File System Implementation pt. 2

Operating Systems

Based on: Three Easy Pieces by Arpaci-Dusseaux

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Directory Organization

- Directory: list of (entry name, inode number) pairs
- Two extra files: “dot” & “dot-dot” for current and parent dirs
  - e.g., `dir` has three files:

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

- File system must track free inodes and data blocks
- In vsfs: two bitmaps
  - New file: search through bitmap for free inode, allocate it
  - **Pre-allocation**: commonly used
    - Look for and allocate contiguous blocks for file

Access Paths

- Open a file (`/foo/bar`), read it, close it
  - Issue an `open(\/foo/bar", O_RDONLY)`
    - **Traverse** pathname to locate desired inode
    - Begin at root: well-known, usually inode 2
    - Read block that contains inode 2
    - Look inside it - read data block to find inode number of `foo`
    - Read inode and data blocks of `foo` to find `bar`
  - Read from the file, repeat:
    - Read `bar` inode to find data block
    - Read data block
    - Write to inode - update access time
  - Close the file

Access Paths

- Writing to a file:
  - Open file (as before)
  - Each write generates five I/Os:
    1. Read data bitmap
    2. Write updated data bitmap (newly-allocated block to use)
    3. Read the inode
    4. Write updated inode with new block location
    5. Write the actual block itself

Access Paths

- Creating a file:
  - Read inode bitmap
  - Write updated inode bitmap with allocated inode
  - Write inode itself
  - Write data to directory containing the file
  - Read and write directory inode to update it
  - Directory needs to grow? Additional I/O
    - To data bitmap, new directory block

Caching and Buffering

- Simple operations: huge number of I/Os
  - e.g., long pathname can lead to hundreds of reads
  - Just to open a file!

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What can a file system do to reduce the costs of many I/Os?

- Use system memory (DRAM) to cache important blocks
  - Early systems used fixed-size cache
    - Static partitioning of memory: can be wasteful
  - Modern systems use **dynamic partitioning**

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  - Cache does not reduce write I/O
- Use **write buffering**
  - Delay writes: **batch** updates to smaller set of I/Os (several updates to inode bitmap)
  - Buffer writes in memory, **schedule** subsequent I/Os
  - **Avoid** writes, e.g., file created and then deleted
- Use `fsync()` to force writes to disk

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- Simple, supports basic abstractions, easy to use
- Problem: terrible performance (2% of disk bandwidth)

UNIX File System

- Disk treated as random-access memory
  - Expensive positioning costs
  - e.g., data blocks of file far away from its inode
- File system **fragmented**
  - Logically contiguous file → back and forth across the disk
- Block size too small (512 bytes)
  - Bad for data transfer
  - Positioning overhead for each block

UNIX File System

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A1	A2	B1	B2	C1	C2	D1	D2

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- Allocate file E, of size four blocks:

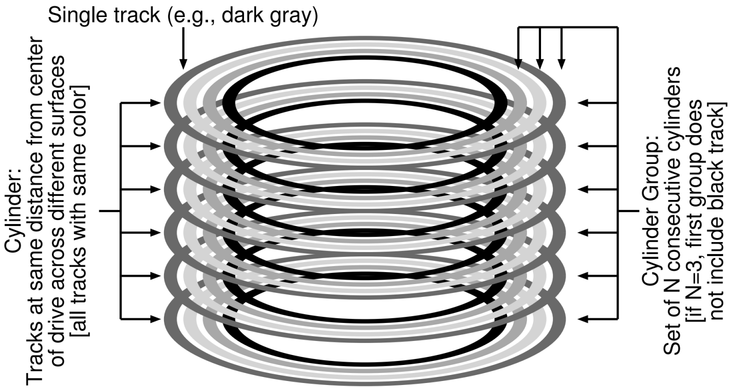
A1	A2	E1	E2	C1	C2	E3	E4

FFS

- **Fast File System**
  - Design structures and allocation to be "disk aware"
- Keep same API
  - `open()`, `read()`, `write()`, `close()`, etc.
  - Change internal implementation
  - Paved the path for new file system construction

Cylinder Group

- FFS divides disk into **cylinders** and **cylinder groups**
  - In modern file systems: **block groups**
  - e.g., Linux ext2, ext3, and ext4



Cylinder Group

- Use groups to improve seek performance
- e.g., place two files within the same group
- Allocate files and directories within each group

G0	G1	G2	G3	G4	G5	G6	G7	G8	G9

Cylinder Group

- Within a single group:
  - Copy of the **super block** (S)
    - For reliability reasons
  - Per-group **inode bitmap** (ib) and **data bitmap** (db)
  - The **inode** and **data block** regions
    - Same as vsfs

Policies

- Keep related stuff together
  - Keep unrelated stuff far apart
- Placement of directories:
  - Find group with low number of allocated directories, high number of free inodes
  - Put directory data and inode in that group
- Placement of files:
  - Allocate data blocks in same group as inode
  - Place files in same group as directory

Policies

- Create 3 dirs (/, /a, /b) and four files (/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   ----------  ----------
    ...                                 ...
    With name locality                  No name locality
```

Large-File Exception

- General policy: exception for large files
  - Entirely fill block group it is placed within
  - Prevents related files from being placed in group

G0	G1	G2	G3	G4	G5	G6	G7	G8	G9
		0 1 2 3 4 5 6 7 8 9							

- For large files: spread chunks across disk
  - Hurts performance, can address by choosing chunk size carefully
  - Reduce overhead by doing more work: **amortization**

G0	G1	G2	G3	G4	G5	G6	G7	G8	G9
8 9		0 1		2 3		4 5		6 7	

Amortization

- For example:
  - Average positioning time: 10 ms, transfer rate: 40 MB/s
  - Goal: Achieve 50% of peak disk performance
  - i.e., 10 ms transferring data for every 10 ms positioning
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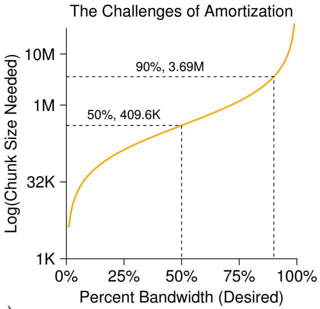
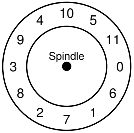


FFS

- Internal fragmentation
  - Most files were small (at the time)
  - Use sub-blocks of 512 bytes
- **Parameterization**
  - Skip over every other block
  - Enough time to request next block before it went past disk head



  - **Track buffer** prevents two spins to read track
- Also introduced: **long file names** and **symbolic links**

Summary

- Divide disk into blocks
  - Commonly-used size (4KB)
  - Data region for user data, metadata region for inodes
  - Allocation structure (data and inode bitmaps)
  - **Superblock**: information about file system
- Data uses **direct** and **indirect pointers**
  - Multi-level approach: pointer to block of indirect pointers
  - **Extents**: disk pointer plus length
- Access paths: huge number of I/Os
  - Cache with **dynamic partitioning**
  - **Write buffering**
- FFS: using **cylinder groups** and **large-file exception**