ITP 30002 Operating System

File System Implementations

Chapters 40 and 41

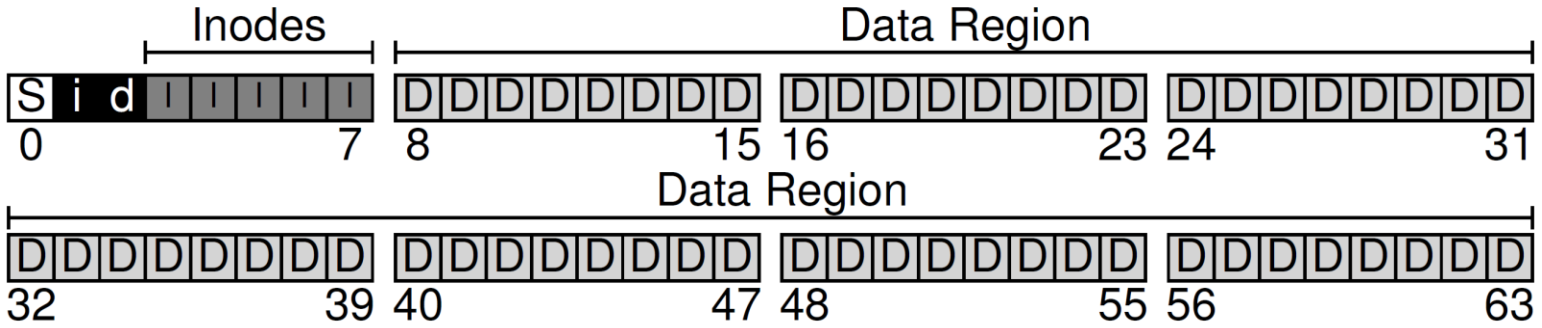
Shin Hong

Very Simple File System

- A simplified imitation of the UNIX file systems to build a mental model to understand the data structure and the operations of the file systems

- On-disk organization
  - a disk partition consists of an array of *N* blocks, each of size 4 KB
  - four regions: **data region** to hold user data, **inode table** to hold metadata, **inode bitmaps**, and **superblock**

- Example
  - 64 blocks where 5 blocks are for inode and 56 for data region
    - 256 bytes per inode, thus, total 80 inodes can be accommodated
  - one block for data bitmap, one for inode bitmap and one for superblock

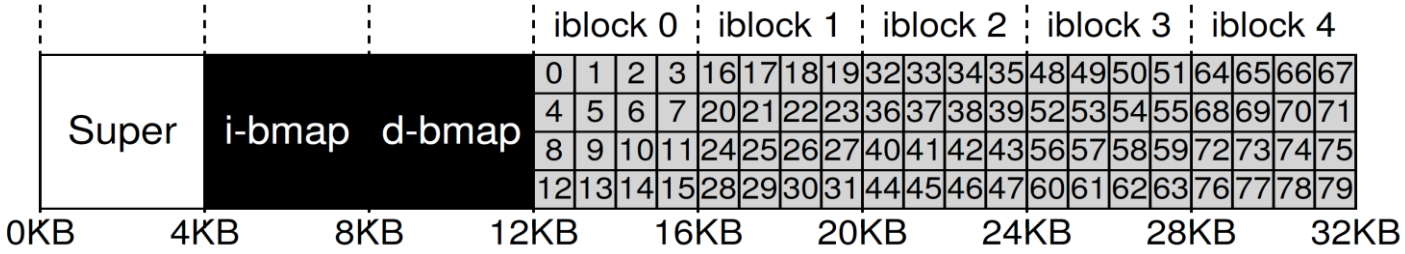


Inode (1/2)

- Each inode (index node) is referred to by a unique number (identifier)
- The metadata of a file is written on a single inode
  - Ex. inode structure for ext-2

Size	Name	What is this inode field for?
2	mode	can this file be read/written/executed?
2	uid	who owns this file?
4	size	how many bytes are in this file?
4	time	what time was this file last accessed?
4	ctime	what time was this file created?
4	mtime	what time was this file last modified?
4	dtime	what time was this inode deleted?
2	gid	which group does this file belong to?
2	links_count	how many hard links are there to this file?
4	blocks	how many blocks have been allocated to this file?
4	flags	how should ext2 use this inode?
4	osd1	an OS-dependent field
60	block	a set of disk pointers (15 total)
4	generation	file version (used by NFS)
4	file_acl	a new permissions model beyond mode bits
4	dir_acl	called access control lists

- ex. inode table layout



Inode (2/2)

- Indirect pointer
  - To accommodate a large file, an inode may use one data block to hold a set of direct pointers each of which points to a data block
  - Ex. 1-level indirect pointer
    - an inode have 12 direct pointers and 1 indirect pointer
    - for 4-byte block addresses, one block can hold 1024 direct pointers through which a file can grow upto 1036 X 4 KB size
  - Ex. 2-level indirect pointer (e.g., ext2, ext3)
    - the indirect pointer of an inode points to a block of indirect pointers each of which points to another block of direct pointers
    - for 4-byte block address, a file can grow upto 1024 X 1024 X 4 KB size

Directory Organization

- A directory is a list of entry name-inode number pairs
  - a directory is treated as a special type of file, thus the content resides in the data blocks
  - example

```
inum | reclen | strlen | name
   5      12        2     .
   2      12        3     ..
  12      12        4     foo
  13      12        4     bar
  24      36       28     foobar_is_a_pretty_longname
```

Free Space Management

- vsfs tracks free inodes using inode bitmap and data bitmap

- operations involved in a file creation
  1. search for a free inode in the inode bitmap, and allocate it to the file
  2. mark the corresponding inode bit (in the inode bitmap) as used
  3. search for a free data block in the data bitmap, and allocate it to the file
  4. mark the corresponding data bit (in the data bitmap) as used

- Some OS's pre-allocate a sequence of free blocks (e.g., 8) when a file is created.
  - to guarantee a portion of the file to be contiguously aligned

Access Path (1/2)

- Assumption
  - the superblock was already on the main memory when the file system is mounted
  - the other blocks are all placed on the disk

- Reading a file from a disk
  - Ex. `open("/foo/bar", O_RDONLY)`
    - find the inode for '/' by checking the superblock attributes (usually, 2)
    - read the inode for '/'; read the inode and iterate over the list to find a direntry for 'foo'; find the inode for 'foo'
    - read the inode for 'foo' to find the inode for 'bar'
    - read the inode of 'bar'; check that all permissions are alright for the user.
    - allocate a file descriptor in the open file table and returns the descriptor

	data bitmap	inode bitmap	root inode	foo inode	bar inode	root data	foo data	bar data [0]	bar data [1]	bar data [2]
open(bar)			**read**			**read**				
				read			**read**			
					read					
read()					**read**			**read**		
					write					
read()					**read**				**read**	
					write					
read()					**read**					**read**
					write					

Access Path (2/2)

- Writing to a file
  1. open a file
     - create a file if the file does not exist
  2. write data
     - allocate a new data block if it is not overwriting
     - update the file size at the inode

- Ex. writing to `/foo/bar`
  - 10 block accesses for a file creation
  - 5 block accesses for each block allocation

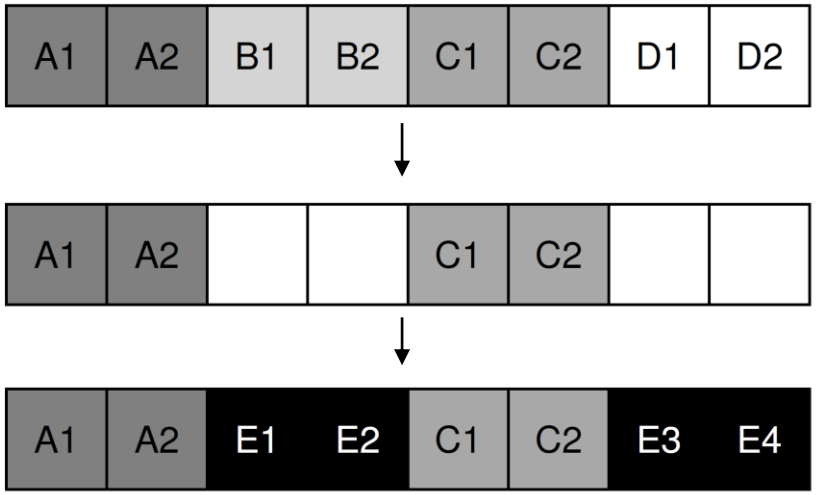
	data bitmap	inode bitmap	root inode	foo inode	bar inode	root data	foo data	bar data [0]	bar data [1]	bar data [2]
create (/foo/bar)		**read write**	**read**	**read**	**read write**	**read**	**read**			
				write			**write**			
write()	**read write**				**read**					
					write			**write**		
write()	**read write**				**read**					
					write				**write**	
write()	**read write**				**read**					
					write					**write**

Caching and Buffering

- Reading/writing files can be expensive for frequent disk block accesses
- File systems use main memory to cache important blocks
  - static partitioning: a fixed-size cache to hold popular blocks (with LRU)
  - dynamic partitioning: integrate virtual memory pages and file system pages into a unified page cache
- Write buffering
  - delay writing to the storage device, and update the buffered status
  - the file system can batch some updates into a small set of I/O operations
  - the file system can have better chance for disk scheduling

Problem of Very Simple File System

- Poor performance since it randomly accesses disk blocks
  - heave seek costs for random accesses
  - careless free space management results in fragmentation
    - example

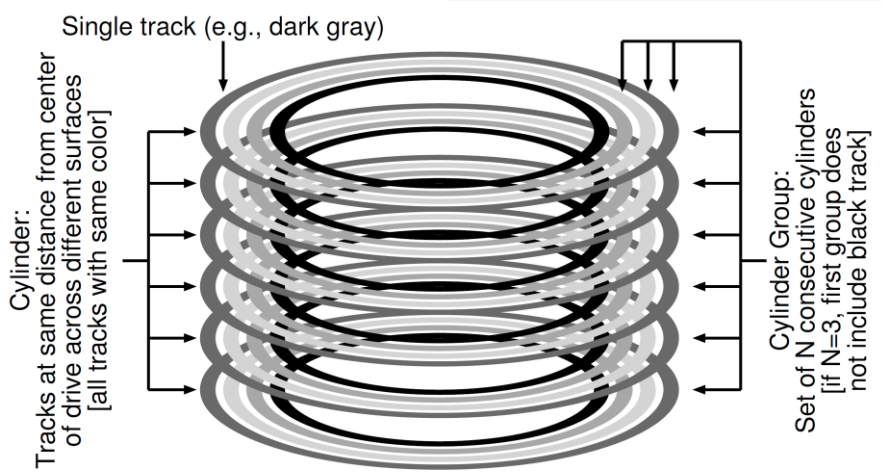


  - small disk block size incures heavy positioning overhead

Fast File System (FFS)

- a file system structure and allocation policies consider the characteristics of disk device for performance optimization

- cylinder group
  - a cylinder is a set of tracks on different surfaces that are the same distance from the spindle
  - FFS aggregates N consecutive cylinders as a cylinder group
  - Accessing two files in a cylinder group will not result in long seek
  - FFS manages a storage device as a set of cylinder groups
    - allocate the related inode, datablocks, and other structures within the same cylinder group



Policies

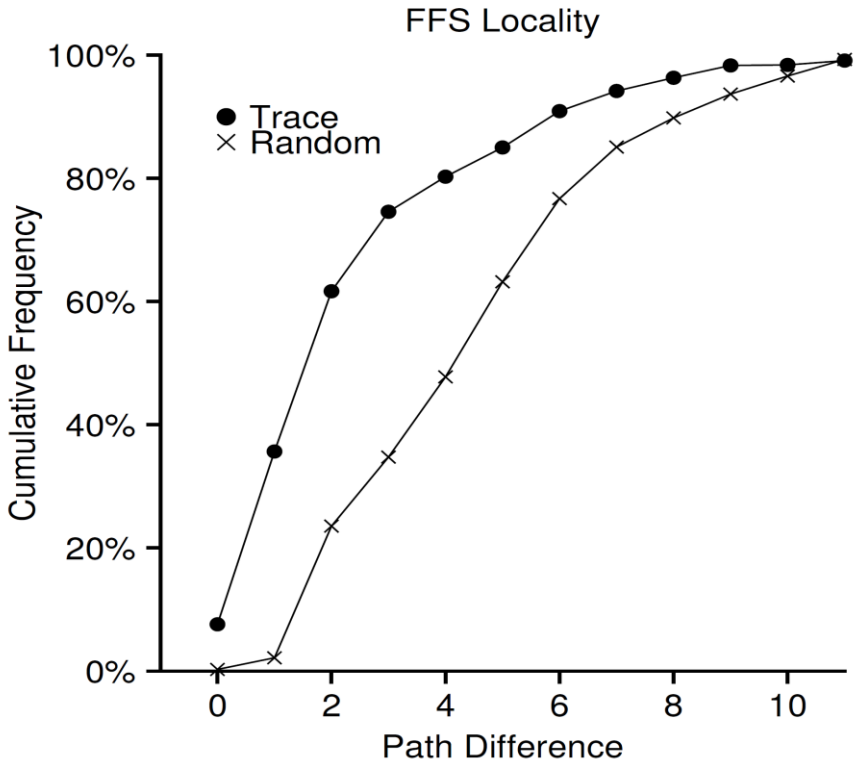
- Collocate related data while keeping unrelated data apart
- Placement heuristics
  - put the inode and the data blocks of the same file (or the same directory) to the same group
  - place all files in a directory to the group where the directory data is placed, because they are often accessed together
  - example: `/a/c, /a/d, /a/e, /b/f`

```
group inodes     data          group inodes     data
    0 /--------- /---------        0 /--------- /---------
    1 acde------ accddee---        1 a--------- a---------
    2 bf-------- bff-------        2 b--------- b---------
    3 ---------- ----------        3 c--------- cc--------
    4 ---------- ----------        4 d--------- dd--------
    5 ---------- ----------        5 e--------- ee--------
    6 ---------- ----------        6 f--------- ff--------
    7 ---------- ----------        7 ---------- ----------
```

File Locality

- It is likely that the next file that a user accesses has a short path difference to the most recently accessed file
  - the path difference between two files is the maximum distance between the common ancestor and each file
  - 0 for the same file, 1 for the two files in the same dir

- The observation from the SEER trace shows that the path difference of more than 60% adjacent file accesses is less than equal to 2



Handling Large File Exceptionally (1/2)

- Without an exceptional handling, a large file will consume a block group and hurt the locality chance of the other files in the same block group
  - E.g.

```
group inodes     data
    0 /a-------- /aaaaaaaaa aaaaaaaaaa aaaaaaaaaa a---------
    1 ---------- ---------- ---------- ---------- ----------
    2 ---------- ---------- ---------- ---------- ----------
```

- For an exceptionally large file, FFS spread the data block across multiple block groups to avoid the file to occupy a single block group
  - E.g.

```
group inodes     data
    0 /a-------- /aaaaa---- ---------- ---------- ----------
    1 ---------- aaaaa----- ---------- ---------- ----------
    2 ---------- aaaaa----- ---------- ---------- ----------
    3 ---------- aaaaa----- ---------- ---------- ----------
    4 ---------- aaaaa----- ---------- ---------- ----------
    5 ---------- aaaaa----- ---------- ---------- ----------
    6 ---------- ---------- ---------- ---------- ----------
```

Handling Large File Exceptionally (2/2)

- How much data should be placed in a block group
  - FFS approach
    - the first twelve (pointed by direct pointers) are placed in the same block group
    - each set of the data blocks pointed through an indirect pointer is placed on a different block group
  - more analytic approach: calculate the chunk size to provide an expected bandwidth
    - e.g., for a disk with 10 ms avg. positioning time and 40 MB/s transfer rate, to provide 50% bandwidth (a half time for seeking, a half time for transfer):

$$\frac{Chunk\ Size}{40\ MB/sec} = 10\ ms$$