, provide info on running process
- ▶ We will focus on standard File I/O using FDs now and touch on some broader uses Later
- ▶ Also must discuss FD interactions with previous System Calls:
What happens with `open()` files when calling `fork()`?

Open and Close: File Descriptors for Files

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

int fd1 = open("firstfile", O_RDONLY); // read only
if(fd1 == -1){                      // check for errors on open
    perror("Failed to open 'firstfile'");
}

int fd2 = open("secndfile", O_WRONLY); // write only, fails if not found
int fd3 = open("thirdfile", O_WRONLY | O_CREAT); // write only, create if needed
int fd4 = open("forthfile", O_WRONLY | O_CREAT | O_APPEND); // append if existing

// 'man 3 open' will list all the O_xxx options when opening.
// Other common options: O_RDONLY, O_RDWR, O_EXEC

...;                                // Do stuff with open files

int result = close(fd1); // close the file associated with fd1
if(result == -1){          // check for an error
    perror("Couldn't close 'firstfile'");
}
```

`open()` / `close()` show common features of many system calls

- ▶ Returns -1 on errors
- ▶ Show errors using the `perror()` function
- ▶ Use of vertical pipe (|) to bitwise-OR several options

read() from File Descriptors

```
1 // read_some.c: Basic demonstration of reading data from
2 // a file using open(), read(), close() system calls.
3
4 #define SIZE 128
5
6 {
7     int in_fd = open(in_name, O_RDONLY);
8     char buffer[SIZE];
9     int bytes_read = read(in_fd, buffer, SIZE);
10 }
```

- ▶ Read up to SIZE from an open file descriptor
- ▶ Bytes stored in buffer, overwrite it
- ▶ Return value is number of bytes read, -1 for error
- ▶ SIZE commonly defined but can be variable, constant, etc
- ▶ **Examine read_some.c:** explain what's happening

Caution:

- ▶ Bad things happen if buffer is actually smaller than SIZE
- ▶ read() does NOT null terminate, add \0 manually if needed

Exercise: Behavior of read() in count_bytes.c

Run count_bytes.c on
file data.txt

```
> cat data.txt
ABCDEFGHIJ
> gcc count_bytes.c
> ./a.out data.txt
???
```

1. Explain control flow
within program
2. Predict output of
program

```
8 // count_bytes.c
9 #define BUFSIZE 4
10
11 int main(int argc, char *argv[]){
12     char *infile = argv[1];
13     int in_fd = open(infile,O_RDONLY);
14     char buf[BUFSIZE];
15     int nread, total=0;
16     while(1){
17         nread = read(in_fd,buf,BUFSIZE-1);
18         if(nread == 0){
19             break;
20         }
21         buf[nread] = '\0';
22         total += nread;
23         printf("read: '%s'\n",buf);
24     }
25     printf("%d bytes total\n",total);
26     close(in_fd);
27     return 0;
28 }
```

Answers: Behavior of read() in count_bytes.c

```
==INITIAL STATE==  
data.txt: ABCDEFGHIJ\n  
position: ^  
buf: |? ? ? ? |  
      0 1 2 3  
nread: 0  
total: 0  
  
==ITERATION 1==  
nread = read(in_fd,buf,3);  
buf[nread] = '\0'  
total+= nread;  
printf("read: '%s'\n",buf);  
  
data.txt: ABCDEFGHIJ\n  
position: ^  
buf: |A B C \0|  
      0 1 2 3  
nread: 3  
total: 3  
output: 'ABC'  
  
==ITERATION 2==  
nread = read(in_fd,buf,3);  
buf[nread] = '\0'  
total+= nread;  
printf("read: '%s'\n",buf);  
  
data.txt: ABCDEFGHIJ\n  
position: ^  
buf: |D E F \0|  
      0 1 2 3  
nread: 3  
total: 6  
output: 'DEF'  
  
==ITERATION 3==  
nread = read(in_fd,buf,3);  
buf[nread] = '\0'  
total+= nread;  
printf("read: '%s'\n",buf);  
  
data.txt: ABCDEFGHIJ\n  
position: ^  
buf: |G H I \0|  
      0 1 2 3  
nread: 3  
total: 9  
output: 'GHI'  
  
==ITERATION 4==  
nread = read(in_fd,buf,3);  
buf[nread] = '\0'  
total+= nread;  
printf("read: '%s'\n",buf);  
  
data.txt: ABCDEFGHIJ\n  
position: ^  
buf: |J \n\0\0|  
      0 1 2 3  
nread: 2  
total: 11  
output: 'J\n'  
  
==ITERATION 5==  
nread = read(in_fd,buf,3);  
if(nread == 0){  
    break;  
}  
  
data.txt: ABCDEFGHIJ\n  
position: ^  
buf: |J \n\0\0|  
      0 1 2 3  
nread: 0  
total: 11  
output: 11 bytes total
```

Answers: Behavior of `read()` in `count_bytes.c`

Take-Aways from `count_bytes.c` include

- ▶ OS maintains **file positions** for each open File Descriptor
- ▶ I/O functions like `read()` use/change position **in a file**
- ▶ `read()`'ing into program arrays overwrites data there
- ▶ OS **does not** update positions in user arrays: programmer must do this in their program logic
- ▶ `read()` returns # of bytes read, may be less than requested
- ▶ `read()` returns 0 when at end of a file

Exercise: write() to File Descriptors

```
1 #define SIZE 128
2
3 {
4     int out_fd = open(out_name, O_WRONLY);
5     char buffer[SIZE];
6     int bytes_written = write(out_fd, buffer, SIZE);
7 }
```

- ▶ Write up to SIZE bytes to open file descriptor
- ▶ Bytes taken from buffer, leave it intact
- ▶ Return value is number of bytes written, -1 for error

Questions on write_then_read.c

- ▶ Compile and Run
- ▶ Explain Output, differences between write() / printf()

Answers: write() to File Descriptors

read()/write() work with bytes

- ▶ In C, general correspondence between byte and the char type
- ▶ Not so for other types: int is often 4 bytes
- ▶ Requires care with non-char types
- ▶ All calls read/write actual bytes

```
#define COUNT 16
int out_ints[COUNT];           // array of 16 integers
int bufsize = sizeof(int)*COUNT; // size in bytes of array
...
write(out_fd, out_ints, bufsize); // write whole buffer

int in_ints[COUNT];
...
read(in_fd, in_ints, bufsize); // read to capacity of in_ints
```

Questions

- ▶ Examine write_read_ints.c, compile/run
- ▶ Examine contents of integers.dat
- ▶ Explain what you see

Standard File Descriptors

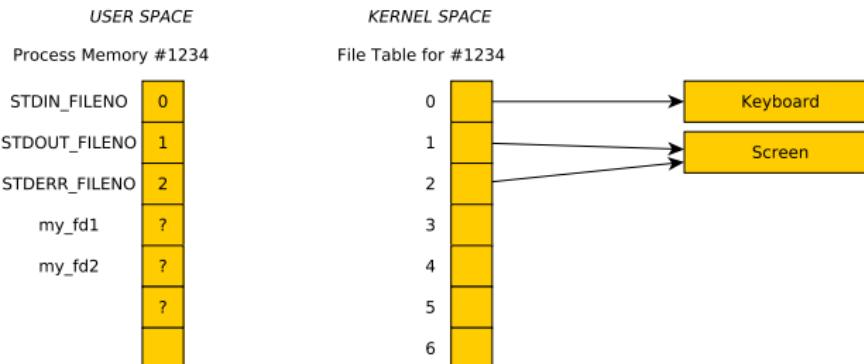
- ▶ When a process is born, comes with 3 open file descriptors
- ▶ Related to FILE* streams in Standard C I/O library
- ▶ Traditionally have FD values given but use the Symbolic name to be safe

Symbol	#	FILE*	FD for...
STDIN_FILENO	0	stdin	standard input (keyboard)
STDOUT_FILENO	1	stdout	standard output (screen)
STDERR_FILENO	2	stderr	standard error (screen)

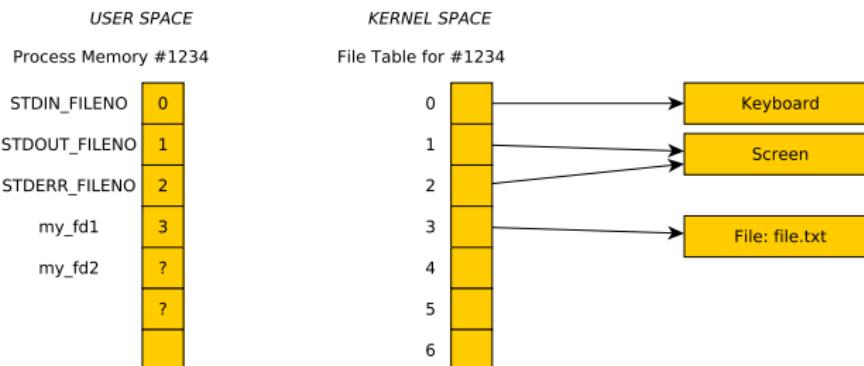
```
// Low level printing to the screen
char message[] = "Wubba lubba dub dub!\n";
int length = strlen(message);
write(STDOUT_FILENO, message, length);
```

See `low_level_interactions.c` to gain an appreciation for what `printf()` and its kin can do for you.

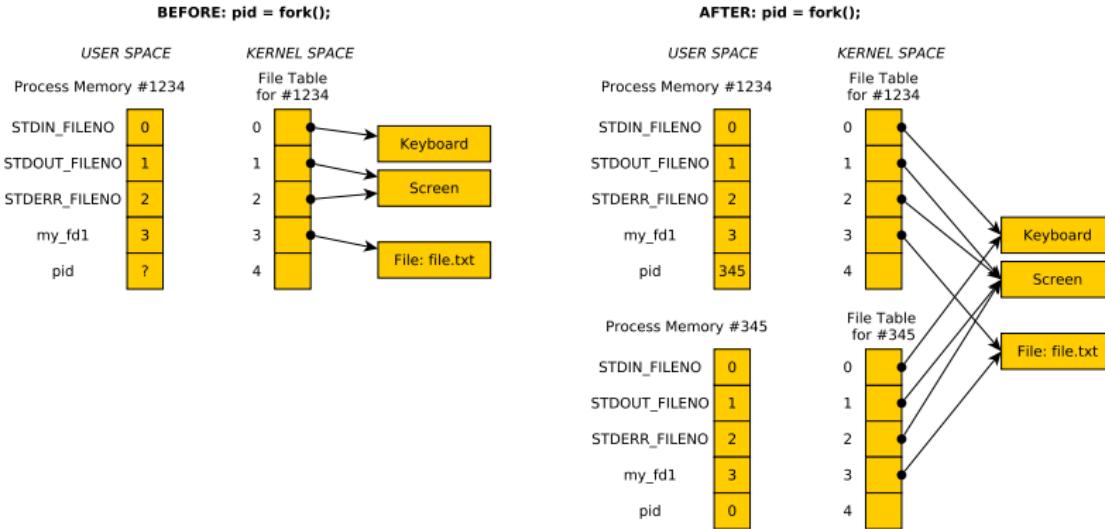
File Descriptors refer to Kernel Structures



```
my_fd1 = open("file.txt", O_RDONLY);
```



Processes Inherit Open FDs: Diagram



Typical sequence:

- ▶ Parent creates an `output_fd` and/or `input_fd`
- ▶ Call `fork()`
- ▶ Child changes standard output to `output_fd` and/or `input_fd`
- ▶ Changing means calls to `dup2()`

Shell I/O Redirection

- ▶ Shells can direct input / output for programs using < and >
- ▶ Most common conventions are as follows

```
$> some_program > output.txt  
# output redirection to output.txt
```

```
$> interactive_prog < input.txt  
# read from input.txt rather than typing
```

```
$> some_program &> everthing.txt  
# both stdout and stderr to file
```

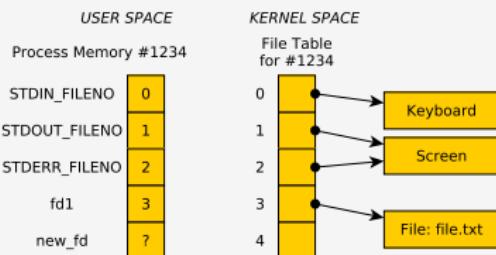
```
$> some_program 2> /dev/null  
# stderr silenced, stdout normal
```

- ▶ Long output can be saved easily
- ▶ Can save typing input over and over
- ▶ Even more fun when you incorporate [Pipes to make Pipelines](#)
- ▶ **Goal:** Demonstrate systems calls to facilitate redirection

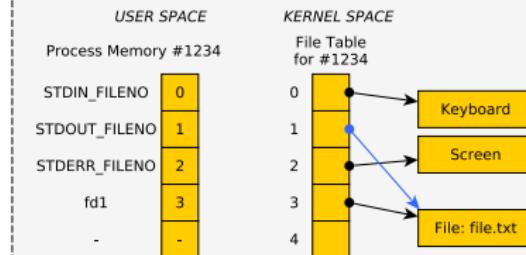
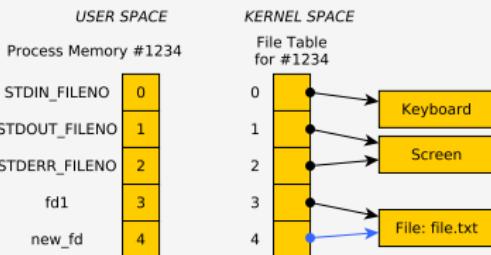
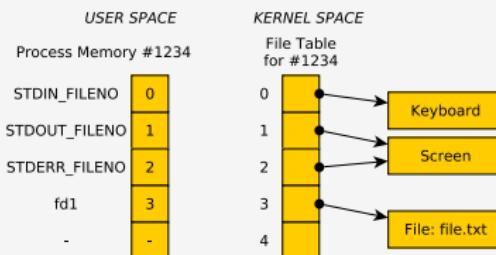
Manipulating the File Descriptor Table

- ▶ System calls `dup()` and `dup2()` manipulate the FD table
- ▶ `int backup_fd = dup(fd);` : copy a file descriptor
- ▶ `dup2(src_fd, dest_fd);` : `src_fd` copied to `dest_fd`

Effect of `dup()`: copy a file descriptor



Effect of `dup2()`: change entry in FD table



Exercise: Redirecting Output with dup() / dup2()

- ▶ `dup()`, `dup2()`, and `fork()` can be combined in interesting ways
- ▶ **Diagram fork-dup.pdf** shows how to redirect standard out to a file like a shell does in: `ls -l > output.txt`

Write a program which

1. Prints PID to screen
2. Opens a file named `write.txt`
3. Forks a Child process
4. Child: **redirect standard output** into `write.txt`
Parent: does no redirection
5. Both: `printf()` their PID
6. Child: **restore standard output** to screen
Parent: makes no changes
7. Both: `printf()` "All done"

```
> gcc duped_child.c
> ./a.out
BEGIN: Process 1913588
MIDDLE: Process 1913588
END: Process 1913588 All done
END: Process 1913590 All done
```

```
> cat write.txt
MIDDLE: Process 1913590
```

Answers: Redirecting Output with dup() / dup2()

```
1 // duped_chld.c: solution to in-class activity on redirecting output
2 // in child process.
3 #include <stdio.h>
4 #include <stdlib.h>
5 #include <unistd.h>
6 #include <errno.h>
7 #include <sys/stat.h>
8 #include <fcntl.h>
9 #include <string.h>
10
11 int main(int argc, char *argv[]){
12     system("echo '' > write.txt");           // ensure file exists, is empty
13     printf("BEGIN: Process %d\n",getpid());
14     int fd = open("write.txt",O_WRONLY); // open a file
15     int backup;
16     pid_t child = fork();                  // fork a child, inherits open file
17     if(child == 0){                      // child only redirects stdout
18         backup = dup(STDOUT_FILENO);    // make backup of stdout
19         dup2(fd,STDOUT_FILENO);        // dup2() alters stdout so child printf() goes into file
20     }
21     printf("MIDDLE: Process %d\n",getpid());
22     if(child == 0){
23         dup2(backup,STDOUT_FILENO);    // child restores stdout
24     }
25     printf("END: Process %d All done\n",getpid());
26     close(fd);
27     if(child != 0){                    // parent waits on child
28         wait(NULL);
29     }
30     return 0;
31 }
```

C FILE Structs Use File Descriptors in UNIX

Typical Unix implementation of standard I/O library FILE is

- ▶ A file descriptor
- ▶ Some buffers with positions
- ▶ Some options controlling buffering

From /usr/include/bits/types/struct_FILE.h

```
struct _IO_FILE {  
    int _flags;           // options  
    char* _IO_read_ptr;   // buffers for read/write and  
    char* _IO_read_end;   // positions within them  
    char* _IO_read_base;  
    char* _IO_write_base;  
    ...;  
    int _fileno;          // unix file descriptor  
    ...;  
    _IO_lock_t *_lock;    // locking  
};
```

Exercise: Subtleties of Mixing Standard / Low-Level I/O

```
3K.txt:  
1 2 3 4 5 6 7 8 9 10 11 12 13 14...  
37 38 39 40 41 42 43 44 45 46 47 ...  
70 71 72 73 74 75 76 77 78 79 80 ...  
102 103 104 105 106 107 108 109 1...  
...
```

```
1 // mixed_std_low.c: mix C Standard  
2 // and Unix I/O calls. pain++;  
3 #include <stdio.h>  
4 #include <unistd.h>  
5  
6 int main(int argc, char *argv[]){  
7     FILE *input = fopen("3K.txt", "r");  
8     int first;  
9     fscanf(input, "%d", &first);  
10    printf("FIRST: %d\n", first);  
11  
12    int fd = fileno(input);  
13    char buf[64];  
14    read(fd, buf, 63);  
15    buf[63] = '\0';  
16    printf("NEXT: %s\n", buf);  
17  
18    return 0;  
19 }
```

Sample compile/run:

```
> gcc mixed_std_low.c  
> ./a.out  
FIRST: 1  
NEXT: 41 1042 1043 1044 1045...
```

- ▶ Explain output of program given input file
- ▶ Use knowledge that **buffering** occurs internally for standard I/O library

Answers: Subtleties of Mixing Standard / Low-Level I/O

- ▶ C standard I/O calls like `printf` / `fprintf()` and `scanf`() / `fscanf()` use internal buffering
- ▶ A call to `fscanf(file, "%d", &x)` will read a large chunk from a file but only process part of it
- ▶ From OS perspective, associated file descriptor has advanced forwards / read a bunch
- ▶ The data is in a hidden “buffer” associated with a `FILE *file`, used by `fscanf()`

Output Also buffered, Always `fclose()`

- ▶ Output is also buffered: `output_buffering.c`
- ▶ Output may be lost if `FILE*` are not `fclose()`'d: closing will flush remaining output into a file
- ▶ See `fail_to_write.c`
- ▶ File descriptors always get flushed out by OS when a program ends BUT `FILE*` requires user action
- ▶ To force output, use `fflush(some_file);`

Controlling FILE Buffering

```
#include <stdio.h>
void setbuf(FILE *stream, char *buf);
void setbuffer(FILE *stream, char *buf, size_t size);
void setlinebuf(FILE *stream);
int setvbuf(FILE *stream, char *buf, int mode, size_t size);
```

Above functions change buffering behavior of standard C I/O

Examples:

```
// 1. Set full "block" buffering for stdout, use outbuf
#define BUFSIZE 64
char outbuf[BUFSIZE] = {};
setvbuf(stdout, outbuf, _IOFBF, BUFSIZE);

// 2. Turn off buffering of stdout, output immediately printed
setvbuf(stdout, NULL, _IONBF, 0);
```

- ▶ When testing lab/project code, buffering is disabled as it makes it easier to understand some bugs

Basic File Statistics via stat

Command	C function	Effect
stat file	int ret = stat(file,&statbuf); int ret = lstat(file,&statbuf);	Get statistics on file Same, don't follow symlinks
	int fd = open(file,...); int ret = fstat(fd,&statbuf);	Same as above but with an open file descriptor

Shell command stat provides basic file info such as shown below

```
>> stat a.out
  File: a.out
  Size: 12944          Blocks: 40          IO Block: 4096   regular file
Device: 804h/2052d      Inode: 6685354      Links: 1
Access: (0770/-rwxrwx---) Uid: ( 1000/kauffman)  Gid: ( 1000/kauffman)
Access: 2017-10-02 23:03:21.192775090 -0500
Modify: 2017-10-02 23:03:21.182775091 -0500
Change: 2017-10-02 23:03:21.186108423 -0500
 Birth: -

>> stat /
  File: /
  Size: 4096          Blocks: 8           IO Block: 4096   directory
Device: 803h/2051d      Inode: 2            Links: 17
Access: (0755/drwxr-xr-x) Uid: (    0/  root)  Gid: (    0/  root)
Access: 2017-10-02 00:56:47.036241675 -0500
Modify: 2017-05-07 11:34:37.765751551 -0500
Change: 2017-05-07 11:34:37.765751551 -0500
 Birth: -
```

See `stat_demo.c` for info on C calls to obtain this info

Attributes of Files from stat()

stat_demo.c shows some attributes that may be obtained about a file after a call to `stat(filename, &statbuf)` which fills in the `statbuff` struct. Attributes include:

Attribute	Notes
Size	In bytes via <code>st_size</code> field
File Type	Via <code>st_mode</code> field and macros like <code>S_ISREG(mode)</code> Limited number of fundamental types: regular, directory, socket, etc.
Permissions	Read/Write/Execute for Owner/Group/Others via <code>st_mode</code> field
Ownership	Via <code>st_uid</code> (user) and <code>st_gid</code> (group), numeric IDs for both
Time Data	Access / Change / Modification times via <code>st_atime</code> , <code>st_ctime</code> , ...

Permissions / Modes

- ▶ Unix enforces file security via *modes*: permissions as to who can read / write / execute each file
- ▶ See permissions/modes with `ls -l`
- ▶ Look for series of 9 permissions

```
> ls -l
total 140K
-rwx--x--- 2 kauffman faculty 8.6K Oct  2 17:39 a.out
-rw-r--r-- 1 kauffman devel   1.1K Sep 28 13:52 files.txt
-rw-rw---- 1 kauffman faculty 1.5K Sep 26 10:58 gettysburg.txt
-rwx--x--- 2 kauffman faculty 8.6K Oct  2 17:39 my_exec
----- 1 kauffman kauffman 128 Oct  2 17:39 unreadable.txt
-rw-rw-r-x 1 root      root   1.2K Sep 26 12:21 scripty.sh
U G O   O   G   S   M T   N
S R T   W   R   I   O I   A
E O H   N   O   Z   D M   M
R U E   E   U   E   E   E   E
P R R   P   P
~~~~~
```

PERMISSIONS

- ▶ Every file has permissions set from somewhere on creation

Changing Permissions

Owner of file (and sometimes group member) can change permissions via chmod

```
> ls -l a.out
```

```
-rwx--x--- 2 kauffman faculty 8.6K Oct 2 17:39 a.out
```

```
> chmod u-w,g+r,o+x a.out
```

```
> ls -l a.out
```

```
-r-xr-x--x 2 kauffman faculty 8.6K Oct 2 17:39 a.out
```

- ▶ chmod also works via octal bits (suggest against this unless you want to impress folks at parties)
- ▶ Programs specify file permissions via system calls
- ▶ Curtained by **Process User Mask** which indicates permissions that are disallowed by the process
 - ▶ umask shell function/setting: \$> umask 007
 - ▶ umask() system call: umask(S_IWGRP | S_IWOTH);
- ▶ Common program strategy: create files with very liberal read/write/execute permissions, umask of user will limit this

Permissions / Modes in System Calls

open() can take 2 or 3 arguments

```
int fd = open(name, flags);
# new file will have NO permissions
# to read/write, not an issue if opening
# existing file

int fd = open(name, flags, perms);
          ~~~~~
# new file will have given permissions
# (subject to the umask), ignored for
# existing files
```

Symbol	Entity	Sets
S_IRUSR	User	Read
S_IWUSR	User	Write
S_IXUSR	User	Execute
S_IRGRP	Group	Read
S_IWGRP	Group	Write
S_IXGRP	Group	Execute
S_IROTH	Others	Read
S_IWOTH	Others	Write
S_IXOTH	Others	Execute

Compare: write_readable.c VERSUS write_unreadable.c

```
char *outfile = "newfile.txt";           // doesn't exist yet
int flags      = O_WRONLY | O_CREAT;    // write/create
mode_t perms   = S_IRUSR | S_IWUSR;    // variable for permissions
int out_fd     = open(outfile, flags, perms);
          ~~~~~
```

Movement within Files, Changing Sizes

- ▶ Can move OS internal position in a file around with `lseek()`
- ▶ Note that size is arbitrary: can seek to any positive position
- ▶ File automatically expands if position is larger than current size - fills holes with 0s (null chars)
- ▶ Can manually set size of a file with `ftruncate(fd, size)`
- ▶ Examine `file_hole1.c` and `file_hole2.c`

C function	Effect
<code>int res = lseek(fd, offset, option);</code>	Move position in file
<code>lseek(fd, 20, SEEK_CUR);</code>	Move 20 bytes forward
<code>lseek(fd, 50, SEEK_SET);</code>	Move to position 50
<code>lseek(fd, -10, SEEK_END);</code>	Move 10 bytes from end
<code>lseek(fd, +15, SEEK_END);</code>	Move 15 bytes beyond end
<code>ftruncate(fd, 64);</code>	Set file to be 64 bytes big If file grows, new space is zero-filled

Note: C standard I/O functions `fseek(FILE*)` and `rewind(FILE*)` mirror functionality of `lseek()`

Directory Access

- ▶ Directories are fundamental to Unix (and most file systems)
- ▶ Unix file system rooted at / (root directory)
- ▶ Subdirectories like bin, ~/home, and /home/kauffman
- ▶ Useful shell commands and C function calls pertaining to directories are as follows

Shell Command	C function	Effect
mkdir name	int ret = mkdir(path,perms);	Create a directory
rmdir name	int ret = rmdir(path);	Remove empty directory
cd path	int ret = chdir(path);	Change working directory
pwd	char *path = getcwd(buf,SIZE);	Current directory
ls	DIR *dir = opendir(path); struct dirent *file = readdir(dir); int ret = closedir(dir);	List directory contents Start reading filenames from dir Call in a loop, NULL when done After readdir() returns NULL

See `dir_demo.c` for demonstrations

Optional Exercise: Code for Total Size of Regular Files

- ▶ Code which will scan all files in a directory
- ▶ Will get file statistics on each file
- ▶ Skips directories, symlinks, etc.
- ▶ Totals bytes of all Regular files in current directory

Use techniques demoed in
`dir_demo.c` and `stat_demo.c`
from codepack

```
> gcc total_size.c
> ./a.out
    26 readable1.txt
   1299 buffered_output.c
   2512 stat_demo.c
...
    584 file_hole2.c
SKIP .
SKIP my_symlink
SKIP subdir
   907 dir_demo.c.bk
...
   1415 write_umask.c
=====
   67106 total bytes
```

Answers: Sketch Code for Total Size of Regular Files

```
// total_size.c
int main(int argc, char *argv[]){
    size_t total_size = 0;
    DIR *dir = opendir(".");
    while(1){
        struct dirent *file = readdir(dir);
        if(file == NULL){
            break;
        }
        struct stat sb;
        lstat(file->d_name, &sb);
        if(S_ISREG(sb.st_mode)){
            printf("%8lu %s\n",
                   sb.st_size, file->d_name);
            total_size += sb.st_size;
        }
        else{
            printf("%-8s %s\n",
                   "SKIP", file->d_name);
        }
    }
    closedir(dir);
    printf("=====\\n");
    printf("%8lu total bytes from REGULAR files\\n",
           total_size);
    return 0;
}
```

- ▶ Scans only current directory
- ▶ **Recursive scanning** is trickier and involves... recursion
- ▶ OR the very useful `nftw()` library function (read about this on your own if curious about systems programming)

Extras: Processes Inherit Open FDs

- ▶ Child processes share all open file descriptors with parents
- ▶ By default, Child prints to screen / reads from keyboard input
- ▶ Redirection requires manipulation prior to `fork()`
- ▶ See: `open_fork.c`
- ▶ Experiment with order
 1. `open()` then `fork()`
 2. `fork()` then `open()`

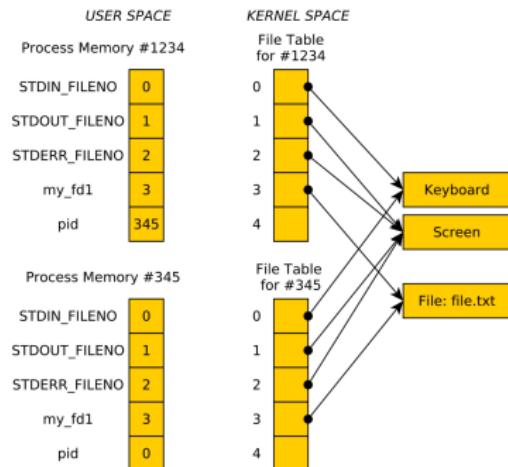
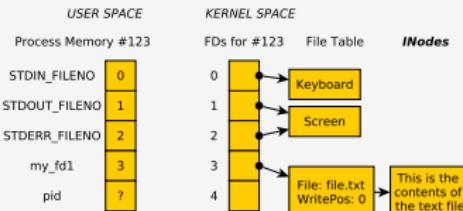


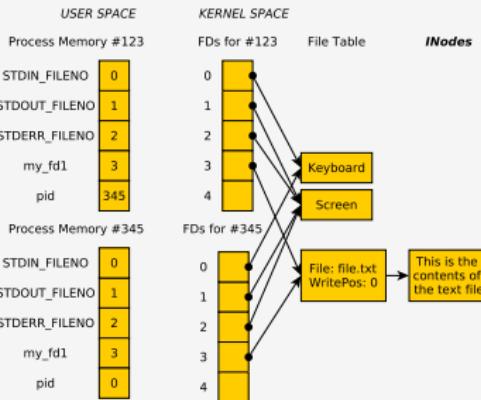
Diagram on next slide shows variations of open-then-fork vs fork-then-open from `open_fork.c`

open() normal file then call fork()

`my_fd = open("file.txt"); // called by parent`

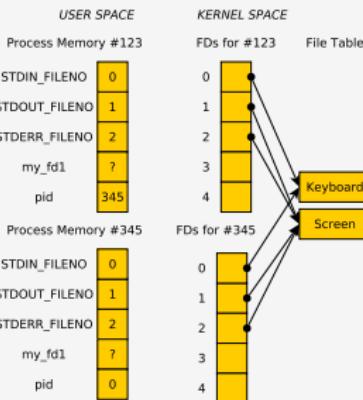


`pid = fork();`

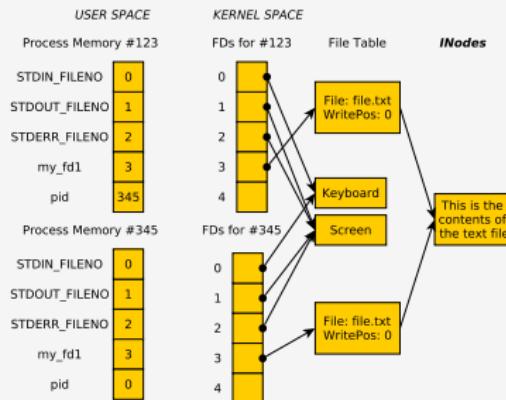


fork() then call open() normal file

`pid = fork();`



`my_fd = open("file.txt"); // called by parent and child`



(Review) Exercise: Regular File Creation Basics

C Standard I/O

- ▶ Write/Read data?
- ▶ Open a file, create it if needed?
- ▶ Result of opening a file?
- ▶ Close a file?
- ▶ Set permissions on file creation?

Unix System Calls

- ▶ Write/Read data?
- ▶ Open a file, create it if needed?
- ▶ Result of opening a file?
- ▶ Close a file?
- ▶ Set permissions on file creation?

Answers: Regular File Creation Basics

C Standard I/O

- ▶ Write/Read data?

```
fscanf(), fprintf()  
fread(), fwrite()
```

- ▶ Open a file, create it if needed?
- ▶ Result of opening a file?

```
FILE *out =  
    fopen("myfile.txt", "w");
```

- ▶ Close a file?

```
fclose(out);
```

- ▶ Set permissions on file creation?
Not possible... dictated by umask

Unix System Calls

- ▶ Write/Read data?

```
write(), read()
```

- ▶ Open a file, create it if needed?
- ▶ Result of opening a file?

```
int fd =  
    open("myfile.txt",  
          O_WRONLY | O_CREAT,  
          permissions);
```

- ▶ Close a file?

```
close(fd);
```

- ▶ Set permissions on file creation?

- ▶ Additional options to
open(), which brings us
to...