CS631 - Advanced Programming in the UNIX Environment
–
Files and Directories

Department of Computer Science
Stevens Institute of Technology
Jan Schaumann
jschauma@stevens.edu
https://www.cs.stevens.edu/~jschauma/631/

Code Reading

HW#1

When reading code...

First understand *what* it does.

Then understand *why* it does it.

Only then pay attention to *how* it does it.

When reading code...

- compare source code and documentation; are they in sync?
- compare documentation and reality; are they in sync?
- review manual pages for system- and library calls made; are there (failure or success) cases unaccounted for?
- what follow-up questions do you have?

Note!

”More code” does not necessarily imply a ”better program”.

“One of my most productive days was throwing away 1,000 lines of code.”
Ken Thompson

Note!

”More comments” does not necessarily imply ”easier to understand”.

- avoid useless comments
- use descriptive variable- and function names
- comments easily become obsolete

Good comments describe *why*, not *what*.

Code Reading

HW#2

`stat(2)` family of functions

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

int stat(const char *path, struct stat *sb);
int lstat(const char *path, struct stat *sb);
int fstat(int fd, struct stat *sb);
```

Returns: 0 if OK, -1 on error

All these functions return extended attributes about the referenced file (in the case of *symbolic links*, `lstat(2)` returns attributes of the *link*, others return stats of the referenced file).

`stat(2)` family of functions

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

int stat(const char *path, struct stat *sb);
int lstat(const char *path, struct stat *sb);
int fstat(int fd, struct stat *sb);
```

Returns: 0 if OK, -1 on error

All these functions return extended attributes about the referenced file (in the case of *symbolic links*, `lstat(2)` returns attributes of the *link*, others return stats of the referenced file).

```
struct stat {
    dev_t     st_dev;       /* device number (filesystem) */
    ino_t     st_ino;       /* i-node number (serial number) */
    mode_t    st_mode;      /* file type & mode (permissions) */
    dev_t     st_rdev;      /* device number for special files */
    nlink_t   st_nlink;     /* number of links */
    uid_t     st_uid;       /* user ID of owner */
    gid_t     st_gid;       /* group ID of owner */
    off_t     st_size;      /* size in bytes, for regular files */
    time_t    st_atime;     /* time of last access */
    time_t    st_mtime;     /* time of last modification */
    time_t    st_ctime;     /* time of last file status change */
    long      st_blocks;    /* number of 512-byte* blocks allocated */
    long      st_blksize;   /* best I/O block size */
};
```

`struct stat`: `st_mode`

The `st_mode` field of the `struct stat` encodes the type of file:

- **regular** – most common, interpretation of data is up to application
- **directory** – contains names of other files and pointer to information on those files. Any process can read, only kernel can write.
- **character special** – used for certain types of devices
- **block special** – used for disk devices (typically). All devices are either *character* or *block special*.
- **FIFO** – used for interprocess communication (sometimes called *named pipe*)
- **socket** – used for network communication and non-network communication (same host).
- **symbolic link** – Points to another file.

Find out more in `<sys/stat.h>`.

struct stat: st_mode

Let's improve `simple-ls.c`.

```
$ ssh linux-lab
$ cc -Wall simple-ls.c
$ ./a.out ~jschauma/tmp/apue
.
..
stdout
file
[...]
$ $EDITOR simple-ls.c
$ cc -Wall simple-ls.c
$ ./a.out ~jschauma/tmp/apue
. (directory - directory)
.. (directory - directory)
stdout (character special - symbolic link)
[...]
```

`struct stat`: `st_mode`, `st_uid` and `st_gid`

Every process has six or more IDs associated with it:

real user ID real group ID	who we really are
effective user ID effective group ID supplementary group IDs	used for file access permission checks
saved set-user-ID saved set-group-ID	saved by `exec` functions

Whenever a file is *setuid*, set the *effective user ID* to `st_uid`. Whenever a file is *setgid*, set the *effective group ID* to `st_gid`. `st_uid` and `st_gid` always specify the owner and group owner of a file, regardless of whether it is setuid/setgid.

struct stat: st_mode

st_mode also encodes the file access permissions (S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH). Uses of the permissions are summarized as follows:

- To open a file, need execute permission on each directory component of the path

struct stat: st_mode

st_mode also encodes the file access permissions (S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH). Uses of the permissions are summarized as follows:

- To open a file, need execute permission on each directory component of the path
- To open a file with O_RDONLY or O_RDWR, need read permission

struct stat: st_mode

st_mode also encodes the file access permissions (S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH). Uses of the permissions are summarized as follows:

- To open a file, need execute permission on each directory component of the path
- To open a file with O_RDONLY or O_RDWR, need read permission
- To open a file with O_WRONLY or O_RDWR, need write permission

struct stat: st_mode

st_mode also encodes the file access permissions (S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH). Uses of the permissions are summarized as follows:

- To open a file, need execute permission on each directory component of the path
- To open a file with O_RDONLY or O_RDWR, need read permission
- To open a file with O_WRONLY or O_RDWR, need write permission
- To use O_TRUNC, must have write permission

struct stat: st_mode

st_mode also encodes the file access permissions (S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH). Uses of the permissions are summarized as follows:

- To open a file, need execute permission on each directory component of the path
- To open a file with O_RDONLY or O_RDWR, need read permission
- To open a file with O_WRONLY or O_RDWR, need write permission
- To use O_TRUNC, must have write permission
- To create a new file, must have write+execute permission for the directory

struct stat: st_mode

st_mode also encodes the file access permissions (S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH). Uses of the permissions are summarized as follows:

- To open a file, need execute permission on each directory component of the path
- To open a file with O_RDONLY or O_RDWR, need read permission
- To open a file with O_WRONLY or O_RDWR, need write permission
- To use O_TRUNC, must have write permission
- To create a new file, must have write+execute permission for the directory
- To delete a file, need write+execute on directory, file doesn't matter

struct stat: st_mode

st_mode also encodes the file access permissions (S_IRUSR, S_IWUSR, S_IXUSR, S_IRGRP, S_IWGRP, S_IXGRP, S_IROTH, S_IWOTH, S_IXOTH). Uses of the permissions are summarized as follows:

- To open a file, need execute permission on each directory component of the path
- To open a file with O_RDONLY or O_RDWR, need read permission
- To open a file with O_WRONLY or O_RDWR, need write permission
- To use O_TRUNC, must have write permission
- To create a new file, must have write+execute permission for the directory
- To delete a file, need write+execute on directory, file doesn't matter
- To execute a file (via exec family), need execute permission

access(2)

```
#include <unistd.h>

int access(const char *path, int mode);
```

Returns: 0 if OK, -1 on error

Tests file accessibility on the basis of the *real* uid and gid. Allows setuid/setgid programs to see if the real user could access the file without it having to drop permissions to do so.

The `mode` paramenter can be a bitwise OR of:

- `R_OK` – test for read permission
- `W_OK` – test for write permission
- `X_OK` – test for execute permission
- `F_OK` – test for existence of file

access(2)

```
$ cc -Wall access.c
$ ./a.out /etc/passwd
access ok for /etc/passwd
open ok for /etc/passwd
$ ./a.out /etc/master.passwd
access error for /etc/master.passwd
open error for /etc/master.passwd
$ sudo chown root a.out
$ sudo chmod 4755 a.out
$ ./a.out /etc/passwd
access ok for /etc/passwd
open ok for /etc/passwd
$ ./a.out /etc/master.passwd
access error for /etc/master.passwd
open ok for /etc/master.passwd
$
```

struct stat: st_mode

Which permission set to use is determined (in order listed):

1. If effective-uid == 0, grant access

struct stat: st_mode

Which permission set to use is determined (in order listed):

1. If effective-uid == 0, grant access
2. If effective-uid == `st_uid`
   2.1. if appropriate user permission bit is set, grant access
   2.2. else, deny access

struct stat: st_mode

Which permission set to use is determined (in order listed):

1. If effective-uid == 0, grant access
2. If effective-uid == `st_uid`
   2.1. if appropriate user permission bit is set, grant access
   2.2. else, deny access
3. If effective-gid == `st_gid`
   3.1. if appropriate group permission bit is set, grant access
   3.2. else, deny access

struct stat: st_mode

Which permission set to use is determined (in order listed):

1. If effective-uid == 0, grant access
2. If effective-uid == `st_uid`
   2.1. if appropriate user permission bit is set, grant access
   2.2. else, deny access
3. If effective-gid == `st_gid`
   3.1. if appropriate group permission bit is set, grant access
   3.2. else, deny access
4. If appropriate other permission bit is set, grant access, else deny access

struct stat: st_mode

Ownership of **new** files and directories:

- st_uid = effective-uid
- st_gid = ...either:
  - effective-gid of process
  - gid of directory in which it is being created

umask(2)

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

mode_t umask(mode_t numask);
```

Returns: previous file mode creation mask

`umask(2)` sets the file creation mode mask. Any bits that are *on* in the file creation mask are turned *off* in the file's mode.

Important because a user can set a default umask. If a program needs to be able to insure certain permissions on a file, it may need to turn off (or modify) the umask, which affects only the current process.

umask(2)

```
$ cc -Wall umask.c
$ umask 022
$ touch foo
$ ./a.out
$ ls -l foo*
-rw-r--r--  1 jschauma  staff  0 Sep 26 18:35 foo
-rw-r--r--  1 jschauma  staff  0 Sep 26 18:36 foo1
-rw-rw-rw-  1 jschauma  staff  0 Sep 26 18:36 foo2
-rw-------  1 jschauma  staff  0 Sep 26 18:36 foo3
```

chmod(2), lchmod(2) and fchmod(2)

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

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

Returns: 0 if OK, -1 on error

Changes the permission bits on the file. Must be either superuser or *effective uid* == st_uid. *mode* can be any of the bits from our discussion of st_mode as well as:

- S_ISUID – setuid
- S_ISGID – setgid
- S_ISVTX – sticky bit (aka “saved text”)
- S_IRWXU – user read, write and execute
- S_IRWXG – group read, write and execute
- S_IRWXO – other read, write and execute

chmod(2), lchmod(2) and fchmod(2)

```
$ rm foo*
$ umask 077
$ touch foo foo1
$ chmod a+rx foo
$ ls -l foo*
-rwxr-xr-x  1 jschaumann  staff  0 Sep 15 23:00 foo
-rw-------  1 jschaumann  staff  0 Sep 15 23:00 foo1
$ cc -Wall chmod.c
$ ./a.out
$ ls -l foo foo1
-rwsr--r-x  1 jschaumann  staff  0 Sep 15 23:01 foo
-rw-r--r--  1 jschaumann  staff  0 Sep 15 23:01 foo1
$
```

chown(2), lchown(2) and fchown(2)

```
#include <unistd.h>

int chown(const char *path, uid_t owner, gid_t group);
int lchown(const char *path, uid_t owner, gid_t group);
int fchown(int fd, uid_t owner, gid_t group);
```

Returns: 0 if OK, -1 on error

Changes st_uid and st_gid for a file. For BSD, must be superuser. Some SVR4's let users chown files they own. POSIX.1 allows either depending on _POSIX_CHOWN_RESTRICTED (a kernel constant).

owner or *group* can be -1 to indicate that it should remain the same. Non-superusers can change the st_gid field if both:

- effective-user ID == st_uid and
- *owner* == file's user ID and *group* == effective-group ID (or one of the supplementary group IDs)

chown and friends clear all setuid or setgid bits.

Directory sizes (on a system using UFS)

```
$ cd /tmp
$ mkdir -p /tmp/d
$ ls -ld /tmp/d
drwxr-xr-x  2 jschauma  wheel  512 Sep 26 19:35 /tmp/d
$ touch d/a d/b d/c d/d d/e d/f d/g
$ ls -ld /tmp/d
drwxr-xr-x  2 jschauma  wheel  512 Sep 26 19:35 /tmp/d
$ touch d/$(jot -b a 255 | tr -d '[:space:]')
$ ls -ld /tmp/d
drwxr-xr-x  2 jschauma  wheel  512 Sep 26 19:35 /tmp/d
$ touch d/$(jot -b b 255 | tr -d '[:space:]')
$ ls -ld /tmp/d
drwxr-xr-x  2 jschauma  wheel  1024 Sep 26 19:37 /tmp/d
$ rm /tmp/d/a*
$ ls -ld /tmp/d
drwxr-xr-x  2 jschauma  wheel  1024 Sep 26 19:37 /tmp/d
$
```

Directory sizes (on a system using HFS+)

```
$ cd /tmp
$ mkdir -p /tmp/d
$ cd /tmp/d
$ ls -ld
drwxr-xr-x  2 jschauma  wheel  68 Sep 24 18:52 .
$ touch a
$ ls -ld
drwxr-xr-x  3 jschauma  wheel  102 Sep 24 18:52 .
$ echo $((102 / 3))
34
$ touch c
$ ls -ld
drwxr-xr-x  4 jschauma  wheel  136 Sep 24 18:52 .
$ rm c
$ ls -ld
drwxr-xr-x  3 jschauma  wheel  102 Sep 24 18:52 .
$
```

Homework

Reading:

- manual pages for the functions covered
- Stevens Chap. 4.1 through 4.13

Playing:

- in your shell, set your umask to various values and see what happens to new files you create (example: Stevens # 4.3)
- Verify that turning off user-read permission for a file that you own denies you access to the file, even if group- or other permissions allow reading.

Midterm Assignment:

`https://www.cs.stevens.edu/~jschauma/631/f15-midterm.html`