UNIVERSITY of WISCONSIN-MADISON
Computer Sciences Department

CS 537
Introduction to Operating Systems

Andrea C. Arpaci-Dusseau
Remzi H. Arpaci-Dusseau

Journaling File Systems

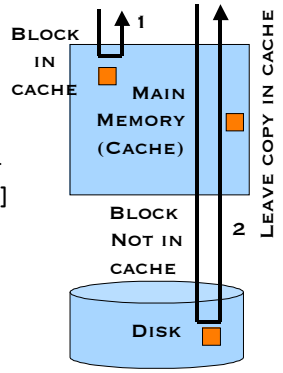
Questions answered in this lecture:

- Why is it hard to maintain on-disk consistency?
- How does the FSCK tool help with consistency?
- What information is written to a journal?
- What 3 journaling modes does Linux ext3 support?

Review: The I/O Path (Reads)

Read() from file

- Check if block is in cache
- If so, return block to user [1 in figure]
- If not, read from disk, insert into cache, return to user [2]



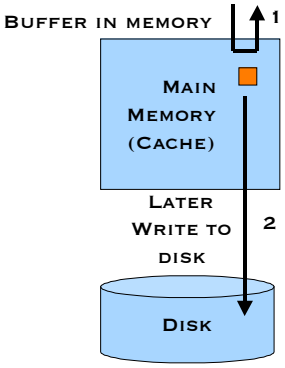
Review: The I/O Path (Writes)

Write() to file

- Write is buffered in memory ("write behind") [1]
- Sometime later, OS decides to write to disk [2]

Why delay writes?

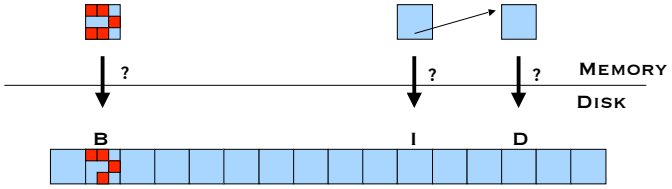
- Implications for performance
- Implications for reliability



Many "dirty" blocks in memory: What order to write to disk?

Example: Appending a new block to existing file

- Write data bitmap B (for new data block), write inode I of file (to add new pointer, update time), write new data block D



The Problem

Writes: Have to update disk with N writes

- Disk does only a single write atomically

Crashes: System may crash at arbitrary point

- Bad case: In the middle of an update sequence

Desire: To update on-disk structures atomically

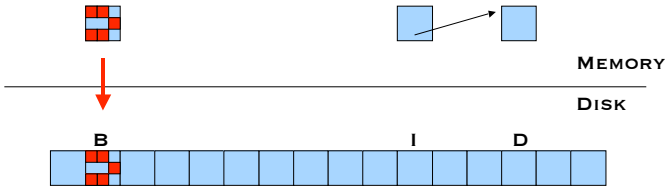
- Either all should happen or none

Example: Bitmap first

Write Ordering: Bitmap (B), Inode (I), Data (D)

- But CRASH after B has reached disk, before I or D

Result?

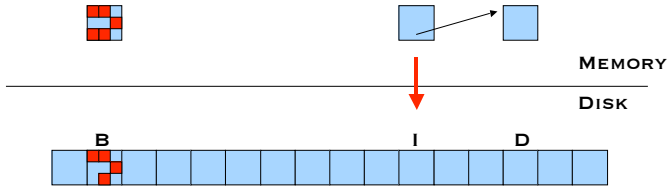


Example: Inode first

Write Ordering: Inode (I), Bitmap (B), Data (D)

- But CRASH after I has reached disk, before B or D

Result?

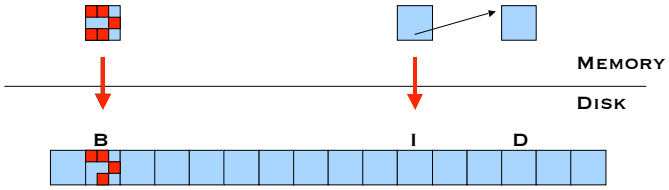


Example: Inode first

Write Ordering: Inode (I), Bitmap (B), Data (D)

- CRASH after I AND B have reached disk, before D

Result?

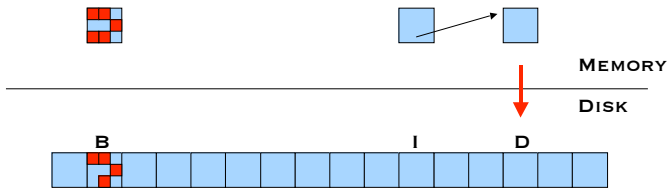


Example: Data first

Write Ordering: Data (D) , Bitmap (B), Inode (I)

- CRASH after D has reached disk, before I or B

Result?



Traditional Solution: FSCK

FSCK: "file system checker"

When system boots:

- Make multiple passes over file system, looking for inconsistencies
  - e.g., inode pointers and bitmaps, directory entries and inode reference counts
- Either fix automatically or punt to admin
- Does fsck have to run upon every reboot?

Main problem with fsck: Performance

- Sometimes takes hours to run on large disk volumes

How To Avoid The Long Scan?

Idea: Write something down to disk before updating its data structures

- Called the "write ahead log" or "journal"

When crash occurs, look through log and see what was going on

- Use contents of log to fix file system structures
- The process is called "recovery"

Case Study: Linux ext3

Journal location

- EITHER on a separate device partition
- OR just a "special" file within ext2

Three separate modes of operation:

- Data: All data is journaled
- Ordered, Writeback: Just metadata is journaled

First focus: Data journaling mode

Transactions in ext3 Data Journaling Mode

Same example: Update Inode (I), Bitmap (B), Data (D)

First, write to journal:

- Transaction begin (Tx begin)
- Transaction descriptor (info about this Tx)
- I, B, and D blocks (in this example)
- Transaction end (Tx end)

Then, "checkpoint" data to fixed ext2 structures

- Copy I, B, and D to their fixed file system locations

Finally, free Tx in journal

- Journal is fixed-sized circular buffer, entries must be periodically freed

What if there's a Crash?

Recovery: Go through log and "redo" operations that have been successfully commited to log

What if …

- Tx begin but not Tx end in log?
- Tx begin through Tx end are in log, but I, B, and D have not yet been checkpointed?
- What if Tx is in log, I, B, D have been checkpointed, but Tx has not been freed from log?

Performance? (As compared to fsck?)

Complication: Disk Scheduling

Problem: Low-levels of I/O subsystem in OS and even the disk/RAID itself may reorder requests

How does this affect Tx management?

- Where is it OK to issue writes in parallel?
  - Tx begin
  - Tx info
  - I, B, D
  - Tx end
  - Checkpoint: I, B, D copied to final destinations
  - Tx freed in journal

Problem with Data Journaling

Data journaling: Lots of extra writes

- All data committed to disk twice (once in journal, once to final location)

Overkill if only goal is to keep metadata consistent

Instead, use ext2 writeback mode

- Just journals metadata
- Writes data to final location directly, at any time

Problems?

Solution: Ordered mode

- How to order data block write w.r.t. Tx writes?

Conclusions

Journaling

- All modern file systems use journaling to reduce recovery time during startup (e.g., Linux ext3, ReiserFS, SGI XFS, IBM JFS, NTFS)
- Simple idea: Use write-ahead log to record some info about what you are going to do before doing it
- Turns multi-write update sequence into a single atomic update ("all or nothing")
- Some performance overhead: Extra writes to journal
  - Worth the cost?