CS3281 / CS5281

# Journaling Filesystems

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# Review of Filesystems

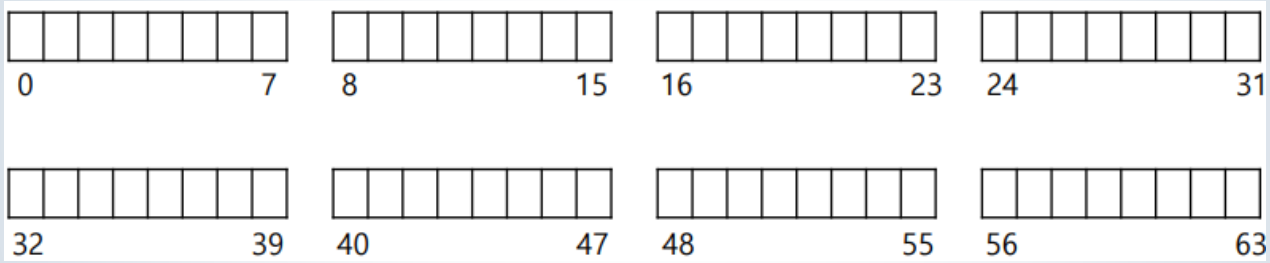
- A filesystem is an organized collection of files and directories
- Linux filesystems use an i-node to store a file's metadata
  - Metadata includes things like file size and permissions
  - Metadata does *not* include a file name
- Today we'll look at journaling and extents

# Filesystem Aspects

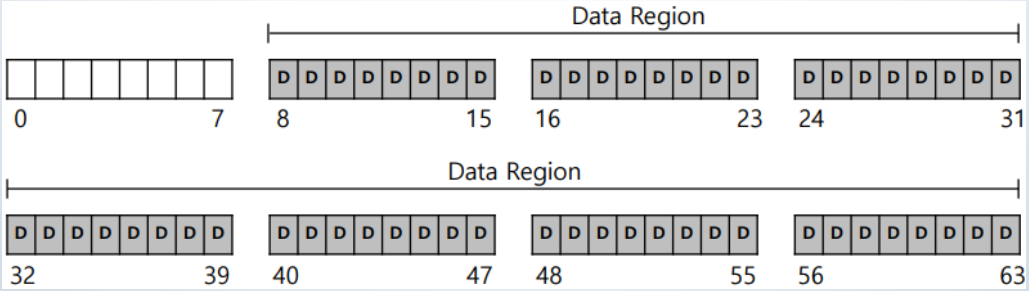
- File system is an on-disk data structure
- Study Very Simple File System (VSFS)
  - A simplified version of UNIX file system
- Two aspects of file system
  - Data structures: on-disk structures to store data and metadata
  - Access methods: mapping system calls, e.g., open(), read(), and write(), to particular structures

# Very Simple File System (VSFS) Data Structures

- Divide disk into blocks
- Use one block size (4KB)
- Blocks are addressed from 0 to *N*-1 (N is the number of blocks)

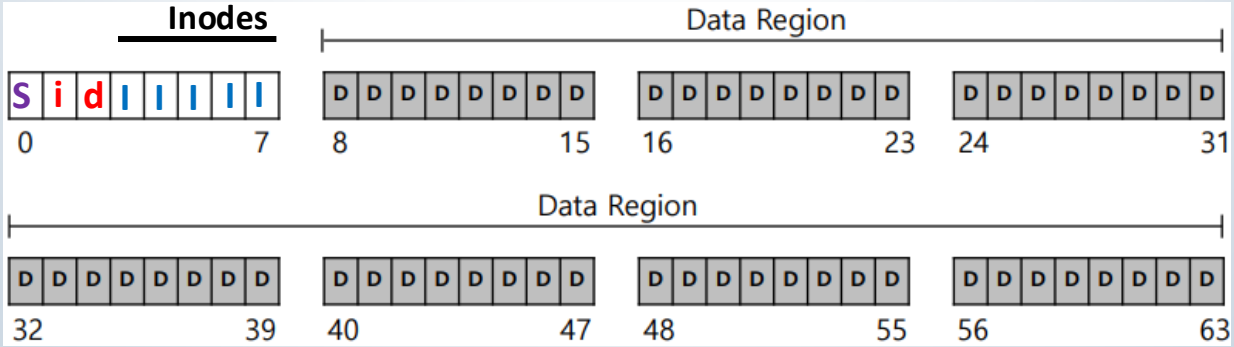



- Store user data in *data region* (e.g., files and directories)



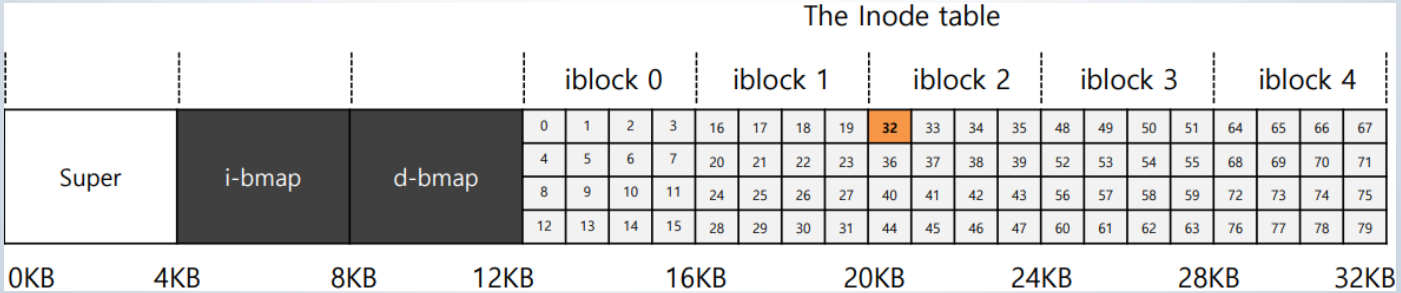
# VSFS Data Structures (cont.)

- File system tracks information (metadata) about files.
  - E.g., a subset of data blocks that form a file, file size, access rights
- Metadata is stored in a structure called *inode*
  - inode table is an array of inodes
  - 256-byte inode
  - 16 inodes per block; 80 inodes in 5 blocks
- Use bitmap for tracking free inodes and data blocks
  - A bit indicates whether an inode or a block is free.
- Superblock stores information about a certain file system.
  - E.g., number of inodes and data blocks, the start of inode table



# The I-Node

- Index node (inode): array of nodes is indexed
- Each inode is identified by an i-number
  - Used for indexing an array of inodes
- Find the byte address for the inode with i-number 32
  - Compute the offset into the inode table: 32 * sizeof(inode) = 8192 (8KB)
  - Add the offset to start address of inode table: 12KB + 8KB = 20KB
- inodes are fetched using *sectors* (a block consists of sectors)
  - 512-byte sectors
  - Sector number: (20 * 1024)/512 = 40



# Crash Scenario

- Consider the following simple filesystem scenario from the textbook
  - One file with one allocated data block


```
owner       : remzi
permissions : read-write
size        : 1
pointer     : 4
pointer     : null
pointer     : null
pointer     : null
```

- Suppose we want to append to this file; we have to
  - (1) write the data to a new data block, (2) update the i-node, (3) update the data bitmap
    - This requires three (separate) writes to disk
  - For example, we want the updated filesystem to look like this:


```
owner       : remzi
permissions : read-write
size        : 2
pointer     : 4
pointer       5
pointer     : null
pointer     : null
```

# Crash Scenario (cont.)

- But what if the system crashes after only 1 of the writes is performed?
  - **Just the data block is written**: the data is there, but the i-node doesn't know about it
  - **Just the i-node is updated**: the data isn't there, so we'll read garbage from disk
    - And the filesystem is inconsistent: the i-node (danglingly) points to a data block, but the data block bitmap thinks it hasn't been allocated.
  - **Just the data block bitmap is updated**: no i-node points to the data block, so there's a space leak

- What if the system crashes after 2 writes (out of 3) are performed?
  - **I-node and bitmap updated, data block not updated**: file contains garbage
  - **I-node and data block are written**: the bitmap thinks the block hasn't been allocated
  - **Bitmap and data block are written**: no i-node points to the data (so the data is effectively lost!). This is a data leak.

i: inode
dm: data (bit) map
db: data block

| Action Sequence | Failure After First Action | Failure After Two Actions |
|---|---|---|
| 1: i->db->dm | Inode points to the garbage data because data block is not updated.<br><br>Inconsistent file system | Inode is updated but data map retains its old value. Because data map says that space is not allocated, the user data is lost.<br><br>Inconsistent file system |
| 2: i->dm->db | See Case 1, Failure After First Action<br><br>Inconsistent file system | See Case 1, Failure After First Action<br><br>Consistent file system |
| 3: db->i->dm | Data block has content but neither the inode nor the data map has any information about it. This is called **data leak**.<br><br>Consistent file system | See Case 1, Failure After Two Actions<br><br>Inconsistent file system |
| 4: db->dm->i | See Case 3, Failure After First Action<br><br>Consistent file system | See Case 3, Failure After First Action<br><br>Inconsistent file system |
| 5: dm->i->db | Data map says that space is allocated but there is nothing in the block nor does any inode point to it. This is called **space leak**. The space does not have any data or has garbage data.<br><br>Inconsistent file system | See Case 1, Failure After First Action and Case 5, Failure After First Action<br><br>Consistent file system |
| 6: dm->db->i | See Case 5, Failure After First Action<br><br>Inconsistent file system | See Case 3, Failure After First Action<br><br>Inconsistent file system |

# The Crash Consistency Problem

- Crashes cause inconsistency in file system data structures.
  - E.g., space or data leaks, data block containing garbage
- Disk performs one write at a time.
  - Crashes or power loss occur between writes.

# A Solution: Filesystem Checker

- A filesystem checker (fsck) scans the filesystem for inconsistencies and repairs them
  - Runs before filesystem is made available to users. It
    - Check the superblock; if it looks corrupted, you can try to use an alternate copy
    - Scan the i-nodes to see which blocks are in use and resolve inconsistencies in the allocation bitmaps
    - Check that each i-node is ok
    - Scan the entire directory tree (starting at root dir) and verify link counts
    - Check for bad blocks (e.g., data pointer points to an invalid address); just clear the bad pointers
    - Check that directories are consistent (e.g., contain "." and "..", there are i-nodes for each file entry)

# Journaling

- A filesystem check can be very slow, especially for large filesystems
- An alternative is journaling, also called write-ahead logging
- Simple idea: before updating the on-disk structures, write information about the update to a *journal* (also called a log)
  - If there's a crash before the disk can be updated, the journal contains enough information to recover
    - You don't have to scan the entire disk!

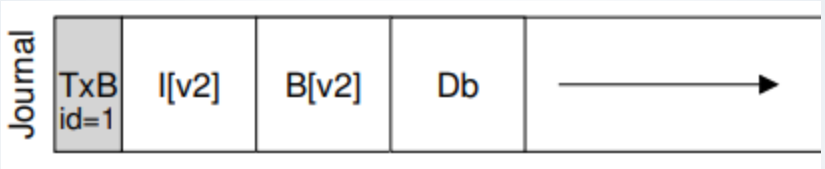
# Example: ext2 vs. ext3

- The basic layout of ext2 (no journaling):

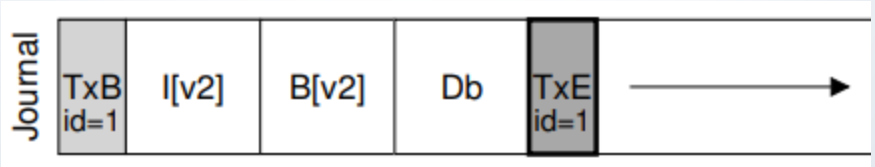

- The basic layout of ext3 (with journaling):

# Data Journaling Phases

- Four basic phases:
  - Journal write: write contents of transaction to journal; wait for these to complete




  - Journal commit: write the transaction commit block; wait for write to complete; transaction is committed




  - Checkpoint: write the contents of the update (metadata and data) to disk

# Timeline for Data Journaling

| Journal contents | | | | File System | |
|---|---|---|---|---|---|
| TxB | (metadata) | (data) | TxE | Metadata | Data |
| issue<br>complete | issue<br>complete | issue<br>complete | | | |
| | | | issue<br>complete | | |
| | | | | issue<br>complete | issue<br>complete |

*any order*

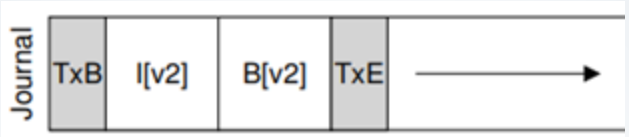
# Recovery

- When a crash happens before *journal commit* completes, pending updates in a transaction are skipped.

- When a crash happens after *journal commit* completes and before *checkpoint* completes, transactions are replayed (redo logging)
  - File system finds out transactions that were committed successfully
  - The blocks of those specific transactions are written to their final disk locations again

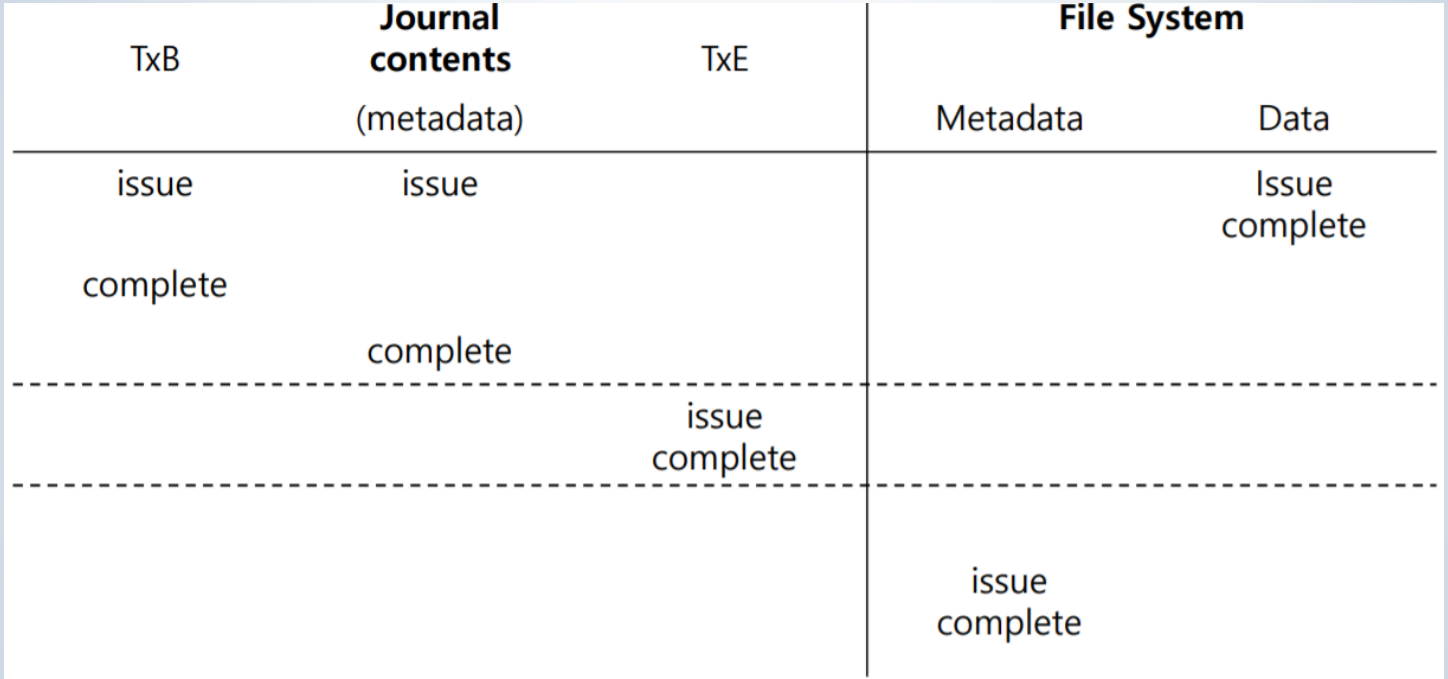
# Ordered (Metadata) Journaling

- Instead of journaling both data and metadata, just do metadata




- In this case, our journaling protocol is:
  - **Data write**: write data to its final location
    - If we crash after this step but before the rest, only the data is lost. Transaction is discarded.
  - **Journal metadata** write: write metadata to the journal
  - **Journal commit**: write the transaction commit block
  - **Checkpoint metadata**: write the metadata update to final location in filesystem

# Timeline for Metadata Journaling

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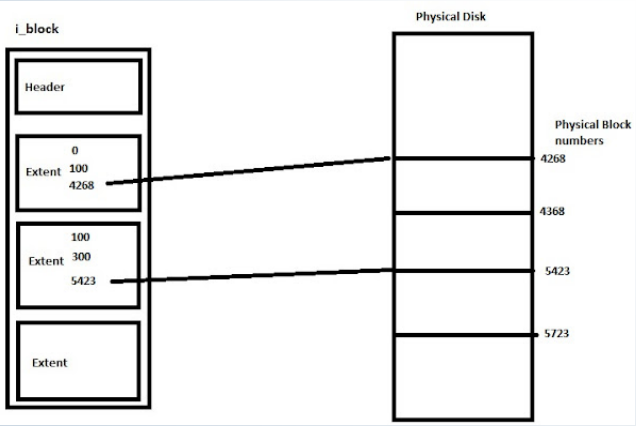
# Extents

- Recall that ext2 and ext3 use indirect pointers to data blocks (Figure on right)
  - Can be inefficient!
- The ext4 filesystem uses extents
  - An extent specifies an (1) an initial block address, and (2) the number of blocks in the extent
    - Large file will have multiple extents




http://ext2read.blogspot.com/2010/03/how-ext4-extents-work-earlier-ext2-and.html

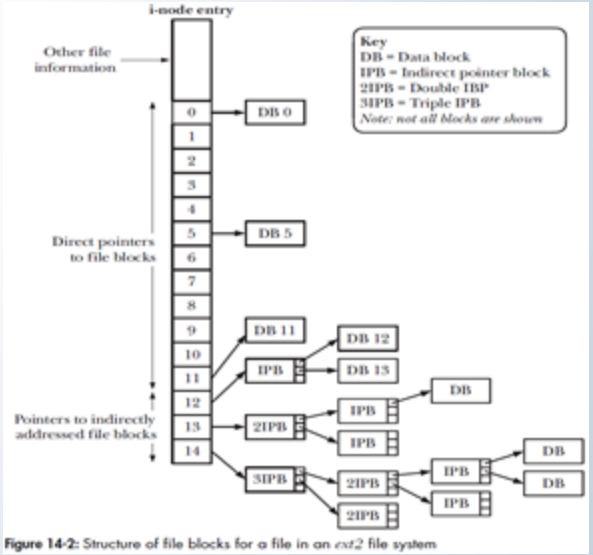



Figure 14-2: Structure of file blocks for a file in an *ext2* file system

*Figure from *The Linux Programming Interface* by Michael Kerrisk