Betriebssysteme

6. Tutorium - Buddy Allocator, Paging, TLB

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ITEC - Operating Systems Group

Buddy Allocator

So far we’ve seen

- Consistent large blocks ⇒ Low external, high internal fragmentation
- Fitted blocks ⇒ High external, low internal fragmentation

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Can we do better for some applications? Any ideas?

Buddy Allocator

Allocator

256 KiB

Buddy Allocator

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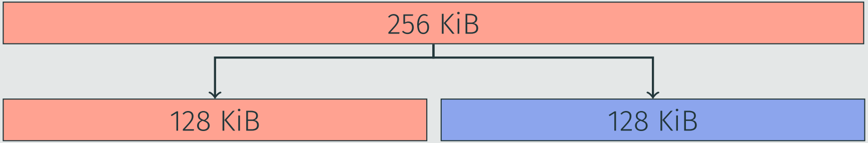

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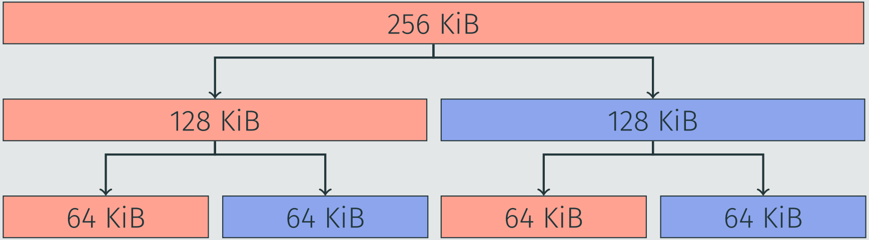

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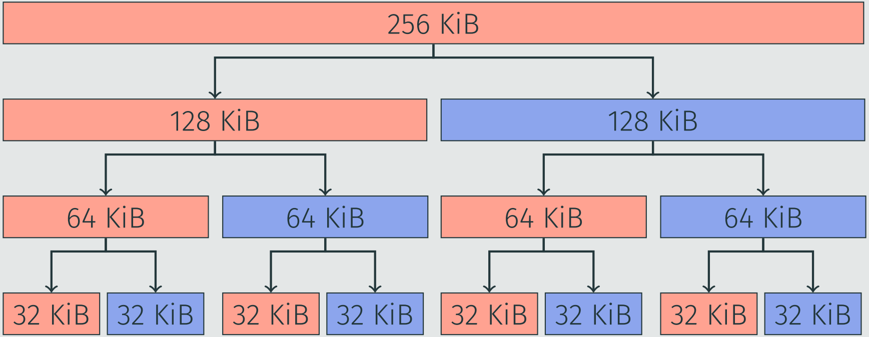

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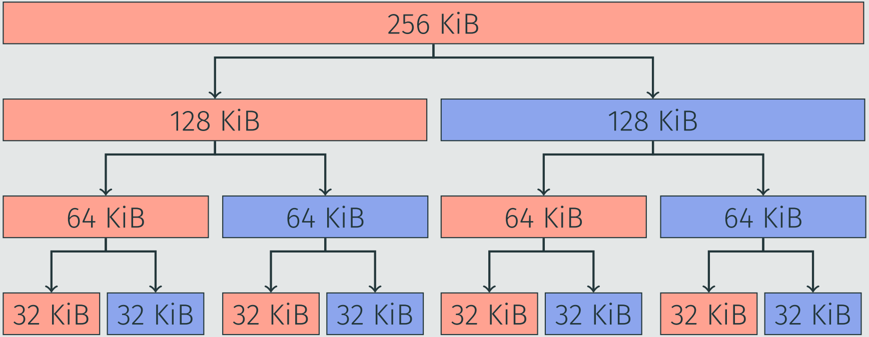

How do you find a fitting Element?

Buddy Allocator

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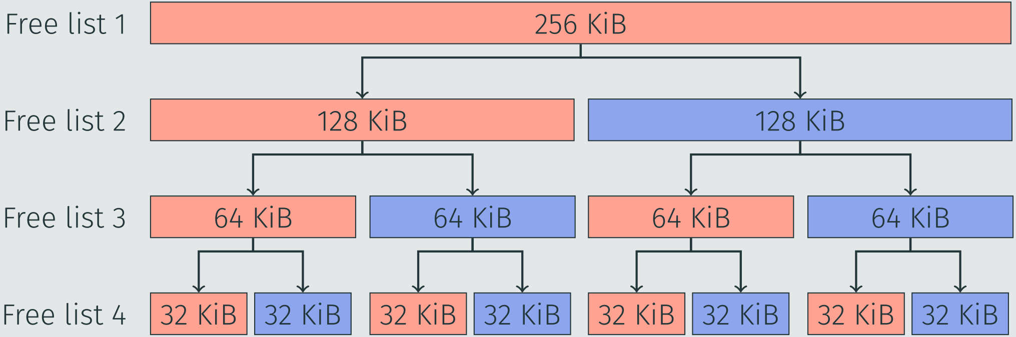

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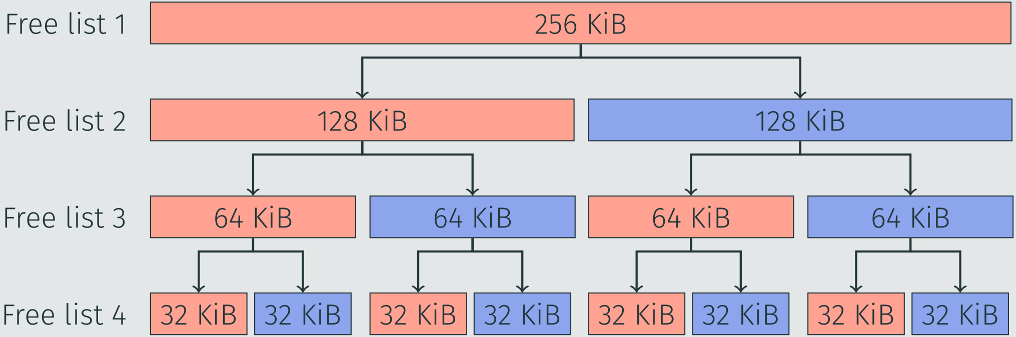

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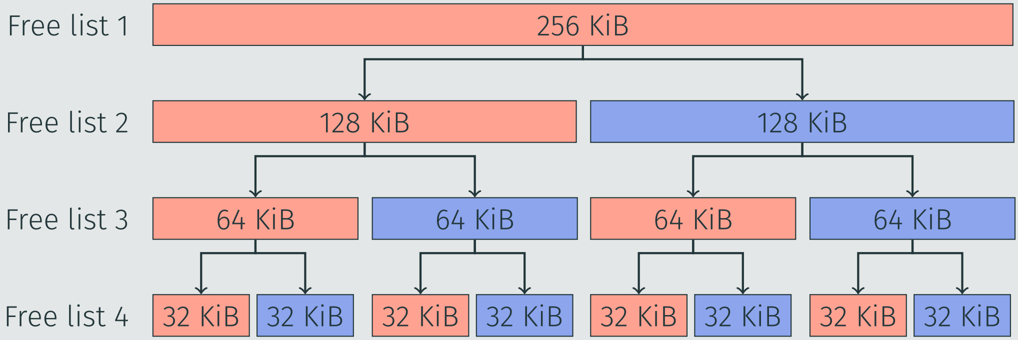
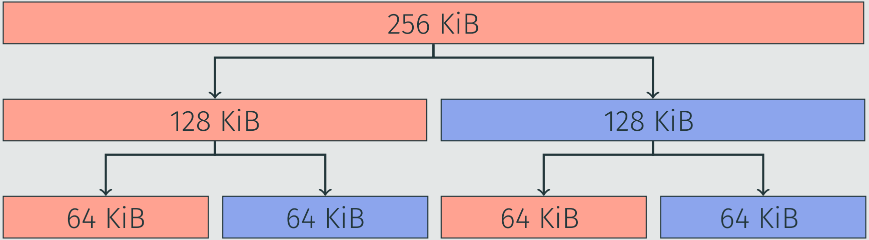


How do you find a fitting Element? *Freelist!*

And if there is no such block? *Recursively split a higher-up block*

Buddy Allocator - Merging

Merging



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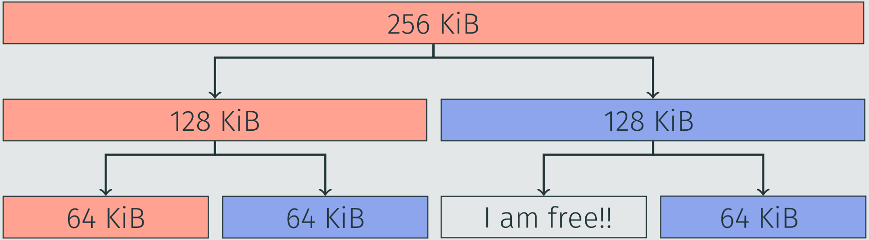

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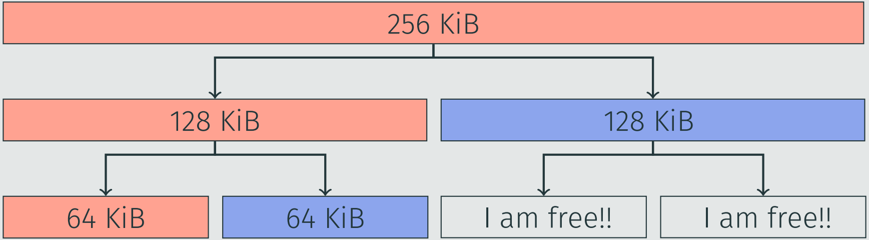

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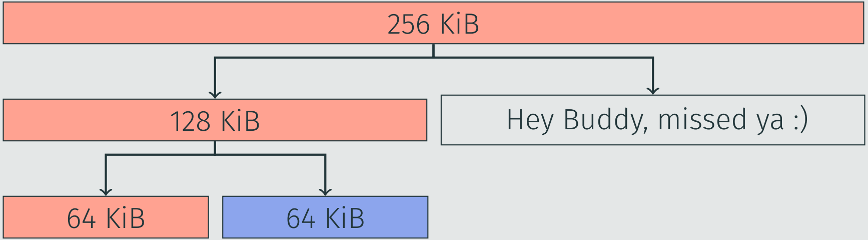
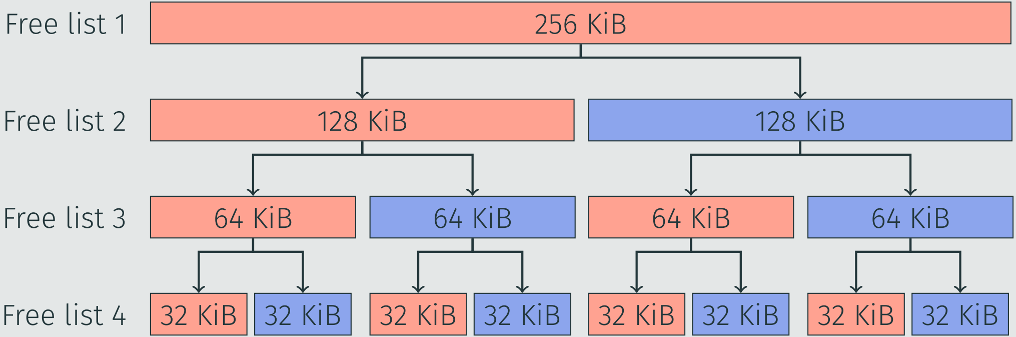


Buddy Allocator

How small/large can the free list be?

Allocate 2^m chunk of memory in a managed Block of 2^k (here: $k = 18$, as $256\ KiB = 2^{18}$)



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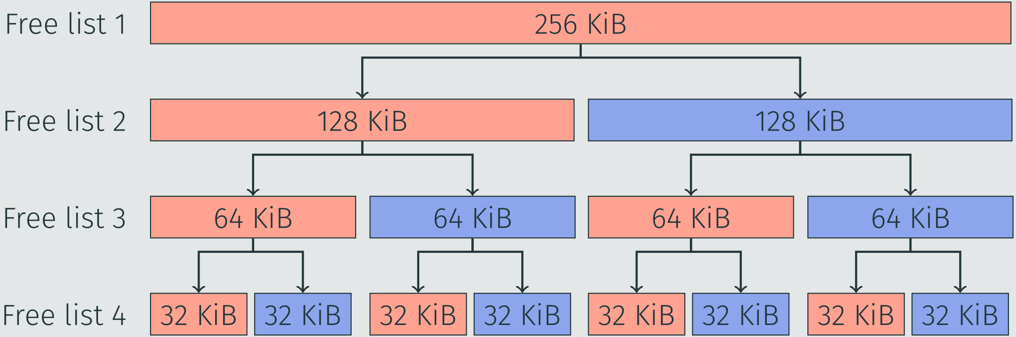

$\Rightarrow$ Max size $\frac{1}{2} \cdot 2^{k-m}$

$\Rightarrow$ Min size 0

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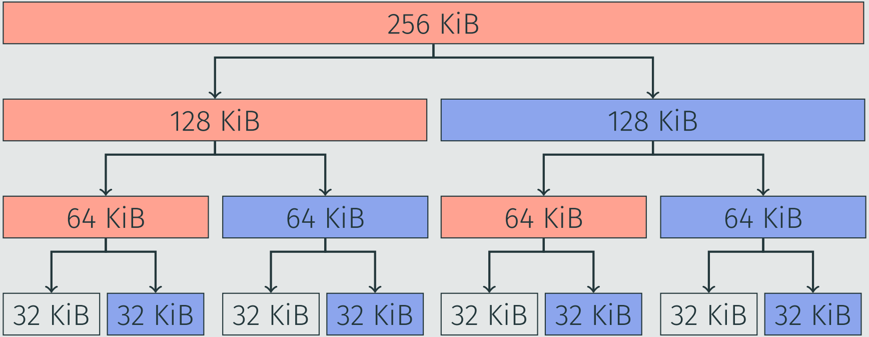
External fragmentation

- Free every other block in a level

Buddy Allocator - Fragmentation

External fragmentation



Buddy Allocator - Fragmentation

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But this works alright for larger sizes. So combine it with...

...the Slab allocator! Allocate large chunks with the buddy allocator and small chunks within them using the slab allocators

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You are a poor kernel and you need lots of inodes

Every inode has the same size, 64 Byte. Can you think of any fast allocation strategy that does not waste a single bit?

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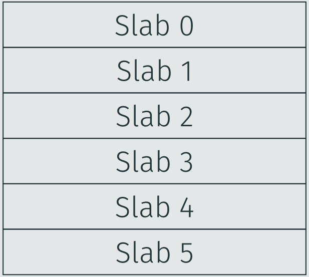

Slab 0

Slab 1

Slab 2

Slab 3

Slab 4

Slab 5

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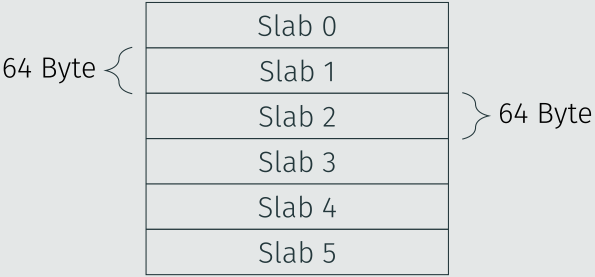

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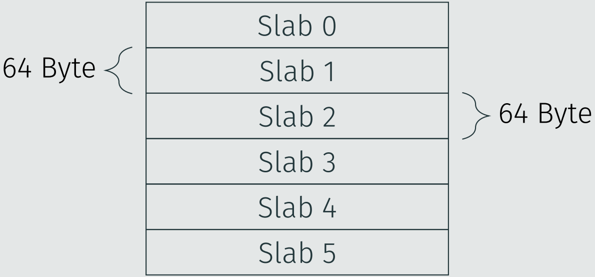

This is called a *Slab allocator*

Paging

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- Virtual memory does not need to map to *continuous* physical memory
- Swapping in/out is easier
- No external fragmentation, little internal

Paging - Single Level Page Table

Segment and Page tables

Segment Number	Base	Limit
0	`0xdead`	`0x00ef`
1	`0xf154`	`0x013a`
2	`0x0000`	`0x0000`
3	`0x0000`	`0x3fff`

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```
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```

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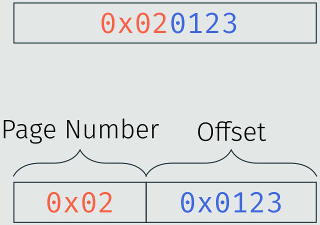

0x020123

Page Number

Offset

0x02

0x0123

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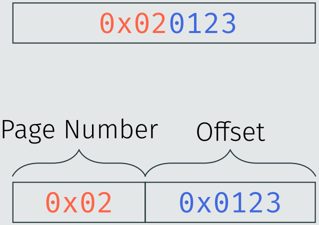

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pfn	flags
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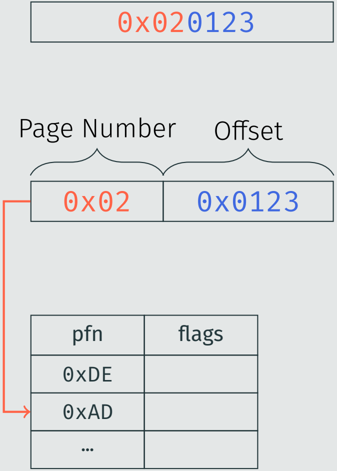

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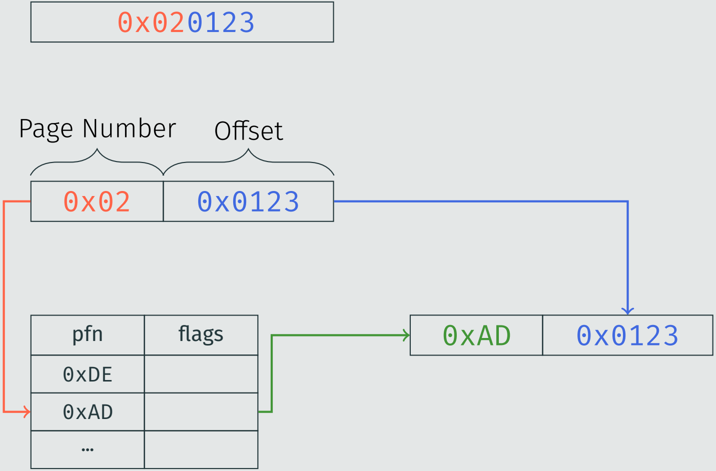

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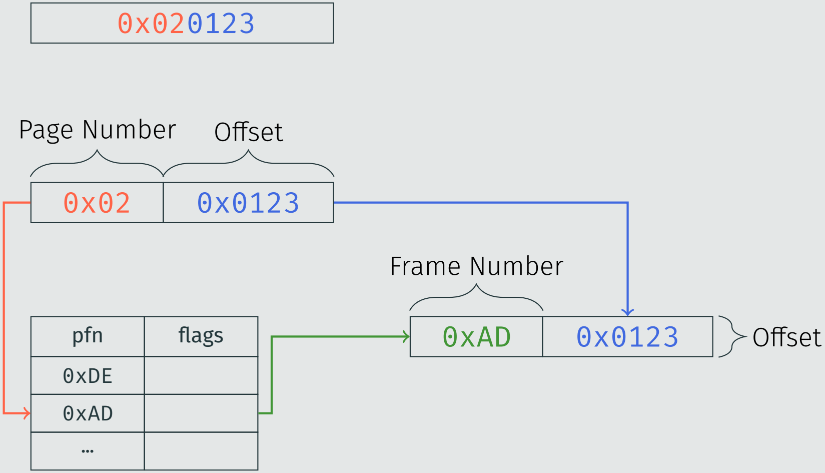

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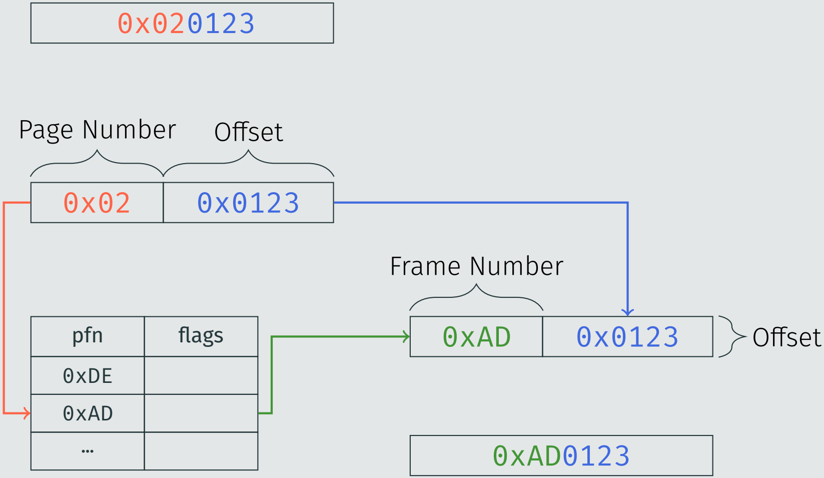

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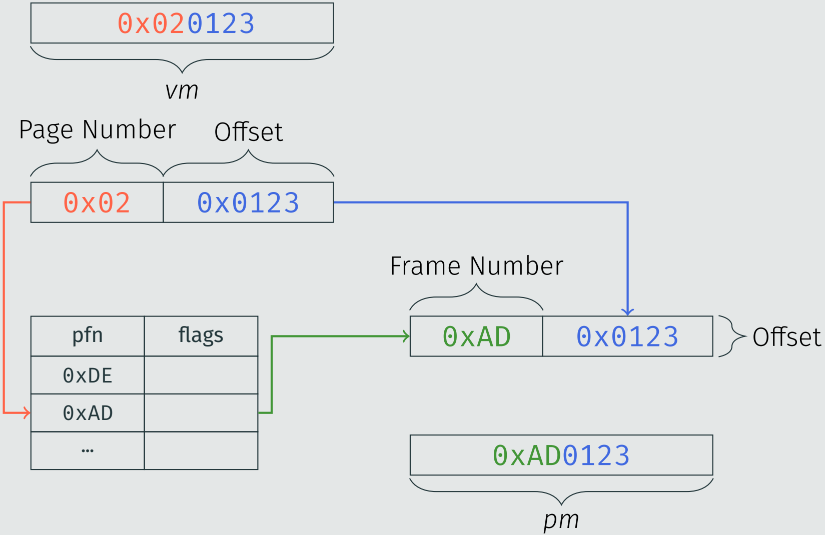

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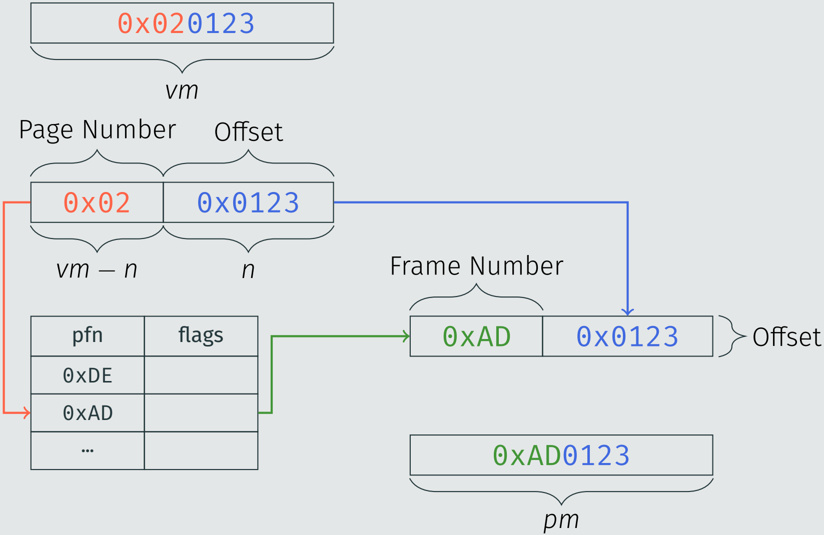

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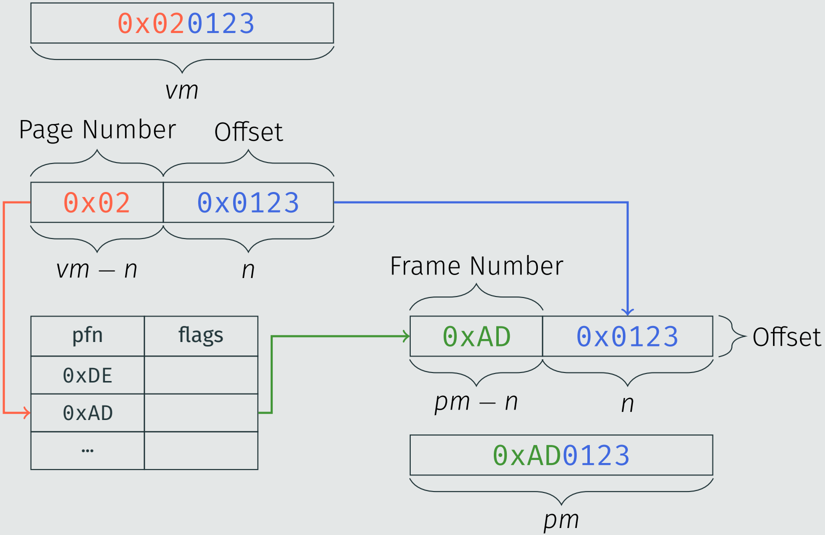

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$\Rightarrow$ If every entry was 1 Bit we'd need (asking `units`...)

```
You have: 2^52 bit
You want: tebibyte
        * 512
        / 0.001953125
```

- You might *not* have that much memory to spare :)

Single Level Page Table - Disadvantages

Math is fun, let’s do some math

Calculate the space requirements for a single level page table with

- 32-bit virtual addresses, 4KiB pages, 4 bytes per page table entry
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48-bit

- vm = 48, 4Kib = $2^{12} \Rightarrow$ n = 12
- $2^{48-12} = 2^{36}$ entries $\Rightarrow 2^{36} \cdot 2^{2} = 2^{38}$ Byte (256 GiB)

Alternatives to Single Level Page Tables

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Mutli-Level page tables

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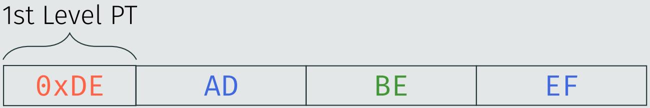

1st Level PT

0xDE AD BE EF

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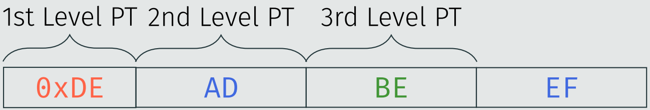

1st Level PT 2nd Level PT 3rd Level PT

0xDE AD BE EF

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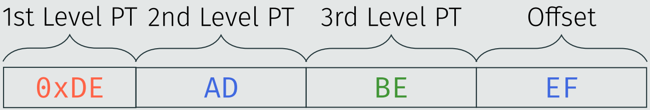

1st Level PT 2nd Level PT 3rd Level PT Offset

0xDE	AD	BE	EF

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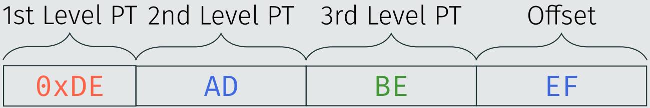
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Benefits and Drawbacks?

- Pointer chasing down each level ⇒ More memory accesses

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Mutli-Level page tables

1st Level PT	2nd Level PT	3rd Level PT	Offset
0xDE	AD	BE	EF

Benefits and Drawbacks?

- Pointer chasing down each level ⇒ More memory accesses
+ Address spaces are *sparse* ⇒ Only instantiate page tables you need

Inverted Page Table

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- We mostly care about *the other direction*, i.e. virtual ⇒ physical
- That requires iteration :(

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How can we speed them up?

After having attended *Algorithmen I* we all know:

Inverted Page Tables

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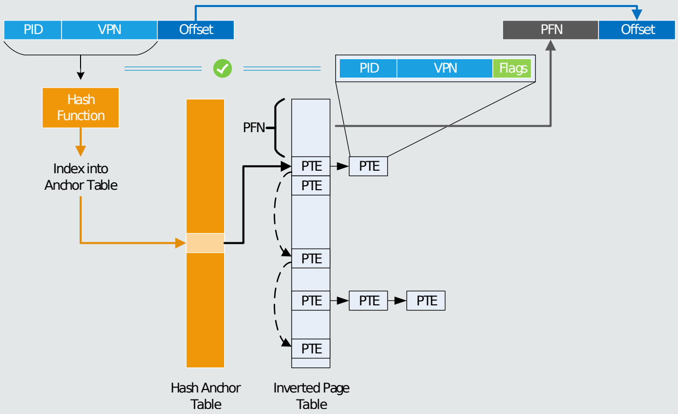
Hashed inverted page tables



Inverted Page Tables

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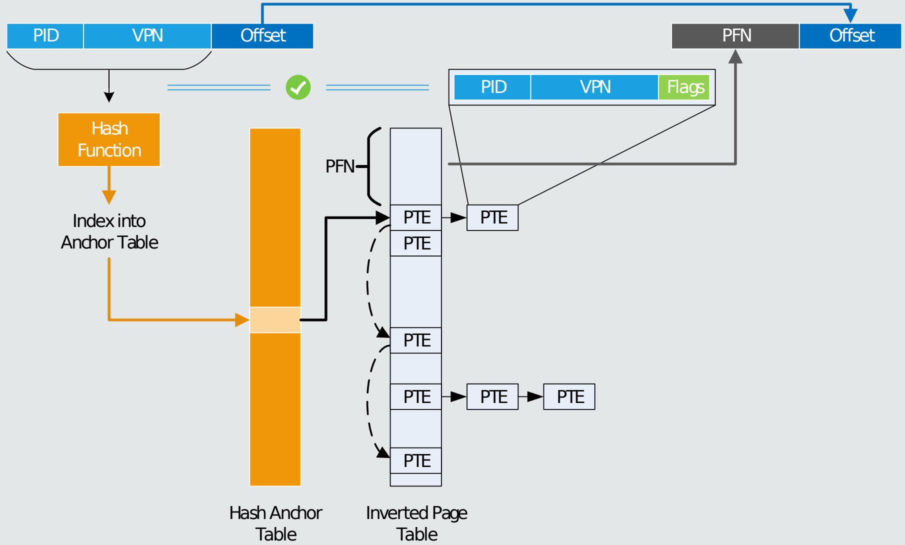

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What happens on access if it is not set?

- Page fault!
- Handle it and do sth. sensible (or crash the process…)

TLB

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⇒ There is no problem you can't solve with another caching layer (except having too many caching layers) Nearly the Fundamental theorem of software engineering

TLB

TLB layout

p	offset

TLB

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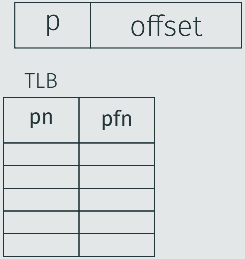

p	offset

TLB

pn	pfn

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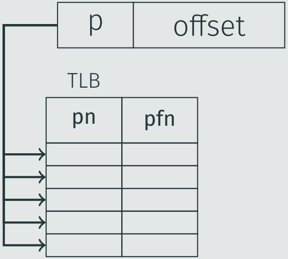

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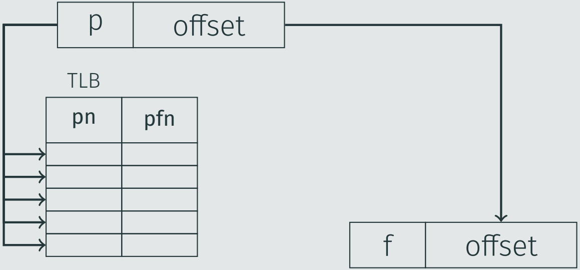

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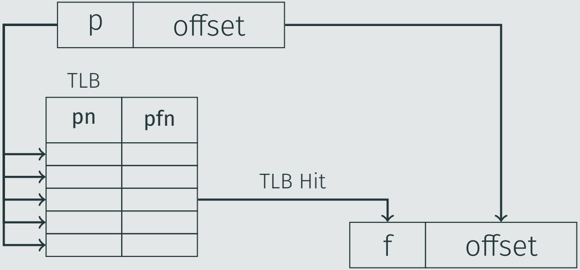

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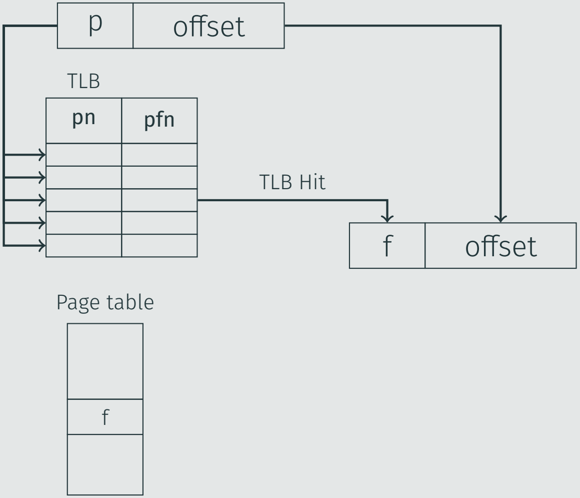

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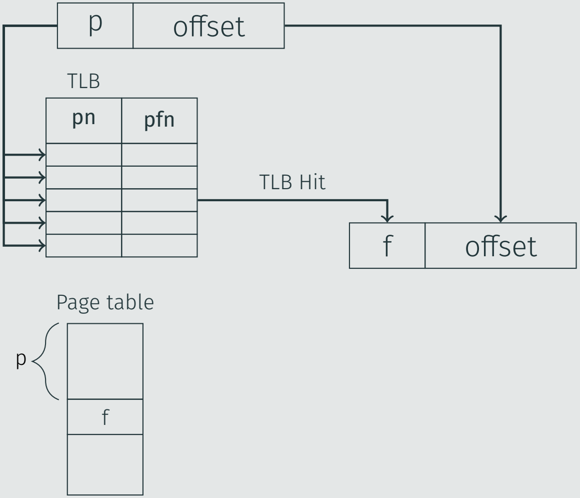

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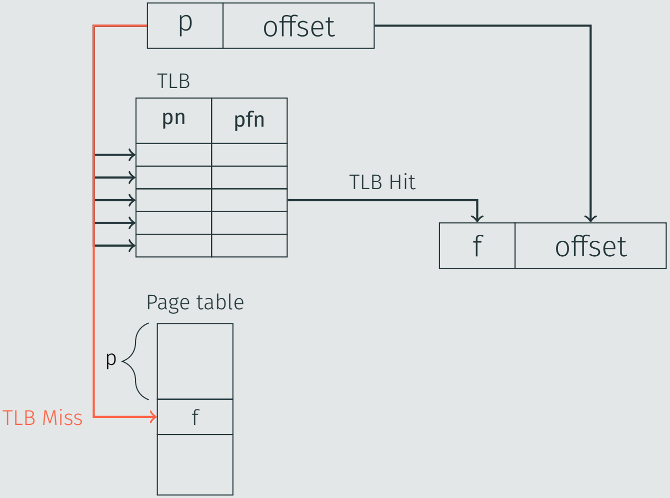

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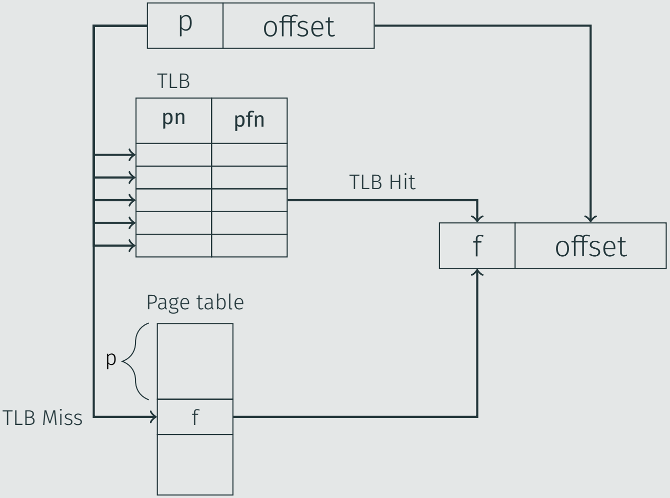

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Software walked

- Transfers control to TLB miss handler
- Kernel routine walks the page table and tries to find a mapping
- Loads that mapping into the TLB and can choose which entry to evict!
- If there is none ⇒ Jump to page fault handler

TLB - Software or hardware walked

What are benefits / drawbacks of software walked TLBs?

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- Greater overhead

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- Modified bit, permissions, ...

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Due to the TLB:

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And other problems: *Invalid access to a mapped page*

- Software walked: Raise some kind of TLB fault if the page is e.g. read-only
- Hardware walked: Page fault raised, page fault handler has to find out what happend

Page Fault Handling

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- Generates lots of page faults before working set is in memory

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Why would you (not?) use Pre-Paging?

- + Might reduce number of page faults
- – Loads more than needed ⇒ Wasteful
- – More I/O ⇒ Slower?
- + HDDs a lot faster when reading chunks

On-Demand Paging

Different kind of page faults

Not all pages are created equal. Do you have any idea what types of page faults typically exist?

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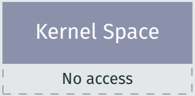

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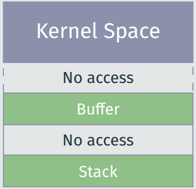

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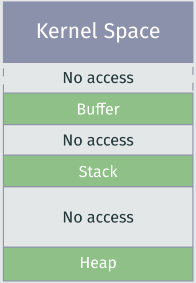

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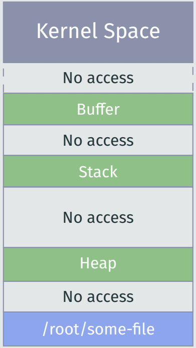

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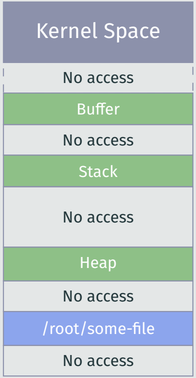

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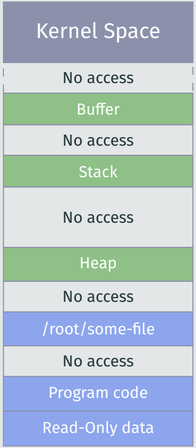

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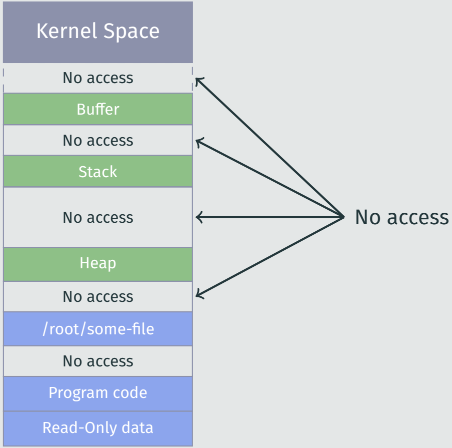

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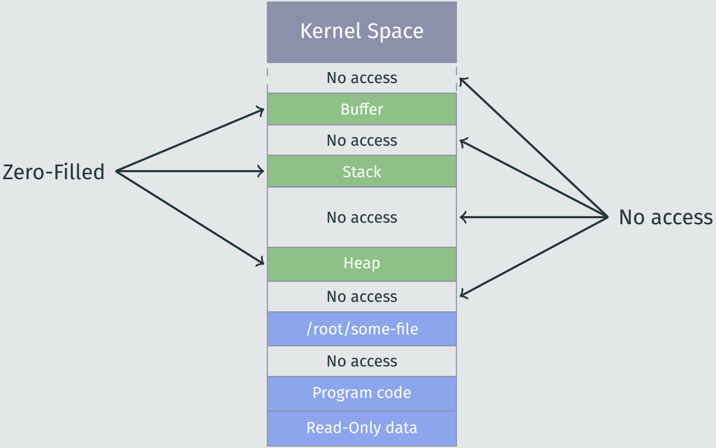

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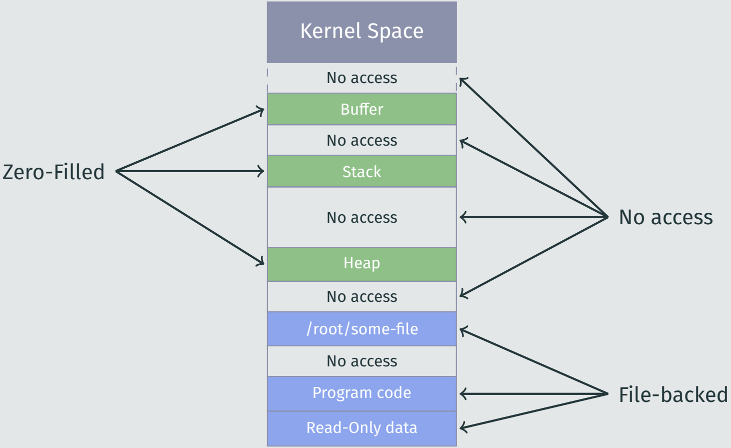

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Also supported on some systems: *Purgable memory*. Stolen from Apple and also implemented in SerenityOS in this video.

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- Access flags: Can the user perform the operation on this page?
- Where to find the most recent version (different for zero filled, file backed, etc.)

CoW

How could you implement Copy-on-Write memory?

CoW

How could you implement Copy-on-Write memory?

- Mark memory as read-only on fork
- Add an additional `CoW` flag: When a page fault is raised check it, copy the page and clear the `CoW` and `ro` flag

Ende

"THIS IS THE EMERGENCY OVERRIDE SYSTEM, WHICH CAN BE USED TO REGAIN CONTROL OF THE AIRCRAFT.
COMPLETE INSTRUCTIONS FOR ACTIVATING THIS SYSTEM ARE AVAILABLE AS A GNU INFO PAGE."

XKCD 912 - Manual Override

FRAGEN?

Bis nächste Woche :)