CSCI 4061: Files, Directories, Standard I/O

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Logistics

Reading

Stevens/Rago Ch 3, 4, 5, 6

Goals for Week

- □ `read()/write()`
- □ I/O Redirection
- □ Pipes
- □ C `FILE*` vs Unix FDs
- □ Filesystem
- □ Permissions
- □ Hard/Symbolic Links
- □ File / Directory Functions

Date		Event
Mon	2/15	Lab: dup2() Basic I/O, Filesystem
Wed	2/17	Filesystem
Fri	6/26	Lab: Files/Dirs, Review
Mon	2/22	Lec/Lab: Review **Project 1 Due**
Wed	2/24	Exam 1 Last day to submit P1 late

P1 Questions?

Due date approaching rapidly

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
    P  R     R        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
- Curtailed 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

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...

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);
                                     ^^^^^
```

Filesystems, inodes, links

- Unix **filesystems** implement physical layout of files/directories on a storage media (disks, CDs, etc.)
- Many filesystems exist but all Unix-centric filesystems share some common features

inode

- Kernel data structure which describes a single file
- Stores some meta data: inode#, size, timestamps, owner
- A table of contents: which disk blocks contain file data
- Does **not** store filename, does store a **link count**

Directories

- List names and associated inode
- Each entry constitutes a **hard link** to an inode or a **symbolic link** to another file
- Files with 0 hard links are deleted

Rough Filesystem in Pictures 1

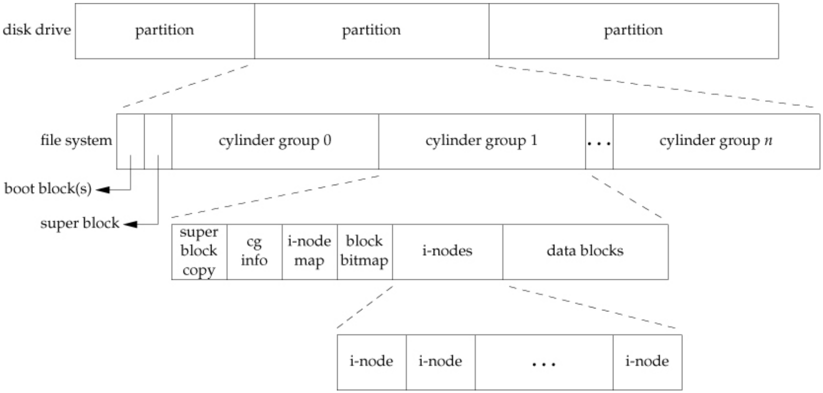


Figure 4.13 Disk drive, partitions, and a file system (Stevens/Rago)

Rough Filesystem in Pictures 2

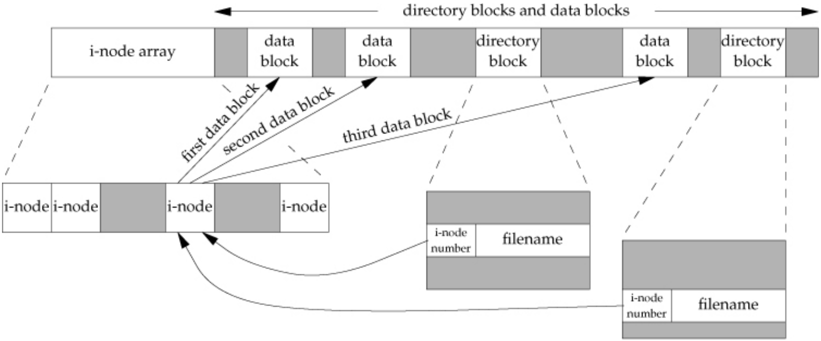


Figure 4.14 Cylinder group's i-nodes and data blocks in more detail (Stevens/Rago)

Shell Demo of Hard and Symbolic Links

```
> rm *
> touch fileX                   # create empty fileX
> touch fileY                   # create empty fileY
> ln fileX fileZ                # hard link to fileX called fileZ
> ln -s fileX fileW             # symbolic link to fileX called fileW
> ls -li                        # -i for inode numbers
total 12K
6685588 -rw-rw---- 2 kauffman kauffman 0 Oct  2 21:24 fileX
6685589 -rw-rw---- 1 kauffman kauffman 0 Oct  2 21:24 fileY
6685588 -rw-rw---- 2 kauffman kauffman 0 Oct  2 21:24 fileZ
6685591 lrwxrwxrwx 1 kauffman kauffman 5 Oct  2 21:29 fileB -> fileA
6685590 lrwxrwxrwx 1 kauffman kauffman 5 Oct  2 21:25 fileW -> fileX
↑↑↑↑↑↑↑ ↑          ↑                                        ↑↑↑↑↑↑↑↑
inode#  regular    hard link count                    symlink target
        or symlink

> file fileW                    # file type of fileW
fileW: symbolic link to fileX
> file fileB                    # file type of fileB
fileB: broken symbolic link to fileA
```

Linking Commands and Functions

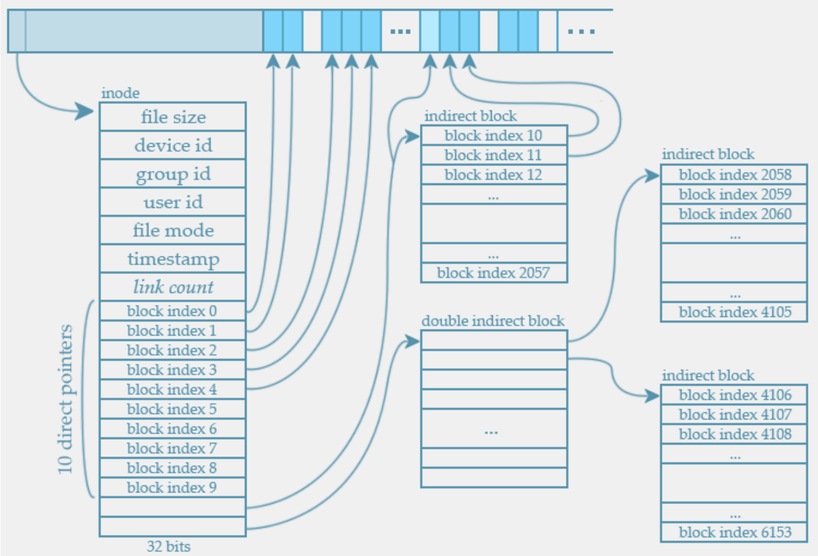
Shell Command	C Function	Effect
`ln fileX fileY`	`link("fileX", "fileY");`	Create a hard link
`rm fileX`	`remove("fileX");`	Unlink (remove) hard link
	`unlink("fileX");`	Identical to `remove()`
`ln -s fileX fileY`	`symlink("fileX", "fileY");`	Create a Symbolic link

- Creating hard links preserves inodes
- Hard links not allowed for directories unless you are root

  ```
  > ln /home/kauffman to-home
  ln: /home/kauffman: hard link not allowed for directo
  ```

  Can create directory cycles if this was allowed
- Symlinks easily identified so utilities can skip them

FYI: inodes are a complex beast themselves



Source: File System Design by Justin Morgan

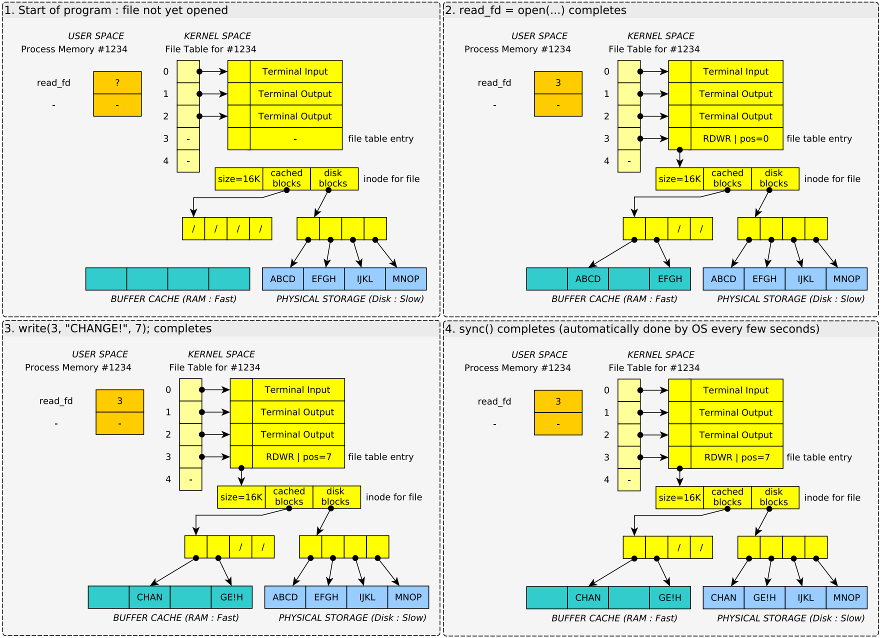
sync() and Internal OS Buffers

- Operating system maintains internal data associated with open files
- Writing to a file doesn't go immediately to a disk
- May live in an internal buffer for a while before being sync'ed to physical medium (OS buffer cache)

Shell Command	C function	Effect
`sync`	`sync();`	Synchronize cached writes to persistent storage
	`syncfs(fd);`	Synchronize cached writes for filesystem of given open `fd`

- Sync called so that one can "Safely remove drive"
- Sync happens automatically at regular intervals (ex: 15s)

File Caching Demo



1. Start of program : file not yet opened

2. read_fd = open(...) completes

3. write(3, "CHANGE!", 7); completes

4. sync() completes (automatically done by OS every few seconds)

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
`int res = lseek(fd, offset, option);`	Move position in file
`lseek(fd, 20, SEEK_CUR);`	Move 20 bytes forward
`lseek(fd, 50, SEEK_SET);`	Move to position 50
`lseek(fd, -10, SEEK_END);`	Move 10 bytes from end
`lseek(fd, +15, SEEK_END);`	Move 15 bytes beyond end
`ftruncate(fd, 64);`	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()`

Basic File Statistics via `stat`

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

Directory Access

- Directories are fundamental to Unix (and most file systems)
- Unix file system rooted at / (root directory)
- Subdirectores 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`		List directory contents
	`DIR *dir = opendir(path);`	Start reading filenames from dir
	`struct dirent *file = readdir(dir);`	Call in a loop, `NULL` when done
	`int ret = closedir(dir);`	After `readdir()` returns `NULL`

See `dir_demo.c` for demonstrations

Exercise: Sketch 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, discussed in upcoming HW
- Techniques required for upcoming P2

Files in Trees

- Frequently one wants to visit all files in a directory tree
- P2: check all files for changes / revision control
- Options for this on the command line and via system calls

find utility on Shell

```
> find .
.
./c
./c/d.txt
./b.txt
./src
./src/tests
./src/tests/results.txt
./src/main.c
./src/code.c
./a.txt

> find . -name '*.c'
./src/main.c
./src/code.c
```

nftw() System Call in C

- File Tree Walk : visit all files in a directory
- A Higher Order function: function parameter

```
nftw(filename, count_file,      ...);
nftw(filename, print_file_info, ...);
nftw(filename, delete_file,     ...);

int print_file_info(const char *filename,
                    const struct stat *sb,
                    ...);
```

- Covered in HW7, used in P2

Multiplexed Input/Output

- Occasions arise when one must `read()` from several sources BUT it is unclear which source is ready and which is not
- OS can provide information on ready sources
- Future HW will cover `poll()` and/or `select()` system calls which are used for this
- Will need it for a project later in the semester
- Remaining slides will be revisited then

`select()` and `poll()`: Non-busy waiting

- Recall **polling** is a busy wait on something: constantly check until ready
- Alternative is **interrupt-driven** wait: ask for notification when something is ready, go to sleep, get woken up
- Waiting is often associated with input from other processes through pipes or sockets
- Both `select()` and `poll()` allow for waiting on input from multiple file descriptors
- Confusingly, **both select() and poll() are interrupt-driven**: will put process to sleep until something changes in one or more files
- `poll()` doesn't do polling (busy wait) - it does interrupt driven I/O (!!)
- Example application: database system is waiting for any of 10 users to enter a query, don't know which one will type first

poll() System Call

- Modern usage favors `poll()` for multiplexed I/O
- Despite name, `poll()` blocks a process until one of several input/output sources are immediately ready
- Allows for an interrupt-driven style of programming
- Covered in Demo usage of the poll() System Call

select() System Call and File Descriptor Sets

- `select()` uses file descriptor **sets**
- `fd_set` tracks descriptors of interest, operated on with macros

```
fd_set my_set;
void FD_ZERO(fd_set *set);          // clear entire set
void FD_SET(int fd, fd_set *set);   // fd now in set
void FD_CLR(int fd, fd_set *set);   // fd now not in set
int  FD_ISSET(int fd, fd_set *set); // test if fd in set
```

- Example: setup set of potential read sources

```
int pipeA[2], pipeB[2], rd_fd;   // set up several read sources
pipe(pipeA);
pipe(pipeB);
rd_fd = open("myfile.txt",RD_ONLY);

fd_set read_set;                 // set of file descriptors for select()
FD_ZERO(&read_set);              // init the set

FD_SET(pipeA[PREAD], &read_set); // include read ends of pipes in set
FD_SET(pipeB[PREAD], &read_set);
FD_SET(rd_fd, &read_set);        // include read file in the set
```

Multiplexing: Efficient input from multiple sources

- select() block a process until at least one of member of the fd_set is "ready"
- Most common use: waiting for input from multiple sources
- Example: Multiple child processes writing to pipes at different rates

```
#include <sys/select.h>
fd_set read_set, write_set,     // sets of fds to wake up for
       except_set;

struct timeval timeout;         // allows timeout: wake up if nothing happens

int nfds =                      // returns nfds changed
  select(maxfd+1,               // must pass max fd+1
         &read_set,             // any of set may be NULL to ignore
         &write_set,
         &except_set,
         &timeout);             // NULL time waits indefinitely
```

- poll() performs similar multiplexed block but has a different interface