Betriebssysteme

13. Tutorium - Files Systems

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6. Februar 2025

ITEC - Operating Systems Group

Disk Space Allocation

Contiguous Allocation

What is that?

Contiguous Allocation

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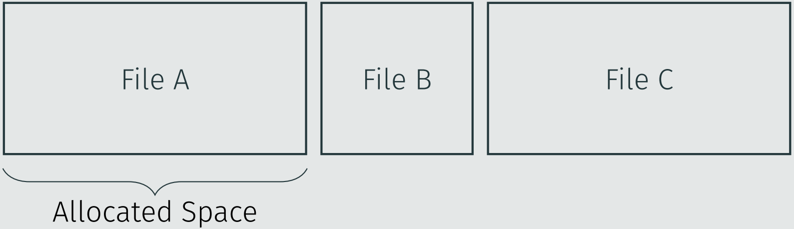

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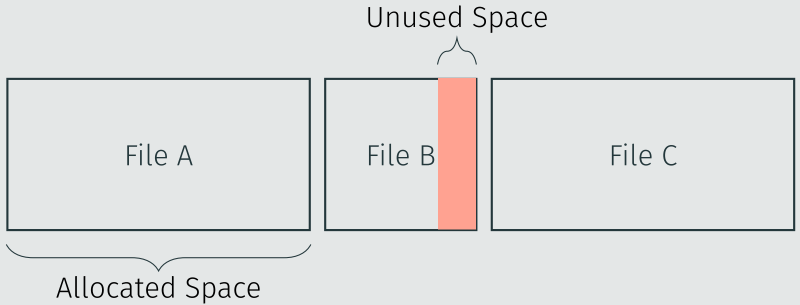

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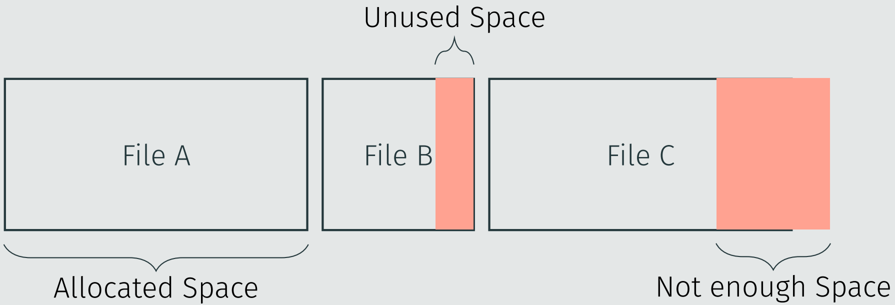

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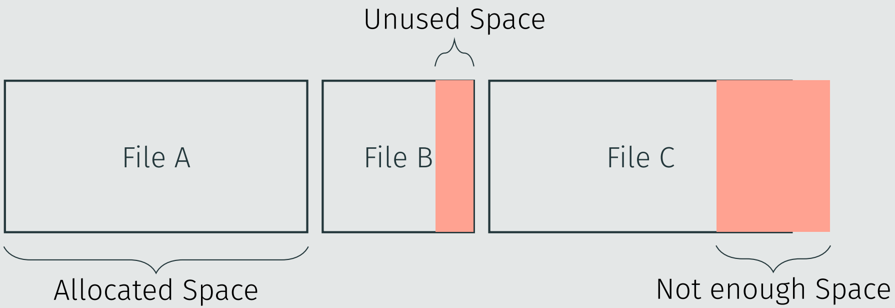

Challenges

- Sizing your block (internal fragmentation, growth)
- External fragmentation

Chained Allocation

What's that?

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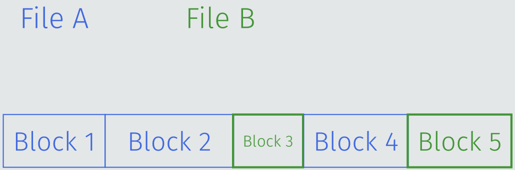

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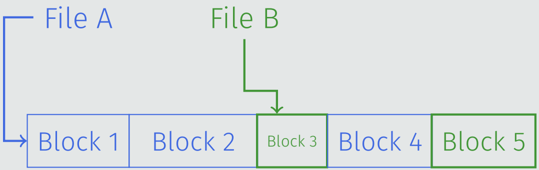

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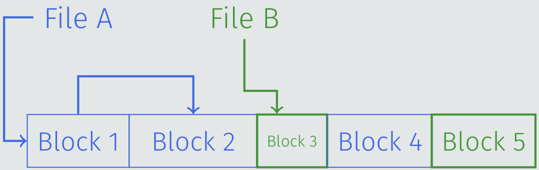

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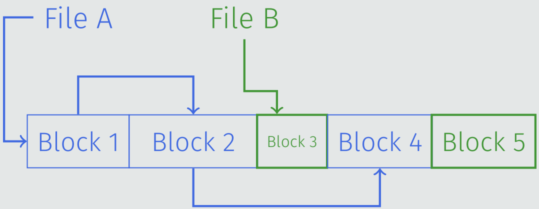

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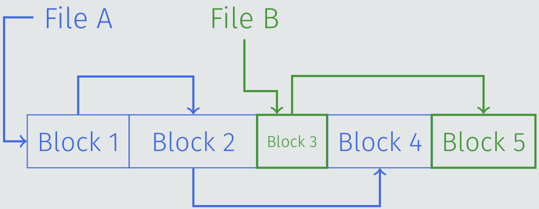

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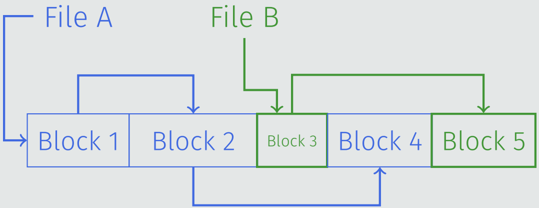

Benefits? Drawbacks?

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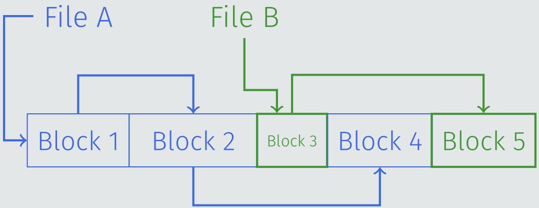

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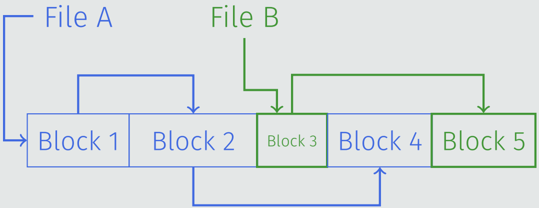

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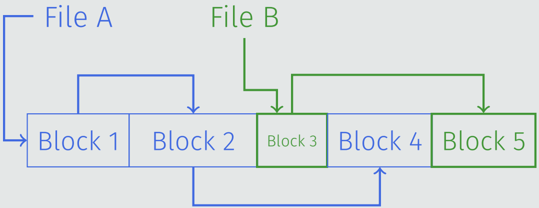

Benefits? Drawbacks?

- \+ No longer need a contiguous chunk
- – Only sequential access
- – A single corrupted pointer is very bad news

Linked List Allocation With FAT

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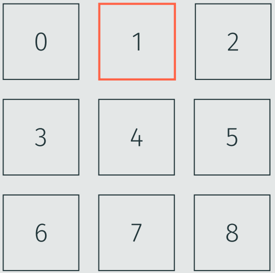

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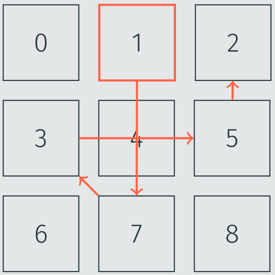

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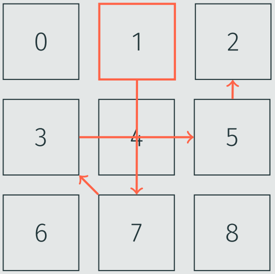

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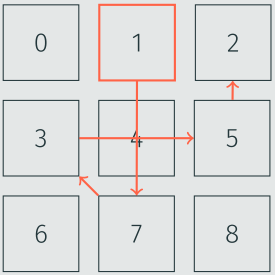

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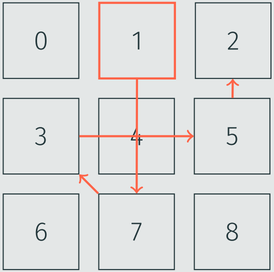

0		
1	7	⇐ File A
2		
3	5	
4		
5		
6		
7	3	
8		

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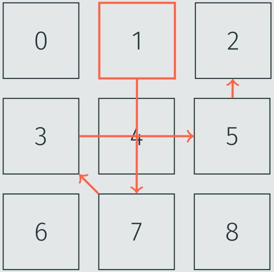

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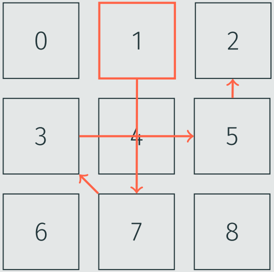

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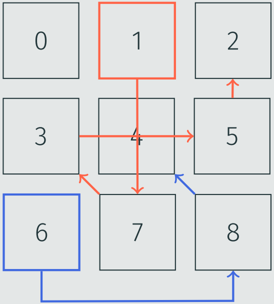

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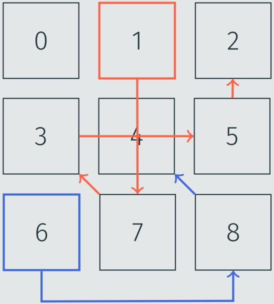

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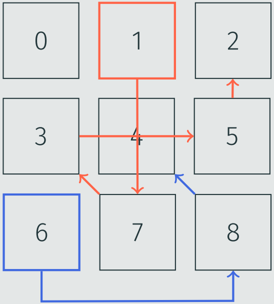

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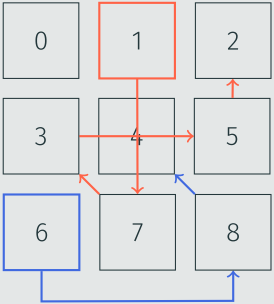

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- \+ Even if it doesn't fit: Less disk seeks
- \- Size depends on size of hard disk (one entry per Block)
- \- Might be too large to be cached in RAM (on large disk)

Indexed Allocation

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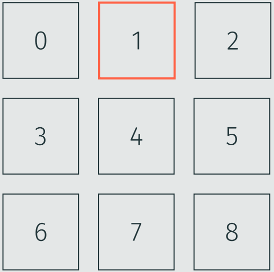

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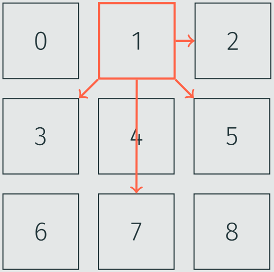

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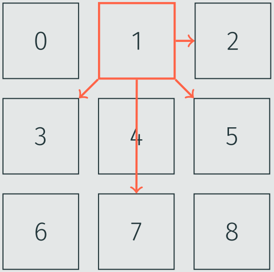

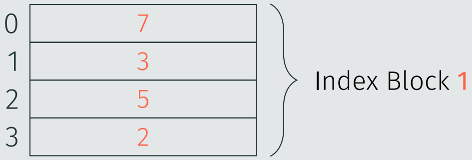

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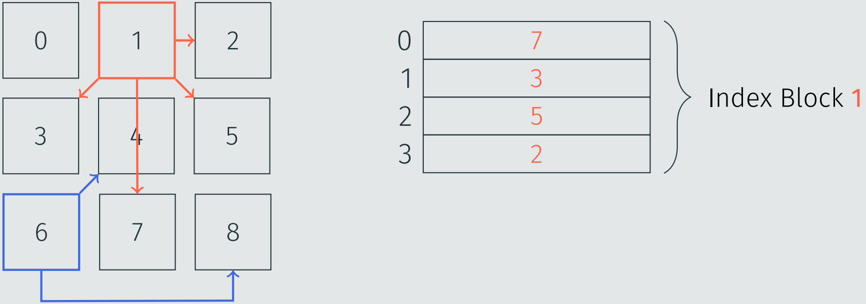

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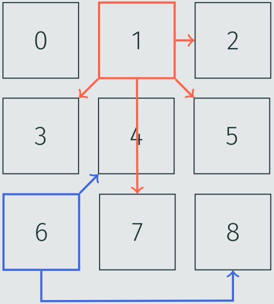

0	7
1	3
2	5
3	2

Index Block 1

0	8
1	4

Index Block 6

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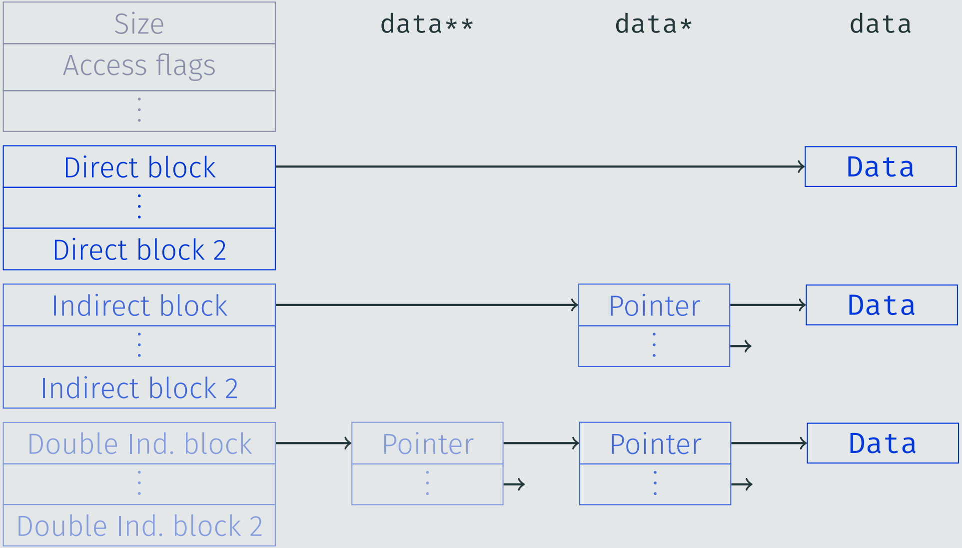
How could you store *Huge* files?

\- Increase the Block size

\+ Indirection! Make the index block link to other index blocks (like pagetables)
You can also mix that: First *N* pointers point to data blocks, next to indirect blocks, next to double-indirect blocks, etc.

Indexed Allocations With Inodes

What does an inode look like?



Indexed Allocations With Inodes

What is the maximum file size?

Assume that disk blocks are 8 KiB in size and a pointer to a disk block is 4 bytes long. An inode contains 12 pointers to direct blocks, and one pointer to a single, double, and triple indirect block, respectively.

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Calculating the amount of pointers to blocks

Pointers per Block: 8 KiB / 4 $bytes = 2^{13} / 2^{2} = 2^{11} = 2048$

Direct pointers

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Final result

$(12 + 2048 + 2048^2 + 2048^3) \cdot 8KiB \approx 64TiB$

File System Implementation

Hard links

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Pointer to the same inode.

$\Rightarrow$ *Everything* is identical: Size, content, access time, mode, ...

Can therefore *not* cross file system boundaries.

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Symlinks

Are (mostly) normal files containing a filepath with their own access time, mode, ... When programs access the file the OS transparently:

1. Reads the contents of the symlink file
2. Resolves the file path it read
3. Performs the operation on that path instead

Can cross file system boundaries or point to non-existent files or change what they point to if the file is moved, ...

Having Fun With Paths I

Hard and symlink renames

```
echo "Hello" > test.txt
ln test.txt hardlink.txt
ln -s test.txt symlink.txt

mv test.txt renamed_test.txt
// Is the hardlink / symlink broken?
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Does this work (on my machine ;)?

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cd /tmp/
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```

No, as `/tmp` is mounted as tempfs and `/` as ext4.

Having Fun With Paths II

Hard and symlink renames

```
echo "Hello" > test.txt
ln test.txt hardlink.txt
ln -s test.txt symlink.txt

cp test.txt renamed_test.txt
rm test.txt
// Is the hardlink / symlink broken?
```

Having Fun With Paths II

Hard and symlink renames

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How can directories be implemented? What information is stored in them?

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How can directories be implemented? What information is stored in them?

As a normal file with variable-length entries consisting of

- The filename
- The inode that represents that file

Inodes

Which of the following data are typically stored in an inode?

1. filename
2. name of containing directory
3. file size
4. file type
5. number of symlinks to file
6. name/location of symlinks
7. number of hardlinks
8. name/location of hardlinks
9. access rights
10. timestamps (last access/modify)
11. file contents
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What happens when you mount a filesystem?

E.g. `mount /dev/sda1 /mnt`.

Makes files from that file system accessible. It will make the given path (e.g. `/mnt`) the *root* of the new file system. Any access to `/tmp/*` is stripped of the `/tmp/` prefix and then searched in the mounted file system.

FUSE

File System in **USE**rspace.

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- Allows users to write their own file system without writing kernel code
- Runs as an unprivileged user process
- Is really awsome! You suddenly can use all your normal tools on whatever the FUSE filesystem exposes!

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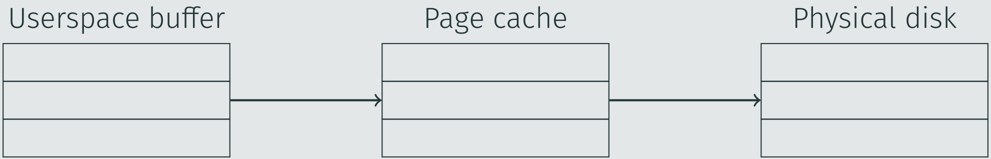
- Temporal and spatial locality
- When exactly is it flushed to disk then? Is that even important to know/control?
- Using `flush` (for buffers) and `fsync` (for the page cache) and after some time by a daemon

Page cache interactions

Let's talk about the page cache



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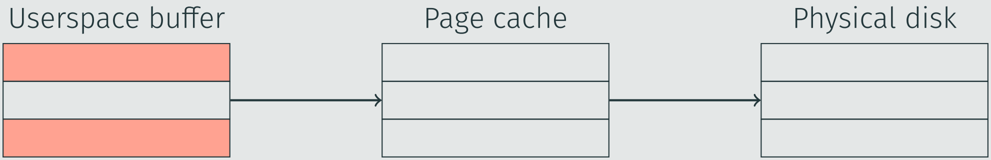

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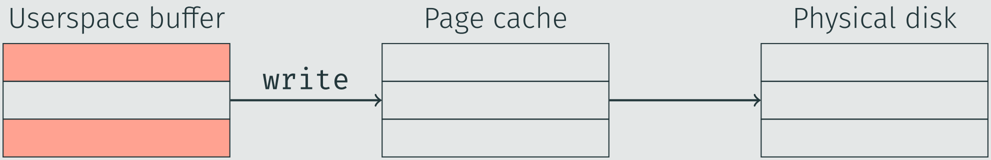

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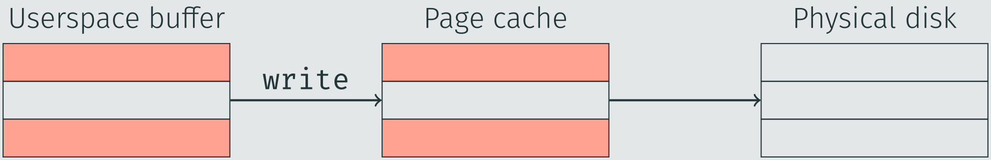

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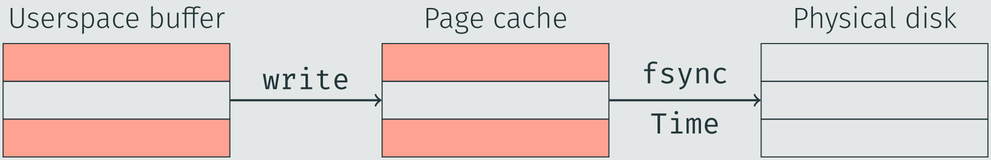

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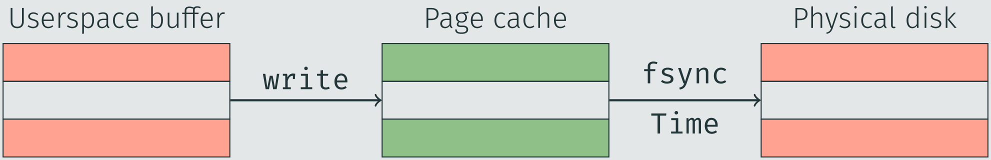

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Read-ahead: Read more data in the cache than requested

- + Good sequential performance
- + Improved throughput if files are sequential
- - Wasted time and memory if not needed

The File System Cache and mmap

How could you implement `mmap` with the file system cache?

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`read()` and `write()` and the file system cache

- `read()`: Copy data from cache to your application buffers
- `write()`: Copy data from your application buffers to the file system cache

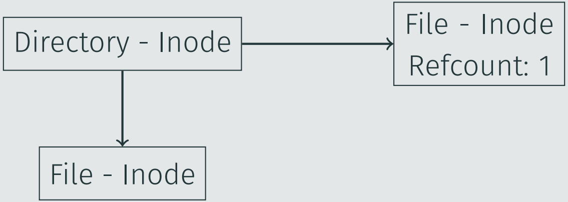
File system synchronizes access!

Modern File Systems

Crashing Is Fun

Your computer crashes (e.g. your power fails). What horrible death does your file system die?

A fun game for the whole family and your „why would I need backups“ crowd



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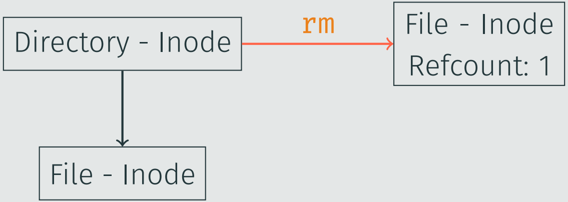

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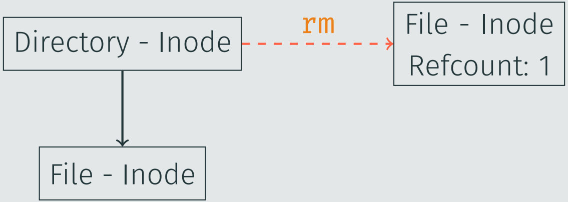

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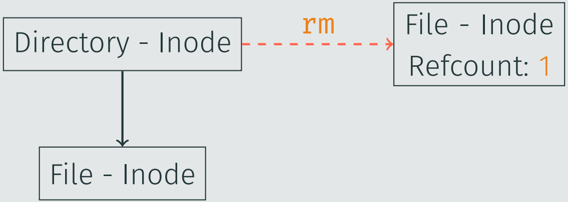
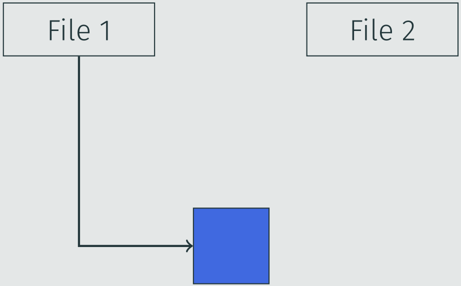


The inode has a refcount of 1 but is no longer referenced!

Crashing Is Fun

Where is Data?



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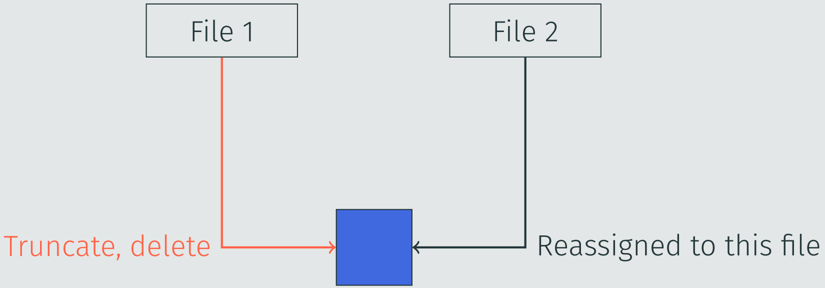

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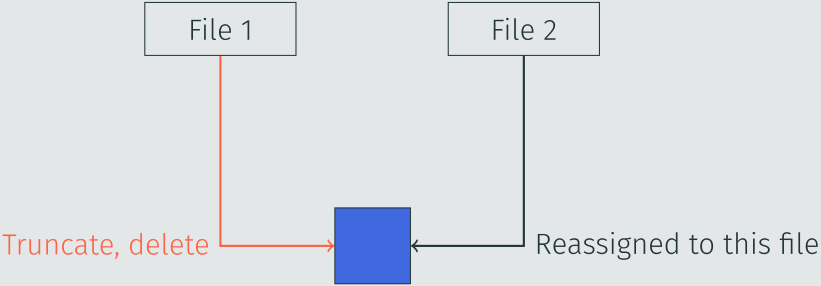

Both files might point to this block!

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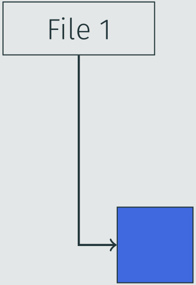

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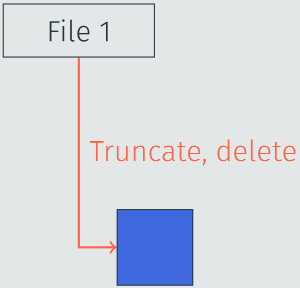

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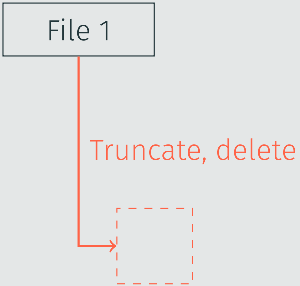

Block still referenced but marked free

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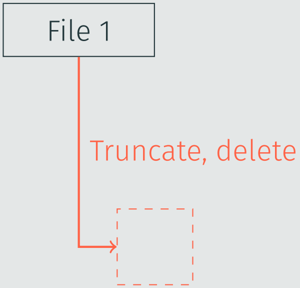

Block still referenced but marked free

Or multiple directory entries with the same name, as another problem

Ordering

What might be the outcome?

```
// create a file
echo "Hey" > a.txt
// And a second
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- No files exist
- Only a exists
- Only b exists !!

Reordering is *allowed* (unless you take precautions)

How could you detect those inconsistencies?

Use the **fsck** (**f**ile **s**ystem **c**onsistency chec**k**) program. And what could that do?

Error Detection

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Can this fix your application data?

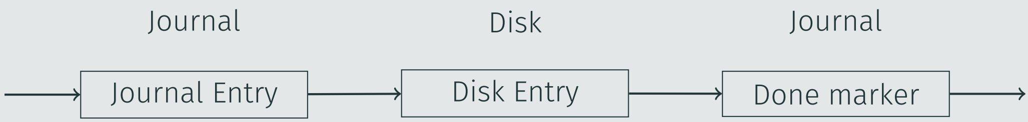
No! It just tries to keep the filesystem internally consistent, it won't find corrupted data blocks

Journal File System - Recovery

General principle

Walk over the journal and execute any outstanding entries.

Let's crash



What to do

The happy path, everything's nice

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What to do

$\Rightarrow$ We didn’t write anything!

$\Rightarrow$ Operation failed

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What to do

⇒ Invalid checksum

⇒ Skip entry

⇒ Operation failed

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What to do

⇒ Non-terminated journal entry

⇒ Retry and complete operation

⇒ Operation successful

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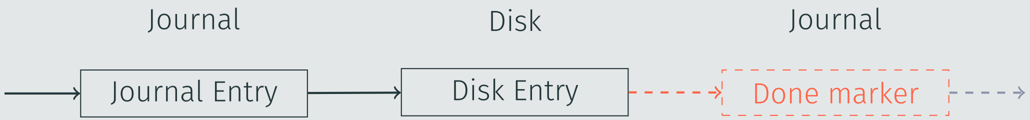

What to do

⇒ Consistent state

⇒ Execute operation again

⇒ Operation successful

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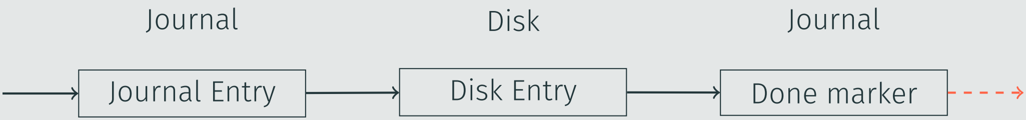

What to do

⇒ Consistent state

⇒ Don’t do anything

⇒ Operation successful

Physical vs logical logging

What data could you log in the journal?

Journal

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Journal

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- **Logical logging**: Store a high level entry (like: „rename **a** to **b**")
- **Physical logging**: Store the file system blocks that will be modified

What might be problems with the journal presented before?

Log Structured File System

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Only write to unused blocks.

Then you can *atomically* update indexing datastructures to point to the new blocks. If it crashes, you either have *all* of the new state or *exactly* the old state.

Letztes Tut

Das letzte Tut ist *nächste Woche*

Das wird ein Wiederholungstut von Sachen, die euch noch irgendwo unklar sind oder über die ihr nochmal reden wollt.

$\Rightarrow$ Daher bitte bis nächste Woche Fragen an mich per Mail
peter.bohner@student.kit.edu