

# CS 318 Principles of Operating Systems

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## Lecture 17: Unix Fast File System

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# 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 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: [[McKusic](#)]

## Approach:

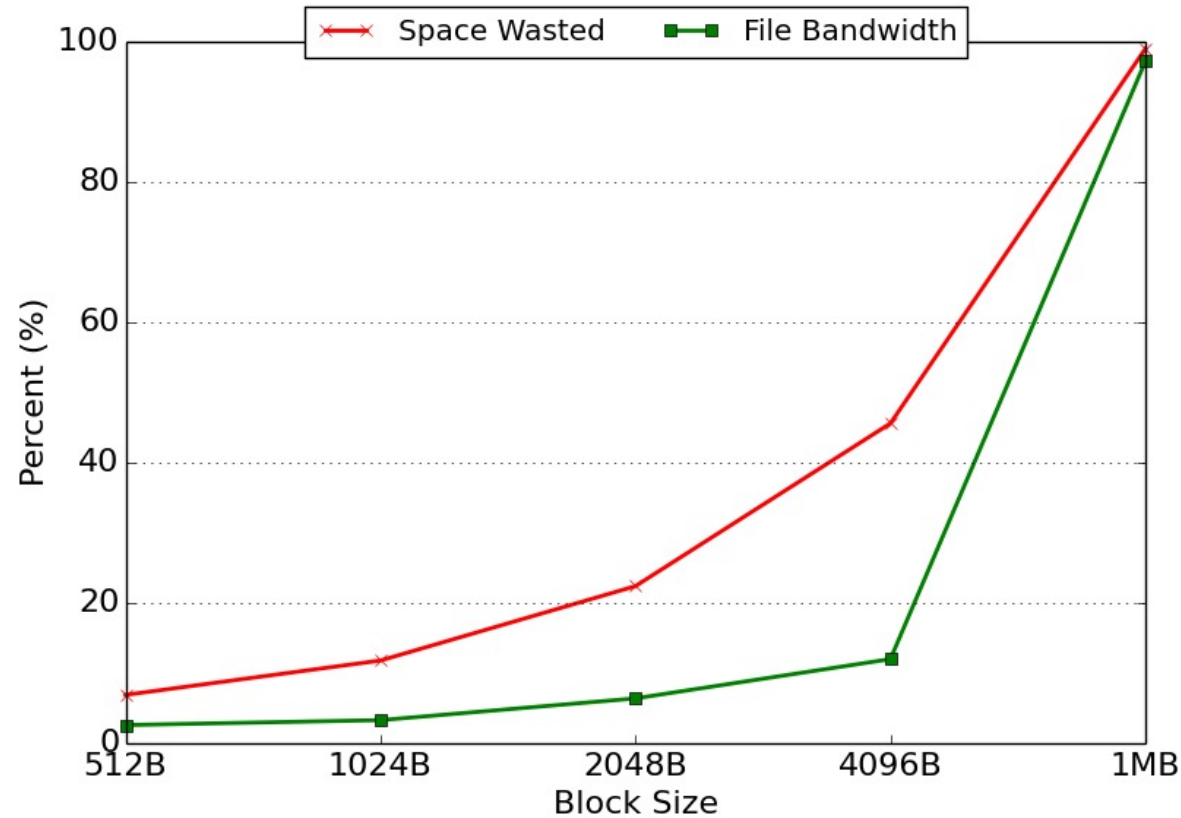
- **measure** an state of the art systems
- identify and understand the fundamental problems
  - The original FS treats disks like random-access memory!
- get an idea and **build** a better systems

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:



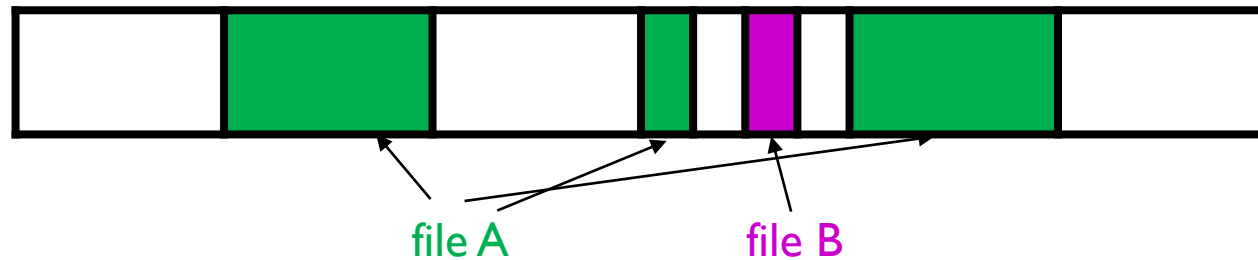
Bigger block increases bandwidth, but how to deal with wastage (“**internal fragmentation**”)?

- 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



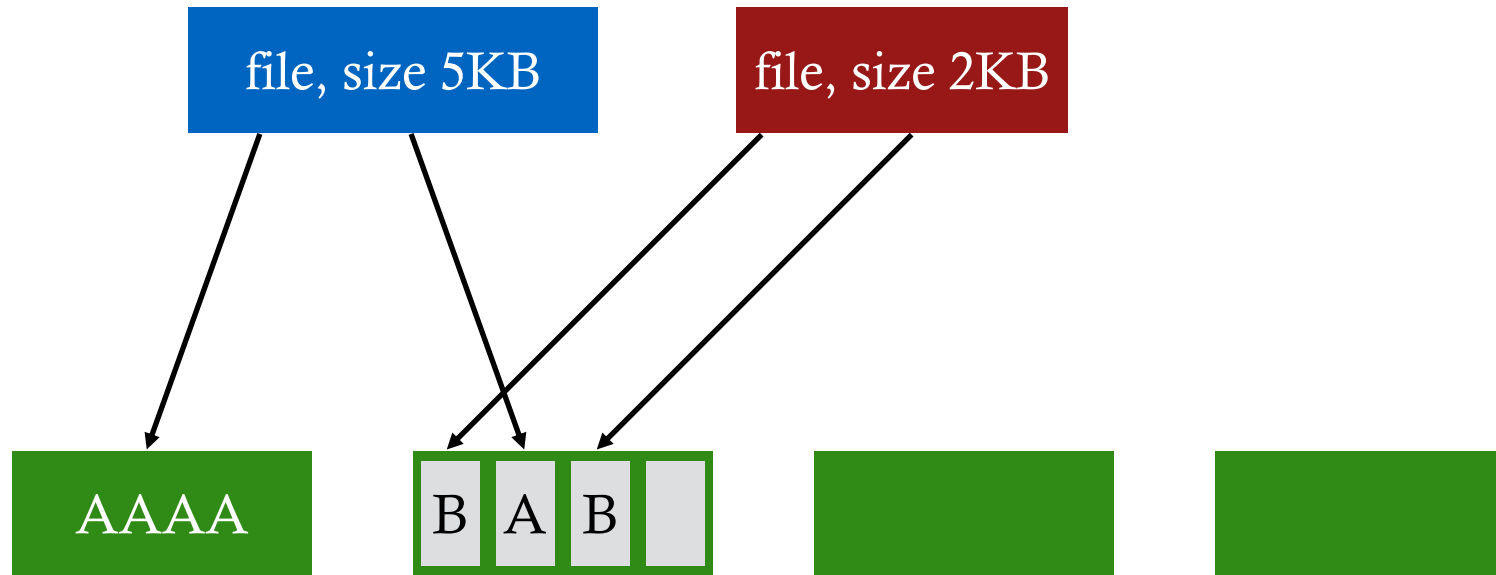
- Fragment size specified at the time that the file system is created
- Limit number of fragments per block to 2, 4, or 8

## 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

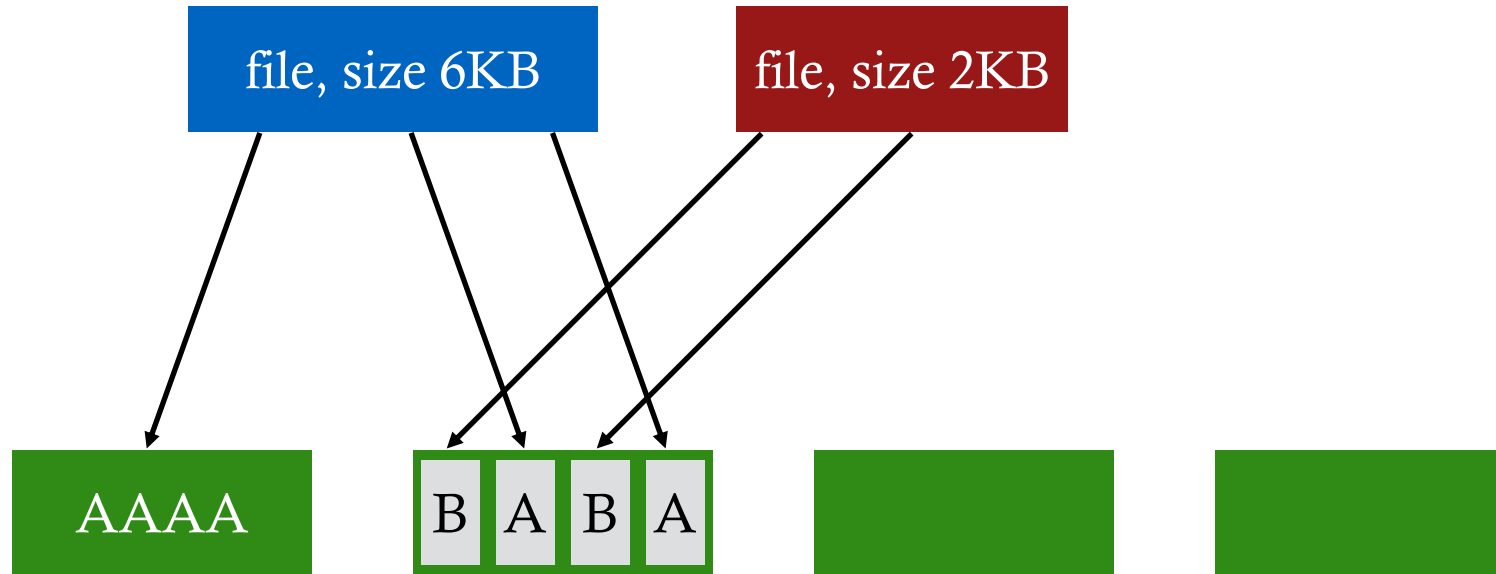




# Fragment Example

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

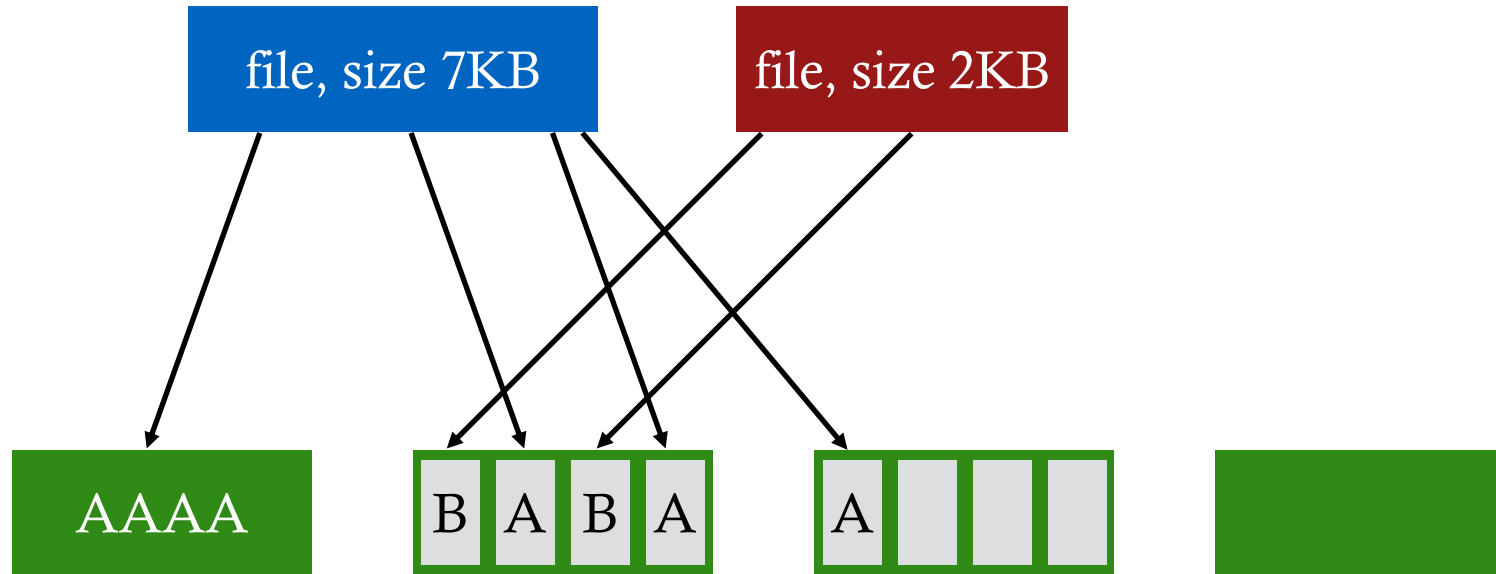
Block size: 4096 B  
Fragment size: 1024 B



# Fragment Example

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

Block size: 4096 B  
Fragment size: 1024 B



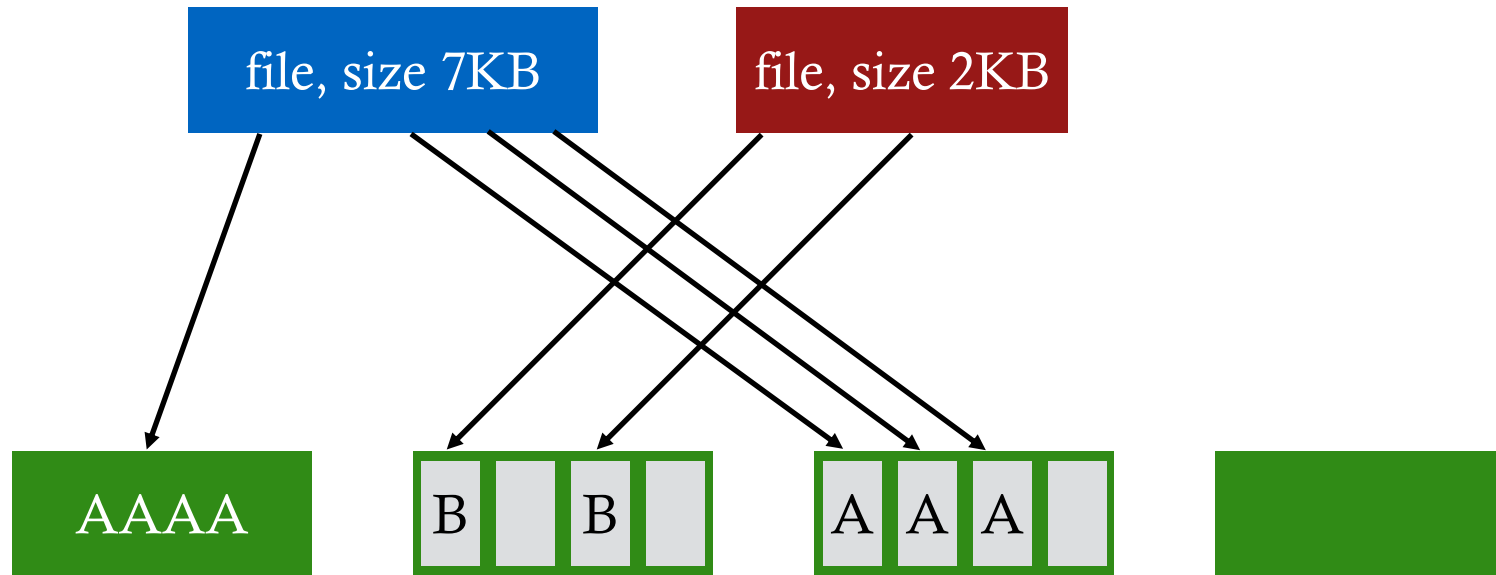
**Not allowed to use fragments across multiple blocks!**

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

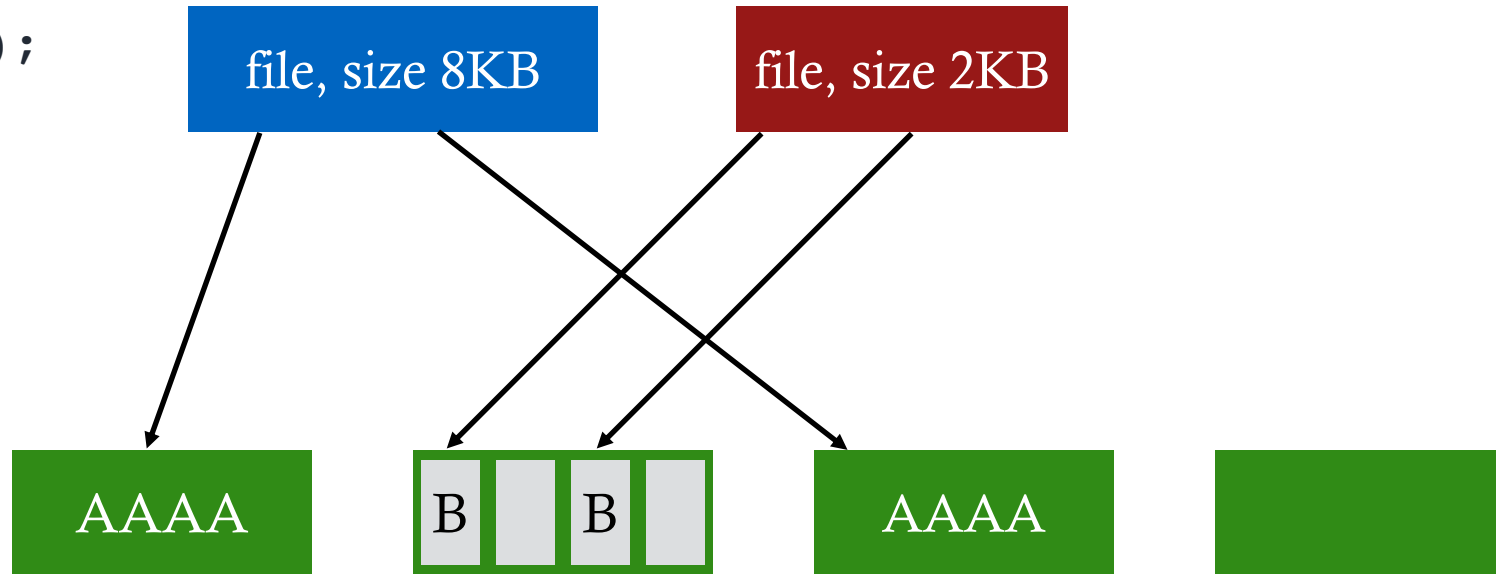


**copy old fragments to new block  
new data use remaining fragments**

# Fragment Example

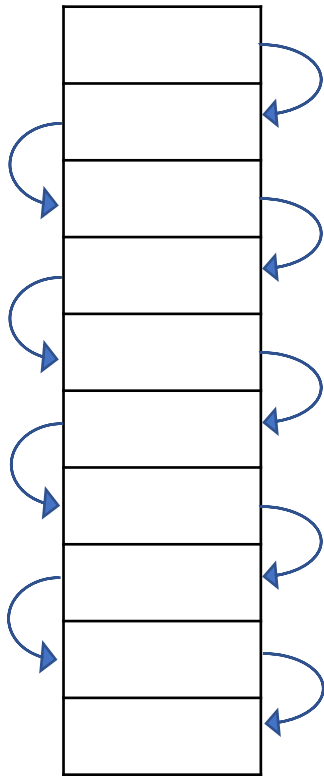
```
write(fd1, "A"); // append A to first file  
write(fd1, "A");  
write(fd1, "A");
```

Block size: 4096 B  
Fragment size: 1024 B

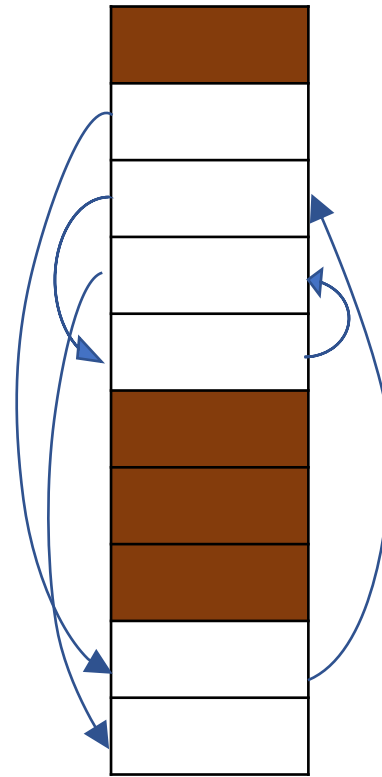


# Problem 2: Unorganized Freelist

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., 1010101111111000001111111000101100
- 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?

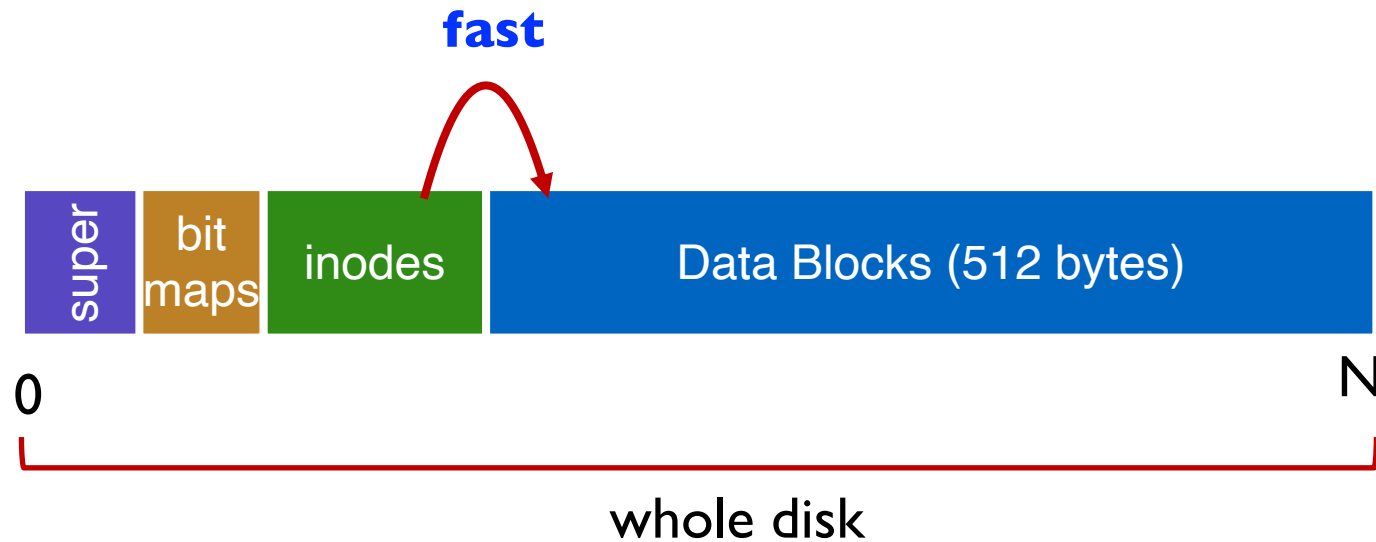
Allocate block close to block  $x$ ?

- 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)



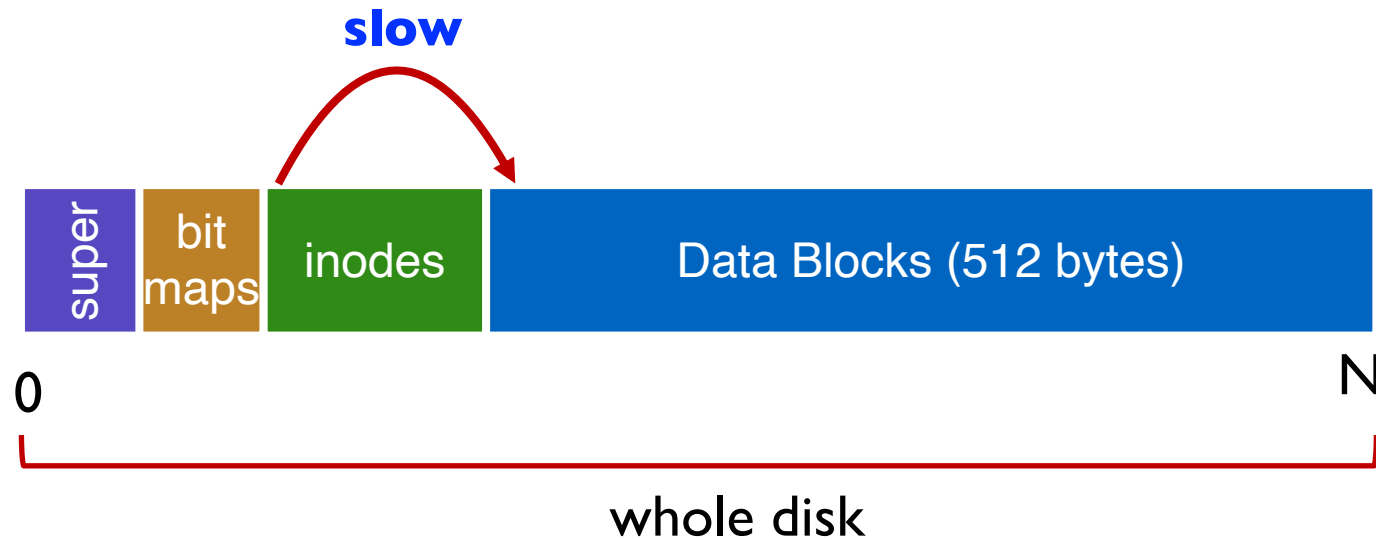
# Problem 3: Poor Locality



**How to keep inode close to data block?**



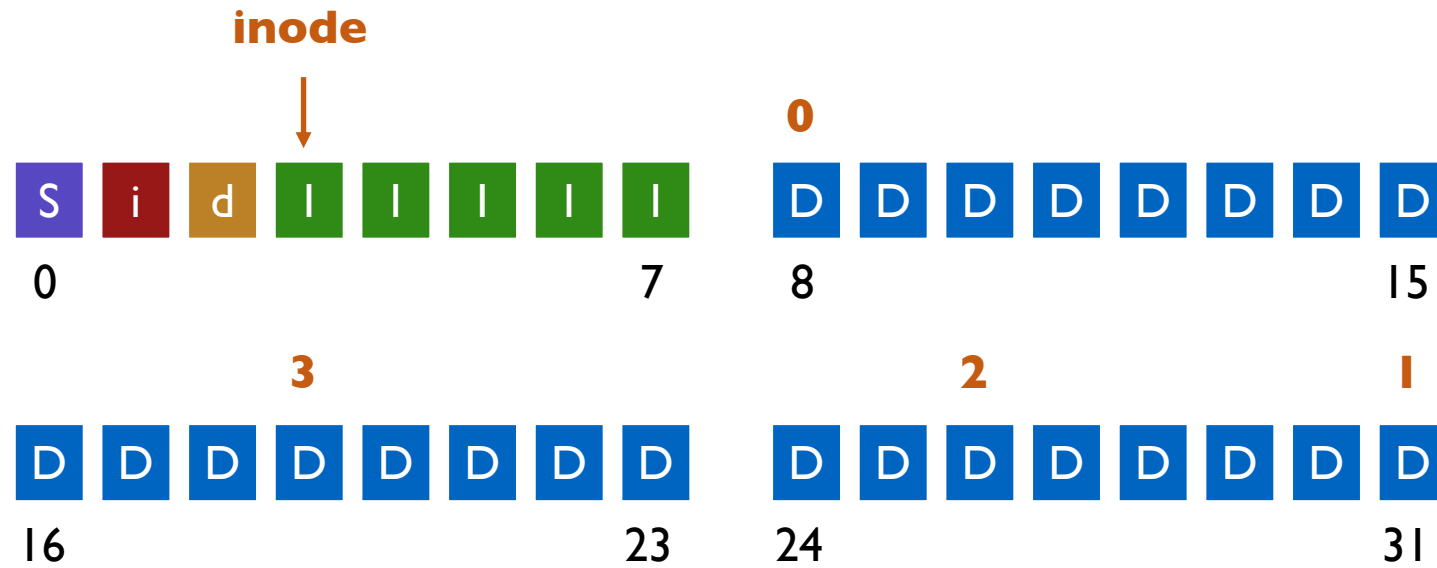
# Problem 3: Poor Locality



**How to keep inode close to data block?**

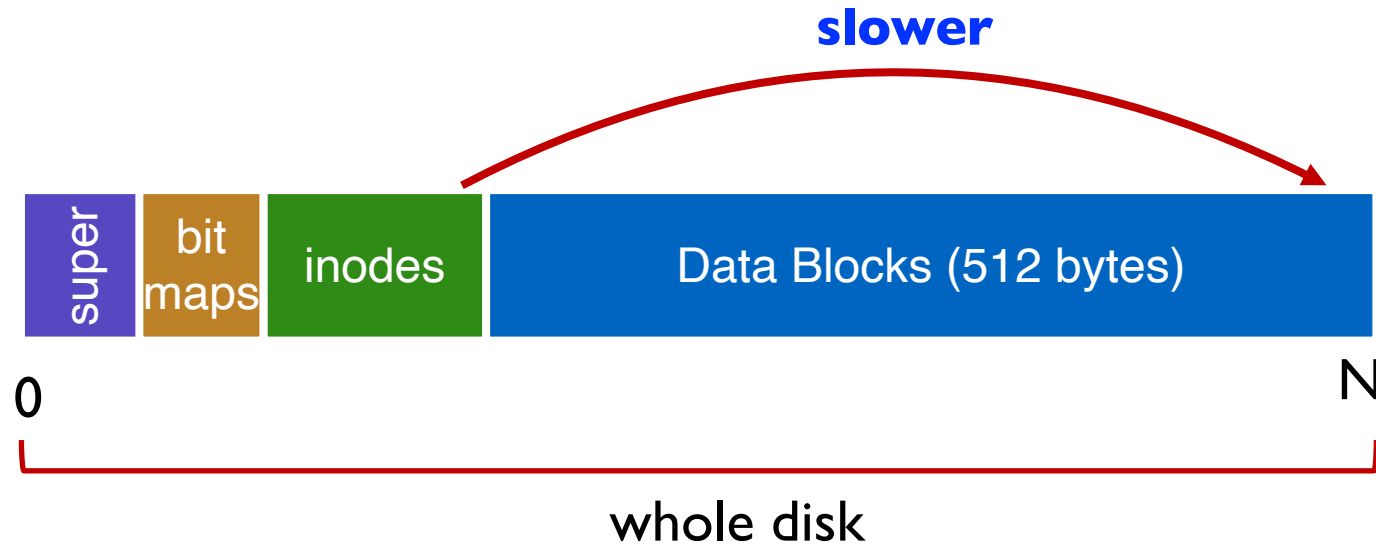
# Problem 3: Poor Locality

Example bad layout:



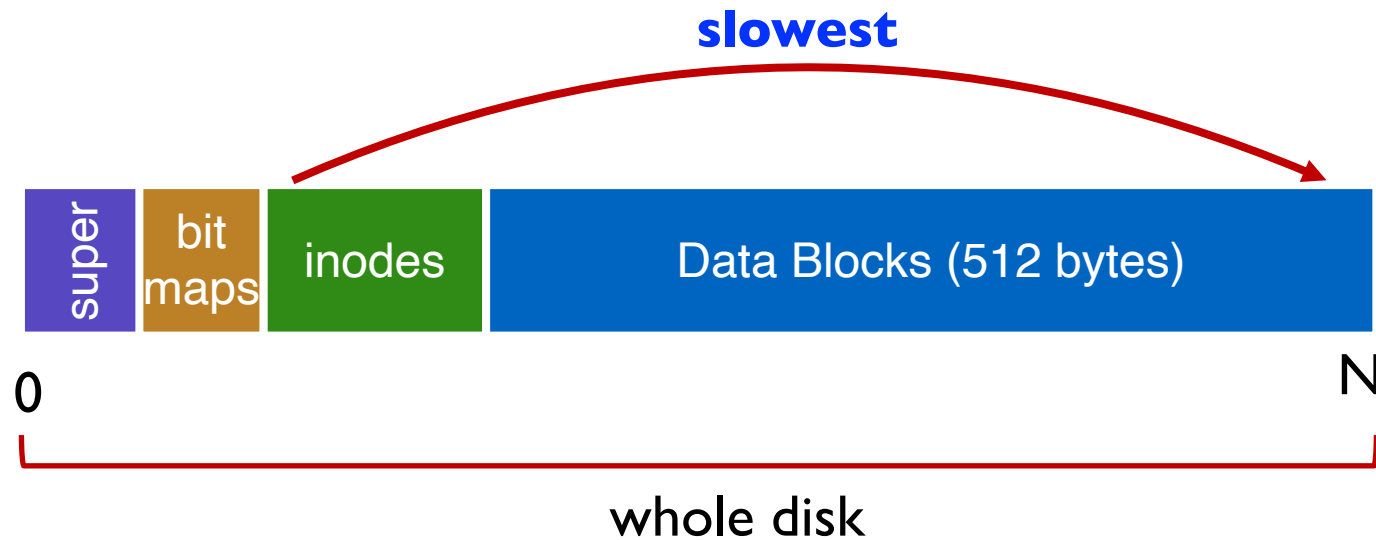
How to keep inode close to data block?

# Problem 3: Poor Locality



**How to keep inode close to data block?**

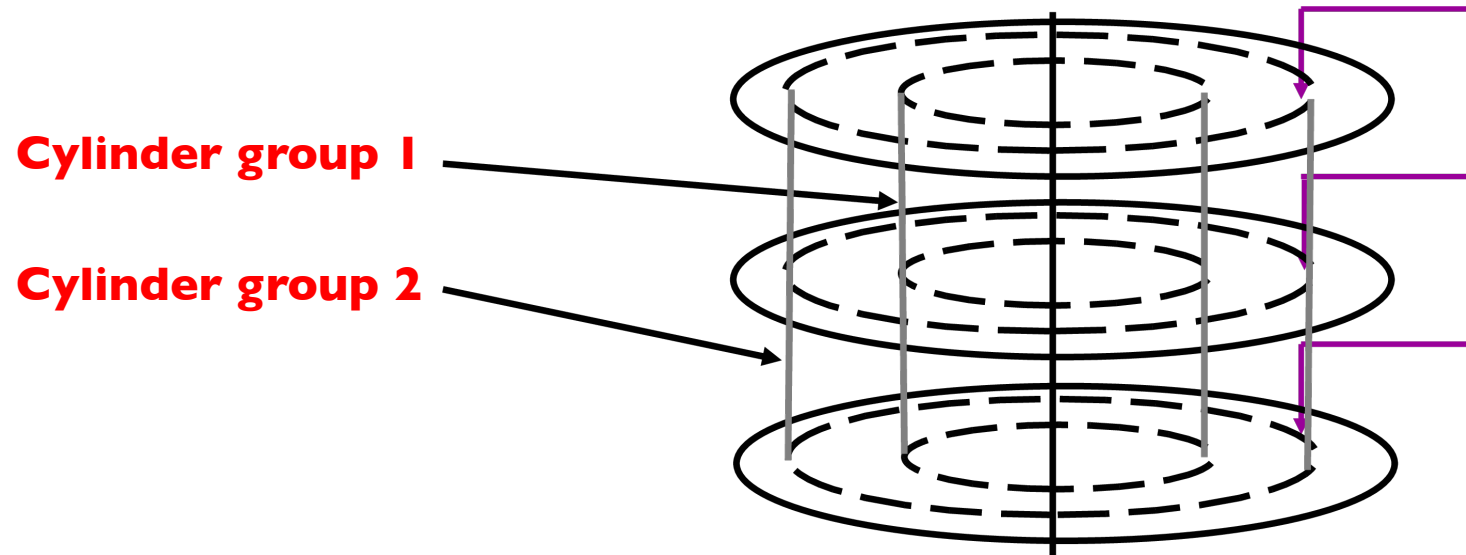
# Problem 3: Poor Locality



**How to keep inode close to data block?**

# FFS Solution: Cylinder Group

Group sets of consecutive cylinders into “**cylinder groups**”

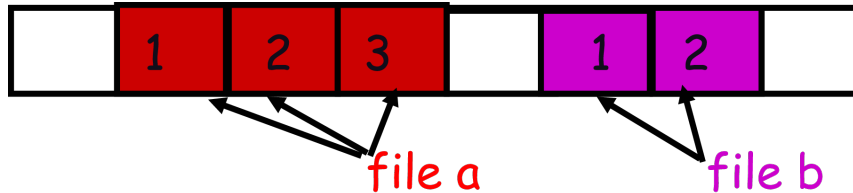


- Key: can access any block in a cylinder without performing a seek. Next fastest place is adjacent cylinder.
- Tries to put everything related in same cylinder group
- Tries to put everything not related in different group

# Clustering in FFS

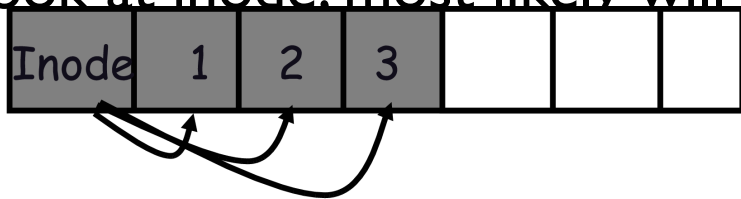
Tries to put sequential blocks in adjacent sectors

- (Access one block, probably access next)



Tries to keep inode in same cylinder as file data:

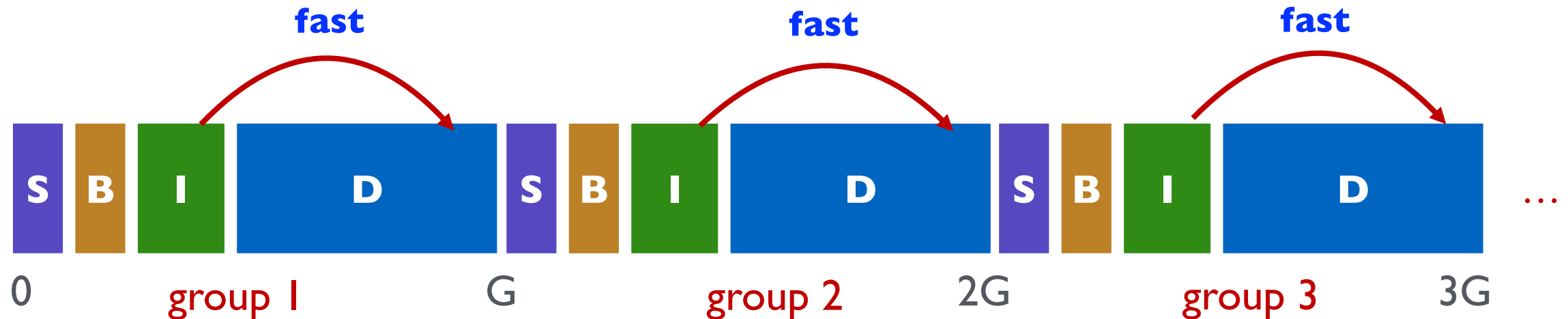
- (If you look at inode, most likely will look at data too)



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**