Persistence: Log-Structured File System

CS 537: Introduction to Operating Systems

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Administrivia

- Project 6 due April 16th @ 11:59pm
- Final Exam:
  - Lec 1 - May 8th, 12:25-2:25 (Biochem 1125)
  - Lec 2 - May 6th, 2:45-4:45 (Sterling Hall 1310)
  - **McBurney: May 6th, 2:40-6:50 (Nancy Nicholas Hall 1135)**
  - If you can't take the exam for a *legitimate reason* at your designated time, please fill out the alternate exam form to take the exam with the other lecture. Legitimate Reasons include:
    - Another exam at the same time, Religious conflict, University Sanctioned conflict, Scheduled Medical conflict, Civic Duty (e.g. jury duty), Military Service, Family Caregiving Responsibility, Family Emergency, Serious Illness, 3 or more exams scheduled during a 24 hour period

Review FSCK & Journaling

- File system consistency can be prevented (**journaling**) or recovered after a crash (**fsck**)
- `fsck` attempts to scan and correct inconsistencies found in the file system.
  - build **used data blocks** from inode table, checks inodes and directory entries for consistency
- Data Journaling and Metadata (or ordered) Journaling
  - Understand protocol of what gets written where and what waits occur to insure consistency

Quiz 20 Journaling

https://tinyurl.com/cs537-sp24-q20

LOG STRUCTURED FILE SYSTEM (LFS)

LFS PERFORMANCE GOAL

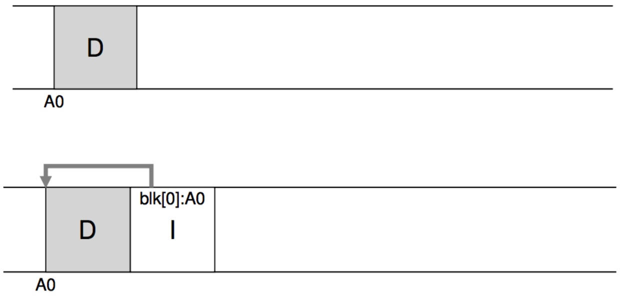
Motivation:

- Growing gap between sequential and random I/O performance
- Especially true in SSDs!
- 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

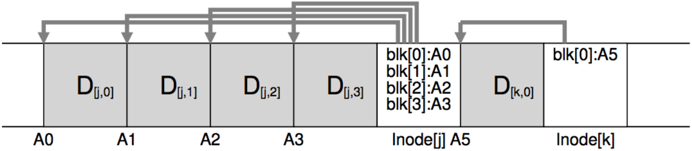
File system buffers writes in main memory until “enough” data

- 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?

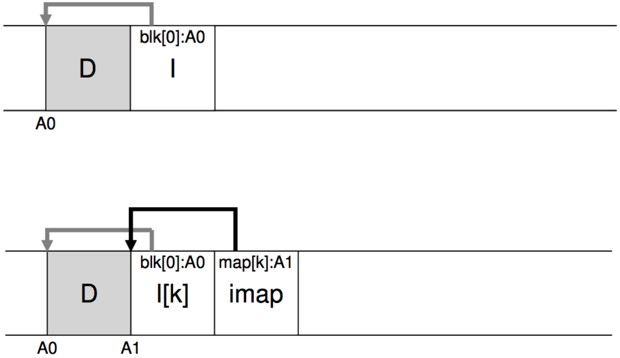
What data structures has LFS removed?

- allocation structs: data + inode bitmaps

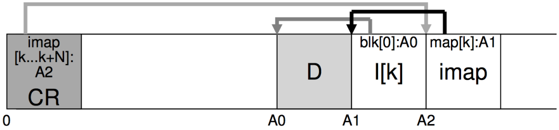
How to do reads?

- Inodes are no longer at fixed offset
- Use imap structure to map:
  inode number => inode location on disk

IMAP EXPLAINED

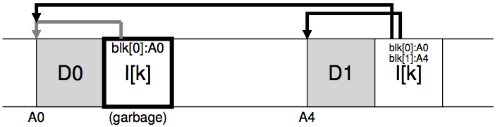


READING IN LFS



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

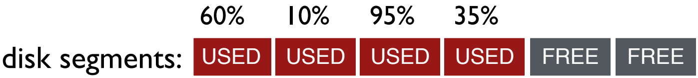
Need to reclaim space:

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

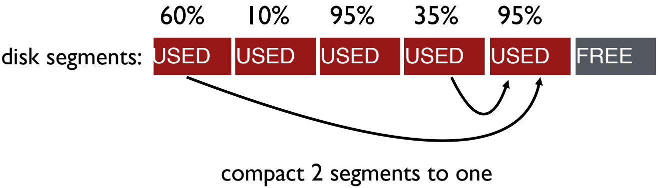
LFS reclaims **segments** (not individual inodes and data blocks)

- 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!

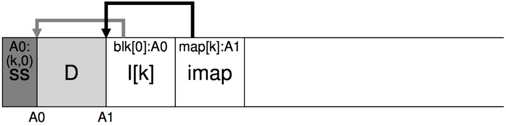
Is a data block the latest version?

- 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)

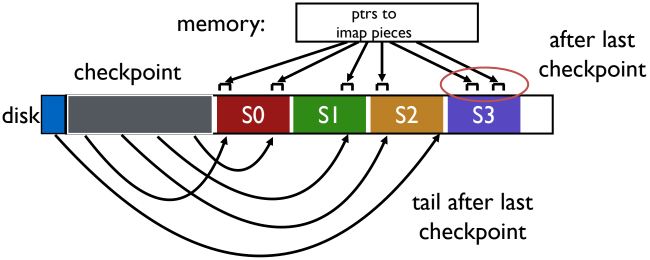
Better approach?

- 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 <u>during</u> 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

Solid State Devices (SSDs) covered next lecture