Unix System Programming

Directories & Continuation

Overview

Last Week:

- Efficiency read/write
- The File
- File pointer
- File control/access
- Permissions, Meta Data, Ownership, umask, holes

This Week:

- How to program with directories more
  - » Reading: (finish Ch 4, skim Ch 5 IO Library (skim), Ch 6 (skim)).
- Repeat looking at the UNIX file system (and structure)
- Links

Outline

- Directory implementation
- UNIX file system
- Links
- Subdirectory creation
- "," and ".."
- `mkdir() & rmdir()`
- Reading directories
- `chdir() & getcwd()`
- Walking over directories
- `telldir() & seekdir()`
- `scandir()`

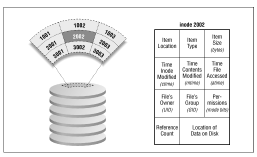
Directory Implementation

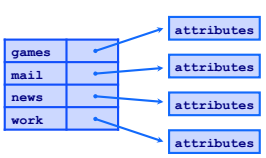
- A UNIX directory is a file:
  - » owner, group owner, size, access, permissions, etc
  - » many file operations can be used on directories
- Differences between file/directory:
  - » modern UNIXs have special directory operations
    - – e.g. `opendir(), readdir()`

Directory Implementation

- Directory system function: Maps ASCII names onto what is needed to locate the data
- Where do we store the file's attributes (Meta Data)?
  - » Option 1: In a simple directory: fixed sized entries attributes stored with the directory entry : MS DOS/Windows approach (start & end of data o file).
  - » Option 2: Directory in each entry just refers to an i-node (UNIX implementation) that contains the attributes (and pointer to actual data).

games	attributes
mail	attributes
news	attributes
work	attributes





Directory Structure

- A directory "file" in UNIX is a sequence of lines; each line holds an i-node number (index-node) and a file name

895690	"."
288767	".."
287243	"maria.html"
287259	"gunnar.txt"

- The data is stored as binary so we cannot simply `cat` to view it:
  - » but some UNIXs allow an "octal dump" (other formats also available) :

```
{atlas:maria:187} od -c .
0000000  \0  \r 252 312  \0  \f  \0 001   .  \0  \0  \0  \0 004   g 377
0000020  \0  \f  \0 002   .   .  \0  \0  \0 004   b 013  \0 024  \0  \n
0000040   m   a   r   i   a   .   h   t   m   l  \0  \0  \0 004   b 033
0000060  \0 024  \0  \n   g   u   n   n   a   r   .   t   x   t  \0  0
```

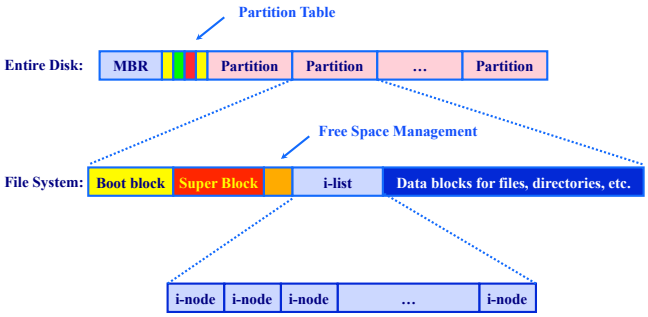
Something about i-nodes.

- "ls -i" lists the inode of a file

```
{nike:maria:22} ls -lai
total 12
23335653 drwxr-xr-x.  3 maria users  4096 Sep 16 11:59 .
23199745 drwxr-x---. 18 maria apache 4096 Sep 16 11:48 ..
23594400 drwxr-xr-x.  2 maria users  4096 Sep 16 11:59 adir
23335656 -rw-r--r--.  1 maria users     0 Sep 16 11:59 afile
```

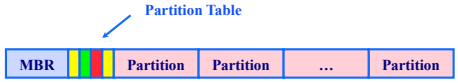
- {nike:maria:36} cd / ; ls -lai | sort -n -k 1
  - » Across partitions Inode numbers could repeat
  - » Inodes are unique per partition
- Find . –inum xxxx –delete (danger)
- Df

Big Picture: The Unix File Structure



Entire Disk & Booting Computer

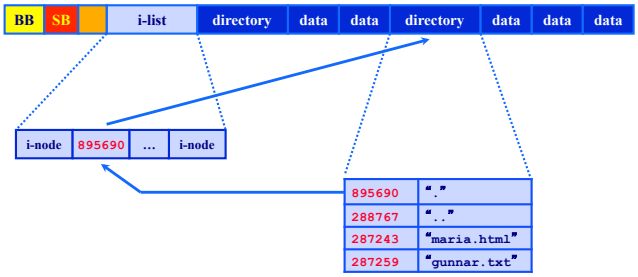
- Disk is divided into 1+ partitions: one file system per partition
- Master Boot Record (typically sector 0) MBR- Pentium
  - » first sector on disk
  - » used to boot computer
- Partition Table
  - » staring and ending address of each partition
- "A program (e.g. the system Basic Input Output System or BIOS for Pentiums)" reads in and executes the MBR
  - » MBR searches for first active partition (noted in the partition table)
  - » reads in its first block (the boot block) and executes it.



Partition Layout

- Boot block:
  - » contains a hardware specific program that is called automatically to load "UNIX" at system startup time (loads OS in kernel space)
- Super block:
  - » file system type, #blocks in file system
- Free space management (two lists):
  - » a chain of free data block numbers
  - » a chain of free i-node numbers
- i-list/i-node table:
  - » administrative information about a file (meta-data: name, type, location, size, protection bits, …) structured into an array: inode table or simply the i-list
  - » An i-node number:
    - – uniquely identifies a file in a file system
    - – is an index to the i-node table

File System Expanded



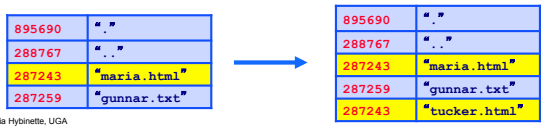
UNIX Directories: *Tree-Structured (not three)*

- Directory listing contains <name, index>, but a name can be directory, making branches.
  - » Directory is stored and treated like a file
  - » Special bit set in meta-data (attributes) for directories
    - – User programs can read directories (stat, fcntl).
    - – Only system programs can write directories
  - » Specify full pathname by separating directories and files with special characters (e.g., \ or /)
- Special directories
  - » Root '/' : Fixed index for meta-data (e.g., 2)
  - » This directory: .
  - » Parent directory: ..
- Example: `mkdir /a/b/c`
  - » Read meta-data 2 '/' (by default 2 is root in linux), look for "a": find <"a", 5>
  - » Read 5, look for "b": find <"b", 9>
  - » Read 9, verify no "c" exists; allocate c and add "c" to directory

Acyclic-Graph Directories

- More general than tree structure
  - » Add connections across the tree (no cycles)
  - » Create links from one file (or directory) to another
- Hard link: "`ln a b`" ("a" must exist already)
  - » Idea: Can use name "a" or "b" to get to same file data
  - » Implementation: Multiple directory entries point to same meta-data

```
link( "maria.html", "tucker.html" );
```



Links - Outline

- Why Links?
- Creating a Link
- Seeing Links
- Removing a Link
- Symbolic Links
- Implementation

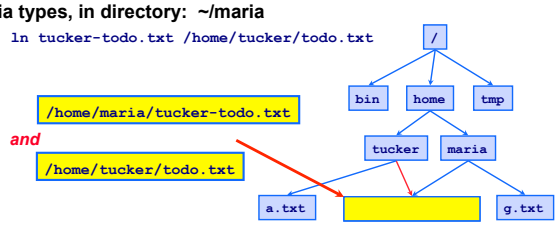
Why Links?

- A link is a pointer to a file
- Useful for sharing files;
  - » A file can be shared by giving each person their own link (pointer to it)

```
ln <existing-file> <new-pointer>
```

- Maria types, in directory: ~/maria

```
ln tucker-todo.txt /home/tucker/todo.txt
```



What is a Link?

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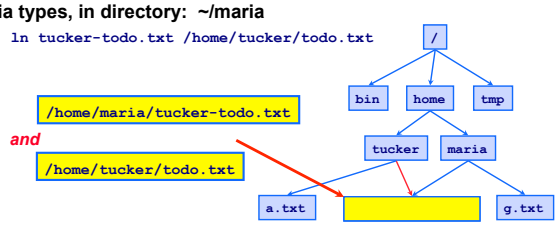


Creating Links

- Changes to a file affect every link:

```
{atlas} cat file_a
This is file A.
{atlas} ln file_a file_b
{atlas} cat file_b
This is file A
{atlas} echo "appending this to b" >> file_b
{atlas} cat file_b
This is file A.
appending this to b
{atlas} cat file_a
This is file A.
appending this to b
```


Seeing Links

- Compare status information :

```
{saffron:maria:104} ls -l file_a file_b file_c
-rw-r--r-- 2 maria 36 May 24 10:52 file_a
-rw-r--r-- 2 maria 36 May 24 10:52 file_b
-rw-r--r-- 1 maria 16 May 24 10:55 file_c
File mode, # links, owners name, group name, #bytes, date,
  pathname
```

- Look at i-node number:

```
{saffron:maria:105} ls -i file_a file_b file_c
3534 file_a   3534 file_b
5800 file_c
```

- Directories may appear to have more links:

```
{saffron:maria:106} ls -ld dir
drwxr-xr-x  2 maria   users      68 Apr  7 17:57 dir/
{saffron:maria:107} mkdir dir/hello
{saffron:maria:108} ls -ld dir
drwxr-xr-x  3 maria   users      68 Apr  7 17:58 dir/
```

- This is because subdirectories (e.g. directories inside `dir/`) have a link back to their parent.

Removing a Link

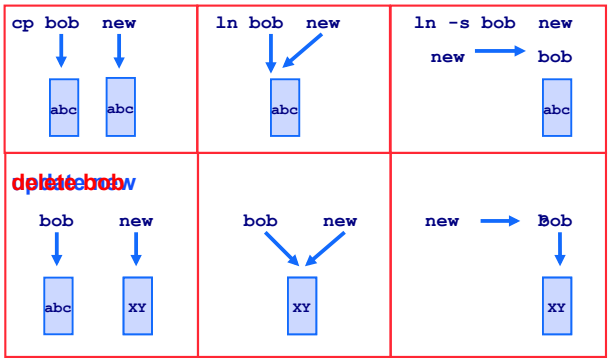
- Removing or deleting a link does not necessarily remove the file
- Only when the file *and* every link is gone will the file be removed

Symbolic Links

- The links described so far are *hard links*
  - » A hard link is a pointer to a file which must be on the same file system
- A symbolic link is an *in-direct pointer* to a file
  - » Stores the pathname of the file that it points to
  - » Symbolic links can link across file systems
- Symbolic links are listed differently:

```
{saffron:ingrid:62} ln -s dir ~/unix/d/Sdir
{saffron:ingrid:62} ls -lFd dir ~/unix/d/Sdir
lrwxr-xr-x 1 ingrid  staff   3 1 Apr 21:51 /home/ingrid/unix/d/Sdir@ -> dir
drwxr-xr-x 3 ingrid  staff 102 1 Apr 21:39 dir/
```

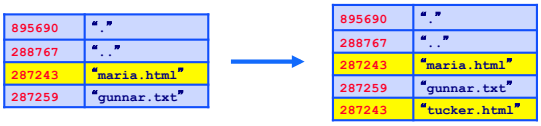

Link Creation, Update & Removal



link()

```
#include        <unistd.h>
long link( const char *oldpath, const char *newpath );
```

- Meaning of:
  - » `link( "maria.html", "tucker.html" );`



unlink()

- clears directory record
  - » usually means that the i-node number is set to 0
  - » the file may not be affected
- The i-node is only deleted when the last link to it is removed; the file data blocks are deleted/reclaimed when there are no processes having the file opened.

Example unlink

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

int main(void)
   {
   if( open( "temp", O_RDWR ) < 0 )
         {
         perror( "open error" );
         exit( 1 );
         }
   if( unlink( "temp" ) < 0 )
         {
         perror( "unlink error " );
         exit( 1 );
         }
   printf( "file temp is unlinked\n" );
   exit( 0 );
   }
```

```
{saffron} make unlinktemp
gcc unlinktemp.c -o unlinktemp
{saffron} ./unlinktemp
file temp is unlinked
{saffron} ./unlinktemp
open error: No such file or directory
```

remove()

```
#include        <stdio.h>
int remove( const char *pathname );
```

- C Library function (not a system call)
- Delete a name and possibly the file it refers to.
  - » It calls `unlink()` for files and `rmdir()` for directories

rename()

```
#include        <stdio.h>
int rename( const char *oldpath, const char *newpath );
```

- Changes the names of `oldpath` to `newpath` (for both directories and files)
- If `oldpath` is open or is a nonexistent file, or if `newpath` names a file that already exists, then the action of `rename()` is implementation dependent.

symlink()

```
#include        <stdio.h>
int symlink( const char *oldpath, const char
  *newpath );
```

- Creates a symbolic link named `newpath` which contains the string `oldpath`
- Symbolic links are interpreted at run-time
- Dangling link - may point to a nonexisting file
- If `newpath` exists it will not be overwritten

readlink()

```
#include        <stdio.h>
int readlink( const char *path, char buf, size_t
  bufsize );
```

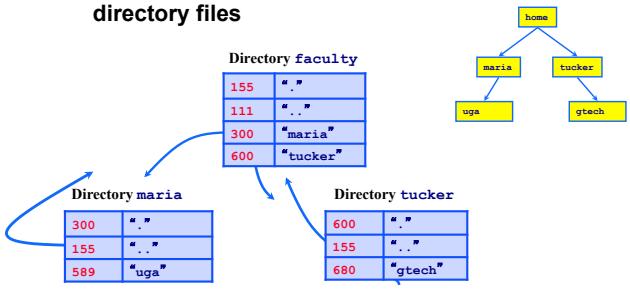
- Read value of a symbolic link (does not follow the link)
  - » Places the contents of the symbolic link path in the buffer buf which has size bufsize
  - » Does not append a NULL character to buf
- Return value
  - » The count of characters placed in the buffer if it succeeds
  - » -1 on error

Subdirectory Creation

- shell command "`mkdir uga`" causes
  - » the creation of uga directory file and new i-node
  - » an i-node number and name are added to the parent directory

"." and ".."

- "." and ".." are stored as ordinary file names with i-node numbers pointing to the correct directory files



mkdir()

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

int mkdir( char *path, mode_t mode );
```

- Creates a new directory with the specified mode
- Returns 0 if OK and -1 on error
- "." and ".." entries are added automatically
- mode must include `execute` permissions so user(s) can use cd
  - » e.g. `0755`

rmdir()

```
#include        <unistd.h>

int rmdir( char *pathname );
```

- Deletes an empty directory
- Returns 0 if OK, -1 on error
- Will delay until other processes have stopped using the directory

Reading Directories

- Directories can be read by any one who have access
- Directories can be modified only by the kernel
  - » Note we may be able to create new files and remove files from a directory

Reading Directories

```
#include        <sys/types.h>
#include        <dirent.h>
DIR *opendir( char *pathname );

struct dirent *readdir( DIR *dp );

void rewinddir( DIR *dp );

int closedir( DIR *dp );
```

returns a pointer if OK NULL on error

returns a pointer if OK NULL at end or on error

returns 0 if OK -1 on error

- `DIR` is a directory stream (similar to FILE)
  - » when a directory is first opened the stream points to the first entry in the directory
- `dirent` next slide

dirent

```
struct dirent
  {
  long d_ino;                 /* i-node number */
  char d_name[NAME_MAX + 1];  /* null terminated file name
  */
  off_t d_off;                /* offset to next record */
  unsigned short d_reclen;    /* record length */
  }
```

- NAME_MAX not available on all UNIXs, may need to use a function to define it (`fpathconf` defined in `unistd.h`) - gets configurable pathname variables)

Example: listdir.c

```
#include <stdio.h>
#include <dirent.h>

int main( void )
   {
   DIR *dp;
   struct dirent *dir;

   if( (dp = opendir( "." )) == NULL )
         {
         fprintf( stderr, "Cannot open dir\n" );
         exit( 1 );
         }
   /* read entries */
   while( (dir = readdir( dp )) != NULL )
         if( dir-> d_ino != 0 ) /* ignore empty records */
                  printf( "%s\n", dir->d_name );
   closedir( dp );
   return 0;
   } /* end main */
```

```
{saffron:50} ./listdir
.
..
listdir.c
listdir
{saffron:51}
```

chdir()

```
#include        <unistd.h>

int chdir( char *pathname );
int fchdir( int fd );
```

- Every process has a current working directory (search for a relative pathname starts here)
- Change the current working director working directory (cwd) of the calling process
- Returns 0 if OK, -1 on error
- Directory change is limited to within the program

Example `to_tmp.c`: Changing current working directory

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

int main( void )
  {
  if( chdir( "/tmp" ) < 0 )
       {
       fprintf( stderr, "chdir failed\n" );
       exit( 1 );
       }
  else
       printf( "In /tmp\n" );
  exit( 0 );
  }
```

```
{saffron} pwd
/usr/lib
{saffron} ./to_tmp
In /tmp
{saffron} pwd
/usr/lib
{saffron}
```


getcwd()

```
#include        <unistd.h>

int *getcwd( char *buf, size_t size );
```

- Store the `cwd` of the calling process in buf
- Return buf if OK, `NULL` on error
- `buf` must be big enough for the pathname string (`size` specifies maximum length of `buf`);

Example `printcwd.c`

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

#define BUFSIZE 255

int main( void )
  {
  char name[BUFSIZE+1];          /* accommodate \0 */

  if( getcwd( name, BUFSIZE+1 ) == NULL )
       perror( "getcwd error\n" );
  else
       printf( "Current directory is %s\n", name );
  exit(0);
  }
```

```
{saffron} pwd
/usr/lib
{saffron} ./printcwd
Current directory is /usr/lib
{saffron}
```


Walking over Directories

- 'Visit' every file in a specified directory and all of its subdirectories
  - » visit means the get name of the file
- Apply a user-defined function to every visited file

`ftw()`

```
#include        <ftw.h>

/* file tree walk starting at dir */
int ftw( char *dir, MyFunc *fp, int depth );

/* apply MyFunc() to each visited file */
typedef int MyFunc( const char *file,
            struct stat *sbuf, int flag );
```

- `depth` is the maximum number of directories that can be opened at once. Safest value is 1, although it slows down `ftw()`
- Returns 0 on success (visiting every file), -1 on error
- `file` is the pathname relative to the start directory, it is passed to `MyFunc()` automatically by `ftw()` as it visits each file
- `sbuf` is a pointer to the stat information for the current file examined

ftw() - (cont)

- The flag argument will be set to one of the following for the item being examined
  - » `FTW_F` Item is a regular file
  - » `FTW_D` Item is a directory
  - » `FTW_NS` Could not get stat info for item
  - » `FTW_DNR` Directory cannot be read
- If `MyFunc()` returns a non-zero value then `ftw()` will terminate

Example: `shower.c`

Print the names of all the file found below the current directory

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


int shower( const char *file, const struct stat
  *sbuf, int flag );

int main( void )
  {
  ftw( ".", shower, 1 );
  }
```


Example: `shower.c` (cont)

```
int shower( const char *file, const struct
  stat *sbuf, int flag )
  {
  if( flag == FTW_F )    /* is a file */
      printf( "Found: %s", file );
  return 0;
  }
```


telldir() & seekdir()

```
#include        <dirent.h>

off_t telldir( DIR *dp );
```

- Returns the location of the current record in the directory, -1 on error

```
#include        <dirent.h>

off_t seekdir( DIR *dp, off_t loc );
```

- Set the location in the directory file

scandir()

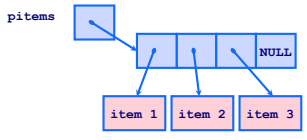
```
#include        <dirent.h>

off_t scandir( char *dir,  struct dirent ***pitems, SelectFnc *sfp,
               CompareFnc *cfp );

/* selection function for searching */
typedef int SelectFnc( const struct dirent *d );

/* comparison function for sorting */
typedef int CompareFnc( const struct dirent *d1,
                        const struct dirent *d2 );
```

- Scan the directory file calling the selection function (`sfp`) on each directory item
- Items for which `sfp` returns non-zero are stored in an array pointed by `pitems`
- The items in the array are sorted using `qsort()` using the comparison function (`cfp`)
- `scandir()` and `alpasort()` not implemented on Solaris

- `dirent.h` includes one predefined comparison function, which compares directory item names

```
int alphasort( const struct dirent *d1,
               const struct dirent *d2 );
```

- Causes the `pitems` array to be sorted in increasing alphabetical order by item name



Example `geth.c`

List files/subdirectories in the current directory which begin with an 'h' sorted in alphabetical order

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

/* our selection function */
int selectH( struct dirent *d );

int main( void )
  {
  struct dirent ** pitems;

  scandir( ".", &pitems, selectH, alphasort );
  while( *pitems != NULL )
       {
       printf( "%s\n", (*pitems)->d_name );
       pitems++:
       }
  exit( 0 );
  }
```



```
int selectH( struct dirent *d )
  {
  if( d-> d_name[0] == 'h' )
       return 1;
  return 0;
  }
```