Lecture 18: Files and Directories

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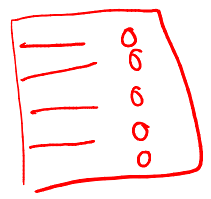
The file abstraction

- File – linear array of bytes, stored persistently
  - Identified with file name (human readable) and a OS-level identifier (“inode number”)
  - Inode number unique within a file system
- Directory contains other subdirectories and files, along with their inode numbers
  - Stored like a file, whose contents are filename-to-inode mappings



Directory tree

- Files and directories arranged in a tree, starting with root ("/")

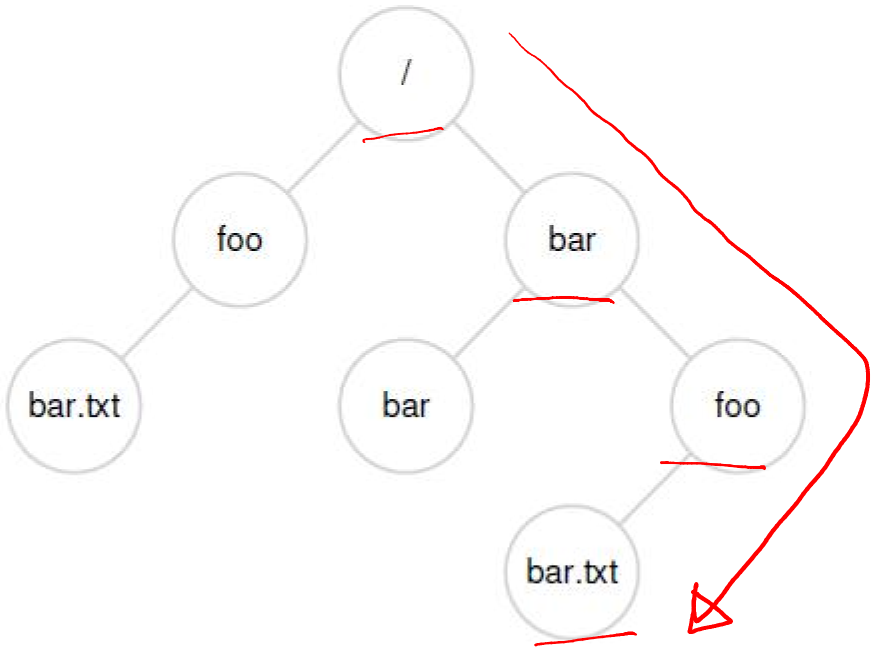


Figure 39.1: **An Example Directory Tree**

Operations on files (1)

- Creating a file
  - `open()` system call with flag to create
  - Returns a number called “file descriptor”

```
int fd = open("foo", O_CREAT|O_WRONLY|O_TRUNC, S_IRUSR|S_IWUSR);
```

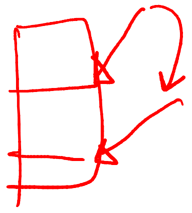
- Opening a file
  - Existing files must be opened before they can be read/written
  - Also uses open system call, and returns fd

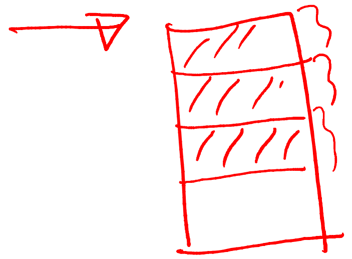
open( )

- All other operations on files use the file descriptor
- `close()` system call closes the file

Operations on files (2)

- Reading/writing files: `read()`/`write()` system calls
  - Arguments: file descriptor, buffer with data, size
- Reading and writing happens sequentially by default
  - Successive read/write calls fetch from current offset
- What if you want to read/write at random location
  - `lseek()` system call lets you seek to random offset
- Writes are buffered in memory temporarily, so `fsync()` system call flushes all writes to disk
- Other operations: rename file, delete (unlink) file, get statistics of a file





Operations on directories

- Directories can also be accessed like files
  - Operations like create, open, read, close
- For example, the "ls" program opens and reads all directory entries
  - Directory entry contains file name, inode number, type of file (file/directory) etc.

```
int main(int argc, char *argv[]) {
    DIR *dp = opendir(".");
    assert(dp != NULL);
    struct dirent *d;
    while ((d = readdir(dp)) != NULL) {
        printf("%lu %s\n", (unsigned long) d->d_ino, d->d_name);
    }
    closedir(dp);
    return 0;
}
```

Hard links

- Hard linking creates another file that points to the same inode number (and hence, same underlying data)
- If one file deleted, file data can be accessed through the other links
- Inode maintains a link count, file data deleted only when no further links to it
- You can only unlink, OS decides when to delete

```
prompt> echo hello > file
prompt> cat file
hello
prompt> ln file file2
prompt> cat file2
hello
```

$$\begin{tikzcd} \text{file} \arrow[r] & \boxed{\text{hello}} \\ \text{file 2} \arrow[ur] & \end{tikzcd}$$

```
prompt> ls -i file file2
67158084 file
67158084 file2
prompt>
```

```
prompt> rm file
removed 'file'
prompt> cat file2
hello
```

Soft links or symbolic links

- Soft link is a file that simply stores a pointer to another filename

```
prompt> ls -al
drwxr-x---   2 remzi remzi   29 May  3 19:10 ./
drwxr-x--- 27 remzi remzi 4096 May  3 15:14 ../
-rw-r-----   1 remzi remzi    6 May  3 19:10 file
lrwxrwxrwx   1 remzi remzi    4 May  3 19:10 file2 -> file
```

- If the main file is deleted, then the link points to an invalid entry: dangling reference

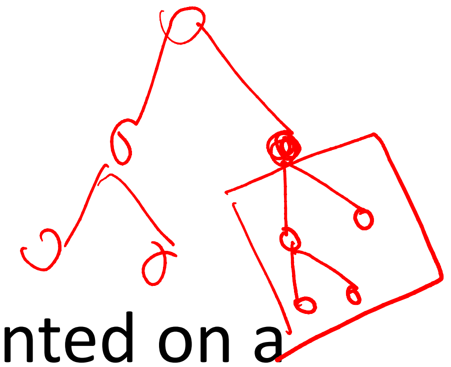
```
prompt> echo hello > file
prompt> ln -s file file2
prompt> cat file2
hello
prompt> rm file
prompt> cat file2
cat: file2: No such file or directory
```

Mounting a filesystem

- Mounting a filesystem connects the files to a specific point in the directory tree

```
prompt> mount -t ext3 /dev/sda1 /home/users

prompt> ls /home/users/
a b
```



- Several devices and file systems are mounted on a typical machine, accessed with `mount` command

```
/dev/sda1 on / type ext3 (rw)
proc on /proc type proc (rw)
sysfs on /sys type sysfs (rw)
/dev/sda5 on /tmp type ext3 (rw)
/dev/sda7 on /var/vice/cache type ext3 (rw)
tmpfs on /dev/shm type tmpfs (rw)
AFS on /afs type afs (rw)
```

Memory mapping a file

- Alternate way of accessing a file, instead of using file descriptors and read/write syscalls
- mmap() allocates a page in the virtual address space of a process
  - "Anonymous" page: used to store program data
  - File-backed page: contains data of file (filename provided as arg to mmap)
- When file is mmaped, file data copied into one or more pages in memory, can be accessed like any other memory location in program