Betriebssysteme

Tutorium 6

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1 Threads

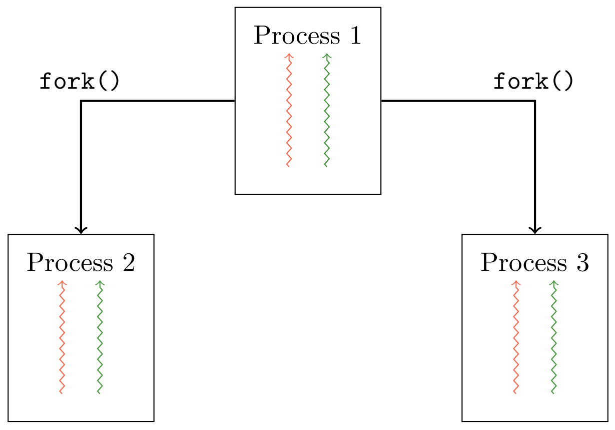
Threads

What are processes, address spaces and threads? How do they relate to each other?

- A thread is an *entity of execution*, the personification of control flow
- A thread lives in an address space, i.e. all the addresses that it can can access and the data that is stored there
- Thread + Address Space = Process

Threads — Forking

Should a fork do this?



Threads — Forking

Who is aware of the fork?

- The thread that executed the fork and the child
- Who else? Nobody!

Can you foresee any problems?

- If you copy the thread it might do weird things
- Locks are memory and will be copied as well! What if a thread holds a critical lock when it is forked?

Do you need thread duplication for our shell example?
No, we `exec` anyways.

Summary
`fork` is not as simple as it once was. Is it still a good abstraction?

Kernel Mode Threads — Kernel Level Threads

What is the difference?

- Kernel Level Thread: The kernel knows about and manages the thread
- Kernel Mode Thread: The thread runs in *kernel mode*

Why would you need kernel *mode* threads?

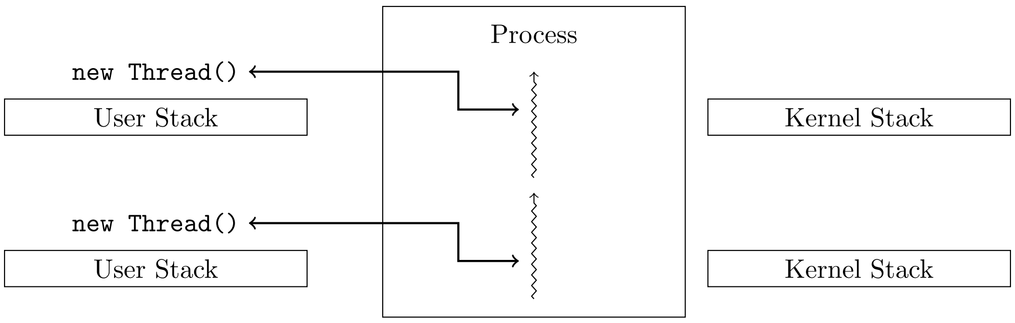
- Sometimes the OS needs to do some housekeeping that doesn't belong in a system call
- Free some pages, swap something in and out of memory
- Flush pages from the disk cache to the hard disk
- Perform VFS Checkpointing
- . . .

Thread-Programming

Spawn a few threads using pthreads!
Write a small program that creates five threads using the pthread library. Each thread should print its number (e.g., `Hello, I am 4`) and the main program should wait for each thread to exit.

Thread models — One To One

One To One



Problems?

Thread models - One To One

Problems and benefits of *One To One*?

+ Scales with core count

+ Conceptually easy — the OS does the hard stuff

+ Blocking does not affect other threads

+ Can piggy-back onto the OS scheduler

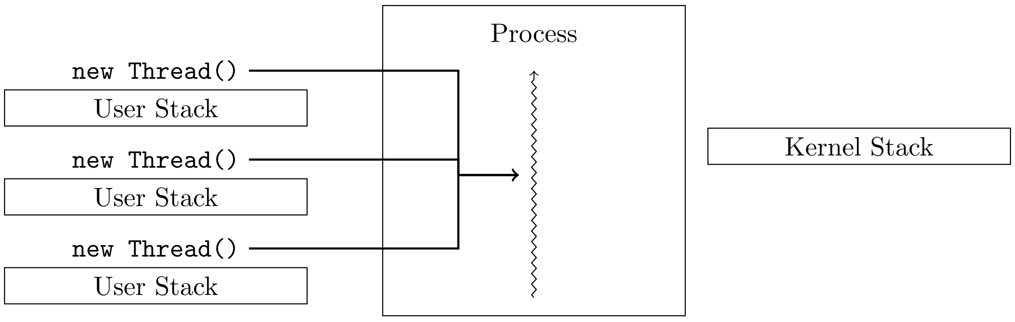
- *Must* piggy-back onto the OS scheduler

- Relatively high overhead due to context switches

- Relatively high overhead *when creating one!!*

Thread models

Many to One



Thread models - Many To One

Problems and benefits of *Many To One*?
Do they improve anything?

- Dummy
- + **Scales with core count?**
- − Can only use one core
- + **Conceptually easy — the OS does the hard stuff?**
- − Harder to implement — the OS doesn't help you much
- + **Blocking does not affect other threads?**
- − Blocking *does* affect other threads
- + **Can piggy-back onto the OS scheduler?**
- − Can *not* piggy-back onto the OS scheduler
- − ***Must* piggy-back onto the OS scheduler?**
- + Can implement its *own* scheduler
- − **Relatively high overhead due to context switches?**
- + Low overhead during context switches
- − **Relatively high overhead *when creating one*?**
- + Low overhead when creating one

Thread models - Many To One

Do you know a programming language / runtime using that?
E.g. `nodejs` using its „event loop“

A small excursion - Structured Programming
Control flow should fall into one of four patterns:

- Sequence: One block is executed after another
- Selection: One or more are executed (i.e. an `if`-statement)
- Iteration: A block is executed more than once (i.e. a loop)
- Recursion: A block calls itself until an exit condition is met (i.e. recursion!)

Do you know any keyword in C which *doesn't* quite adhere to that but can instead totally spaghettify your control flow? *`goto`*

Famous paper by a proponent of Structured Programming: *„Go To Statement Considered Harmful“* by Edsger W. Dijkstra

Thread models - Many To One

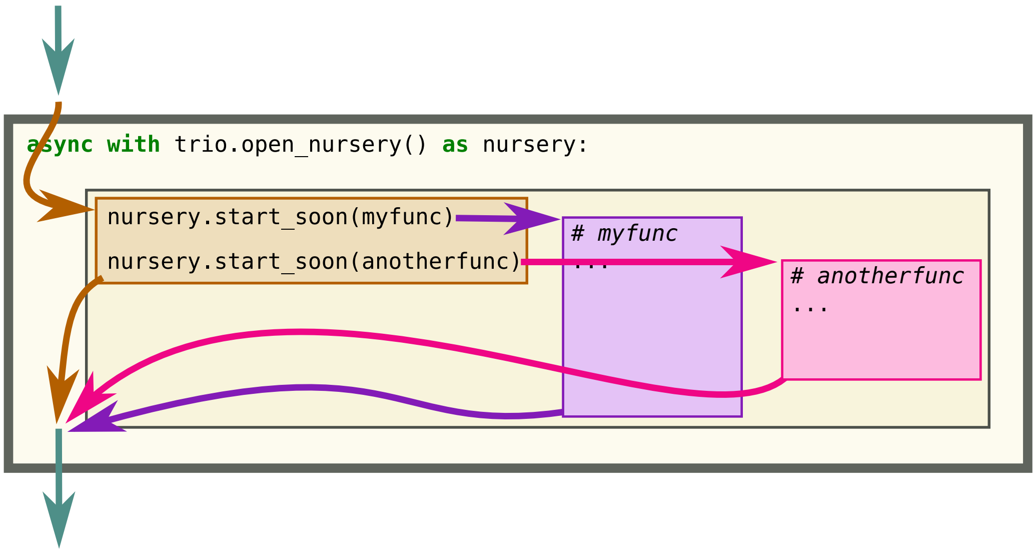
And what about threads?

- Can outlive the methods they were spawned in
- Can use variables and fields after they went out of scope in a method
- Can split up or transfer their control flow arbitrarily

So that might sound familiar…

Thread models - Many To One

Structured Concurrency



async with trio.open_nursery() as nursery:
nursery.start_soon(myfunc)
nursery.start_soon(anotherfunc)
# myfunc
...
# anotherfunc
...

Taken from vorpus.org

Thread models - Many To One

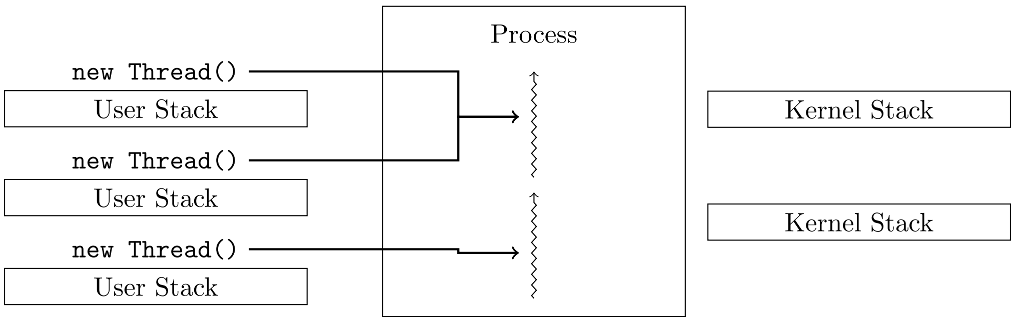
Nice, but what does this have to do with ULTs?

- Spawning lots of threads for small operations *is too slow otherwise*

Further reading: Notes on Structured Concurrency ULTs and Structured concurrency in Java - Project Loom

Thread models - Many To Many

Many To Many



Thread models - Many To Many

Problems and benefits of *Many To Many*?
Important: The kernel *knows about the user level scheduler*

- Dummy

+ **Scales with core count?**

+ Scales with core count

+ **Conceptually easy — the OS does the hard stuff?**

− Harder to implement — the OS doesn't help you much

+ **Blocking does not affect other threads?**

+ Blocking does not affect other threads as the kernel informs the user scheduler (`upcalls`) and does *not* pause the whole kernel level thread

+ **Can piggy-back onto the OS scheduler?**

− Can *not* piggy-back onto the OS scheduler

− ***Must* piggy-back onto the OS scheduler?**

+ Can implement its *own* scheduler

− **Relatively high overhead due to context switches?**

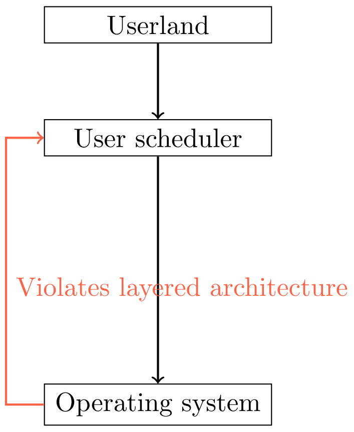
+ Low overhead during context switches (unless you need to interact with the kernel threads, e.g. to schedule between them)

− **Relatively high overhead *when creating one*?**

+ Low overhead when creating one

Thread models - Many To Many

Problems the second
You have all attended SWT 1! So let's have a look.



And preemption is now possible, which might complicate user code.

Thread models - One To One

What events can trigger a context switch?

- Voluntary: yield, blocking system call
- Involuntary:
  - interrupts, exceptions, syscalls
  - end of time-slice
  - high priority thread becoming ready

Thread models - Many To One

What events can trigger a context switch?

- Most libraries only support *cooperative scheduling*
- Why is switching with preemption, interrupts, blocking system calls hard? Kernel is not aware of the ULTs and will return where it came from — *but not call out to the scheduler and carry on*
- The benefit of platforms: How can `Java` (using Project Loom) or `Node.js` switch on most of the above? You can not execute syscalls directly, but need to call library methods! Suspension points can be inserted there.

Thread models - Many To One

„Jobs are either I/O-bound or compute-bound. In neither case would user-level threads be a win. Why would one go for pure user-level threads at all?"

- Program structure (e.g. Structured Concurrency, channels or just easier pipelines)
- The same or higher I/O throughput if on an abstracted platform

2 Memory Management Basics

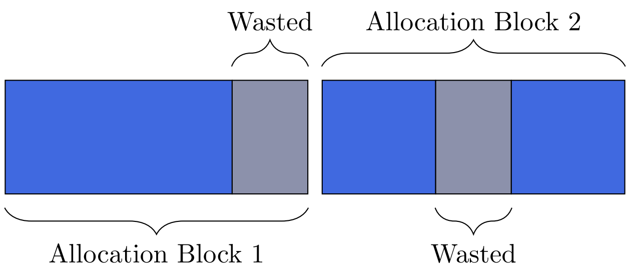
Physical And Virtual Addresses

And once again: What is the difference?

- We assume no 1:1 mapping (i.e. we have virtual memory)
- *All program addresses are virtual*
- Mapped to *physical* addresses as needed by the memory management unit

Fragmentation

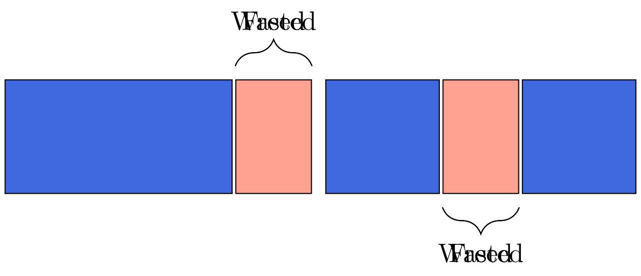
What is *internal* fragmentation?



Internal, i.e. *within* a block

Fragmentation

What is *external* fragmentation?



External, i.e. due to *external factors* (different time-to-free)

Fragmentation

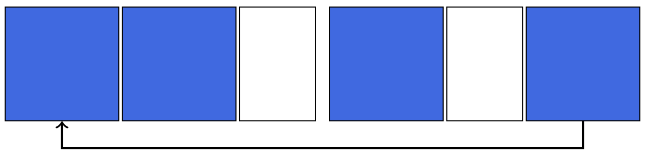
Can you have *both* types at the same time?
Yes!

- Allocate in *chunks* by e.g. rounding up to 2^x
- Have different lifetimes

⇒ Wasteful allocations scattered throughout RAM

Fragmentation

What do we do now? This sounds bad!



This is called *Compaction*

Compaction - Is that even possible?

- C uses direct pointers

⇒ They are all garbage now!

- Works just fine in languages with indirections (e.g. garbage collection)
- Also works for segments in physical memory! How? Update base addresses in MMU

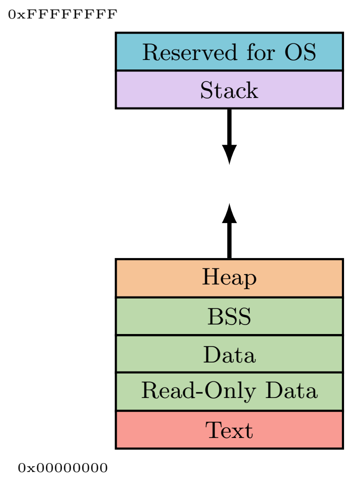
3 Segmentation

Segmentation

Where have you seen that word before while sadly staring at your screen?
```
> Segmentation fault (core dumped)
```

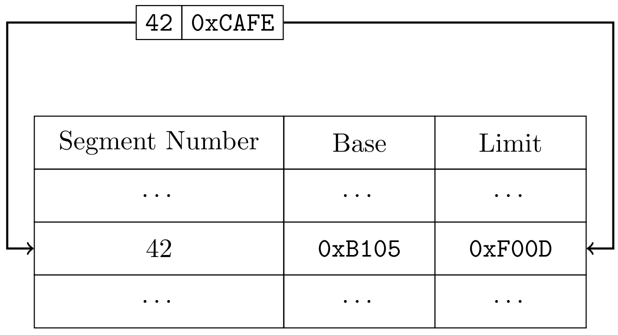
Segmentation

A few example segments



A Virtual Address

What does it look like?



`0xCAFE < 0xF00D` `0xCAFE < 0xF00D`

`0xB105 + 0xCAFE = 0x17C03`

And let's try it

Segments

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

Your task

Virtual Address	Segment Number	Offset	Valid?	Physical Address
	3	0x3999		
0x2020				
		0x0204	yes	
			yes	0xf15f

And let's try it

Solution

Virtual Address	Segment Number	Offset	Valid?	Physical Address
0xf999	3	0x3999	yes	0x3999
0x2020	0	0x2020	no	Offset outside limit
0xc204	3	0x0204	yes	0x0204
0x400b	1	0x000b	yes	0xf15f

4 Memory allocation policies

Some common strategies

Which strategies for finding free blocks do you know?
First Fit, Best Fit, Worst Fit

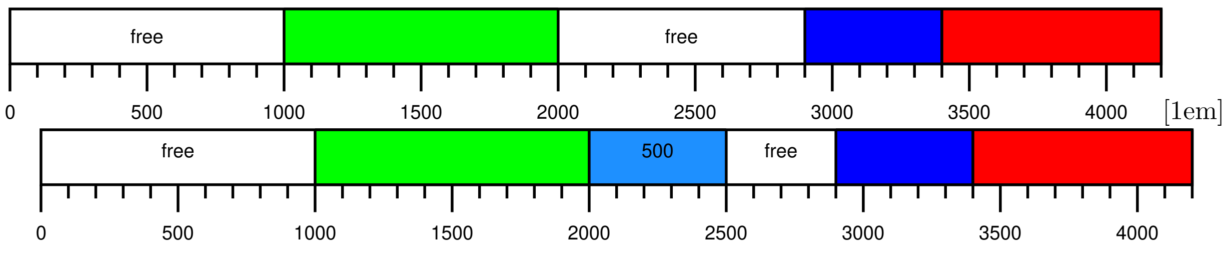
First Fit
Pick the first block that is large enough

Best Fit
Pick the *smallest* block that fits

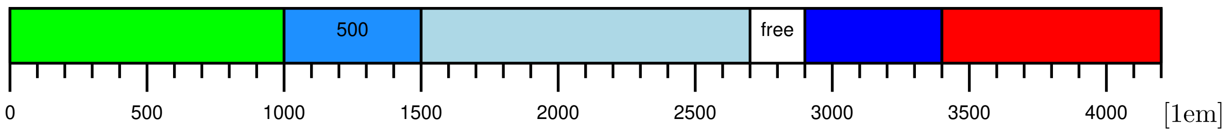
Worst Fit
Pick the *largest* block that fits

Let's try them

Best fit
Allocate 500, 1200, and 200, fail if not possible.



And compact it to fit the next one!



4.1 Buddy Allocator

Buddy Allocator

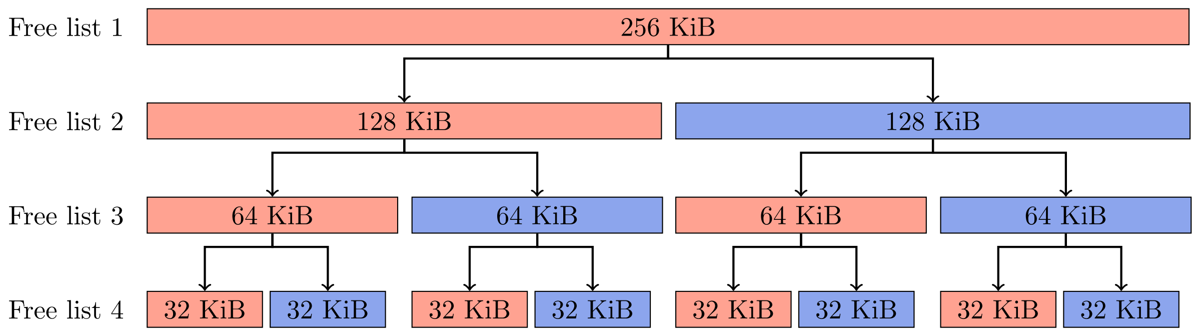
So far we've seen

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

Can we do better for some applications? Any ideas?

Buddy Allocator

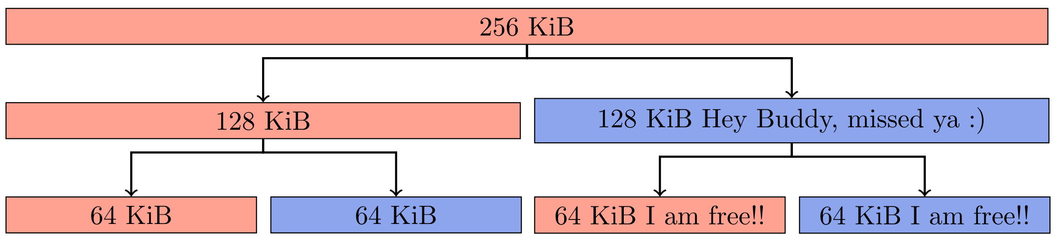
Allocator



How do you find a fitting Element? *Freelist!*
And if there is no such block? *Recursively split a higher-up block*

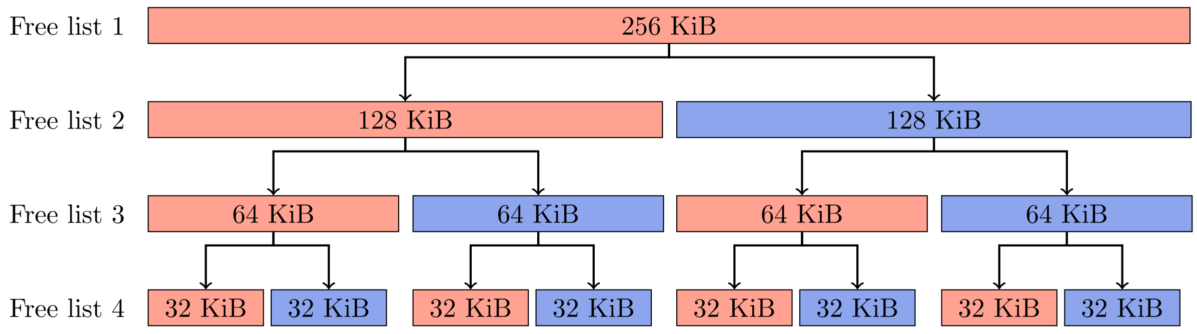
Buddy Allocator - Merging

Merging



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 $256\ KiB = 2^{18}$)



$\Rightarrow$ Max size $\frac{1}{2} \cdot 2^{k-m}$ $\Rightarrow$ Min size 0

What kind of fragmentation can occur?

Internal fragmentation

- Power of two blocks

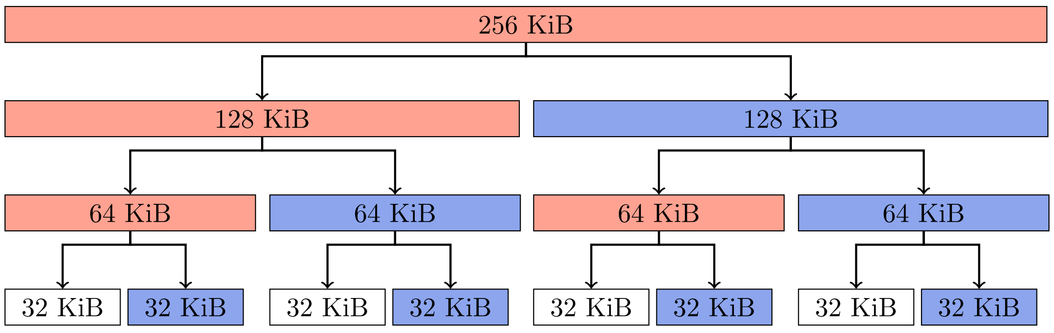
$\Rightarrow$ Request memory of size $2^k + 1, k \in \mathbb{N}_0$

External fragmentation

- Free every other block in a level

Buddy Allocator - Fragmentation

External fragmentation



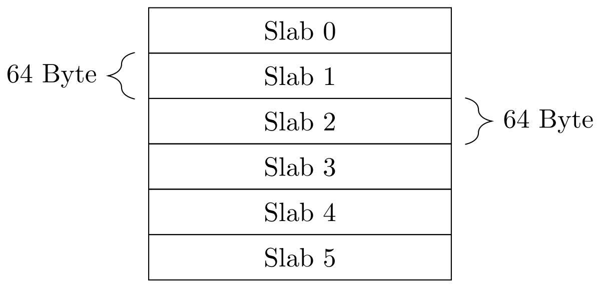
Buddy Allocator - Fragmentation

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

4.2 SLAB Allocator

What allocator would you make up for this?

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?



This is called a *Slab allocator*