PERSISTENCE: FSCK, JOURNALING

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CS 537, Spring 2019

ADMINISTRIVIA

Project 4b: Due today!

Project 5: Out by tomorrow

Discussion this week: Project 5

AGENDA / LEARNING OUTCOMES

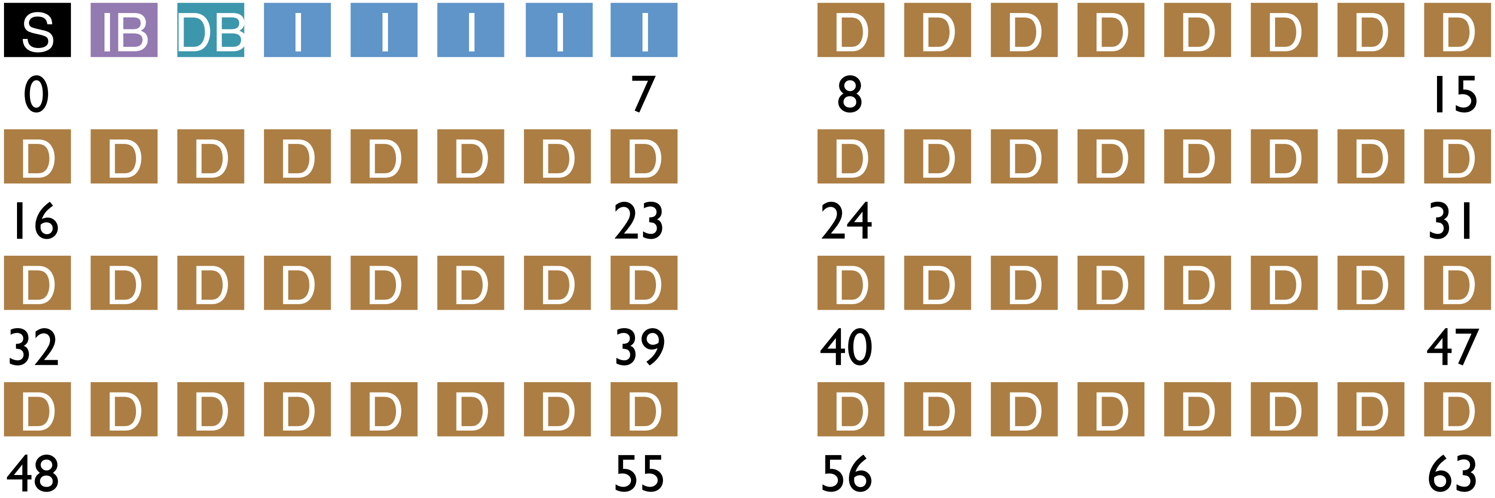
How does FFS improve performance?

How to maintain consistency with power failures / crashes?

RECAP

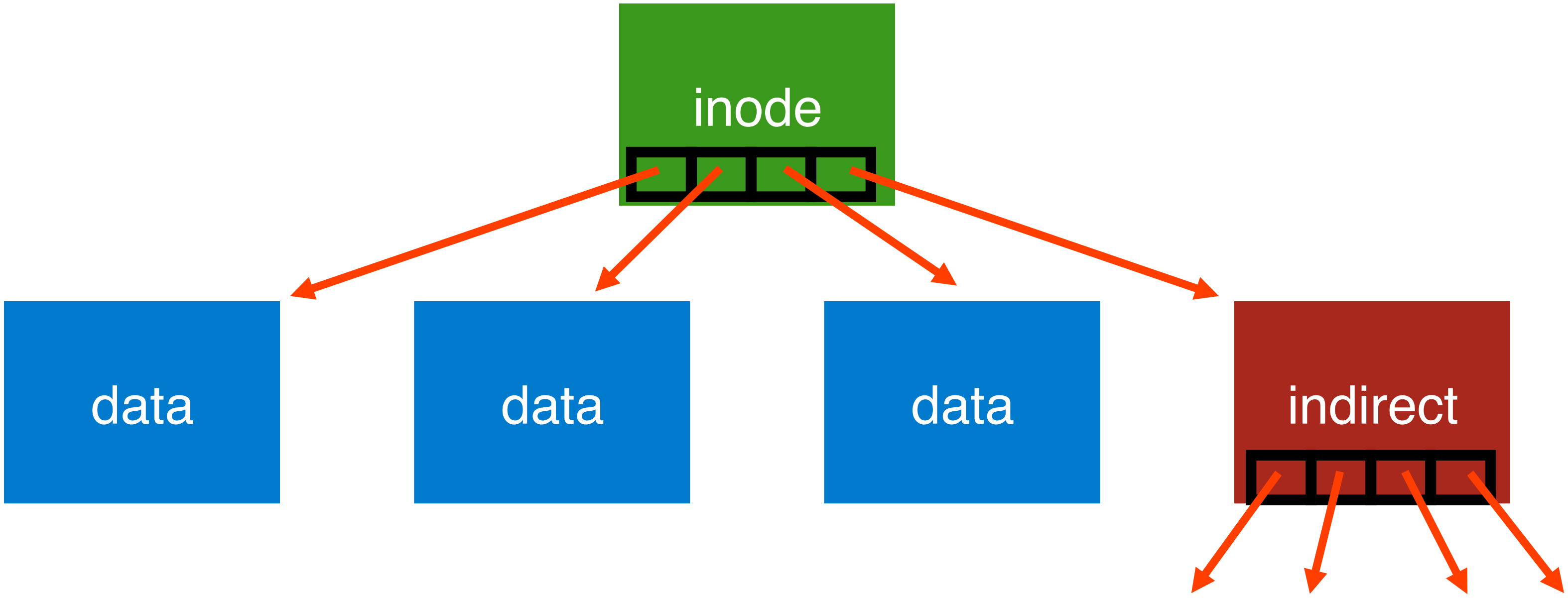
FS STRUCTS: SUPERBLOCK

Basic FS configuration metadata, like block size, # of inodes



INODE

type (file or dir?)
uid (owner)
rwx (permissions)
size (in bytes)
Blocks
time (access)
ctime (create)
links_count (# paths)
addrs[N] (N data blocks)


inode
data
data
data
indirect

FFS PLACEMENT GROUPS

Key idea: Keep inode close to data

Use groups across disks;

Strategy: allocate inodes and data blocks in same group.

POLICY SUMMARY

File inodes: allocate in same group with dir

Dir inodes: allocate in new group with fewer used inodes than average group

First data block: allocate near inode

Other data blocks: allocate near previous block

SPLITTING LARGE FILES

```
group inodes      data
    0 /a-------- /aaaaa---- ---------- ---------- ----------
    1 ---------- aaaaa----- ---------- ---------- ----------
    2 ---------- aaaaa----- ---------- ---------- ----------
    3 ---------- aaaaa----- ---------- ---------- ----------
    4 ---------- aaaaa----- ---------- ---------- ----------
    5 ---------- aaaaa----- ---------- ---------- ----------
    6 ---------- ---------- ---------- ---------- ----------
    ...
```

Define "large" as requiring an indirect block

Starting at indirect (e.g., after 48 KB) put blocks in a new block group.

Each chunk corresponds to one indirect block
Block size 4KB, 4 byte per address => 1024 address per indirect
1024*4KB = 4MB contiguous "chunk"

BUNNY 16

https://tinyurl.com/cs537-sp19-bunny16

BUNNY 16

Assume that the average positioning time (i.e., seek and rotation) = 10 ms.
Assume that disk transfers data at 100 MB/s.

If FFS large file chunk size is 4MB, what is the effective throughput we are getting?

What is the effective throughput with 8MB chunk size?

POLICY SUMMARY

File inodes: allocate in same group with dir

Dir inodes: allocate in new group with fewer used inodes than average group

First data block: allocate near inode

Other data blocks: allocate near previous block

Large file data blocks: after 48KB, go to new group.

Move to another group (w/ fewer than avg blocks) every subsequent 1MB.

OTHER FFS FEATURES

FFS also introduced several new features:

- large blocks (with libc buffering / fragments)
- long file names
- atomic rename
- symbolic links

FFS SUMMARY

First disk-aware file system

- Bitmaps
- Locality groups
- Rotated superblocks
- Smart allocation policy

Inspired modern files systems, including ext2 and ext3

FILE SYSTEM CONSISTENCY

FILE SYSTEM CONSISTENCY EXAMPLE

Superblock: field contains total number of blocks in FS

DATA = N

Inode: field contains pointer to data block; possible DATA?

DATA in {0, 1, 2, …, N - 1}

Pointers to block N or after are invalid!

Total-blocks field has redundancy with inode pointers

WHY IS CONSISTENCY CHALLENGING?

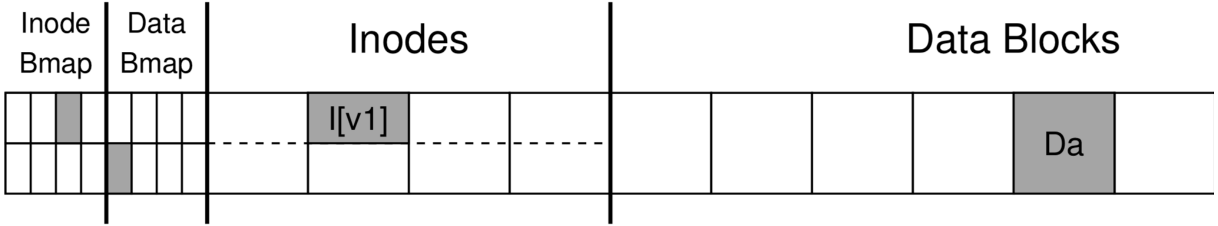
File system may perform several disk writes to redundant blocks

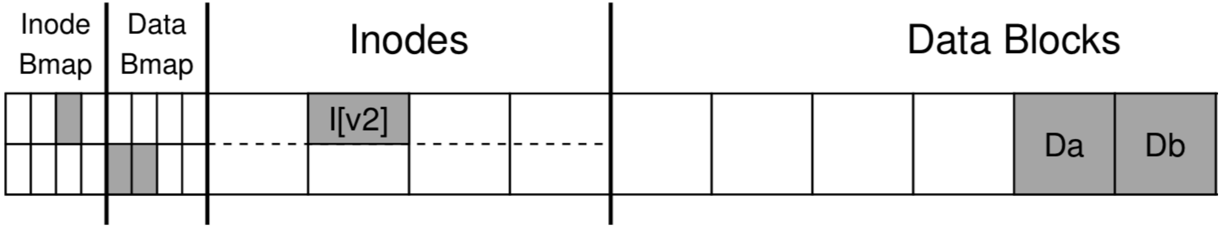
If file system is interrupted between writes, may leave data in inconsistent state

What can interrupt write operations?

- power loss
- kernel panic
- reboot

FILE APPEND EXAMPLE





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

FSCK CHECKS

Do superblocks match?

Is the list of free blocks correct?

Do number of dir entries equal inode link counts?

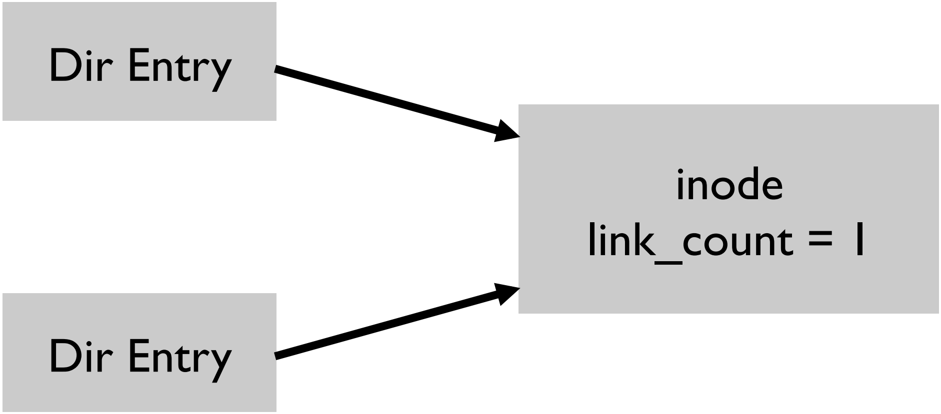
Do different inodes ever point to same block?

Are there any bad block pointers?

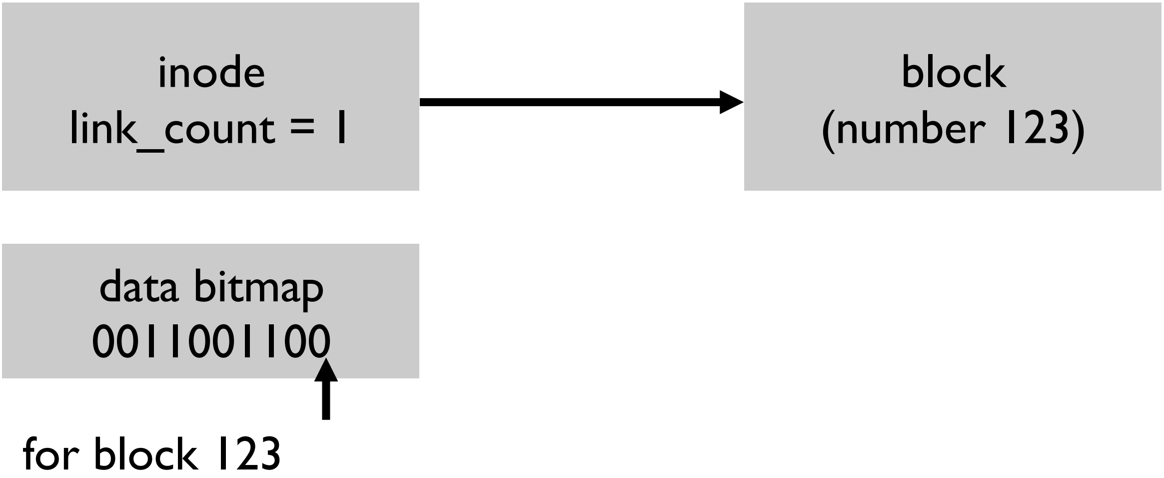
Do directories contain "." and ".."?

…

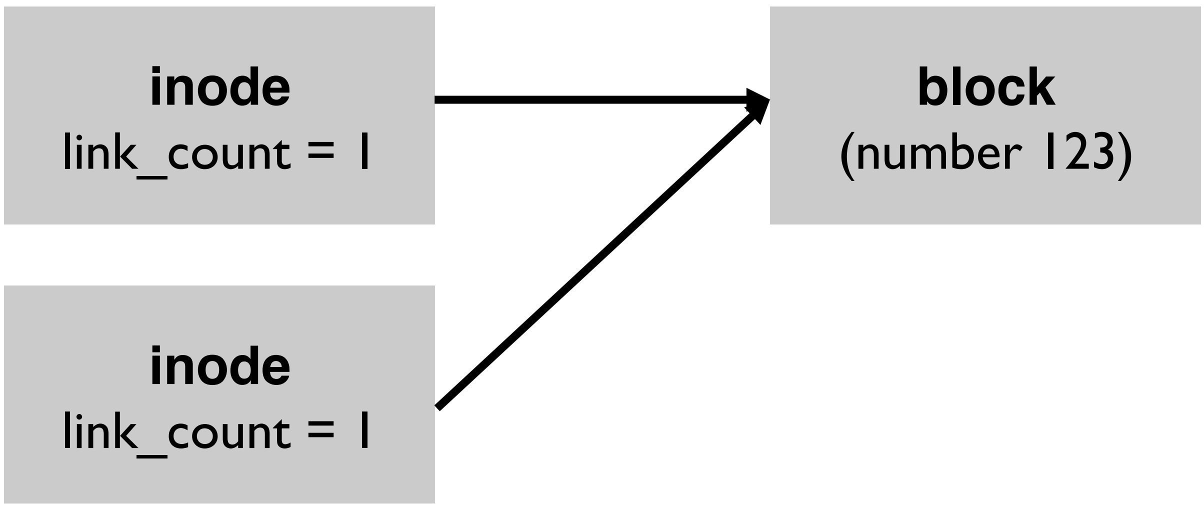
LINK COUNT EXAMPLE



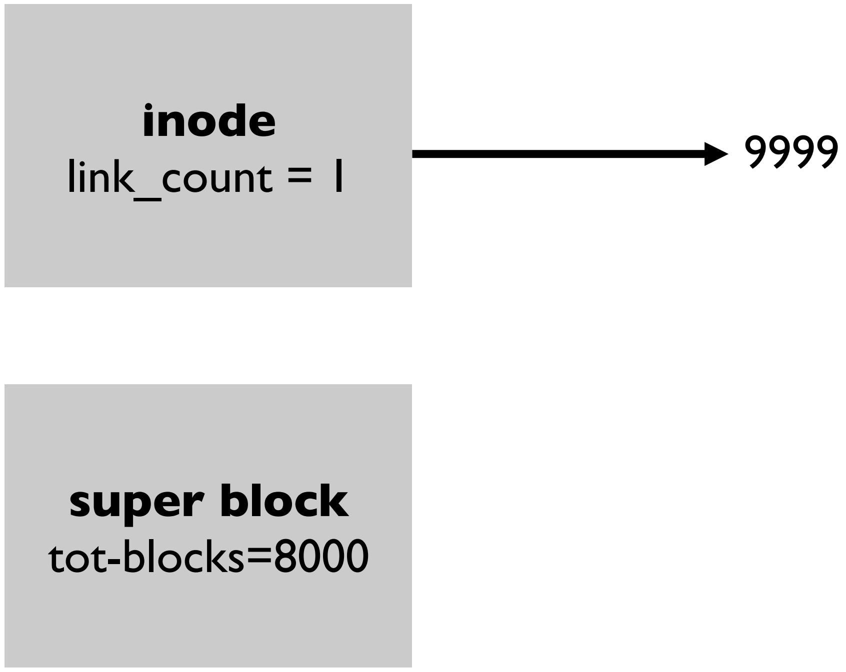
FREE BLOCKS EXAMPLE

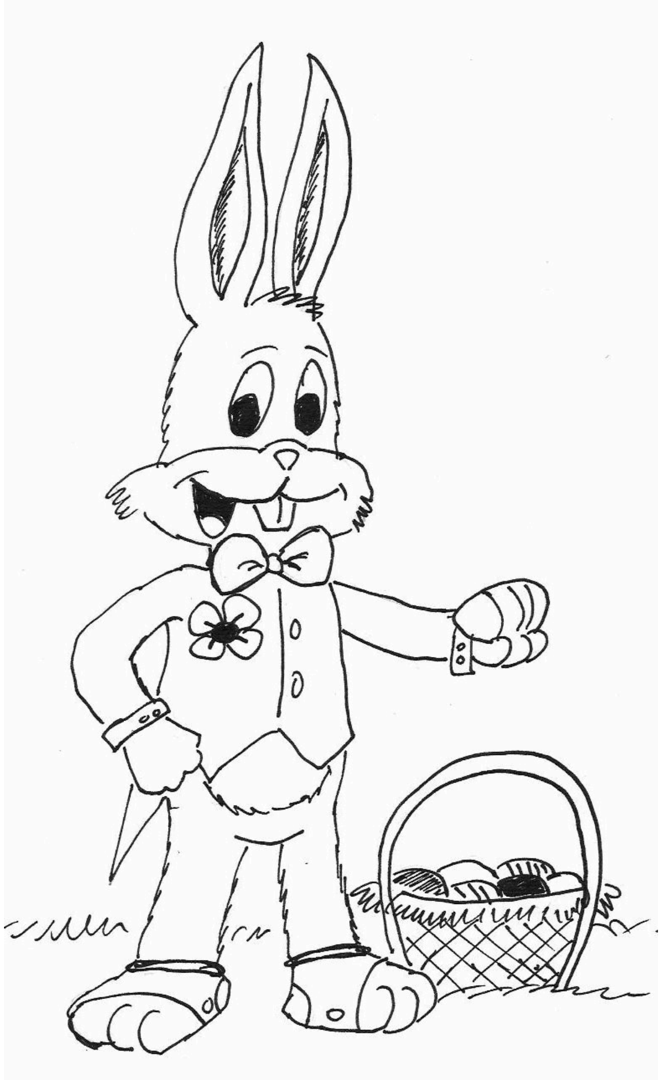


DUPLICATE POINTERS



BAD POINTER





BUNNY 17

https://tinyurl.com/cs537-sp19-bunny17

BUNNY 17

(a) FILE SYSTEM STATE: Consistent or inconsistent? If inconsistent, how to fix?

```
Inode Bitmap : 11111111
Inode Table  : [size=1,ptr=0,type=d] [] [] [] [] [] [] []
Data Bitmap  : 10000000
Data         : [("." 0),(".." 0)] [] [] [] [] [] [] []
```

```
Inode Bitmap : 11000000
Inode Table  : [size=1,ptr=0,type=d] [size=1,ptr=1,type=d] [] [] [] [] [] []
Data Bitmap  : 11000000
Data         : [("." 0),(".." 0),("a" 1)] [("." 1),(".." 1)] [] [] [] [] [] []
```

PROBLEMS WITH FSCK

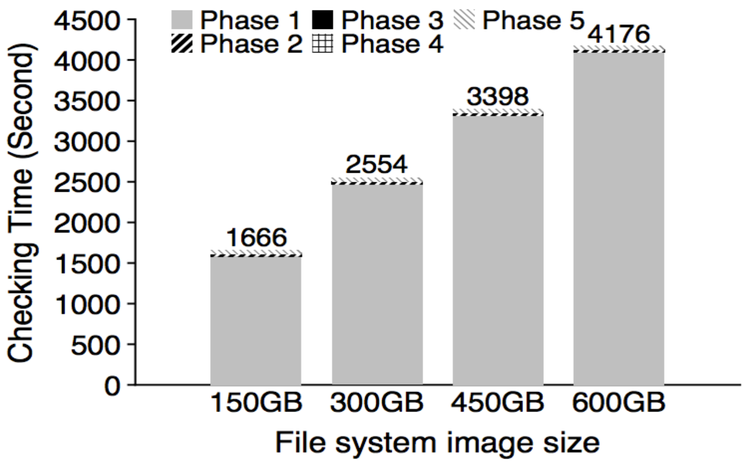
Problem 1:

– Not always obvious how to fix file system image

– Don’t know “correct” state, just consistent one

– Easy way to get consistency: reformat disk!

PROBLEM 2: FSCK IS VERY SLOW



Checking a 600GB disk takes ~70 minutes

ffsck: The Fast File System Checker
Ao Ma, Chris Dragga, Andrea C. Arpaci-Dusseau, and Remzi H. Arpaci-Dusseau

CONSISTENCY SOLUTION #2: JOURNALING

Goals

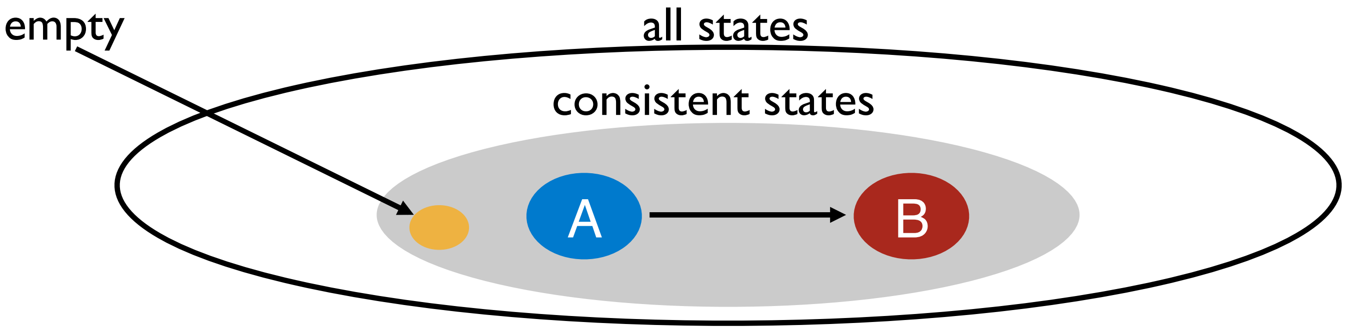
- Ok to do some **recovery work** after crash, but not to read entire disk
- Don't move file system to just any consistent state, get **correct** state

Atomicity

- Definition of atomicity for **concurrency:** operations in critical sections are not interrupted by operations on related critical sections
- Definition of atomicity for **persistence:** collections of writes are not interrupted by crashes; either (all new) or (all old) data is visible

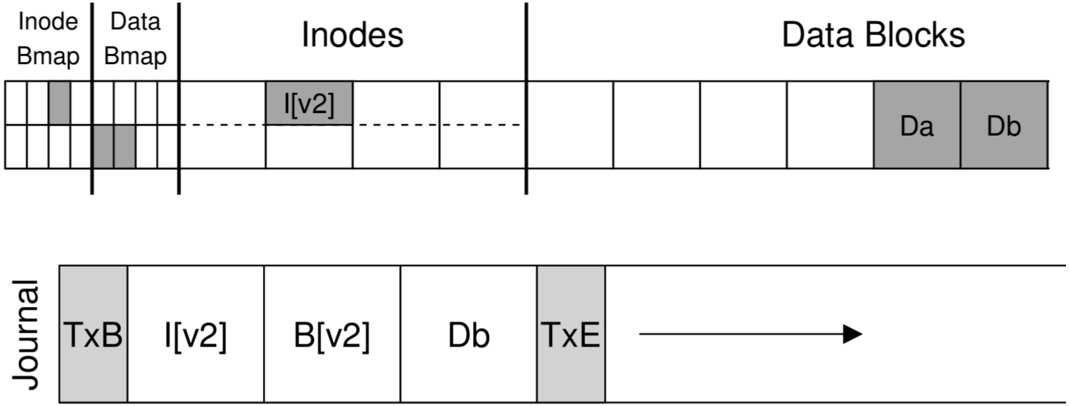
CONSISTENCY VS ATOMICITY

Say a set of writes moves the disk from state A to B



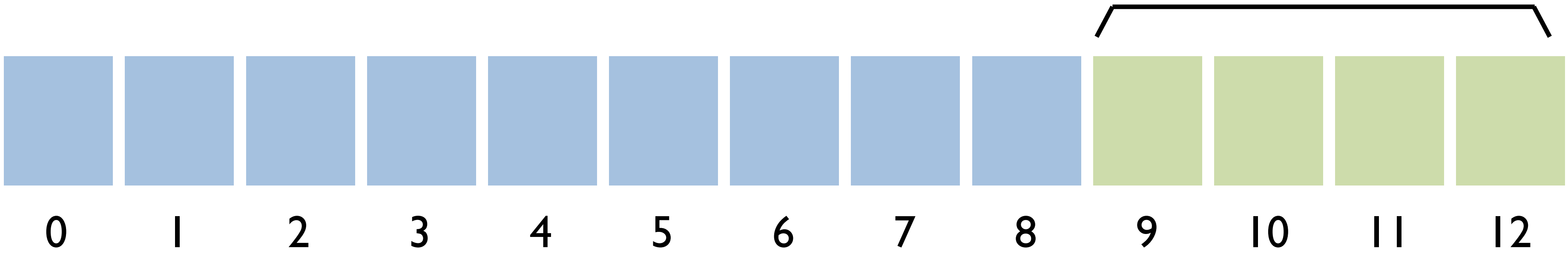
fsck gives consistency
Atomicity gives A or B.

JOURNAL LAYOUT



Transaction

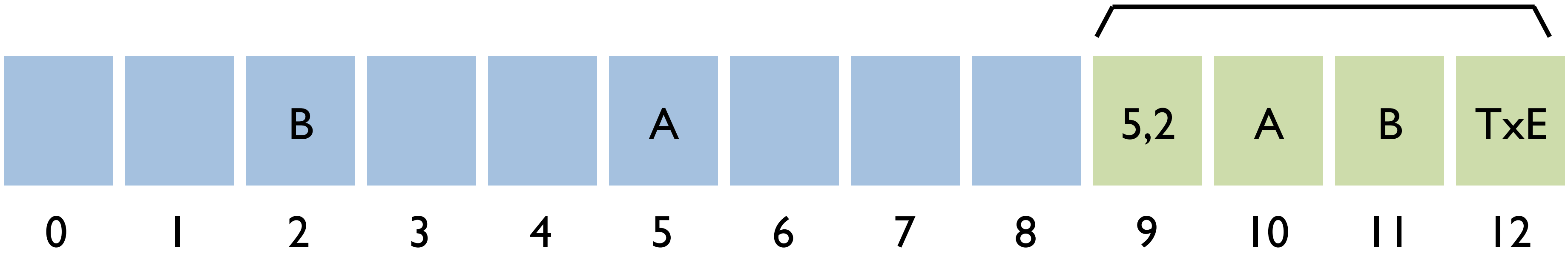
JOURNAL WRITE AND CHECKPOINTS



transaction: write A to block 5; write B to block 2

Checkpoint: Writing new data to in-place locations

JOURNAL REUSE AND CHECKPOINTS

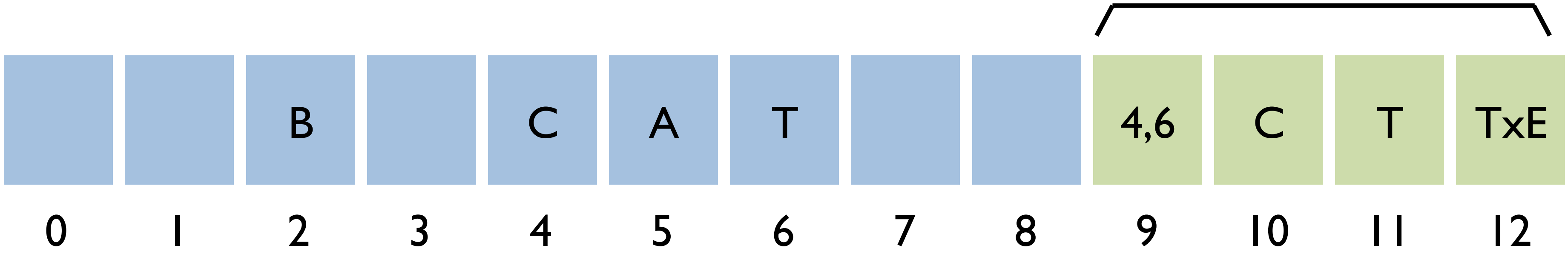


transaction: write A to block 5; write B to block 2

Checkpoint: Writing new data to in-place locations

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

ORDERING FOR CONSISTENCY



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

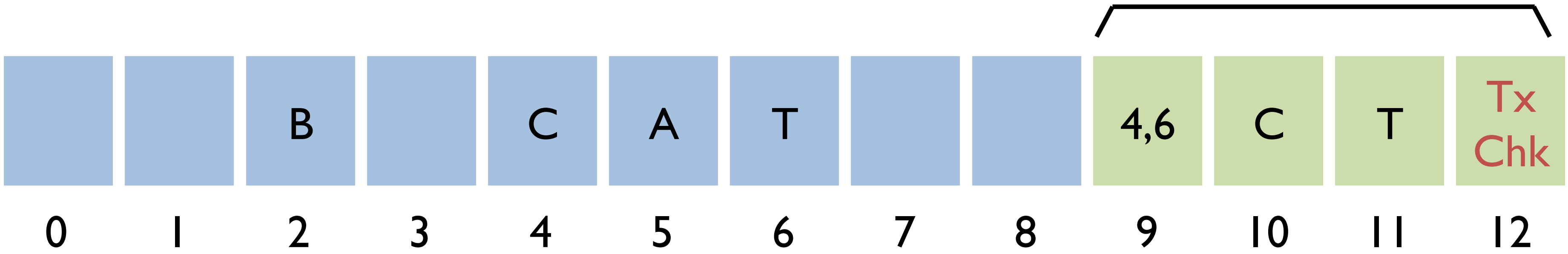
write order: 9,10,11 | 12 | 4,6 | 12

Barriers

1) Before journal commit, ensure journal transaction entries complete
2) Before checkpoint, ensure journal commit complete
3) Before free journal, ensure in-place updates complete

CHECKSUM OPTIMIZATION

Can we get rid of barrier between (9, 10, 11) and 12 ?



write order: 9,10,11 | 12 | 4,6 | 12

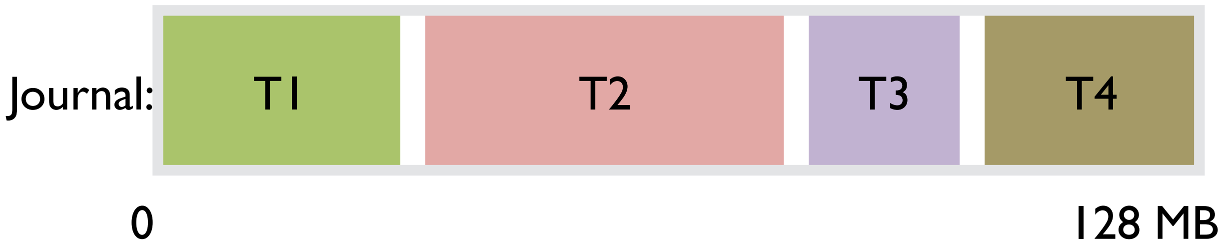
In last transaction block, store checksum of rest of transaction
During recovery: If checksum does not match, treat as not valid

OTHER OPTIMIZATIONS

Batched updates

- If two files are created, inode bitmap, inode etc. get written twice
- Mark as dirty in-memory and batch updates

Circular log



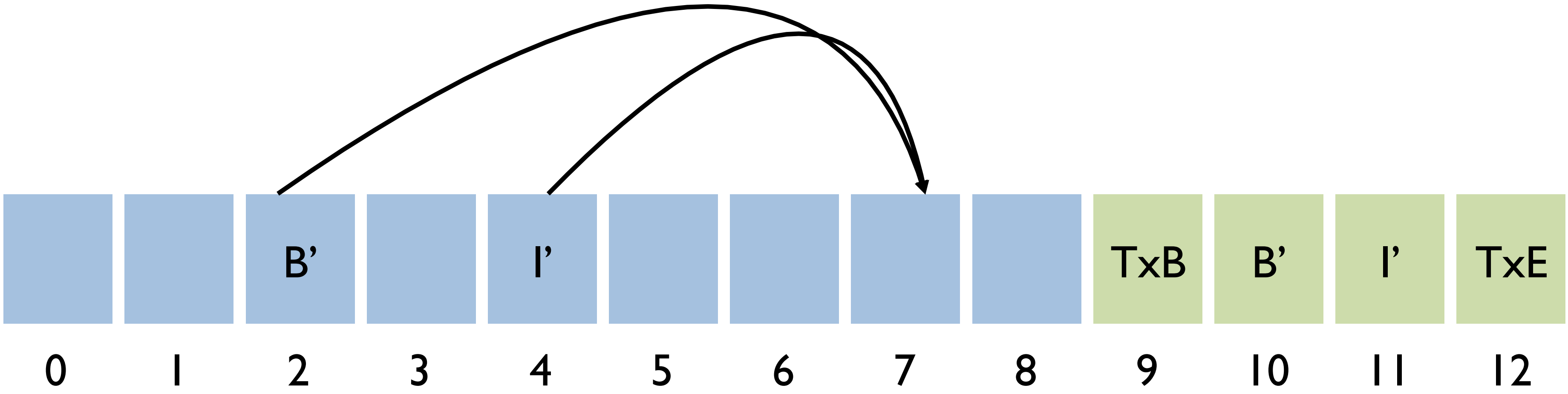
HOW TO AVOID WRITING ALL DISK BLOCKS TWICE?

Observation: Most of writes are user data (esp sequential writes)

Strategy: journal all metadata, including
superblock, bitmaps, inodes, indirects, directories

For regular data, write it back whenever convenient.

METADATA JOURNALING



transaction: append to inode I

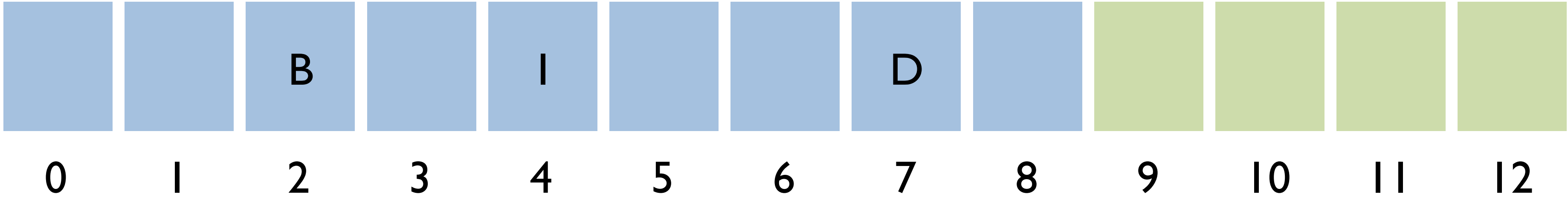
Crash !?!

ORDERED JOURNALING

Still only journal metadata

But write data **before** the transaction!

ORDERED JOURNAL



What happens if crash now?
B indicates D currently free, I does not point to D;
Lose D, but that might be acceptable

SUMMARY

Crash consistency: Important problem in filesystem design!

Two main approaches

FSCK:

- Fix file system image after crash happens
- Too slow and only ensures consistency

Journaling

- Write a transaction before in-place updates
- Checksum, batching, ordered journal optimizations

NEXT STEPS

Next class: How to create a file system optimized for writes

Project 4b due today!

Discussion on Thu: Project 5