

CE 440 Introduction to Operating System

Lecture 19: Log-Structure File System Fall 2025

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Slides courtesy of Manuel Egele, Ryan Huang and Baris Kasikci

Administrivia

Thanksgiving break!

- No class
- Assignments
 - food, lots of it
 - sleep, lots of it
 - warm clothes, winter is coming
 - Stay safe

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?

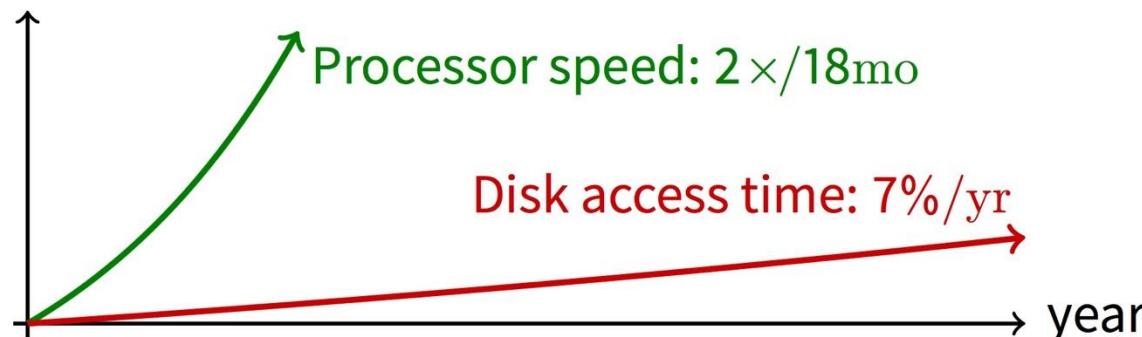
LFS: Log-structured File System

An influential work designed by Mendel Rosenblum (VMWare co-founder) and John Ousterhout

- A classic example of system designs driven by technology trends

Motivation

- Faster CPUs: I/O becomes more and more of a bottleneck



- More memory: file cache is effective for reads
- **Implication:** writes compose most of disk traffic

Motivation

Problems with previous FS

- Perform many small writes
 - Good performance on large, sequential writes, but many writes are still small, random
- Synchronous operation to avoid data loss
- Depends upon knowledge of disk geometry (Fast File System)

LFS Idea

Insight: treat disk like a tape-drive

- Best performance from disk for sequential access
- What is Fast-File-System's insight about disk?

File system buffers writes in main memory until “enough” data

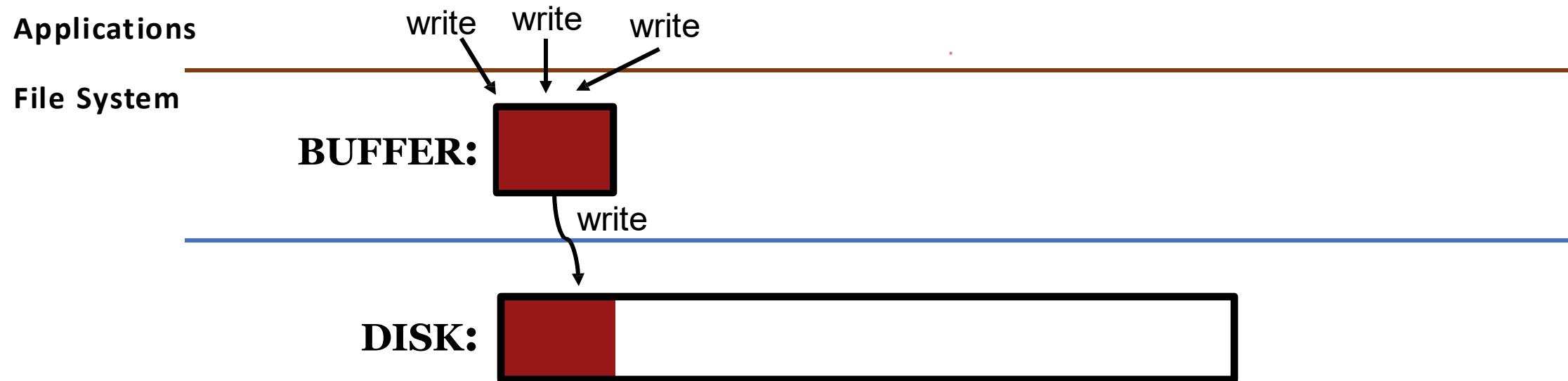
- How much is enough?
- Enough to get good sequential bandwidth from disk (MB)
- Unit called a “segment”

Write Data to a Sequential Log

Write buffered data to new segment on disk in a sequential log

- Transfer all updates into a series of sequential writes
- Do not overwrite old data on disk
 - i.e., old copies left behind
- Write both data and metadata in one operation

Write in LFS



Absorb many small writes into one buffer write!

Write in LFS

Applications

File System

BUFFER:



DISK:



Write in LFS

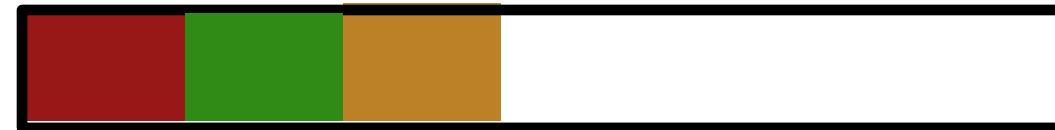
Applications

File System

BUFFER:



DISK:



Write in LFS

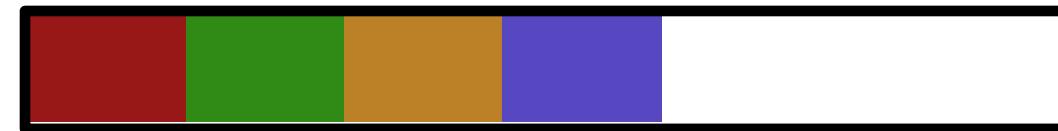
Applications

File System

BUFFER:



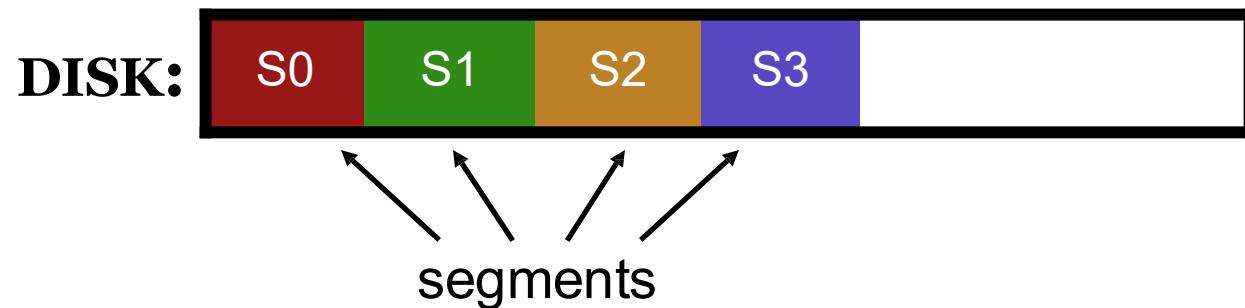
DISK:



Write in LFS

Applications

File System



Write in LFS

Applications

File System

BUFFER:

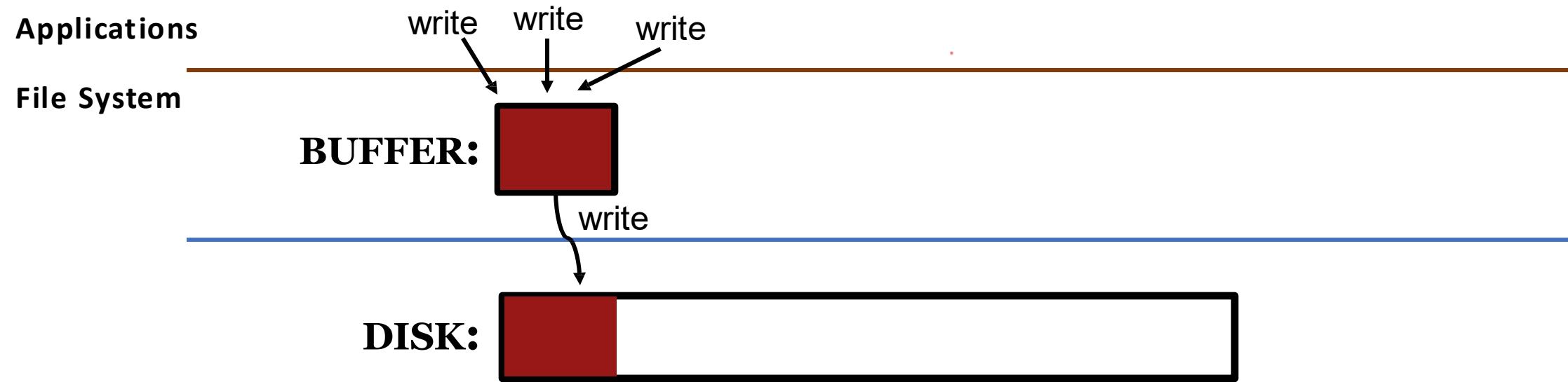


DISK:

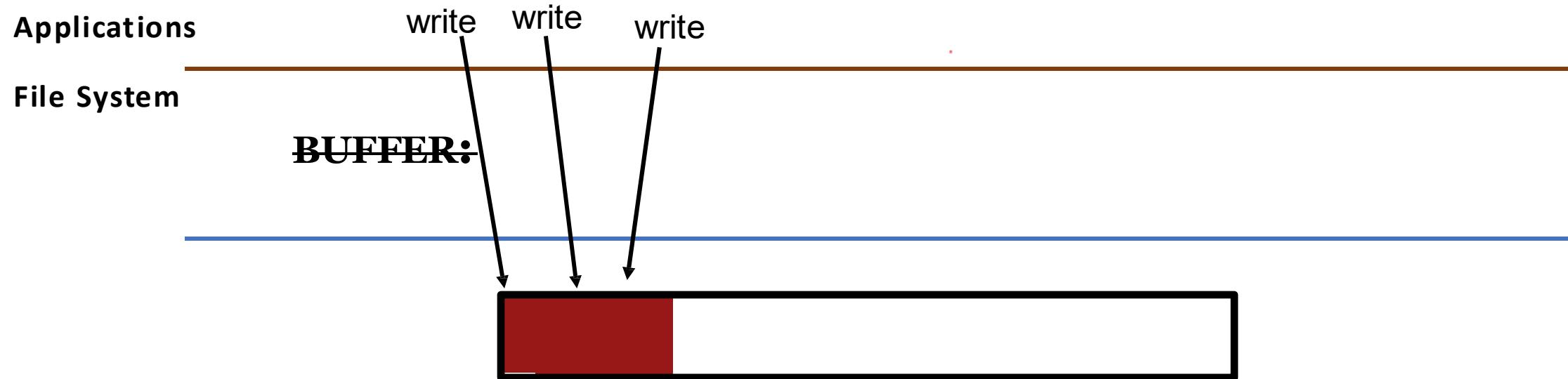


Why do we buffer the write?

Write in LFS



Write in LFS



Why not directly write to the log on disk sequentially?

- Sequential write alone is not enough
- Disk is constantly rotating!
- Must issue a large number of **contiguous** writes

Pros And Cons

Pros

- Always large sequential writes → good performance
- No knowledge of disk geometry
 - Assume sequential better than random

Potential problems

- How do you find data to read?
- What happens to metadata during write?
- What happens when you fill up the disk?

Read in LFS

Same basic structures as Unix

- Directories, inodes, indirect blocks, data blocks
- Reading data block implies finding the file's inode
 - Unix FS: inodes in a fixed region (array) on disk
 - LFS: inodes spread around on disk

Solution: inode map ([imap](#)) indicates where each inode is stored

- Can keep cached copy in memory
- inode map written to log with everything else
- Periodically written to known checkpoint location on disk for crash recovery

Data Structures for LFS – Attempt 1

DISK:



What data structures from FFS can LFS remove?

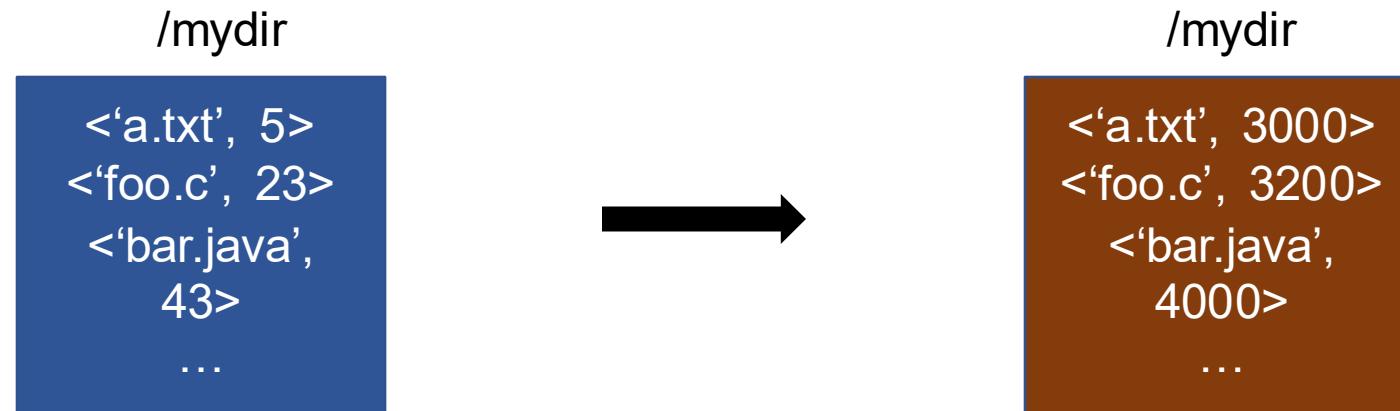
- allocation structs: data + inode bitmaps ([why?](#))

What type of structure is much more complicated?

- Inodes are no longer at fixed offset!
- Use [current offset on disk](#) instead of table index for name
- Note: [when update inode, inode changes!](#) ([why?](#))

Attempt 1: Data Structures for LFS

Directory Entry



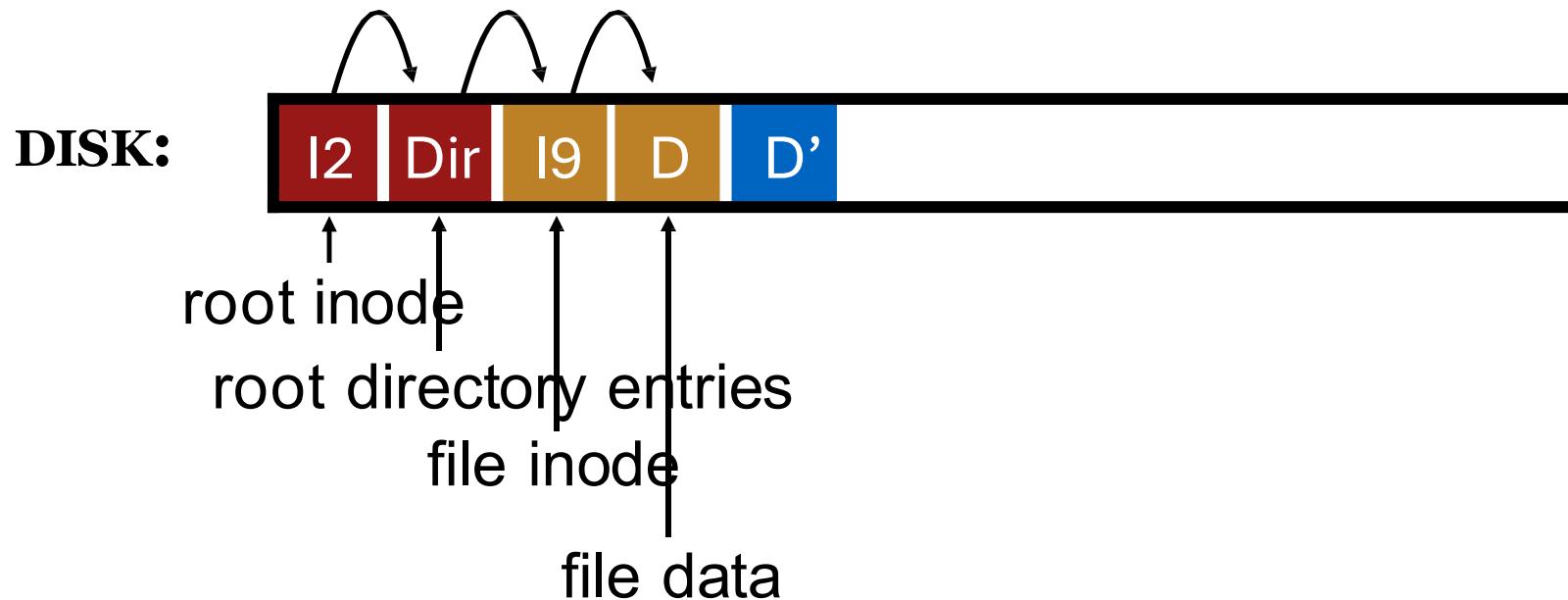
Previously,
each dir entry is
<name, inode #>

Now,
each dir entry is
<name, disk offset>

Would this attempt work?

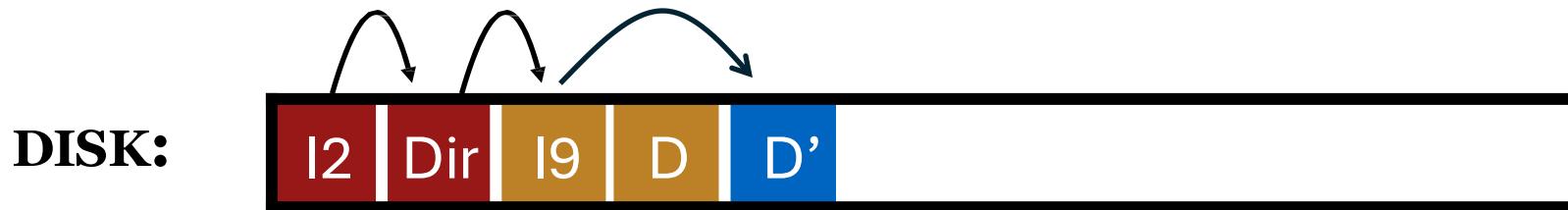
Attempt 1: Overwrite Data in LFS

Overwrite data in /file.txt



Attempt 1: Overwrite Data in LFS

Overwrite data in /file.txt

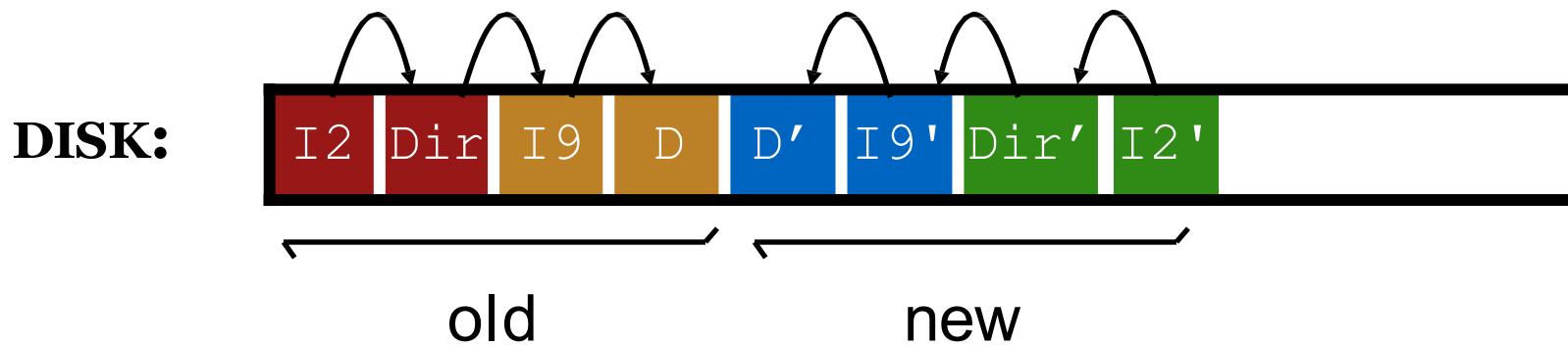


Can LFS update inode 9 to point to new D'?

- NO! This would be a random write..

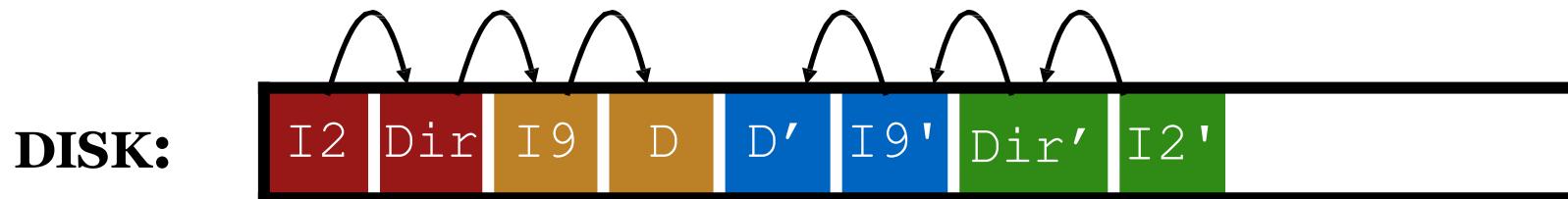
Attempt 1: Overwrite Data in LFS

Overwrite data in /file.txt



Must update *all* structures in sequential order to log

Attempt 1: Problem w/ Using Offset



Problem:

- For every data update, must propagate updates all the way up directory tree to root

Why?

- When we copy & modify the inode, its location (disk offset) changes

Solution:

- Keep inode numbers constant; don't base name on disk offset

Data Structures for LFS (attempt 2)

What data structures from FFS can LFS remove?

- allocation structs: data + inode bitmaps

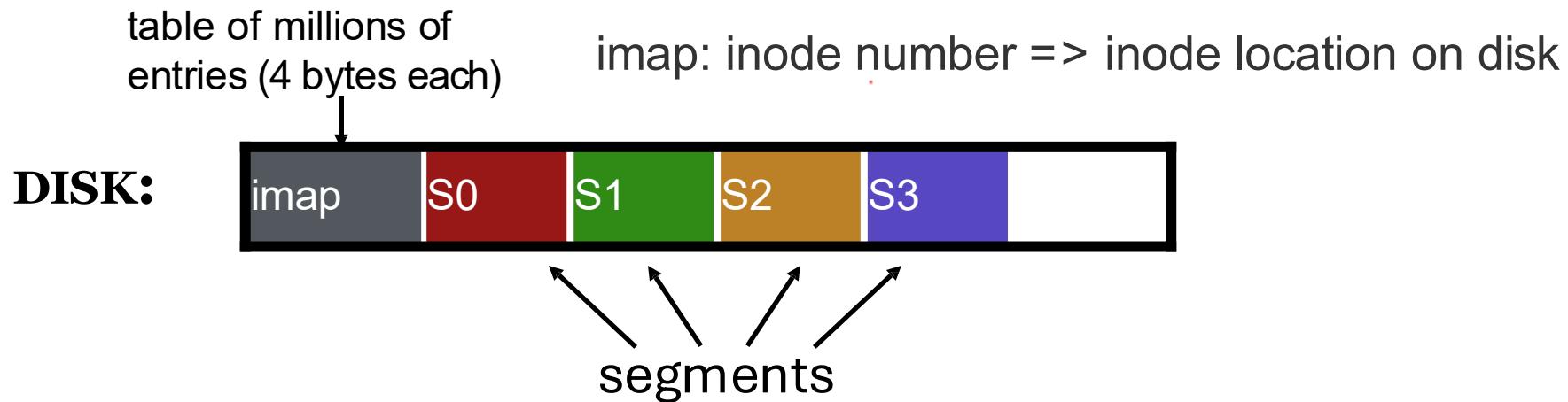
What type of struct is much more complicated?

- Inodes are no longer at fixed offset
- Use current offset on disk instead of table index for name
- Keep inode number in dir constant
- Use `imap` structure to map `inode number` => most recent inode location on disk

FFS found inodes with math. How now?

- `imap`

Where to Keep imap?



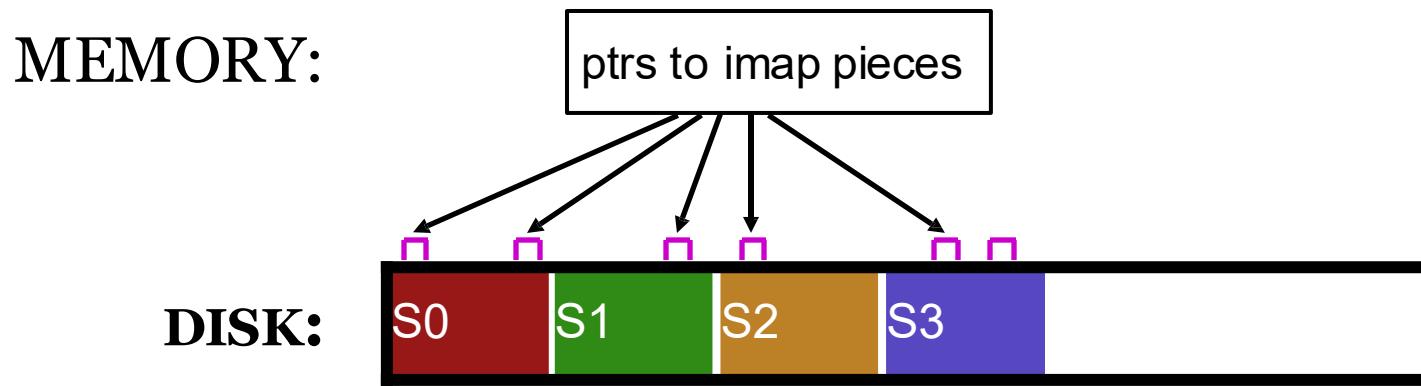
Where can imap be stored? Dilemma:

1. imap too large to keep in memory
2. don't want to perform random writes for imap

Solution: Write imap in segments

- Keep pointers to pieces of imap in memory

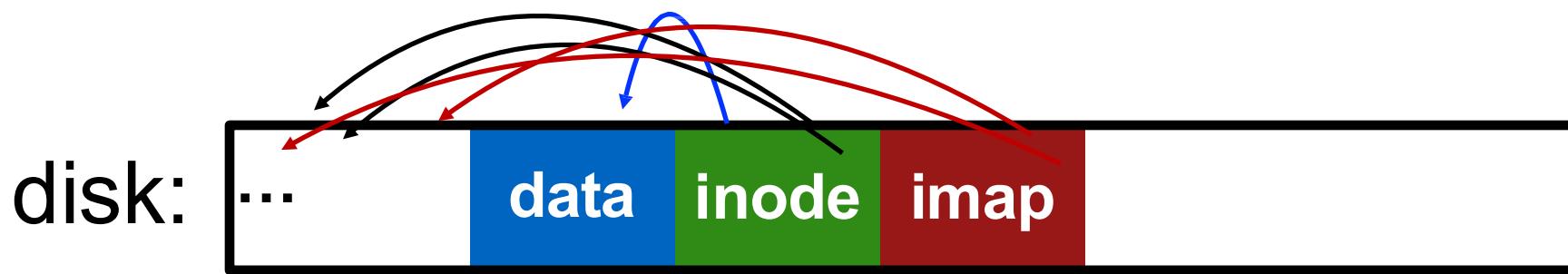
Solution: imap in Segments



Solution:

- Write imap in segments
- Keep pointers to pieces of imap in memory
- Keep recently accessed imap cached in memory

Example Write



Solution:

- Write imap in segments
- Keep pointers to pieces of imap in memory
- Keep recently accessed imap cached in memory

Disk Cleaning

When disk runs low on free space

- Run a disk cleaning process
- Compacts live information to contiguous blocks of disk

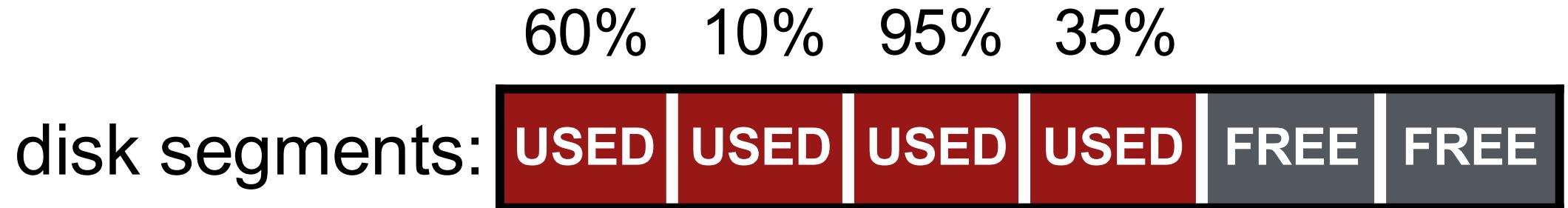
Problem: long-lived data repeatedly copied over time

- Solution: partition disk into segments
- Group older files into same segment

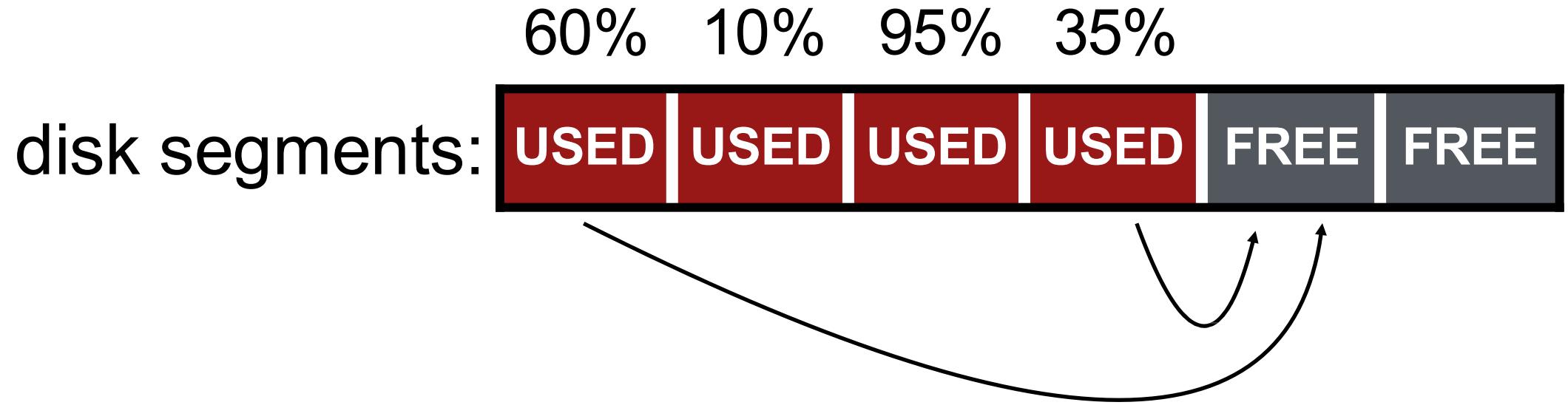
LFS reclaims segments (not individual inodes and data blocks)

- Want future overwrites to be to sequential areas
- Tricky, since segments are usually partly valid

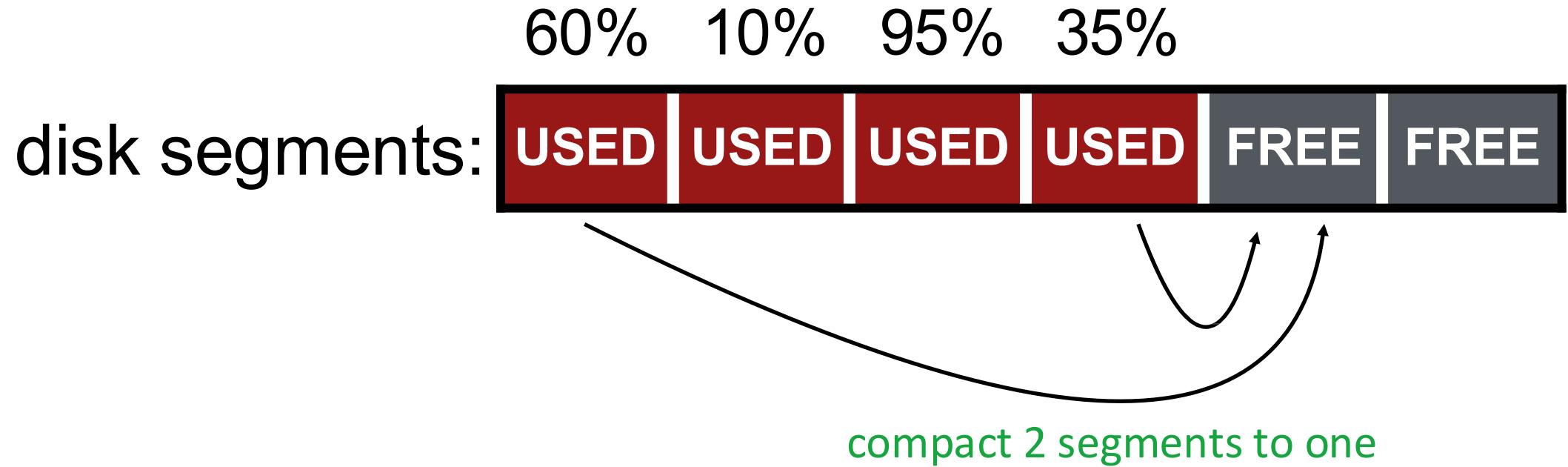
Cleaning: Copy & Compact Segments



Cleaning: Copy & Compact Segments

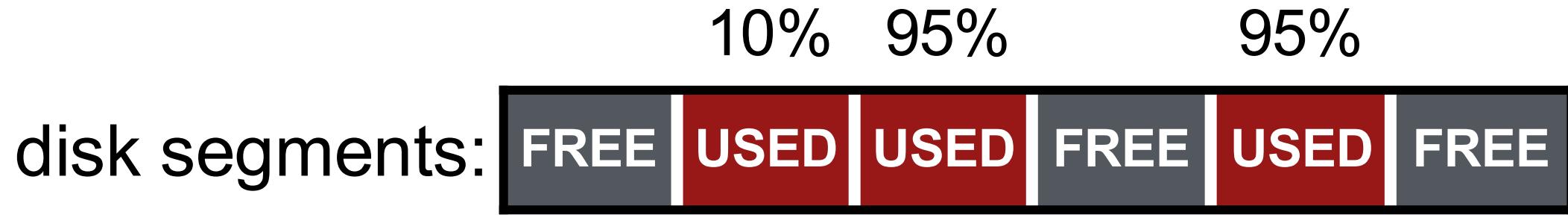


Cleaning: Copy & Compact Segments



- When move data blocks, copy new inode to point to it
- When move inode, update imap to point to it

Cleaning: Copy & Compact Segments



release the two input segments

Next Time...

Chapter 42