PERSISTENCE: LOG-STRUCTURED FILESYSTEM

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ADMINISTRIVIA

AGENDA / LEARNING OUTCOMES

How to optimize a filesystem that performs better for writes?

What are some challenges and how to overcome them?

RECAP

IN-CLASS QUIZ

LOG STRUCTURED FILE SYSTEM (LFS)

LFS PERFORMANCE GOAL

Motivation:

- Single operation (create a new file) requires multiple random writes
- RAID-4 and RAID-5 random write performance is poor
- Large gap between sequential and random I/O performance

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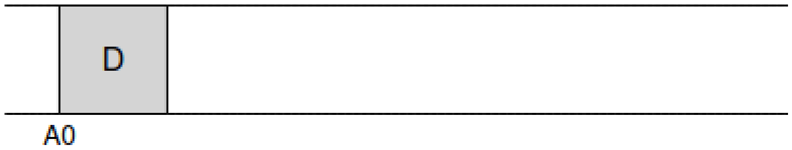
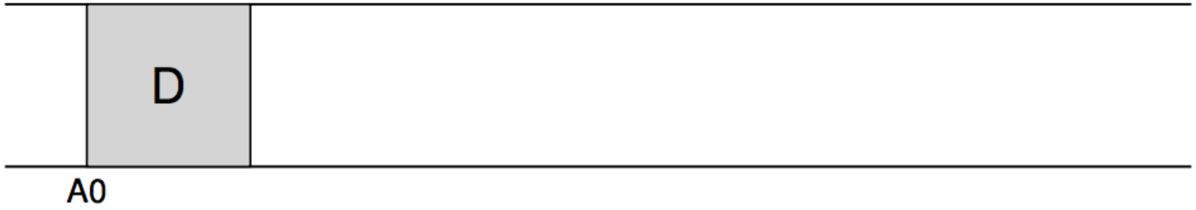
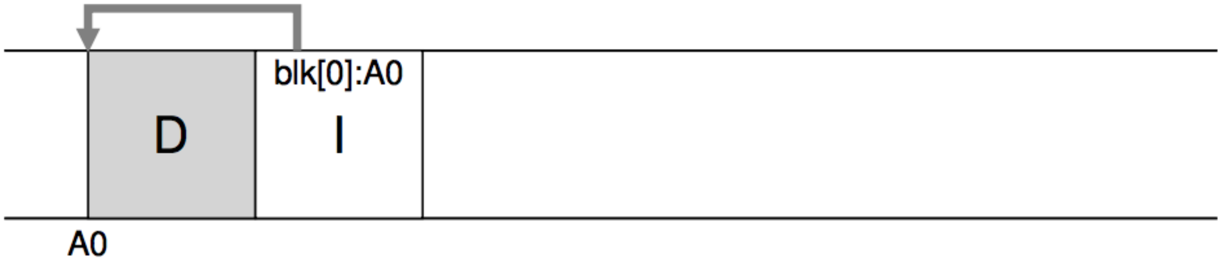
Idea: use disk purely sequentially

No random writes!



WHERE DO INODES GO?





IS WRITING SEQUENTIALLY SUFFICIENT?

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No!

Example:

Write block

Perform computation

Write block (but disk has already rotated past the desired block)

LFS STRATEGY

File system buffers writes in main memory until "enough" data

Write buffered data sequentially to new **segment** on disk

Never overwrite old info: old copies left behind

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Write buffered data sequentially to new **segment** on disk

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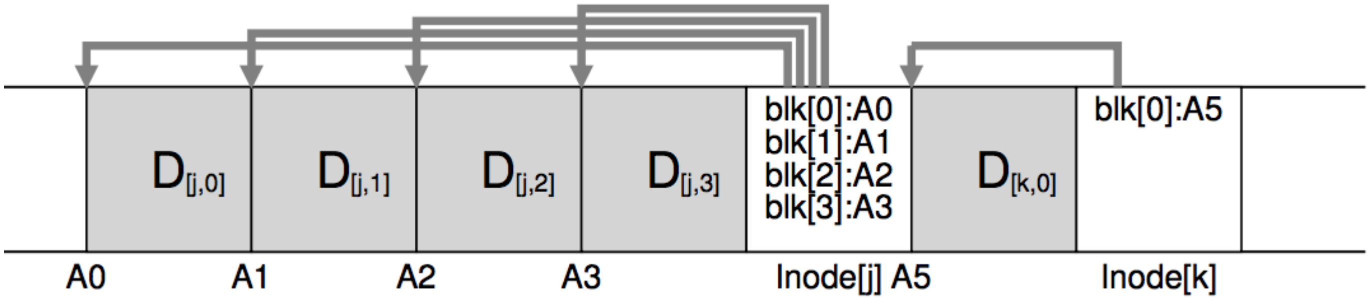
- How much to buffer?
- Enough to get good sequential bandwidth from disk (MB)

BUFFERED WRITES



WHAT IS DIFFERENT FROM FFS?

1) What data structures has LFS removed?

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   allocation structs: data + inode bitmaps

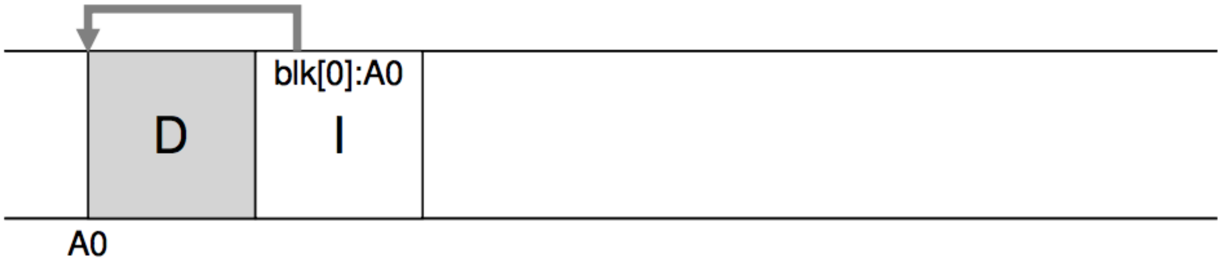
CHALLENGE 1: HOW TO LOCATE LATEST INODES?

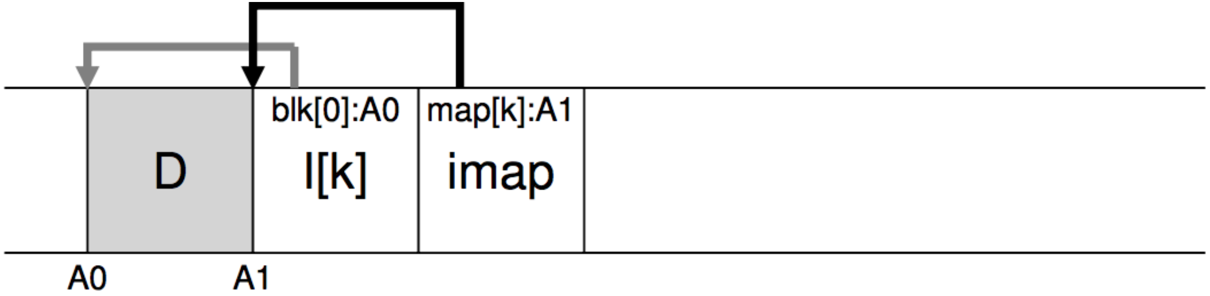
Problem: Inodes are no longer at fixed offset; multiple versions

Solution: Use imap structure

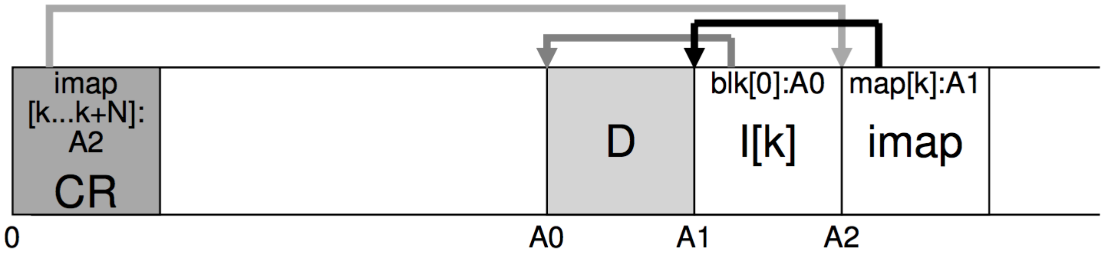
imap = maps inode number -> location on disk

IMAP EXPLAINED





READING IN LFS



1. Read the Checkpoint region
2. Read all imap parts, cache in mem
3. To read a file:
   1. Lookup inode location in imap
   2. Read inode
   3. Read the file block

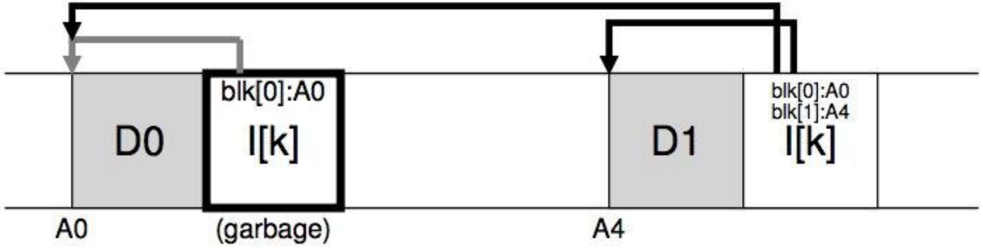
CHALLENGE 2: WHAT TO DO WITH OLD DATA?

Old versions of files → garbage

Approach 1: garbage is a feature!

- Keep old versions in case user wants to revert files later
- Versioning file systems
- Example: Dropbox

Approach 2: garbage collection



Garbage Collection

Need to reclaim space:

1. When no more references (any file system)
2. After newer copy is created (COW file system)

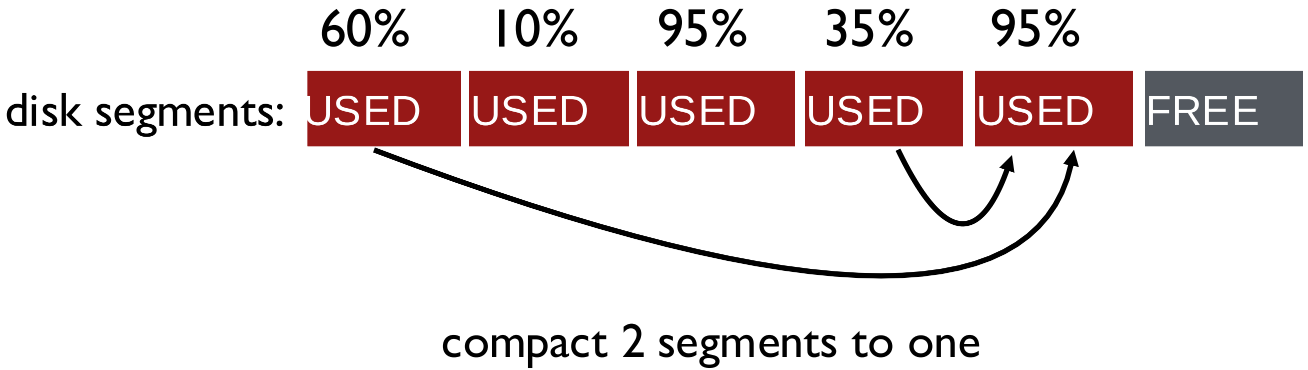
LFS reclaims **segments** (not individual inodes and data blocks)

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

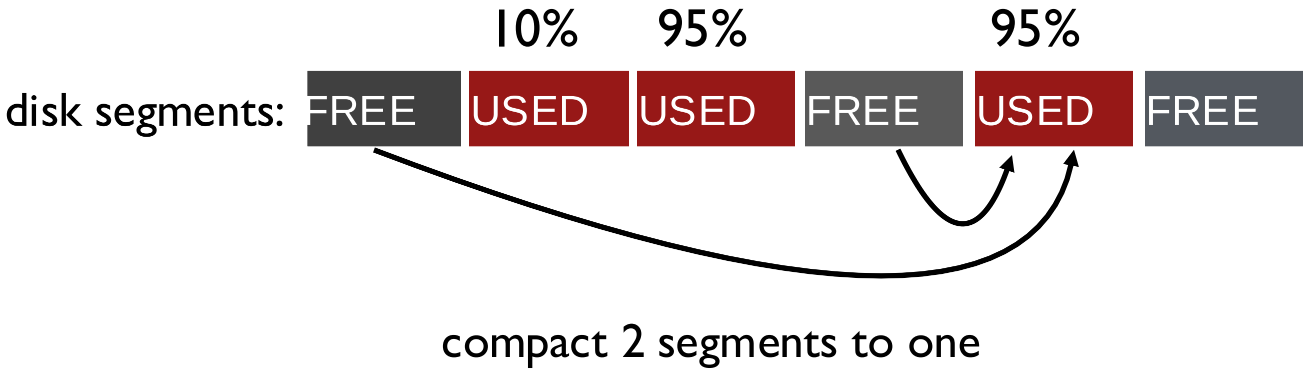
GARBAGE COLLECTION

	60%	10%	95%	35%		
disk segments:	USED	USED	USED	USED	FREE	FREE

Garbage Collection



Garbage Collection



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

GARBAGE COLLECTION

General operation:

Pick M segments, compact into N (where N < M).

Mechanism:

How does LFS know whether data in segments is valid?

Policy:

Which segments to compact?

GARBAGE COLLECTION MECHANISM

Is an inode the latest version?

- Check imap to see if this inode is pointed to
- Fast!

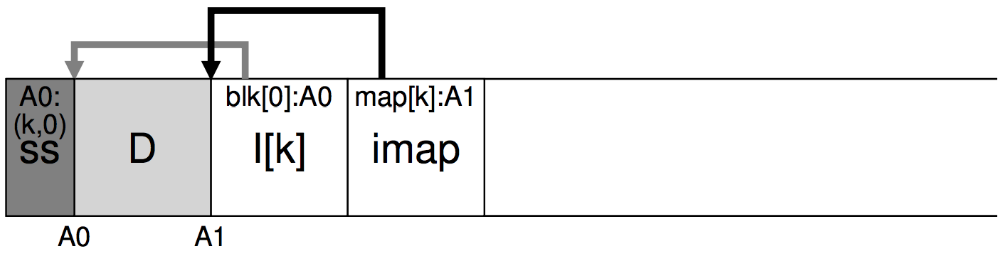
Is a data block the latest version?

- Scan ALL inodes to see if any point to this data
- Very slow!

How to track information more efficiently?

- **Segment summary** lists inode and data offset corresponding to each data block in segment (reverse pointers)

SEGMENT SUMMARY




```
(N, T) = SegmentSummary[A];

inode = Read(imap[N]);

if (inode[T] == A)
    // block D is alive
else
    // block D is garbage
```

GARBAGE COLLECTION

General operation:

Pick M segments, compact into N (where N < M).

Mechanism:

Use segment summary, imap to determine liveness

Policy:

Which segments to compact?

- clean most empty first
- clean coldest (ones undergoing least change)
- more complex heuristics…

Challenge 3: Crash Recovery

What data needs to be recovered after a crash?

- Need imap (lost in volatile memory)

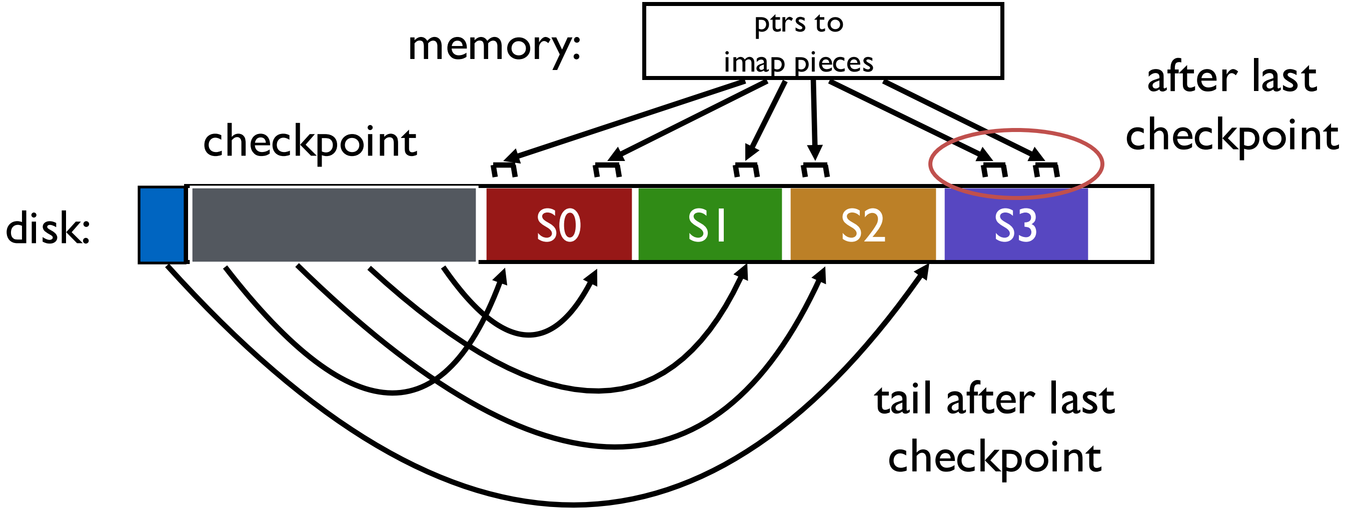
Better approach?

- Occasionally save to checkpoint region the pointers to imap pieces

How often to checkpoint?

- Checkpoint often: poor performance (random I/O)
- Checkpoint rarely: lose more data, recovery takes longer
- Example: checkpoint every 30 secs

CRASH RECOVERY



Checkpoint Summary

Checkpoint occasionally (e.g., every 30s)

Upon recovery:

- read checkpoint to find most imap pointers and segment tail
- find rest of imap pointers by reading past tail

What if crash during checkpoint?

CHECKPOINT STRATEGY

Have two checkpoint regions

Only overwrite one checkpoint at a time

Use checksum/timestamps to identify newest checkpoint

LFS SUMMARY

Journaling:

Put final location of data wherever file system chooses

(usually in a place optimized for future reads)

LFS:

Puts data where it's fastest to write, assume future reads cached in memory

Other COW file systems: WAFL, ZFS, btrfs

NEXT STEPS

Next class: SSDs!