CE 440 Introduction to Operating System

Lecture 18: Fast File System
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Slides courtesy of Manuel Egele, Ryan Huang and Baris Kasikci

Midterm Result

Means: 39.78, Maximum: 60, std Dev: 9.23

Distribution:

- **> 60: 1**
- **(50, 60]:4**
- **(45, 50]: 6**
- **(40,45]: 14**
- **(35,40]: 12**
- **<35: 12**

Administrivia

Midterm solution will not be directly posted online

- The Rubric items are published in gradescope
- Can request to see the copy of sample solution in my office hour

Lab 4 is out, this is optional

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:

Unix disk layout

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 acces
- 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: [McKusic]

Approach:

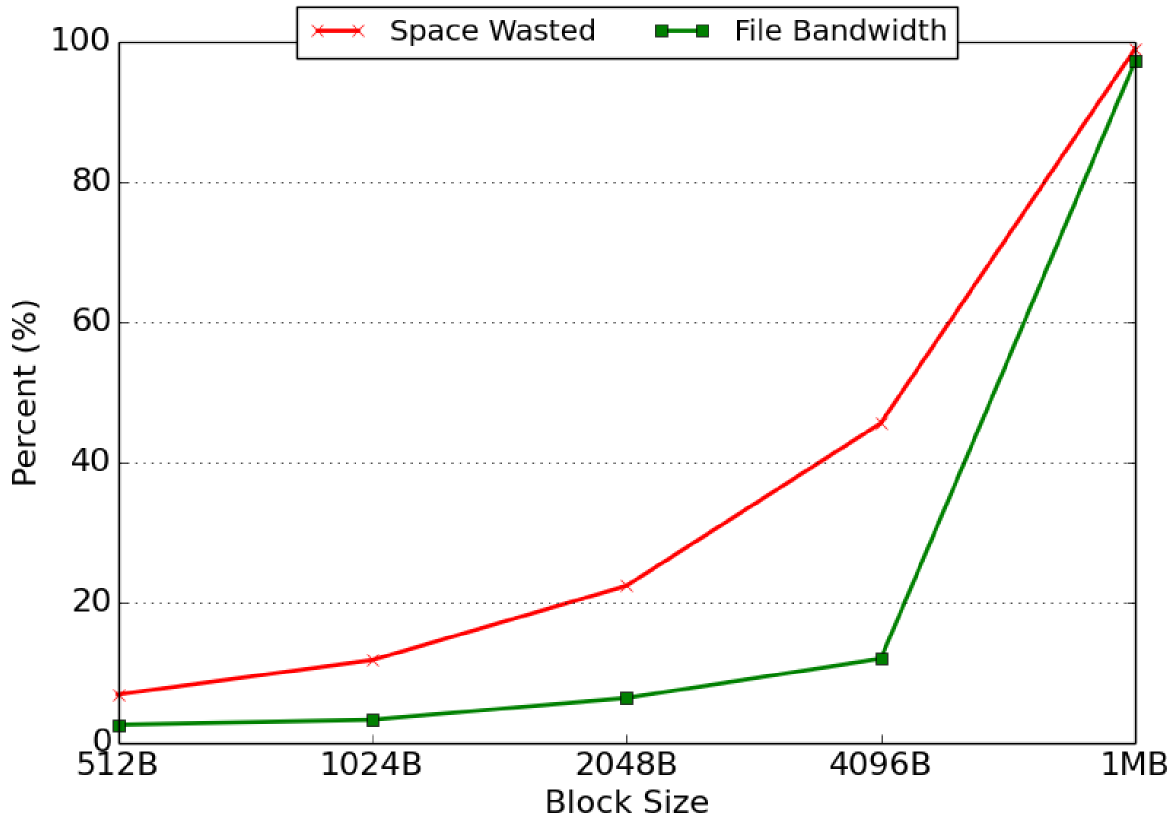
- Measure an state of the art systems
- Identify and understand the fundamental problems
  - The original FS treats disks like random-access memory!
- Get an idea and build a better systems

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

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

Problem 1: Blocks Too Small

Measurement:



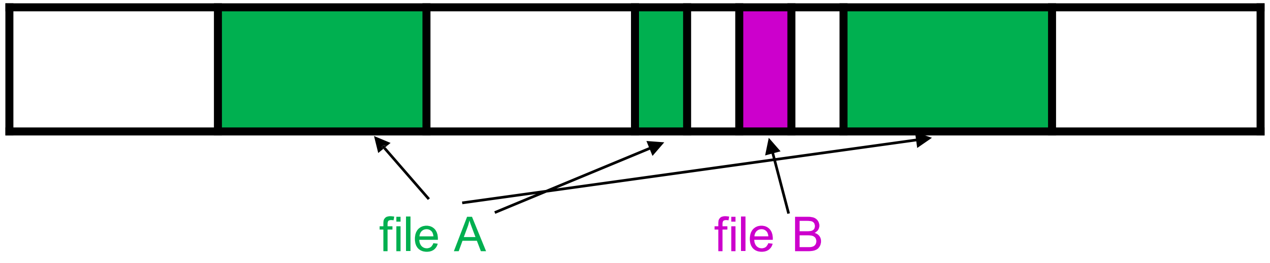
Bigger block increases bandwidth, but how to deal with wastage ("internal fragmentation")?

- 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



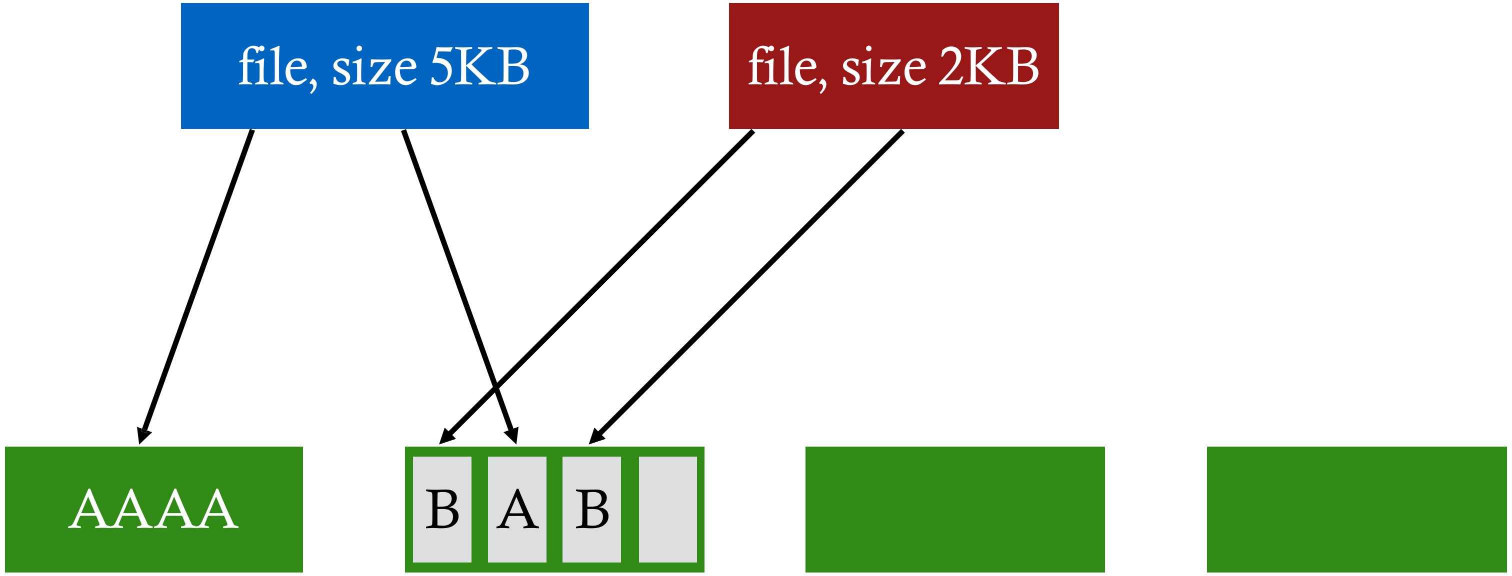
  - Fragment size specified at the time that the file system is created
  - Limit number of fragments per block to 2, 4, or 8

Pros

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

Fragment Example

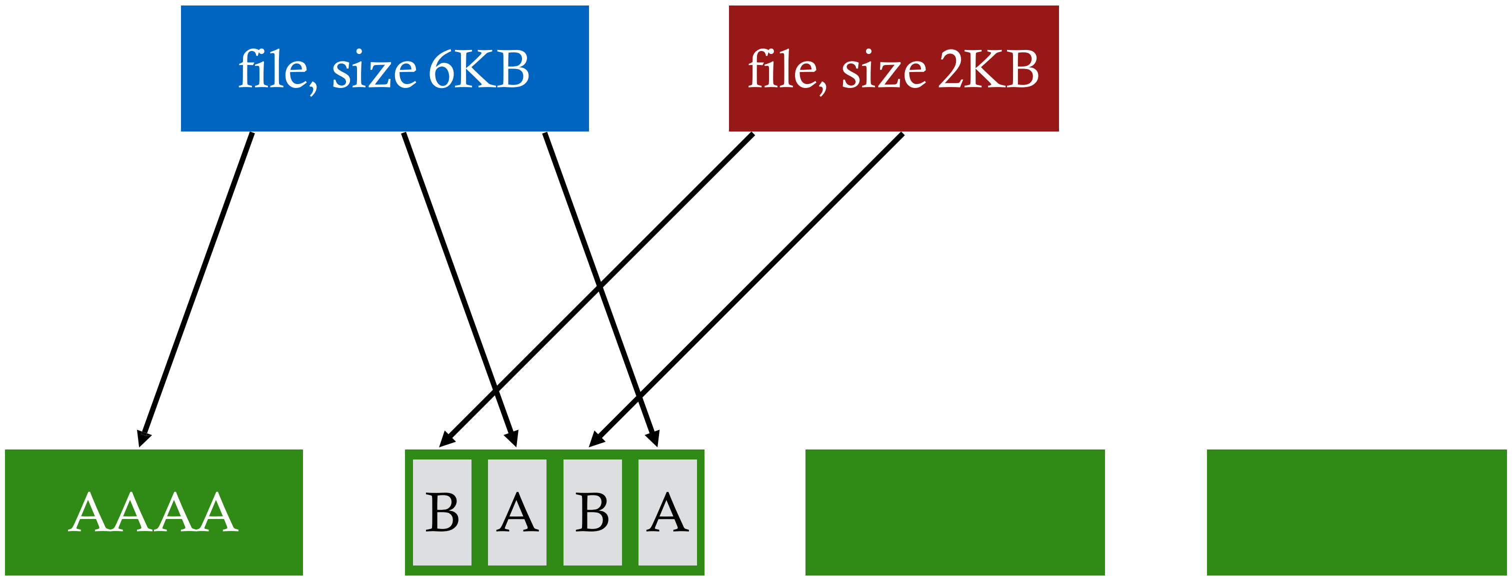
Block size: 4096 B
Fragment size: 1024 B



Fragment Example

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

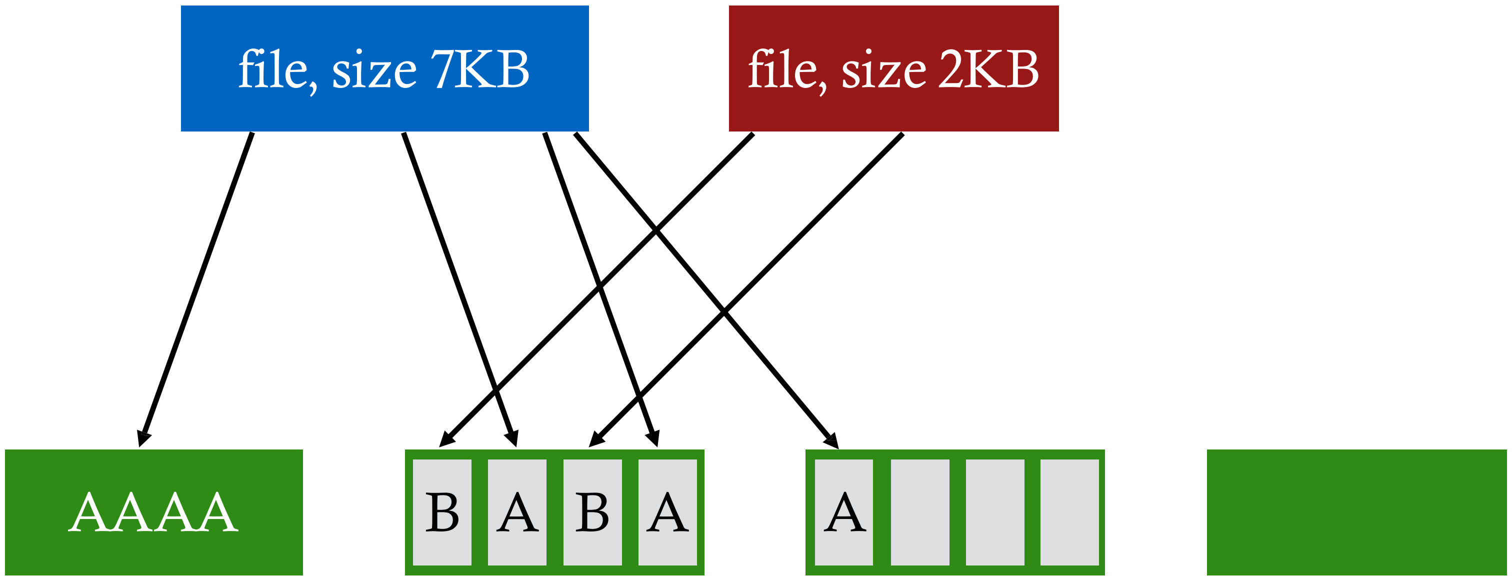
Block size: 4096 B
Fragment size: 1024 B



Fragment Example

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

Block size: 4096 B
Fragment size: 1024 B



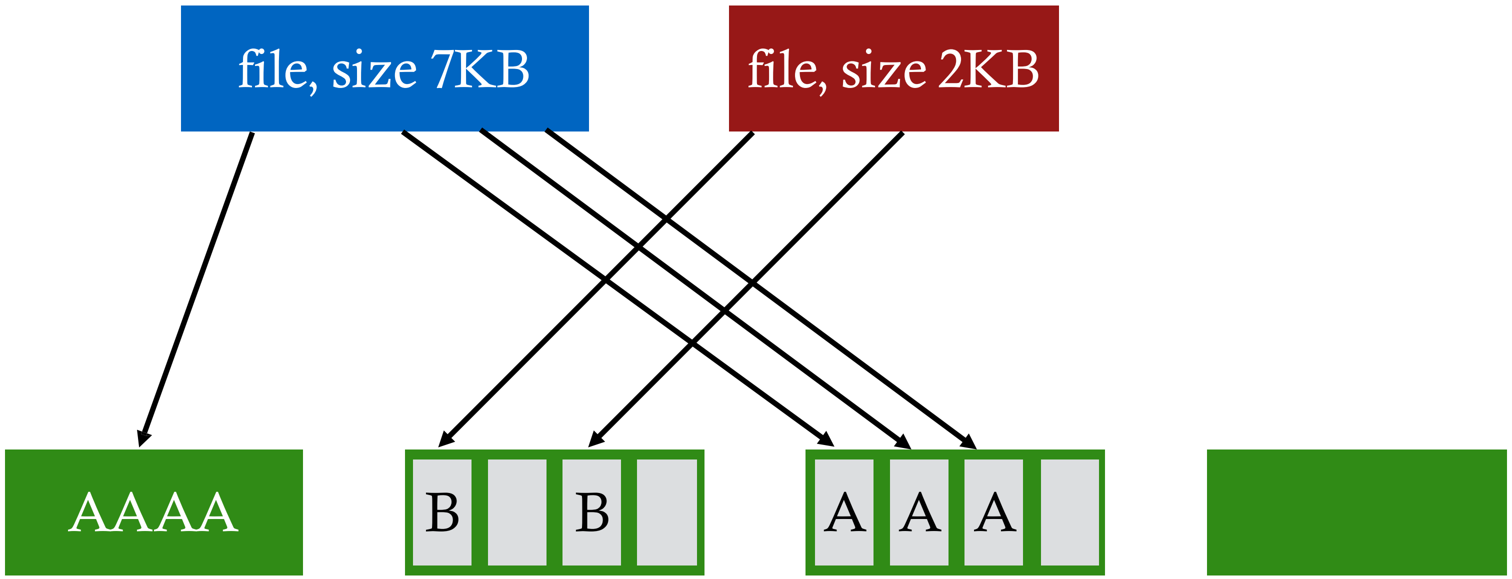
Not allowed to use fragments across multiple blocks!

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

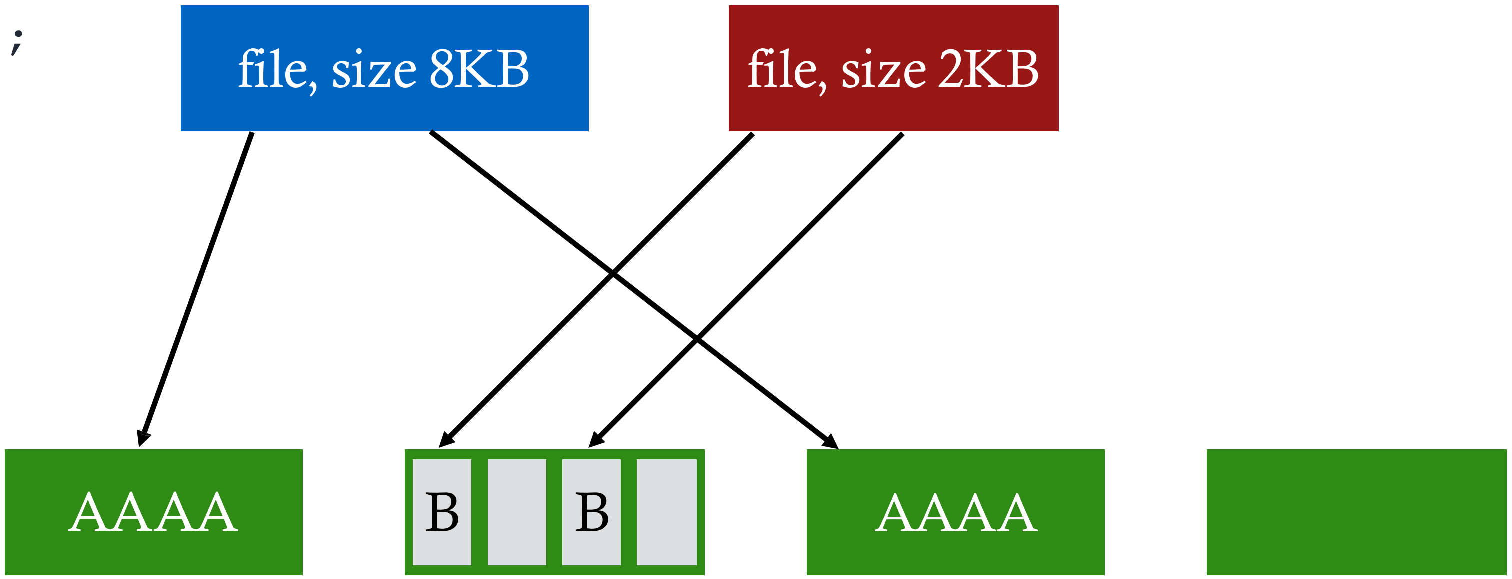


copy old fragments to new block
new data use remaining fragments

Fragment Example

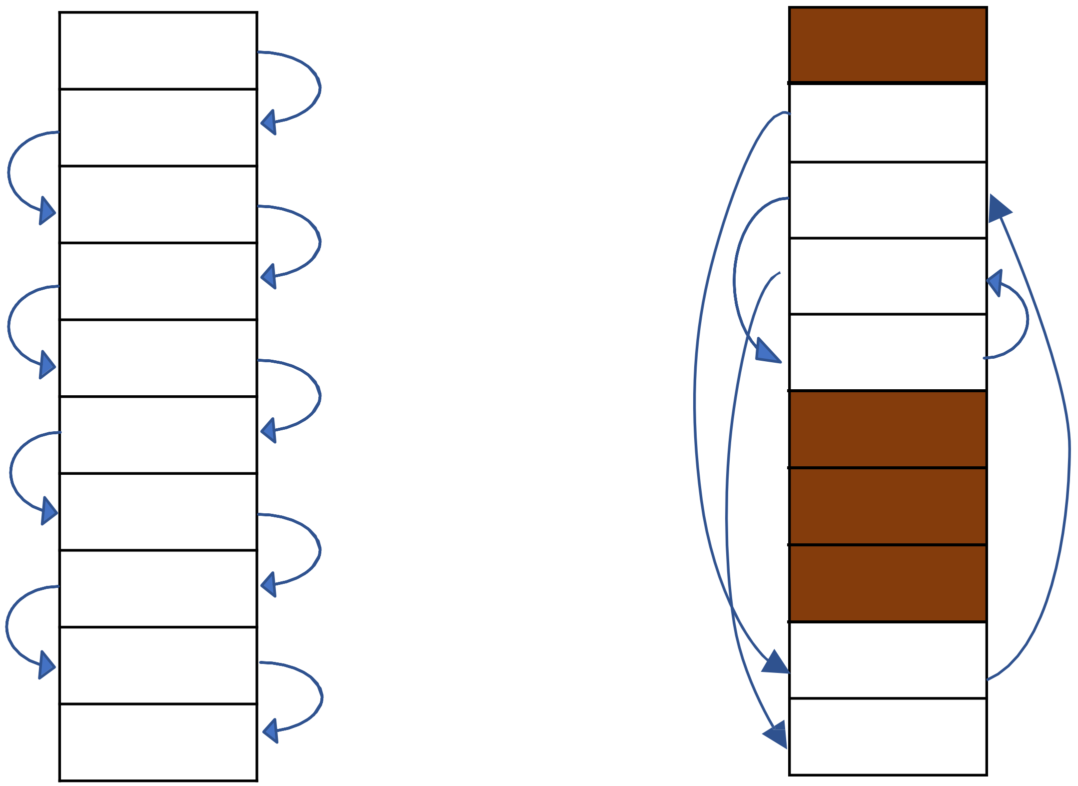
```
write(fd1, "A"); // append A to first file
write(fd1, "A");
write(fd1, "A");
```

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 blocks

- Each bit indicates whether block is free
  - E.g., 101010111111000001111111000101100
- Easier to find contiguous blocks
- Small, so usually keep entire thing in memory
- Time to find free blocks increases if fewer free blocks
- What about fragments in a block?

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:

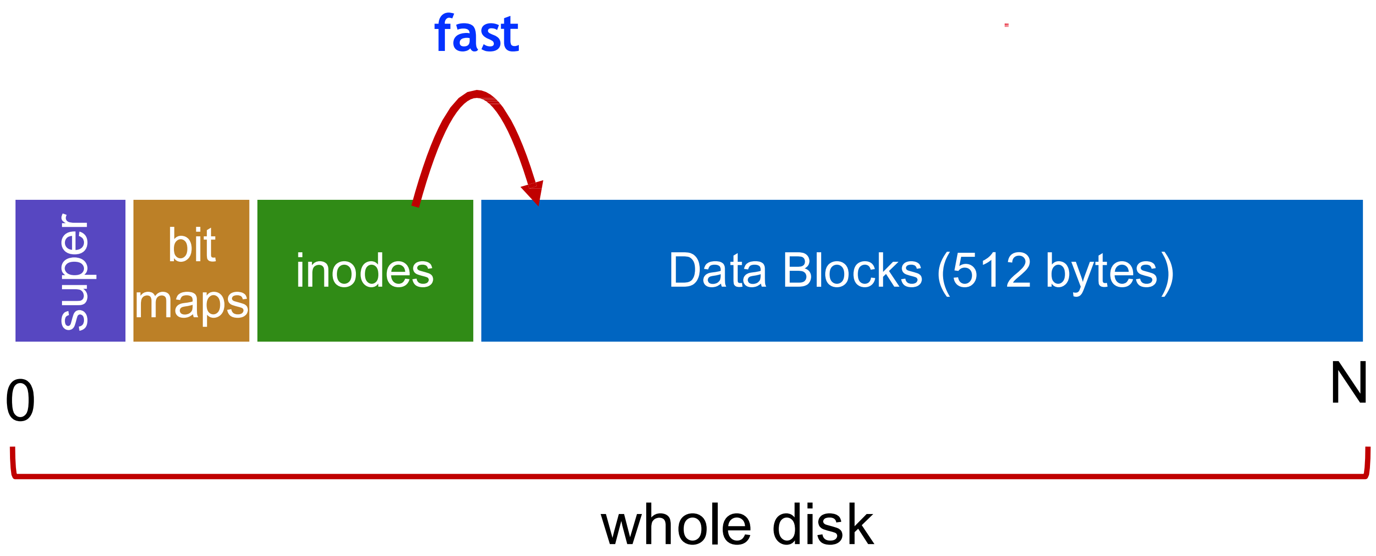
- 4G disk / 4K byte blocks. How big is map?

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

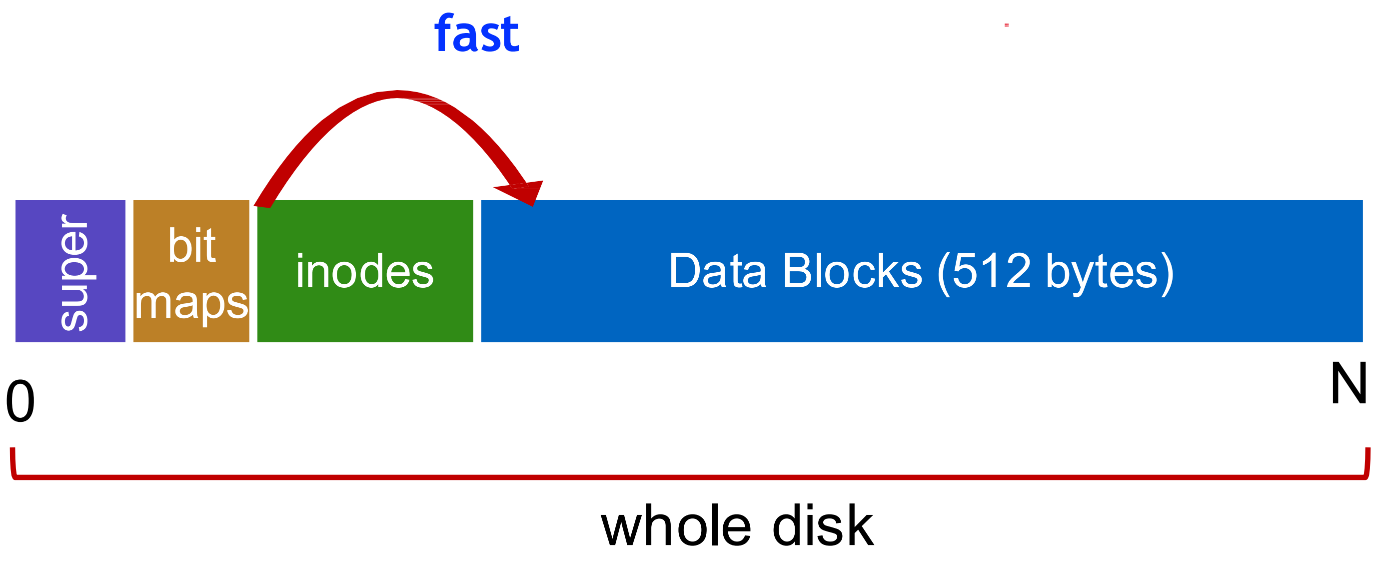
Trade space for time (search time, file access time)

Problem 3: Poor Locality



How to keep inode close to data block?

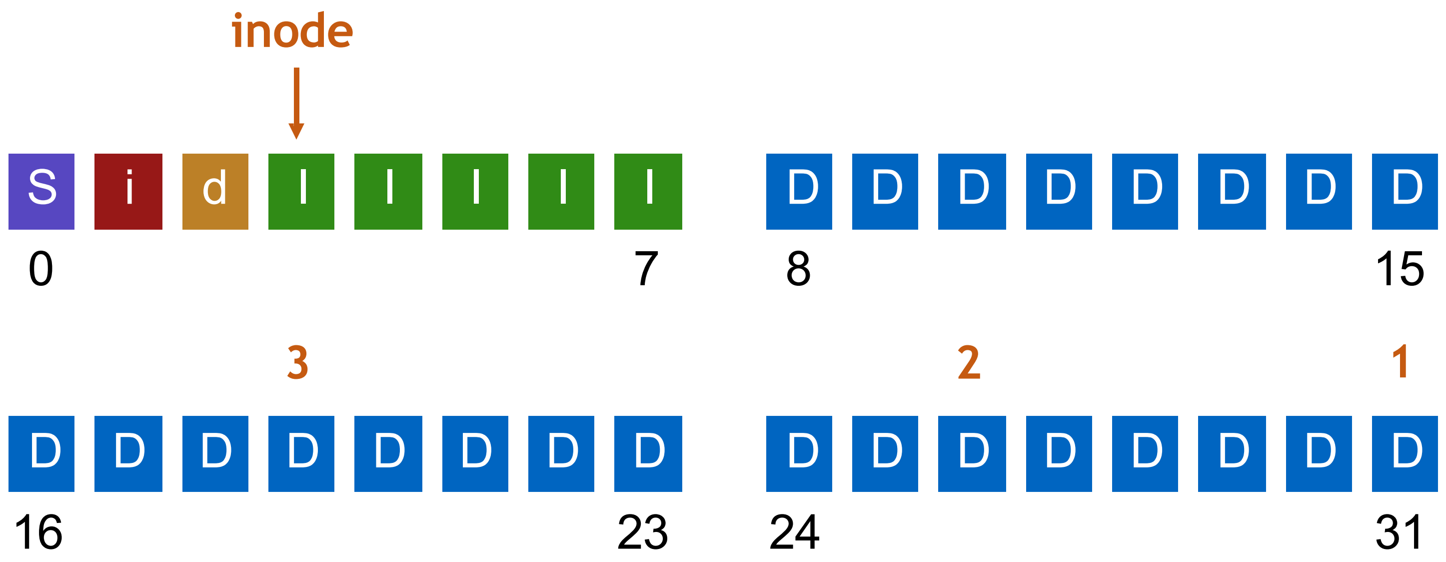
Problem 3: Poor Locality



How to keep inode close to data block?

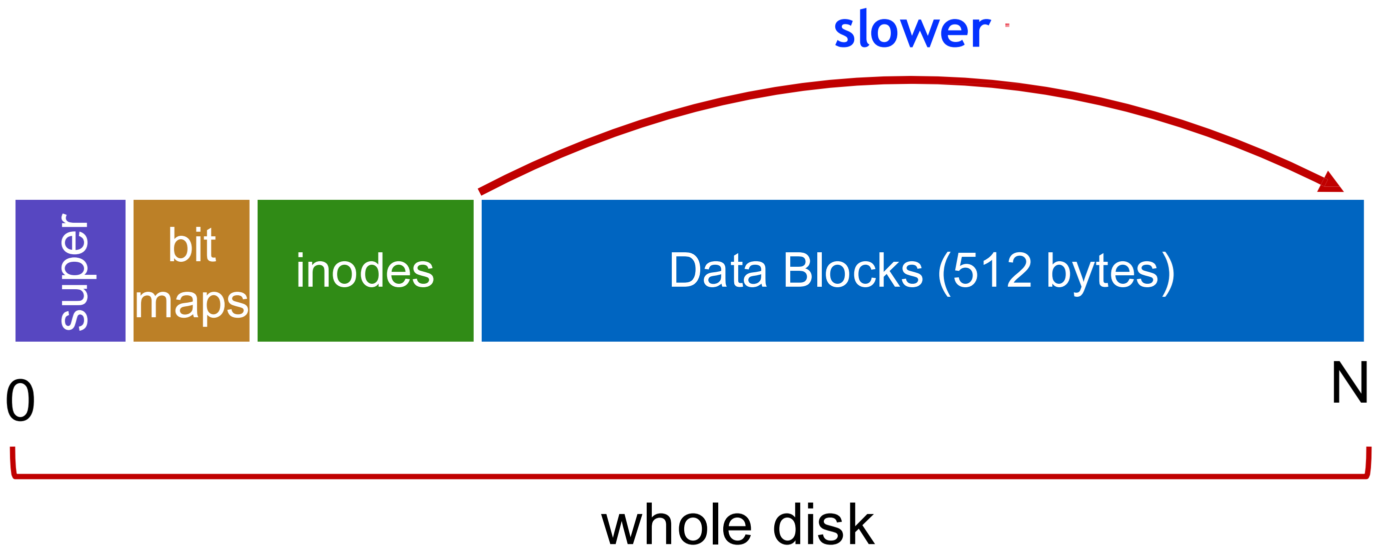
Problem 3: Poor Locality

Example bad layout:



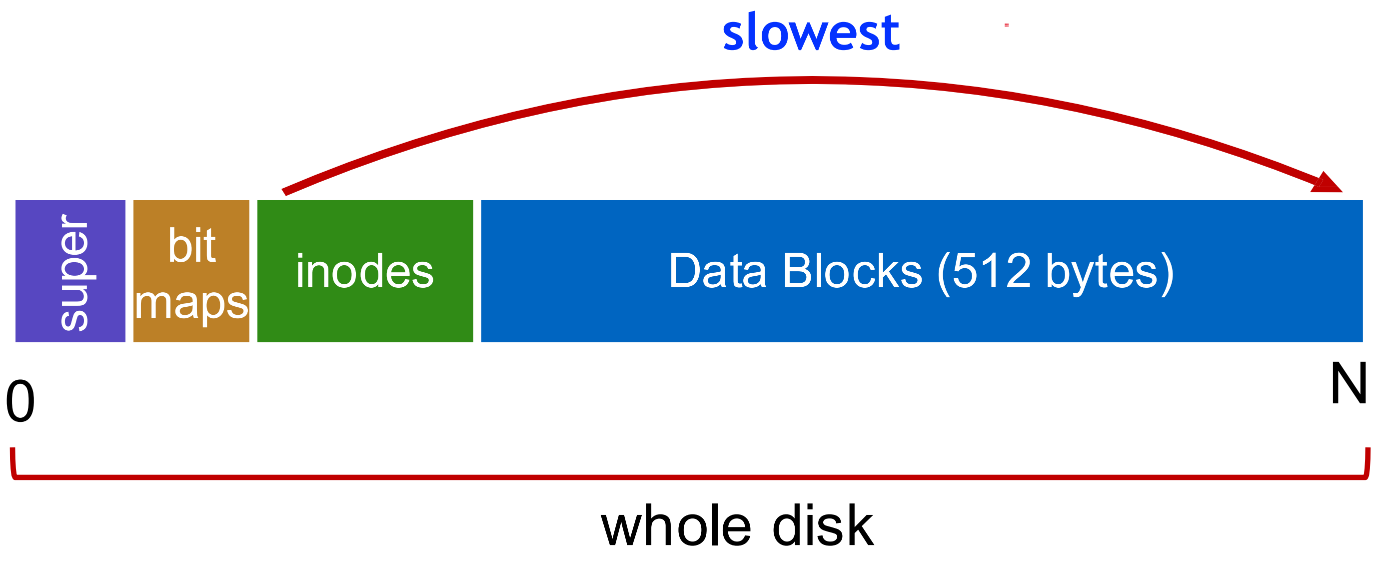
How to keep inode close to data block?

Problem 3: Poor Locality



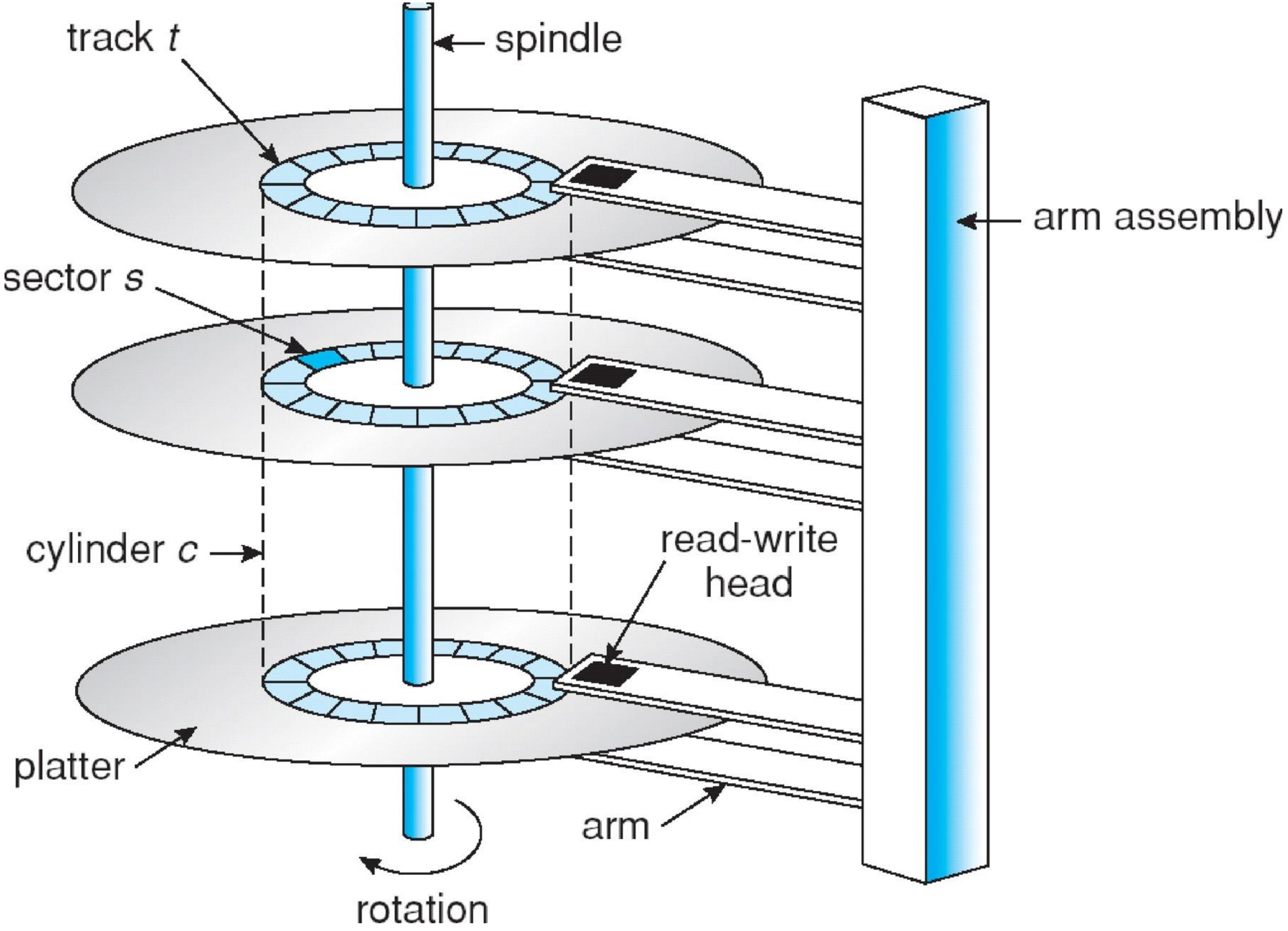
How to keep inode close to data block?

Problem 3: Poor Locality



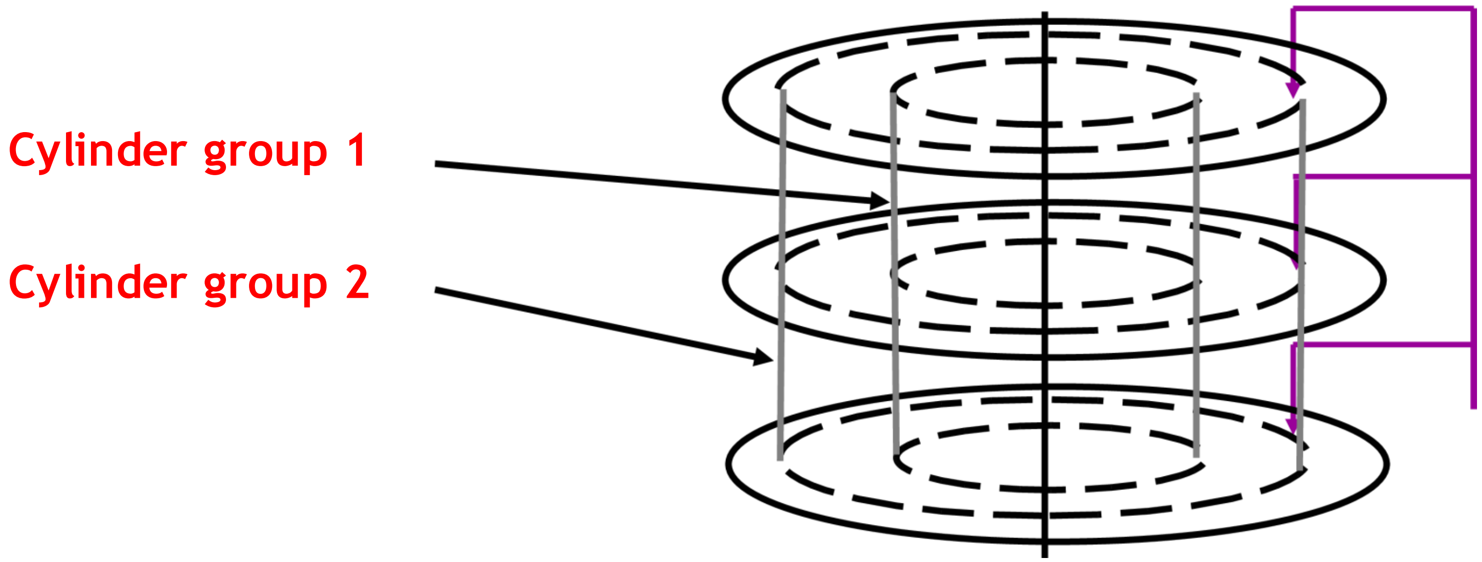
How to keep inode close to data block?

Recap: Cylinders, Trackers, & Sectors



FFS Solution: Cylinder Group

Group sets of consecutive cylinders into "cylinder groups"



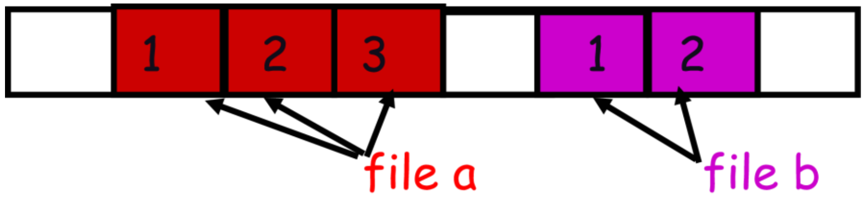
Key: can access any block in a cylinder without performing a seek. Next fastest place is adjacent cylinder.

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

Clustering in FFS

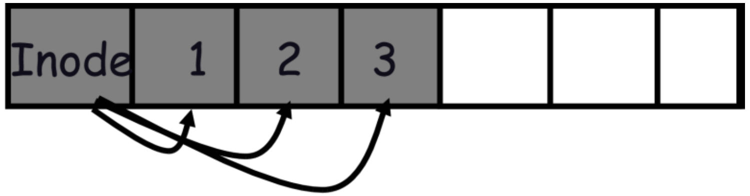
Tries to put sequential blocks in adjacent sectors

- (Access one block, probably access next)



Tries to keep inode in same cylinder as file data:

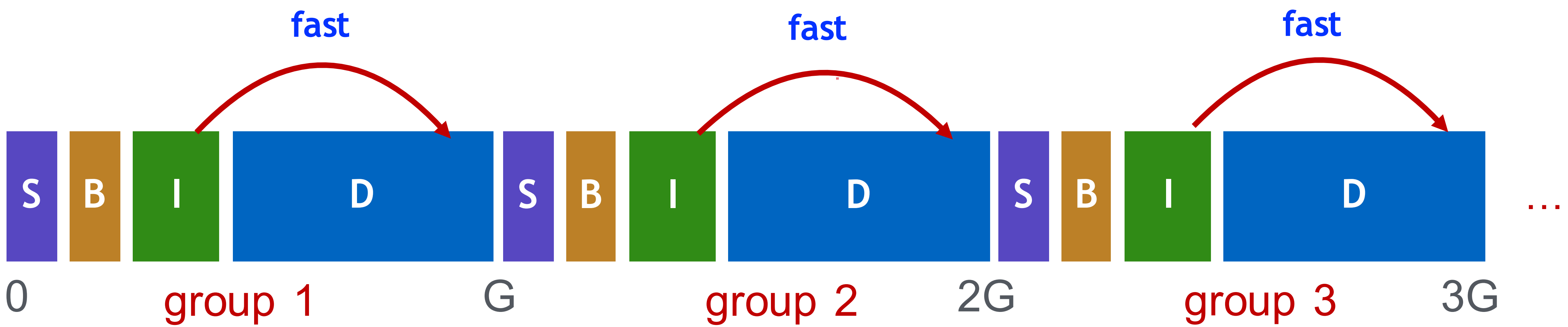
- (If you look at inode, most likely will look at data too)



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…

Read Chapter 43