Qualitative and quantitative evaluation of writing an OS kernel in Rust.

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Why OS in Rust?

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- Algebraic types (will see later)
- Most of type checking and memory management is planned compile time and so minimal overhead after it is compiled

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- Drivers comprise over 70% of kernel code. They do not need all privileges given to kernel mode but usually run in Ring 0 for efficiency.
  - Rust can limit the scope of potential damage caused by drivers
- **Goal: Write a kernel in Rust to evaluate its benefits for kernel programming and the cost we pay**

Problem Background and Related Work

- Cody Cutler, M. Frans Kaashoek, and Robert T. Morris: **Writing Kernel in Go**
  - Similar motivation and goals
  - They had to port GC to bare metal and most of their issues were connected with this
- Stanford's experimental OS course in Rust
  - Ran only one semester, built for ARM
- Tock
- Philip Opperman's Blog OS

Approach

- Build a kernel modeled after xv6 but still in idiomatic Rust
- Pause and evaluate advantages of C and advantages of Rust during development whenever there is an opportunity (in following slides)
- Quantify
    - developer performance cost of satisfying Rust requirements
    - the hardware performance cost of abstraction

Implementation

- OS in a nutshell

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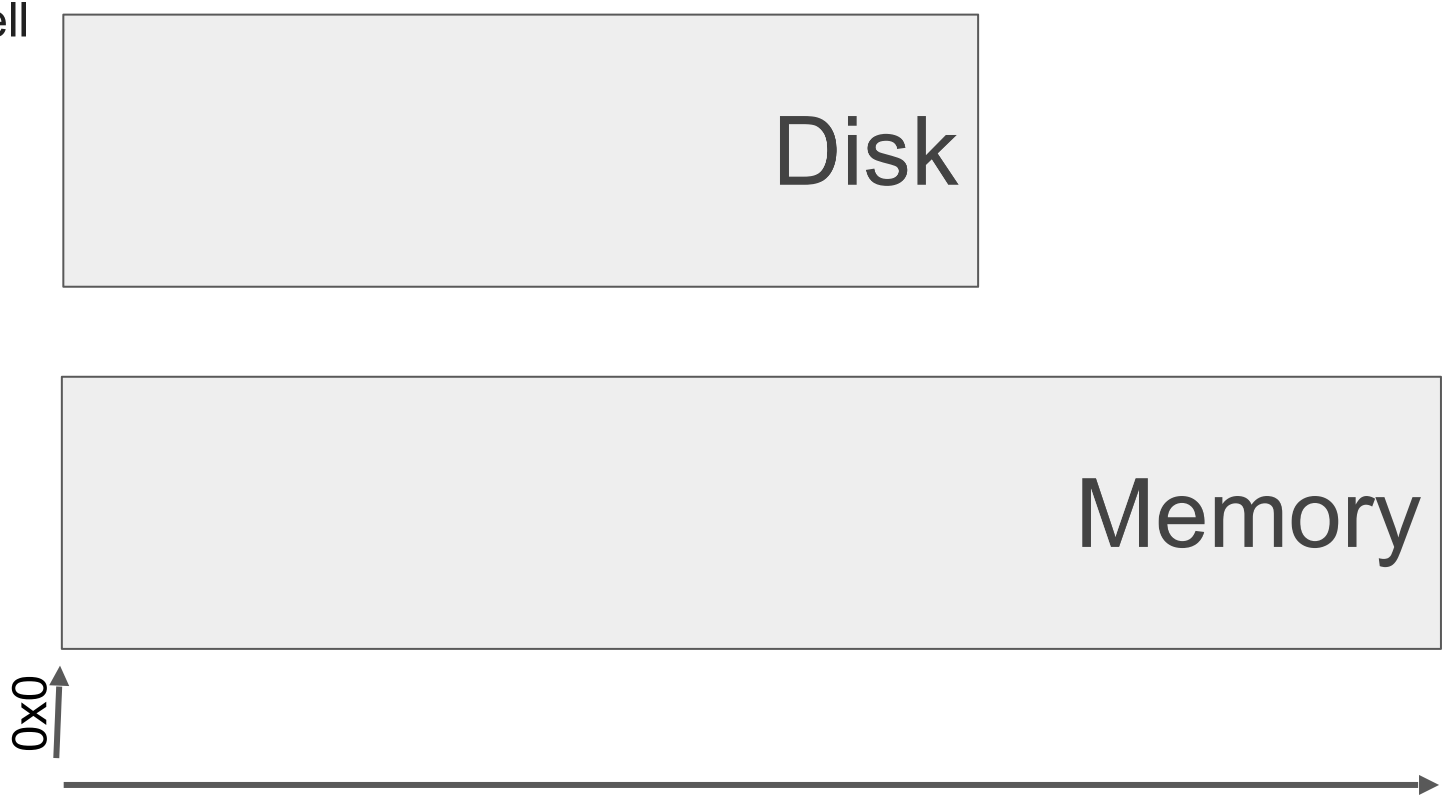

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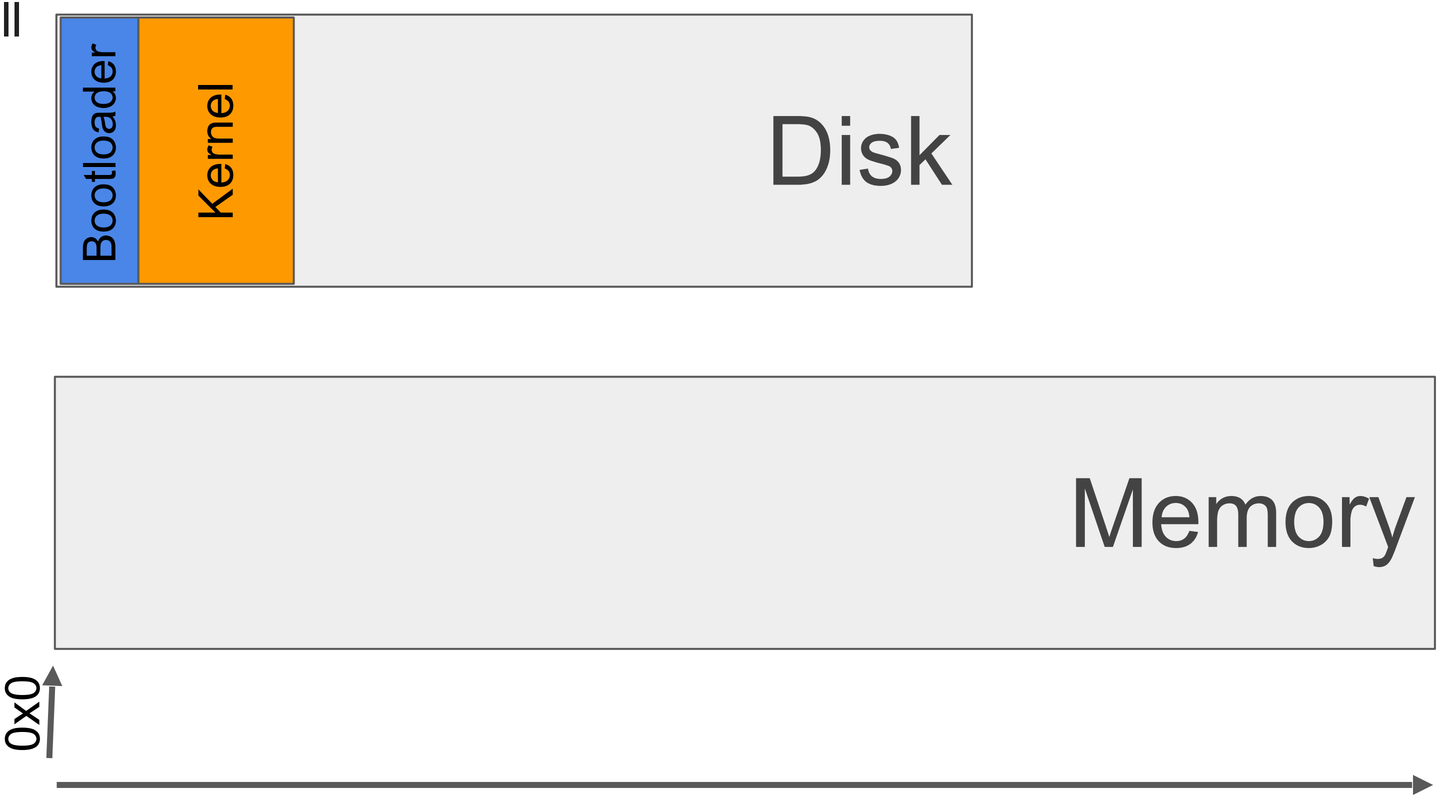

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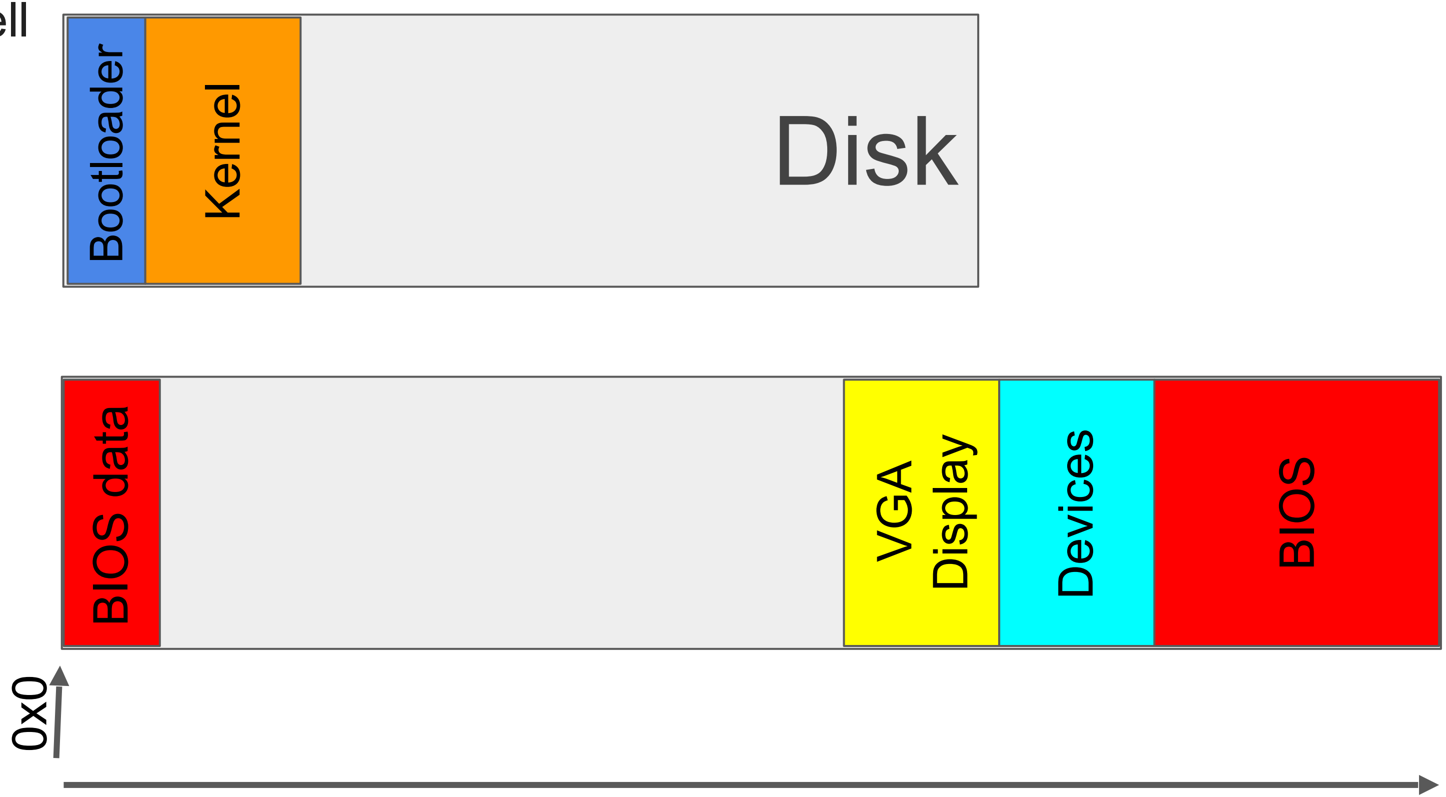

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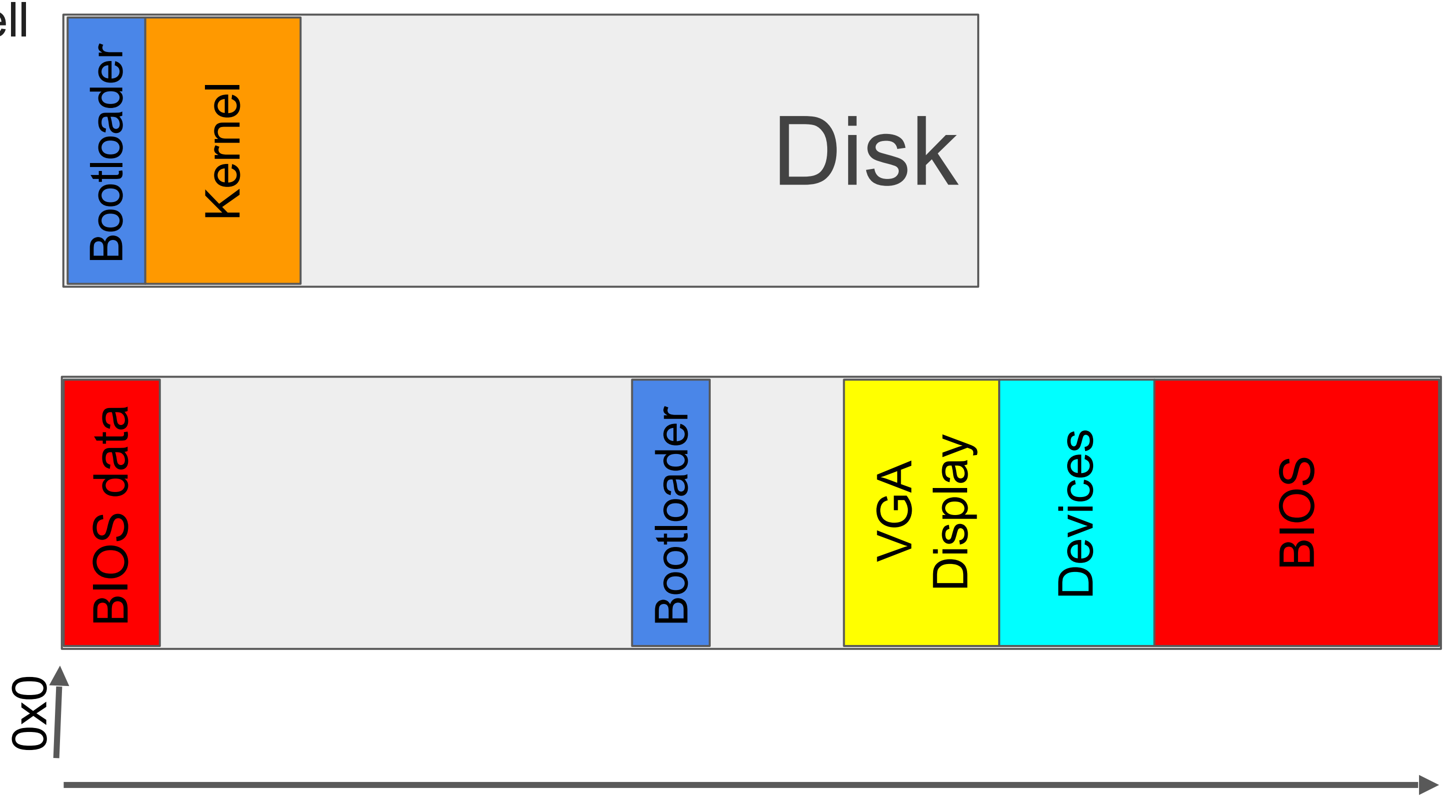

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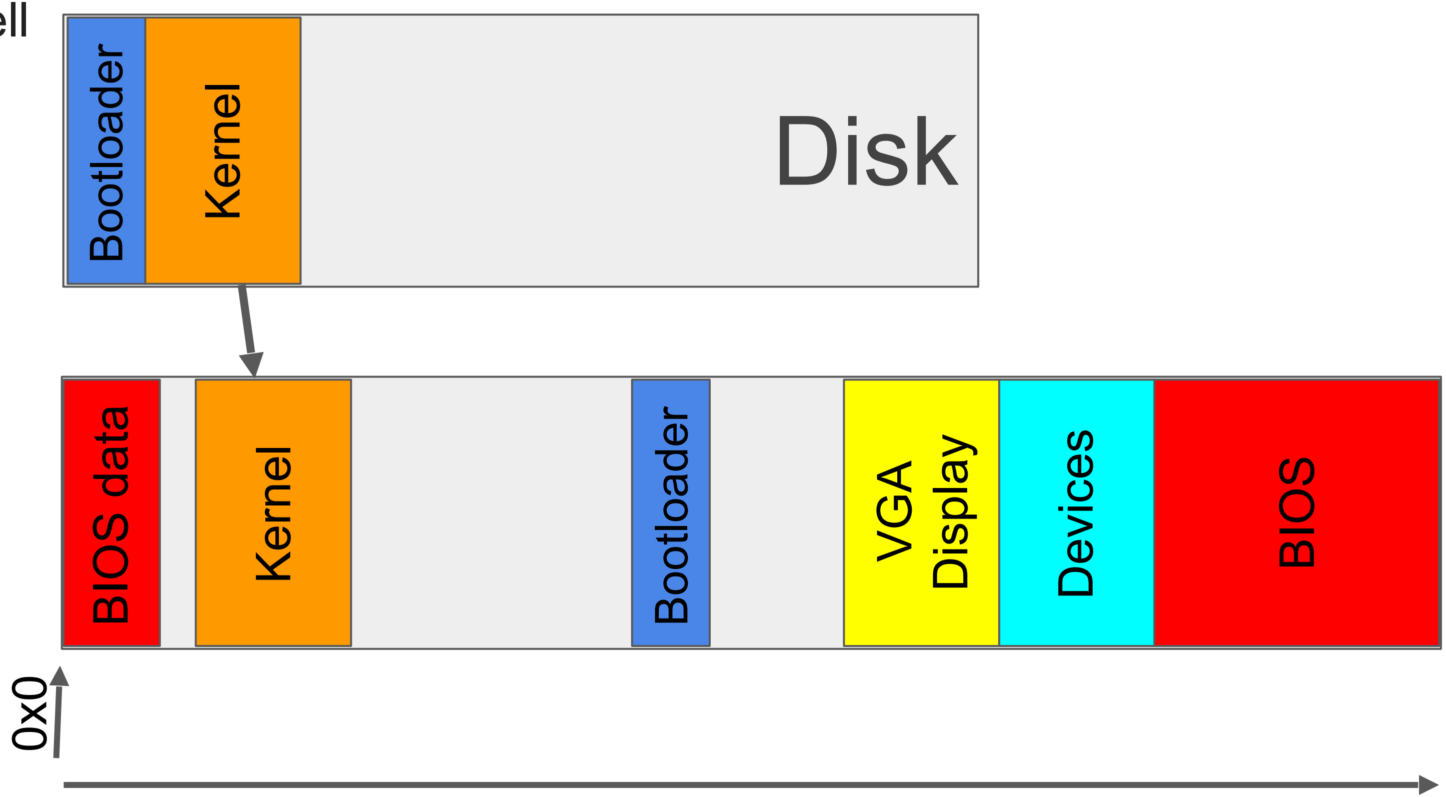

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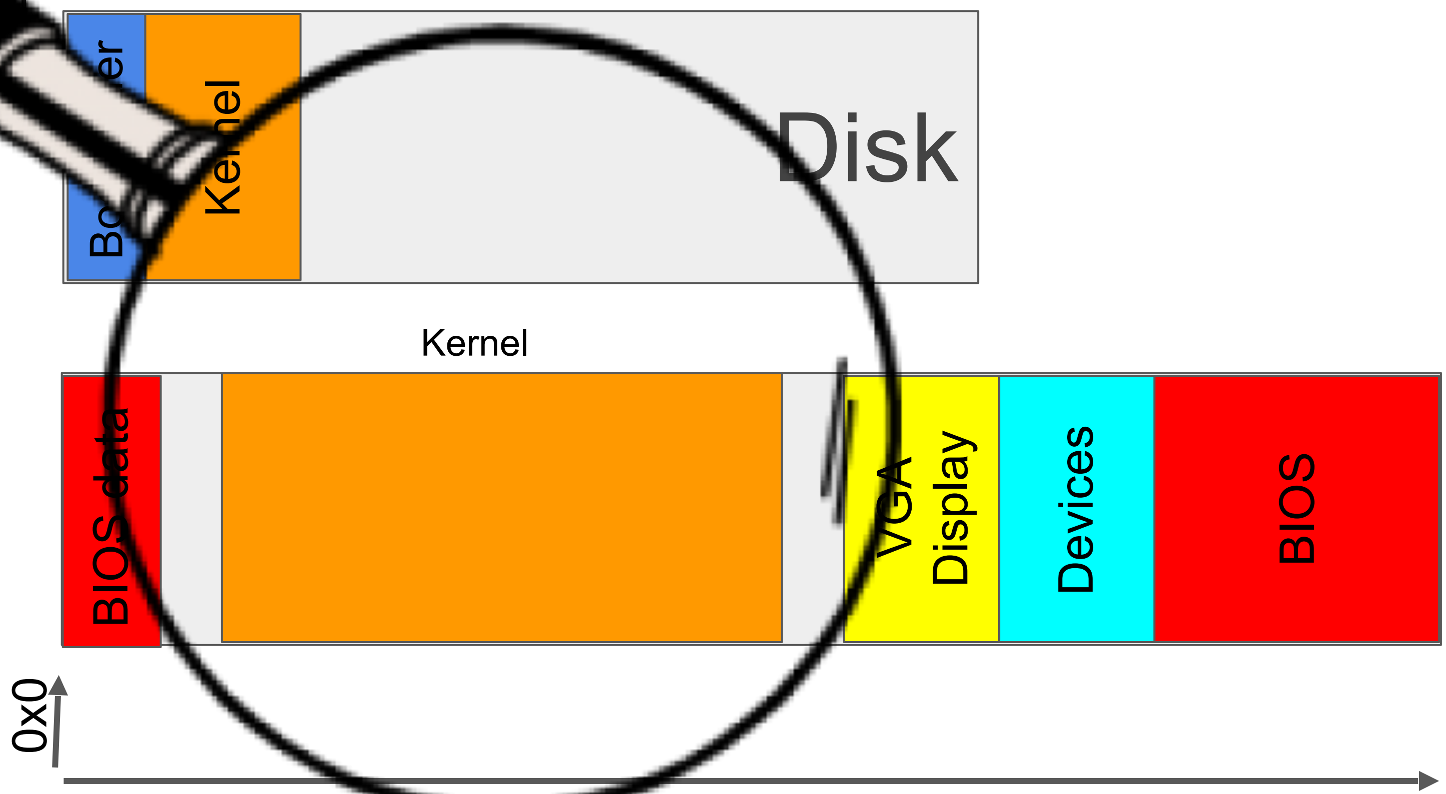

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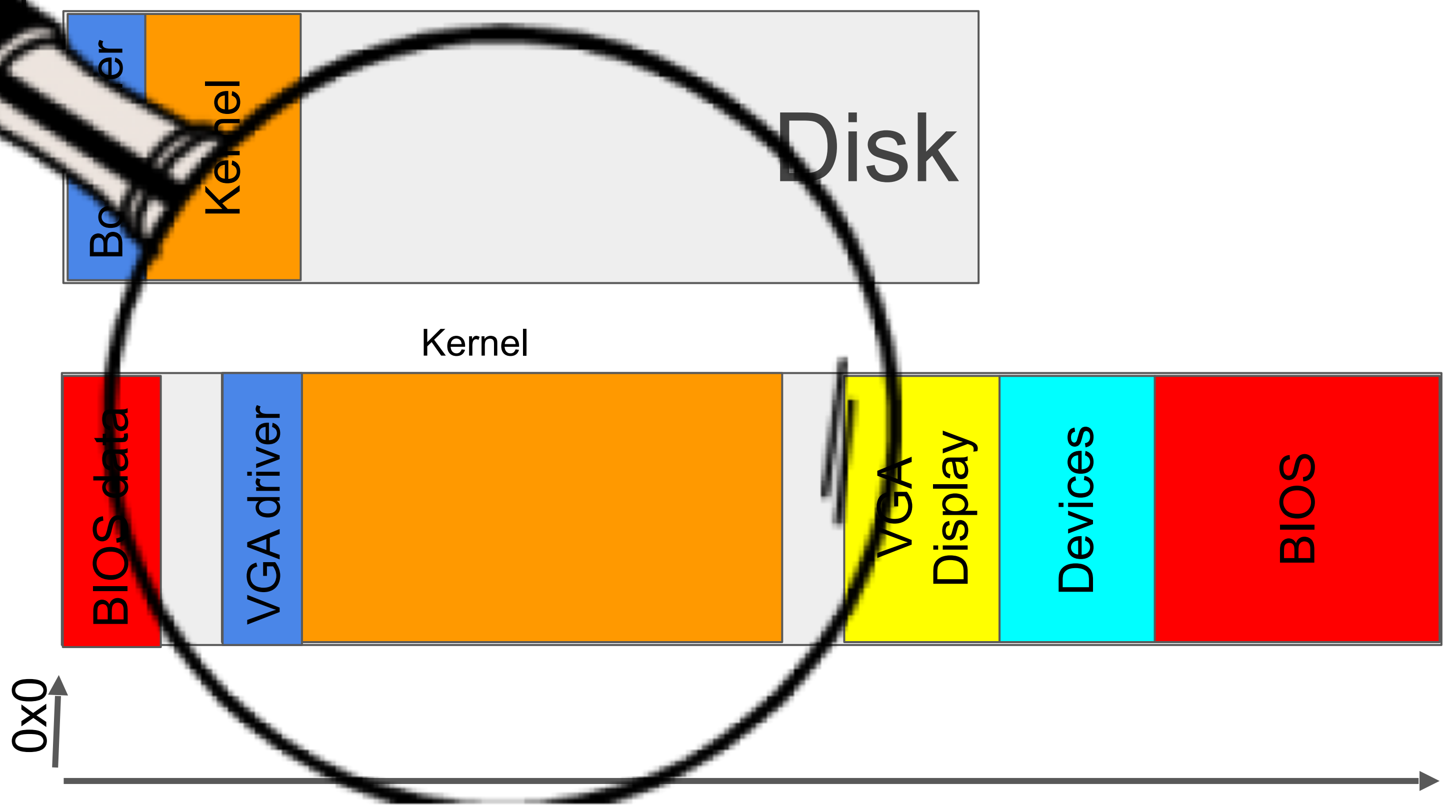

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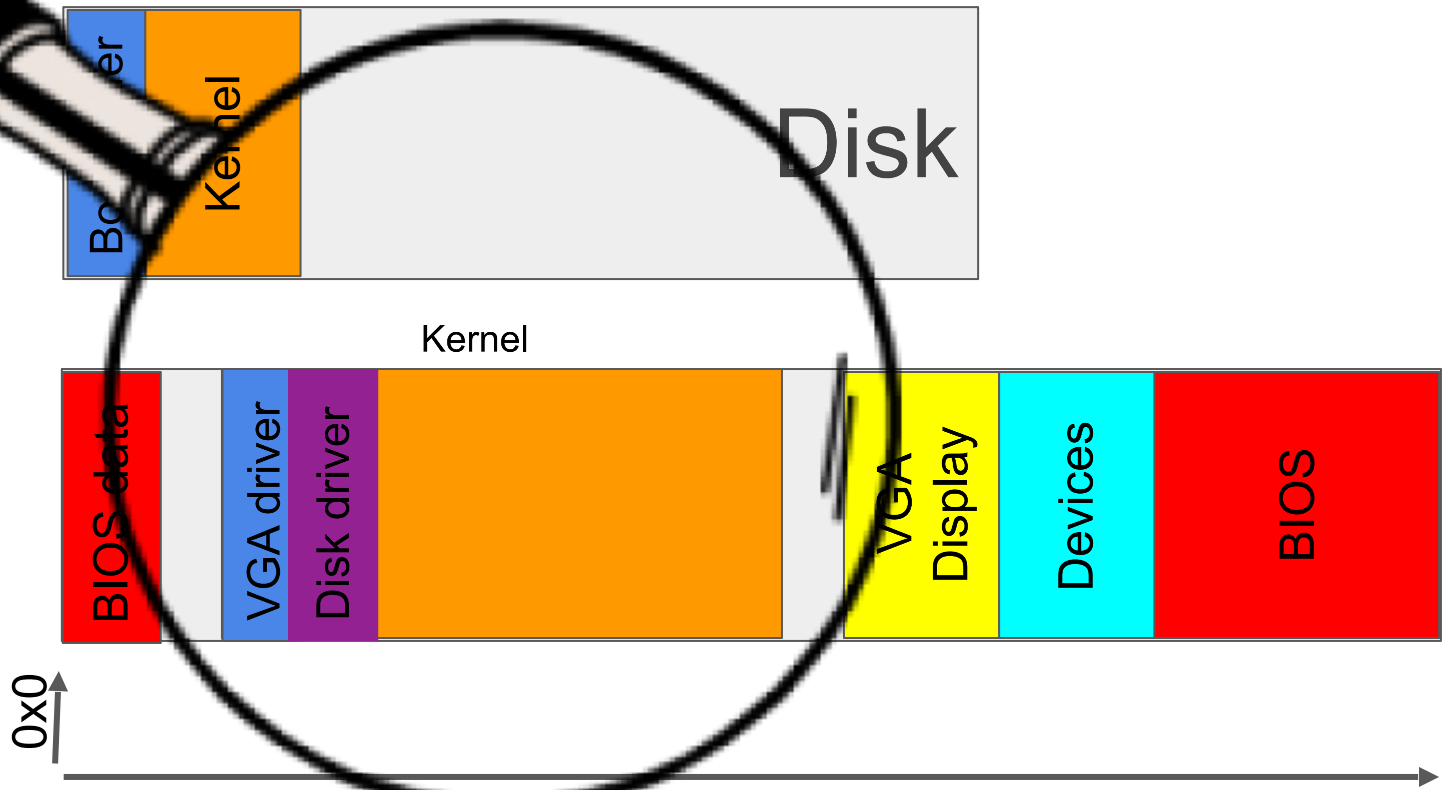

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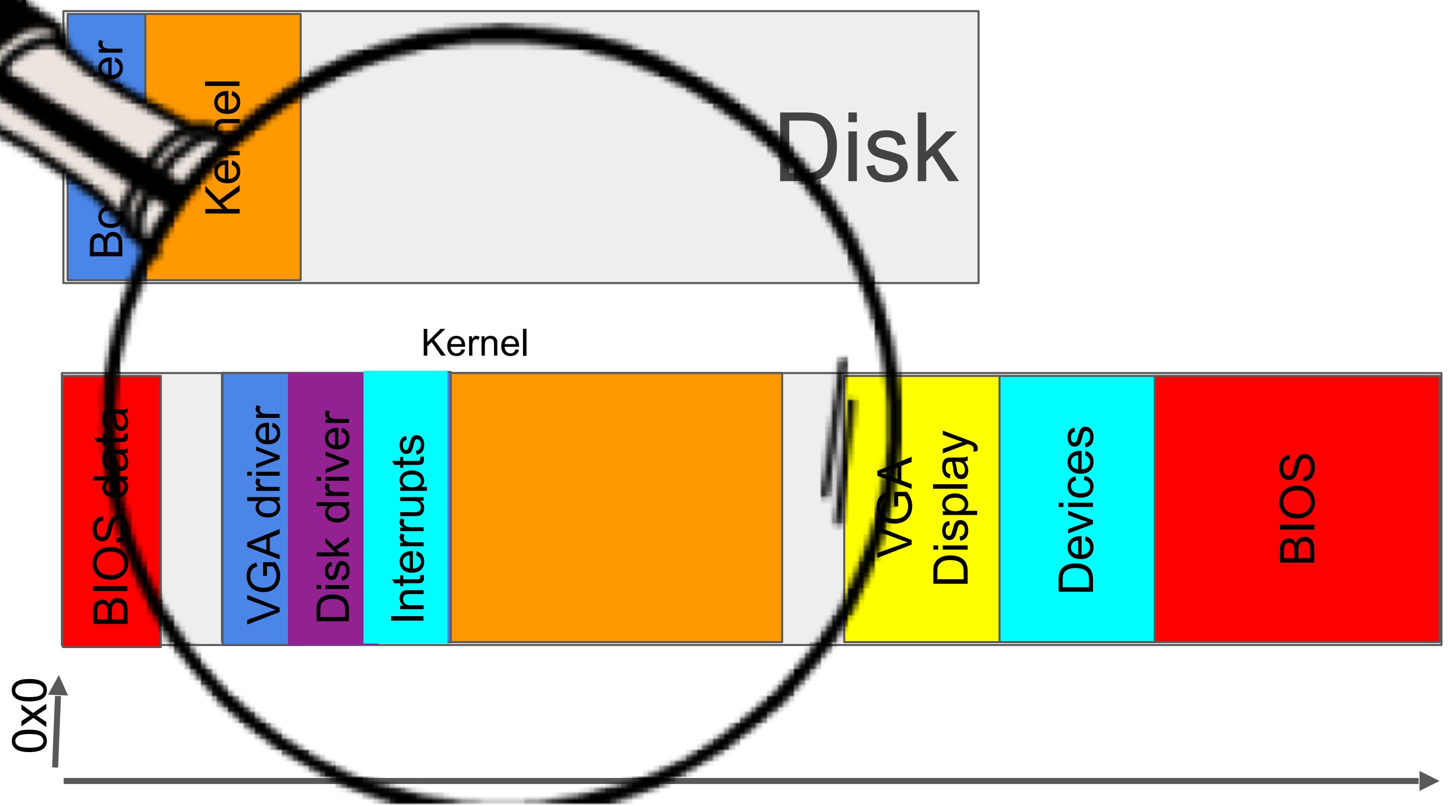

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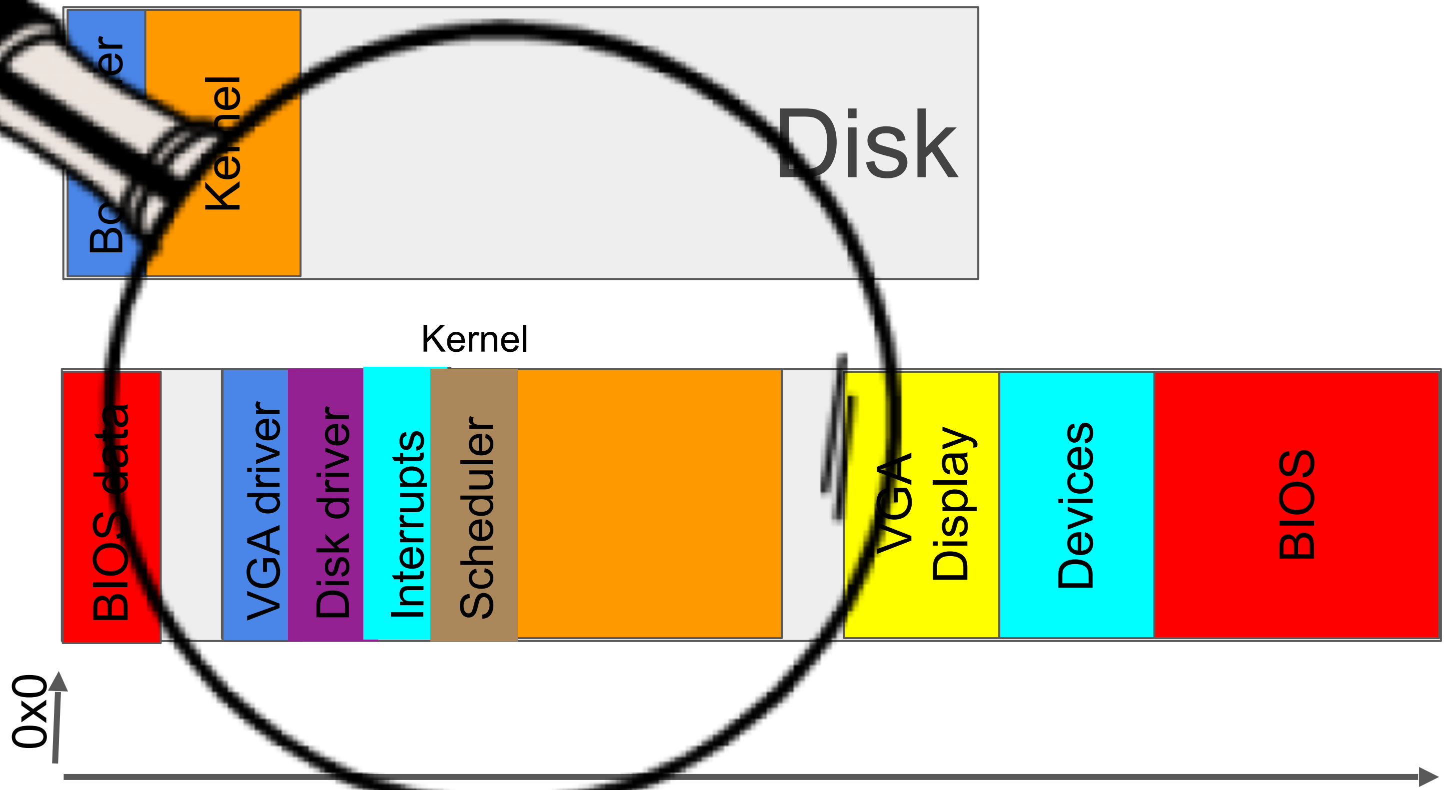

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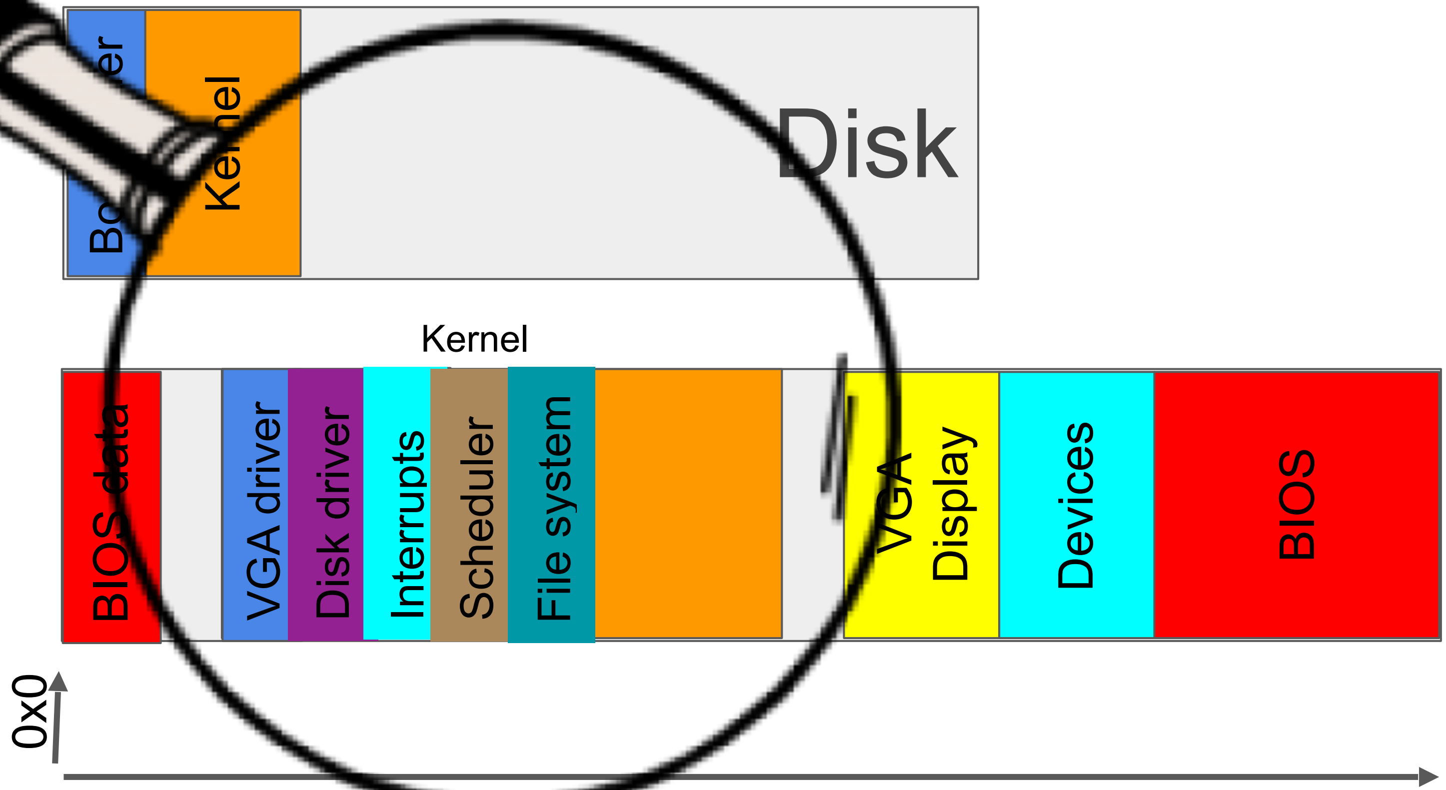

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- Task: provide necessary data access isolation primitives
- Advantage of Rust: Language guarantees that locks are acquired before data usage

Rust with spin lock

```
f.lock().read()
```

C

```
int fread(struct file *f)
{
  int r;
  ilock(f->ip);
  if((r = read(f->ip)) > 0)
  iunlock(f->ip);
  return r;
}
```

Implementation: x86_64 interface

- Hardware primitives specified by x86_64 architecture that are necessary in other parts of the kernel
- Task: provide Rust api to the primitives
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```
#[inline(always)]
pub unsafe fn idewait(checkerr: bool) -> bool
{
    let r :u8 = inb( port: 0x1f7);

    while (r & (0x80 | 0x40)) != 0x40 {}
    ;
    if checkerr && (r & (0x20 | 0x01)) != 0 {
        return false;
    }
    return true;
}
```

Implementation: DiskIO

- Hardware provides byte level sequential disk controllers through I/O in and out assembly instructions
- Task: Build a safe data streaming API on top of this
- Advantage of Rust: Has enough expressive power that allows to safely expose inherently unsafe I/O functionality

Implementation: DiskIO

```
fn command_to_drive(ctrl: IdeController, port: IdePortArgs, value: u8) {
    unsafe {
        outb( port: ctrl as u16 | port as u16, value);
    }
}
```

Implementation: DiskIO

```rust
#[derive(Debug, Clone, Copy, PartialEq, Eq)]
#[repr(u16)]
enum IdeController {
    Primary = 0x1f0,
    Secondary = 0x170,
}
```

```rust
#[allow(non_camel_case_types)]
#[repr(u16)]
enum IdePortArgs {
    ATA_REG_DATA = 0x00,
    ATA_REG_LBA3 = 0x09,
    /****/
    ATA_REG_CONTROL = 0x0C,

}
```

```rust
fn command_to_drive(ctrl: IdeController, port: IdePortArgs, value: u8) {
    unsafe {
        outb( port: ctrl as u16 | port as u16, value);
    }
}
```

Analysis: Zero Cost Abstractions

- Load args
- Command logic
- Return

```
example::command_to_drive:
        pushq   %rax
        movb    %dl, %al
        movb    %sil, %cl
        movw    %di, %r8w
        movzbl  %cl, %edx
        movw    %dx, %r9w
        orw     %r9w, %r8w
        movzwl  %r8w, %edi
        movzbl  %al, %esi
        callq   *example::outb@GOTPCREL(%rip)
        popq    %rax
        retq
```

Conclusion: So should we rewrite OS in Rust?

- Yes
  - Macros inside language semantics
  - Compiler helps a lot and makes the code easier to maintain
  - Language protection is very useful when hardware protection is not available

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Cor

- May

```c
void encodeGdtEntry(uint8_t *target, struct GDT source)
{
    // Check the limit to make sure that it can be encoded
    if ((source.limit > 65536) &&
        ((source.limit & 0xFFF) != 0xFFF)) {
        kerror("You can't do that!");
    }
    if (source.limit > 65536) {
        // Adjust granularity if required
        source.limit = source.limit >> 12;
        target[6] = 0xC0;
    } else {
        target[6] = 0x40;
    }
    ...
}
```

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  - Benefits of rewriting existing monolithic OSes are marginal

Conclusion: So should we rewrite OS in Rust?

- Maybe Not
    - Too high level to be productive, sometimes even C is too high level
    - Benefits of rewriting existing monolithic OSes are marginal
    - Qualitatively it is harder to write an OS in Rust

Bibliography

- *The case for writing a kernel in Rust*, Amit Levy, Bradford Campbell, Branden Ghena, Pat Pannuto, Prabal Dutta, and Philip Levis. 2017. The Case for Writing a Kernel in Rust. In Proceedings of the 8th Asia-Pacific Workshop on Systems (APSys '17). ACM, New York, NY, USA, Article 1, 7 pages. DOI: https://doi.org/10.1145/3124680.3124717
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- *Writing an OS in Rust (Second Edition) Philipp Oppermann's blog*, https://os.phil-opp.com/
- *CS140e (Winter 2018) An Experimental Course on OSes,* https://cs140e.sergio.bz/
- *Is It Time to Rewrite the Operating System in Rust?* Qcon 2019 talk by Bryan Cantrill, https://www.infoq.com/presentations/os-rust

Appendix - Ownership

```
// will not work
struct Node {
    next: &mut Node,
    previous: &mut Node,
    data: Foo,
}
// will work, requires unsafe
struct Node_raw {
    next: *mut Node_raw,
    previous: *mut Node_raw,
    data: Foo,
}
```

Appendix - Lifetimes

```
int *danger() {
    int a = 4;
    return &a;
}
```

```
int *evenMoreDanger(){
    int *a = malloc(sizeof(int));
    if (a) *a = 4;
    return a
}
```

Implementation: VGA Driver

- Hardware provides memory mapped video graphics array
- Task: Implement safe API around unsafe memory accesses
- Advantages of Rust:
  - Type checked arguments
  - Bound checked arrays

```
#[repr(u8)]
pub enum Color {
    Black = 0,
    Blue = 1,
    Green = 2,
    /***/
    White = 15,
}
```

Implementation: Safe Scheduler

- Rust detects memory safety and concurrency issues
- These are often not very crucial in low level kernel programming
- When writing more complex conceptually higher level algorithmic code (like a scheduler) it is good to

Implementation: Safe Scheduler

- When writing complex conceptually high level algorithmic code (like a scheduler) it is good to guarantee local scope for any bug
    - Round Robin, First-Come First-Served, Multi-level queues, etc
- Would be great to be able to write a scheduler in safe Rust without significant runtime overhead

Implementation: Safe Scheduler

```
#[no_mangle]
pub fn schedule(pcbMutex: &Mutex<[PCB;NUM_PROCS]>, current:usize) -> usize {
    /* scheduling logic:
    // e.g.
    (current + 1) % NUM_PROCS
    */
}
```