PERSISTENCE: LOG-STRUCTURED FILESYSTEM

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CS 537, Spring 2020

ADMINISTRIVIA

Project 5: One week to go!

Discussion today: Prep for final exam

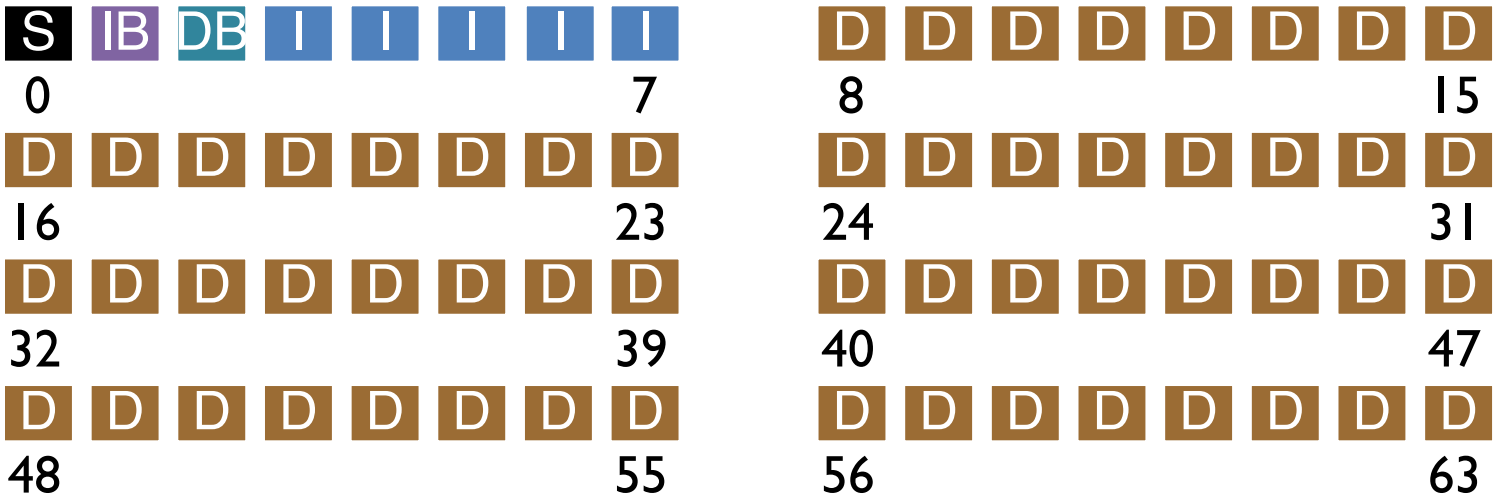
AGENDA / LEARNING OUTCOMES

How to design a filesystem that performs better for small writes?

What are some similarities or differences with FFS?

RECAP

FS STRUCTS


S IB DB I I I I I
0 7
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8 15
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16 23
D D D D D D D D
24 31
D D D D D D D D
32 39
D D D D D D D D
40 47
D D D D D D D D
48 55
D D D D D D D D
56 63

HOW CAN FILE SYSTEM FIX INCONSISTENCIES?

Solution #1:

FSCK = file system checker

Strategy:

After crash, scan whole disk for contradictions and "fix" if needed

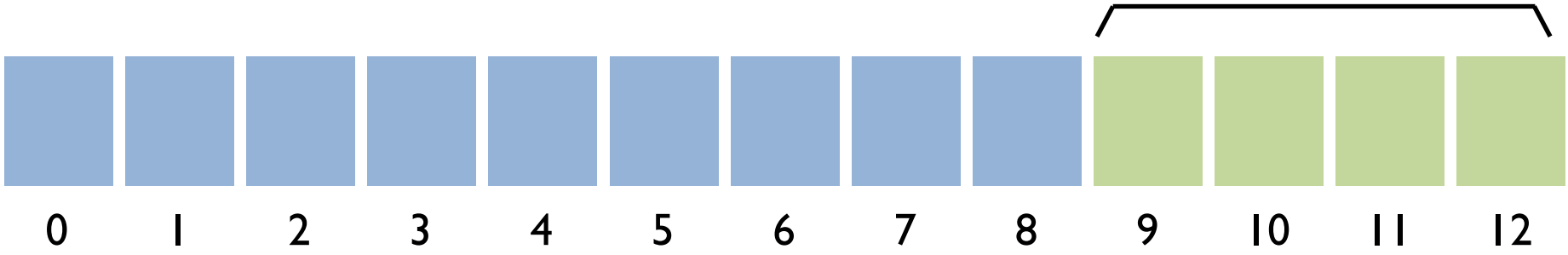
Keep file system off-line until FSCK completes

For example, how to tell if data bitmap block is consistent?

Read every valid inode+indirect block

If pointer to data block, the corresponding bit should be 1; else bit is 0

ORDERING FOR CONSISTENCY



Transaction: write C to block 4; write T to block 6

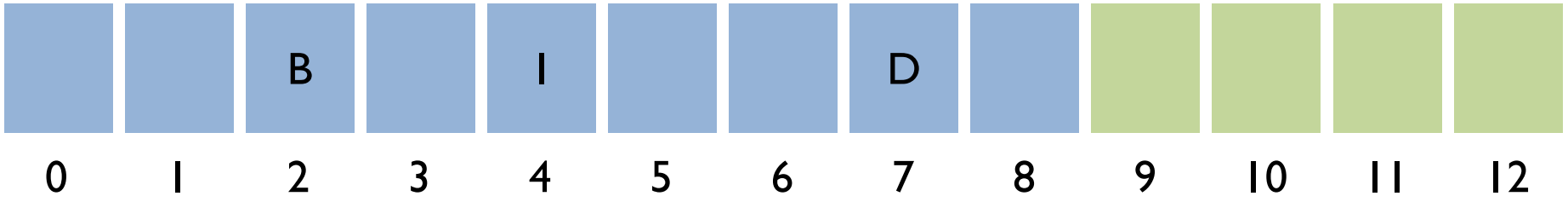
write order

9,10,11

12

4,6

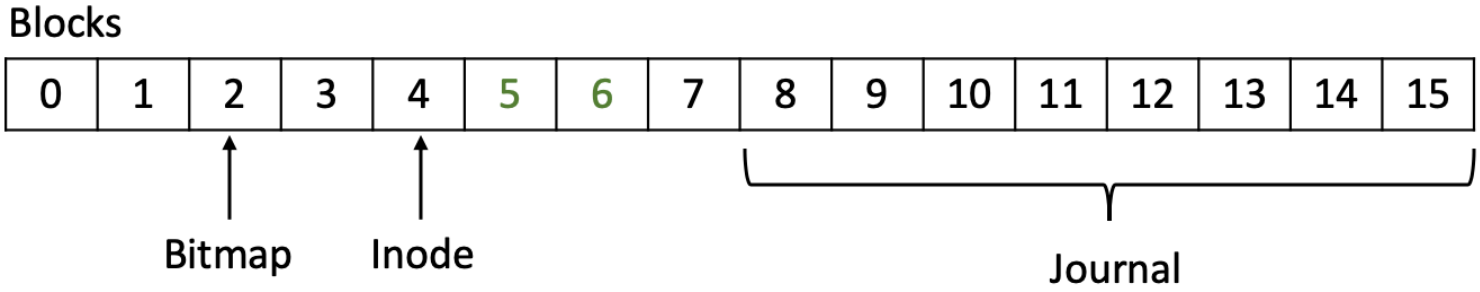
ORDERED JOURNAL



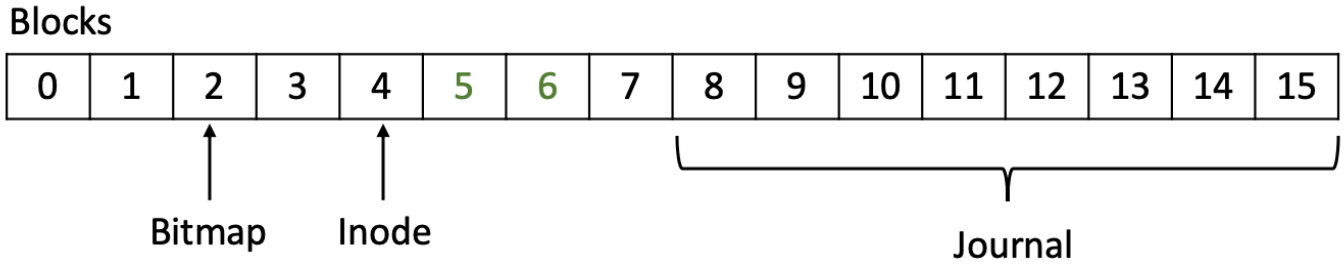
Append to a file
Data (D) in block 7
Inode (I) in block 4
Bitmap (B) in block 2

QUIZ 28

https://tinyurl.com/cs537-sp20-quiz28



Write 5,6
Write 8, 9, 10
Barrier
Write 11
Barrier
Write 4, 2



Write 8, 9, 10,11,12
Barrier
Write 13
Barrier
Write 2,4,5,6

Write 8, 9, 10,11,12, 13
Barrier
Write 2,4,5,6

LOG STRUCTURED FILE SYSTEM (LFS)

LFS PERFORMANCE GOAL

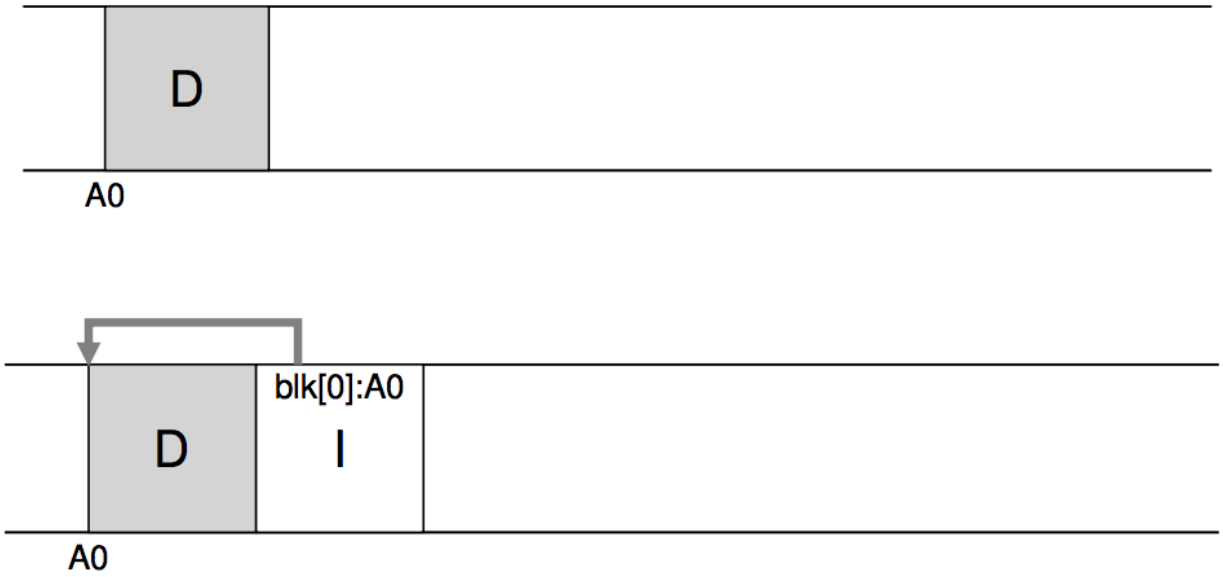
Motivation:

- Growing gap between sequential and random I/O performance
- RAID-5 especially bad with small random writes

Idea: use disk purely sequentially

Design for writes to use disk sequentially – how?

WHERE DO INODES GO?



LFS STRATEGY

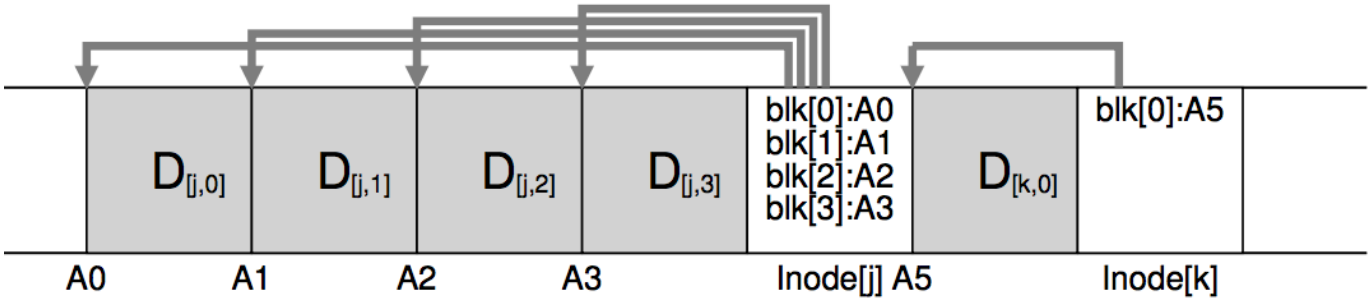
File system buffers writes in main memory until "enough" data

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

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

Never overwrite old info: old copies left behind

BUFFERED WRITES



WHAT ELSE IS DIFFERENT FROM FFS?

What data structures has LFS removed?

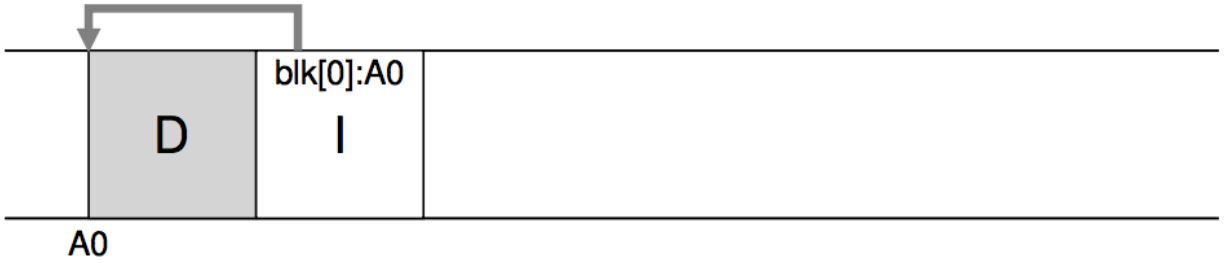
allocation structs: data + inode bitmaps

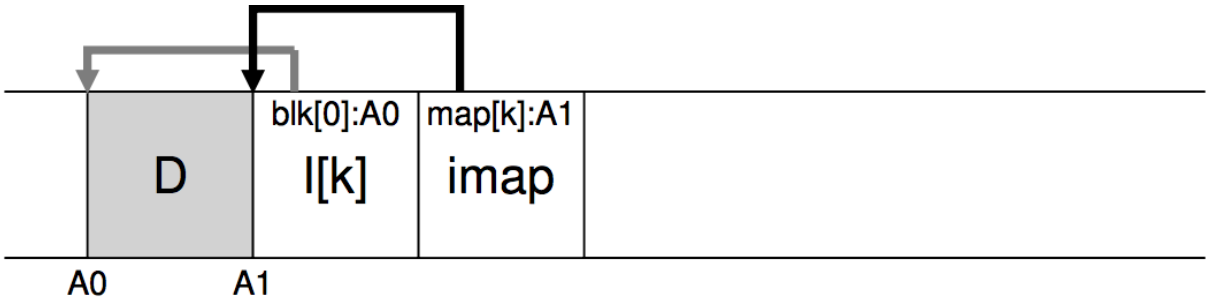
How to do reads?

Inodes are no longer at fixed offset

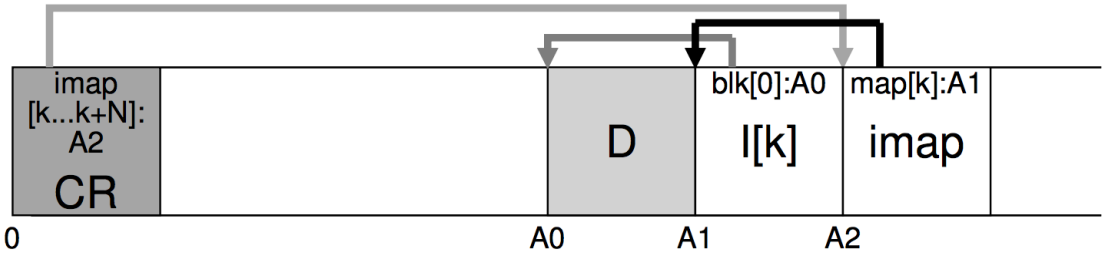
Use imap structure to map:
inode number => inode location on disk

IMAP EXPLAINED



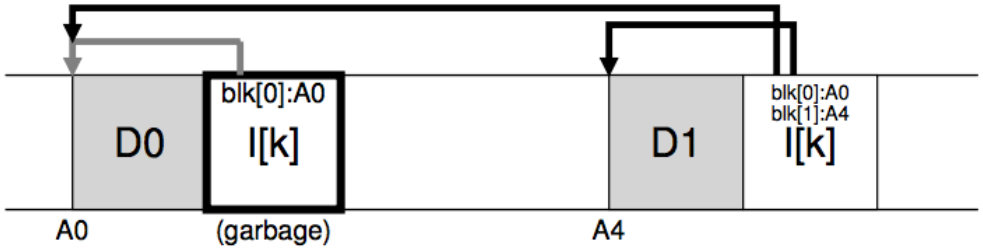


READING IN LFS



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

GARBAGE COLLECTION



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

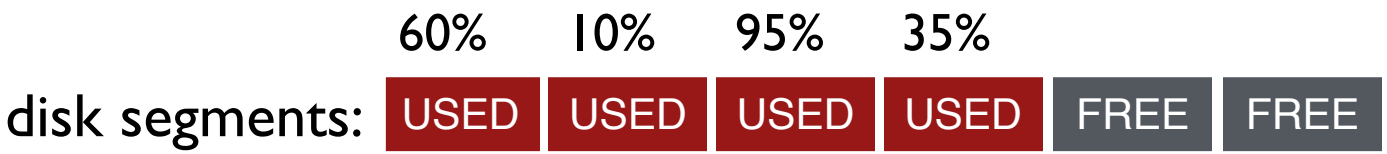
Need to reclaim space:

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

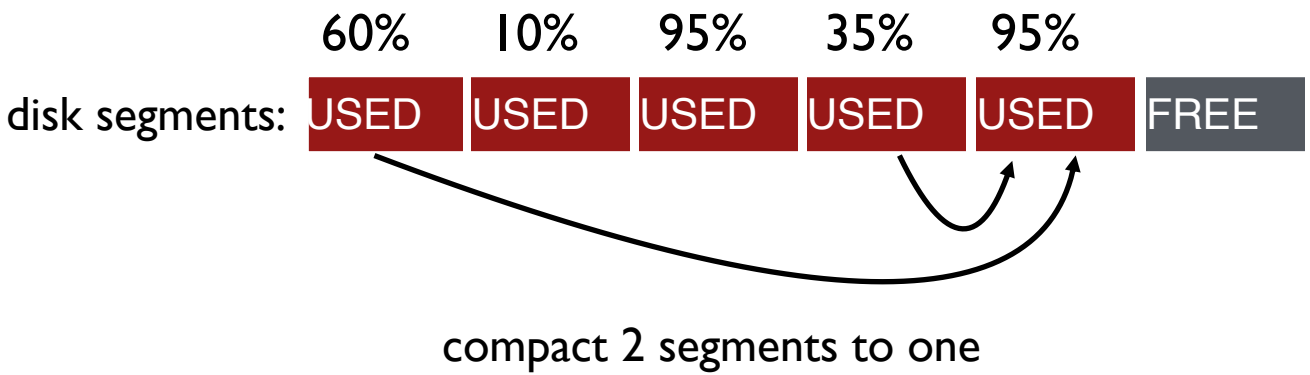
LFS reclaims **segments** (not individual inodes and data blocks)

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

GARBAGE COLLECTION



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!

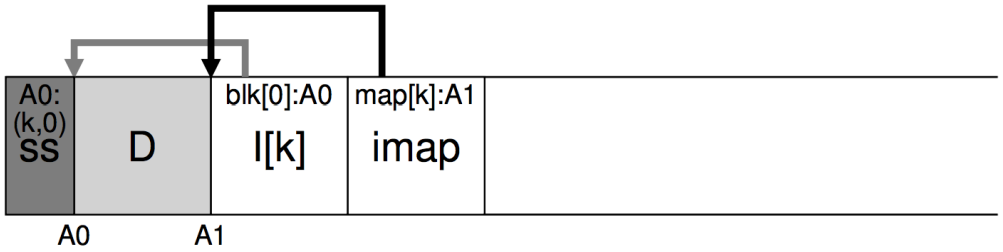
Is a data block the latest version?

- 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…

CRASH RECOVERY

What data needs to be recovered after a crash?

- Need imap (lost in volatile memory)

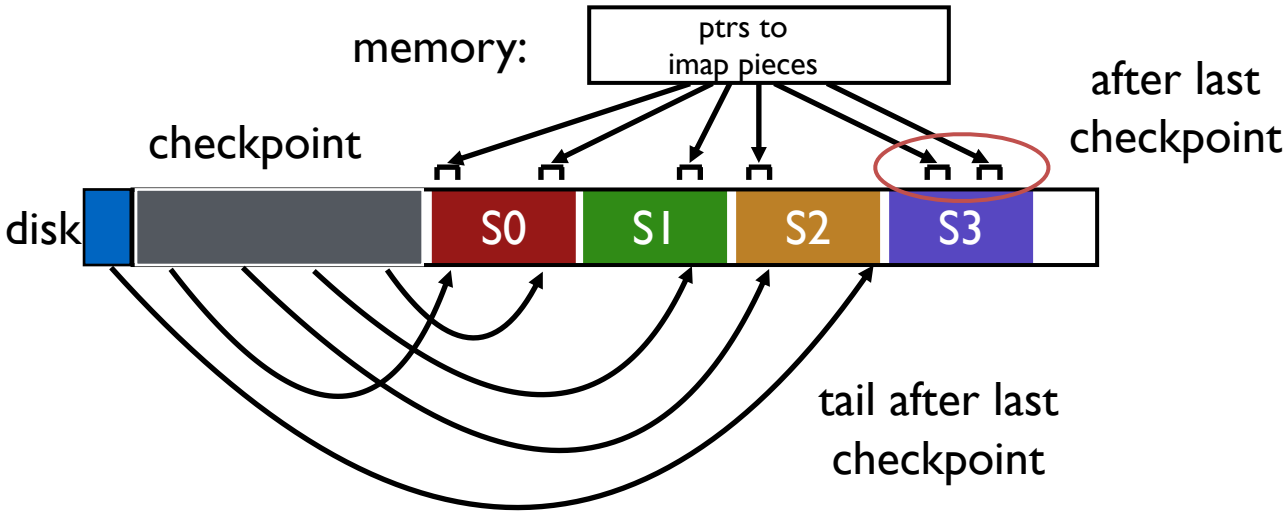
Better approach?

- Occasionally save to checkpoint region the pointers to imap pieces

How often to checkpoint?

- Checkpoint often: 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

QUIZ 29

https://tinyurl.com/cs537-sp20-quiz29

```
block 100: [("." 0), (".." 0), ("foo" 1)]   // a data block
block 101: [size=1,ptr=100,type=d]          // an inode
block 102: [size=0,ptr=-,type=r]            // an inode
block 103: [imap: 0->101,1->102]            // a piece of the imap
```

```
block 104: [SOME DATA]                          // a data block
block 105: [SOME DATA]                          // a data block
block 106: [size=2,ptr=104,ptr=105,type=r]      // an inode
block 107: [imap: 0->101,1->106]                // a piece of the imap
```

If we fill out 100 segments in a newly created LFS, how long does it take to complete a write?

If we read this file (reads do not hit cache), how long does it take to read the entire file?

If we now read this file backwards, one segment at a time (and reads do not hit in cache), how long does this backwards read take?

NEXT STEPS

Project 5 is one week away!

Discussion: Final practice quiz