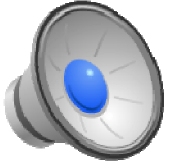
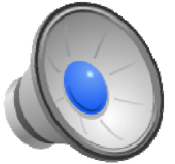


# File Systems: Recovery

- Learning Objectives
  - Identify ways that a file system can be corrupt after a crash.
  - Articulate approaches a file system can take to limit the kinds of failures that can occur.
  - Describe different approaches to recovering a file system after a crash.
  - Evaluate the tradeoffs between the different approaches.
- Topics
  - Identify ways a file system can be corrupt.
  - Figure out some approaches to avoiding corruption.
  - Things you can do in the system while it's running.
  - Things you do after a crash.

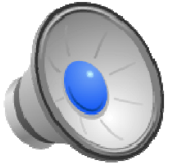
# Exercise 1: File System Corruption

- List all the things that you could imagine going wrong in FFS when the system crashes.
  - Consider the following data structures: bitmaps, inodes, indirect blocks, directories
  - Identify individual data structures that could be corrupted as well as ways in which different data structures could be inconsistent.
  - It is sometimes useful to think in terms of pointers: directories contain pointers to inodes; inodes contain pointers to data blocks, etc
- For each problem you find, determine whether it:
  - Is a security problem
  - Could cause your system to crash
  - Could result in lost data
- Of those failure modes, which are most/least severe?



# What kinds of bad things could happen?

- Individual data structures could be corrupted:
  - The superblock or cylinder group headers
  - Bitmaps could get trashed
  - Individual inodes could be in an invalid state
  - A directory could become corrupted
- Inconsistencies between data structures:
  - Directory entries that don't point to valid files
  - Files without directory entries
  - Files containing disk blocks to which they have not written data.
  - Files not containing disk blocks to which they have written data.
  - Data blocks not attached to any file
  - Disk blocks allocated but still in free list
  - Disk blocks unallocated but NOT in free list



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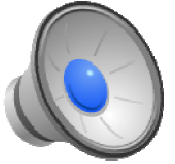

# Remedies (1)

- Individual data structures could be corrupted:
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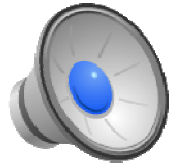
Avoid writing it.
Keep multiple
copies of it.



# Remedies (2)

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  - Files without directory entries
  - Files containing disk blocks to which th
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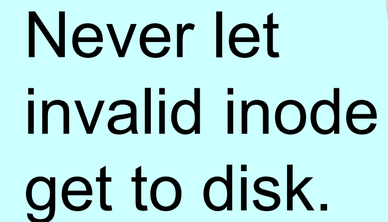
Rebuild them from inodes after a crash.

# Remedies (3)

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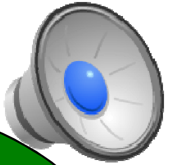

# Remedies (4)

Reconstruct the directory.

- Individual data structures could be corrupte
  - The superblock or cylinder group headers
  - Bitmaps could get trashed
  - Individual inodes could be in an invalid s ate
  - A directory could become corrupted
- Inconsistencies between data structures:
  - Directory entries that don't point to valid files
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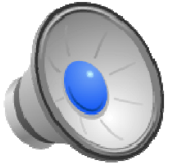

# Remedies (5)

Write directory entry AFTER you create the file.

- Individual data structures could be corru[pted]
  - The superblock or cylinder group headers
  - Bitmaps could get trashed
  - Individual inodes could be in an invalid state
  - A directory could become corrupted
- Inconsistencies between data structures:
  - Directory entries that don't point to valid files
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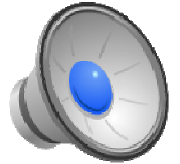
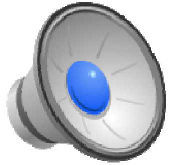


# Remedies (6)

- Individual data structures could be corrupted:
  - The superblock or cylinder group headers
  - Bitmaps could get trashed
  - Individual inodes could be in an invalid state
  - A directory could become corrupted
- Inconsistencies between data structures:
  - Directory entries that don’t point to valid files
  - Files without directory entries
  - Files containing disk blocks to w… h they have not written data.
  - Files not containing disk blocks to…
  - Disk blocks allocated but still i…
  - Disk blocks unallocated but …

Read all the inodes; traverse directory tree; find all disconnected files.



# Remedies (7)

- Individual data structures c
  - The superblock or cylinder
  - Bitmaps could get trashed
  - Individual inodes could be in an invalid s
  - A directory could become corrupted
- Inconsistencies between data structur
  - Directory entries that don't point to valid es
  - Files without directory entries
  - Files containing disk blocks to which they have not written data.
  - Files not containing disk blocks to which they have written data.
  - Disk blocks allocated but still in free list
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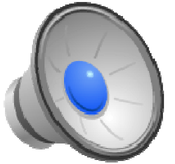
> Write new disk blocks before letting updated inodes get to disk.



# Remedies (8)

- Individual data structures c
  - The superblock or cylinder
  - Bitmaps could get trashed
  - Individual inodes could be in an invalid st
  - A directory could become corrupted
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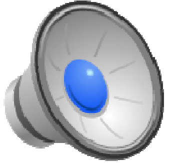
Maybe this is OK: we allow some recent writes to be lost?



# Remedies (9)

- Individual data structures could be corrupted:
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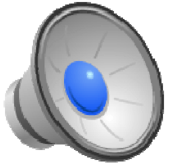
You'll find these when you rebuild the bitmaps after a crash.



# Remedies (10)

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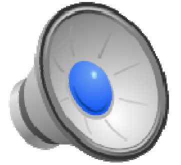
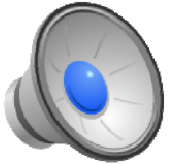


# Recovery Principles

- Do what is necessary on the live file system to ensure that after a failure, you can fix any inconsistencies that could happen.
- Have a recovery process that can fix up any remaining problems in the file system upon startup.
- Two key things we do:
  - Enforce ordering on when we write things to disk.
  - Use what we know about those orderings to fix/rebuild things at startup.



# Which are ordering constraints?

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**Ordering constraint**

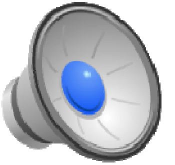
# Exercise 2

- One way of ensuring that writes happen in the correct order is to make each write synchronous. Sadly, this makes your system pigdog slow. Can you think of two other ways you might accomplish this ordering?

- Hint 1: Can you think of a way to enforce ordering using asynchronous writes?
- Hint 2: Think outside the box – is there a way to perform the writes in whatever order you want, but after a crash do something to make it look like you did the writes in the correct order?

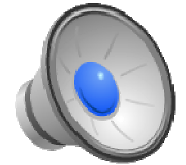
# Two Alternatives to Synchronous Writes for Write-ordering

- Maintain dependencies in-memory and when it's necessary to write things, make sure they get written in order (called *soft updates*).
- Keep a *log* (or *journal*) of all the things you do so that after a crash you can read through the log and figure out precisely what you have to do.



# Approach 0: Synchronous Writes

- Goal is to ensure that you never write a pointer to something that has not been properly written/initialized:
  - Entries in directories reference valid inodes.
  - A block cannot belong to multiple files
  - Inodes are valid



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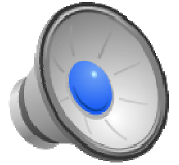
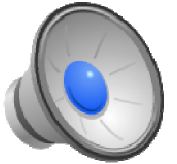
- Goal is to ensure that you never write a pointer to something that has not been properly written/initialized:
  - Entries in directories reference valid inodes.
  - A block cannot belong to multiple files
  - Inodes are valid
- Entries in directories reference valid inodes:
  - On create: synchronously write inode to disk before updating directory entry.
  - On delete: synchronously write the directory with the name removed before deallocating the inode.
- A block cannot belong to multiple files:
  - On unlink/truncate: synchronously write the deallocated (or truncated) inode to disk before its blocks are freed.
- Inodes are valid:
  - Fill in all inode fields before synchronous write (above).



# Directories, Files, and Inodes (oh my)

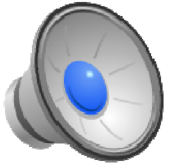


Delete Foo
Create Bar
Allocate block to Bar



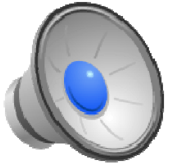
# Now, what happens after a crash?

- The behavior of the file system ensures that it's possible to get to a consistent state after a crash, but it does not ensure that you are always in a consistent state.
- So, how do we make sure that the file system is in a consistent state after a crash?
- Well, first we have to define what consistent means…



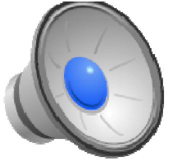
# FFS Consistency

- What does consistent mean in FFS?



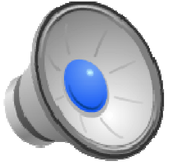
# FFS Consistency

- What does consistent mean in FFS?
  - Superblocks and cylinder groups have accurate counts.
  - Every directory entry references a valid inode.
  - Every valid inode appears in a number of directory entries equal to its link count.
  - Blocks allocated to valid inodes are marked inuse in bitmaps.
  - A block belongs to only one file/directory.
  - The first two entries in every directory are . and ..
  - What makes an inode valid?
    - Its length and number of blocks are consistent with the blocks allocated to it.
    - All block pointers are valid in the given file system.
    - If an inode references a directory, its size is a multiple of DIRBLKSIZ.
    - Its inode number is correct.



# FSCK: The File System Checker

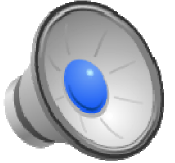
- The FFS fsck program fixes the following errors:
  - Unreferenced inodes
  - Improper link counts
  - Missing blocks in free map
  - Incorrect superblock counts
  - First two entries in a directory are not . and ..
- For your amusement, the next two slides outline all the checks that FSCK makes. (You need not memorize them; it would be good to check that you understand what each one means.)



# FSCK Detail (1)

- FSCK analyzes the file system, reports inconsistencies and optionally fixes them:
  - Read superblock (indicates number of cylinder groups, file system block size, etc).

1. Read cylinder group summary and every inode.
   a. Verify type (directory, file, etc).
   b. Verify size (does not exceed maximum file/directory size).
   c. Verify that blocks in file are set correctly in bit maps.
   d. Verify link count non zero.
   e. Verify size and block count.
   f. Verify fragment summary in cylinder.
2. Verify directory hierarchy (BFS entire directory tree)
   a. Verify directory link counts.
   b. Verify directories contain . and .. and have valid references.
   c. Verify directory is appropriately sized.



# FSCK Detail (2)

3. Iterate over all inodes (checking for proper connectivity)
   a. Verify that every directory we ever found has a valid parent.
4. Check block allocations & reference counts
   a. Verify proper block and fragment accounting and consistency with bitmaps.
   b. Verify that all the link counts are correct.
5. Check cylinder group meta-data
6. Check quotas

# Ordering Writes (1)

- Given how slow synchronous writes are, ordering writes is an appealing idea.
- Unfortunately, it's more complicated than we might like.
- Consider the example from before:
  - Delete foo with inode 10 (from directory D)
  - Create bar with inode 11 (also in directory D)
- Given the directory block $B_d$ and the inode block $I_d$, which one should be written first?

# Ordering Writes (2)

- Creating a file requires that we write inodes before directory blocks.
- Deleting a file requires that we write directory blocks before inodes.
- If the directory block and inode block are the same, no single ordering works.
- Approaches people have tried:
  - As soon as an update would create a circular dependency, write a block to break up the cycle.
  - Maintain information about changes at a finer granularity (e.g., particular directory entries and inodes) and then back out a change to break the cycle before writing an item to disk.
- Read: https://lwn.net/Articles/339337/ for a lovely discussion.