Lecture 17: Unix Fast Filesystem

601.418/618 Operating Systems

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Agenda

- Unix FS performance problems, FFS solutions
  - Small block size
  - Free space management
  - Locality

Acknowledgments: These slides are shamelessly adapted from Prof. Ryan Huang's Fall 2022 slides, which in turn are based on Prof. David Mazières's OS lecture notes.

File Systems Examples

BSD Fast File System (FFS)

- What were the problems with the original Unix FS?
- How did FFS solve these problems?

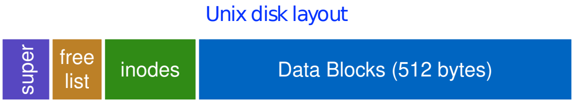
Log-Structured File system (LFS) – next lecture

- What was the motivation of LFS?
- How did LFS work?

Original Unix FS

From Bell Labs by Ken Thompson

Simple and elegant:



Components

- Data blocks
- Inodes (directories represented as files)
- Free list
- Superblock. (specifies number of blks in FS, counts of max # of files, pointer to head of free list)

Problem: slow

- Only gets 2% of disk maximum (20Kb/sec) even for sequential disk transfers!

Why So Slow?

Problem 1: blocks too small (512 bytes)

- File index too large
- Require more indirect blocks
- Transfer rate low (get one block at time)

Problem 2: unorganized freelist

- Consecutive file blocks not close together
  - Pay seek cost for even sequential access
- Aging: becomes fragmented over time

Problem 3: poor locality

- inodes far from data blocks
- inodes for directory not close together
  - poor enumeration performance: e.g., "`ls`", "`grep foo *.c`"

FFS: Fast File System

Designed by a Berkeley research group for the BSD UNIX

- A classic file systems paper to read: McKusick et. al.[1]

Approach:

- **measure** a state of the art systems
- identify and understand the fundamental problems
  - **The original FS treats disks like random-access memory!**
- get an idea and **build** a better systems

Idea: design FS structures and allocation polices to be "disk aware"

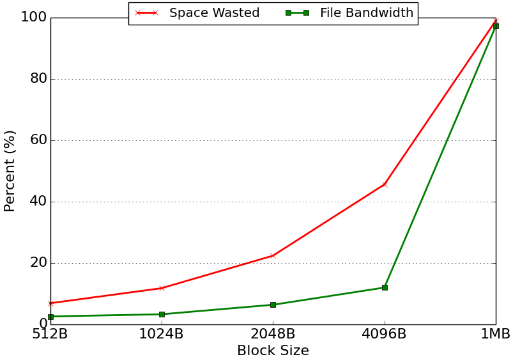
Next: how FFS fixes the performance problems (to a degree)

[1] Marshall Kirk McKusick, William N. Joy, Samuel J. Leffler, Robert S. Fabry, *A Fast File System for UNIX*

Problem 1: Blocks Too Small

Bigger block increases bandwidth, but how to deal with wastage ("internal fragmentation")?

Measurement:

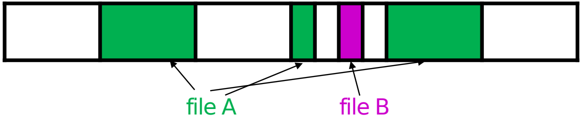


- Use idea from malloc: split unused portion

Solution: Fragments

BSD FFS:

- Has large block size (4096B or 8192B)
- Allow large blocks to be chopped into small ones called “fragments”
- Ensure fragments only used for little files or ends of files



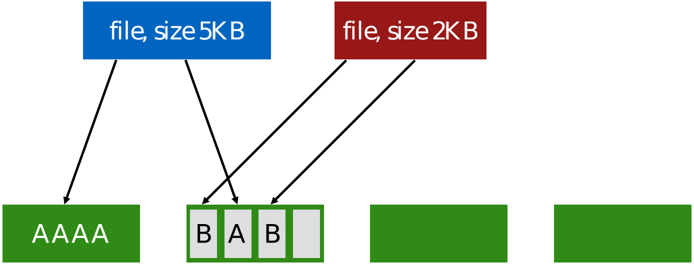
  - Fragment size specified at the time that the file system is created
  - Limit number of fragments per block to 2, 4, or 8

Pros

- High transfer speed for larger files
- Low wasted space for small files or ends of files

Fragment Example

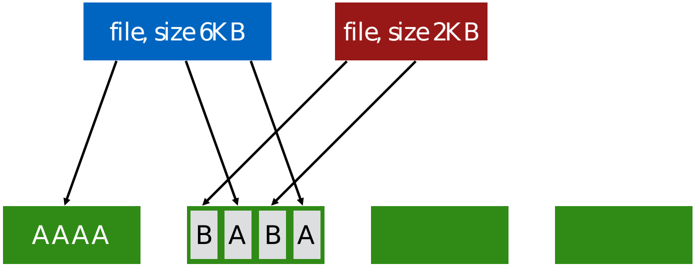
Block size: 4096 B
Fragment size: 1024 B



Fragment Example

`write("fd1", "A");` // append A to first file

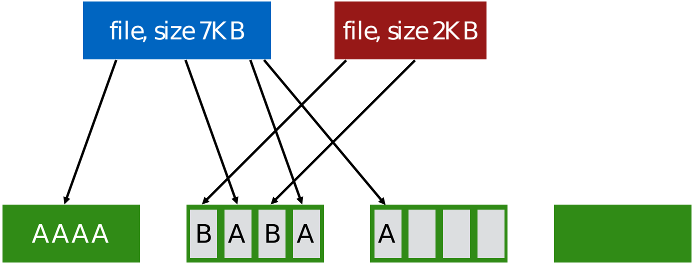
Block size: 4096 B
Fragment size: 1024 B



Fragment Example

```
write(fd1, "A"); // append A to first file
write(fd1, "A");
```

Block size: 4096 B
Fragment size: 1024 B



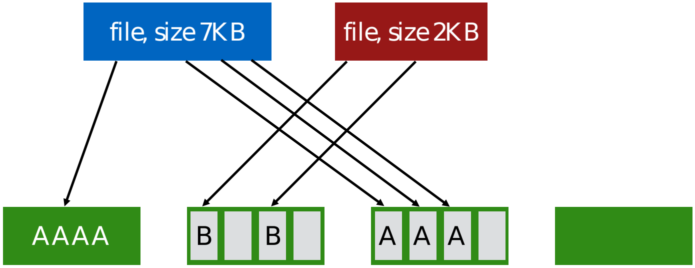
Not allowed to use fragments across multiple blocks!

What to do instead?

Fragment Example

```
write(fd1, "A"); // append A to first file
write(fd1, "A");
```

Block size: 4096 B
Fragment size: 1024 B

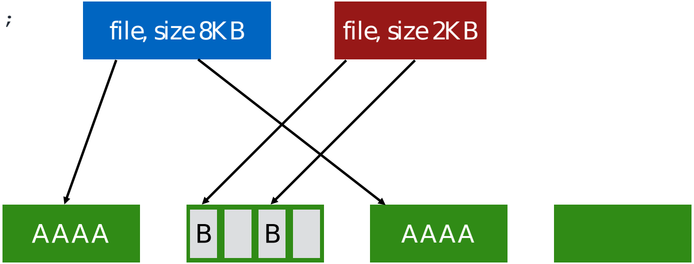


copy old fragments to new block
new data use remaining fragments

Fragment Example

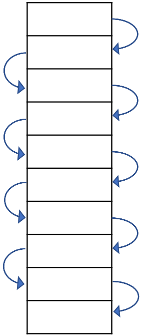
```
write(fd1, "A"); // append A to first file
write(fd1, "A");
write(fd1, "A");
```

Block size: 4096 B
Fragment size: 1024 B

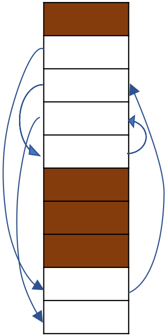


Problem 2: Unorganized Freelist

Leads to random allocation of sequential file blocks overtime



Initial performance good



Get worse over time

Measurement:

- New FS: **17.5%** of disk bandwidth
- Few weeks old: **3%** of disk bandwidth

Fixing the Unorganized Freelist

Periodical compact/defragment disk

- Cons: locks up disk bandwidth during operation

Keep adjacent free blocks together on freelist

- Cons: costly to maintain

FFS: bitmap of free fragments

- Each bit indicates whether fragment is free
  - E.g., 10101011111100000111111000101100
- Easier to find contiguous blocks
  (all aligned fragments 0 $\rightarrow$ block is free)
- Small, so usually keep entire thing in memory
- Time to find free blocks increases if fewer free blocks

Bits in map	XXXX	XXOO	OOXX	OOOO
Fragment numbers	0-3	4-7	8-11	12-15
Block numbers	0	1	2	3

Using a Bitmap

Usually keep entire bitmap in memory:

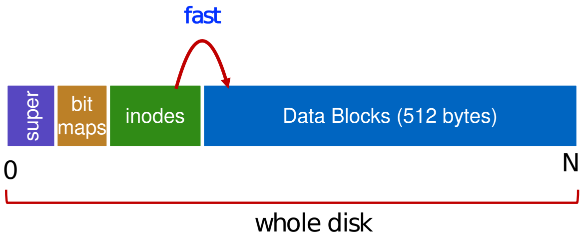
- 4G disk / 4K byte blocks. How big is map?

Allocate block close to block `x`?

- Check for blocks near `bmap[x/32]`
- If disk almost empty, will likely find one near
- As disk becomes full, search becomes more expensive and less effective

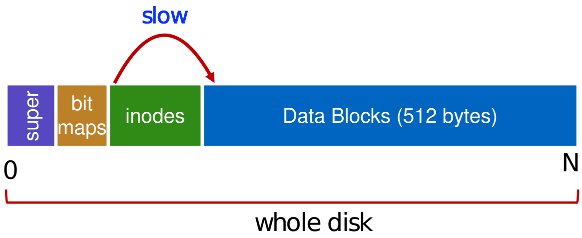
Trade space for time (search time, file access time)

Problem 3: Poor Locality



How to keep inode close to data block?

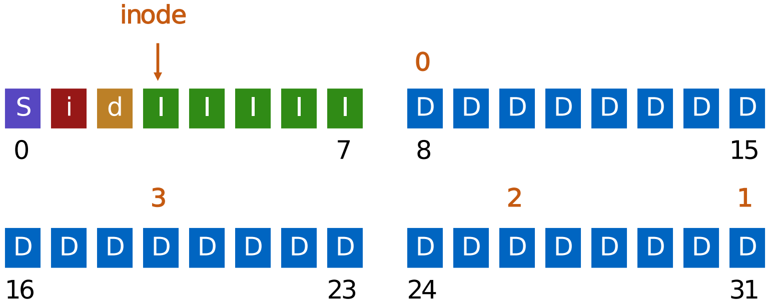
Problem 3: Poor Locality



How to keep inode close to data block?

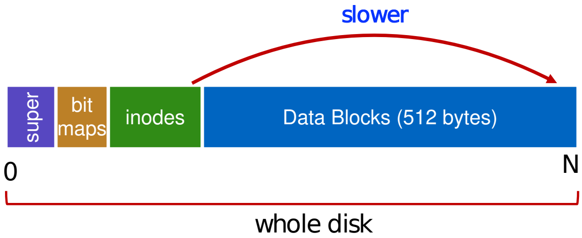
Problem 3: Poor Locality

Example bad layout:



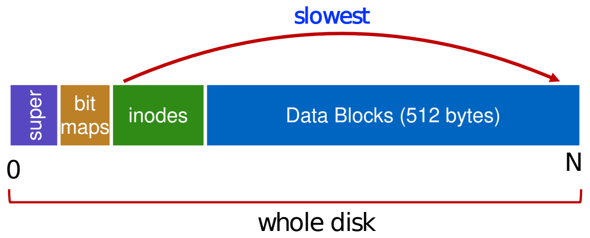
How to keep inode close to data block?

Problem 3: Poor Locality



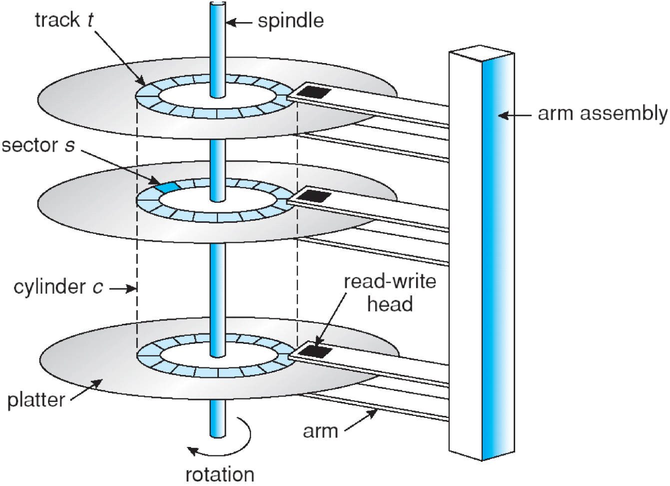
How to keep inode close to data block?

Problem 3: Poor Locality



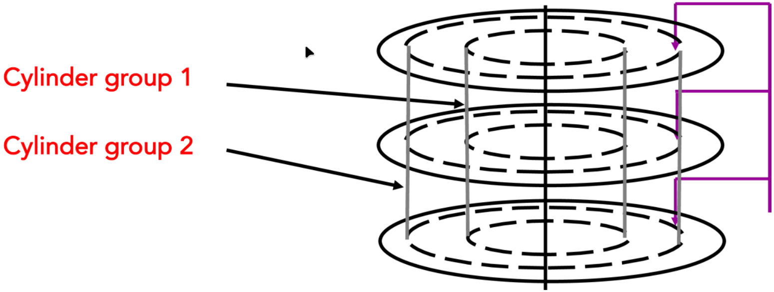
How to keep inode close to data block?

Cylinders, Tracks, & Sectors



FFS Solution: Cylinder Group

Group sets of consecutive cylinders into "cylinder groups"



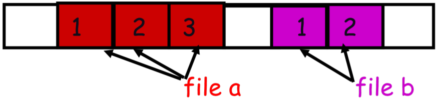
Key: can access any block in a cylinder without performing a seek. Next fastest place is **adjacent cylinder**.

- Tries to put everything related in same cylinder group
- Tries to put everything not related in different group

Clustering in FFS

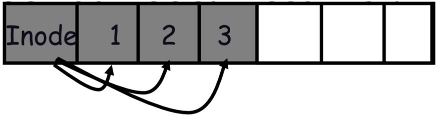
Tries to put sequential blocks in adjacent sectors

- (Access one block, probably access next)



Tries to keep inode in same cylinder as file data:

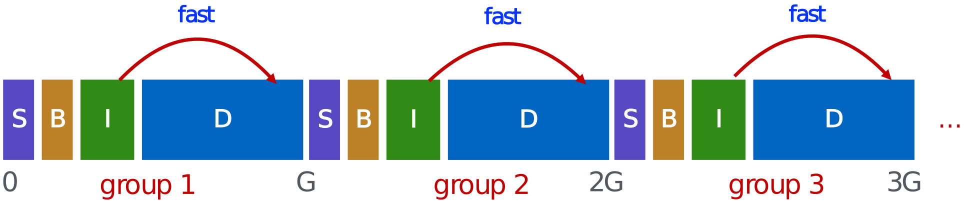
- (If you look at inode, most likely will look at data too)



Tries to keep all inodes in a dir in same cylinder group

- Access one name, frequently access many, e.g., "`ls -l`"

What Does Disk Layout Look Like Now?



How to keep inode close to data block?

- Answer: Use groups across disks
- Strategy: allocate inodes and data blocks in same group
- Each cylinder group basically a mini-Unix file system

Is it useful to have multiple super blocks?

- Yes, if some (but not all) fail

FFS Results

Performance improvements:

- Able to get 20-40% of disk bandwidth for large files
- 10-20x original Unix file system!
- Stable over FS lifetime
- Better small file performance (why?)

Other enhancements

- Long file names
- Parameterization
- Free space reserve (10%) that only admin can allocate blocks from

Next Time

Log Structured Filesystem (LFS)