Unix System Programming

Files

Outline

Previously (and Chap 1 & 2 from text)

- Covered Brief UNIX history/interface
- UNIX overview - process, shell, file
- Brief intro to basic file I/O - open(), close(), read(), write(), lseek(), fprintf (library call)
- Week of C

This Week:

- Read Chapter 3
- Administrative: Rock.c
- The Operating System & System Calls
- UNIX history - more on the key players
- Efficiency of read/write
- The File: File pointer, File control/access

Administrative

- HW2 posted
- Review `rock.c`

Abstraction: *File*

- **User view**
  - » Named collection of bytes (defined by user)
    - – Untyped or typed
    - – Examples: text, source, object, executables, application-specific
  - » Permanently and conveniently available
- **Operating system view**
  - » Map bytes as collection of blocks on physical non-volatile storage device
    - – Magnetic disks, tapes, NVRAM, battery-backed RAM
    - – Persistent across reboots and power failure

Preview: Files Attributes: *Meta-Data*

System information associated with each file:

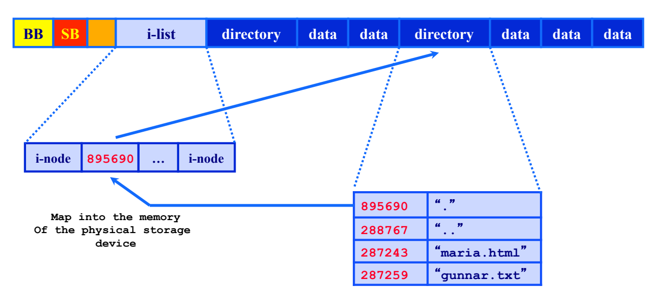
- *Name* – only information kept in human-readable form.
- Type – needed for systems that support different types.
- Location – pointer to file location on device/disk.
- Size – current file size.
- Protection bits – controls who can do reading, writing, executing.
- Time, date, and user identification – data for protection, security, and usage monitoring.
- Special file?
  - » Directory, Symbolic link… more about links shortly.

Meta-data is stored on disk:

- » Conceptually: meta-data can be stored as an array on disk (e.g., directory)

```
{atlas:maria:143} ls -lig ch11.ppt
231343 -rw-r--r--    1 profs      815616 Nov  4  2002 ch11.ppt
```


Preview: File System Expanded



Focus: File I/O Implementation

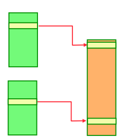
- **Create a file:**
  - » Find space in the file system, and add a directory entry.
- **Write in a file:**
  - » System call specifying name & information to be written.
    - – Given name, system searches directory structure to find file. System keeps *write pointer* to the location where next write occurs, updating as writes are performed. Update meta-data.
- **Read a file:**
  - » System call specifying name of file & where in memory to stick contents. Name is used to find file, and a *read pointer* is kept to point to next read position. (can combine write & read to *current file position pointer*). Update meta-data.

***Thought* Questions: How should files be accessed on `read()` and `write()`? How can we avoid reading/ searching *directory* on every read/write access?**

- **Cache open file descriptors.**
  - » HINT: we have file descriptors in UNIX, there is a *reason* for this! It just must be.
- **How do we do this procedurally?**

`open()`: Opening Files

- **Observation: Expensive to access files with full pathnames**
  - » On every read/write operation:
    - – Traverse directory structure
    - – Check access permissions
    - \
- **Idea!: Separate `open()` before first access.**
  - » User specifies mode: read and/or write
  - » Search directories once for filename and check permissions
  - » Diving in:
    - – Copy relevant meta-data to *system wide open file table* in memory (all open files, system wide)
  - » Return index in open file table to process (file descriptor)
  - » Process uses file descriptor to read/write to file
- **Multi-process support: via a separate *per-process-open file table* where each process maintains**
  - » Current file position in file (offset for read/write)
  - » Open mode

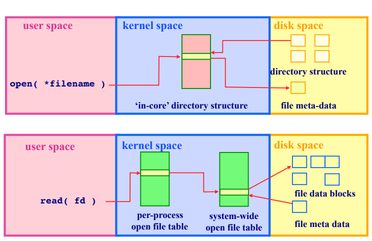


Multi-Process (User) File Access Support

- **Two level of internal tables:**
  - » **Per-process open file table**
    - – Tracks all files open by a process (process-centric information):
      - Current position pointer (on read/write) where did it read/write last, and access Rights
      - Indexes into the system-wide table for other sytem wide info.
  - » **System-wide *open* file table**
    - – Process Independent information
      - Location of file on disk
      - Access dates, file size
      - File open count (# processes accessing file)
        - » No one points to it, delete the entry (not cache anymore)

Mechanics: Accessing Files (Steps via `open()`)

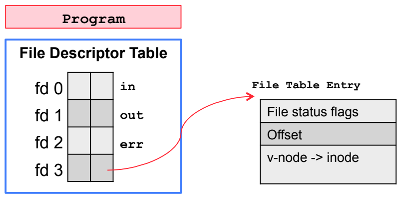
1. Search directory structure (part may be cached in memory)
2. Get meta-data, copy (if needed) into system-wide open file table
3. Adjust count of #processes that have file open in the system wide table.
4. Entry made in per-process open file table, w/ pointer to system wide table
5. Return pointer to entry in per-process file table to application



File Descriptor

- **POSIX it is an integer of type int**
  - » 0 for standard input (stdin)
  - » 1 for standard output (stdout)
  - » 2 for standard error (stderr)
  - » These are actually shell attributes, so higher level than the "kernel"
  - » POSIX standard should uses STDIN_FILENO, STDOUT_FILE_NO, and STDERR_FILE_NO.
- **Index to an entry in "kernel"-resident data structure called the file descriptor table containing all open files.**

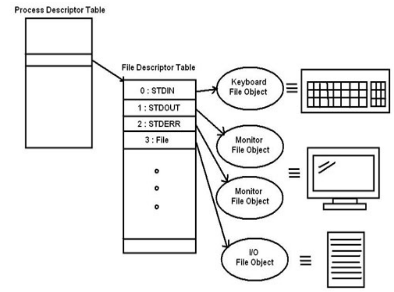
Big Picture



http://en.wikipedia.org/wiki/inode

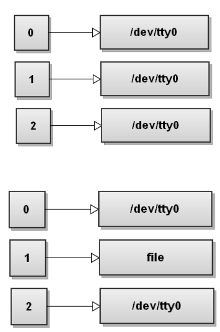
Preview: Redirection <, >, <<

- Shell gives you 3 file descriptors, 0-2
- You can get more (via open)
- You can copy file descriptors (duplicate)
- Initially 0-2 goes to the terminal (display -output, keyboard – input)



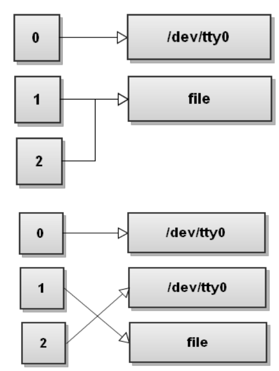
Redirection of file descriptors

- When you run a command at the shell prompt (1) it creates a new process that inherits the file descriptors of the parent, and (2) then executes the command that typed.
- Redirect standard output to a file (instead of terminal)
  - » Command > file
  - » Command 1> file [Command 2> file?]
- Redirect standard input from a file (instead of reading what you typed).
  - » Command < file



Redirection of file descriptors

- Redirect standard output and error
  - » Command &> file {bash}
  - » Command > file 2>&1
    - – Stdout goes to file, then
    - – 2>&1 : duplicates file descriptor 2 to be a copy of file descriptor 1
    - – So they now both goes to the file
- Order of redirection matters
  - » Command 2>&1 > file
    - – First copies stderr to go to same place as stdout (a terminal)
    - – Then moves stout to go to file



Redirection of file descriptors

- More on this later ..
- Lets go back to reading an writing.

What we got so far …

```
#include <fcntl.h>          /* for open oflags */
#include <unistd.h>         /* for read, and write */

int open(const char *path, int oflag, ... /* mode_t mode */ );
int read(int fd, char *buf, unsigned nbytes);
                            /* 0 if EOF, -1 error, o/w nbytes*/
ssize_t write(int fd, const void *buf, size_t nbytes);
```

- **path** – is the file name (path)
- **oflag** – is formed by ORing together one or more of the following constants from the <fcntl.h> header.
- And then we can read and write …
- Example Application for both read and write
  - » Copying a file does both!

OR'ing FLAGS

```
int fd = open("test.txt", O_WRONLY | O_TRUNC | O_CREAT, 0644);
```

- OR'ing:
  - » O_WRONLY | O_TRUNC | O_CREAT
- Options are combined using bit-wise OR operator, notice it is only one single |, the function is that it OR's a BIT MASK together (accumulates the 1 bits)

```
00000000000000000000000000000001       O_WRONLY
00000000000000000000010000000000       O_TRUNC
00000000000000000000001000000000       O_CREAT
---------------------------------- OR
00000000000000000000011000000001       O_WRONLY | O_TRUNC | O_CREAT
```


read/write and efficiency

- Evaluated by copyfile that reads from one file and writes to another:

```
while( nread = read( infile, buffer, BUFSIZE )
    if( write( outfile, buffer, nread ) < nread )
      close_return( outfile, infile );
```

- Time Command
  - » Granularity is a factor (50, 60, 100 ticks per second)
  - » User time (not system call)
  - » System time (kernel time, e.g. performing read() and writes())
  - » Real time (elapsed time from start to completion)
- What is an appropriate `BUFSIZE`?
  - » 1 byte?
  - » 512 bytes?
  - » 1000 bytes?

read/write and efficiency (cont)

- 68,307 byte file on computer running SVR 4 UNIX with block size 512

BUFSIZE	Real Time	User Time	System Time
1	24.49	3.13	21.16
64	0.46	0.12	0.33
512	0.12	0.02	0.08
4096	0.07	0.00	0.05
8192	0.07	0.01	0.05

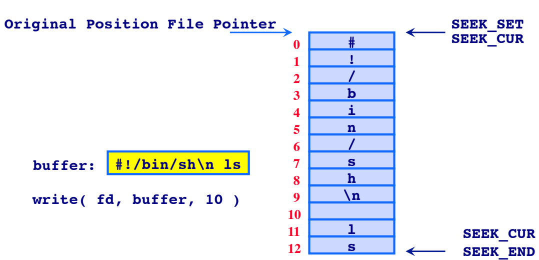
- 1 byte at a time bad performance
- Best performance when BUFSIZE is a multiple of block size
  - » Less system calls, reduces context switches

» (check book for more current data – same principle)

Where are we? Ask the File Pointer

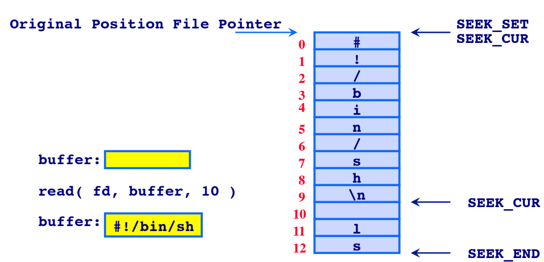
- Both `read()` and `write()` changes the file pointer.
- The pointer is incremented by exactly the number of bytes read or written.
- `lseek()` - repositions the file pointer for direct access to any part of the file

`write()` - File Pointer of `whereareyou.sc`



- Output file descriptor traditional 1 for standard output, better to use constants defined in `<unistd.h>` : `STDOUT_FILENO`.

`read()` - File Pointer



- Output file descriptor traditional 0 for standard output, better to use constants defined in `<unistd.h>` : `STDIN_FILENO`.
- Recall: Returns -1 on error, 0 end of file, or #bytes read
- SEEK_SET relative to beginning of file, rest is self explanatory!

lseek()

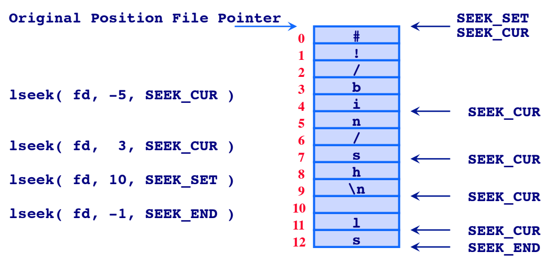
```
#include        <sys/types.h>
#include        <unistd.h>
long lseek( int fd, off_t offset, int whence );
```

- Repositions the offset of the file descriptor `fd` to argument `offset`.
- `Whence constants:`
  - » SEEK_SET (usually 0)
    - – The file pointer is set to `offset` bytes from beginning of file (default 0)
  - » SEEK_CUR (usually 1)
    - – The file pointer is set to its current location plus `offset` bytes (default 1, may be negative).
  - » SEEK_END (usually 2)
    - – The file pointer is set to the size of the file plus `offset` bytes.
- The return value is the new value of the pointer if the routine has executed successfully (`offset` of 0 returns current value of pointer, -1 indicates an error, negative offsets possible for non-regular files)

lseek: Simple Examples

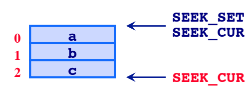
- **Random access**
  - » Jump to any byte in a file
- **Move to byte #16**
  - » `newpos = lseek( file_descriptor, 16, SEEK_SET );`
- **Move forward 4 bytes**
  - » `newpos = lseek( file_descriptor, 4, SEEK_CUR );`
- **Move to 8 bytes from the end**
  - » `newpos = lseek( file_descriptor, -8, SEEK_END );`

lseek - Examples



- lseek(fd, (off_t) -1, SEEK_END) - 1 bytes *before* the end of file
- OK to specify a position *beyond* the end of a file - next write creates a hole
- Not OK to specify a position *before* the beginning of the file

lseek - Hole (1) hole.c

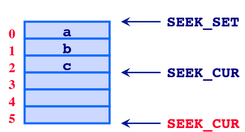



```
#include  <sys/types.h>
#include  <sys/stat.h>
#include  <fcntl.h>
#include  <unistd.h>

#define FILE MODE
    (S_IRUSR|S_IWUSR|S_IRGRP|S_IROTH)

int fd;
```

```
char buf1[]         = "abc";
char buf2[]         = "ABC";

int main()
{
if( (fd = creat( "hole.txt", FILE_MODE )) < 0 )
        perror( "creat error" );
if( write( fd, buf1, 3 ) != 3 )
        perror( "buf1 write error" );
if( lseek( fd, 6, SEEK_SET ) == -1 )
        perror( "lseek error" );
if( write( fd, buf2, 3 ) != 3 )
        perror( "buf2 write error" );
}
```

- OK to specify a position *beyond* the end of a file - next write creates a hole (see example, slightly different)
- Not OK to specify a position *before* the beginning of the file

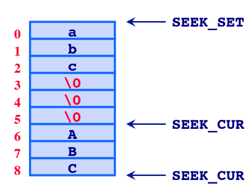
lseek - Hole (2)




```
char buf1[]         = "abc";
char buf2[]         = "ABC";

int main()
{
if( (fd = creat( "hole.txt", FILE_MODE )) < 0 )
        err_sys( "creat error" );
if( write( fd, buf1, 3 ) != 3 )
        err_sys( "buf1 write error" );
if( lseek( fd, 6, SEEK_SET ) == -1 )
        err_sys( "lseek error" );
if( write( fd, buf2, 3 ) != 3 )
        err_sys( "buf2 write error" );
}
```

- OK to specify a position *beyond* the end of a file - next write creates a hole
- Not OK to specify a position *before* the beginning of the file

lseek - Hole (3)




```
{cinnamon:ingrid:35} od -c hole.txt
0000000    a    b    c   \0   \0   \0    A    B    C
0000011
od -a
```

```
char buf1[]         = "abc";
char buf2[]         = "ABC";

int main()
{
if( (fd = creat( "hole.txt", FILE_MODE )) < 0 )
        err_sys( "creat error" );
if( write( fd, buf1, 3 ) != 3 )
        err_sys( "buf1 write error" );
if( lseek( fd, 6, SEEK_SET ) == -1 )
        err_sys( "lseek error" );
if( write( fd, buf2, 3 ) != 3 )
        err_sys( "buf2 write error" );
}
```

- subsequent write cause file to be extended
- All bytes that have not been written are read back as 0.

File Control - via `fcntl()`

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

int fcntl( int fd, int cmd );
int fcntl( int fd, int cmd, long arg );
int fcntl( int fd, int cmd, struct lock *ldata )
```

- Performs operations on an open file, pertaining to the `fd`, the file descriptor (changes properties of a file)
- Performs a variety of functions instead of having a single well-defined role (duplicates fd, gets info on them, sets info on them).
- Possible values of cmd is listed in `fcntl.h`
- Third parameter and its type depends on `cmd`

`cmd is IMPORTANT!`

fcntl: `cmd` – get/set file status flags

- F_GETFL
  - » Returns the current file status flags as set by `open()`.
  - » Access mode can be extracted from AND'ing the return value
    - – return_value & O_ACCMODE
      - Gets the access mode out of the string, so: it returns e.g. O_WRONLY
- F_SETFL
  - » Sets the file status flags associated with fd.
  - » Only O_APPEND, O_NONBLOCK and O_ASYNC may be set.
  - » Other flags are unaffected

File Status Flag	Description
O_RDONLY	open for reading only
O_WRONLY	open for writing only
O_RDWR	open for read & write
O_APPEND	append on each write
O_NONBLOCK	Non blocking mode
O_SYNC	wait for writes to finish
O_ASYNC	asynchronous I/O

fcntl: `cmd` – get/set file status flags

- Example 1: takes a single command line argument that specifies a file descriptor and prints out a descriptor of the file flags for that descriptor (p 85 Steven's)

```
{saffron} a.out 0 < /dev/tty      # stdin file descriptor
read only
{saffron} a.out 1 > tmp.foo       # stdout file descriptor
write only
{saffron} a.out 2  2>>temp.txt    # stderr file descriptor
write only, append
```


accmode.c
Example 1: fcntl - F_GETFL

```
#include <stdio.h>
#include <sys/types.h>
#include <fcntl.h>
#include <stdlib.h>   /* exit() */

int main( int argc, char *argv[] )
  {
  int accmode, val;

  if( argc != 2 )
        {
        fprintf( stderr, "usage: %s <descriptor#>", argv[0] );
        exit(1);
        }

  if( (val = fcntl( atoi(argv[1]), F_GETFL, 0 ) ) < 0 )
        {
        perror( "fcntl error for fd" );
        exit( 1 );
        }

  accmode = val & O_ACCMODE;
```



```
if( accmode == O_RDONLY )
        printf( "read only" );
  else if(accmode == O_WRONLY )
        printf( "write only" );
  else if( accmode == O_RDWR )
        printf( "read write" );
  else
        {
        fprintf( stderr, "unknown access mode" );
        exit(1);
        }

  if( val & O_APPEND )
        printf( ", append");
  if( val & O_NONBLOCK)
        printf(", nonblocking");
  if( val & O_SYNC )
        printf(", synchronous writes");
  putchar( '\n' );
  exit(0);
}
```


fcntl - FGET_FL & FSET_FL

```
#include <stdio.h>
#include <sys/types.h>
#include <fcntl.h>

/* flags are file status flags to turn on */
void set_fl( int fd, int flags )
  {
  int val;

  if( (val = fcntl( fd, F_GETFL, 0 )) < 0 )
        {
        perror( "fcntl F_GETFL error" );
        exit( 1 );
        }
  val |= flags;      /* turn on flags */
  if( fcntl( fd, F_SETFL, val ) < 0 )
        {
        perror( "fcntl F_SETFL error" );
        exit( 1 );
        }
  }
```

errno and perror()

- Unix provides a globally accessible integer variable that contains an error code number
- Error variable: errno – errno.h
- perror(" a string "): a library routine, not a system call

```
{atlas} more /usr/include/sys/*errno.h
.
.
.
#define EPERM           1       /* Operation not permitted */
#define ENOENT          2       /* No such file or directory */
#define ESRCH           3       /* No such process */
#define EINTR           4       /* Interrupted system call */
#define EIO             5       /* I/O error */
#define ENXIO           6       /* No such device or address */
.
.
.
```



```
#include <fcntl.h>
#include <unistd.h>
#include <stdio.h>

int main()
  {
  extern int errno;
  int fd;

  /* open file "ughugh" for reading */
  if( (fd = open( "ughugh.txt", O_RDONLY )) == -1 )
        {
        fprintf( stderr, "Error %d\n", errno );
        perror( "ugh" );
        }
  } /* end main */

{saffron:ingrid:57} gcc ugga.c -o ugga
{saffron:ingrid:57} ls
ugga ugga.c
{saffron:ingrid:57} ./ugga
Error 2
ugh: No such file or directory
```


Stepping Back: Why use system calls read()/write()/open()/exit()… ?

- Maximize performance
  - » IF you know exactly what you are doing
  - » No additional hidden overhead from stdio
- Control exactly what is written/read at what times
- File access system calls form basis for all input and output by UNIX programs

Alternatives: Library Calls: Standard I/O Library

`#include <stdio.h>`

- System calls are hard to program
  - » low-level, thinks of data only in a sequence of bytes
    - – file descriptors (recall it is an index to a kernel resident data structure)
    - – stream of bytes
  - » Less layers (more efficient, but harder to use)
- "Higher-Level" library
  - » programming-friendly interface
  - » automatic buffering

Library: `FILE *`

- `FILE *` construct instead of file descriptors
  - – a pointer or address to the top of an additional interface and management layer (the stdio file stream interface), which is stacked on top of an actual low level file descriptor on Unix-like systems.

The Standard IO Library

- `fopen,`
- `fclose,`
- `printf, fprintf, sprintf, scanf, fscanf, getc, putc, gets, fgets, etc.`
- `#include <stdio.h>`

Dwell Deeper: File Concept - An Abstract Data Type

- File Types
- File Operations
- File Attributes
- Internal File Structure

File Types

- Regular files (text or binary)
- Directory files (names and pointers of files)
- Character special files (used by certain devices)
- Block special files (typically disk devices)
- FIFOs (used for interprocess communication)
- Sockets (usually for network communication)
- Symbolic Links (points to another file)

File Mix on a Typical System

File Type	*Count*	*Percentage*
regular file	30,369	91.7%
directory	1,901	5.7
symbolic link	416	1.3
char special	373	1.1
block special	61	0.2
socket	5	0.0
FIFO	1	0.0

File Operations

- Creating a file
- Writing a file
- Reading a file
- Repositioning within a file
- Deleting a file
- Truncating a file

Files Attributes: Meta-Data

System information on disk associated with each file:

- Name – only information kept in human-readable form.
- Type – needed for systems that support different types.
- Location – pointer to file location on device/disk.
- Size – current file size.
- Protection bits – controls who can do reading, writing, executing.
- Time, date, and user identification – data for protection, security, and usage monitoring.
- Special file?
  - » Directory, Symbolic link, …
  - » Information about files are kept in the directory structure, which is maintained on the disk (later)

```
{atlas:maria:143} ls -lig ch11.ppt
231343 -rw-r--r--   1 profs     815616 Nov  4  2002 ch11.ppt
```


Obtaining File Information

Great for analyzing files.

- `stat(), fstat(), lstat()`
- Retrieve all sorts of information about a file
  - » Which device it is stored on
  - » Don't need access right to the file, but need search rights to directories in path leading to file
  - » Information:
    - – Ownership/Permissions of that file,
    - – Number of links
    - – Size of the file
    - – Date/Time of last modification and access
    - – Ideal block size for I/O to this file

stat, fstat, lstat

```
#include <sys/stat.h>
#include <unistd.h>
int stat( const char *file_name, struct stat *buf );
int fstat( int fd,               struct stat *buf );
int lstat( const char *file_name,struct stat *buf );
```

- `stat( ), fstat( )`
  - » Stats the file pointed to by *file_name* or by *fd* and fills in *buf.*
- `lstat( )`
  - » Same as `stat( )` except that the symbolic link is stated itself (i.e. do not follow the link).

struct stat

```
struct stat
  {
  dev_t     st_dev;     /* device num.           */
  dev_t     st_rdev;    /* device # special files */
  ino_t     st_ino;     /* i-node num.           */
  mode_t    st_mode;    /* file type, perms      */
  nlink_t   st_nlink;   /* num. of links         */
  uid_t     st_uid;     /* uid of owner          */
  gid_t     st_gid;     /* group-id of owner     */
  off_t     st_size;    /* size in bytes         */
  time_t    st_atime;   /* last access time      */
  time_t    st_mtime;   /* last mod. time        */
  time_t    st_ctime;   /* last stat chg time    */
  long      st_blksize; /* best I/O block size   */
  long      st_blocks;  /* # of 512 blocks used  */
  }
```


st_dev & st_rdev

- `st_dev` holds the device number of the *file system* where the file is located:
  - » usually a hard disk
- `st_rdev` holds the device number for a *special file.*
  - » A special file is used to describe a device (peripheral) attached to the machine:
  - » CD drives, keyboard, hard disk, microphone, etc.
  - » Special files are usually stored in `/dev`

st_mode

- File types (regular file, directory, socket, …)
- File permissions

st_mode: Getting the Type Information

- AND the `st_mode` field with `S_IFMT` to get the type bits.
- then test the result against:
  - » `S_IFREG` Regular file
  - » `S_IFDIR` Directory
  - » `S_IFSOCK` Socket
  - » etc.

Example

```
struct stat sbuf;
      :
if( stat( file, &sbuf ) == 0 )
  if( ( sbuf.st_mode & S_IFMT ) == S_IFDIR )
          printf( "A directory\n" );
```

Type Info. Macros

- Modern UNIX systems include test macros in `<sys/stat.h>` and `<linux/stat.h>`:
  - » `S_ISREG()` regular file
  - » `S_ISDIR()` directory file
  - » `S_ISCHR()` char. special file
  - » `S_ISBLK()` block special file
  - » `S_ISFIFO()` pipe or FIFO
  - » `S_ISLNK()` symbolic link
  - » `S_ISSOCK()` socket

Type Info. Macros: Example

```
struct stat sbuf;
         :
   if( stat(file, &sbuf ) == 0 )
      {
      if( S_ISREG( sbuf.st_mode ) )
            printf( "A regular file\n" );
      else if( S_ISDIR(sbuf.st_mode) )
            printf( "A directory\n" );
      else ...
      }
```


st_mode: Permission Code

owner group public
chmod 761 game

- Determines **who** can access and manipulate a directory or file
- **Mode of access**: read, write, execute
- Three classes of users (3 fields of 3 bits each)

			RWX
a) owner access	7	⇒	1 1 1
b) group access	6	⇒	1 1 0
c) public access	1	⇒	0 0 1

`drw-r—r---   maria profs 512 May 15 22:15 hello.txt`

- Group contains a set of users
  `chgrp mgroup game`

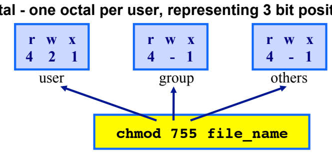
chmod shell command

`chmod [-options] modes file/directory`

- options ⇒ option: -R
- modes:
  - » Who? u|g|o|a
  - » Operator? =|+|-
  - » Permissions? r|w|x

Example:
`chmod u=rwx,g+w,o-w  maria.txt`

- » Octal - one octal per user, representing 3 bit positions



chmod and fchmod

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

int chmod( const char *path, mode_t mode ) ;
int fchmod( int fd, mode_t mode );
```

- Change permissions of a file.
- The mode of the file given by *path* or referenced by *fd* is changed.
- *mode* is specified by OR'ing the following.
  - S_ISUID, S_ISGID, S_ISVTX, S_I{R,W,X}{USR,GRP,OTH}
- Effective uid of the process must be zero (**superuser**) or must **match the owner** of the file.
- On success, zero is returned. On error, -1 is returned

chmod example

- Modify permission on files foo (666) and bar (600)

```
{atlas} ls -l foo bar
-rw------- 1 maria    0 Nov 15    15:43  bar
-rw-rw-rw- 1 maria    0 Nov 15    15:43  foo
```

- So that new state is

```
{atlas} ls -l foo bar
-rw-r--r-- 1 maria    0 Nov 15    15:43  bar
-rw-rwSrw- 1 maria    0 Nov 15    15:43  foo
```

- Group execute is listed as 'S' to set Group ID

Example: chmod()

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/stat.h>

int main(void)
   {
   struct stat statbuf;

   /* turn on set-group-ID and turn off group-execute */
   if( stat("foo", &statbuf) < 0 )
        {
        perror("stat error for foo" );
        exit(1);
        }
   if( chmod("foo",  (statbuf.st_mode & ~S_IXGRP) | S_ISGID) < 0 )
        {
        perror("chmod error for foo");
        exit(1);
        }
```



```
/* set absolute mode to "rw-r--r--" */
if( chmod("bar", S_IRUSR|S_IWUSR|S_IRGRP|S_IROTH) < 0)
        {
        perror("chmod error for bar");
        exit(1);
        }
   exit(0);
   }
```


chown, fchown, lchown

```
#include <sys/types.h>
#include <unistd.h>
int chown( const char *path, uid_t owner, gid_t group );
int fchown( int fd, uid_t owner, gid_t group );
int lchown( const char *path, uid_t owner, gid_t group );
```

- Change user ID of a file and the group ID of a file.
- Only the superuser may change the owner of a file.
- The owner of a file may change **the group** of the file to any group of which that owner is a member.
- When the owner or group of an executable file are changed by a non-superuser, the S_ISUID and S_ISGID mode bits are *cleared*.

st_uid: Users and Ownership: /etc/passwd

- Every file is owned by one of the system's users – identity is represented by the user-id (UID) of owner (st_uid in stat)
- Password file associated UID with system users.

`maria:x:65:20:M. Hybinette:/home/maria:/bin/ksh`

- login name
- [encrypted password]
- user ID
- group ID
- "real" name
- home directory
- command interpreter

/etc/group

- Information about system groups

`faculty:x:23:maria,eileen,dkl`

- group name
- [encrypted group password]
- group ID
- list of group members

Real uids

- The uid of the user who *started* the program is used as its *real uid*.
- The real uid affects what the program can do (e.g. create, delete files).
- For example, the uid of `/usr/bin/vi` is `root` (it resides in /usr/bin/):

```
{atlas:maria:371} ls -l /usr/bin/vi
-r-xr-xr-x 5 root bin 227828 Jun 19  2002 /usr/bin/vi*
```

- But when I use `vi`, its *real uid* is `maria` (not **`root`), so I can only edit my files.
- Every file has an owner and a group owner. The owner is specified by the `st_uid` member of the `stat` structure that we will talked about earlier.

**root is a special user who can modify every file in the system

Effective UID

Hypothetical Example (and why effective uids was introduced in the first place).

- Scenario: Passwords used to be stored in `/etc/passwd` file that we saw earlier. This file is owned by the user `root`.
- Suppose we want to *change* our password.
  - » Question: why not use `vi` and change the file directly?
    - – file /etc/passd
  - » Problem: only root can change the file
  - » Solution: we can contact root, then ask root to modify our password in the file.
  - » Command/program called `/usr/bin/passwd` that changes a file called `/etc/passwd` (one is an executable program and the other is a file)

Effective uids

- Normally executing program's ***effective uid*** is the same as the real uid, however sometimes a process may change to use the owner's ID of a file/program.
  - » the uid of the program *owner*
  - » e.g. the `passwd` program changes to use its effective uid (`root`) so that it can edit the `/etc/passwd` file
- The process determines its ***effective uid*** by looking at the file's mode flag (`st_mode`)
- This feature is used by many system tools, such as logging programs.

Real and Effective Group-ids

- There are also real and effective group-ids.
- Usually a program uses the ***real group-id*** (i.e. the ***group-id of the user***).
- Sometimes useful to use ***effective group-id*** (i.e. group-id of program ***owner***):
  - » e.g. software shared across teams

Extra File Permissions

- ***Octal Value Meaning***

Octal Value	Meaning
`04000`	Set user-id on execution. Symbolic: `--s --- ---`
`02000`	Set group-id on execution. Symbolic: `--- --s ---`
`01000`	Save-text-image (sticky bit) Symbolic: `--- --- --t`

- These specify that a program should use the effective user/group id during execution.
- For example:
  - »
```
$ ls -alt /usr/bin/passwd
-rwsr-xr-x 1 root root 25692 May 24...
```


Sticky Bit

- ***Octal*** ***Meaning***

Octal	Meaning
`01000`	Save text image on execution. Symbolic: `--- --- --t`

- This specifies that the program code should stay resident in memory after termination.
  - » this makes the start-up of the next execution faster
- Obsolete due to virtual memory.

`st_mode`: Permissions

- This field contains type and permissions (12 lower bits) of file in bit format.
- It is extracted by AND-ing the value stored there with various constants
  - » see `man stat`
  - » also `<sys/stat.h>` and `<linux/stat.h>`
  - » some data structures are in `<bits/stat.h>`

Getting Permission Information

- AND the `st_mode` field with one of the following masks and test for non-zero:

» S_IRUSR	0400	user read
S_IWUSR	0200	user write
S_IXUSR	0100	user execute
» S_IRGRP	0040	group read
S_IWGRP	0020	group write
S_IXGRP	0010	group execute
» S_IROTH	0004	other read
S_IWOTH	0002	other write
S_IXOTH	0001	other execute

- <sys/stat.h>

Getting Permission Information

- AND the `st_mode` field with one of the following masks and test for non-zero:

» S_IRUSR	0400	user read
S_IWUSR	0200	user write
S_IXUSR	0100	user execute
» S_IRGRP	0040	group read
S_IWGRP	0020	group write
S_IXGRP	0010	group execute
» S_IROTH	0004	other read
S_IWOTH	0002	other write
S_IXOTH	0001	other execute

- <sys/stat.h>

Example

```
struct stat sbuf;
    :
printf( "Permissions: " );
if( ( sbuf.st_mode & S_IRUSR ) != 0 )
    printf( "user read, " );
if( ( sbuf.st_mode & S_IWUSR ) != 0 )
    printf( "user write, " );
    :
```

- Or use octal values, which are easy to combine:

```
if( ( sbuf.st_mode & 0444 ) != 0 )
  printf( "readable by everyone\n" );
```


st_mode: Getting Mode Information

- AND the `st_mode` field with one of the following masks and test for non-zero:
  - » S_ISUID set-user-id bit is set
  - » S_ISGID set-group-id bit is set
  - » S_ISVTX sticky bit is set
- **Example:**

```
if( (sbuf.st_mode & S_ISUID) != 0 )
  printf( "set-user-id bit is set\n" );
```


The superuser

- Most system admin. tasks can only be done by the *superuser* (also called the *root* user)
- Superuser
  - » has access to all files/directories on the system
  - » can override permissions
  - » owner of most system files
- Shell command: `su <username>`
  - » Set current user to superuser or another user with proper password access

User Mask: umask

- Unix allows "masks" to be created to set permissions for "newly-created" directories and files.
- The umask command automatically sets the permissions when the user creates directories and files (umask stands for "user mask").
- Prevents permissions from being accidentally turned on (hides permissions that are available).
  - » Disables if setting stuff
- Set the bits of the umask to permissions you want to mask out of the file permissions.
- This process is useful, since user may sometimes forget to change the permissions of newly-created files or directories.

```
fd = open( path, O_CREAT, mode ) ⇒
  fd = open( path O_CREAT, (~umask) & mode)
```

umask (1)

- Defaults (executable must be manually set - after they are created)

File Type	Default Mode
Non-executable files	666
Directories	777

From this initial mode, Unix subtracts the value of the umask.

mask	Directory (777)	File (666)
0	7 (rwx)	6 (rw-)
1	6 (rw-)	6 (rw-)
2	5 (r-x)	4 (r--)
3	4 (r--)	4 (r--)
4	3 (-wx)	2 (-w-)
5	2 (-w-)	2 (-w-)
6	1 (--x)	0 (---)
7	0 (---)	0 (---)

umask: Calculations (2)

- If you want a file permission of 644 on a regular file, the umask would need to be 022 (turn of "write" permissions for `group` and `other`).

```
Default Mode              666
umask                    -022
New Allowable File Mode   644
```

- Bit level: new_mask = mode & ~umask (~ takes complement, i.e. flips 0's to 1's and flips 1's to 0's).

```
umask           = 000010010 = ----w--w = 0022

~umask          = 111101101
(default) mode  = 110110110 = rw-rw-rw = 0666
   new_mask     = 110010010 = rw-r--r- = 0644
```


umask (3)

- Common Settings:

mask	Directory (777)	File (666)
000 (public)	777 (rwx rwx rwx)	666 (rw- rw- rw-)
011 (public)	766 (rwx rw- rw-)	666 (rw- rw- rw-)
022 (write protected)	755 (rwx r-x r-x)	644 (rw- r-- r--)
007 (project private)	770 (rwx rwx ---)	660 (rw- rw- ---)
077 (private)	700 (rwx --- ---)	600 (rw- --- ---)

umask

```
#include <sys/types.h>
#include <sys/stat.h>
mode_t        umask( mode_t mask );
```

- Set file mode creation ***mask*** and returns the old value. ***mask*** is formed as the bitwise OR of any of the nine file permission constants from <sys/stat.h>: S_IRUSR, S_IWUSR, S_IXUSR, …
- There is no error return
- When creating a file, permissions are turned off if the corresponding bits in ***mask*** are set.
- Return value
  - This system call always succeeds and the previous value of the mask is returned.
  - "umask" shell command

Example: umask

```
int main(void)
   {
   umask(0);                                      /* --- --- --- */

   if( creat( "foo", S_IRUSR|S_IWUSR|S_IRGRP|S_IWGRP|S_IROTH|S_IWOTH ) < 0 )
         {           /* rw- rw- rw- **/
         perror("creat error for foo");
         exit(1);
         }

    umask( S_IRGRP|S_IWGRP|S_IROTH|S_IWOTH );     /* --- rw- rw- */
    if( creat( "bar", S_IRUSR|S_IWUSR|S_IRGRP|S_IWGRP|S_IROTH|S_IWOTH) < 0 )
         {            /* rw- rw- rw- */
          perror("creat error for bar");
          exit(1);
         }
   exit(0);
   }

{saffron:maria:68} ls -ltra foo bar
-rw-rw-rw-       1 maria   faculty          0 Apr  1 20:35 foo
-rw-------       1 maria   faculty          0 Apr  1 20:35 bar
```