Journaling
and
Log-structured file systems

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KTH

2019

The file system

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- a *file* is persistent i.e. it survives the termination of a process
- a *file* can be access by several processes i.e. a shared resource
- a *file* can be located given a *path* name

let's write to a file

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In what order should we perform these operations?

what if we crash

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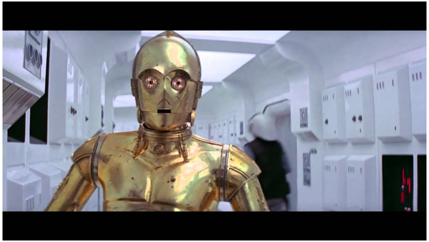

We’re doomed!

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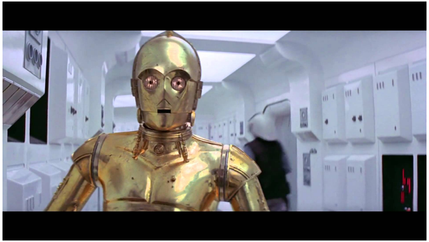

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How do we cope with crashing drives?

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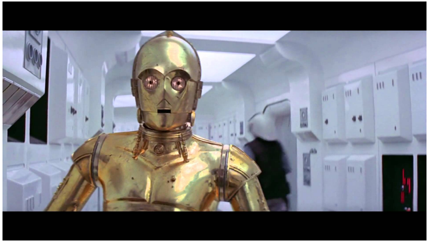

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How do we cope with the operating system crashing?

one or two out of three

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write to `bar.txt`

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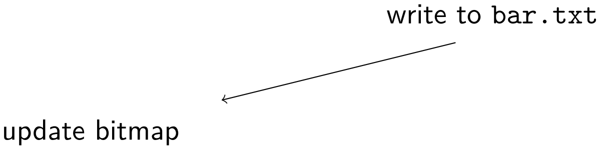

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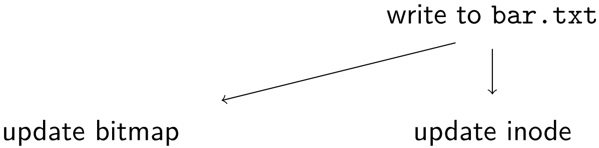
one or two out of three



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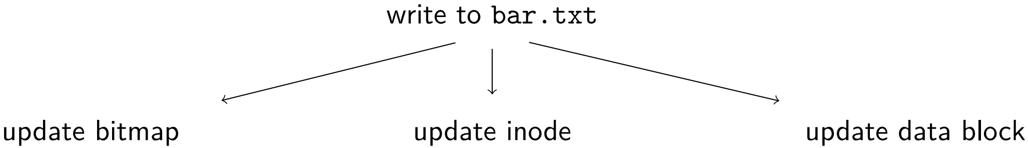

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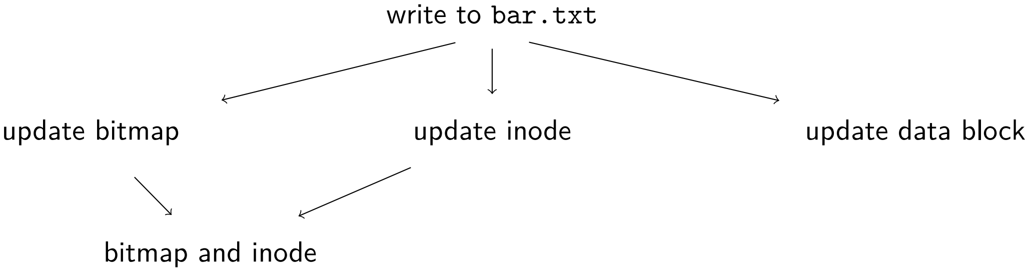

write to `bar.txt`

update bitmap

update inode

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bitmap and inode

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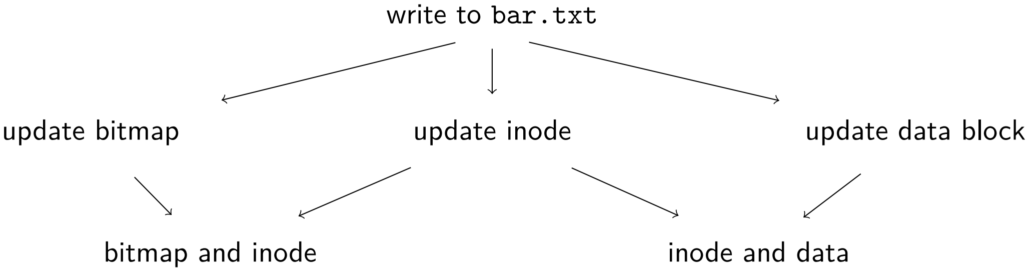

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bitmap and inode

inode and data

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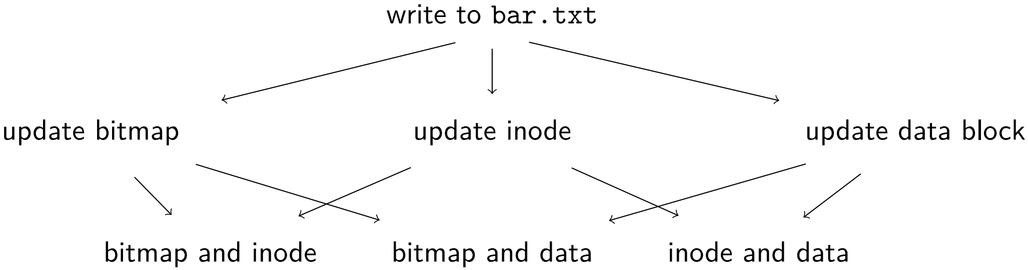

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bitmap and inode

bitmap and data

inode and data

two out of three ...

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Two out of three is - when it comes to file systems - bad.

Survive a crash

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Approaches:

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crash recovery

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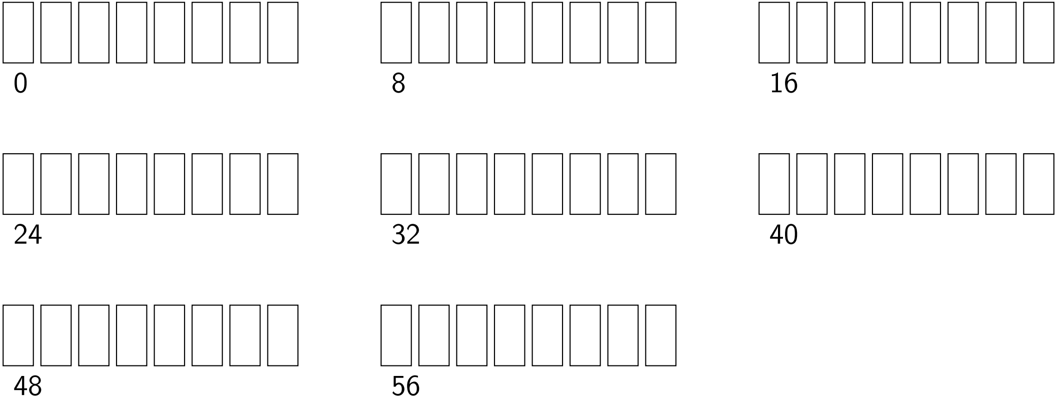

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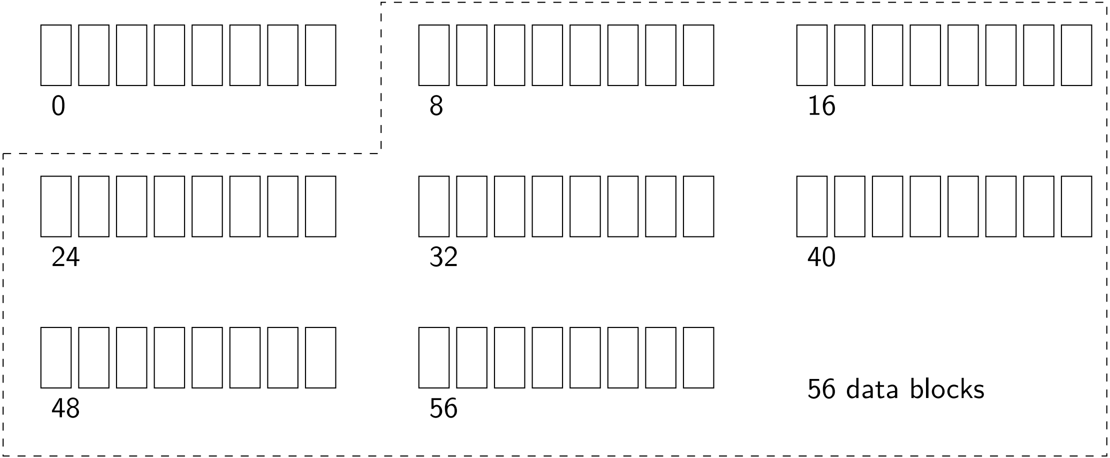

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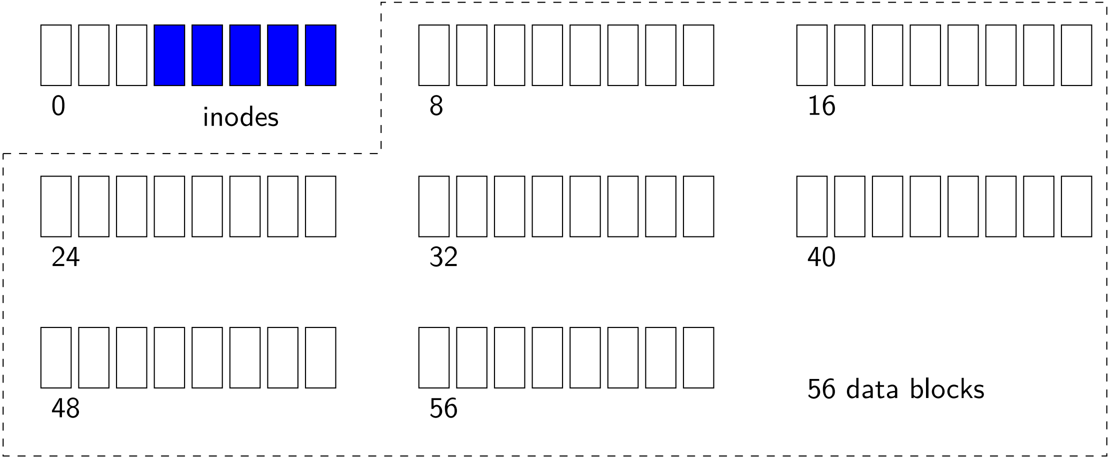

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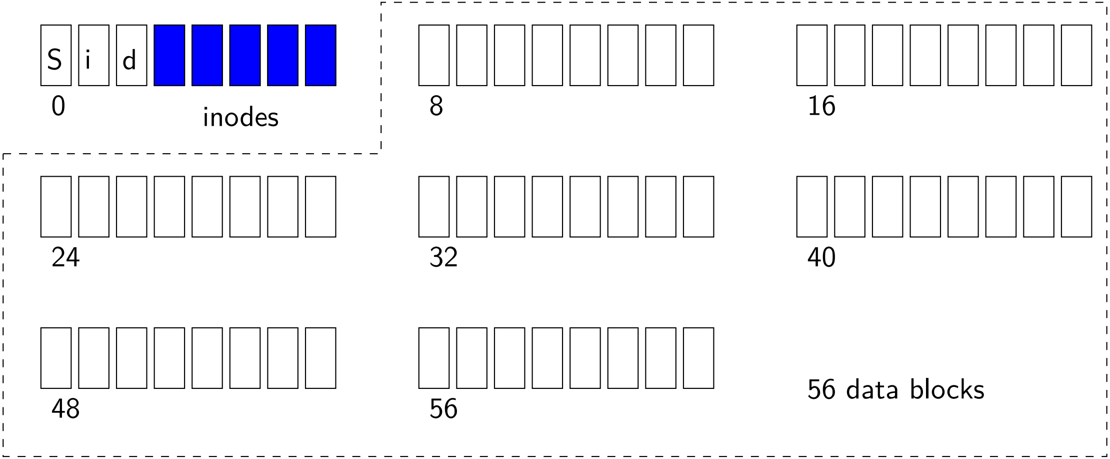

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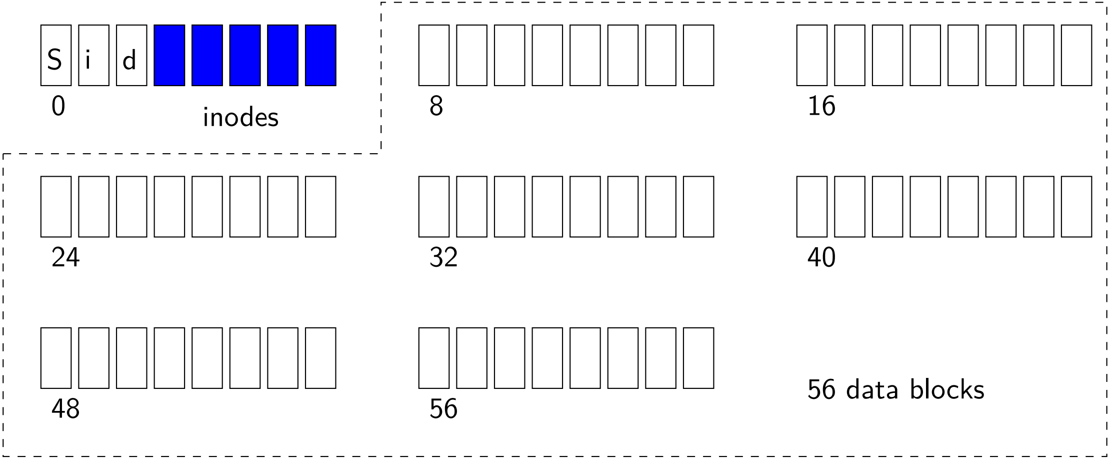

fsck /dev/sdb1

```
$ sudo fsck  -f /dev/sdb1
fsck from util-linux 2.27.1
e2fsck 1.42.13 (17-May-2015)
Pass 1: Checking inodes, blocks, and sizes
Pass 2: Checking directory structure
Pass 3: Checking directory connectivity
Pass 4: Checking reference counts
Pass 5: Checking group summary information
/dev/sdb1: 3339/125952 files (0.1% non-contiguous), 318256/503808 blocks
```

the lost and found

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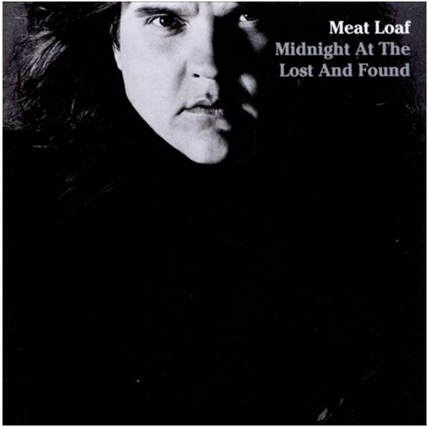

lost+found

```
> ls -il /
    :
    :

11010049 drwxr-xr-x   2 root root 12288 nov 28 17:49 libx32

      11 drwx------   2 root root 16384 maj  8  2016 lost+found

14155777 drwxr-xr-x   3 root root  4096 jun 29 14:13 media

  262145 drwxr-xr-x   3 root root  4096 okt 22 10:17 mnt

    :
    :
```

journal

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Journal or Write-Ahead Logging

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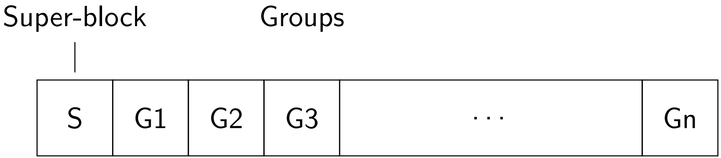
Let's keep a *journal* of things we are about to do.

Journal or Write-Ahead Logging

If we crash we can look at the journal to repeat the last sequence of operations.

Linux ext2 - no journaling



Super-block

Groups

S	G1	G2	G3	· · ·	Gn

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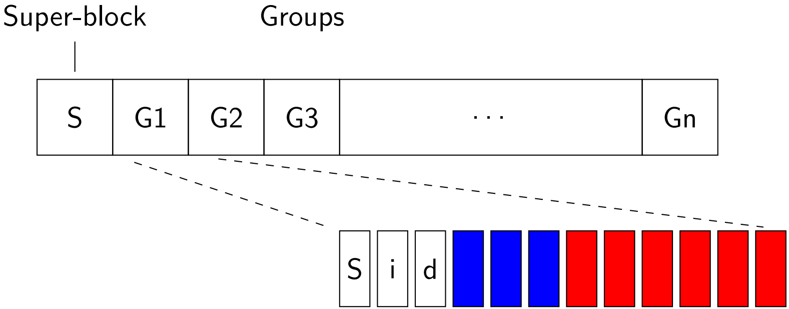

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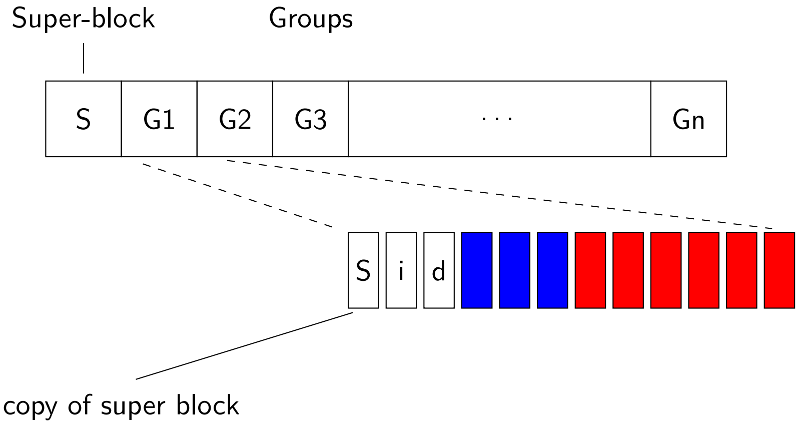

Super-block

Groups

copy of super block

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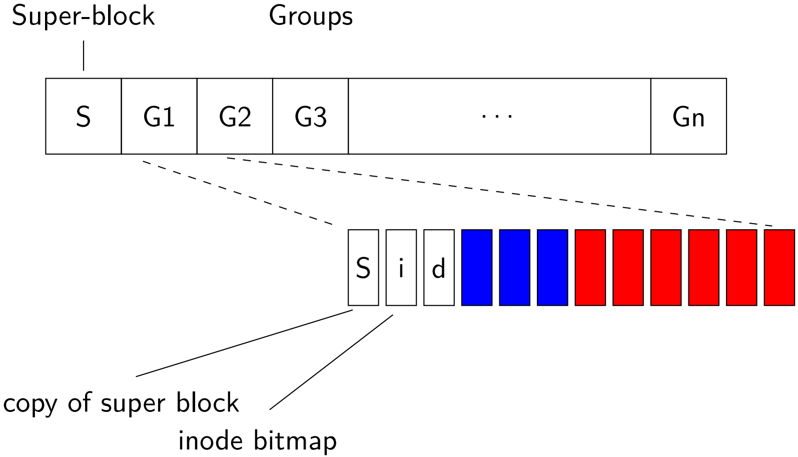

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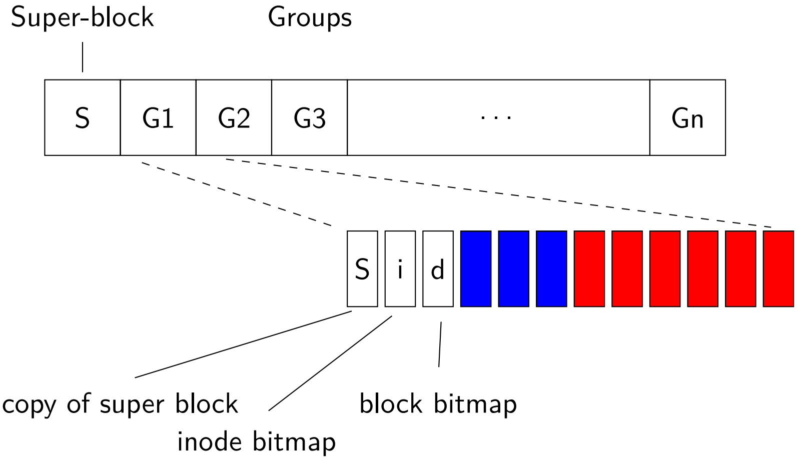

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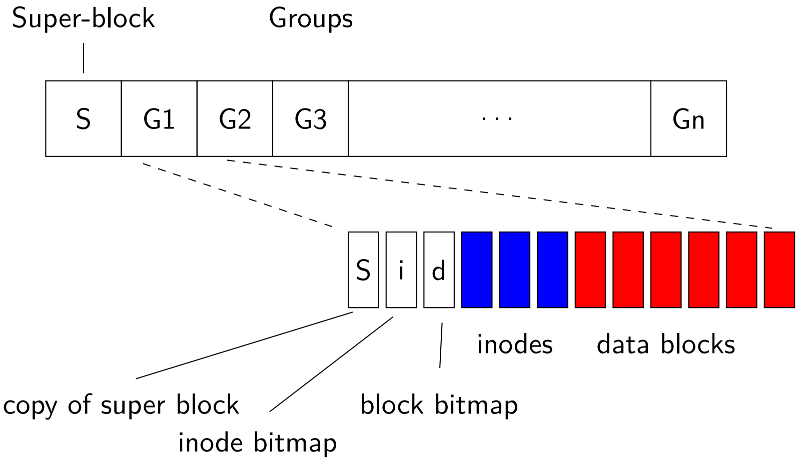
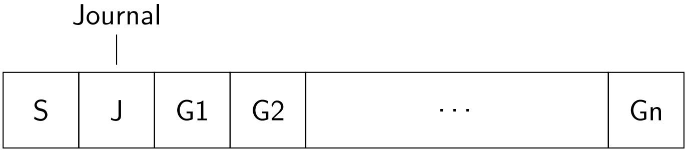


Linux ext3 - journaling



Journal

S J G1 G2 ... Gn

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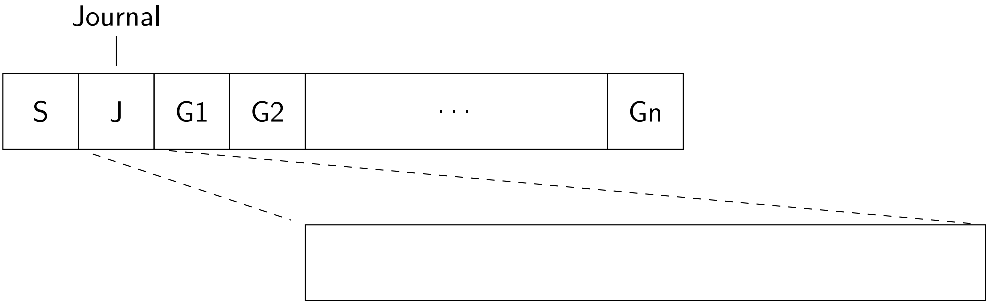

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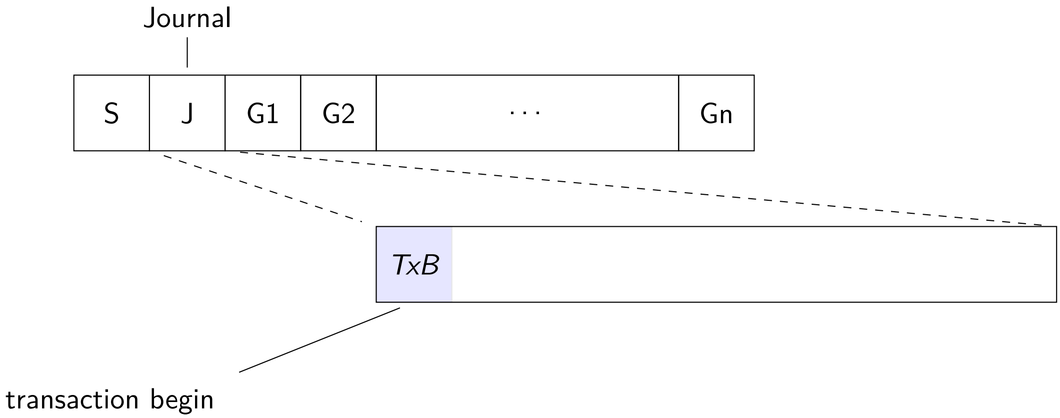

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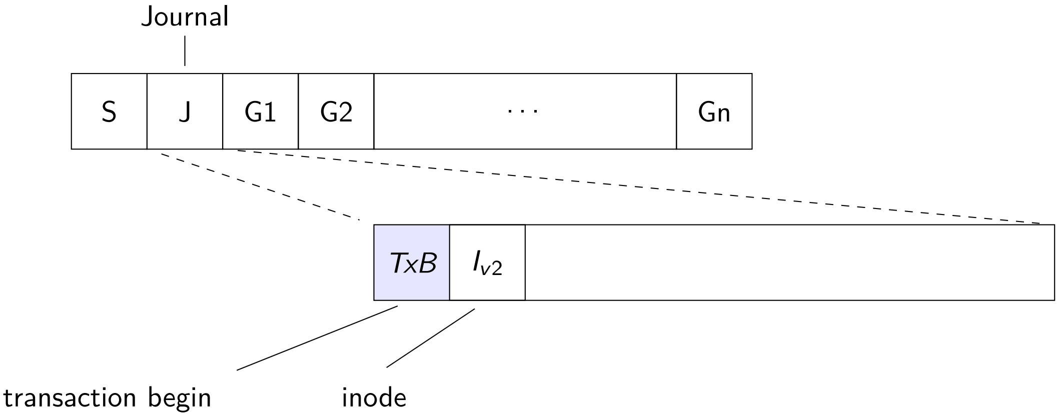

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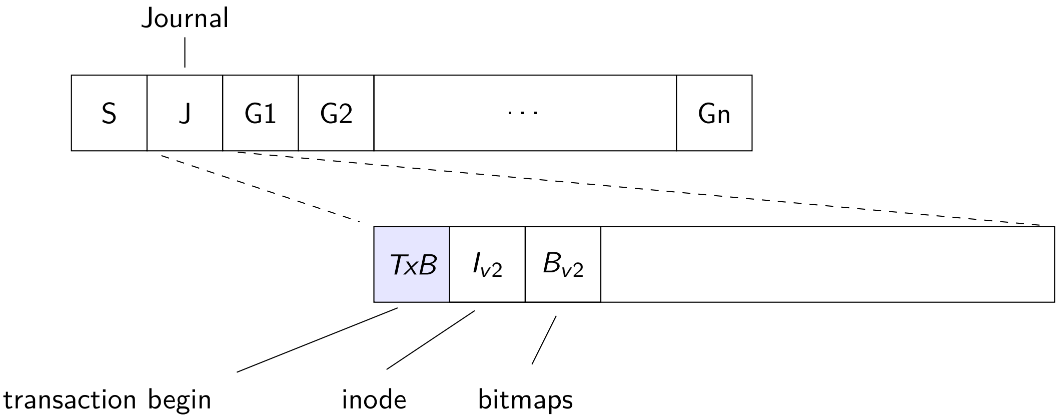

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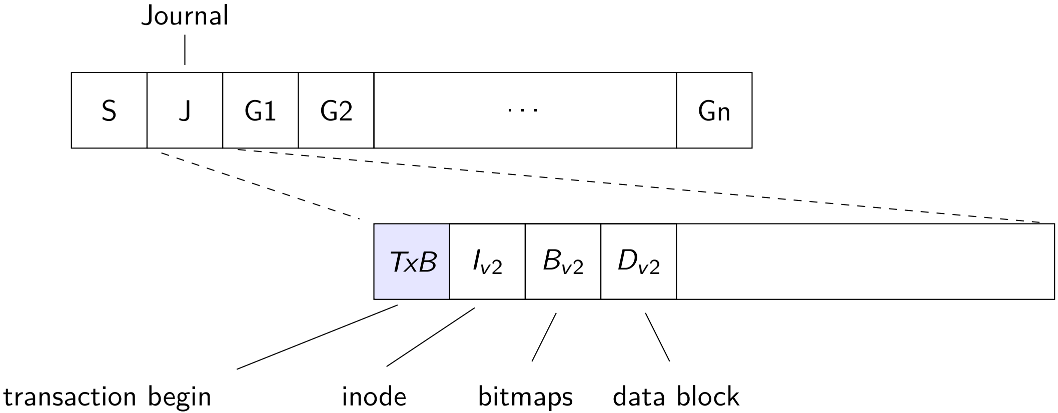

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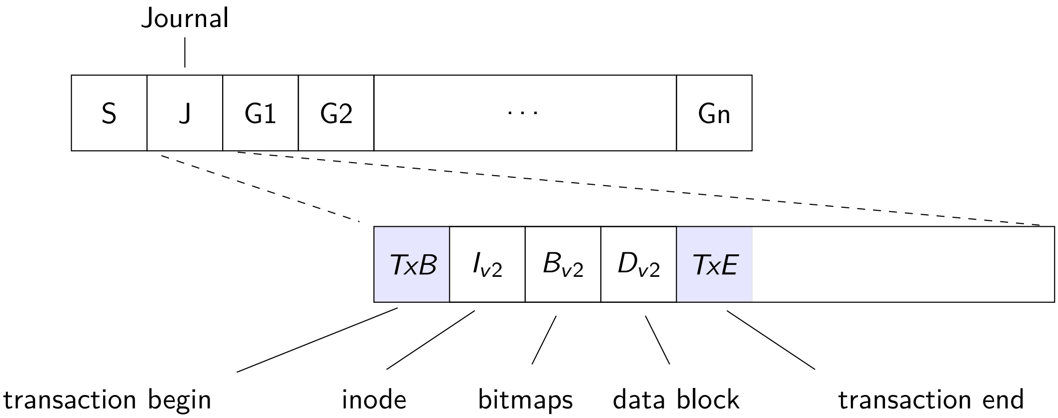

the safe way

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    - *TxB* : transaction id, inode id, bit map id, data block id

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disaster scenarios

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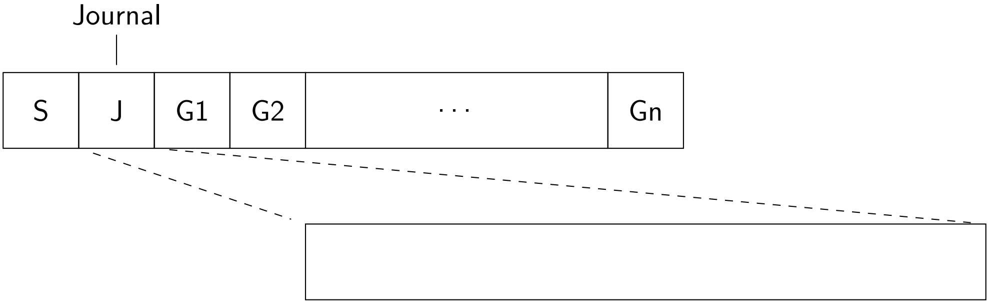
pending transactions



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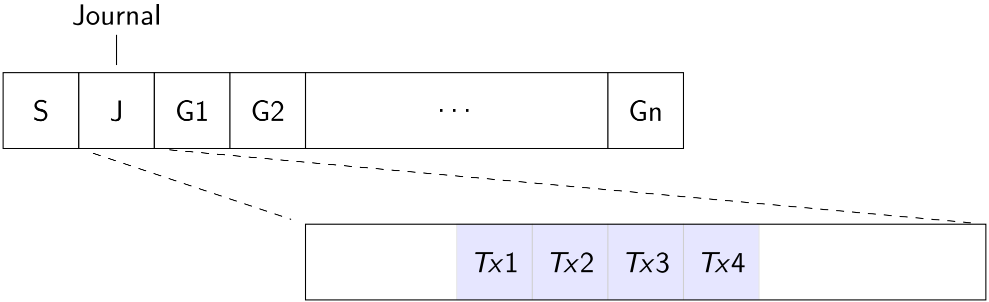

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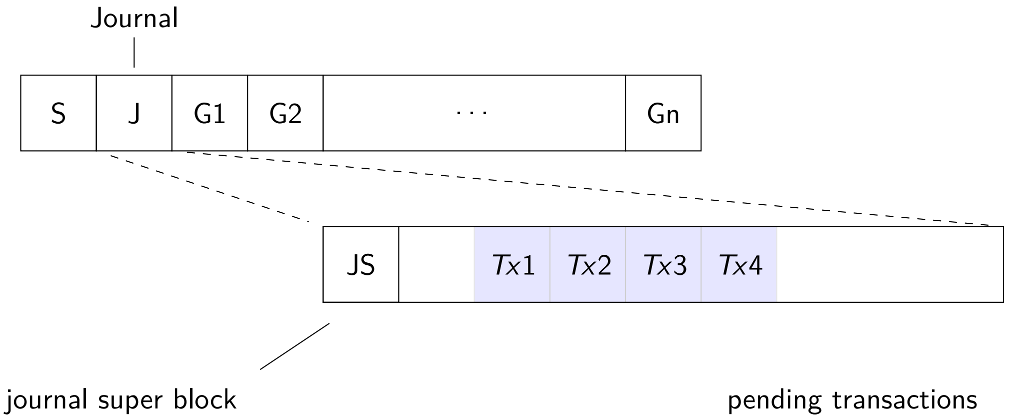

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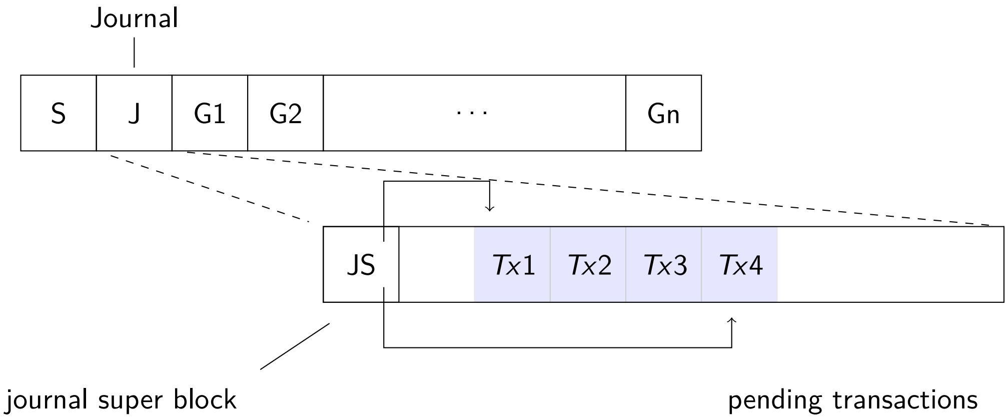

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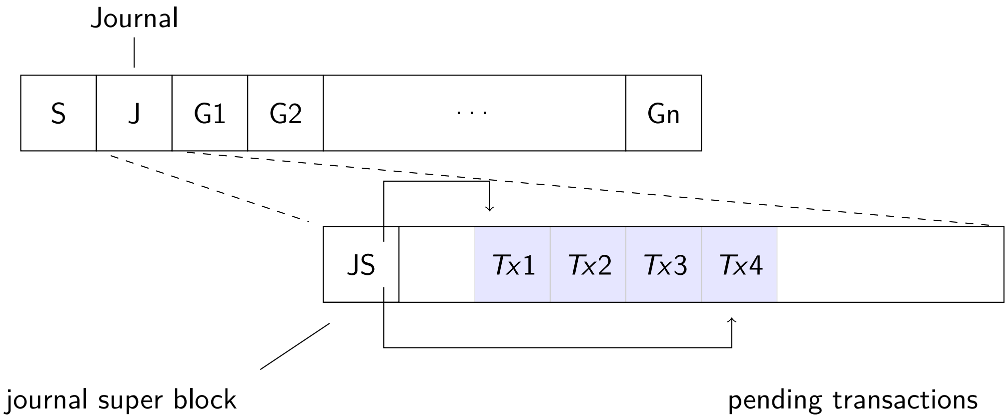
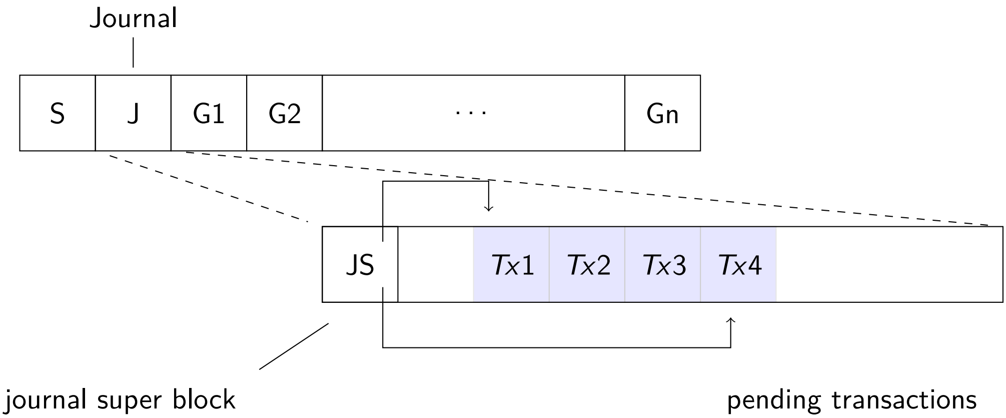


What is the state of the file system?

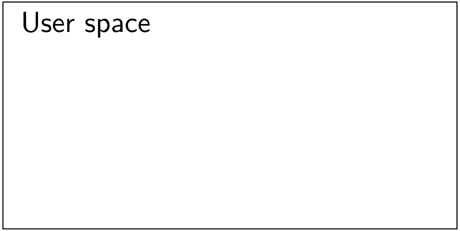
pending transactions



What is the state of the file system?

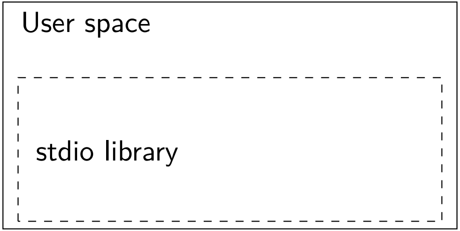
Can we read from the file system?

Layers of caches



User space

Layers of caches



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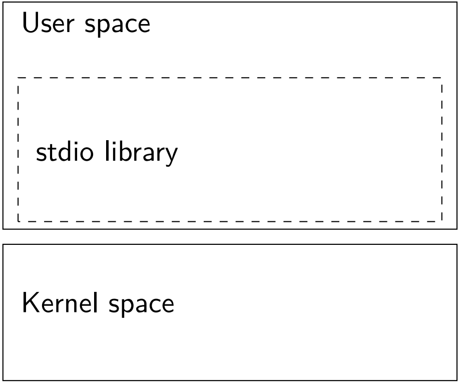
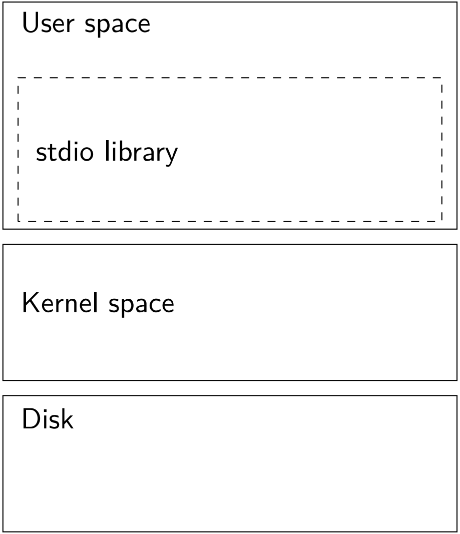


User space

stdio library

Kernel space

Layers of caches



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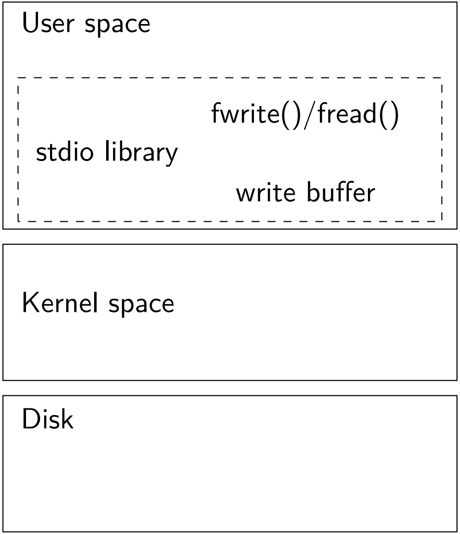
Disk

Layers of caches



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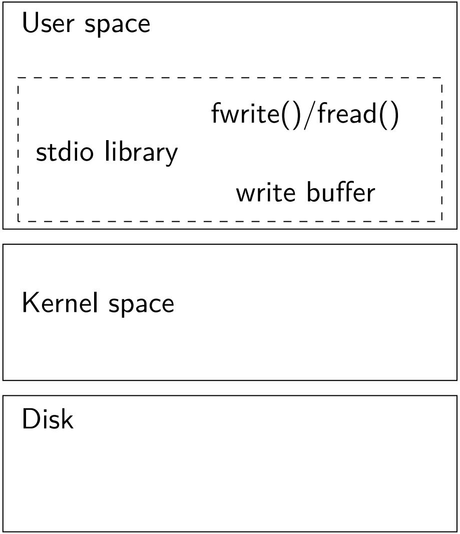


User space

fwrite()/fread()

stdio library

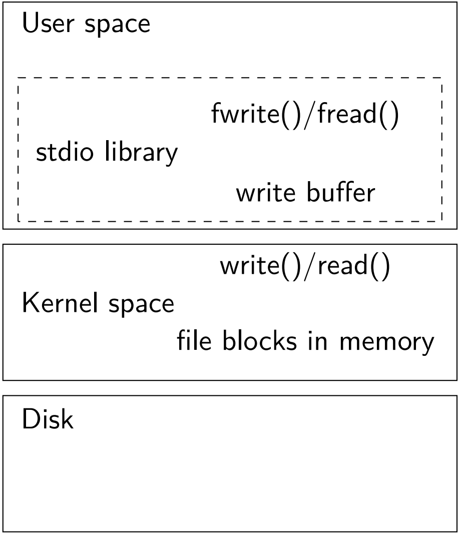
write buffer

Kernel space

Disk

- flush(): changes in buffer to kernel

Layers of caches



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Kernel space

file blocks in memory

Disk

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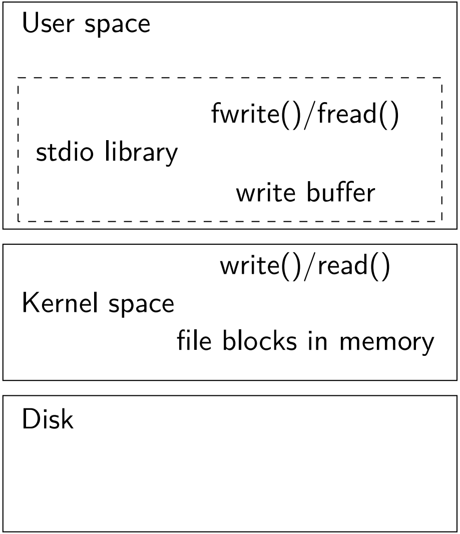
Layers of caches



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fwrite()/fread()

write buffer

Kernel space

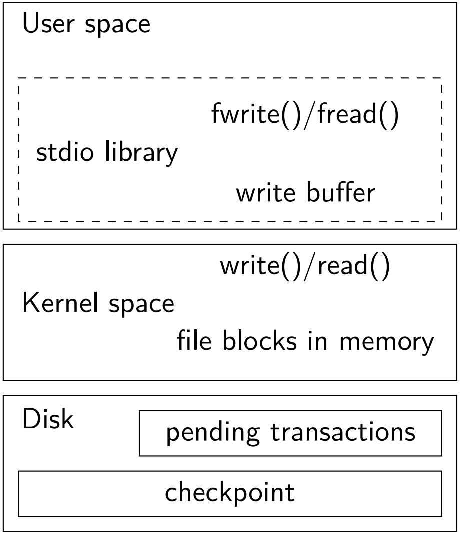
write()/read()

file blocks in memory

Disk

- flush(): changes in buffer to kernel
- sync(): changes to file system journal/checkpoint

Layers of caches



User space

stdio library

fwrite()/fread()

write buffer

write()/read()

Kernel space

file blocks in memory

Disk

pending transactions

checkpoint

- flush(): changes in buffer to kernel
- sync(): changes to file system journal/checkpoint
- checkpointing: from journal to inodes, maps and blocks

do the right thing....?

Journal is slow:

- Commit: write meta-data and data in a transaction (make sure it's a complete transaction).

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Everything is written twice to disk!

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Idea - do the wrong thing and pray for the best.

data only once

Faster:

- Commit data : write data directly to block.

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Even faster:

- Commit data : write data directly to block... eventually, hopefully.

data only once

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ext4/jdb2

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ext4/jdb2

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- `write-back` : data is not guaranteed to be written before meta-data

inode - is everything important

```
> sudo istat /dev/sda1 2236582
inode: 2236582                                Group: 273
Generation Id: 3805640679
uid/gid: 1000/1000      mode: rrw-rw-r--   Flags: Extents,

size: 43  num of links: 1

Inode Times:
Accessed: 2016-12-06 14:51:17.003254544 (CET)
File Modified: 2016-12-06 15:46:55.667041193 (CET)
Inode Modified: 2016-12-06 15:46:55.667041193 (CET)
File Created: 2016-12-06 13:39:15.084806928 (CET)

Direct Blocks:  6946002
```

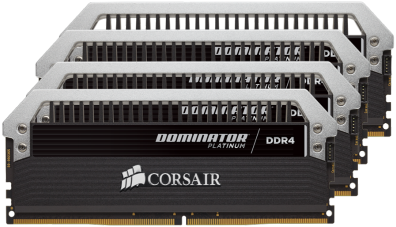
What about this?

What about this?

This album has nothing to do with the following material.

Disk vs Memory

Disk vs Memory



Log-structured file systems

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Reading is mostly done from cached copies in memory.

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Focus on write operations, try to avoid moving the arm.

Writing is best done in large consecutive segments.

The state of the file system is *a log of events*.

the log

D

the log

D	D

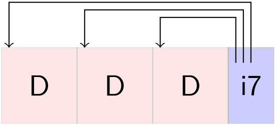
the log

D	D	D

the log

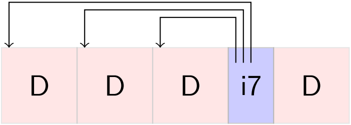
D	D	D	i7

the log



D	D	D	i7

the log



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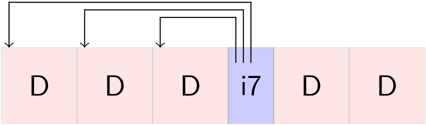
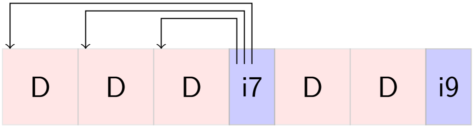


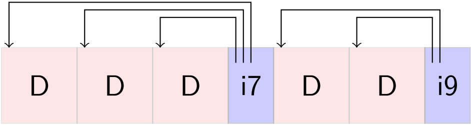
D D D i7 D D

the log

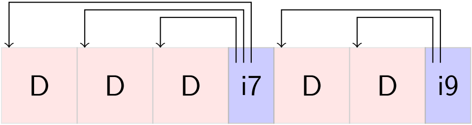


D D D i7 D D i9

the log



the log



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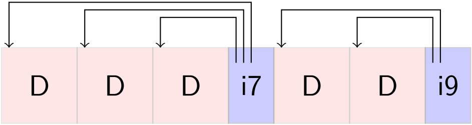

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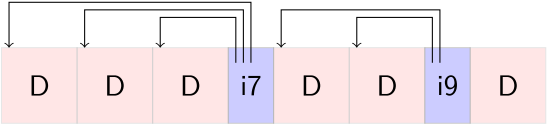

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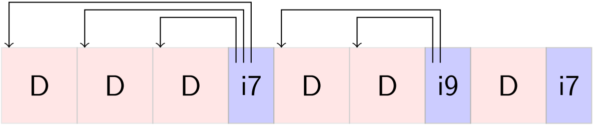

D D D i7 D D i9 D i7

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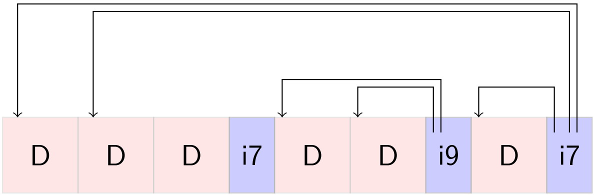

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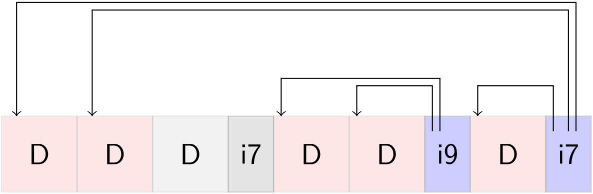

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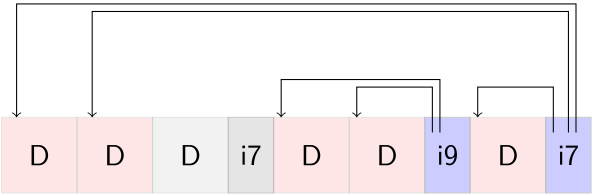
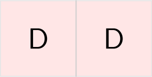


How do we find the inodes?

the inode map

D

the inode map



D D

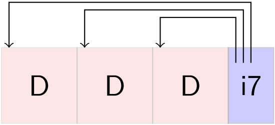
the inode map

D	D	D

the inode map

D	D	D	i7

the inode map



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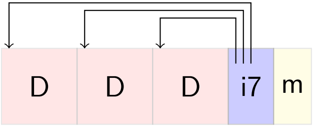

The inode map holds mapping from inode number to block addresses.

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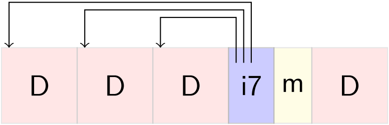

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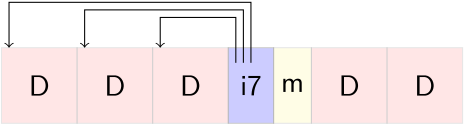

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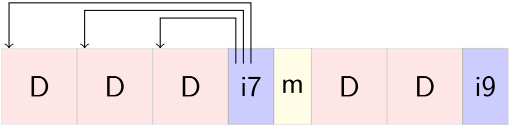

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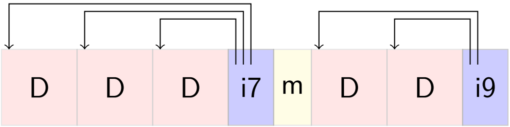

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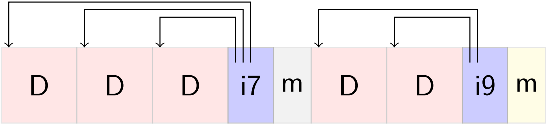

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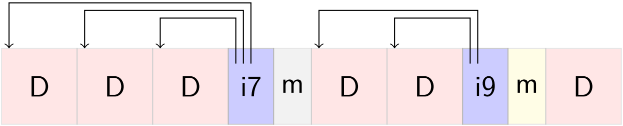

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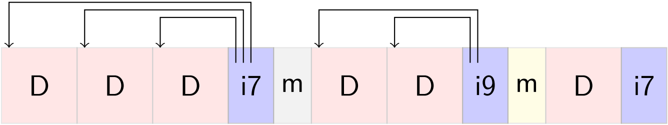

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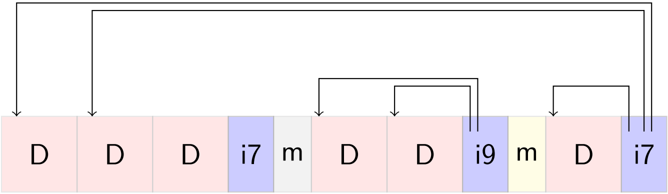

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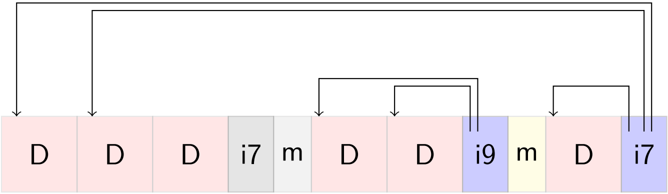

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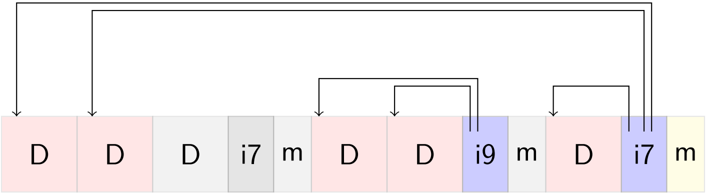

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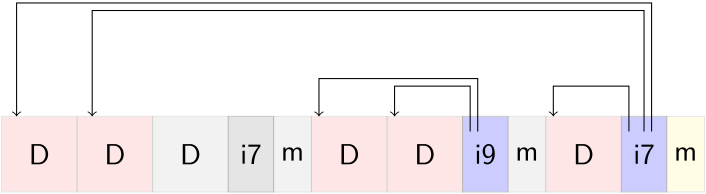
How do we find the last inode map?

the inode map



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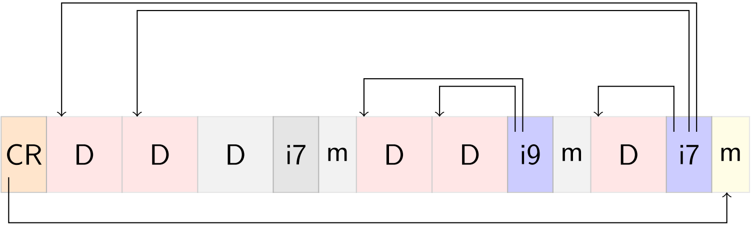

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pros and cons

reading a file

- read the check region
- find the location of the inode map
- find inode
- read data block

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How much can we cache in memory?

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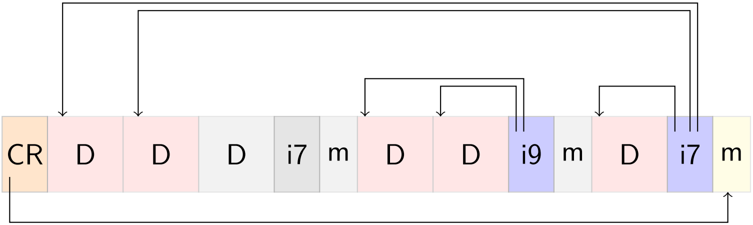
How much can we cache in memory?

Can we delay updating the check region?

reclaim sectors



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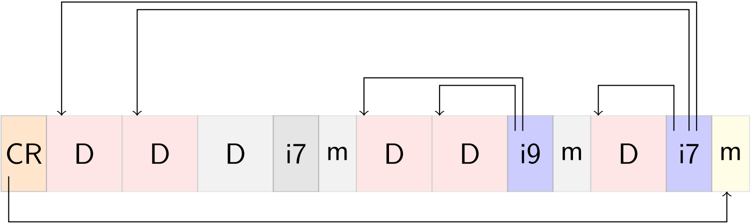

Where is the bit map that keeps track of available blocks?

Hmmm.....

Do we want to know where to find blocks ..

Hmmm.....

Do we want to know where to find blocks ..

if they are scattered around the disk?

garbage collection and compaction

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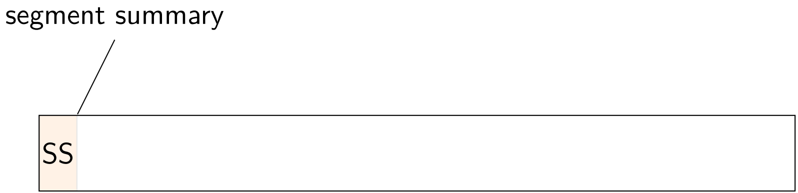

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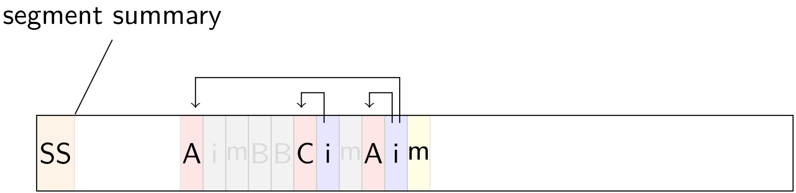

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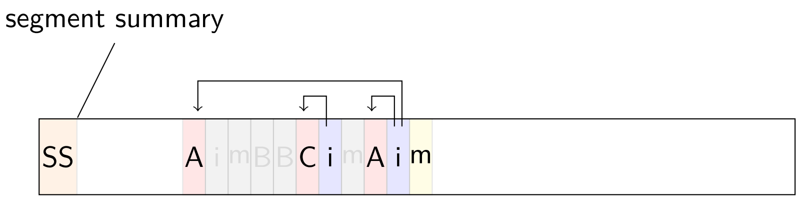
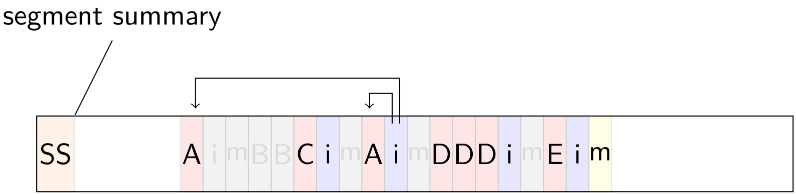


Segment summary keeps a mapping from block to inode.

garbage collection and compaction



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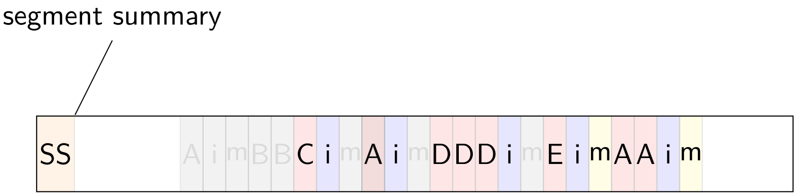

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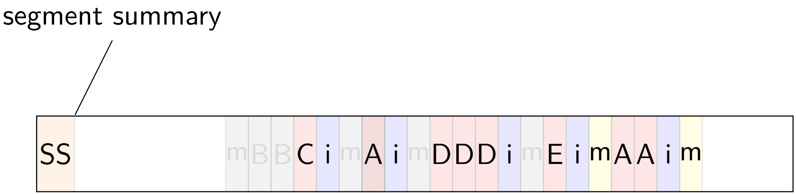

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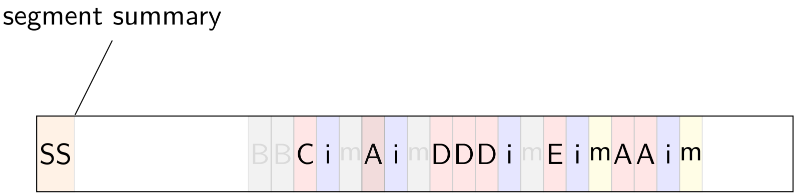

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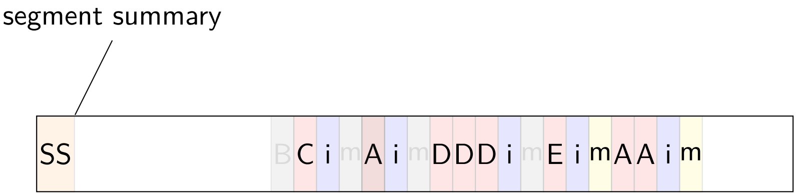

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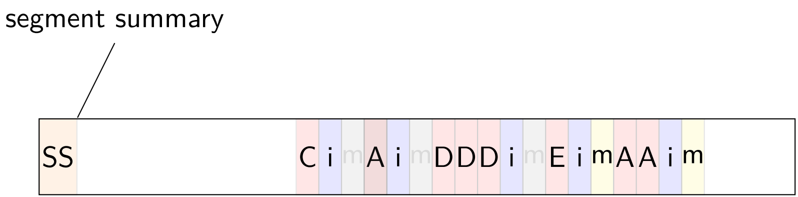

Segment summary keeps a mapping from block to inode.

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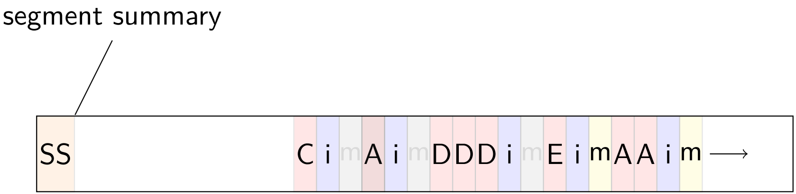
segment summary

SS C i m A i m D D D i m E i m A A i m →

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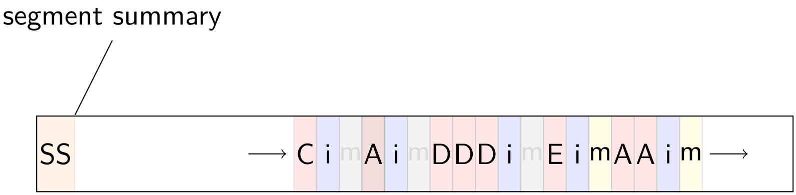

Segment summary keeps a mapping from block to inode.

What about SSDs?

What about SSDs?

old enough to remember this

The file system UDF used a log structure to do updates on a write-once CD/DVD

Some file systems

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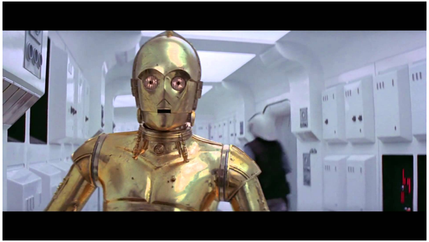
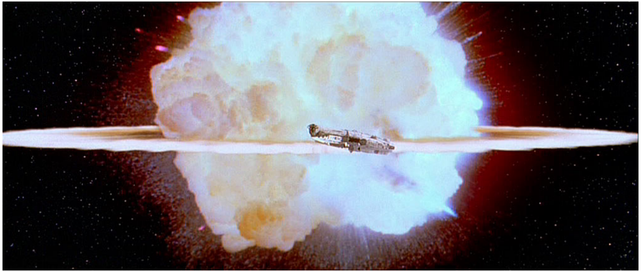


We're doomed!

Summary



Saved!