WARNING
This lecture contains usages of the Papyrus and Comic Sans fonts.
Observer discretion is advised.

Everything is a File

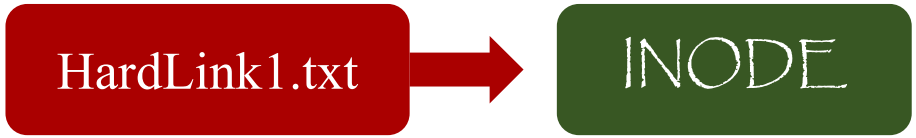
Benjamin Brewster

WARNING
Papyrus font on next slide

Files!

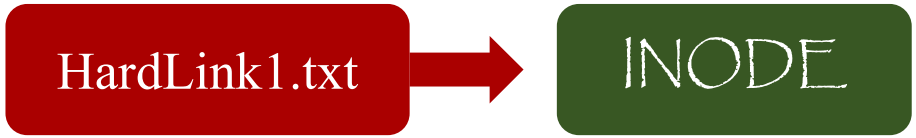
- Files are “inodes” with “hard links” that point to them.

- Inodes are maintained by the file system itself and contain:
  - Pointers to actual file data
  - All meta-information (size, permissions, etc)
  - A “reference count”: how many hard links point to the inode
  - A unique “inode number”

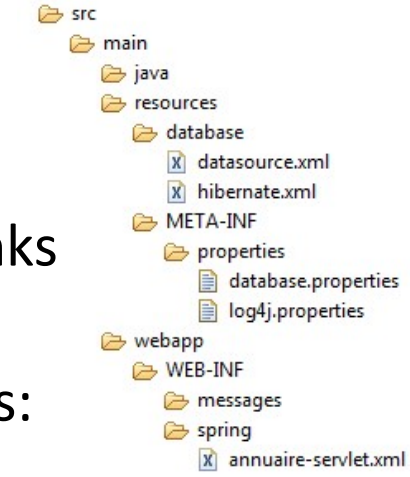


Hard Links

- A text entry in a file system directory that points to an inode
- Connects a **text filename** to an inode on disk



Directories!



- Directories are essentially text files that organize hard links hierarchically
- Create or remove directories with these UNIX commands:
  - mkdir, rmdir
- Because directories *are* files, you can also read the contents of a directory (in C):
  - opendir(), closedir(), readdir(), rewinddir()
- Directory hard link that represents itself: **.**
- Directory hard link that represents its parent directory: **..**

What's in a directory file?

```
$ vim .
" ============================================================================
" Netrw Directory Listing                                        (netrw v149)
"   /nfs/stak/faculty/b/brewsteb/codesamples
"   Sorted by      name
"   Sort sequence: [\/]$,\<core\%(\.\d\+\)\=\>,\.h$,\.c$,\.cpp$,\~\=\*$,*,\.o$,\
"   Quick Help: <F1>:help  -:go up dir  D:delete  R:rename  s:sort-by  x:exec
" ============================================================================
../
./
Curses.pdf
IntroToUnixShell.html
OnE1.txt
OnE1FAQ.txt
OnE1_sol.txt
Prog1.html
Prog1.test
Prog1FAQ.txt
Prog2.html
Prog2FAQ.txt
cursesDemo.c
index.html
```

Directories Can Be Read Like a File

```c
#include <stdio.h>
#include <string.h>
#include <dirent.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <unistd.h>

void main() {
  int newestDirTime = -1; // Modified timestamp of newest subdir examined
  char targetDirPrefix[32] = "brewsteb.rooms."; // Prefix we're looking for
  char newestDirName[256]; // Holds the name of the newest dir that contains prefix
  memset(newestDirName, '\0', sizeof(newestDirName));

  DIR* dirToCheck; // Holds the directory we're starting in
  struct dirent *fileInDir; // Holds the current subdir of the starting dir
  struct stat dirAttributes; // Holds information we've gained about subdir

  dirToCheck = opendir("."); // Open up the directory this program was run in

  if (dirToCheck > 0) { // Make sure the current directory could be opened
    while ((fileInDir = readdir(dirToCheck)) != NULL) { // Check each entry in dir
      if (strstr(fileInDir->d_name, targetDirPrefix) != NULL) { // If entry has prefix
        printf("Found the prefex: %s\n", fileInDir->d_name);
        stat(fileInDir->d_name, &dirAttributes); // Get attributes of the entry

        if ((int)dirAttributes.st_mtime > newestDirTime) { // If this time is bigger
          newestDirTime = (int)dirAttributes.st_mtime;
          memset(newestDirName, '\0', sizeof(newestDirName));
          strcpy(newestDirName, fileInDir->d_name);
          printf("Newer subdir: %s, new time: %d\n", fileInDir->d_name, newestDirTime);
        }
      }
    }
  }

  closedir(dirToCheck); // Close the directory we opened
  printf("Newest entry found is: %s\n", newestDirName);
}
```

This code searches for the most recently modified/created directory whose name matches a certain prefix

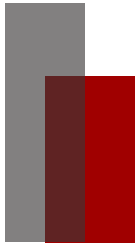
Note the funky single equals sign!

Creating Links

- When you create a file (using `touch`, a C function, etc.), an inode is allocated and a hard link is automatically created

- However, you can create multiple hard links to the same inode
  - So a file can appear in multiple directories at the same time!
  - The same file can also appear under different names
    - Even in the same directory
      - That's pretty weird

- To create a link, use the `ln` or `link` commands

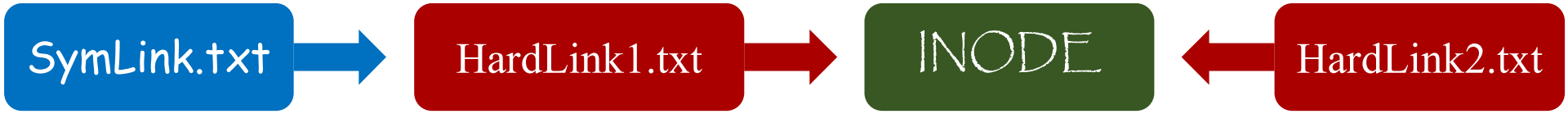


Removing Files in C

- Removing is approximately unlinking everything
  - The inode is garbage collected when ref count == 0
- One way to "remove" a file:
  - `unlink(file_name)`
  - can't unlink directories
- Another way to "remove" a file
  - `remove(file_name)`
  - unlike `unlink()`, remove will delete empty directories
  - if file, `remove()` is identical to `unlink()`
  - if directory, `remove()` is identical to `rmdir()`

Symbolic Link

- A symbolic link is like a Windows shortcut - it's not actually a file, it points to a hard link
- If you delete, rename, or move the hard link a symbolic link points to, the symbolic link become unusable
- You can symbolically link to directories or to files across the network
- Hard links are only available on the local file system

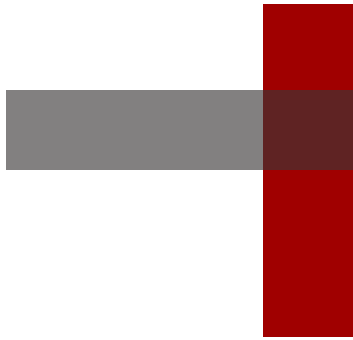


Symbolic Link Example

- I’m on a new server and want access to my home directory’s files stored on my original server

```
NewServer$ ln -s /nfs/rack/u2/b/brewsteb ./myFilesLink
NewServer$ cd myFilesLink
```

- I am now in my filesystem on the new server



Linking Example

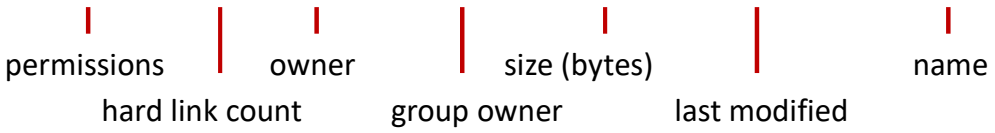
```
$ mkdir 1
$ mkdir 2
$ touch ./1/hardlink1
$ ln ./1/hardlink1 ./2/hardlink2
$ ln -s ./1/hardlink1 ./symlink
$ find -samefile ./1/hardlink1
./1/hardlink1
./2/hardlink2
$ ls -plaR
.:
drwxrwx---. 1 brewsteb upg57541 124 Aug 29 15:11 ./
drwxrwx---. 1 brewsteb upg57541 636 Aug 29 14:56 ../
drwxrwx---. 1 brewsteb upg57541  84 Aug 29 15:11 1/
drwxrwx---. 1 brewsteb upg57541  84 Aug 29 15:11 2/
lrwxrwxrwx. 1 brewsteb upg57541  13 Aug 29 15:11 symlink -> ./1/hardlink1
./1:
drwxrwx---. 1 brewsteb upg57541  84 Aug 29 15:11 ./
drwxrwx---. 1 brewsteb upg57541 124 Aug 29 15:11 ../
-rw-rw----. 2 brewsteb upg57541   0 Aug 29 15:11 hardlink1
./2:
drwxrwx---. 1 brewsteb upg57541  84 Aug 29 15:11 ./
drwxrwx---. 1 brewsteb upg57541 124 Aug 29 15:11 ../
-rw-rw----. 2 brewsteb upg57541   0 Aug 29 15:11 hardlink2
```

Find all files that share an inode with this hard link

Reference count: 2

What's in a directory?

```
% ls -pla
drwxr-xr-x  2 brewsteb upg22026   512 Jun 22 16:44 ./
drwxr-xr-x  8 brewsteb ftp       1024 Jun 22 15:46 ../
-rw-r--r--  1 brewsteb upg22026  1027 Jun 22 15:47 cursesDemo.c
-rw-r--r--  1 brewsteb upg22026 42558 Jun 22 15:55 Curses.pdf
-rw-r--r--  1 brewsteb upg22026  4208 Jun 22 16:24 index.html
-rw-r--r--  1 brewsteb upg22026 61554 Jun 22 15:46 IntroToUnixShell.html
-rw-r--r--  1 brewsteb upg22026    38 Jun 22 15:46 OnE1FAQ.txt
-rw-------  1 brewsteb upg22026   467 Jun 22 15:46 OnE1_sol.txt
-rw-r--r--  1 brewsteb upg22026   288 Jun 22 15:46 OnE1.txt
-rw-r--r--  1 brewsteb upg22026    38 Jun 22 15:55 Prog1FAQ.txt
-rw-r--r--  1 brewsteb upg22026  8098 Jun 22 15:46 Prog1.html
-rw-r--r--  1 brewsteb upg22026  7114 Jun 22 15:46 Prog1.test
-rw-r--r--  1 brewsteb upg22026    38 Jun 22 15:46 Prog2FAQ.txt
-rw-r--r--  1 brewsteb upg22026  4517 Jun 22 16:14 Prog2.html
```

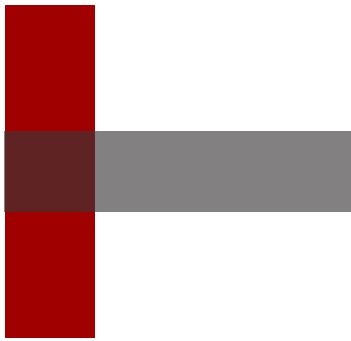


Possibilities include:

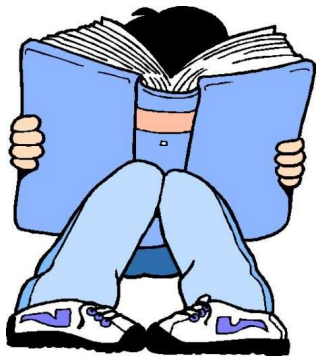
- Hard links
- Symbolic links
- Named pipes
- Device character special file
- Device block special file
- Named socket

Permissions

- Files in UNIX have access permissions for three classes of users:
  - **u**ser (the owner of the file - can set all permissions)
  - **g**roup
  - all **o**thers
- Three kinds of access permissions for each:
  - **r**ead
  - **w**rite
  - E**x**ecute
- Every file belongs to exactly one user and one group



Read Permissions



- File
  - The file's contents can be read
- Directory
  - The directory's contents can be read (ie, a listing of the files in the directory can be returned)

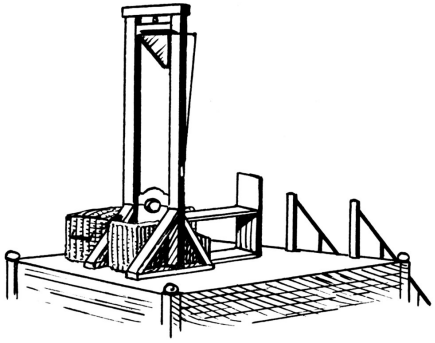
Write Permissions

- File
  - The file can be written to (ie, the contents of the file can be changed)
- Directory
  - Files can be added/removed/renamed/etc. to/in the directory

Execute Permissions

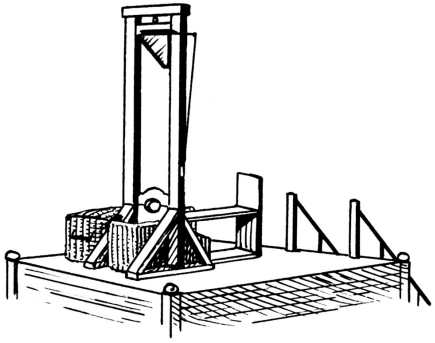
- File
  - The file can be executed (program, shell script)

- Directory
  - The directory can be cd'd into
  - File contents can be listed, and meta-information accessed, if name is known



Execute Permissions

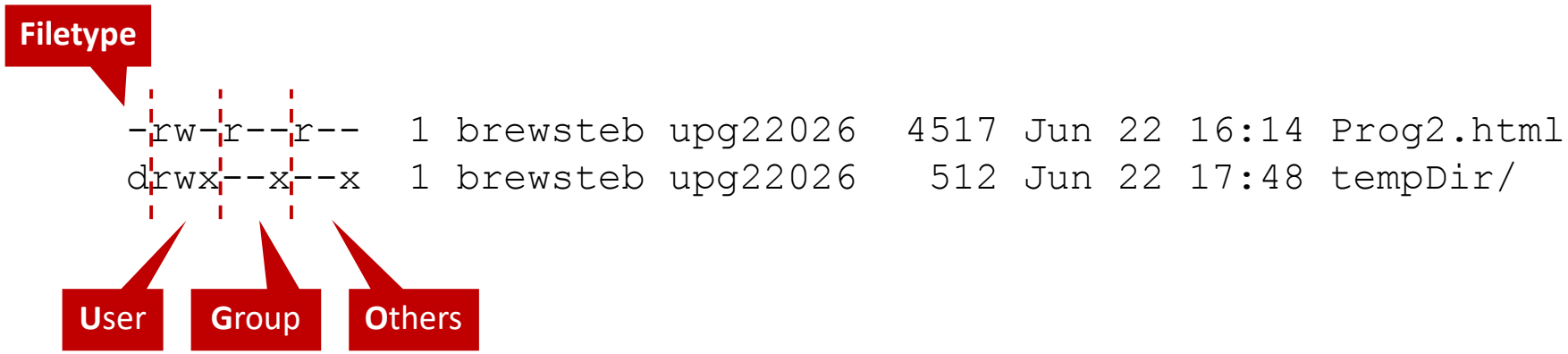
- File
  - The file can be executed (program, shell script)
- Directory
  - The directory can be cd'd into
  - File contents can be listed, and meta-information accessed, if name is known



chmod

- You can change the permissions on a file by using the `chmod` (**ch**ange **mod**e) command

- Here is a sample file listing (generated by `ls -pla`) of a file and dir:



chmod - octal math

- The traditional method of assigning permissions with chmod uses octal
- Why does everything in UNIX have to be so hard?
  - r = 4
  - w = 2
  - x = 1

```
-rw-r--r--   1 brewsteb upg22026  4517 Jun 22 16:14 Prog2.html
drwxr-xr-x   1 brewsteb upg22026   512 Jun 22 17:48 tempDir/
```

4 + 2 + 1 = 7

4 + 0 + 1 = 5

```
$ chmod 644 Prog2.html
```

Standard rights for a publicly viewable **webpage**

```
$ chmod 755 tempDir
```

Standard rights for a publicly viewable **directory**

Setting Permissions the Easy Way

- With this file:

```
----------  1 brewsteb upg22026  4517 Jun 22 16:14 Prog2.html
```

- Set permissions like this:

```
$ chmod u+rwx Prog2.html
-rwx------  1 brewsteb upg22026  4517 Jun 22 16:14 Prog2.html

$ chmod g+rx,o+rwx Prog2.html
-rwxr-xrwx  1 brewsteb upg22026  4517 Jun 22 16:14 Prog2.html

$ chmod o-w Prog2.html
-rwxr-xr-x  1 brewsteb upg22026  4517 Jun 22 16:14 Prog2.html
```

`umask`

- The *creation mask* setting defines the *default permissions* for new files.
- You can set this mask with the UNIX utility `umask`
- If no argument is included, `umask` displays the current setting

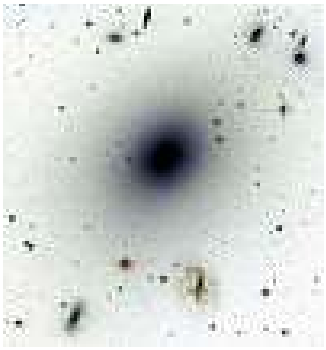
`umask`

- Since this is a mask we're talking about, it's inverted from what we saw with `chmod`

- Set the default permissions on new files to give the owner full privileges, while the group and all others do not have write privileges:

```
$ umask 022
```

- Note that execute permissions still are often not set by default, even if your umask indicates that they should



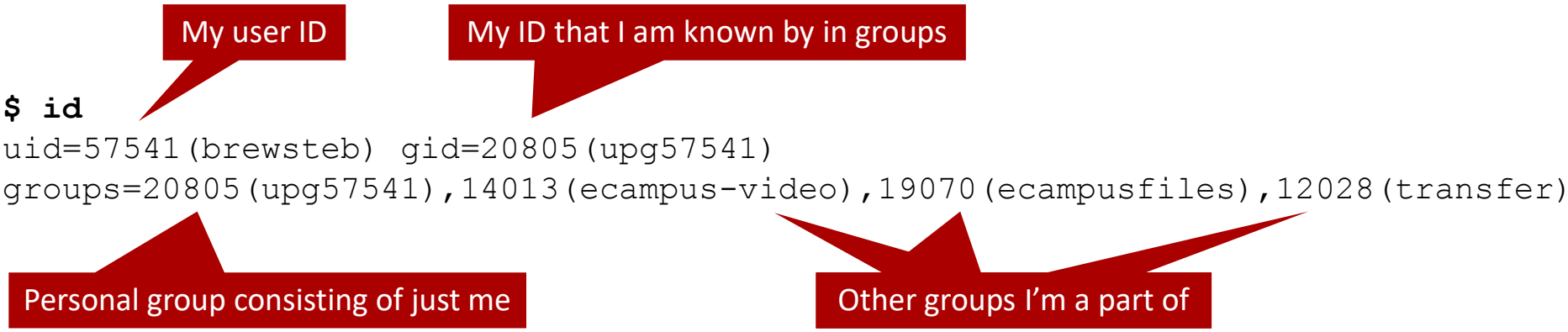
umask

```
$ umask
0007
$ touch tempfile
$ ls -pla tempfile
-rw-rw----. 1 brewsteb upg57541 0 Mar 30 08:17 tempfile
$ rm tempfile
rm: remove regular empty file ‘tempfile’? y
$ umask 022
$ umask
0022
$ touch tempfile
$ ls -pla tempfile
-rw-r--r--. 1 brewsteb upg57541 0 Mar 30 08:18 tempfile
```

Yes, there are actually four digits: the farthest left controls the SUID, SGID, and sticky bits, which are rarely used - you can always leave them off

Note that not all leading zeroes are necessary

What are UNIX groups?



- These groups are the same groups referred to when using the `chmod` command

Common UNIX Commands - Directories & Files

- **du** - Returns the total usage in kilobytes of the specified directory

```
$ du .
4       ./inodetest/1
4       ./inodetest/2
16      ./inodetest
8       ./permissionstests
96      .
```

Common UNIX Commands - Directories & Files

- **`df`** - Returns the total usage in kilobytes of filesystems

```
$ pwd
/nfs/stak/faculty/b/brewsteb/tempdir
$ df .
Filesystem                          1K-blocks        Used  Available  Use%  Mounted on
128.193.40.234:/stak_faculty/data  2147483648  1404256256  743227392   66%  /nfs/stak/faculty
```

Common UNIX Commands - Directories & Files

- **`stat`** - Get details about a file

```
$ stat testfile
  File: ‘testfile’
  Size: 9               Blocks: 8          IO Block: 262144 regular file
Device: 35h/53d Inode: 3238033175  Links: 1
Access: (0000/----------)  Uid: (57541/brewsteb)   Gid: (20805/upg57541)
Context: system_u:object_r:nfs_t:s0
Access: 2016-08-30 09:38:11.386951000 -0700
Modify: 2016-08-30 09:40:01.075970000 -0700
Change: 2016-08-30 09:40:11.156727000 -0700
 Birth: -
$ touch testfile
$ stat testfile
  File: ‘testfile’
  Size: 9               Blocks: 8          IO Block: 262144 regular file
Device: 35h/53d Inode: 3238033175  Links: 1
Access: (0000/----------)  Uid: (57541/brewsteb)   Gid: (20805/upg57541)
Context: system_u:object_r:nfs_t:s0
Access: 2016-08-30 11:19:33.386465000 -0700
Modify: 2016-08-30 11:19:33.386465000 -0700
Change: 2016-08-30 11:19:33.386480000 -0700
 Birth: -
```

Timestamp types

- **Access:** When file was last read
- **Modify:** When file contents were last modified
- **Change:** When meta data about file was last changed (renaming, permissions, etc.)
- **Birth:** Creation date of file (unsupported on Linux, but works on BSD & Windows)

Common UNIX Commands - Directories & Files

- **touch** - Create files and modify time stamps

```
$ ls -l
$ touch testfile
$ ls -l
-rw-rw----. 1 brewsteb upg57541 0 Aug 30 12:02 testfile
$ echo "testtext" > testfile
$ ls -l
-rw-rw----. 1 brewsteb upg57541 9 Aug 30 12:02 testfile
$ touch -d 20120101 fakefile
$ ls -l
-rw-rw----. 1 brewsteb upg57541 0 Jan  1  2012 fakefile
-rw-rw----. 1 brewsteb upg57541 9 Aug 30 12:02 testfile
$ touch -r fakefile testfile
$ ls -l
-rw-rw----. 1 brewsteb upg57541 0 Jan  1  2012 fakefile
-rw-rw----. 1 brewsteb upg57541 9 Jan  1  2012 testfile
```

- Security warning: this is how easy it is to modify the Access and Modify values!
- Only the “Change” value remains unchanged
- You can also arbitrarily update “Change” by setting the system time (with root) to whatever you want, running these commands, then changing the time back

Standard Directories

- Root dir:
  - `/`
- Home dir:
  - `~`
- Bad idea:
  - `rm -rf /*`

Easier to delete everything than you might think!

If you want to delete all of the files in your current directory, and all directories underneath, the command is:

$ rm -rf ./*

I know because I've done it. :(