1 Exam Related Questions and Tips

- I wonder how system call for reading file/directory works in UNIX. Does it check for bitmap?
- I wonder how system call for deleting file/directory works in UNIX
- I wonder how system call for creatubg file/directory works in UNIX
- Learned that
  - Missing Inode Bitmap - multiple file paths may point to same inode

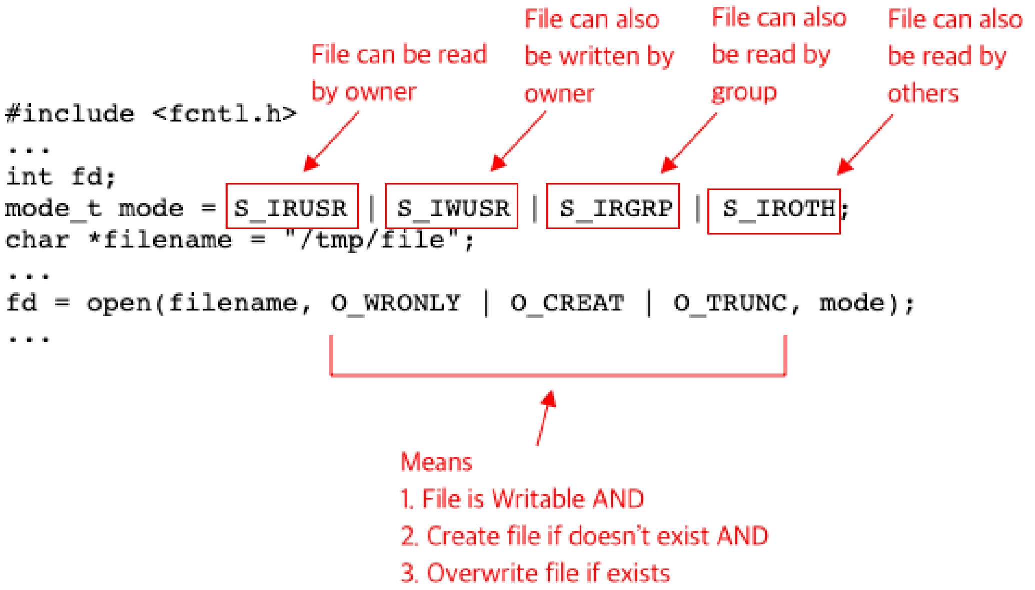
2 File API

- `open` (create/access file)
  - Is a system call
  - Reads target inode into memory (when loading)
  - Does three things on creation
    1) make structure (inode) that racks all relevant information about file
    2) link human readible name to the file, and put that link to a directory
    3) increment **reference count** in inode
  - **Syntax:**

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

    * `O_CREAT` - Creates file ”foo” if does not exist
    * `O_WRONLY` - Open file for writing only (default)
    * `O_TRUNC` - Overwrites existing file Need example/Clarification
    * Can have multiple flags
  - Returns **file descriptor** or `fd` for short
    * Is an integer
    * Is used to access a file
    * Is private per process
    * Can be used to `read()` and `write()` files

    Example



```
#include <fcntl.h>
...
int fd;
mode_t mode = S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH;
char *filename = "/tmp/file";
...
fd = open(filename, O_WRONLY | O_CREAT | O_TRUNC, mode);
...
```

File can be read by owner
File can also be written by owner
File can also be read by group
File can also be read by others

Means
1. File is Writable AND
2. Create file if doesn't exist AND
3. Overwrite file if exists

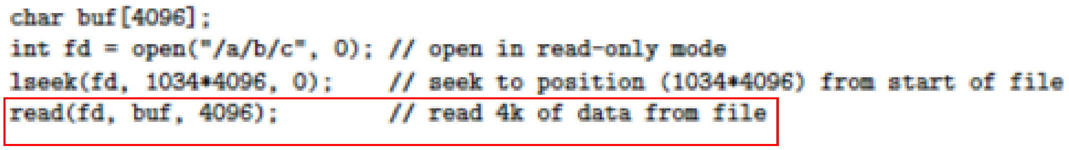
- Amount of I/O generated by `open()` is proportional to length of pathname (wait. How is I/O involved in open()?)

- (read) (read file)
  - Is a system call
  - **Syntax:**

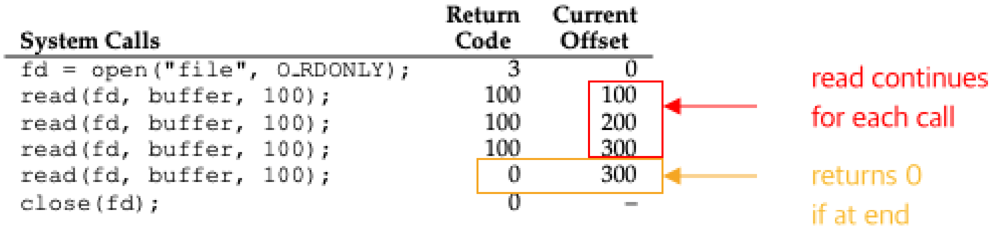
    ```
    ssize_t read (int fd, void *buf, size_t count)
    ```

    - ∗ `fd` - file descriptor (from `open()`)
    - ∗ `buf` - container for the read data
    - ∗ `count` - number of bytes to read
  - Returns number of bytes read, if successful
  - Returns 0 if is at, or past the end of file

  <u>**Example**</u>



```
char buf[4096];
int fd = open("/a/b/c", 0); // open in read-only mode
lseek(fd, 1034*4096, 0);    // seek to position (1034*4096) from start of file
read(fd, buf, 4096);        // read 4k of data from file
```



System Calls	Return Code	Current Offset
fd = open("file", O_RDONLY);	3	0
read(fd, buffer, 100);	100	100
read(fd, buffer, 100);	100	200
read(fd, buffer, 100);	100	300
read(fd, buffer, 100);	0	300
close(fd);	0	–

read continues for each call

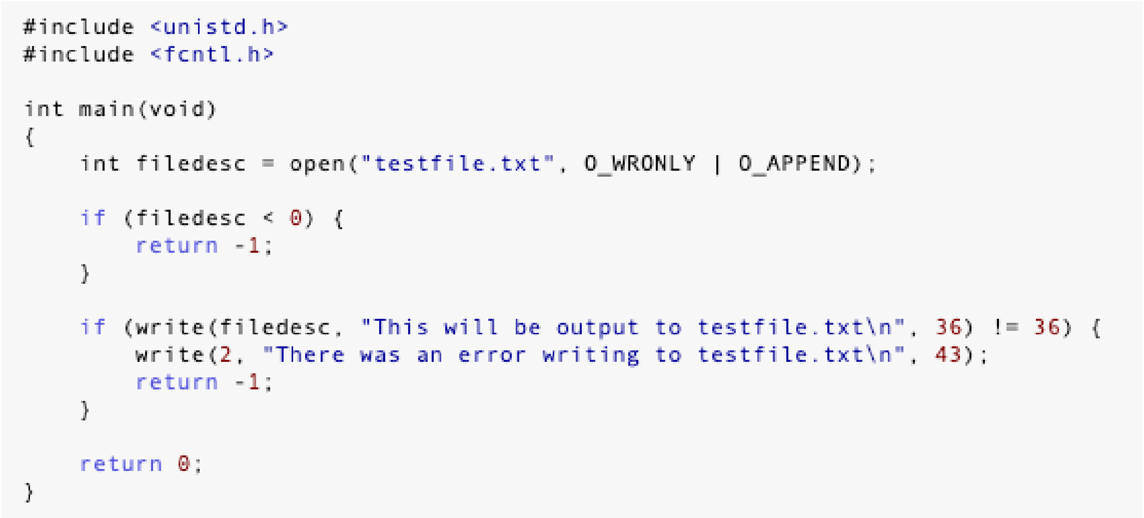
returns 0 if at end

- `write` (write file)
  - Is a system call
  - Writes data out of a buffer
  - **Syntax:**

    `ssize_t write (int fd, const void * buf, size_t nbytes)`

    * `fd` - file descriptor
    * `buf` - A pointer to a buffer to write to file
    * `nbytes` - number of bytes to write. If smaller than buffer, the output is truncated

Example



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

int main(void)
{
    int filedesc = open("testfile.txt", O_WRONLY | O_APPEND);

    if (filedesc < 0) {
        return -1;
    }

    if (write(filedesc, "This will be output to testfile.txt\n", 36) != 36) {
        write(2, "There was an error writing to testfile.txt\n", 43);
        return -1;
    }

    return 0;
}
```

- `lseek`
  - Reads or write to a specific offset within a file

- **Syntax:**

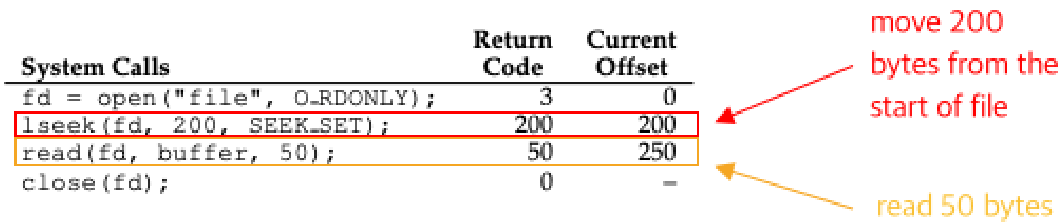
  `off_t lseek (int fd, off_t offset, int whence)`

  - `fd` - file descriptor
  - `offset` - the offset of pointer within file (in bytes)
  - `whence` - the method of offset

    `SEEK_SET` - offset from the start of file (absolute)
    `SEEK_CUR` - offset from current location + offset bytes (relative)
    `SEEK_END` - offset from the end of file

- Returns offset amount (in bytes) from the beginning of file
- Returns -1 if error

Example



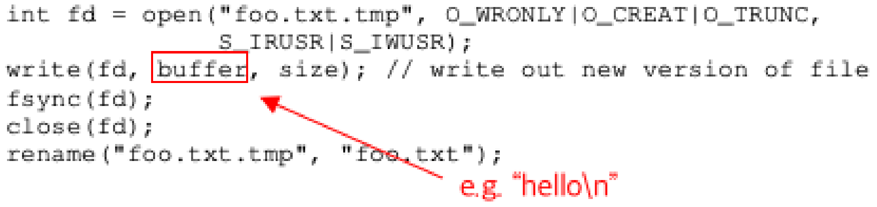
System Calls	Return Code	Current Offset
`fd = open("file", O_RDONLY);`	3	0
`lseek(fd, 200, SEEK_SET);`	200	200
`read(fd, buffer, 50);`	50	250
`close(fd);`	0	–

move 200 bytes from the start of file

read 50 bytes

- `rename` (update file name)
  - Is a system call
  - Changes the name of file
  - Is **atomic** (after crash, it will be either old or new, but not in-between)
  - **Syntax:** `int rename(const char *old, const char *new)`
    - `old` - name of old file
    - `new` - name of new file
  - Returns 0 if successful
  - Returns -1 if error

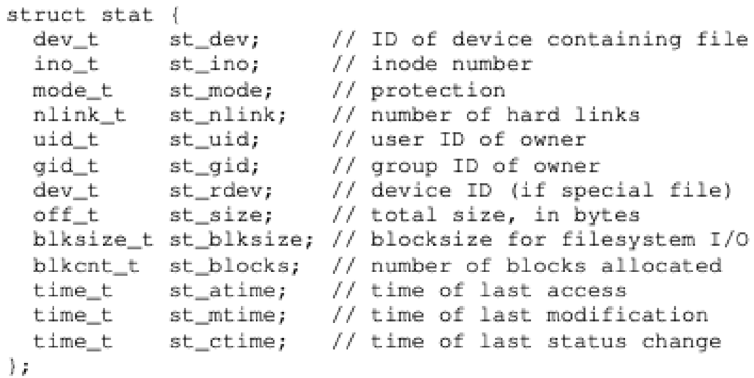
Example



```
int fd = open("foo.txt.tmp", O_WRONLY|O_CREAT|O_TRUNC,
              S_IRUSR|S_IWUSR);
write(fd, buffer, size); // write out new version of file
fsync(fd);
close(fd);
rename("foo.txt.tmp", "foo.txt");
```

e.g. “hello\n”

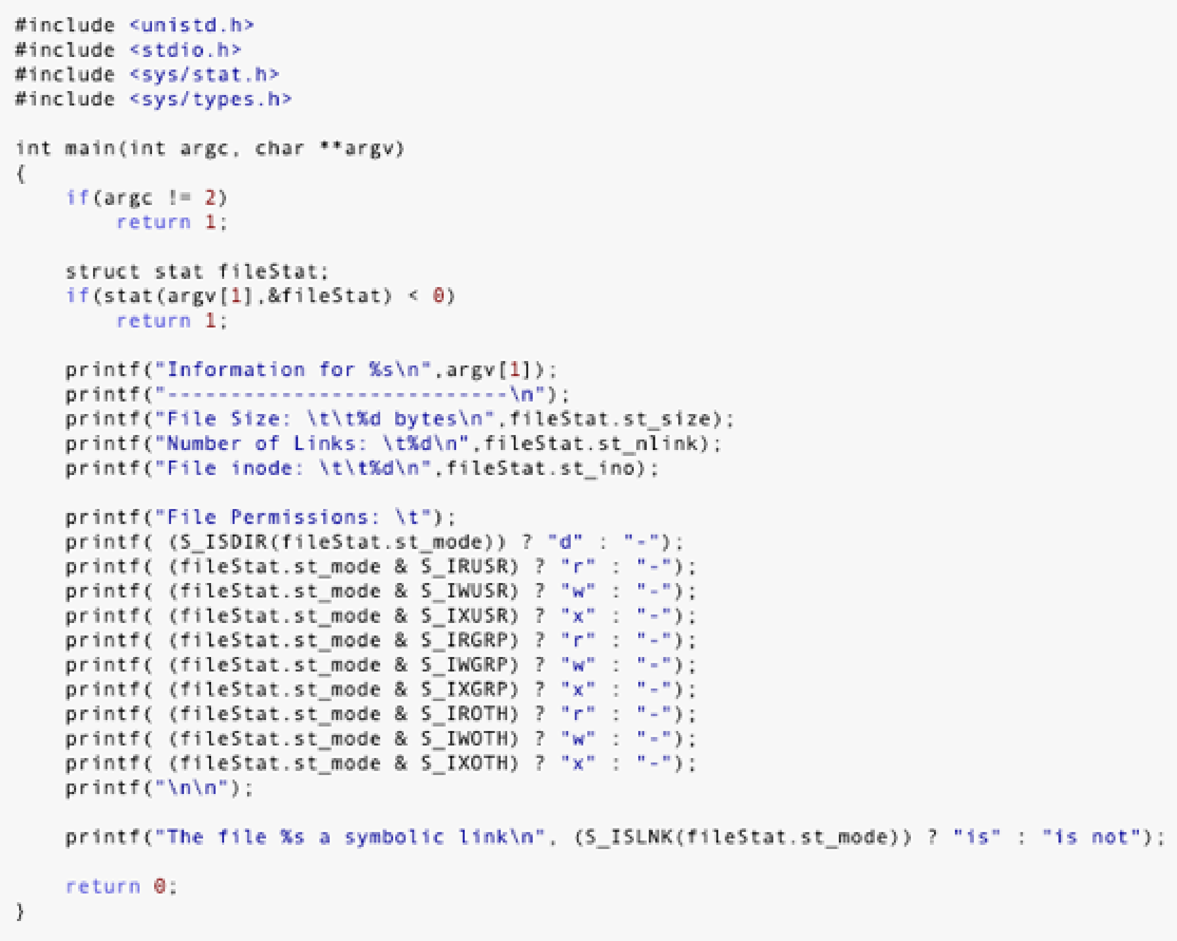
- `stat` (get file info)
  - displays metadata of a certain file stored in **inode**
  - **Syntax:** `int stat(const char *path, struct stat *buf)`
    - `path` - file descriptor of file that's being inquired
    - `buf` - A `stat` structure where data about the file will be stored (see below)



```
struct stat {
  dev_t     st_dev;     // ID of device containing file
  ino_t     st_ino;     // inode number
  mode_t    st_mode;    // protection
  nlink_t   st_nlink;   // number of hard links
  uid_t     st_uid;     // user ID of owner
  gid_t     st_gid;     // group ID of owner
  dev_t     st_rdev;    // device ID (if special file)
  off_t     st_size;    // total size, in bytes
  blksize_t st_blksize; // blocksize for filesystem I/O
  blkcnt_t  st_blocks;  // number of blocks allocated
  time_t    st_atime;   // time of last access
  time_t    st_mtime;   // time of last modification
  time_t    st_ctime;   // time of last status change
};
```

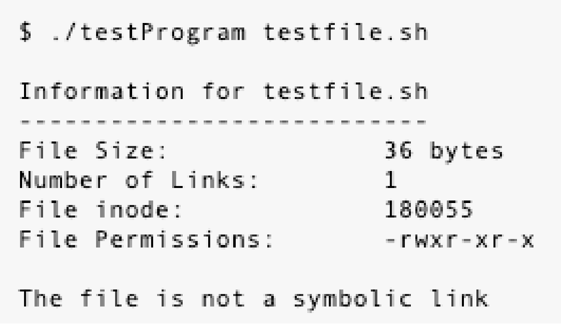
Figure 39.5: The **stat** structure.

Example



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

int main(int argc, char **argv)
{
    if(argc != 2)
        return 1;

    struct stat fileStat;
    if(stat(argv[1],&fileStat) < 0)
        return 1;

    printf("Information for %s\n",argv[1]);
    printf("--------------------------\n");
    printf("File Size: \t\t%d bytes\n",fileStat.st_size);
    printf("Number of Links: \t%d\n",fileStat.st_nlink);
    printf("File inode: \t\t%d\n",fileStat.st_ino);

    printf("File Permissions: \t");
    printf( (S_ISDIR(fileStat.st_mode)) ? "d" : "-");
    printf( (fileStat.st_mode & S_IRUSR) ? "r" : "-");
    printf( (fileStat.st_mode & S_IWUSR) ? "w" : "-");
    printf( (fileStat.st_mode & S_IXUSR) ? "x" : "-");
    printf( (fileStat.st_mode & S_IRGRP) ? "r" : "-");
    printf( (fileStat.st_mode & S_IWGRP) ? "w" : "-");
    printf( (fileStat.st_mode & S_IXGRP) ? "x" : "-");
    printf( (fileStat.st_mode & S_IROTH) ? "r" : "-");
    printf( (fileStat.st_mode & S_IWOTH) ? "w" : "-");
    printf( (fileStat.st_mode & S_IXOTH) ? "x" : "-");
    printf("\n\n");

    printf("The file %s a symbolic link\n", (S_ISLNK(fileStat.st_mode)) ? "is" : "is not");

    return 0;
}
```

The result of above is:

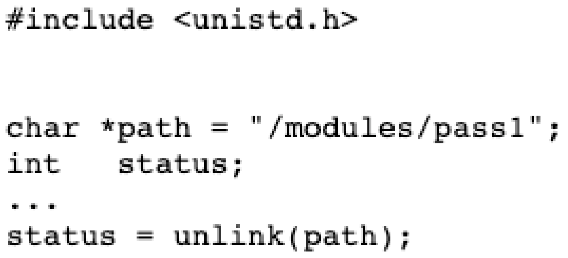


```
$ ./testProgram testfile.sh

Information for testfile.sh
---------------------------
File Size:              36 bytes
Number of Links:        1
File inode:             180055
File Permissions:       -rwxr-xr-x

The file is not a symbolic link
```

- `unlink` (removing file)
  - Is a system call
  - Removes a file (including symbolic link) from the system
  - **Syntax:** `int unlink(const char *pathname)`

    - pathname - path to file
  - Returns 0 if successful
  - Returns -1 if error

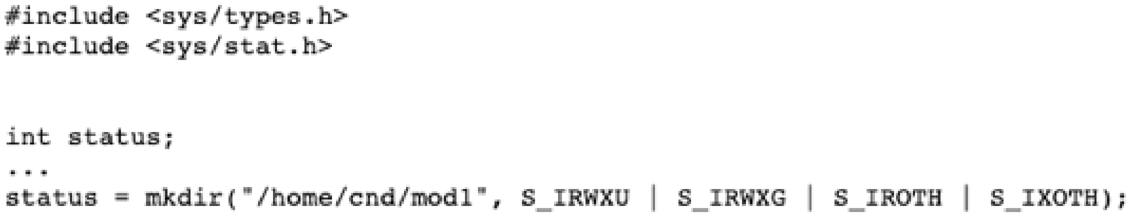
Example



```
#include <unistd.h>


char *path = "/modules/pass1";
int   status;
...
status = unlink(path);
```

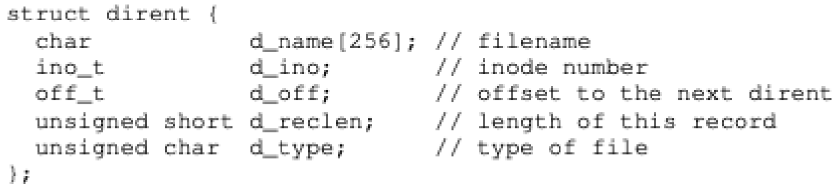
- mkdir (creating directory)
  - Is a system call
  - **Syntax:** `int mkdir(const char *path, mode_t mode)`
    - path - path of directory (including name)
    - mode - permission group
  - Returns 0 if successful
  - Returns -1 if error
  - directories can never be written directly
    - directory is in format called **File System Metadata**
    - directory can only be updated directly
  - creates two directories on creation . (current) and .. (parent)

Example



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


int status;
...
status = mkdir("/home/cnd/mod1", S_IRWXU | S_IRWXG | S_IROTH | S_IXOTH);
```

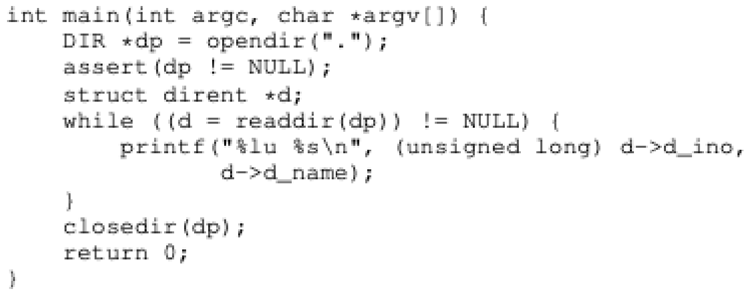
- `opendir, readdir, closedir` (reading directory)
  - Are system calls
  - Are under `<dirent.h>` library
  - Requires `struct dirent` data structure



```
struct dirent {
  char           d_name[256]; // filename
  ino_t          d_ino;       // inode number
  off_t          d_off;       // offset to the next dirent
  unsigned short d_reclen;    // length of this record
  unsigned char  d_type;      // type of file
};
```

  - **Syntax (opendir):** `DIR *opendir(const char *dirname)`
    - `dirname` - directory path
    - Returns a pointer to the directory stream
    - The stream is positioned at the first entry in the directory.
  - **Syntax (readdir):** `struct dirent *readdir(DIR *dirp);`
    - `dirp` - directory stream
    - Returns a pointer to a dirent structure representing the next directory entry in the directory stream
    - Returns NULL on reaching the end of the directory stream
  - **Syntax (closedir):** `int closedir(DIR *dirp));`
    - `dirp` - directory stream
    - Returns 0 if successful
    - Returns -1 otherwise

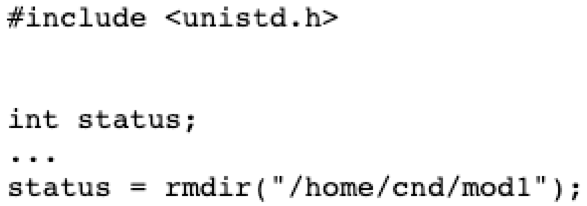
Example



```
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;
}
```

- rmdir (Deleting Directories)
    - Removes a directory whose name is given by path
    - Is performed only when directory is empty
    - Is included in `<unistd.h>` library
    - Fails if is symbolic link
    - **Syntax:** `int rmdir(const char *path)`
        - `path` - path of directory
    - Returns 0 if successful
    - Returns -1 if error

Example



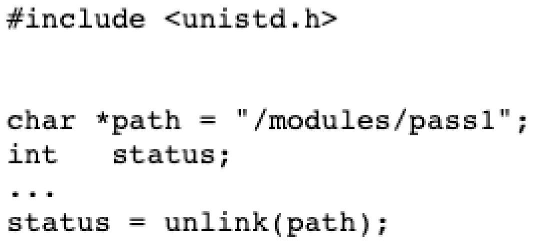
```
#include <unistd.h>


int status;
...
status = rmdir("/home/cnd/mod1");
```

- `unlink` (Remove file)
    - Remove a link to a file
    - Is called **unlink** because it decrements **reference count** in inode
        - Deletes file completely when reference count within the inode number is 0
    - **Syntax:**

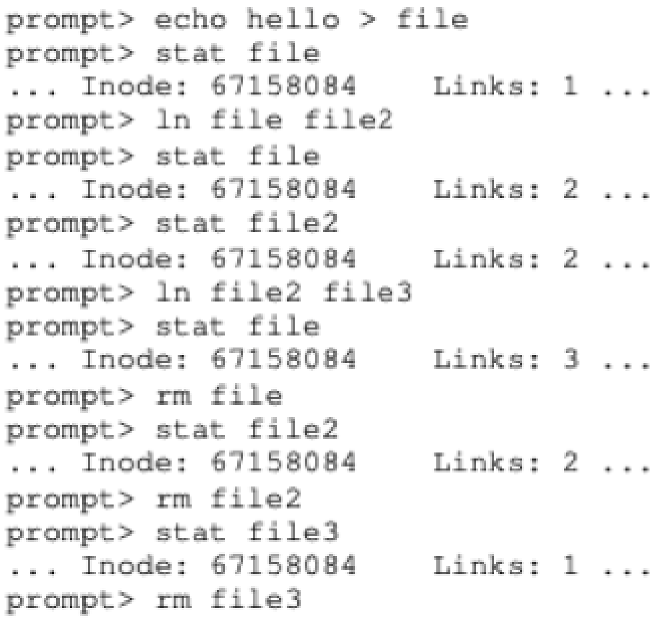
      ```
      #include <unistd.h>

      int unlink(const char *pathname);
      ```

        - `pathname` - pathname to file
    - Returns 0 if successful
    - Returns -1 if error
    - Is used by linux command `rm`

Example



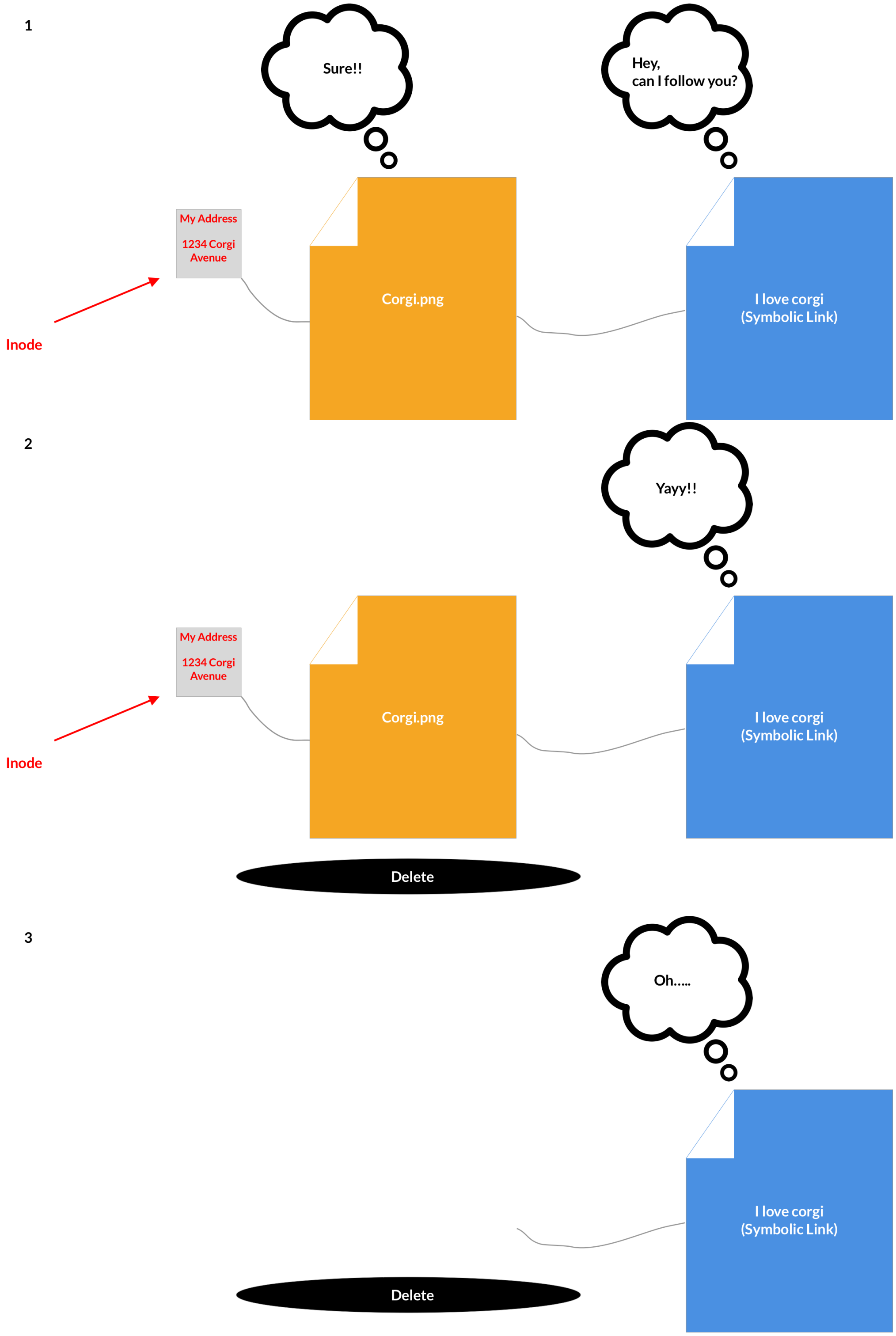
```
#include <unistd.h>


char *path = "/modules/pass1";
int   status;
...
status = unlink(path);
```



```
prompt> echo hello > file
prompt> stat file
... Inode: 67158084    Links: 1 ...
prompt> ln file file2
prompt> stat file
... Inode: 67158084    Links: 2 ...
prompt> stat file2
... Inode: 67158084    Links: 2 ...
prompt> ln file2 file3
prompt> stat file
... Inode: 67158084    Links: 3 ...
prompt> rm file
prompt> stat file2
... Inode: 67158084    Links: 2 ...
prompt> rm file2
prompt> stat file3
... Inode: 67158084    Links: 1 ...
prompt> rm file3
```

3 Symbolic Link:

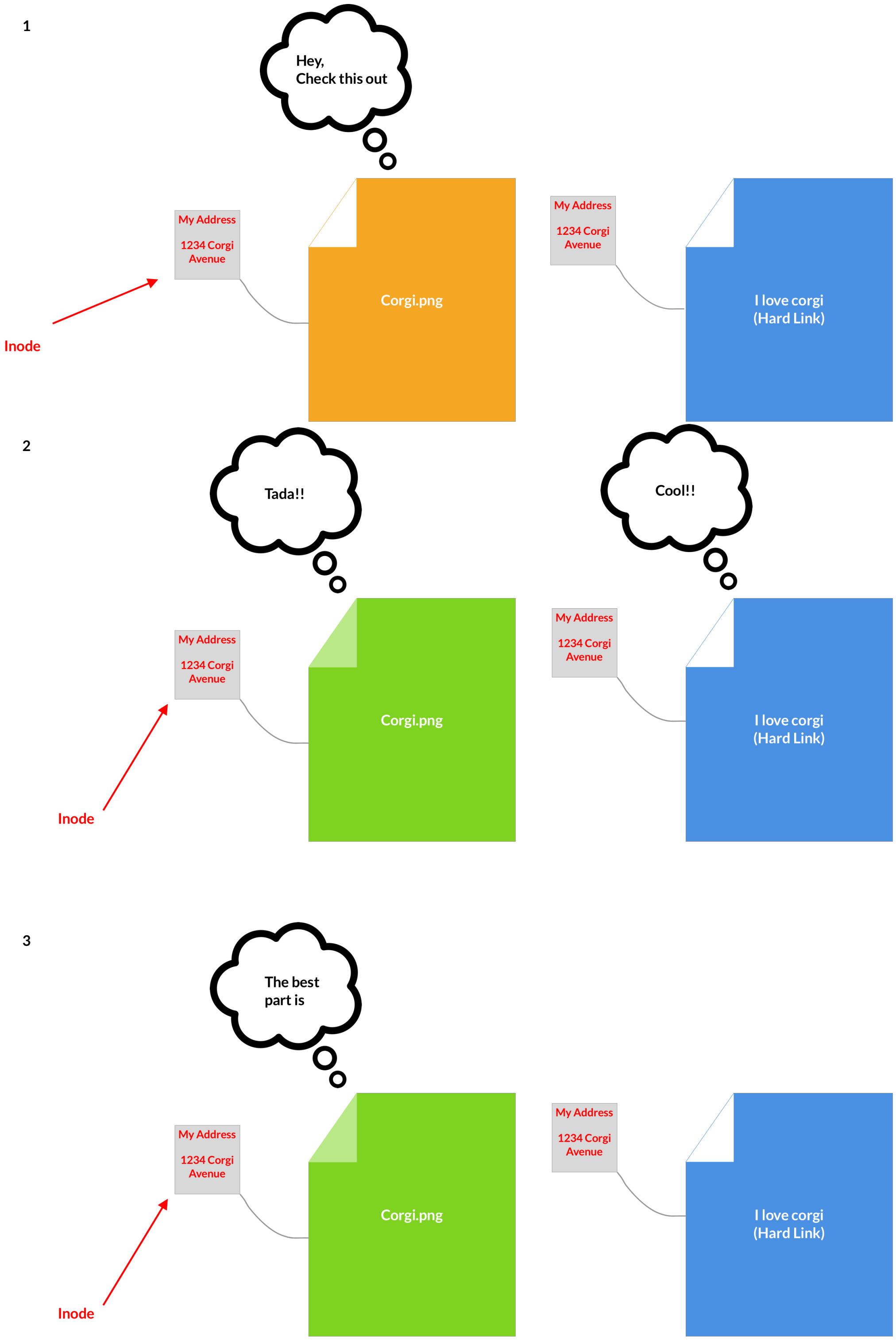
- Is directory entry containing "true" path to the file
- Is a shortcut that reference to a file instead of inode value [2]

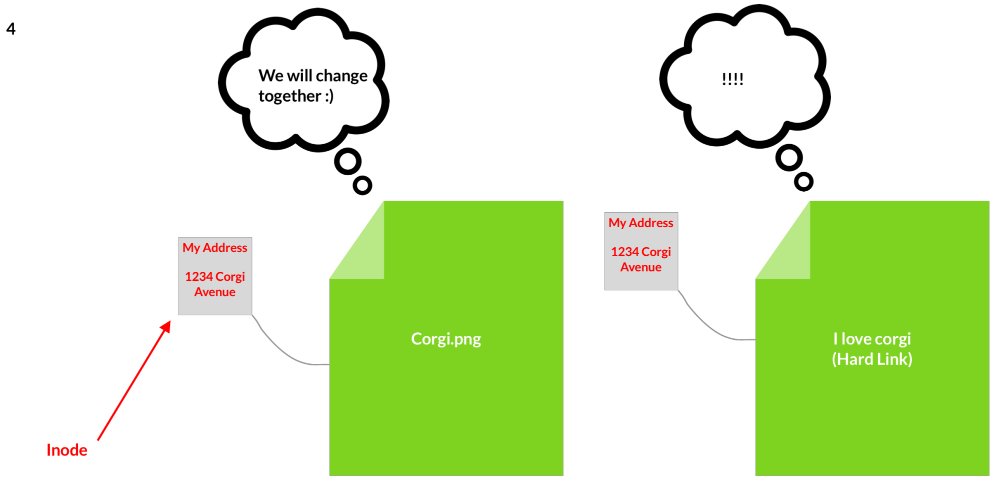


4 Hard Link:

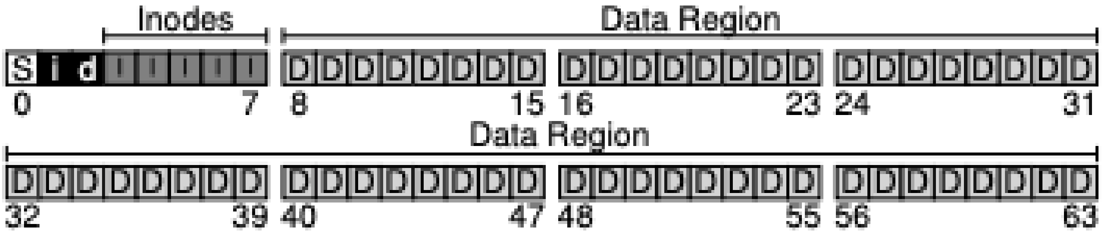
- Is a direct reference to a file via its inode [2]

- Is second directory entry identical to first





5 Index-based File System



- Has following parts
  - Superblock
  - Inode Bitmap
  - Data Bitmap
  - Inodes
  - Data Region
- Each block in file system is 4KB
- Uses a large amount of metadata per file (especially for large files)

6 Kilobyte

- 1 kilobyte is 1024 bytes

7 file

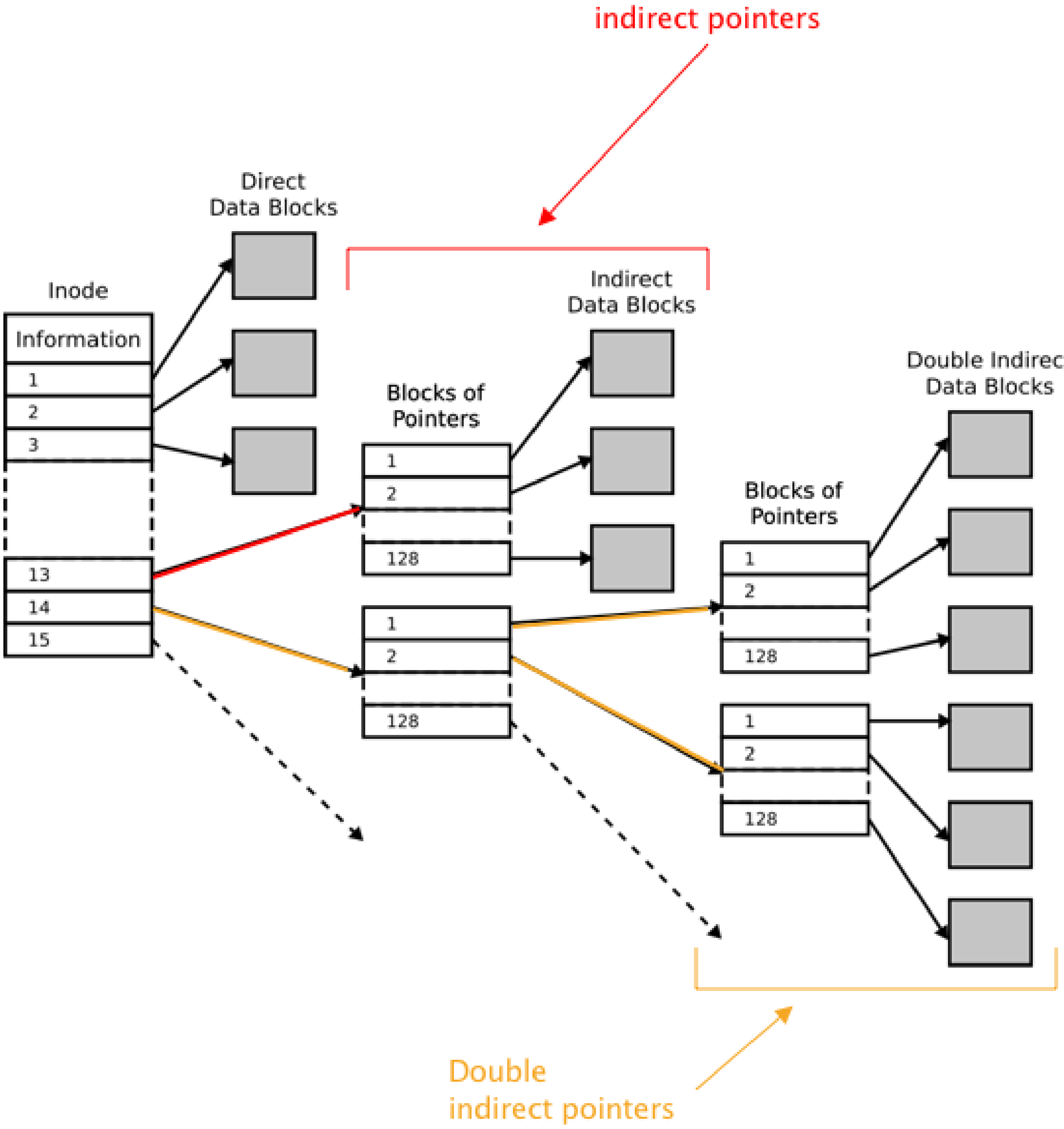
- is an array of bytes which can be created, read, written and deleted
- low-level name is called **inode number** or **i-number**

8 Indirect Pointers

- Is allocated to data-block if file grows large enough
- Has total size of 4 KB or 4096 bytes
- Has $4096/4 = 1024$ pointers
- Each pointer points to 4KB data-block
- File can grow to be $(12 + 1024) \times 4\text{K} = 4144\text{KB}$

9 Double Indirect Pointers

- is allocated when single indirect pointer is not large enough
- each pointer in first pointer block points to another pointer block
- has 1024^2 pointers
- each of 1024^2 pointers point to 4KB data block
- File can grow to be $(12 + 1024 + 1024^2) \times 4\text{K} = 4198448\text{KB}$ or $\approx 4.20\text{GB}$



10 Triple Indirect Pointers

- is allocated when double indirect pointer is not large enough
- has 1024^3 pointers
- each of 1024^3 pointers point to 4KB data block
- File can grow to be $(12 + 1024 + 1024^2 + 1024^3) \times 4K = 4299165744KB$ or $\approx 4.00TB$

11 Static Partitioning

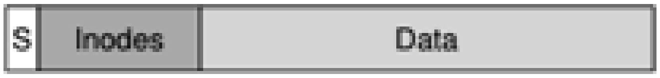
- Divides resources into fixed proportion once
  - e.g. two possible users of memory → give fraction of memory to one user and rest to the other
- Advantages
  - Ensures each user receives some share of the resource
  - Delivers more predictable performance (usually)
  - Easier to implement
- Disadvantages
  - Is wasteful
  -

12 Dynamic Partitioning

- Gives out different amounts of resources over time
- Lets resource-hungry users consume idle resources
- Advantages
  - Flexible
  - Can achieve better utilization than **static partitioning**
- Disadvantages
  - More complex to implement
  - Could lead to worse performance
    - e.g idle resource got consumed by others and take long time to reclaim it when needed (the perodic frozen feeling when loading screen)

13 Old UNIX File system

- was simple, and looked like the following on disk



- has terrible performance

- suffers from **external fragmentation**
- had small data block (512 bytes) and transfer of data took too long

14 FFS Policies: Allocating Files and Directories

- Basic Idea: keep related stuff together, and keep related stuff far apart
- Directories Step
  1) Find the **cylinder group** with a low number of allocated directories and a high number of free inodes
     - low number of allocated directories → to balance directories across groups
     - high number of free nodes → to subsequently be able to allocate a bunch offiles
  2) Put directory data and inode to the **cylinder group**
- Files Step
  1) Allocate the data blocks of a file in the same **cylinder group** as its inode
  2) Place all files in the same directory in the cylinder group of the directory they are in

     Example

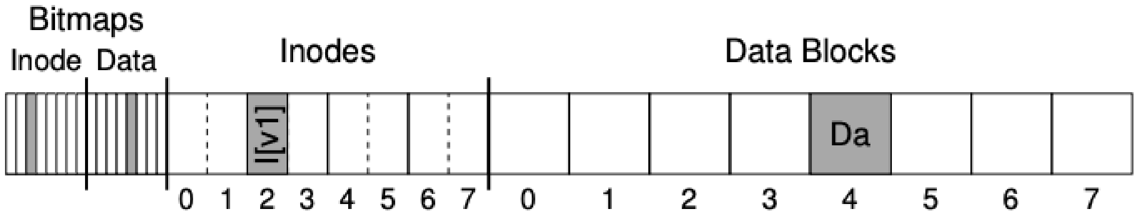
     On putting `/a/c`, `/a/d`, `/b/f`, FFS would place
     - `/a/c`, `/a/d` as close as possible in the same **cylinder group**,
     - `/b/f` located far away (in some other **cylinder group**)

15 Crash Consistency

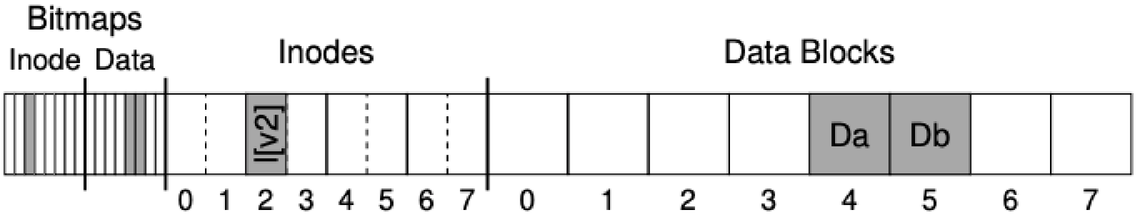
- Goal: How to update persistent data structures despite the presence of a **power loss** or **system crash**?

16 Crash Scenarios

Before



After



1) Just the data block (Db) is written to disk

- No inode that points to it
- No bitmap that says the block is allocated
- It is as if the write never occured
- There is no problem here. All is well. (In file system's point of view)

2) Just the updated inode (I[v2]) is written to disk

- Inode points to the disk where `Db` is about to be written
- No bitmap that says the block is allocated
- No `Db` is written
- Garbage data will be read
- Also creates **File-system Inconsistency**
  - Caused by on-disk bitmap telling us Db 5 is not allocated, but inode saying it does

3) Just the updated bitmap (B[v2]) is written to disk

- Bitmap indicates tht block 5 is allocated
- No inode exists at block 5
- Creates **file-system inconsistency**
- Creates **space-leak** if left as is
  - block 5 can never be used by the file system

4) Inode (I[v2]) and bitmap (B[v2]) are written to disk, and not data

- File system metadata is completely consistent (in perspective of file system)
- Garbage data will be read

5) Inode (I[v2]) and data block (Db) are written, but not the bit map

- Creates **file-system inconsistency**
- Needs to be resolved before using file system again

6) Bitmap (B[v2]) and data block (Db) are written, but not the inode (I[v2])

- Creates **file-system inconsistency** between inode and data bitmap
- Creates **space-leak** if left as is
  - Inode block is lost for future use
- Creates **data-leak** if left as is
  - Data block is lost for future use

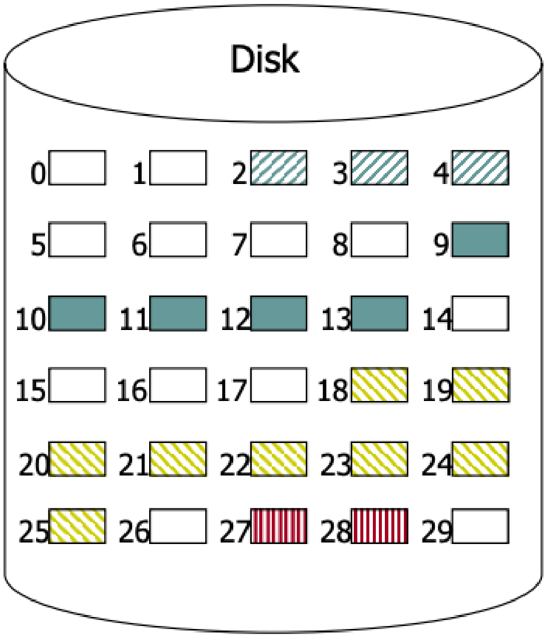
17 External Fragmentation

- Is various free holes that are generated in either your memory or disk space. [8]
- Are available for allocation, but may be too small to be of any use [8]

18 Internal Fragmentation

- Is wasted space within each allocated block [8]
- Occurs when more computer memory is allocated than is needed

19 Extent Based File System



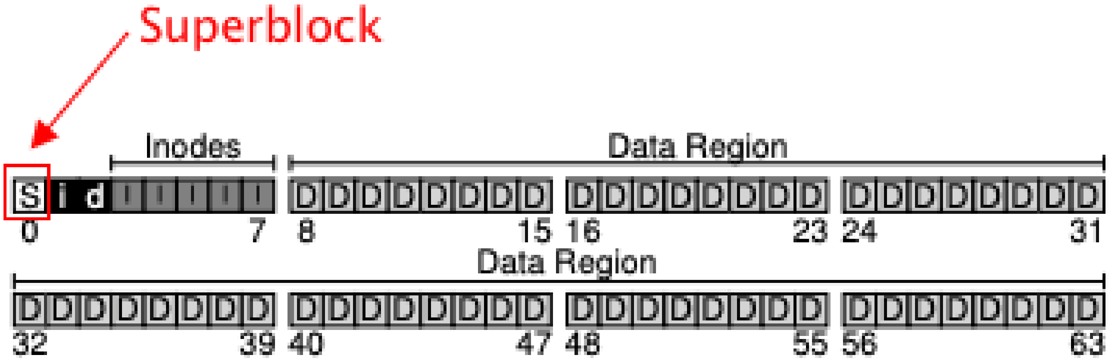
directory

File Name	Start Blk	Length
File A	2	3
File B	9	5
File C	18	8
File D	27	2

- Is simply a disk pointer plus a length (in blocks)
  - Together, is called **extent**
- Often allows more than one extent
  - resolve problem of finding continuous free blocks
- Is less flexible but more compact
- Works well when there is enough free space on the disk and files can be laid out contiguously

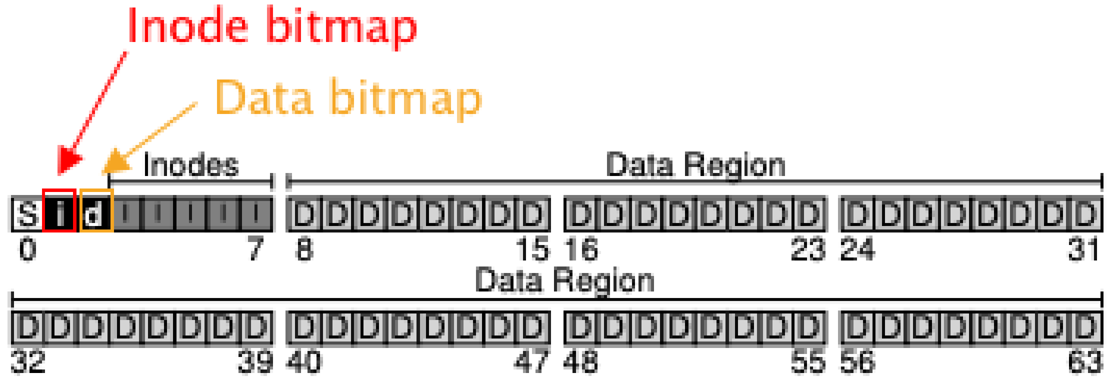
20 File System Implementation

21 Superblock



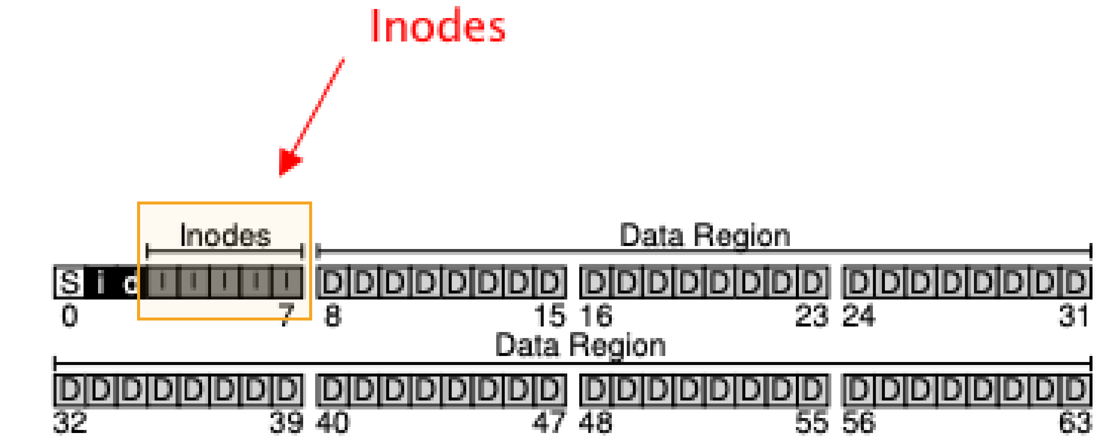
- Contains information about the following
  - The number of inodes and data blocks in a particular file system
  - The magic number of some knd to identify the file system type
  - Where the inode table begins
- Is read first on mount before attaching to file system

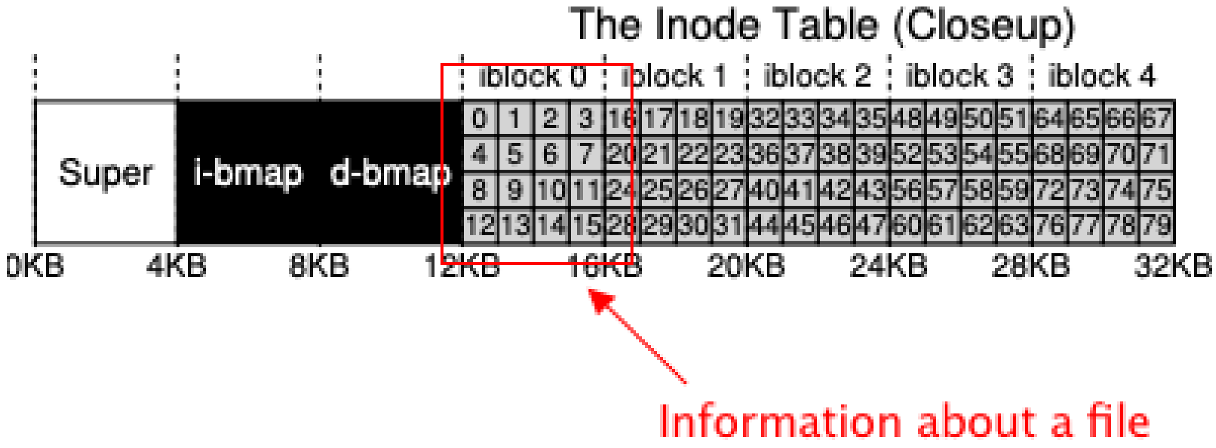
21.1 Inode/Data bitmap



- Accessed only when allocation/deallocation is needed
  - `Read()` → no bitmap required
- Uses bit to indicate whether the corres object/block is free
  - 0 means free
  - 1 means in use

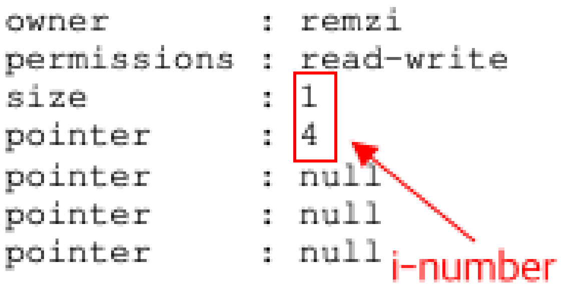
21.2 Inode





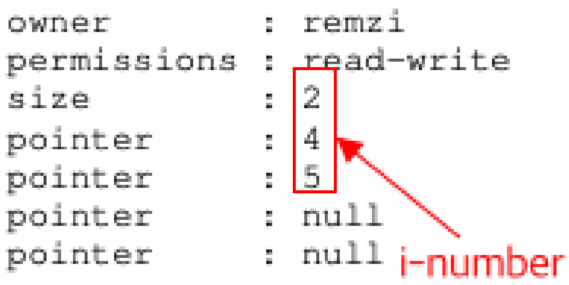
- Is a short form for **index node**
- Contains all the information you need about a file (i.e. metadata)
  - File Type
    - e.g. regular file, directory, etc
  - Size
  - Number of blocks allocated to it
  - Protection information
    - such as who owns the file, as well as who can access it
  - Time information
    - e.g. When file was created, modified, or last accessed
  - Location of data blocks reside on disk
- total size may vary

- inode pointer has size of 4 byte
- Has 12 **direct pointers** to 4KB data blocks
- Has 1 **indirect pointer** [when file grows large enough]
- Has 1 **double indirect Pointer** [when file grows large enough]
- Has 1 **triple indirect Pointer** [when file grows large enough]
- Inode before update



```
owner        : remzi
permissions  : read-write
size         : 1
pointer      : 4
pointer      : null
pointer      : null
pointer      : null
```

- Inode after update

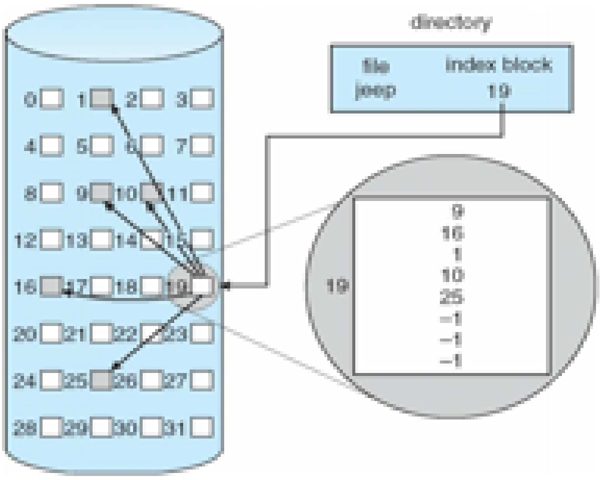


```
owner        : remzi
permissions  : read-write
size         : 2
pointer      : 4
pointer      : 5
pointer      : null
pointer      : null
```

22 Data Block

- Size of each block is 4KB

22.1 Index Based File System

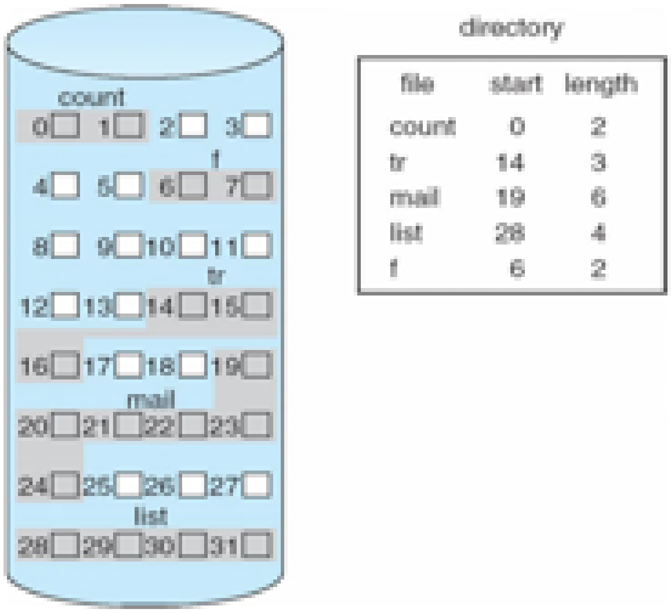


- Has 15 blocks of pointers that points to either inode, indirect pointers, or data block
- No external fragmentation
- Files can be easily grown

Example

Linux's ext2, ext3

22.2 Extent Based File System



directory

file	start	length
count	0	2
tr	14	3
mail	19	6
list	28	4
f	6	2

- Requires only a disk pointer + length (in blocks)
- Is also called **contiguous allocation**
- Stores starting block and total length
- Is less flexible but more compact
- Works well when there is enough free space on the disk and files can be laid out contiguously

  Example

  Linux's ext 4

- Advantage
  - Is simple
    - Finding data block = beginning of data block + length
- Disadvantage
  - Growing file size could cause problems
  - Fragmentation

22.3 Reading a File from Disk

Example

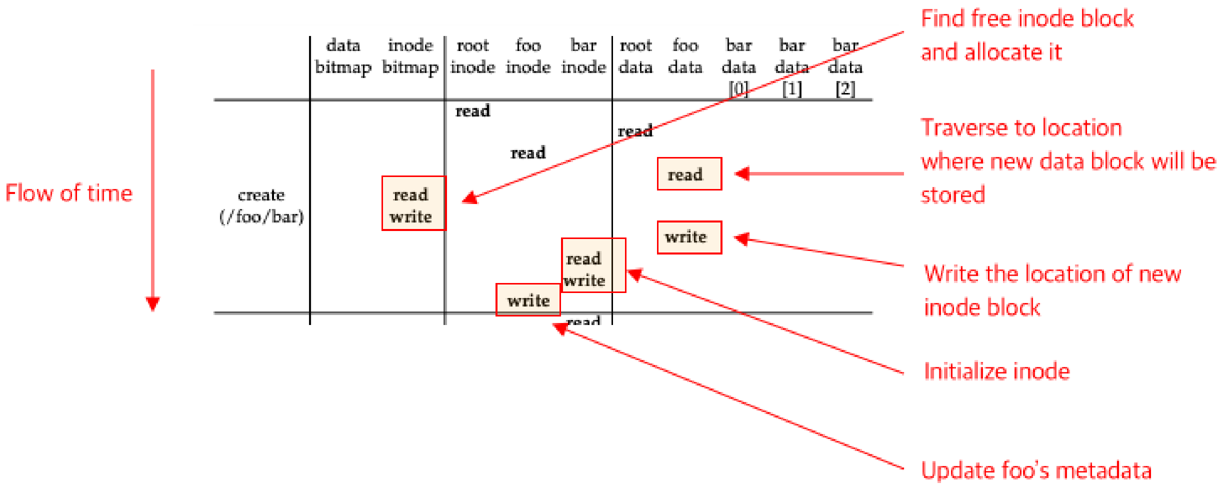
When

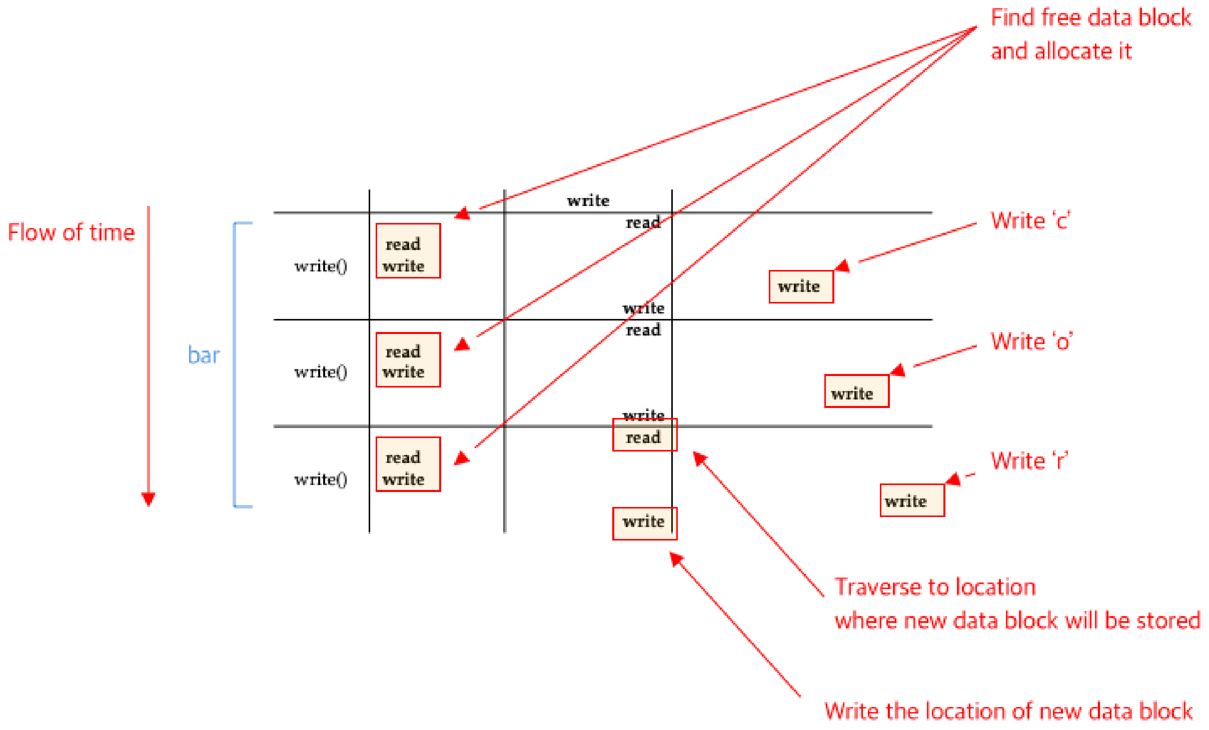
`open("/foo/bar", O_READONLY)`

is called

- the goal is to find the inode of the file `bar` to read its basic information (i.e. includes permission, information, file size etc)
- done by traversing the pathname and locate the desired inode
- Steps
  1. Find **inode** of the root directory by looking for **i-number** (or **inode number**)
     - Root directory has no parent directory
     - Root directory's **inode number** is 2 (for UNIX file systems)
  2. Read the **inode** of root directory
  3. Once its **inode** is read, read through its directory data (pointers to **data blocks**) until the inode number of `foo` is found (e.g 42)
  4. Recursively traverse the pathname until the desired inode is found (more specifically, the **inode number** of bar)
  5. Issue a `open()` to read `bar`'s inode to memory
  6. Issue a `read()` system call to read from file `bar`
     - without `lseek()`, reads file from the first file data block (e.g. `bar data[0]`)
     - `lseek(..., offset_amt * size_of_file_block)` is used to offset/move to desired block in `bar`
  7. Trasnfer data to `buf` data block
  8. Read until `read()` returns 0, or desired data block has been read
  9. Close `fd`. No I/O is read.

22.4 Writing to Disk





Given a call

`create(...)` (Note: `open` to be exact)

- 5 I/Os are generated per write

  - Read inode (to traverse to the location of new data block)
  - Reading data bitmap
  - Writing data bitmap
  - Write data block
  - Write inode (to update data block's location in inode)

- 10 I/Os are generated per file creation:
  - Read inode bitmap (to find free inode)
  - Write inode bitmap (to mark it allocated)
  - Create one new inode (to initialize it)
  - Write the location of new inode block in `foo` (by linking high-level name of file `bar` to its inode number and storing in data block)
  - Perform one read and write to the directory inode and update it

22.5 Static Partitioning

- Divides resources into fixed proportion <u>once</u>
  - e.g. two possible users of memory → give fraction of memory to one user and rest to the other
- Advantages
  - Ensures each user receives some share of the resource
  - Delivers more predictable performance (usually)
  - Easier to implement
- Disadvantages
  - Is wasteful
  -

22.6 Dynamic Partitioning

- Gives out different amounts of resources over time
- Lets resource-hungry users consume idle resources
- Advantages
  - Flexible
  - Can achieve better utilization than **static partitioning**

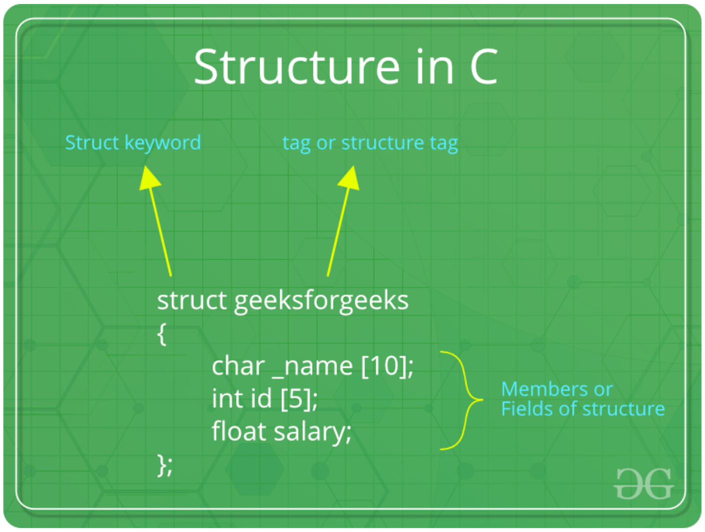
- Disadvantages
  - More complex to implement
  - Could lead to worse performance
    - e.g idle resource got consumed by others and take long time to reclaim it when needed (the perodic frozen feeling when loading screen)

Example

Linux's ext4 file system

23 Fields

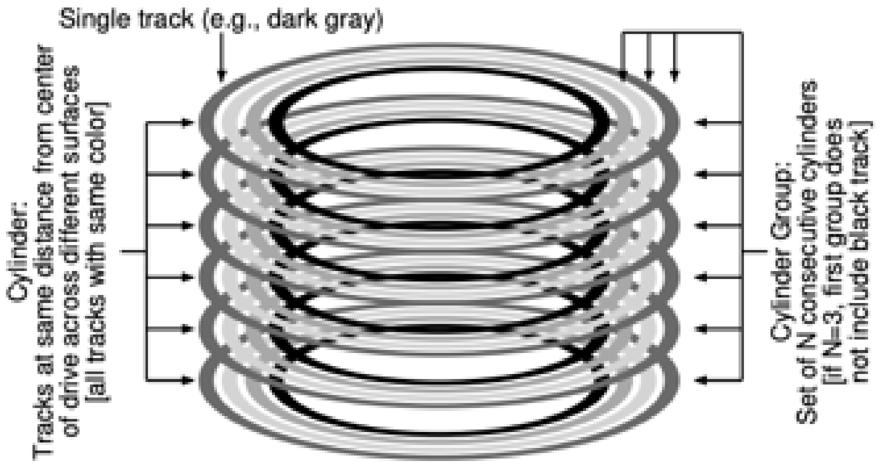
- Is the members in a structure



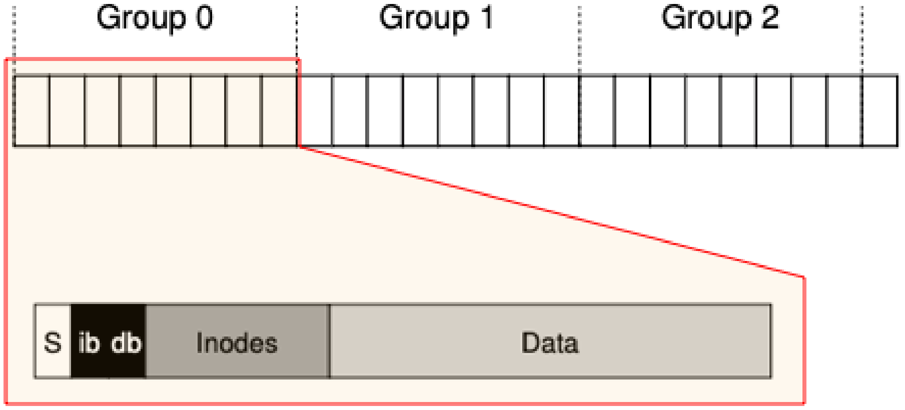
```
struct geeksforgeeks
{
        char _name [10];
        int id [5];
        float salary;
};
```

24 Fast File System

- Modern file system has same APIS (`read()`, `write()`, `open()`, `close()`)
- Divides inode/bitmap tables into chunks and stores in different **cylinder groups**


Single track (e.g., dark gray)
Cylinder:
Tracks at same distance from center
of drive across different surfaces
[all tracks with same color]
Cylinder Group:
Set of N consecutive cylinders
[if N=3, first group does
not include black track]

- Each **block group** or **cylinder group** is consecutive portion of disk's address



- Advantages
  - No external fragmentation
- Disadvantages
  - Extra overhead: creates and updates many intermediary files (inode, data block) during a write

25 Log Structured File System

- Wait. This sounds very similar to **extent-based file system**
- Buffers all updates (including metadata) in an in-memory **segment**, and when segment is full, it is written to disk in one long, sequential transfer to unused part of the disk

- Instead of overwriting files, always writes unused portion of the disk, and reclaim the old space through cleaning
- Motivations
  1. **System memories are growing**
     - Data is cached in memory
     - Reads are serviced by cache
     - Disk traffic is increasingly consists of writes
     - File performance ≈ write performance
  2. **There is a large gap between random I/O performance and sequential I/O performance**
     - More bits stored on hard drive ⇒ bandwith of acessing bits ↑
     - Harder to create cheap, small motors that spin platters faster, and move arm more quickly
  3. **Existing file systems perform poorly on many common workloads**
     - Many intermediary writes performed per data block (e.g. Bitmap, inode, data block)
     - Many short seeks + rotation delays = performance less than the peak
  4. **File systems are not raid aware**
- How it works (Writing to Disk)

  Basic idea: Write all updates (e.g. data blocks inodes) to the disk sequentially (**write buffering**)

  1. Buffer updates in an in-memory **segment**
  2. Write the **segment** all at once sequentially when received sufficient number of updates
- Advatages
  1. Has very high performance
- Disadvantages
  1. Is complex
  2. Generates lots of garbages
  3. Scattered old data. Needs to run **compaction** periodically [2]

26 Crash Consistency Problem: File System Checker

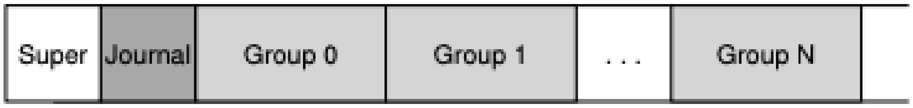
- Desired: **atomic** updates. That is, on crash, the file on write is either in (state 1 - before the file got updated) or (state 2 - after the file got updated)
- Reality: This is not possible
- Is the reason why computers have 'Don't turn off computer' message

26.1 File System Checker

- Basic Idea: Let inconsistencies happen and fix them later (when rebooting)
- Is used by UNIX tool **fsck** ('file system checker')
- Summary of how it works
  - **Inode State**
    - Corruption in file is checked (e.g. does it have valid file type such as directory file, or links)
    - Solved by removing it, and updating the bitmap if inode cannot be fixed easily
  - **Inode links**
    - Number of references in each inode is checked
    - Check is done by reading the entire directory tree and building its own link count
    - Solved by fixing the count if there is mismatch, or by moving to `lost+found` directory if there is no directory refers to it
  - **Duplicates**
    - Duplicate pointers (i.e. two different inodes pointing to same block) is checked
    - Solved by either removing one of two inodes, or creating a copy for each
  - **Bad Blocks**
    - A pointer that points to something outside is partition is checked
    - Solved by removing the block
  - **Directory Checks**
    - Making sure that `.` and `..` are first entry is checked
    - Allocation of inodes referred to in a directory entry is checked
    - Making sure that no directory is linked more than once is checked
- Disadvantage
  - Way too slow. May take Hours.
  - Wasteful (Make mistake once, and check everything)
  - Doesn't solve all problems (e.g. inode with incorrect data blocks)

27 Journaling

- Is a popular solution to **crash-consistency problem**
- Many file systems use this idea (e.g. ext3, ext4, windows NTFS)
- Basic idea
  - before overwriting the structures in place, write down (in a well-known location) a little note of what you are about to do
  - If crash occurs, read note and try again



- Advantage
  - Greatly reduces amount of work required during recovery

27.1 Transaction Beginning (TxB)

- Where does computer read update instruction (journal ? journal superblock ?)?
- In data Journaling, where is comitted data generated and stored prior to putting it in file system?
- Includes information about current update
- Contains **Transaction Identifier** or TID

27.2 Transaction End (TxE)

- Is marker of the end of transaction
- Also contains **Transaction Identifier** or TID

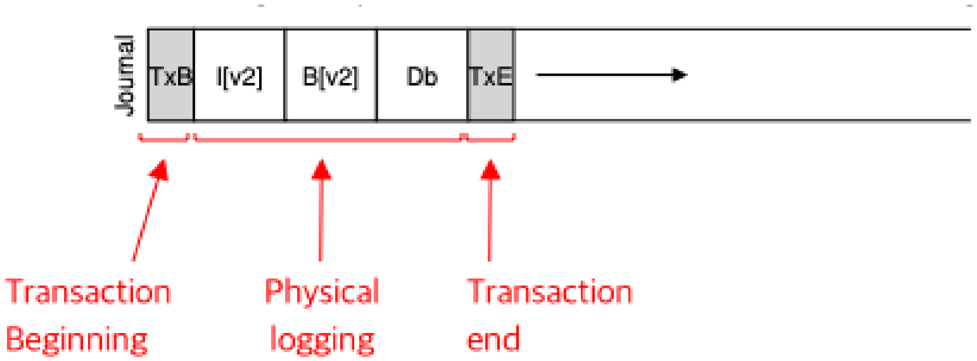
27.3 Checkpointing

- Act of overwriting of old structure in the file system between **transaction beginning** and **transaction end**

27.4 Journaling Superblock

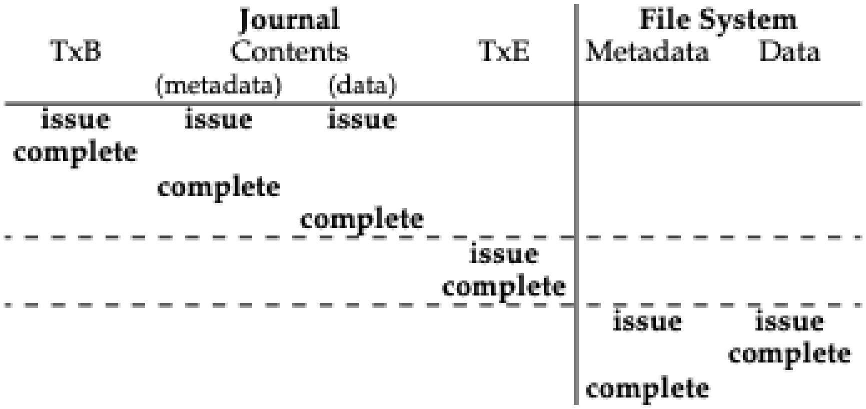
- Records information on which transactions have not yet been checkpointed
- Oldest and newest non-checkpointed transactions exist here
- Is different from file system superblock

27.5 Data Journaling



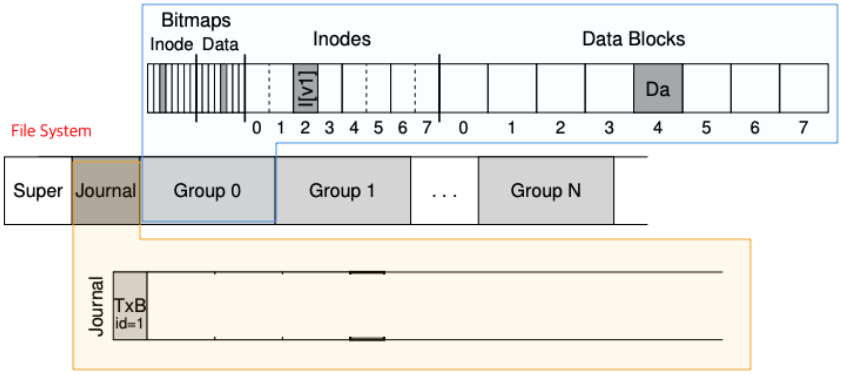
Important Is written to journal before putting onto file system!!!

- Steps

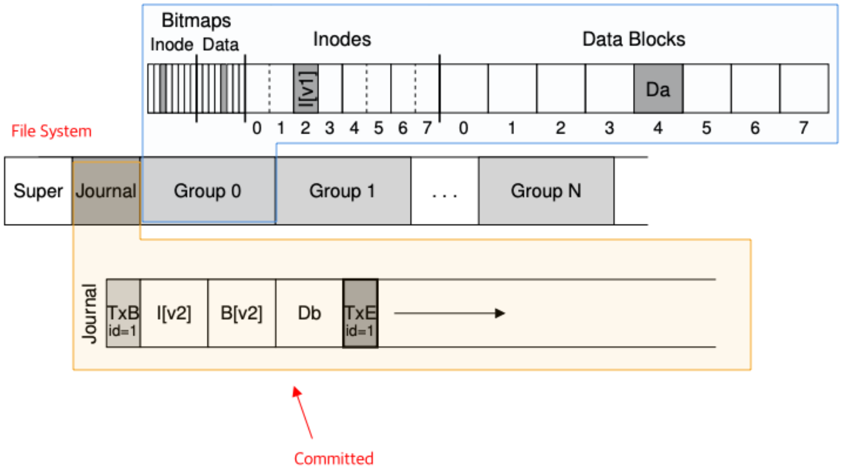


TxB	Journal Contents (metadata)	(data)	TxE	File System Metadata	Data
issue	issue	issue			
complete					
	complete				
		complete			
			issue		
			complete		
				issue	issue
					complete
				complete	

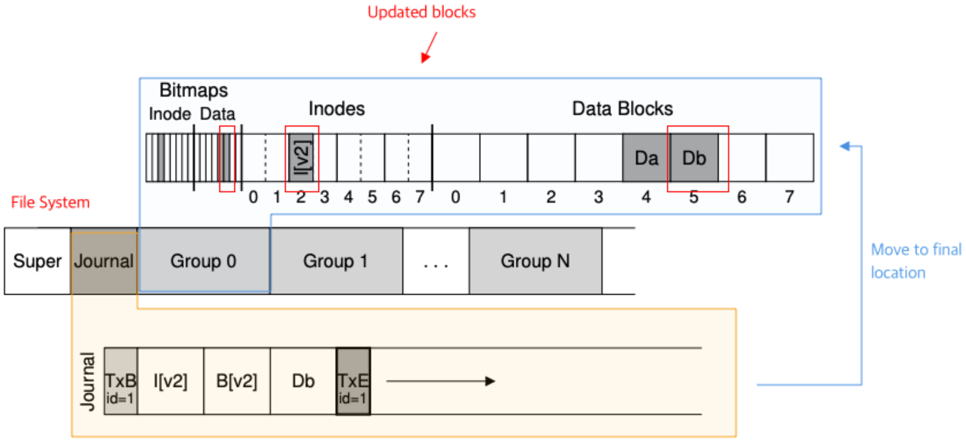
1. **Journal Write**: Write the contents of the transaction (including TxB, metadata and data) to log



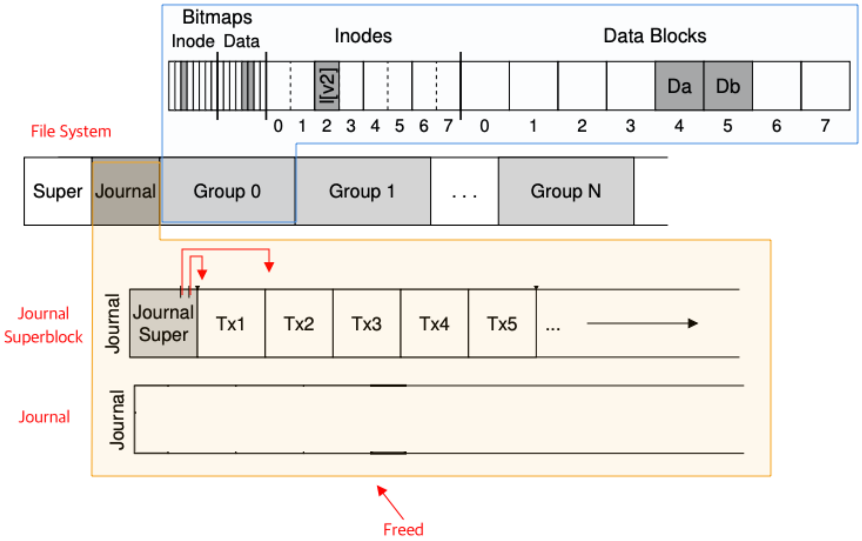
2. **Journal Commit:** Write the transaction commit block (containing TxE) to log; wait wait for write to complete
   - After this, transaction is **committed**



3. **Checkpoint:** Write the contents of the update (metadata and data) to their final on-disk location



4. **Free:** Mark the transaction free in the journal by updating the journal superblock

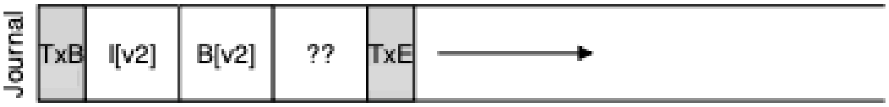


5. Repeat until done

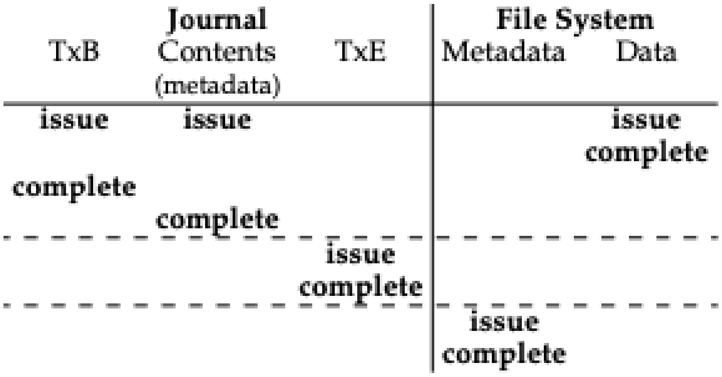
- Disadvantage
  - Each data block is written twice
- Recovery Steps
  - Crash at step 1 → skip pending update
  - Crash during step 2 and 3 → replay the update
    - Happens during boot

27.6 Metadata Journaling

- Goal: Reduce number of writes
- Data block is written to file system first
- Metadata (inode and bitmap information) are written to journal before checkpoint
- Is order dependent
  - e.g. I[v2] and B[v2] make to disk and data block does not
  - If data block is a garbage data, file-system will assume all is okay
  - Writing data block first guarentees that a pointer will never point to garbage

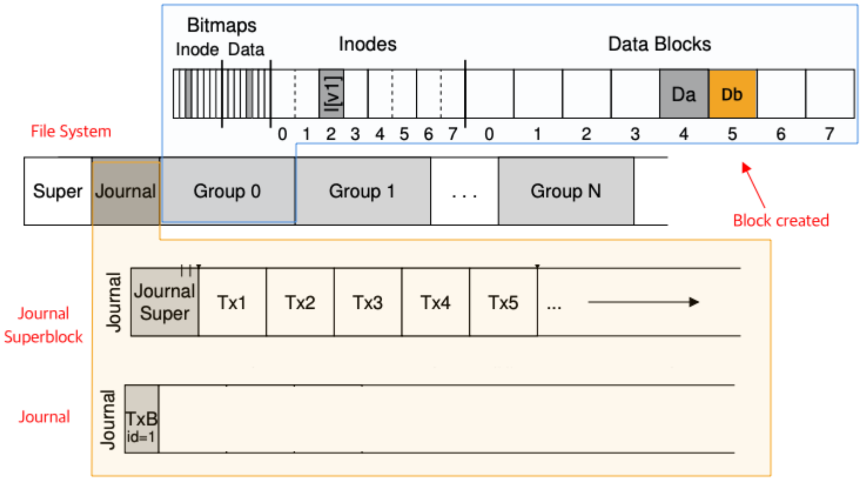


- Steps

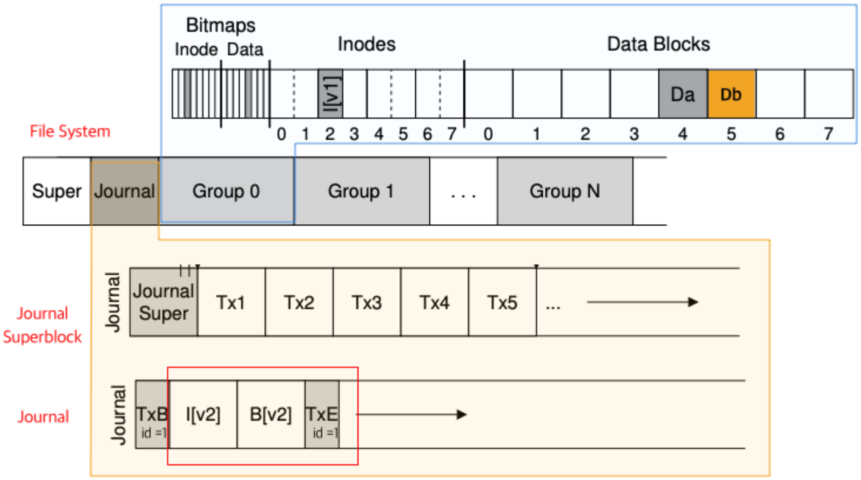


TxB	Journal Contents (metadata)	TxE	File System Metadata	File System Data
issue	issue			issue
				complete
complete				
	complete			
		issue		
		complete		
			issue	
			complete	

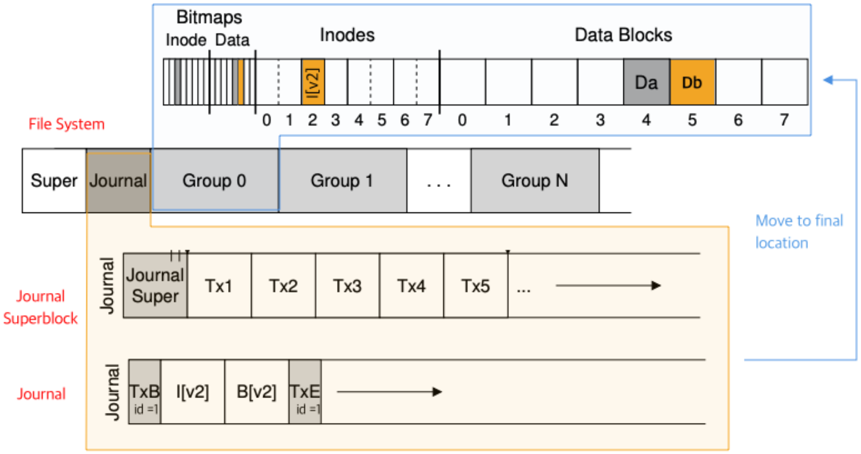
1. **Data Write:** Write data to final location; wait for completion



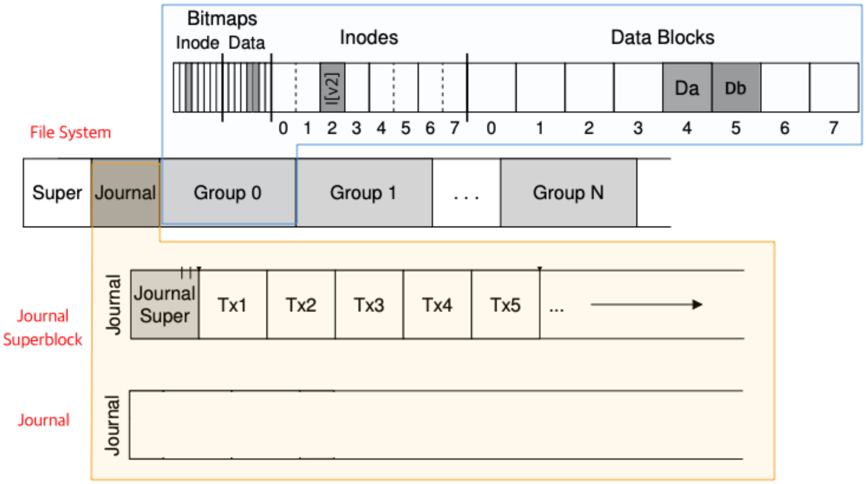
2. **Journal Metadata Write:** Write the begin block and metadata to the log; wait for writes to complete
3. **Journal Commit:** Write the transaction commit block (containing TxE) to the log; wait for the write to complete



4. **Checkpoint Metadata:** Write the contents of the metadata update to their final locations within the file system



5. **Free:** Mark the transaction free in journal superblock



- Block Reuse
  - Never reuse blocks until checkpointed out of the journal
- Advantage
  - Solves double write problem in **data journaling**