Lab 4 Details

Administrivia

- Lab 4 is out and DD **due Monday (12/2)!** (No late days)
- Lab 4 Code & Questions **due 12/9** (No late days)
- Lab 3 DD Revisions due Monday (12/2)
  - For W credit

More mkfs Details

mkfs.c Explained

Just as a reminder, mkfs writes the initial file system image upon `make`

Mkfsc sets up the inodetable, inum_count = number of inodes needed for the initial fs image (user program binaries, inodetable itself, root dir)

How do we set up the inodes?

- `ialloc` allocates an empty inode, writes it to the fs image, returns the inode number
- read in the inode with `rinode`, update/write the inode with `winode`

mkfs.c Explained

```c
uint
ialloc(ushort type)
{
  uint inum = freeinode++;
  struct dinode din;

  bzero(&din, sizeof(din));
  din.type = xshort(type);
  din.size = xint(0);
  winode(inum, &din);
  return inum;
}
```

by default, all fields of an inode are set to 0, except for the type of the file

when you change the data layout, you may want to adjust ialloc to set default values (if non zero) for your new fields

mkfs.c Explained

When you update the data layout of the disk inode, you should search for any reference to `data.startblkno` and `data.nblocks`, and change it to work with your new data layout

If you do an array of extents, you can update these to refer to the first entry of your extent array!

mkfs.c Explained

FAQ: Can you use ialloc to create a new on disk inode in xk?

Answer: No! ialloc is a mkfs function. Since mkfs is not build as a part of your kernel, you cannot call ialloc in your kernel code. The same applies to all mkfs functions!

Any Questions on mkfs?

Bitmap API

You interact with the block bitmap via fs.c: `balloc` & `bfree`

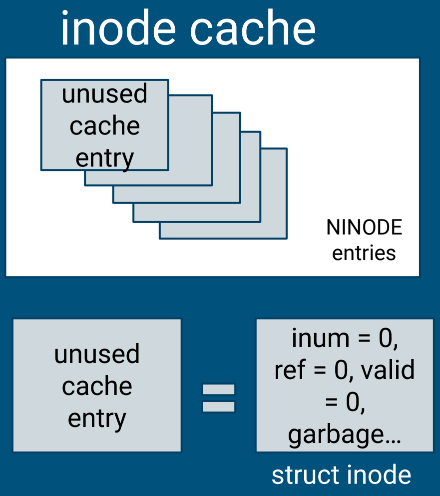
- `balloc` and `bfree` *only updates cached bitmap* sectors in memory
  - this is done through setting the bp->flag dirty in bmark
- if you want to *write the changed bitmap sector back to disk*, you must call bwrite yourself!
  - hint: you can update balloc and bfree

Block Cache API

You can read and write disk blocks via the Block Cache in bio.c !

- brings blocks/sectors into memory and manages them (evict, writeback)
- struct buf
  - metadata for managing buffer
  - buf->data = block data
  - buf->blockno = the cached block #, very helpful for debugging!
- APIs
  - bread: brings the block into memory, locks (exclusive access) the cached block
  - bwrite: marks the block dirty and issues a write
  - brelse: releases the lock on the cached block

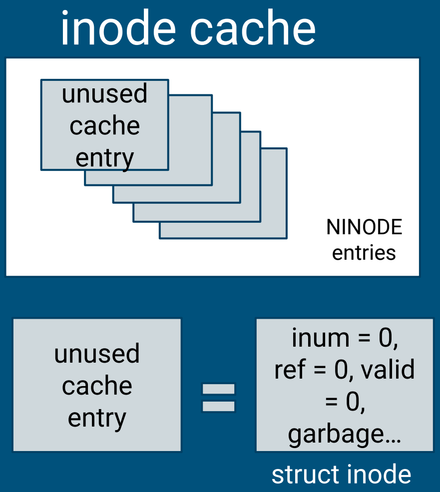
In-memory inode



initially, all entries of icache.inodes are unused

*diagram skipped cached root dir inode for simplicity

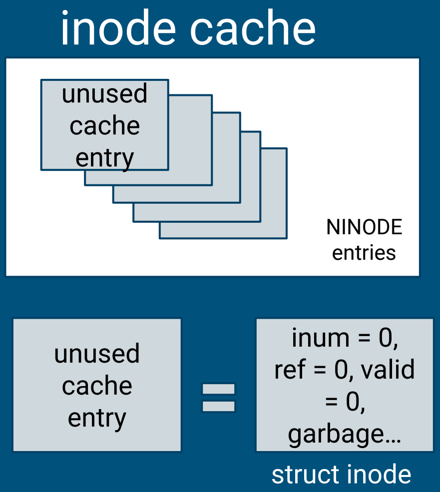
In-memory inode



user program:
open(file, O_RDWR)

*diagram skipped cached root dir inode for simplicity

In-memory inode



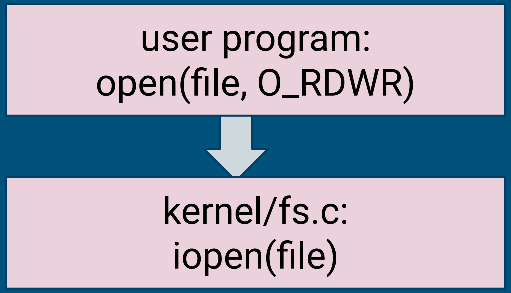
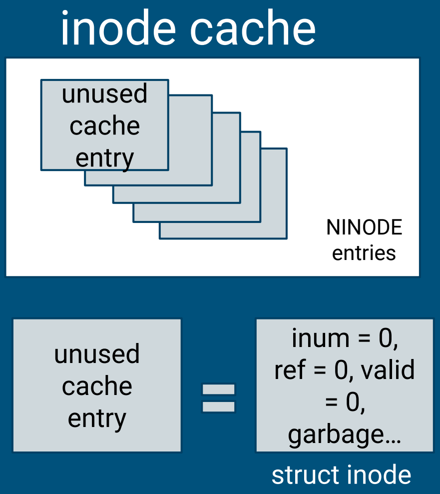


*diagram skipped cached root dir inode for simplicity

In-memory inode



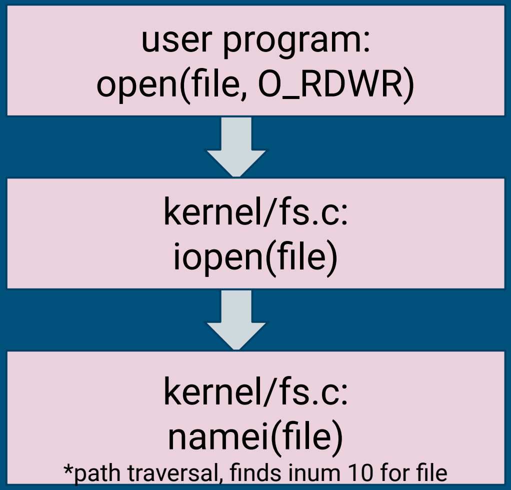
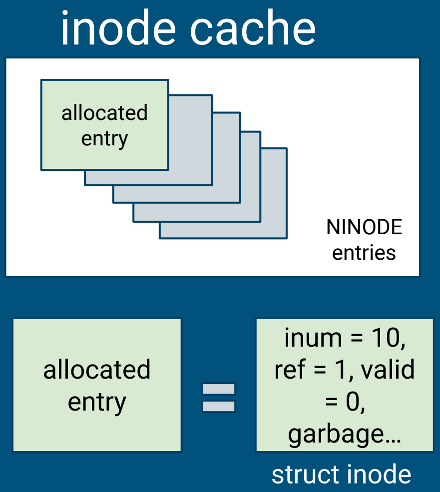


*diagram skipped cached root dir inode for simplicity

In-memory inode



*in this example, inode 10 is opened for the first time, if inode 10 is already cached, iget simply increments existing entry's ref count and returns a pointer to it

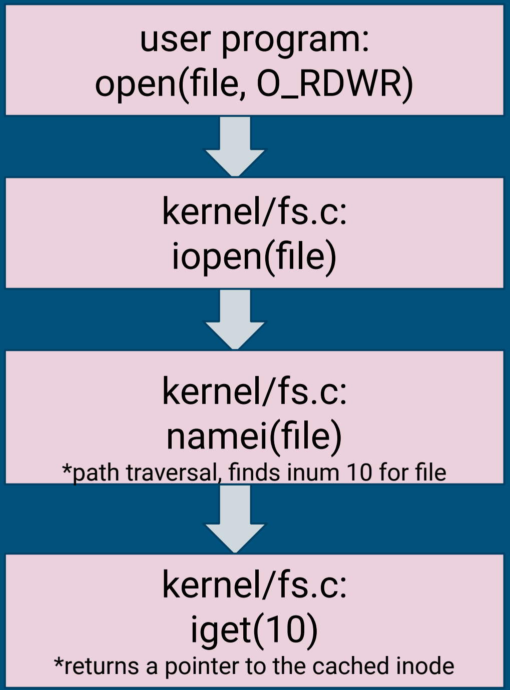
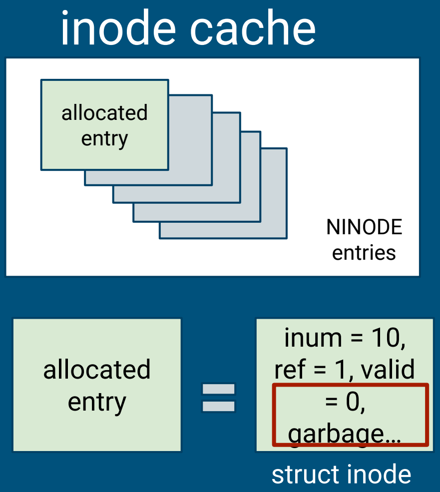
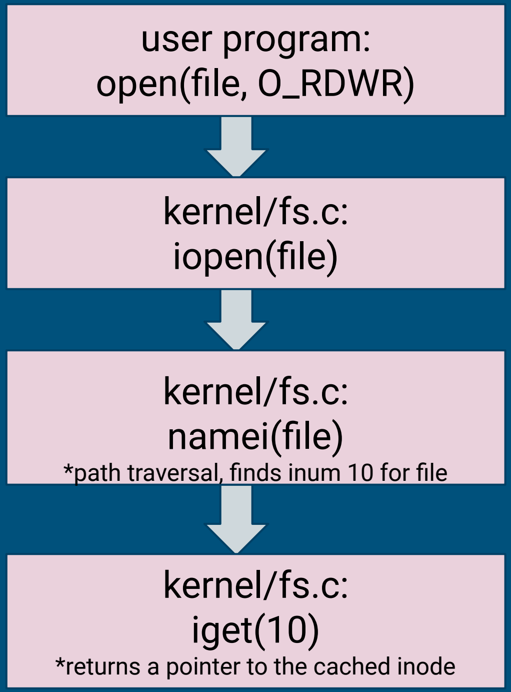


*diagram skipped cached root dir inode for simplicity

In-memory inode



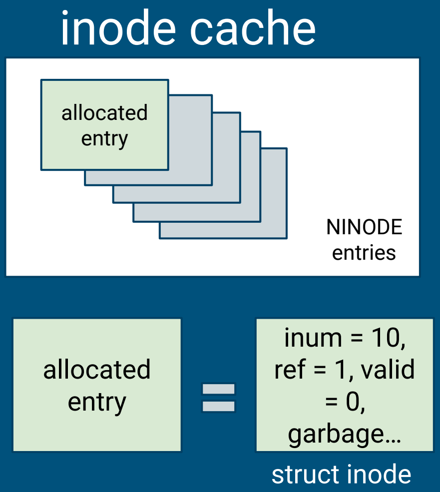


*in this example, inode 10 is opened for the first time, if inode 10 is already cached, iget simply increments existing entry's ref count and returns a pointer to it

freshly allocated (valid ==0) inode returned by `iget` does not contain accurate disk inode data yet (hence garbage)!

*diagram skipped cached root dir inode for simplicity

In-memory inode



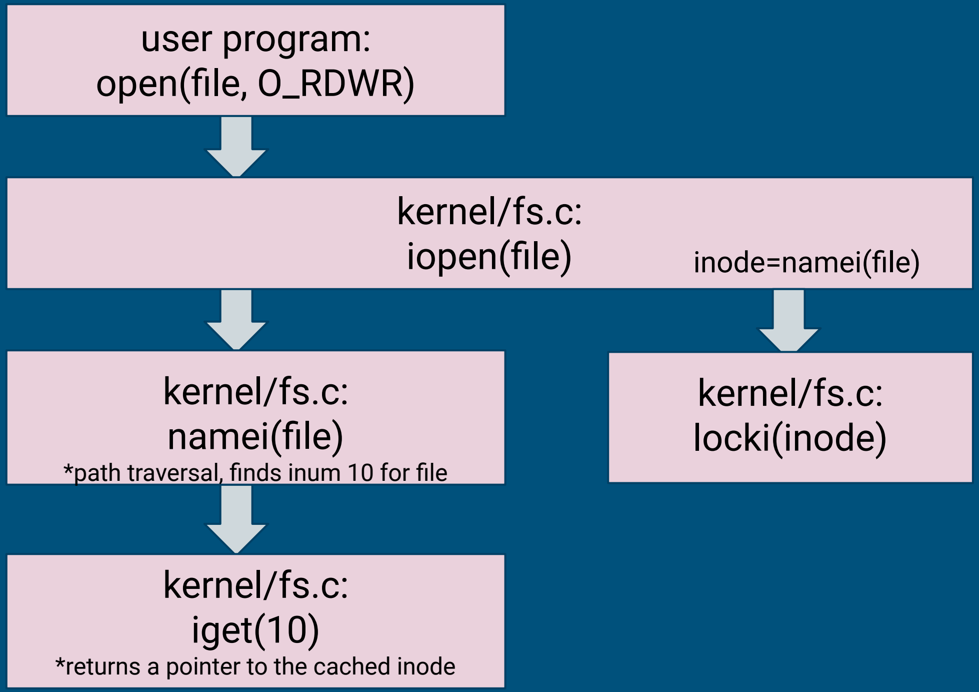
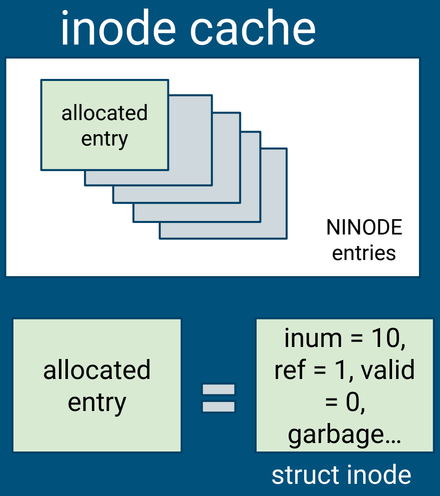


*diagram skipped cached root dir inode for simplicity

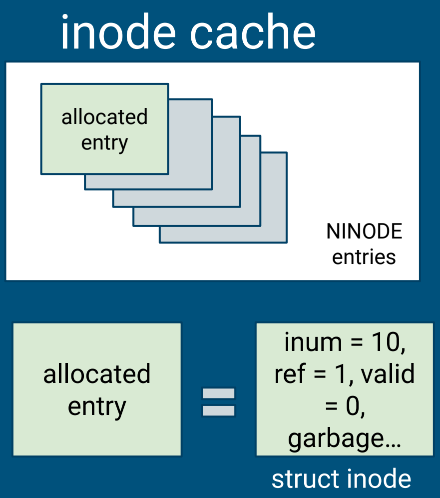
In-memory inode



kernel/fs.c:
locki(inode)

*diagram skipped cached root dir inode for simplicity

In-memory inode



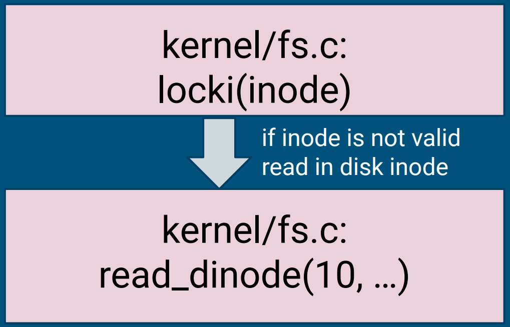
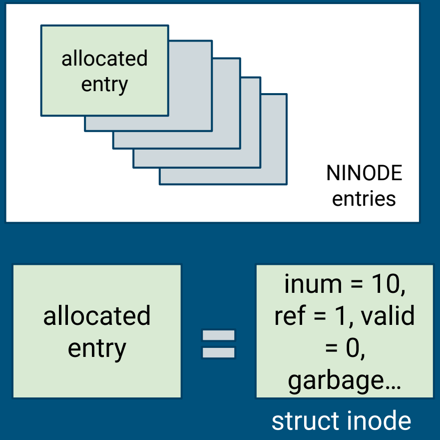


*diagram skipped cached root dir inode for simplicity

In-memory inode

inode cache



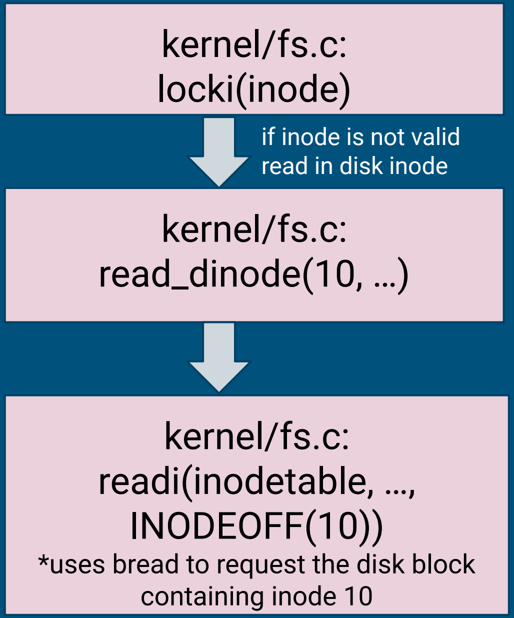
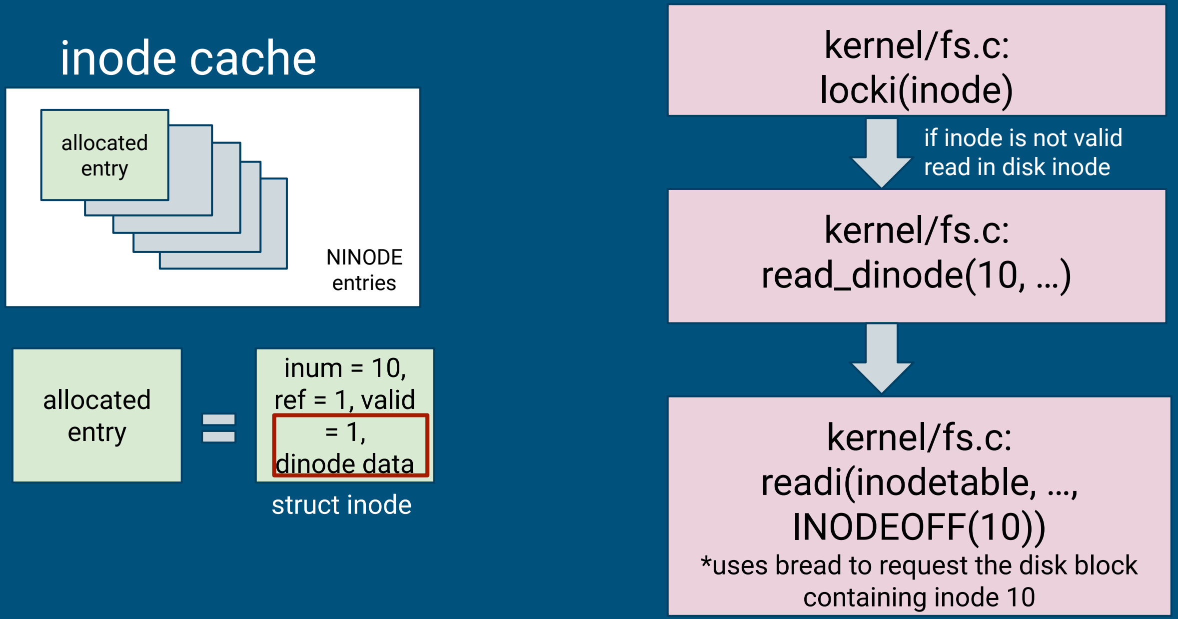


*diagram skipped cached root dir inode for simplicity

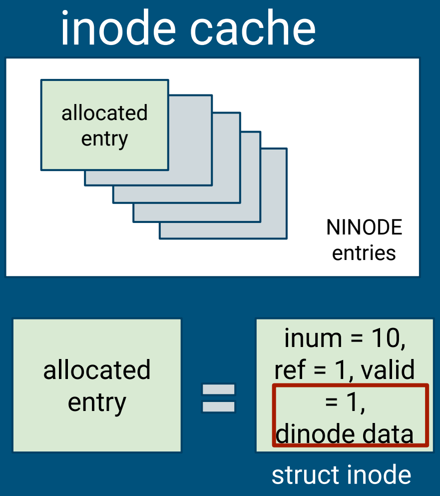
In-memory inode

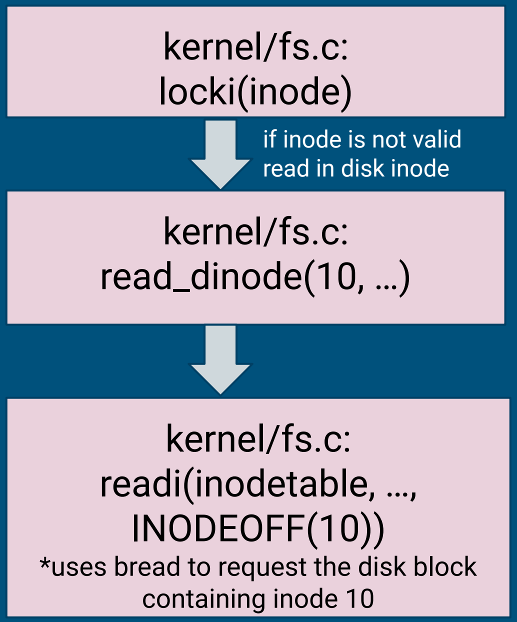


use the result of read_dinode to populate the in memory inode!

*diagram skipped cached root dir inode for simplicity

In-memory inode





use the result of read_dinode to populate the in memory inode!

And now this inode is ready to be used for fs operations!

*diagram skipped cached root dir inode for simplicity

Part B: Concurrency

Notes

- concurrent_* should protect the corresponding inode functions
- what happens if multiple processes try to create the same file?
  - only 1 process should succeed in creating the file
  - all other processes should simply open the created file
  - how can you determine if a file exists?
    - be careful of time of check to time of use problem!

Part B: Concurrent FS Ops

Concurrent Create

- When there are multiple create calls to a single file, only 1 process can actually create the file!
    - How can we achieve this?
        - only one process can look up whether the file exists and create it at a time!
        - time of check to time of use! the entire read modify needs to be atomic
            - hint: is there any lock on the path traversal that can be used to prevent concurrent lookups?

Concurrent Delete

- When a file being deleted has open references, it cannot be deleted!
  - how to check if a file has open references?
    - all opened files have their inodes in the inode cache!
    - that's what each file info struct track to request fs operations!
- When there are multiple delete calls to a single file, only 1 process can successfully delete the file!
  - should only allow one process to check whether the file has open reference and perform the delete atomically (similar to create)!

Part C: Crash Safety

Guaranteeing Atomic Operations

Now that our file system is writable, we need to ensure that it is crash consistent. But what do we mean by crash consistent? Let's take a look at an example:

Say we have "file.txt" which is 512 bytes long. We try to append 50 bytes to this file.

Is this operation atomic?

Guaranteeing Atomic Operations

No! We need to multiple **block writes** to accomplish this simple append:

1. Invoke file_write
2. Compute new file size
3. **Update size + extents on disk (dinode)**
4. **Update bitmap**
5. **Write the new file contents to disk**

That’s three block writes!

Guaranteeing Atomic Operations

What happens if we crash before we write the new file contents to disk?

1. Invoke file_write
2. Compute new file size
3. **Update size + extents on disk (dinode)**
4. **Update bitmap**
5. ~~**Write the new file contents to disk**~~ **CRASH**

When we reboot the system… We think “file.txt” is 562 bytes long, but the last 50 bytes are garbage, not what we tried to write!

So how do we solve this problem?

Journaling

For any operation which must write multiple disk blocks atomically…

1) Write new blocks into the log, rather than target place. Track what target is.
2) Once all blocks are in the log, mark the log as "committed"
3) Copy data from the log to where they should be (apply the log!)
4) Clear the commit flag

On file system initialization(iinit) check the log for recovery

If not committed, do nothing

If so, apply the log (this is idempotent!)

Designing Your Log

- Specify a log header (metadata for the log)
  - a structure that lives on disk
  - should not exceed a sector
- Designed by you! Should at least track:
  - transaction status (committed or not)
  - usage status of log region
  - where to apply logged blocks

Log API

- The spec recommends designing an API for yourself for log operations:
  - `log_begin_tx`: (optional) begin the process of a transaction
  - `log_write`: wrapper function around normal block writes
  - `log_commit_tx`: complete a transaction and write out the commit block
  - `log_apply`: apply the actual content of the log
    - use at commit time and during recovery time

More on `log_write`

- `log_write` is intended to be a wrapper function for bwrite() operations
- Instead of writing the block to its location on disk, we want to:
  - Write the block information to our log region
  - Update the log header with the location of the block

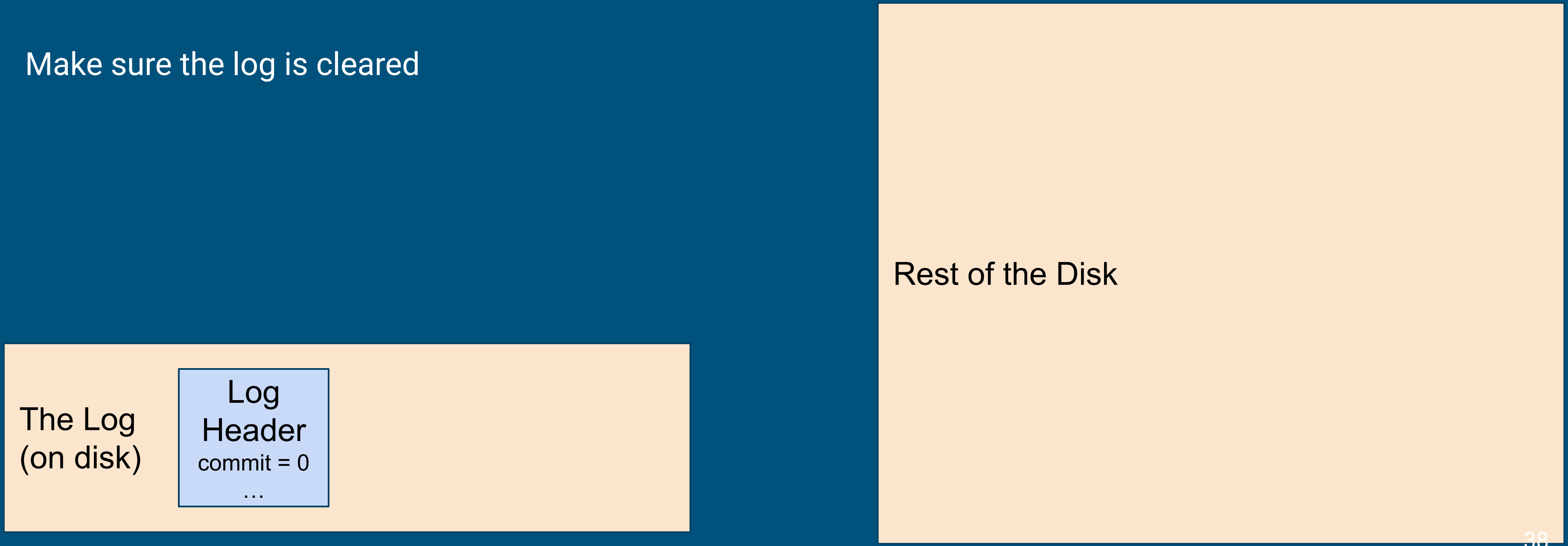
More on `log_commit_tx`

- Should first write the log header to disk to indicate that txn is committed
- Then apply the log content (`log_apply`)
    - Copy blocks from previous log_writes to their actual location on disk
- Reset commit flag when done

How journaling works without crashes

Step 1: “log_begin()”

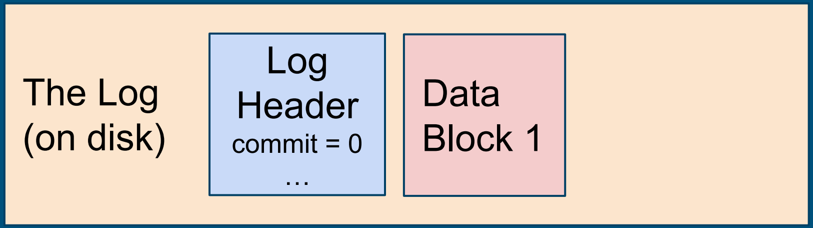
Make sure the log is cleared

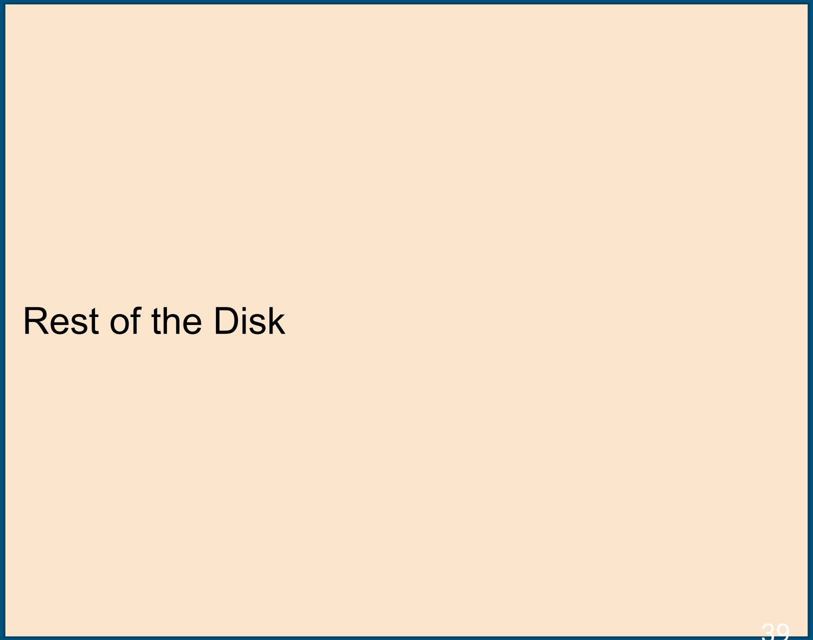


Step 2: “log_write(data block 1)”

Write into the log, rather than the place in the inode/extents region we want it to go

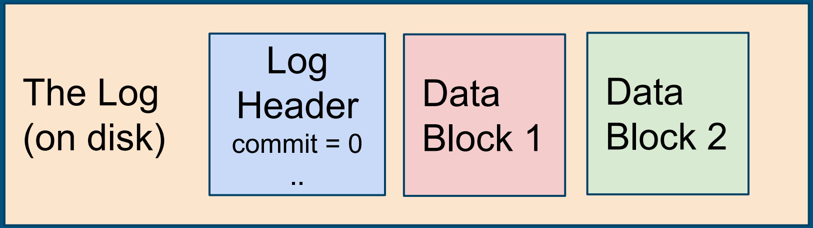
Also need to track the actual location of the data block so you know where to write logged blocks to on recovery!

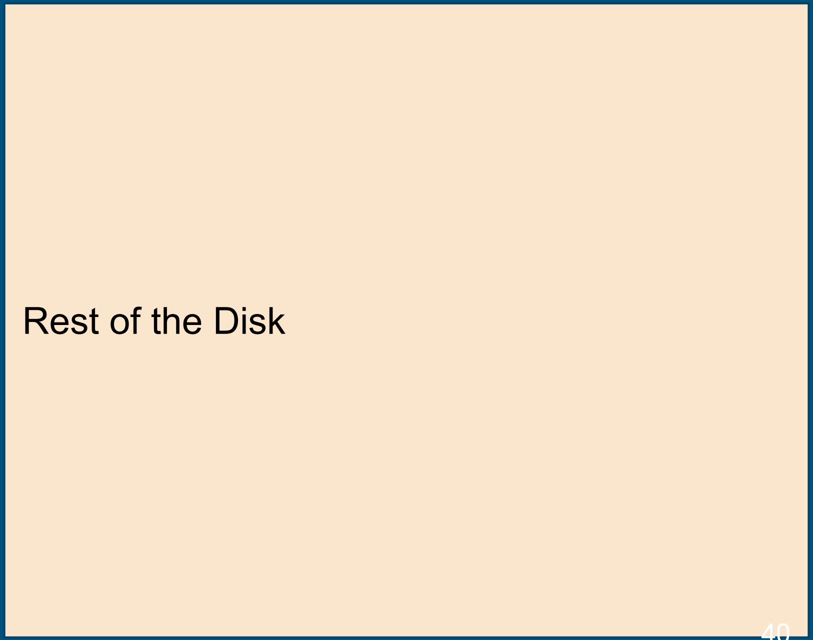




Step 3: “log_write(data block 2)”

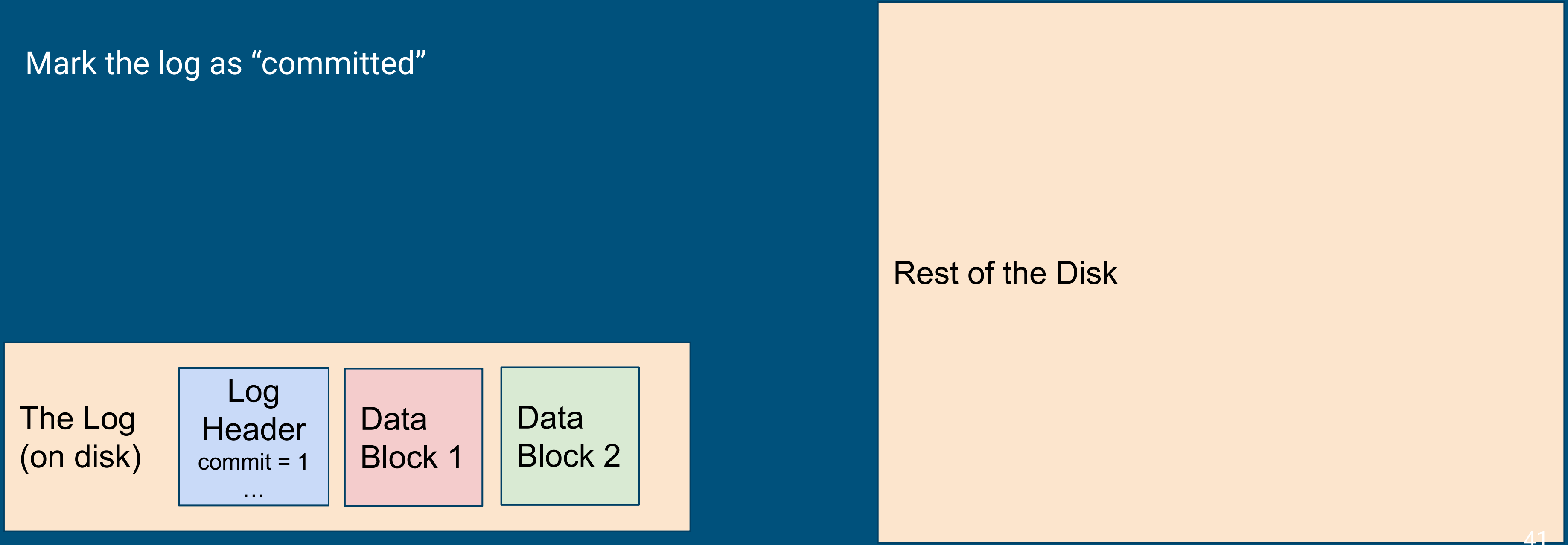
Write into the log, rather than the place in the inode/extents region we want it to go





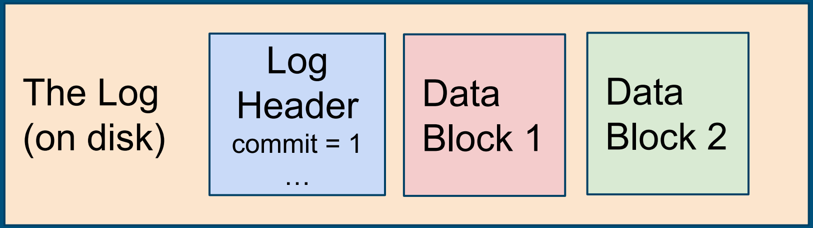
Step 4: “log_commit()” [1]

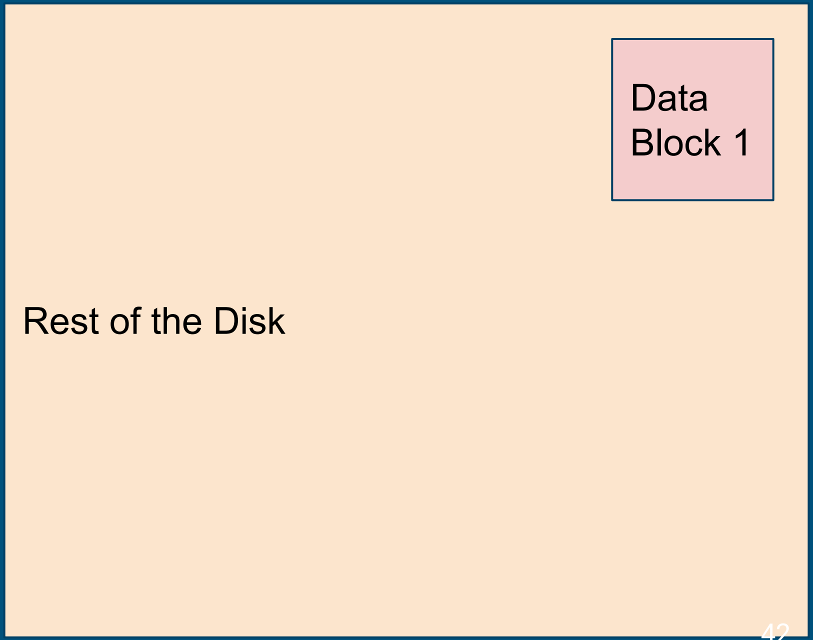
Mark the log as “committed”



Step 5: “log_commit()” [2]

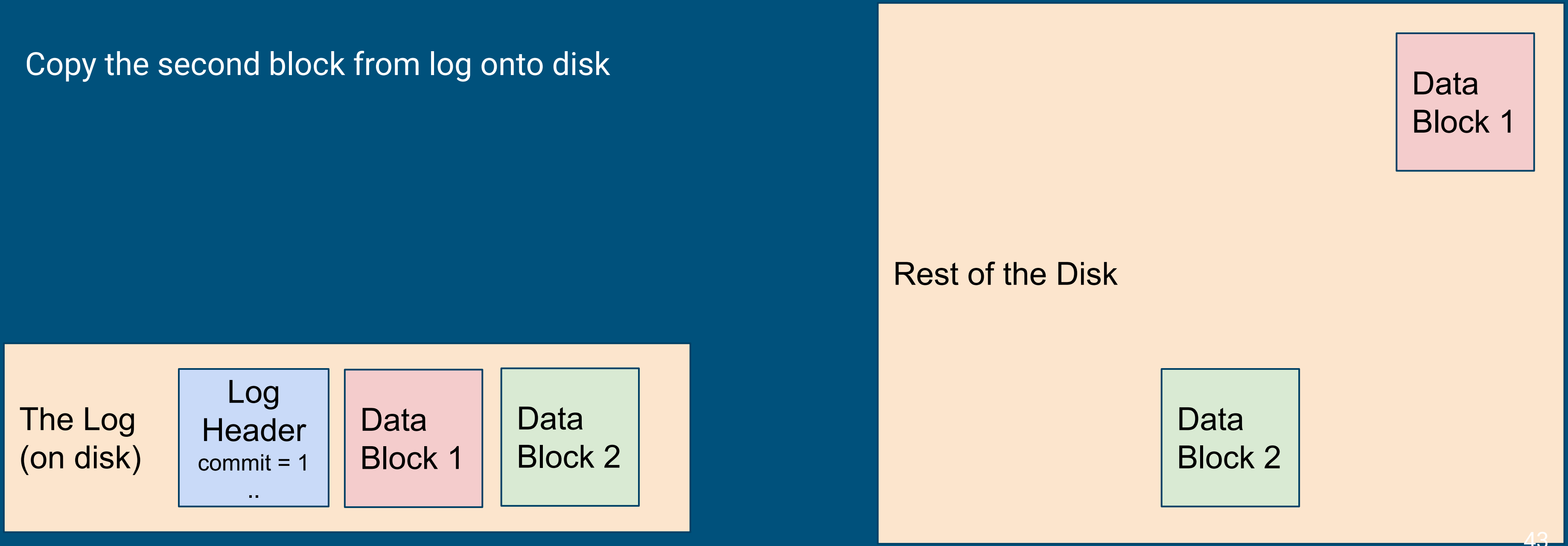
Copy the first block from log onto disk





Step 6: “log_commit()” [3]

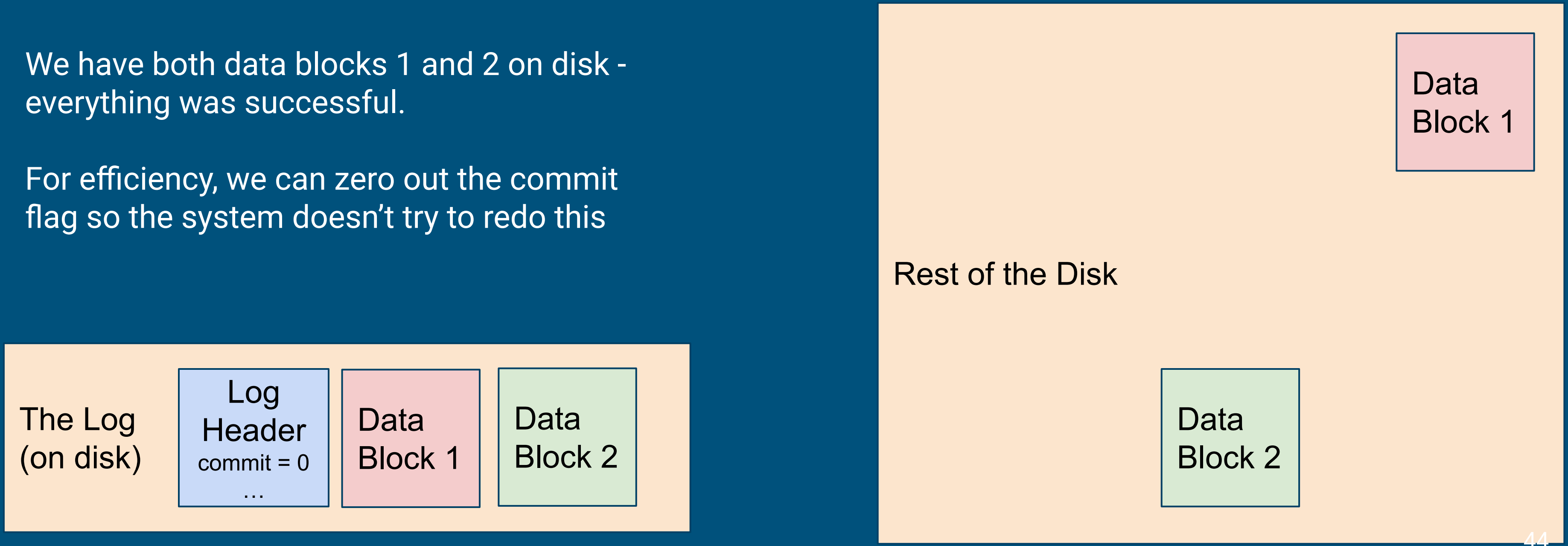
Copy the second block from log onto disk



Done!

We have both data blocks 1 and 2 on disk - everything was successful.

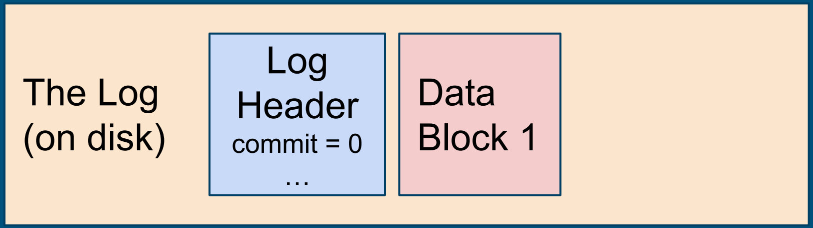
For efficiency, we can zero out the commit flag so the system doesn't try to redo this

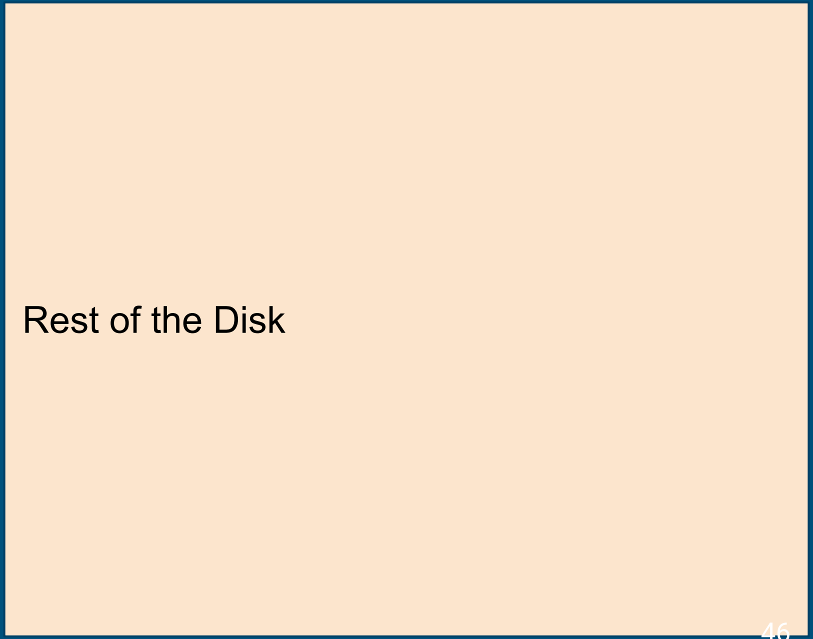


But what if we crash?

Example: **before** commit—CRASH

On reboot (start up)...
There's no commit in the log, so we should *not* copy anything to the disk

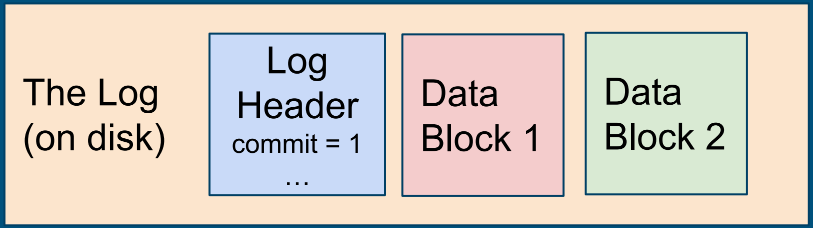


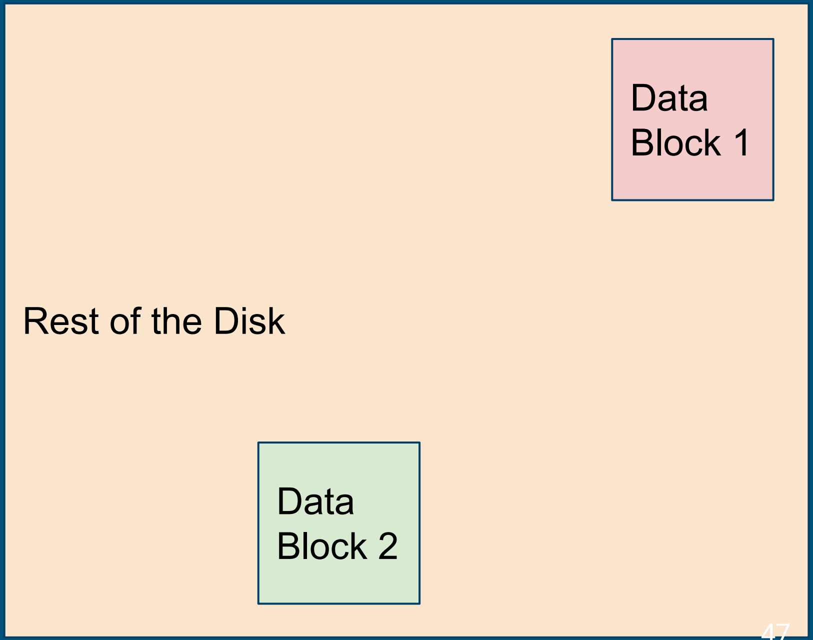


Example: **after** commit, **before** clear–CRASH

On reboot, we see that there *is* a commit flag

We can then copy block 1 and 2 to disk -- even though DB1 *was* already copied over, overwriting it with the same data is fine

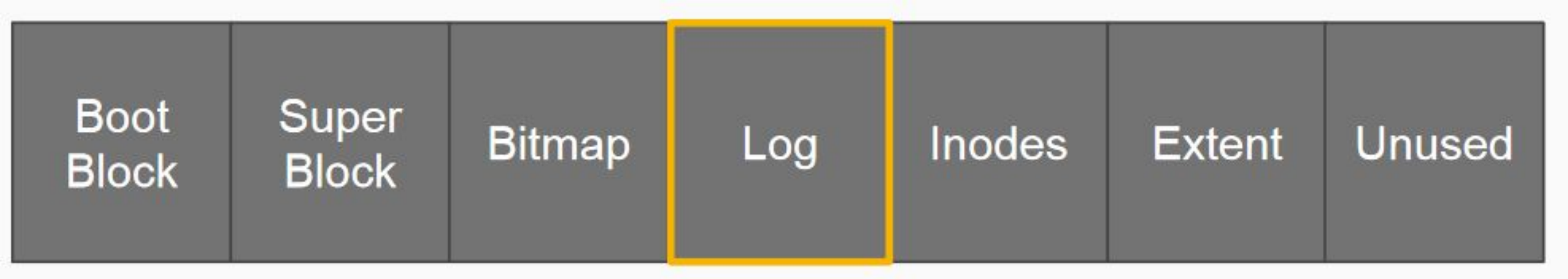




Where Do I put the Log?

It's just blocks on disk, so you can put it anywhere you want (within reason)

- After-bitmap, before-inodes is a pretty good place



Reflect the log on disk

In order to reflect log region in the initial disk image, what do you need to update?

- Mkfs.c
- Superblock struct
    - to track the location of the log region

What should log_write() do differently?

- log_write() instead of bwrite()
  - Just replace the bwrite calls with log_write!
- Instead of writing the block to its location on disk, we want to:
  - Write the block information to our log region
  - Update the log header with the location of the block

How do we synchronize log access?

We recommend tracking a single transaction in the log

- How do we ensure that log access remains synchronized?

Questions?