Journaling and Log-Structured File Systems

(Chapters 42, 43)

CS 4410
Operating Systems

Cornell CIS
COMPUTING AND INFORMATION SCIENCE

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Fault-tolerant Disk Update

Problem: many file system operations required multiple disk updates. What if there is a crash half-way?

Use Journaling / Write-Ahead Logging

- **Idea**: Protocol where performing a **single** disk write causes multiple disk writes to take effect.
- **Implementation**: New on-disk data structure ("journal") with a sequence of blocks containing updates *plus* …

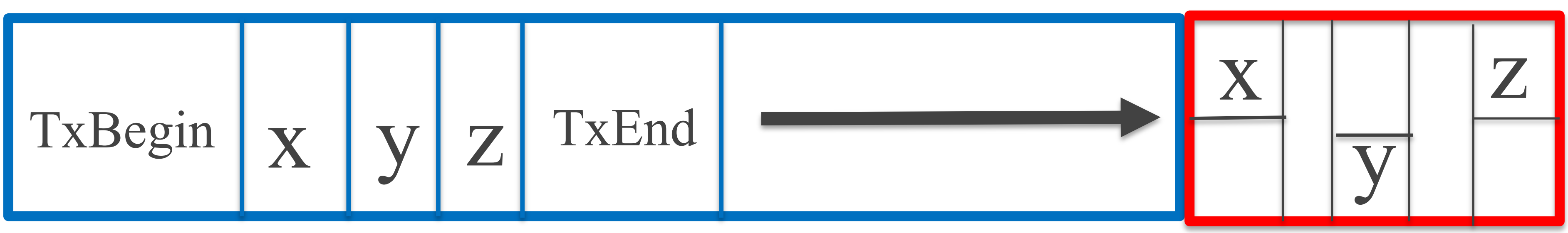
Journal-Update Protocol

write x; write y; write z

implemented by

- Append to journal: TxBegin, x, y, z
- Wait for completion of disk writes.
- Append to journal: TxEnd
- Wait for completion of disk write.
- Write x, y, z to final locations in file system

called **checkpoint step**



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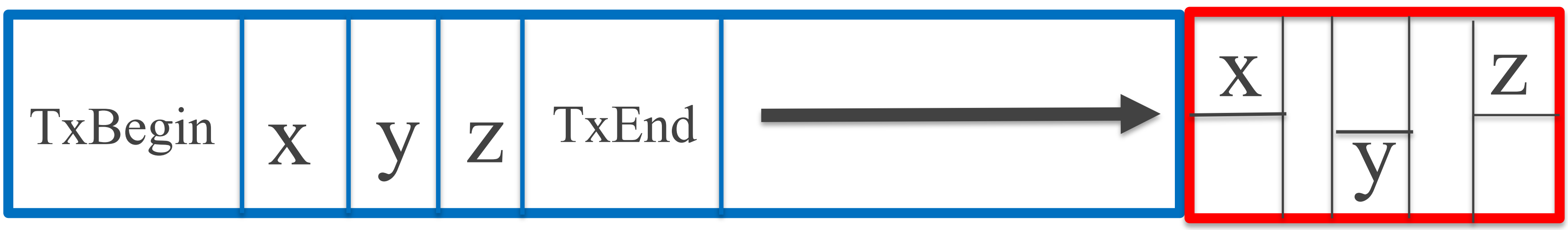
why?

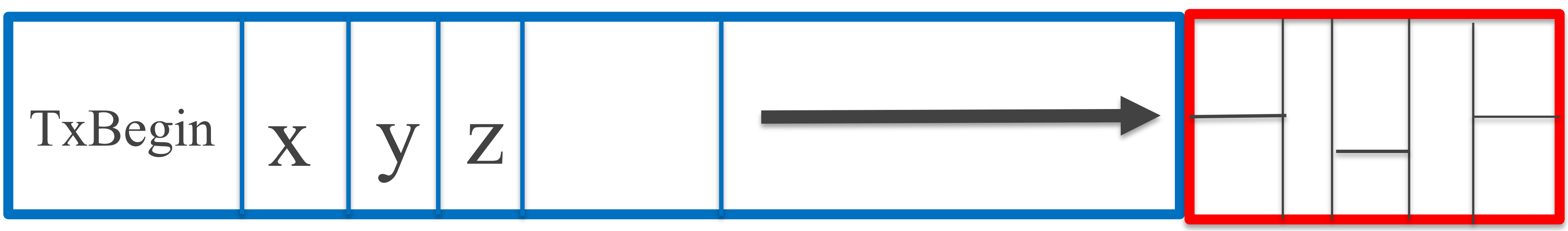


What if Crash?

write x; write y; write z

implemented by

- Append to journal: TxBegin, x, y, z
- Wait for completion of disk writes.
- Append to journal: TxEnd
- Wait for completion of disk write. crash!
- Write x, y, z to final locations in file system.



Recovery protocol for TxBegin … TxEnd:

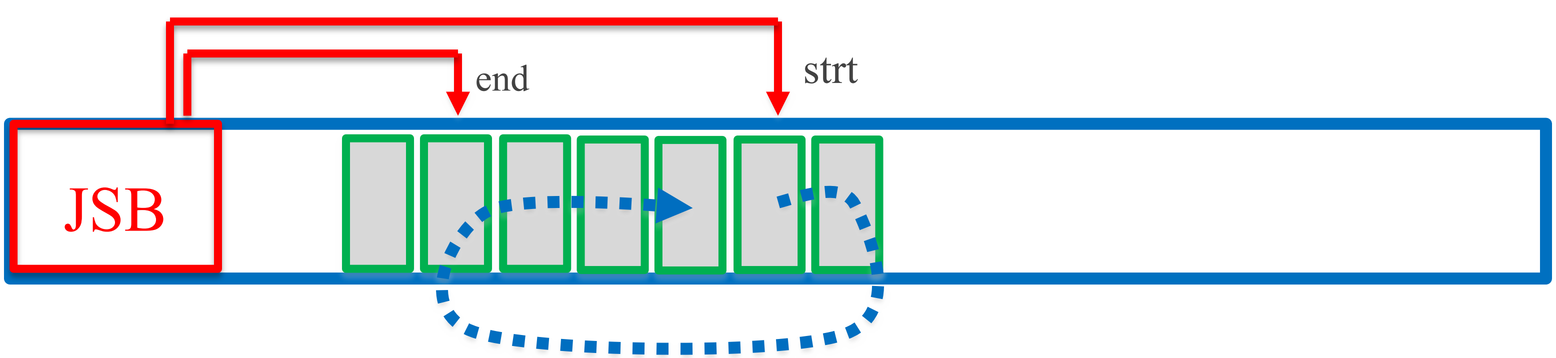
- **if** TxEnd present **then** redo writes to final locations following TxBegin
- **else** ignore journal entries following TxBegin

Full-Journal Recovery Protocol

- Replay journal from start, writing blocks as indicated by checkpoint steps.

Infinite Journal → Finite Journal:

- introduce **journal super block** (JSB) as first entry in journal: JSB gives start / end entries of journal.
- view journal as a circular log
- delete journal entry and update JSB once writes in checkpoint step complete



Performance Optimizations

- Eliminate disk write of TxEnd record.
  - Compute checksum of xxx in “TxBegin xxx TxEnd”
  - Include checksum TxBegin.
  - Recovery checks whether all log entries present.
- Eliminate disk write of xxx when data block
  - Step 1: Write data block to final disk location
  - Step 2: Await completion
  - Step 3: Write meta-data blocks to journal
  - Step 4: Await completion

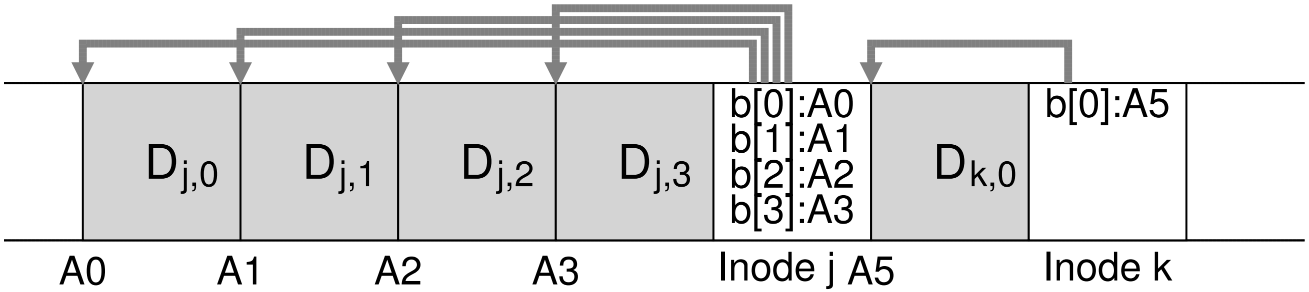
Log-Structured File Systems

Technological drivers:

- System memories are getting larger
    - Larger disk cache
    - Reads mostly serviced by cache
    - Traffic to disk mostly writes.
- Sequential disk access performs better.
    - Avoid seeks for even better performance
    - Better wear leveling on SSDs!

Idea: Buffer writes and store as single log entry on disk. Disk becomes one long log!

Storing Data on Disk



- Updates to file j and k are buffered.
- Inode for a file points to log entry for data
- An entire <u>segment</u> is written at once.

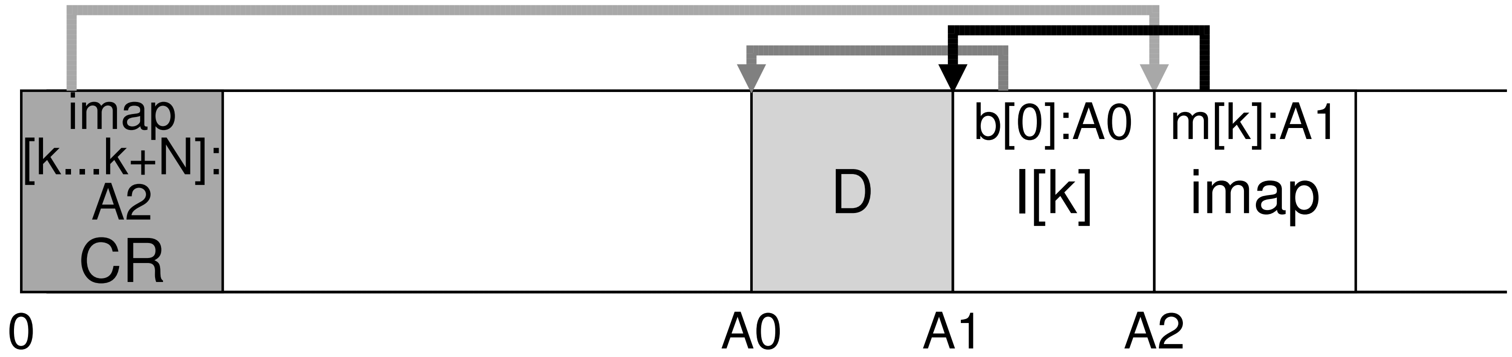
How to Find Inode on Disk

In UFS: F: inode nbr → location on disk

In LFS: location of inode on disk changes…

LFS: Maintain **inode Map** in pieces and store updated piece on disk.

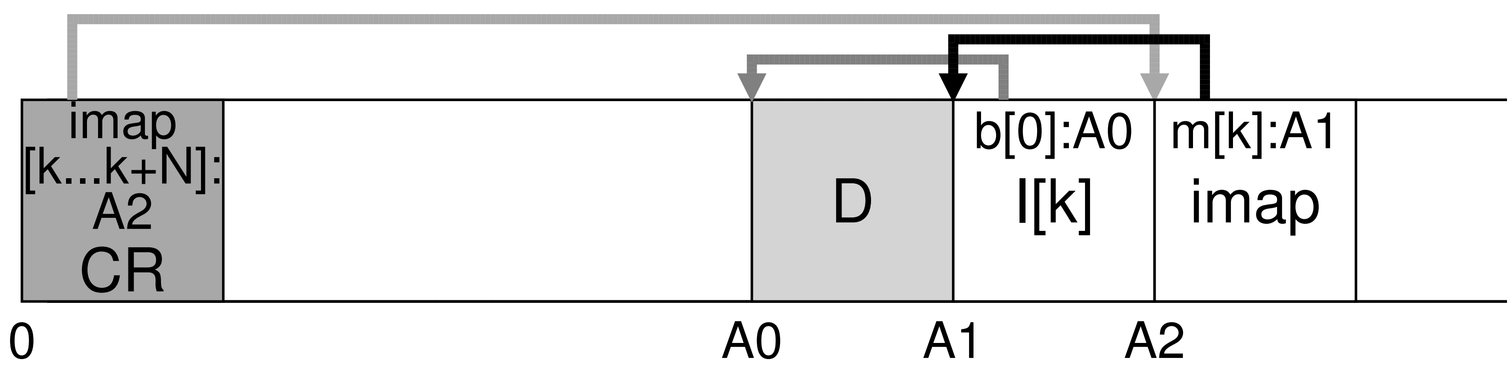
- For write performance: Put piece(s) at end of segment
- **Checkpoint Region**: Points to all inode map pieces and is updated every 30 secs. Located at fixed disk address. Also buffered in memory



To Read a File in LFS

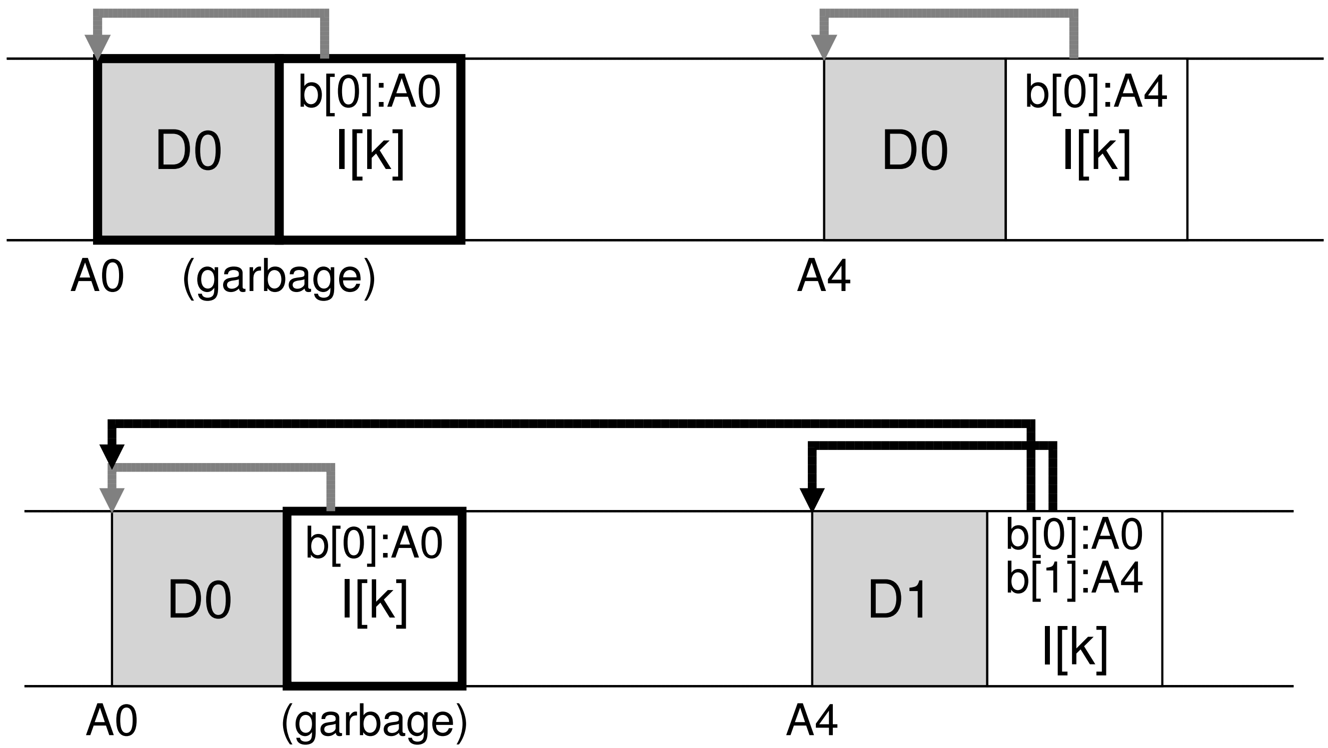
- [Load checkpoint region CR into memory]
- [Copy inode map into memory]
- Read appropriate inode from disk if needed
- Read appropriate file (dir or data) block

[…] = step not needed if information already cached.



Garbage Collection

Eventually disk will fill. But many blocks ("garbage") not reachable via CR, because they were overwritten.



LFS Cleaner

Protocol:

1. read segment;
2. identify garbage blocks within;
3. copy non-garbage blocks to new segment;
4. append new segment to disk log

Each segment includes **segment summary block** that includes for each data block D in segment:

- inode number
- Offset in the file for that inode

Retrieve the block number for that <inode, offset> from LFS to reveal if D is live (=) or it is garbage (=!).

Crash Recovery

LFS writes to disk: CR and segment.

After a crash:

- Find most recent consistent CR (see below)
- Roll forward by reading next segment for updates.

Crash-resistant atomic CR update:

- Two copies of CR: at start and end of disk.
- Updates alternate between them.
- Each CR has timestamp ts(CR,start) at start and ts(CR,end) at end.
  - CR consistent if ts(CR,start)=ts(CR,end)
- Use consistent CR with largest timestamp