FILE SYSTEMS

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CSCE 313 Spring 2020

The UNIX File System

- File Systems and Directories
- UNIX inodes
- File protection/access control

Why Study File Systems?

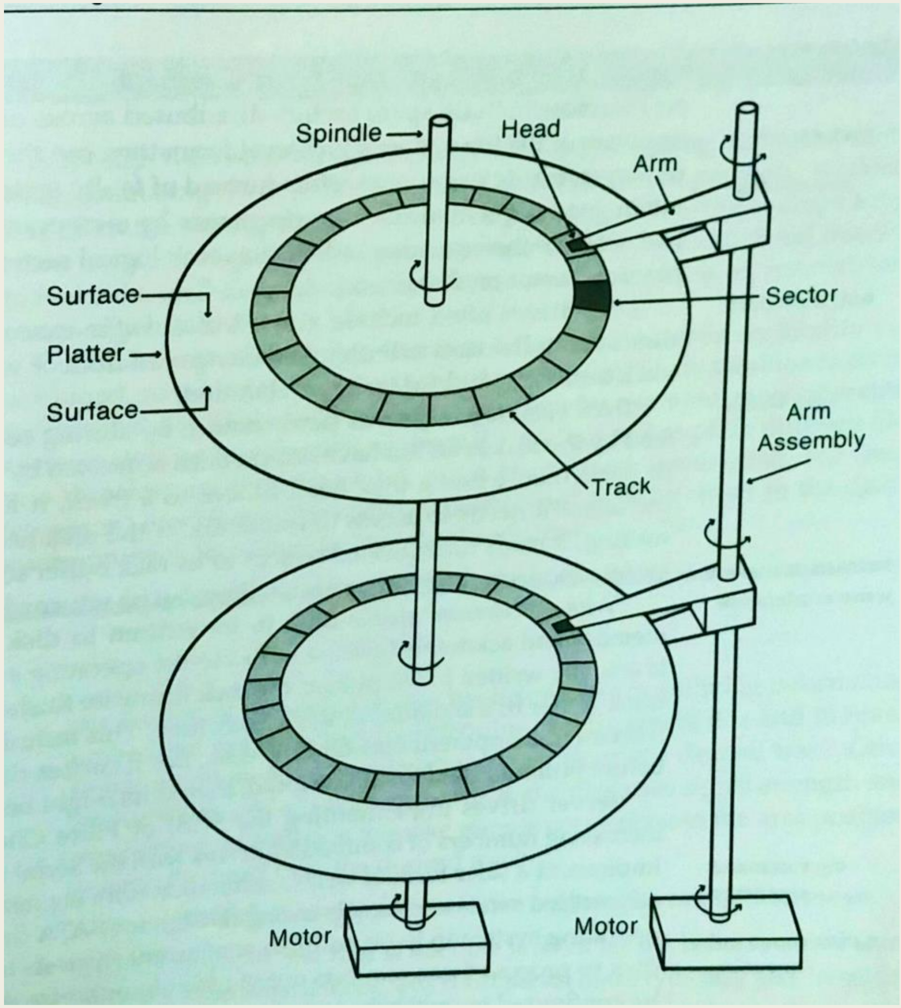
- The main subject is non-volatile storage, e.g.,
  - *Magnetic disk*
  - *Tape drives*
  - *Flash disks*
  - *SSDs*
- These retain data between shutdown and reboots
  - *Important for keeping the OS, programs, and user data*
- But these devices have unique characteristics and limitations not found in main memory
  - *First, they do not allow random accesses to individual bytes – only allow block level access (512 bytes or multiple)*
  - *Second, accesses are much slower (10ms compared to 0.1ms of memory)*

Why Study File Systems?

- The physical characteristics drive the following keys features of file systems:
  - ***Named data:*** *Human-readable names (e.g. file names) given to data*
  - ***Performance:*** *By grouping, ordering, scheduling disk operations so that high latency is hidden/amortized*
  - ***Reliability:*** *Unexpected power-cycles do not corrupt the data*
  - ***Controlled sharing:*** *Determine who can read/write/execute certain files sequentially/simultaneously w/o corrupting*

Now, Why Are Disks Slow?

- Consider a typical magnetic disk
  - *Platters are rotating at a constant speed*
  - *Each surface has data in the form of a number of tracks*
    - Each track is separated in sectors/blocks
  - *Arm moves the disk head to place that on the right track. This is called “seek”*
    - Extremely slow (> 10 ms)
  - *Then, the head waits for the correct sector to come below*
    - Relatively faster because of constant motion (<10 ms), determined by disk RPM
  - *Read the sector and send to the CPU*
    - Much faster (at SATA rate: ~500MB/s)



Disk Access Time

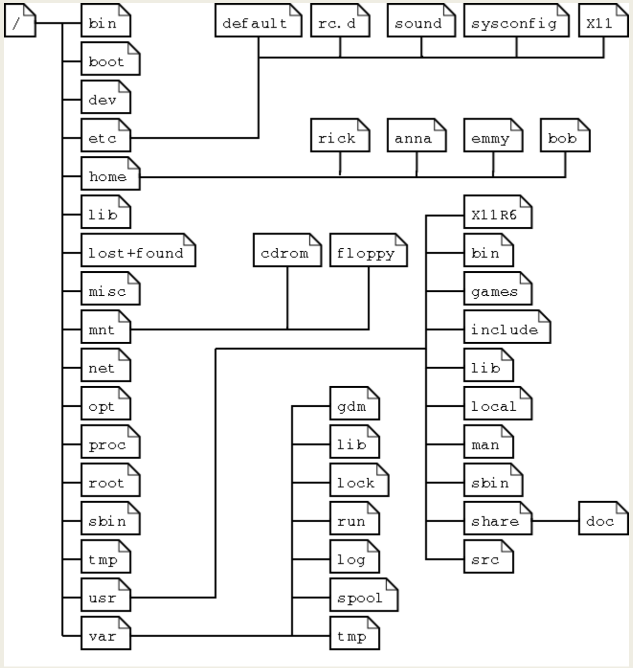
- disk access time = seek time + rotation time + transfer time
- The mechanical movement of the disk arm makes the seek time often the bottleneck
- Sequentially read => less disk seeking
  - *It takes less time to move between adjacent tracks*
- If data is read randomly, the disk arm has to seek randomly, leading to very slow operation
  - *Even then, it applies algorithms similar to the ones in elevators to service requests*

How About SSDs?

- Are they “true random access” – meaning do they take same time as sequential even when accessed randomly?
  - *The answer is NO*
  - *Because accesses are still at sector or page level*
  - *Accessing just 1 byte experiences the full page transfer latency*
  - *In addition, prefetching an adjacent page is a common practice, which hides latency for sequential, but not for random*
  - *Overall, random access is faster than magnetic, but not as fast as sequential*
- From that same logic, even RAM is not truly random access
  - *You will always have a leverage accessing sequantially*

File System Abstraction

- Definition: "*File system is an OS abstraction that provides persistent and named data*"
- Key components:
  - ***Files:*** *contain* ***metadata*** *and actual* ***data***
  - ***Directories:*** *Special files that contain* ***names*** *and* ***pointers*** *to actual files*
- Because of directories and sub-directories, the File System looks like a **tree**

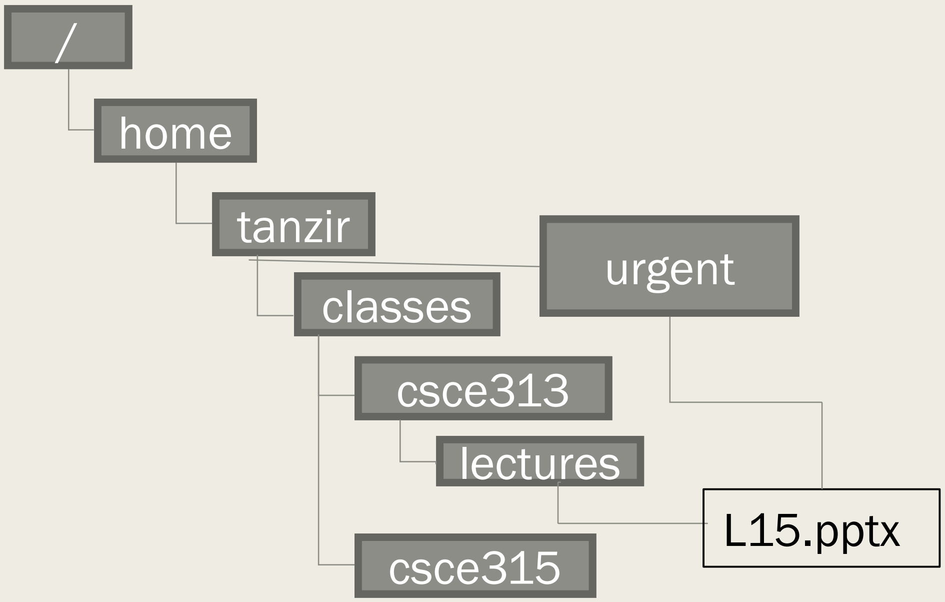


File Systems Terms

- **path**: a string identifying a file (e.g., `/home/tanzir/Work/hw1.cpp`)
- **root directory:** think of the directory as a tree whose root is the *root directory*
  - *Often denoted by the "/"*
- **absolute path**: a path starting with "/"
- **relative path**: a path relative to the **current working directory**. Does not start with a "/"

File System “Tree”

- **hard link:** The mapping between the name and the underlying file
  - *There can be multiple hard links to the same file (e.g., short cuts)*
  - *Means that the directory tree is not always a tree*



UNIX Directory API: Current Directory

```
#include <unistd.h>

char * getcwd(char * buf, size_t size);
/* get current working directory */
```

Example:

```
void main(void) {
    char mycwd[PATH_MAX];

    if (getcwd(mycwd, PATH_MAX) == NULL) {
        perror ("Failed to get current working directory");
        return 1;
    }
    printf("Current working directory: %s\n", mycwd);
    return 0;
}
```

UNIX Directory API – Open, Read, Close

- Read is stateful with a cursor
  - *Reading the same directory again gives back the next file in the directory*

```
#include <dirent.h>
int main(int argc, char * argv[]) {
    struct dirent * direntp;
    DIR * dirp = opendir(argv[1]);
    while ((direntp = readdir(dirp)) != NULL)
        printf(%s\n", direntp->d_name);

    closedir(dirp);
    return 0;
}
```

UNIX Directory API – Traversal

- Read is stateful with a cursor
  - *Reading the same directory again gives back the next file in the directory*
  - *You can even do "seek" to the beginning using rewindir()*

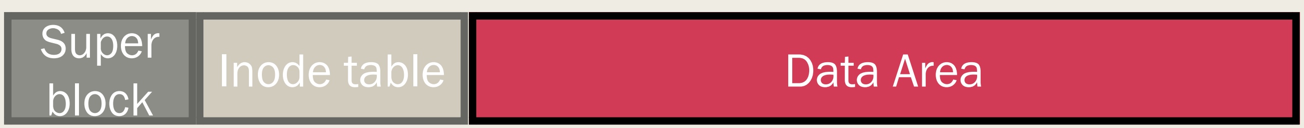
```
#include <dirent.h>

DIR* opendir(const char * dirname);
/* returns pointer to directory object          */
struct dirent * readdir(DIR * dirp);
/* read successive entries in directory 'dirp'  */
int closedir(DIR *dirp);
/* close directory stream                       */
void  rewinddir(DIR * dirp);
/* reposition pointer to beginning of directory */
```

File System Organization

- First, each sector/block is numbered from 0, 1, ….
  - *The larger the disk, the more the sectors*
- Then, the file system contains the following components:

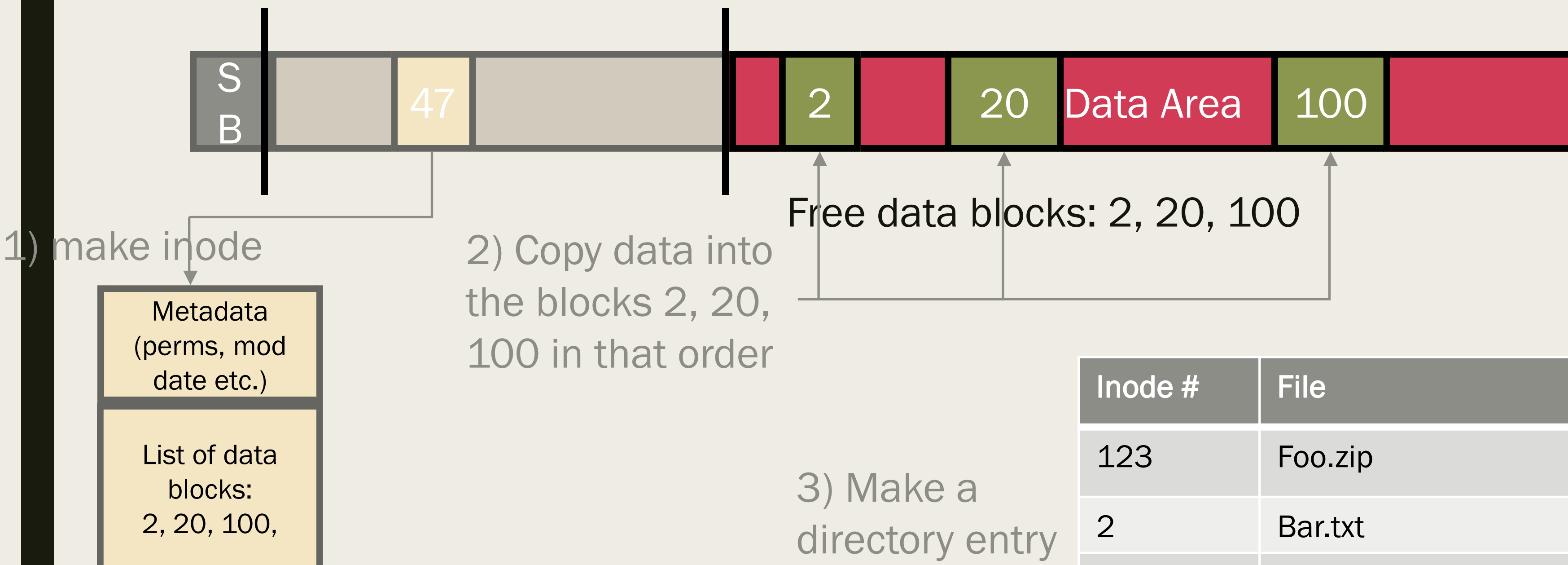
Component	Purpose
Superblock	Contains metadata about the file system. Size is OS dependent
Inode table	An array of inode structs, where each struct contains info of a file (e.g., size, owner id, last modification). Each inode has a number, which is the index into the inode table
Data Area	Contains file content. Each file can be >= 1 block



Creating a New File

Let us create a file called “**newfile**” that is 12KB in size, and a disk block is 4KB.

First, we need a free inode to put the file metadata, then find 3 free disk blocks to put the actual data



3) Make a directory entry

Inode #	File
123	Foo.zip
2	Bar.txt
47	newfile

Steps in Creating a File

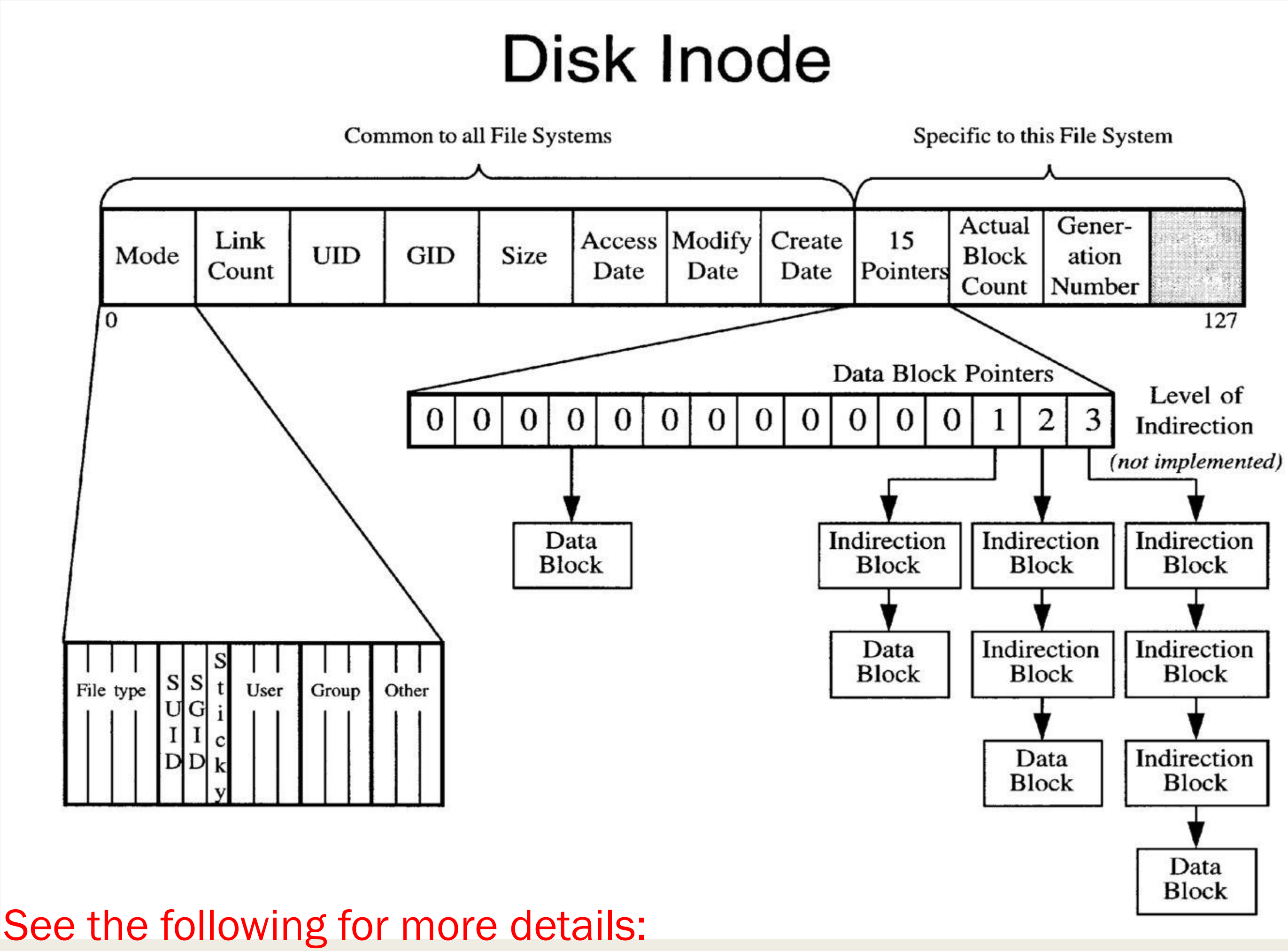
- 1) Store Properties: Kernel looks for a free inode and stores the metadata (e.g., permissions, size, creation date) in that
- 2) Store Data and Record Allocations: Kernel then looks for free disk blocks (and enough of those) and copies content there. Kernel updates the inode with which blocks contain data for that file
- 3) Add file name to directory: Kernel stored the (inode#, filename) pair in the directory entry

Reading a File

- 1) Search the directory for the file name and extract its inode
- 2) Locate and read the inode, find the data block number from there
- 3) Read each data block in sequence and output that

- This is how out “`$cat newfile`” command will work
  - *Output will go to standard output*

What goes inside a inode??



See the following for more details:
http://man7.org/linux/man-pages/man7/inode.7.html

Ref: UCLA, cs111 sp 14 lec 12b

Inode's Features: Protection

- File owner/creator should be able to control:
  - *what can be done*
  - *by whom*

- Types of access
  - ***Read***
  - ***Write***
  - ***Execute***
  - ***Append***
  - ***Delete***
  - ***List***

Access Lists and Groups

- Mode of access: read, write, execute
- Three classes of users

			RWX
a) **owner access**	7	$\Rightarrow$	1 1 1
			RWX
b) **group access**	6	$\Rightarrow$	1 1 0
			RWX
c) **public access**	1	$\Rightarrow$	0 0 1

- Ask manager to create a group (unique name), say G, and add some users to the group.
- For a particular file (say *game*) or subdirectory, define an appropriate access.

owner group public

chmod 761 game

Attach a group to a file: `chgrp G game`

A Five-Year Study of File-System Metadata

NITIN AGRAWAL
University of Wisconsin, Madison
and
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Microsoft Research

Characteristics of Files

- Observations:
  - *Most files are small*
  - *Most of the space is occupied by the rare big ones*

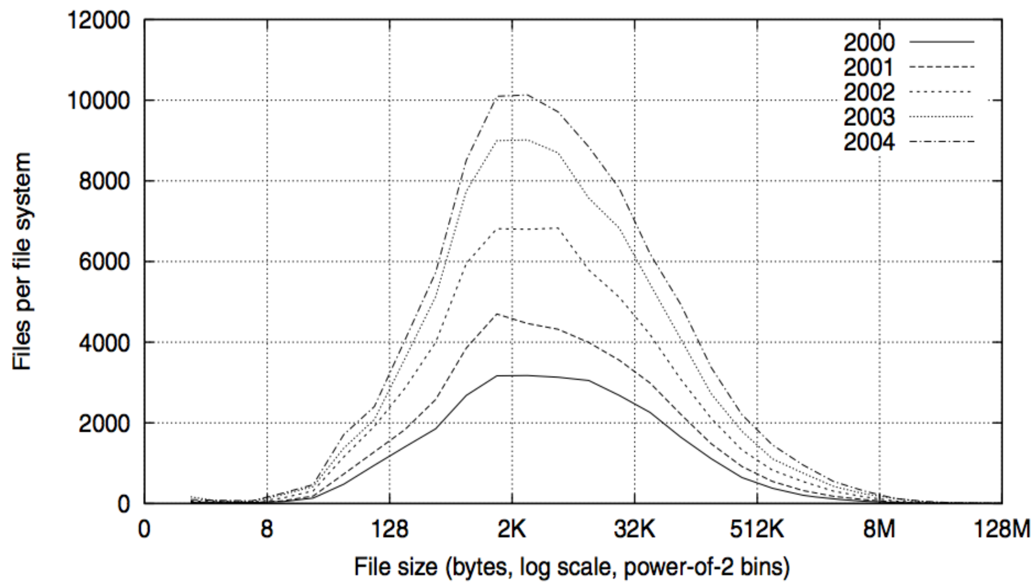
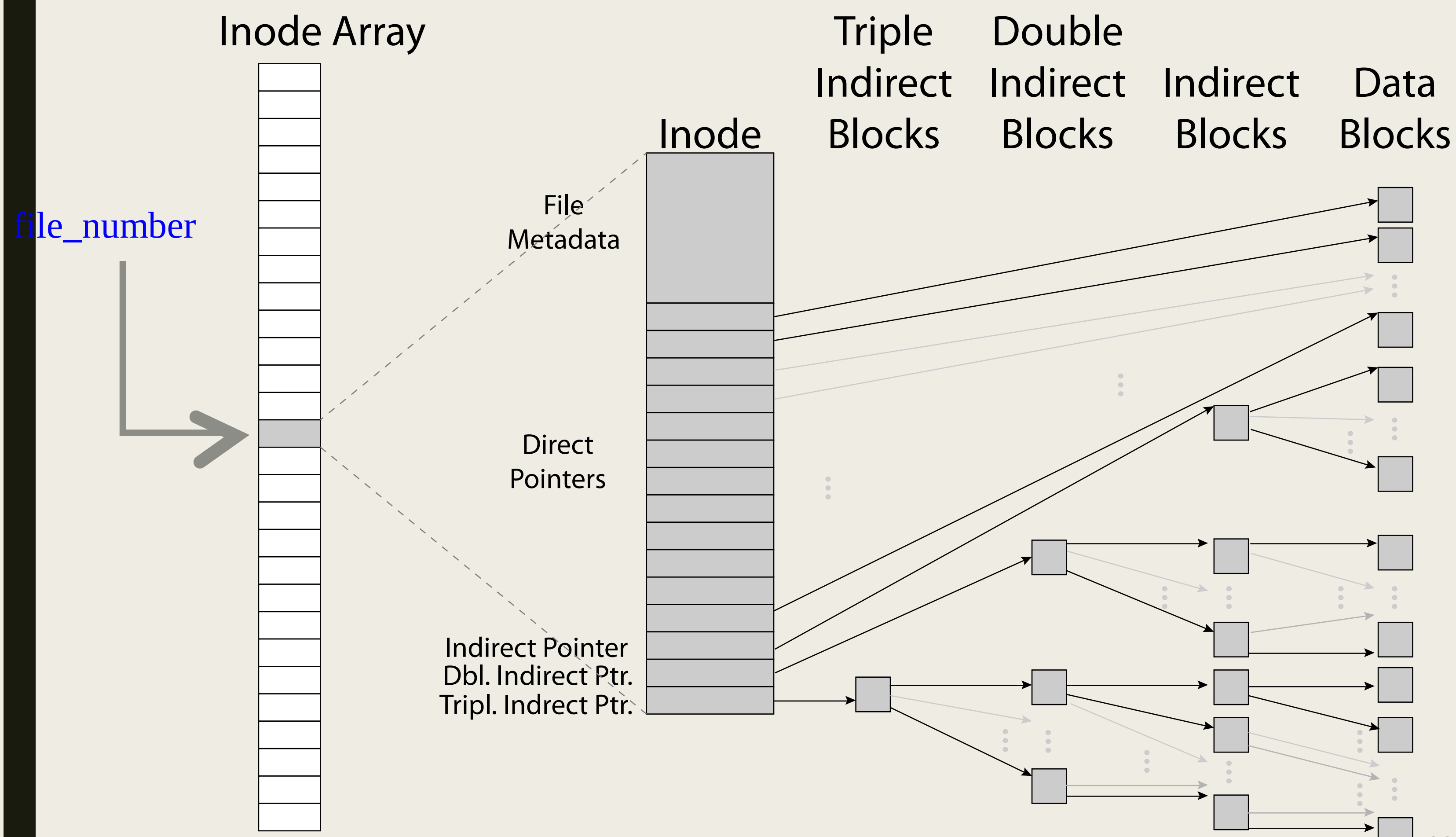


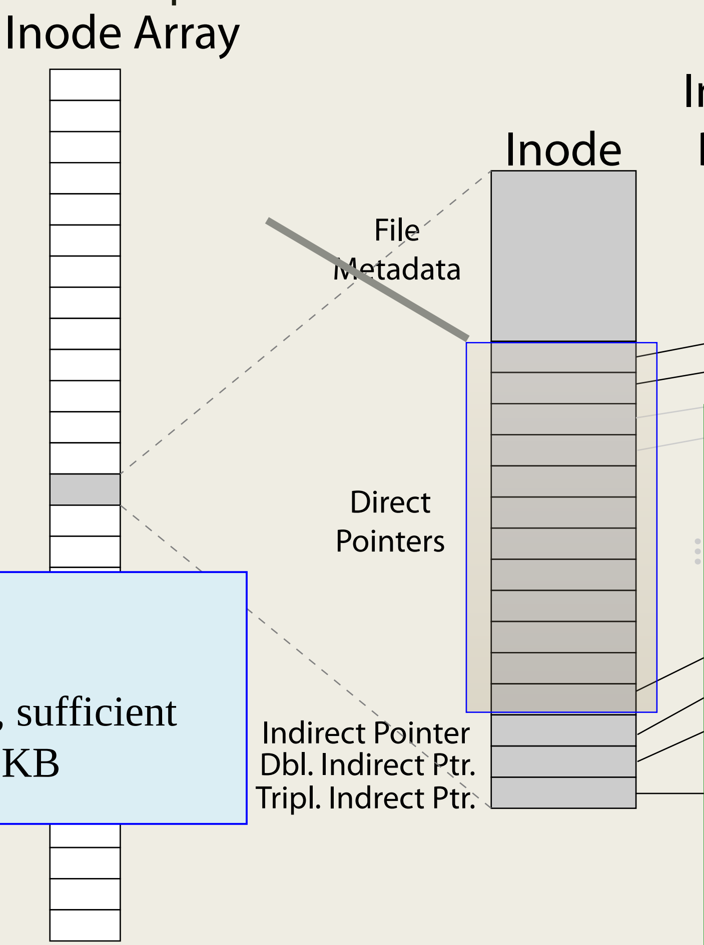
Fig. 2. Histograms of files by size.

Does this help deciding the inode structure?



FFS: Data Storage

- Small files: 12 pointers direct to data blocks



Direct pointers

With 4kB blocks, sufficient
For files up to 48KB

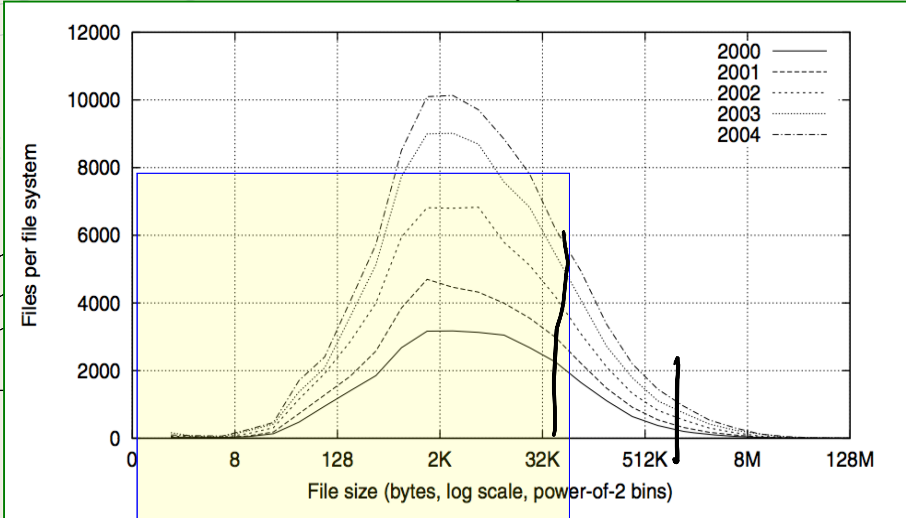
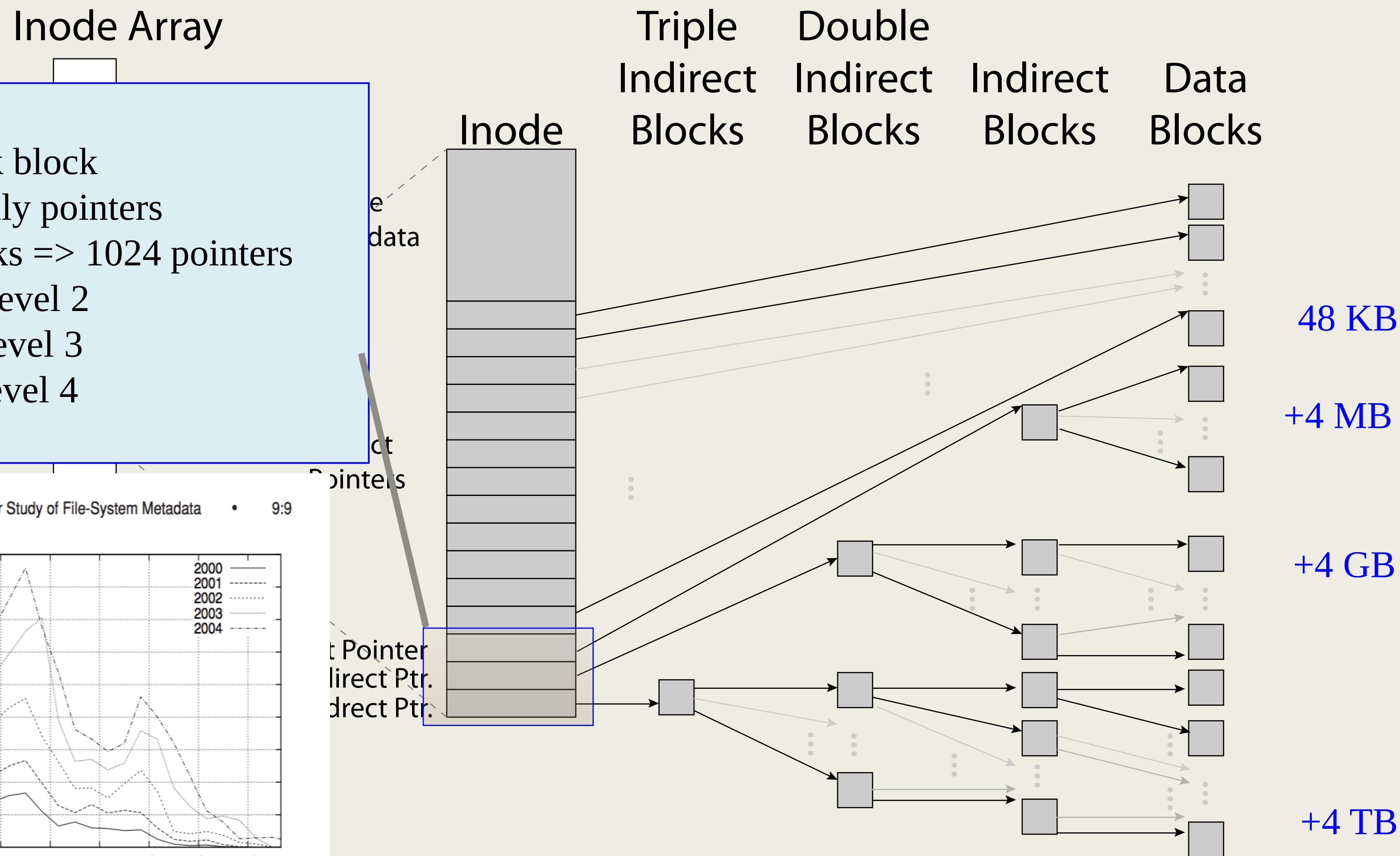


Fig. 2. Histograms of files by size.

FFS: Data Storage

- Large files: 1,2,3 level indirect pointers



Indirect pointers
- point to a disk block containing only pointers
- eg. 4 kB blocks => 1024 pointers
  => 4 MB @ level 2
  => 4 GB @ level 3
  => 4 TB @ level 4

A Five-Year Study of File-System Metadata • 9:9

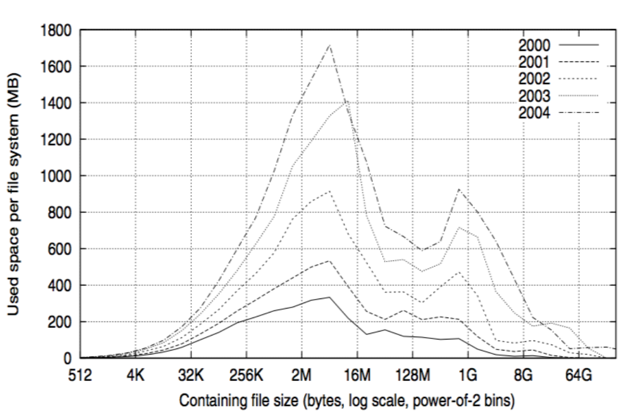
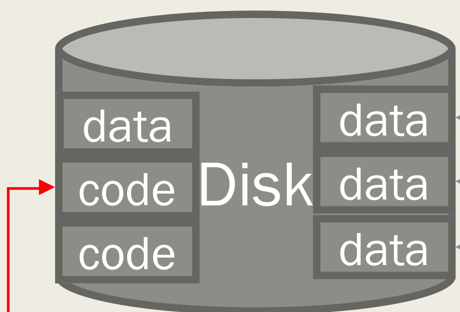


Fig. 4. Histograms of bytes by containing file size.

Device Files and inodes

- How to handle device files (e.g., terminal input, output, printer)?



Inode #	Type	Filename
123	Reg.	Foo.zip
2	Reg.	Bar.txt
47	Reg.	newfile
…	…	…
100	Dev.	tty

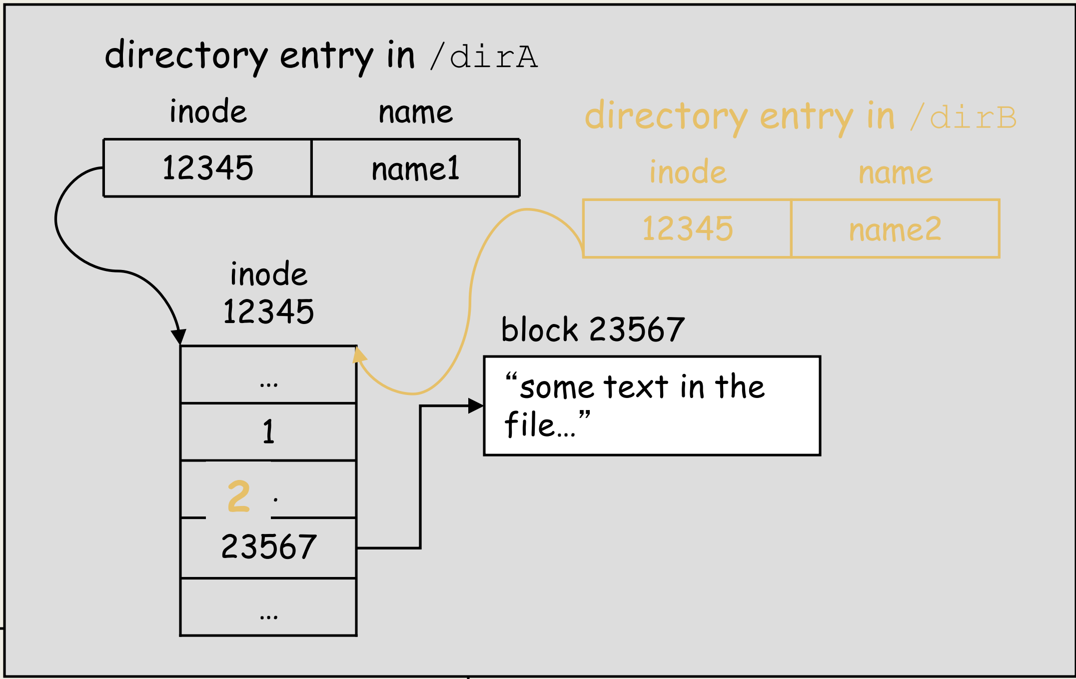
Inode’s for device files and regular files are different:

- They both point to disk blocks
- However, device files’ inodes point to device driver code instead of regular data blocks

Links

- Hard link
  - *Directory entry contains the **inode number***
  - *Creates another name (path) for the file*
  - *Each is "first class"*
- Soft link or Symbolic Link
  - *Directory entry contains the **name of the file***
  - *Map one name to another name*

Hard Links



shell command

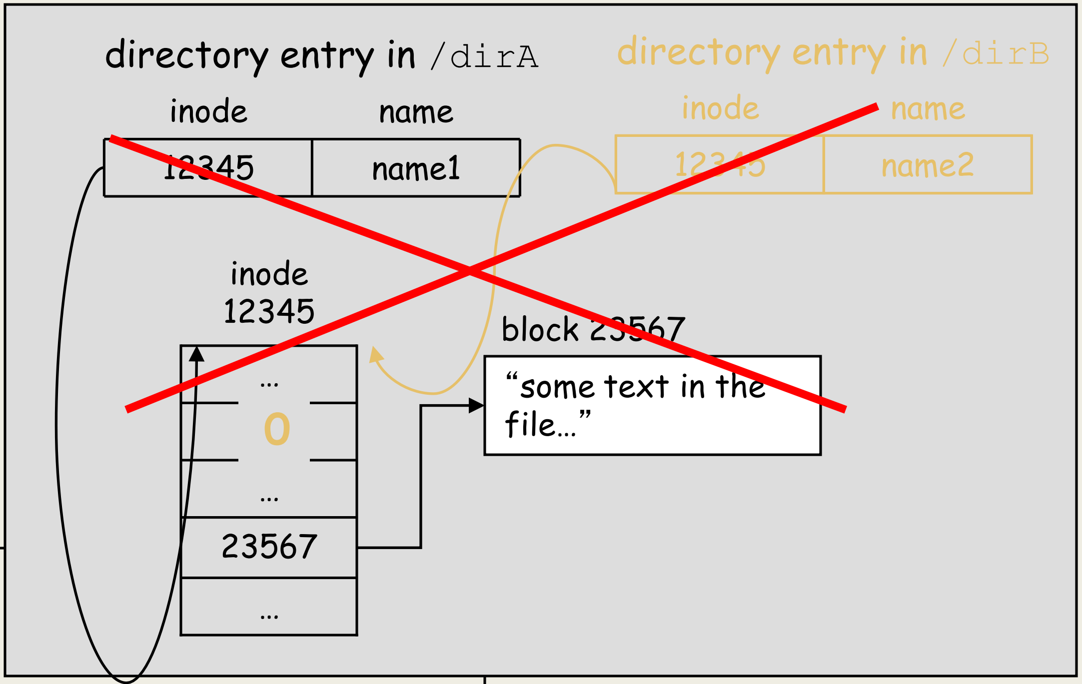
```
ln /dirA/name1 /dirB/name2
```

is typically implemented using the link system call:

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

if (link("/dirA/name1", "/dirB/name2") == -1)
  perror("failed to make new link in /dirB");
```

Hard Links: `unlink`

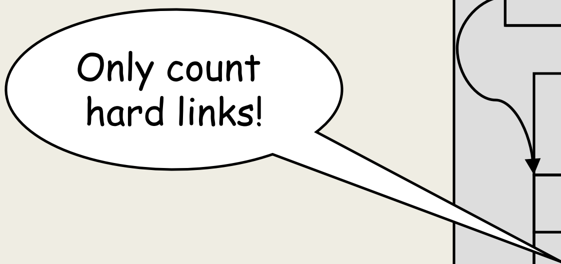


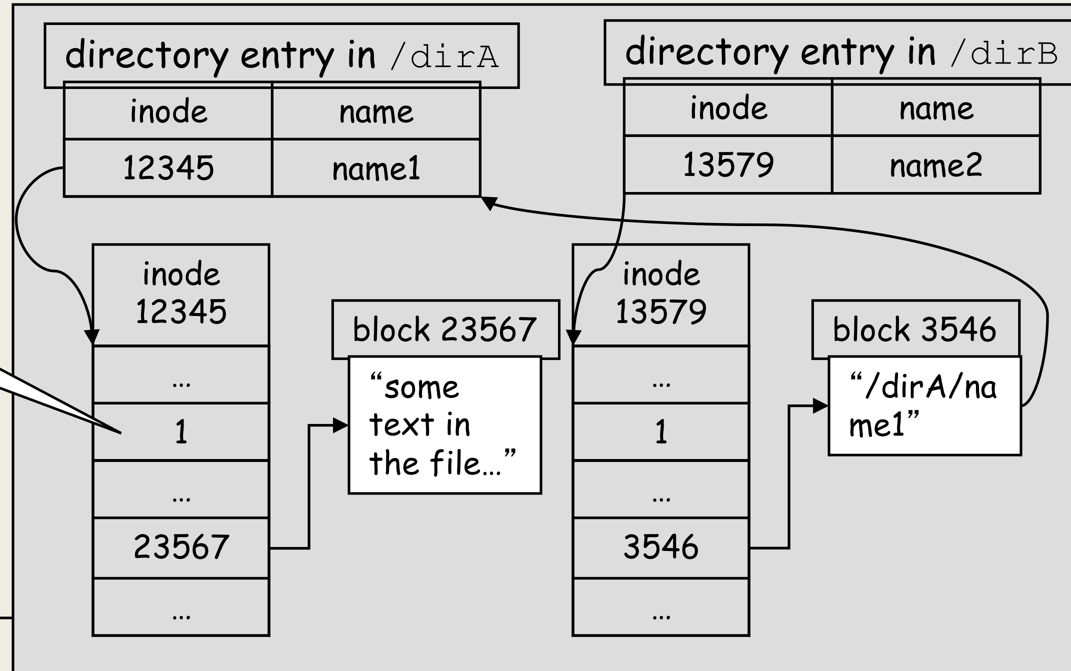

```
#include <stdio.h>
#include<unistd.h>

if (unlink("/dirA/name1") == -1)
  perror("failed to delete link in /dirA");


if (unlink("/dirB/name2") == -1)
  perror("failed to delete link in /dirB");
```

Symbolic (Soft) Links





shell command

```
ln -s /dirA/name1 /dirB/name2
```

is typically implemented using the link system call:

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

if (symlink(“/dirA/name1”, “/dirB/name2”) == -1)
  perror(“failed to create symbolic link in /dirB”);
```

Links: Example

```
[tanzir@compute PA7]$ ls -lrt
total 16
-rwxr-xr-x. 1 tanzir CSE_csfac 2251 Apr  7 03:21 semaphore.h
-rwxr-xr-x. 1 tanzir CSE_csfac  520 Apr  7 03:26 BoundedBuffer.h
-rwxr-xr-x. 1 tanzir CSE_csfac  765 Apr  7 03:28 BoundedBuffer.cpp
-rwxr-xr-x. 1 tanzir CSE_csfac  533 Apr 19 20:20 makefile
-rwxr-xr-x. 1 tanzir CSE_csfac 1445 Apr 19 21:02 netreqchannel.h
-rwxr-xr-x. 1 tanzir CSE_csfac 3784 Apr 21 11:31 netreqchannel.cpp
-rwxr-xr-x. 1 tanzir CSE_csfac 1012 Apr 21 11:46 dataserver.cpp
-rwxr-xr-x. 1 tanzir CSE_csfac 7631 Apr 21 11:57 client.cpp
-rwxr-xr-x. 1 tanzir CSE_csfac 1576 Apr 24 17:39 Untitled-1.cpp
[tanzir@compute PA7]$ ln semaphore.h ./sema.h
[tanzir@compute PA7]$ ln -s semaphore.h ./softsema.h
[tanzir@compute PA7]$ ls -lrt
total 18
-rwxr-xr-x. 2 tanzir CSE_csfac 2251 Apr  7 03:21 semaphore.h
-rwxr-xr-x. 2 tanzir CSE_csfac 2251 Apr  7 03:21 sema.h
-rwxr-xr-x. 1 tanzir CSE_csfac  520 Apr  7 03:26 BoundedBuffer.h
-rwxr-xr-x. 1 tanzir CSE_csfac  765 Apr  7 03:28 BoundedBuffer.cpp
-rwxr-xr-x. 1 tanzir CSE_csfac  533 Apr 19 20:20 makefile
-rwxr-xr-x. 1 tanzir CSE_csfac 1445 Apr 19 21:02 netreqchannel.h
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-rwxr-xr-x. 1 tanzir CSE_csfac 1576 Apr 24 17:39 Untitled-1.cpp
lrwxrwxrwx. 1 tanzir games       11 Apr 26 19:34 softsema.h -> semaphore.h
```

Files: Big Picture