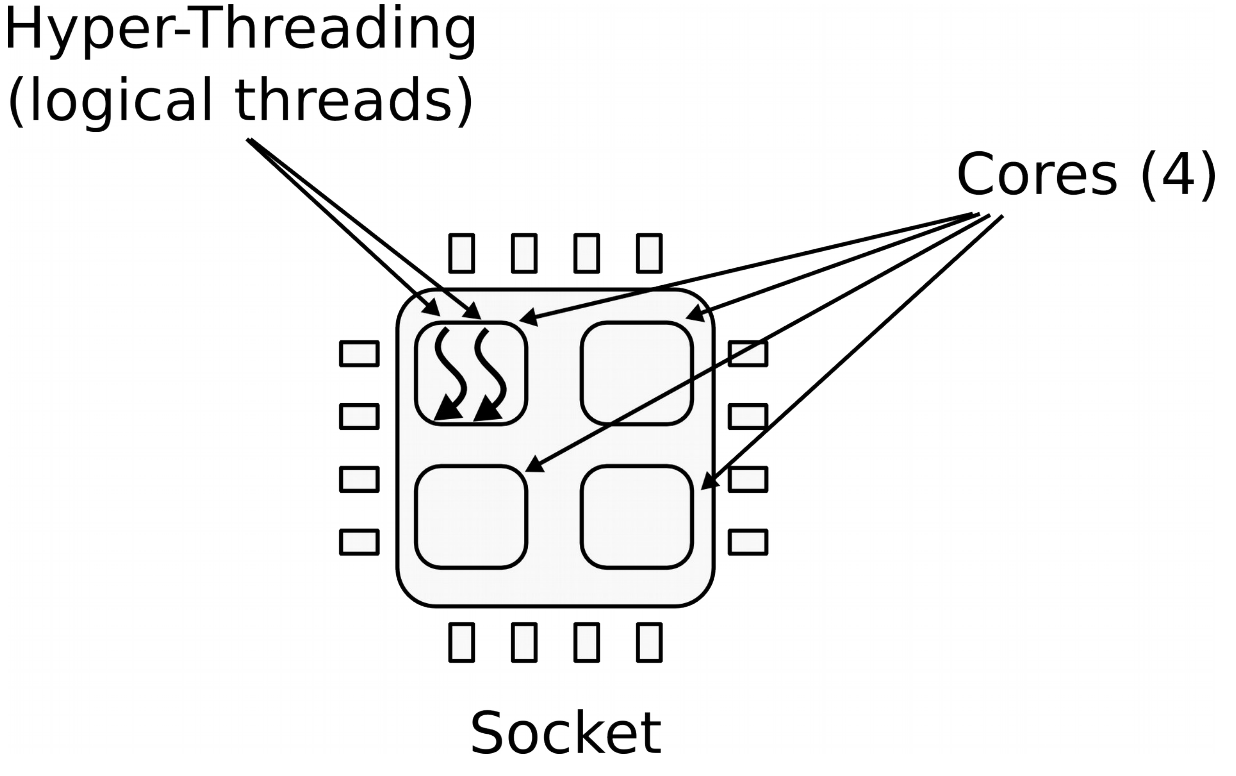
Lecture 01: Introduction

Anton Burtsev

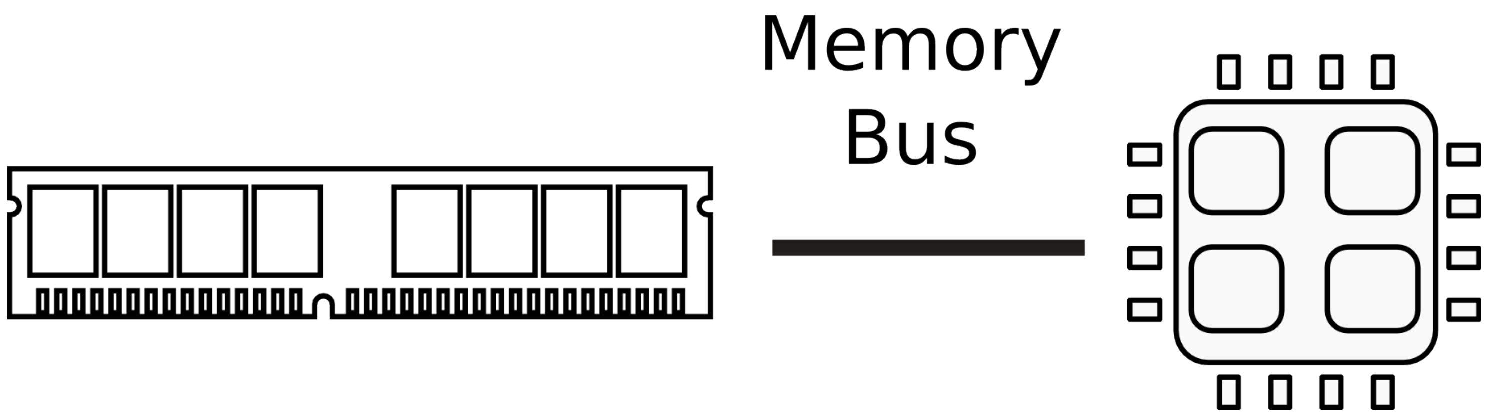
Lets take a brief look at how computers work

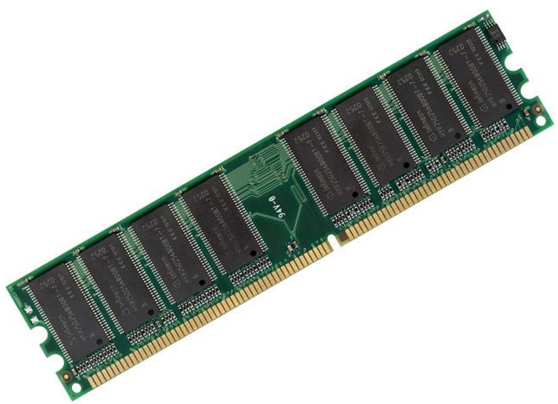
CPU

- 1 CPU
  - 4 cores
  - 2 logical (HT) threads each



Memory

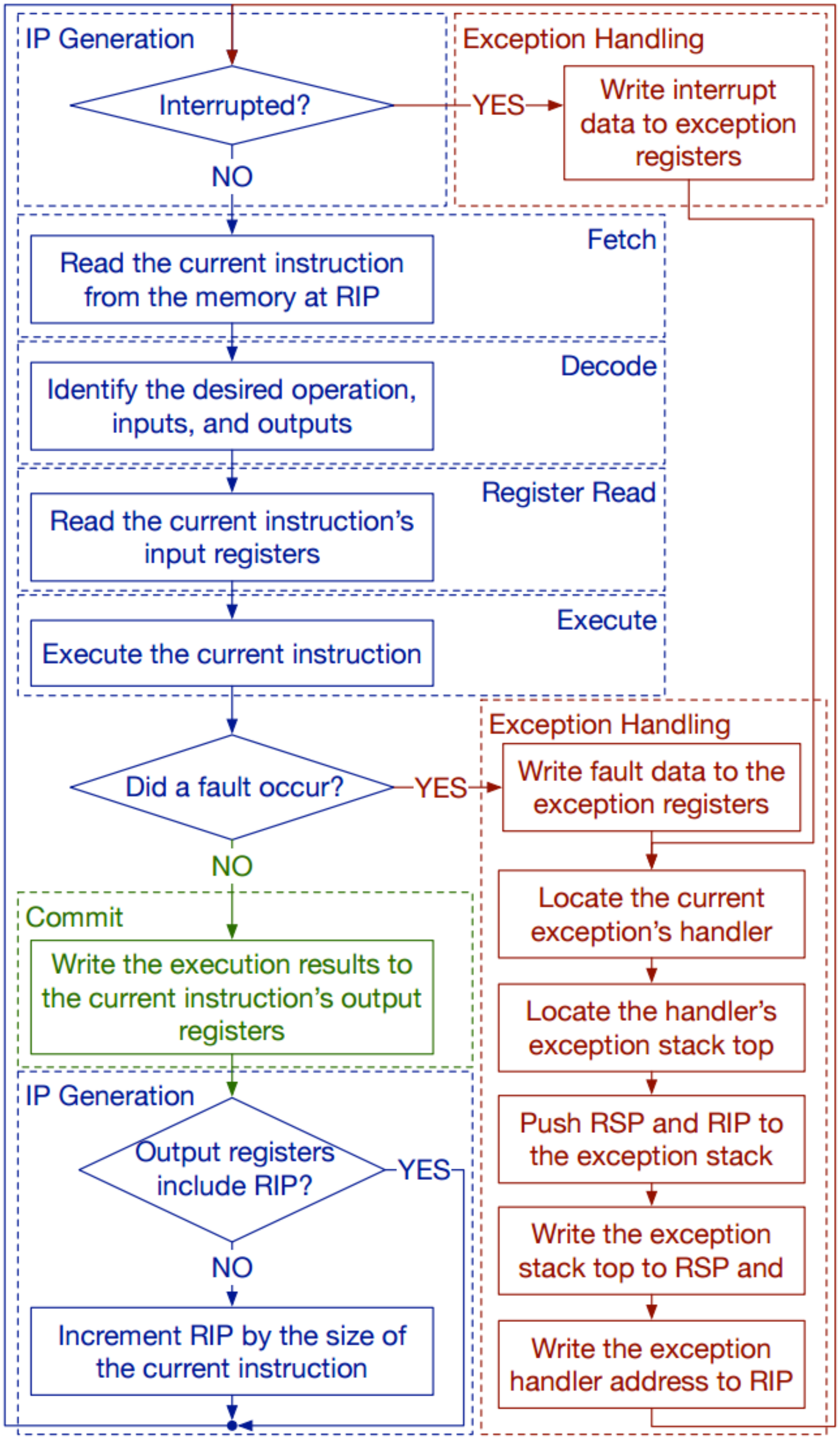




Memory abstraction

WRITE(*addr*, *value*) $\rightarrow \emptyset$ Store *value* in the storage cell identified by *addr*.
READ(*addr*) $\rightarrow$ *value* Return the *value* argument to the most recent WRITE call referencing *addr*.

What does CPU do internally?

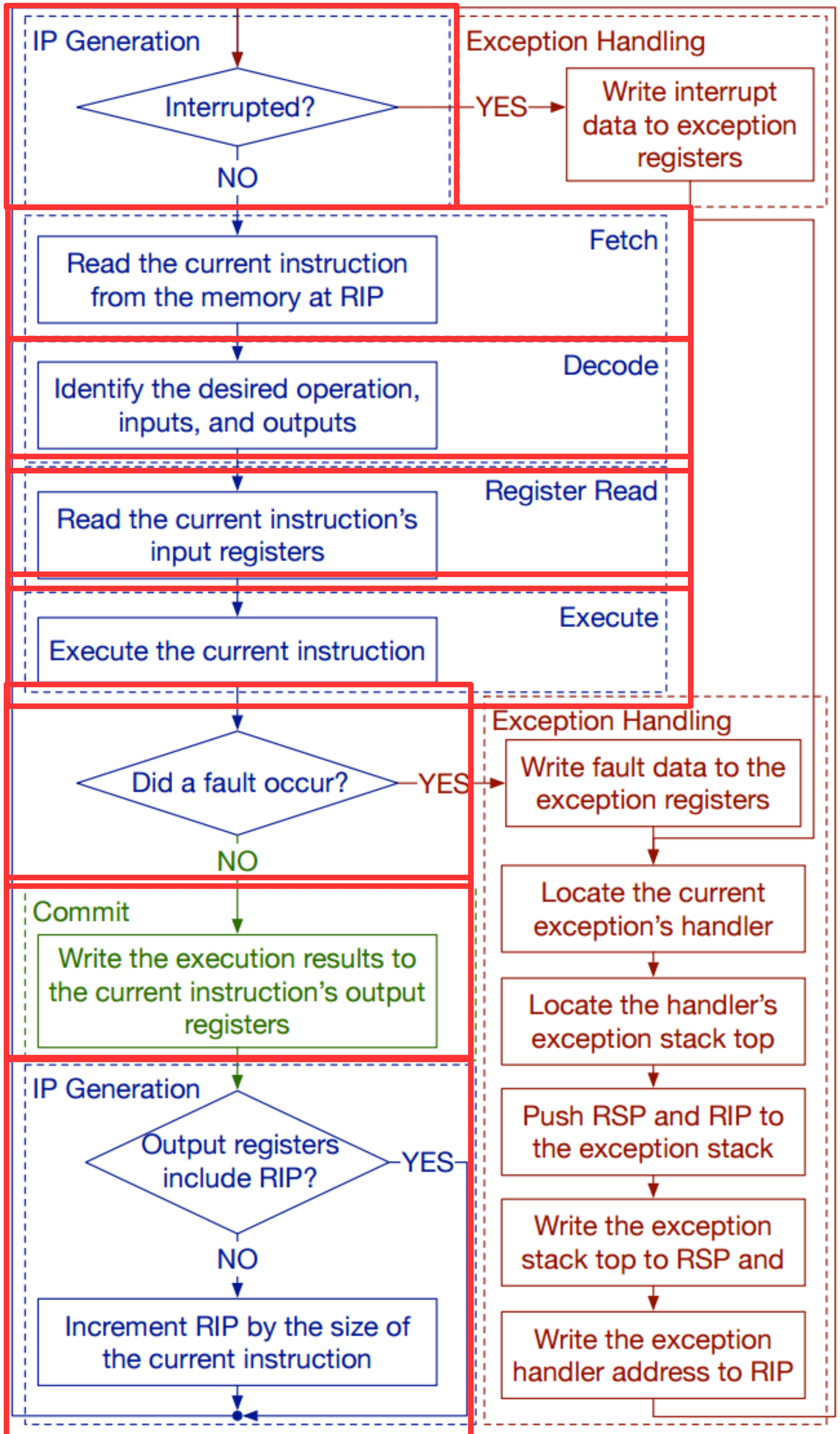


CPU execution loop

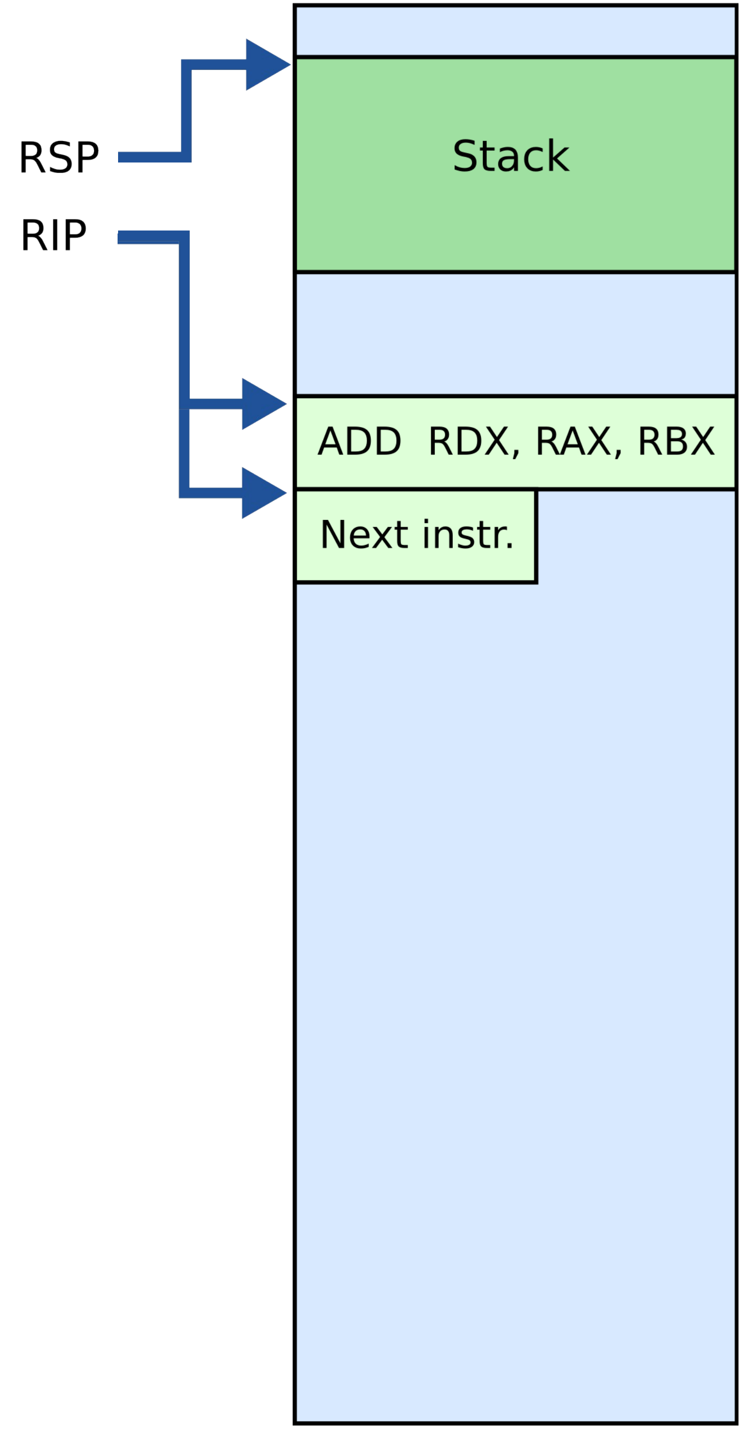
- CPU repeatedly reads instructions from memory
- Executes them
- Example

```
ADD EAX, EBX

// EAX = EAX + EBX
```



IP Generation
Interrupted?
YES
NO
Exception Handling
Write interrupt data to exception registers
Fetch
Read the current instruction from the memory at RIP
Decode
Identify the desired operation, inputs, and outputs
Register Read
Read the current instruction's input registers
Execute
Execute the current instruction
Did a fault occur?
YES
NO
Exception Handling
Write fault data to the exception registers
Locate the current exception's handler
Locate the handler's exception stack top
Push RSP and RIP to the exception stack
Write the exception stack top to RSP and
Write the exception handler address to RIP
Commit
Write the execution results to the current instruction's output registers
IP Generation
Output registers include RIP?
YES
NO
Increment RIP by the size of the current instruction



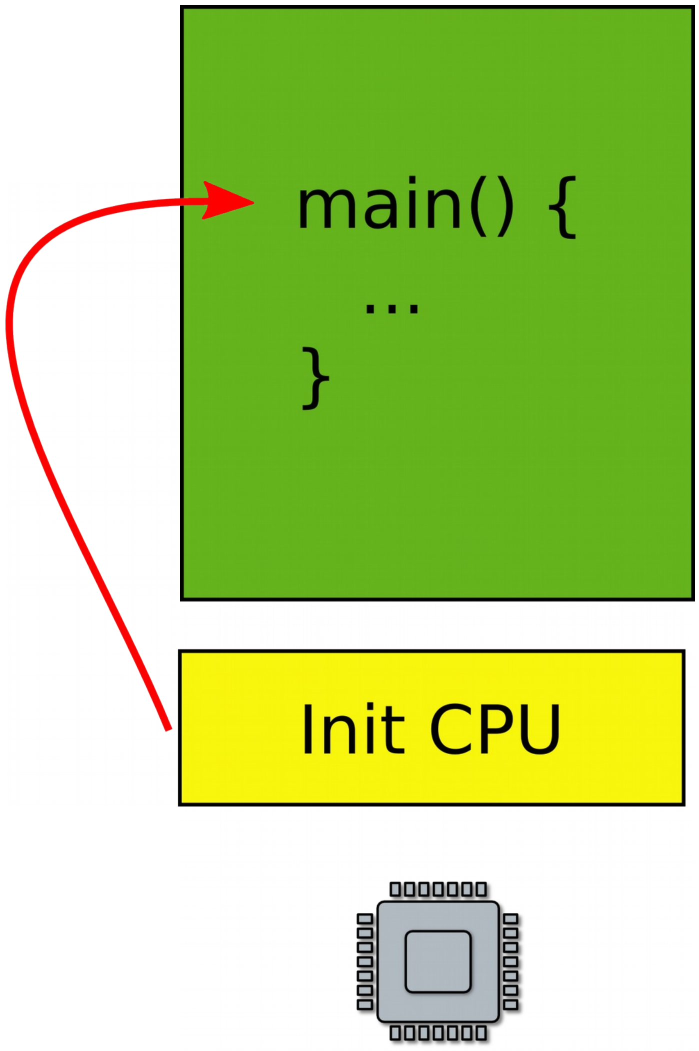
RSP
RIP
Stack
ADD RDX, RAX, RBX
Next instr.

Simple observation

- Hardware executes instructions one by one

What is an operating system?

Task #1: Run your code on a piece of hardware



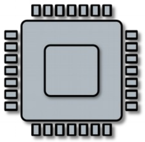
- Read CPU manual
- A tiny boot layer
  - Initialize CPU
  - Jump to the entry point of your program
    - main()
  - **This can be the beginning of your OS!**

Task #2: Print something on the screen

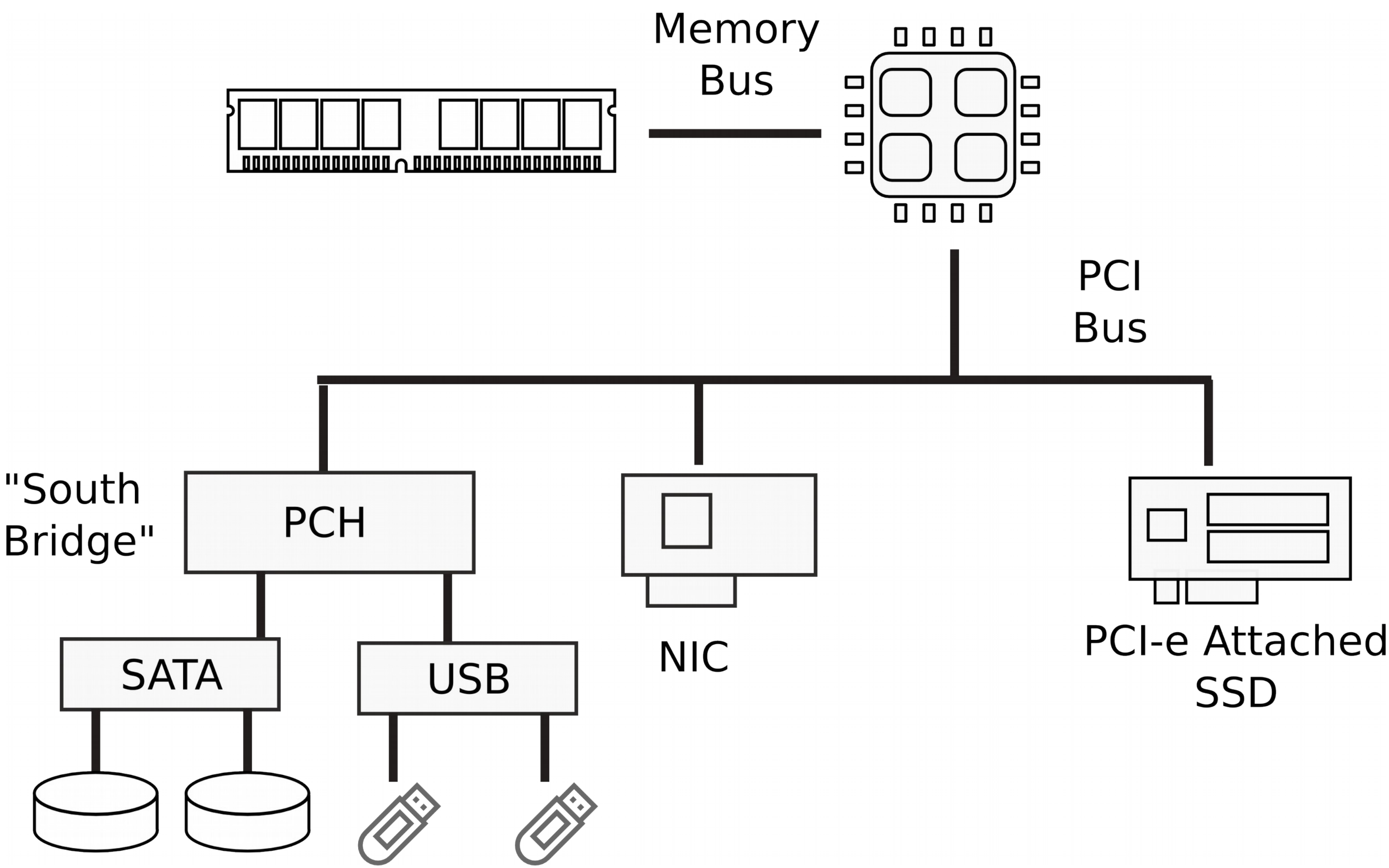
- On the screen or serial line

```
printf() {
   ...
   asm("mov [<magic constant>], char");
   ...
}
```

OS



I/O Devices

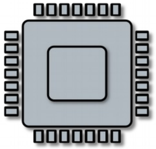

Memory
Bus
PCI
Bus
"South
Bridge"
PCH
SATA
USB
NIC
PCI-e Attached
SSD

Task #2: Print something on the screen

- On the screen or serial line

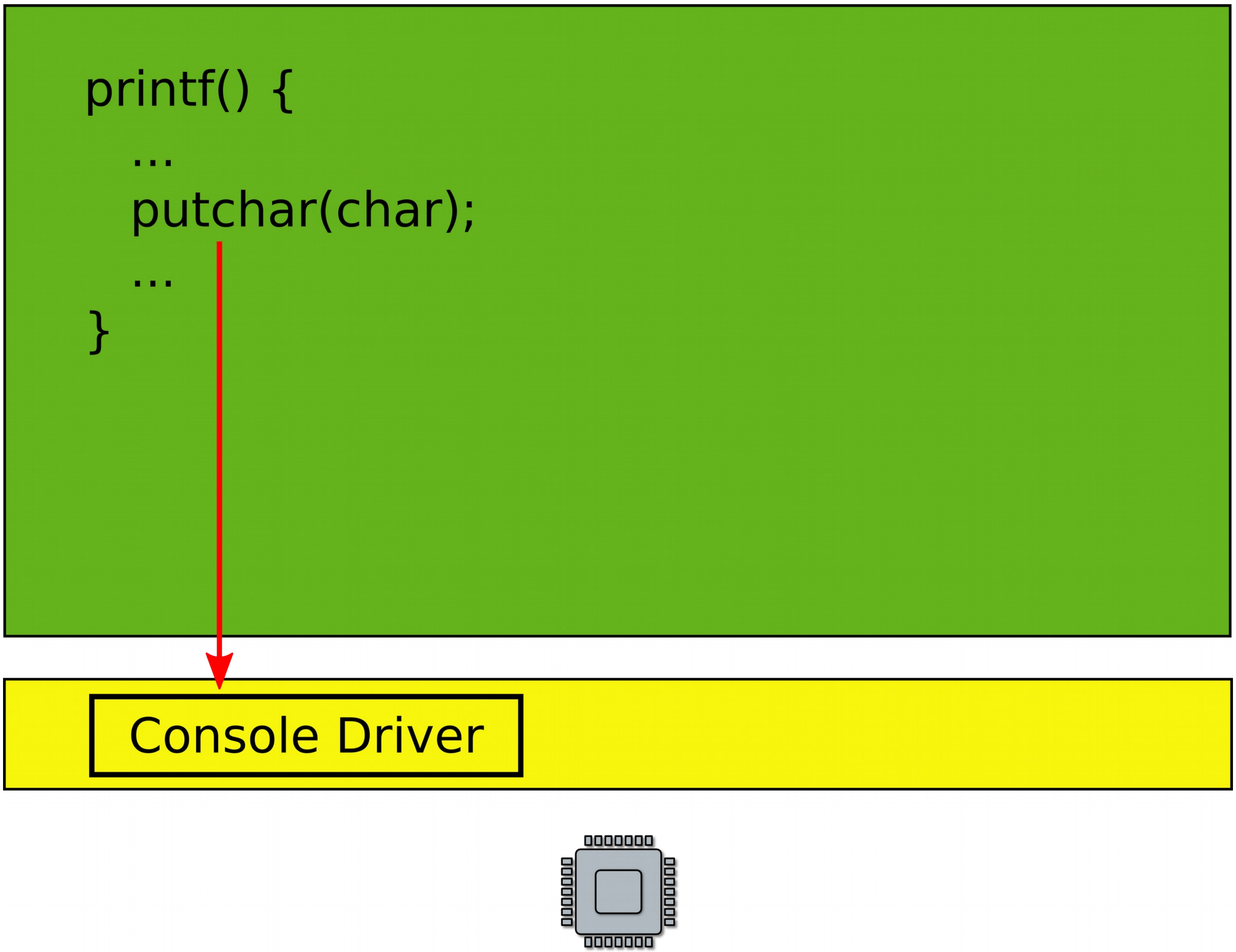
```
printf() {
   ...
   if (vga) {
       asm("mov [<magic constant 1>], char");
   } else if (serial) {
       asm("out <magic constant 2>, char");
   }
   ...
}
```

OS



A more general interface

- First device driver

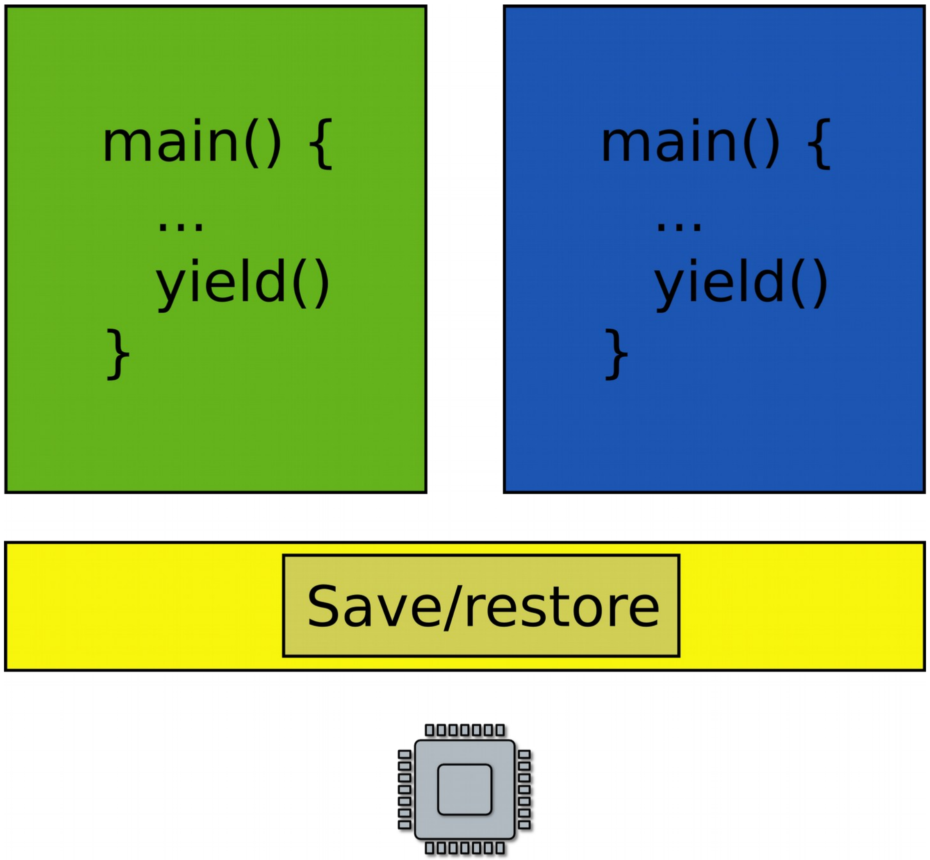


Device drivers

- Abstract hardware
  - Provide high-level interface
  - Hide minor differences
  - Implement some optimizations
    - Batch requests
- Examples
  - Console, disk, network interface
  - ...virtually any piece of hardware you know

OS is like a library that provides a collection of useful functions

Task #3: Want to run two programs



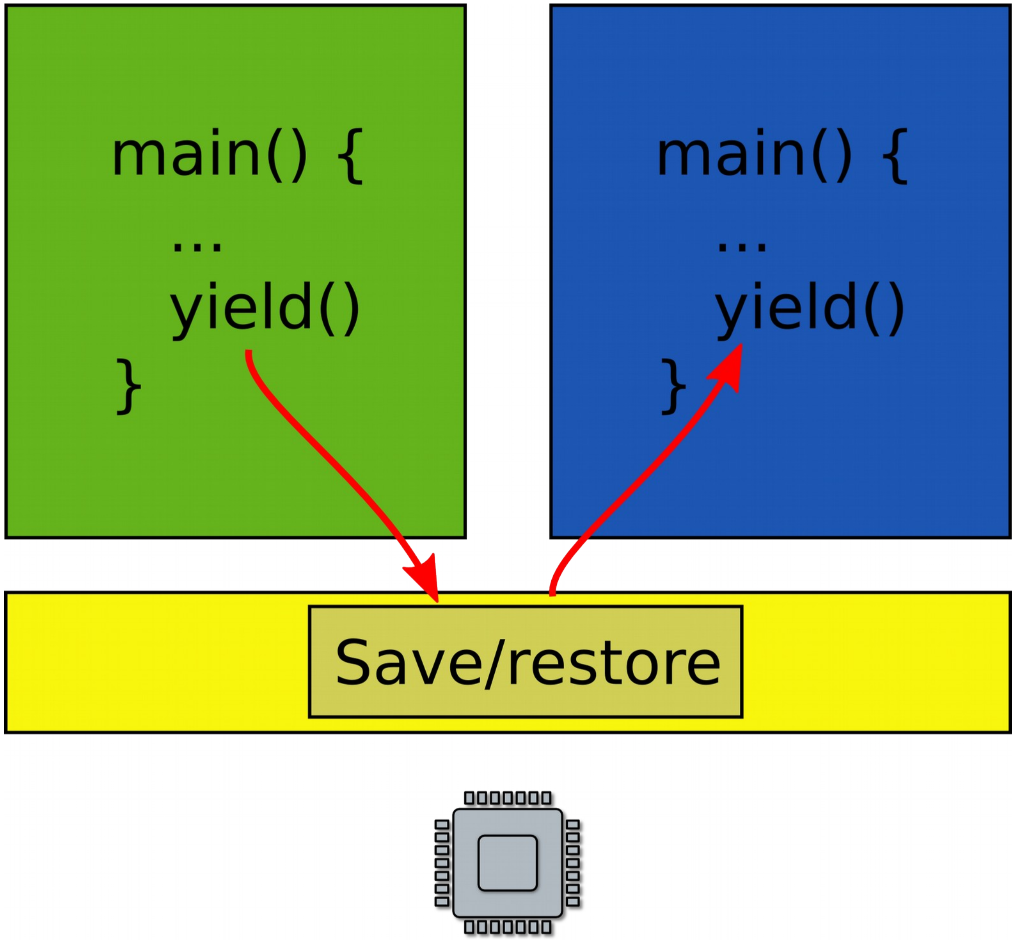
- What does it mean?
  - Only one CPU
- Run one, then run another one

Very much like car sharing

Time sharing

- Programs use CPU in turns
  - One program runs
  - Then OS takes control
  - Launches another program
  - Then another program runs
  - OS takes control again
  - ...

Task #3: Want to run two programs



- Exit into the kernel periodically
- Context switch
  - Save state of one program
  - Restore state of another program

What is this state?

State of the program

- Roughly it's
  - Registers
  - Memory

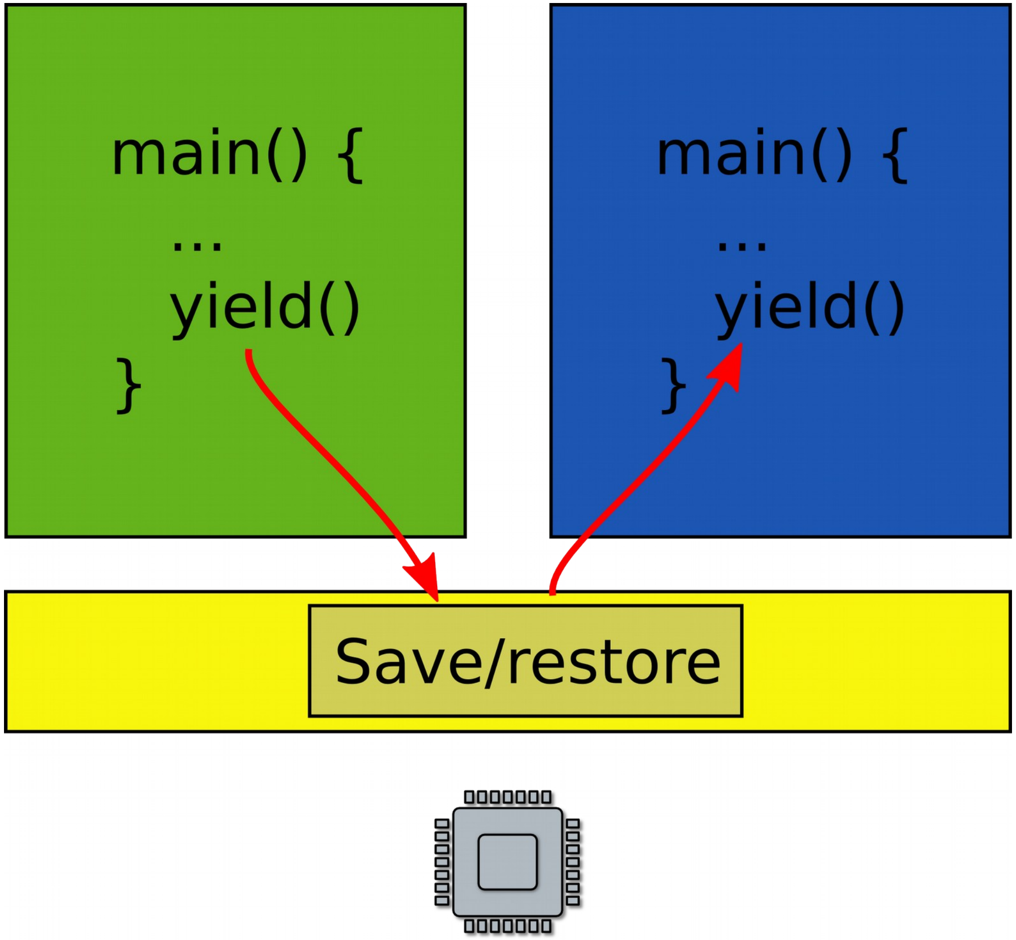
  - Plus some state (data structures) in the kernel associated with the program
    - Information about files opened by the program, i.e. file descriptors
    - Information about network flows
    - Information about address space, loaded libraries, communication channels to other programs, etc.

Saving and restoring state

- Note that you do not really have to save/restore in-kernel state on the context switch
  - It’s in the kernel already, i.e., in some part of the memory where kernel keeps its data structures
  - You only have to switch from using one to using another
    - i.e., instead of using the file descriptor table (can be as simple as array) for program X start using at file descriptor table for program Y

What about memory?

- Two programs, one memory?



Time-share memory

- Well you can copy in and out the state of the program into a region of memory where it can run
  - Similar to time-sharing the CPU

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Time-share memory

- Well you can copy in and out the state of the program into a region of memory where it can run
  - Similar to time-sharing the CPU

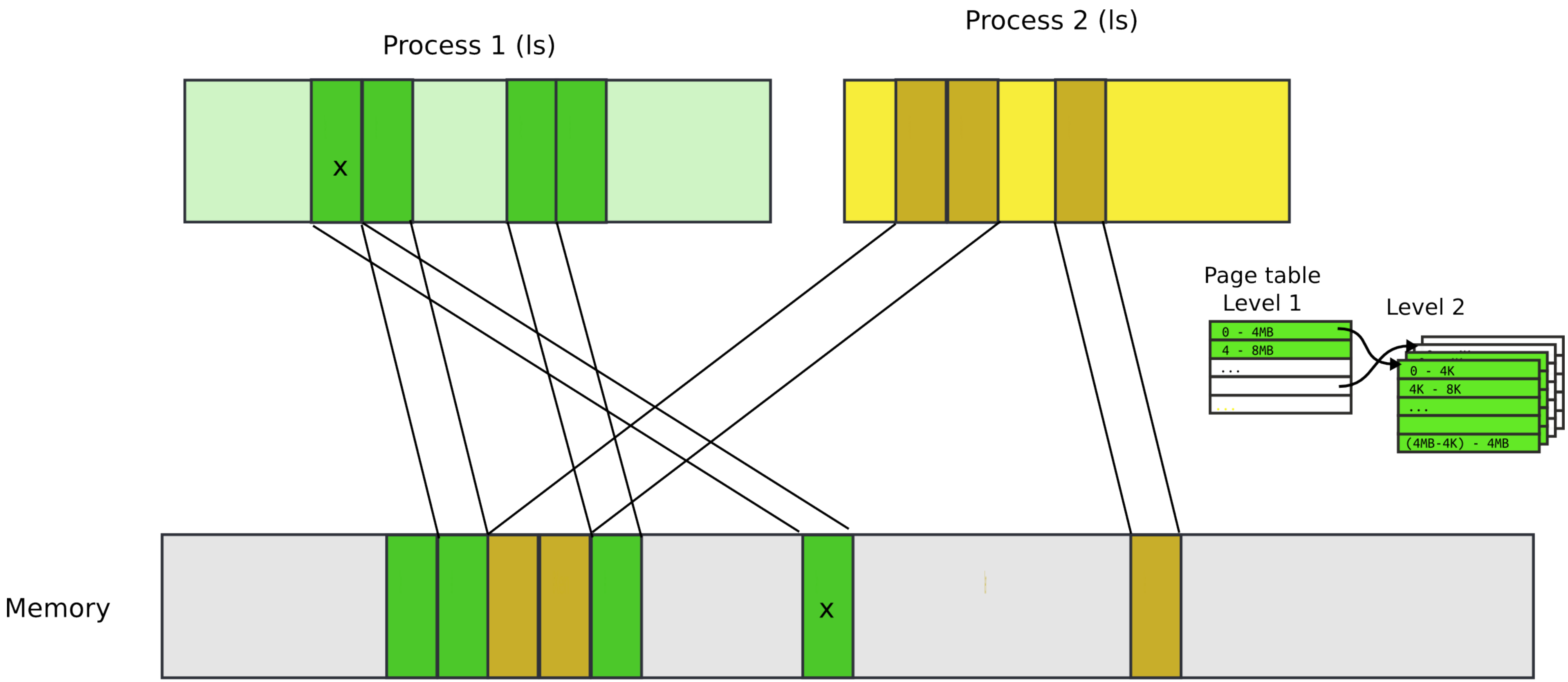
- What do you think is wrong with this approach?
  - Unlike registers the state of the program in memory can be large
  - Takes time to copy it in and out

Virtual address spaces

- Illusion of a private memory for each application
  - Keep a description of an address space
  - In one of the registers

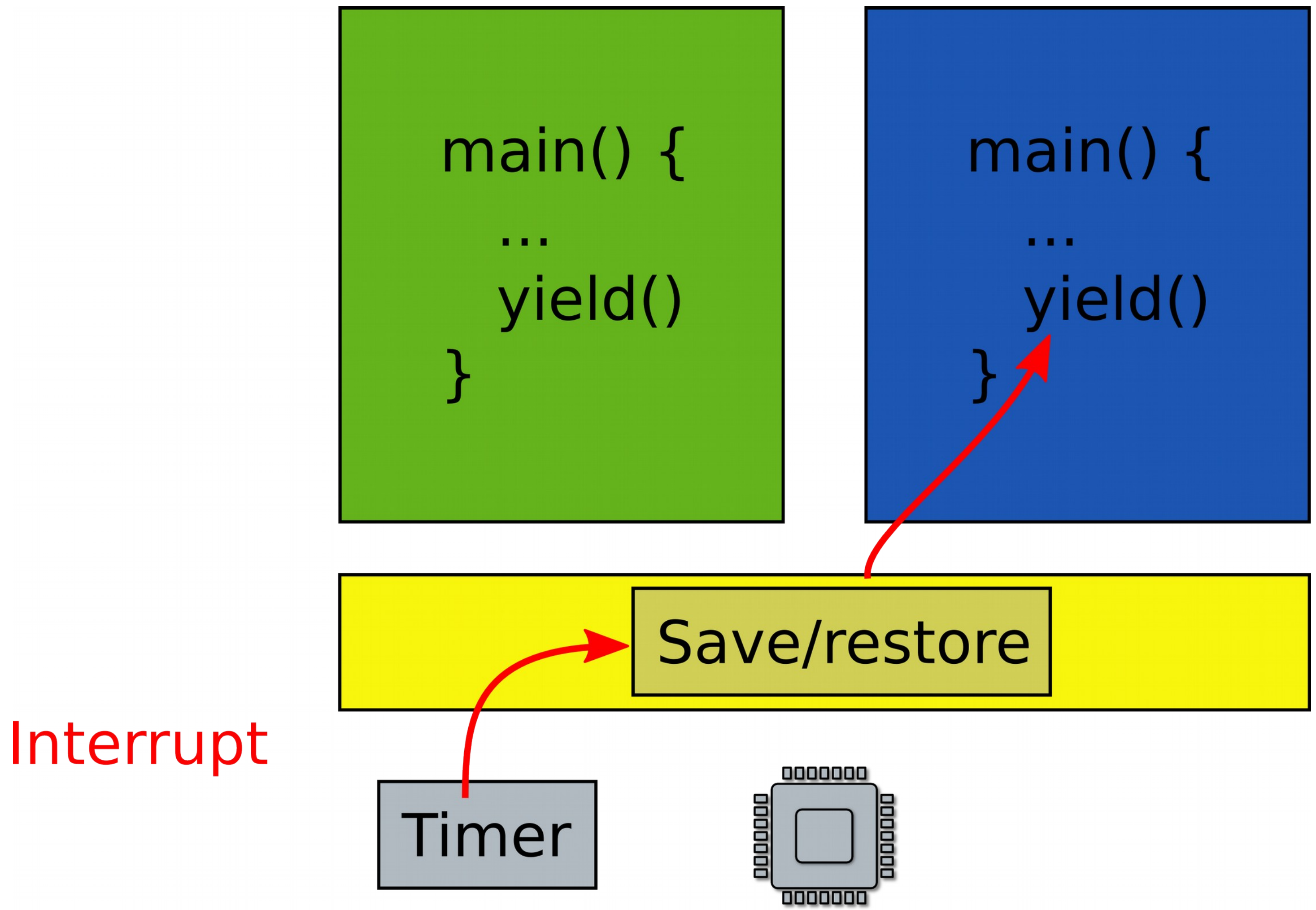
- OS maintains description of address spaces
  - Switches between them

Address spaces with page tables



Staying in control

- What if one program fails to release the CPU?
- It will run forever. Need a way to preempt it. How?

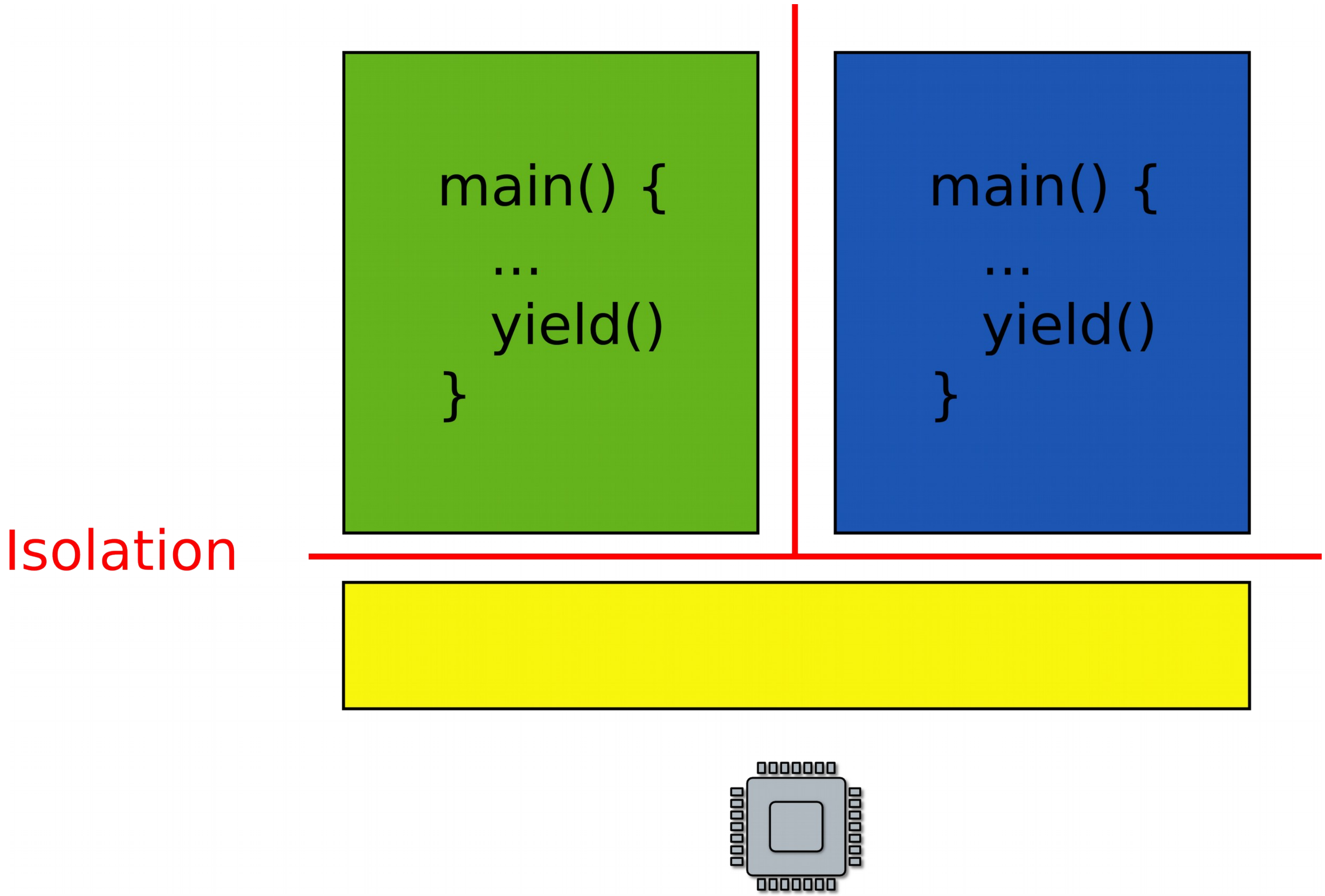


Scheduling

- Pick which application to run next
  - And for how long
- Illusion of a private CPU for each task
  - Frequent context switching

Isolation

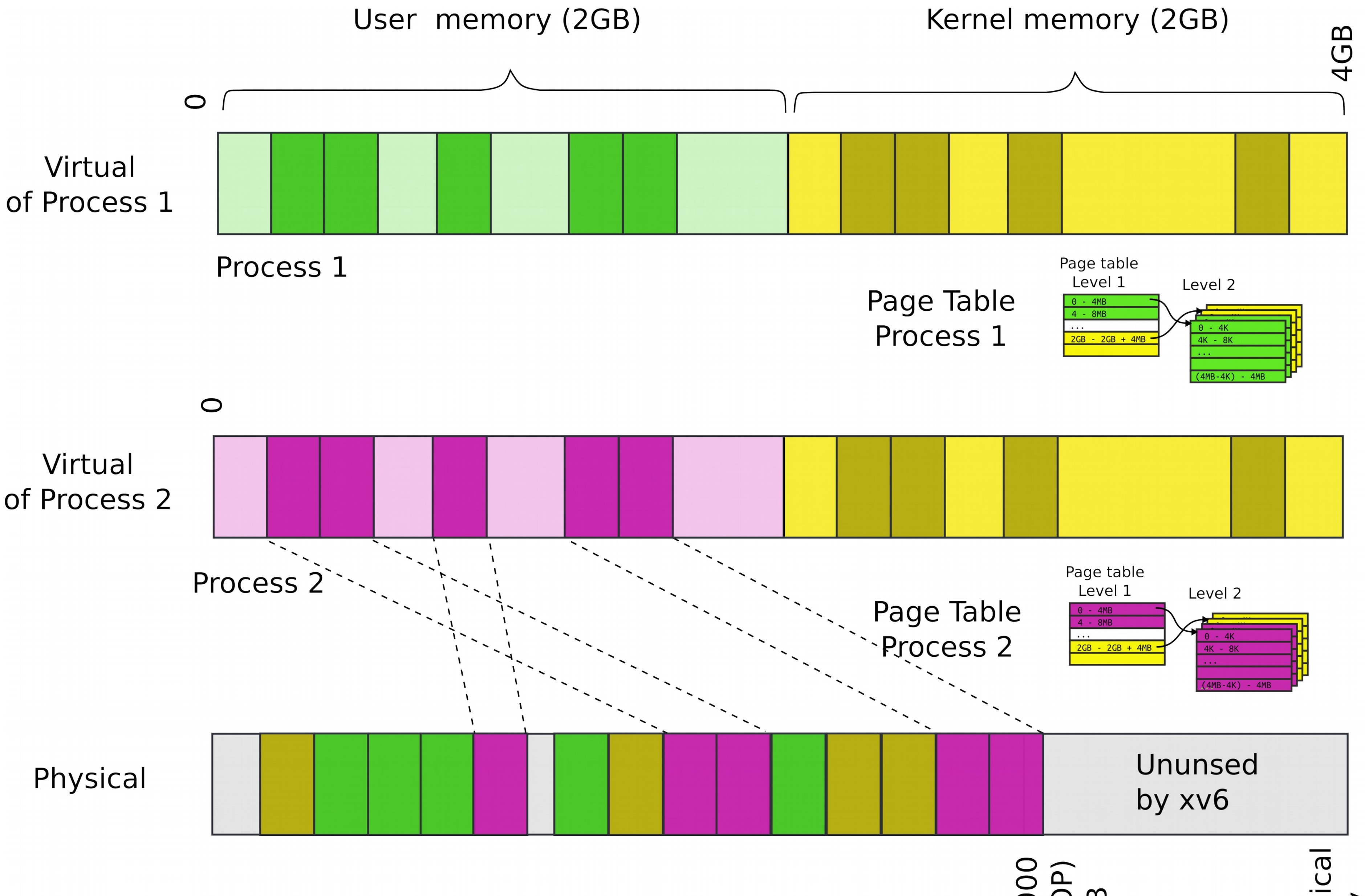
- What if one faulty program corrupts the kernel?
- Or other programs?



No isolation: open space office

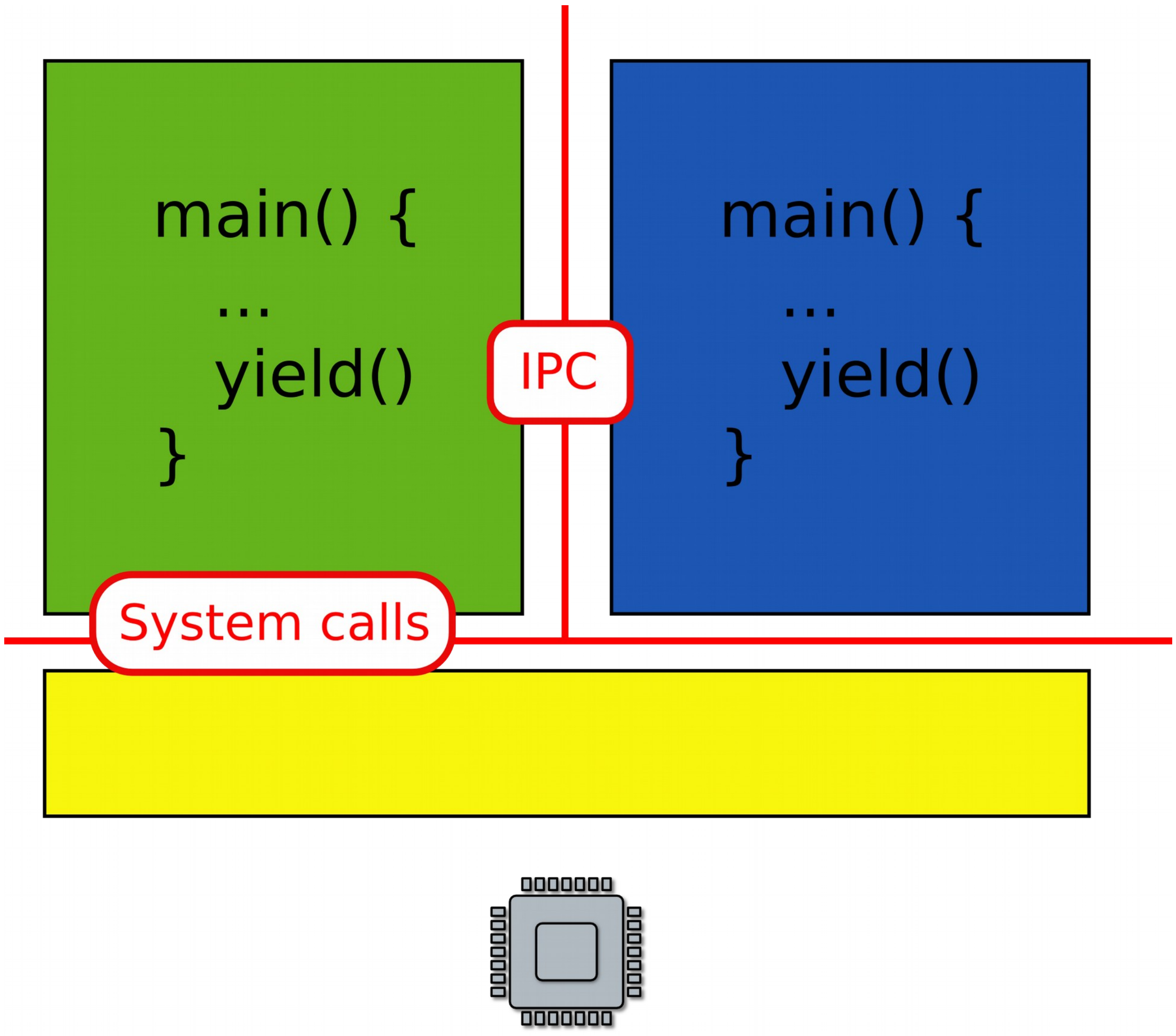
Isolated rooms

Each process has a private address space



P1 and P2 can't access each other memory

- What about communication?
- Can we invoke a function in a kernel?



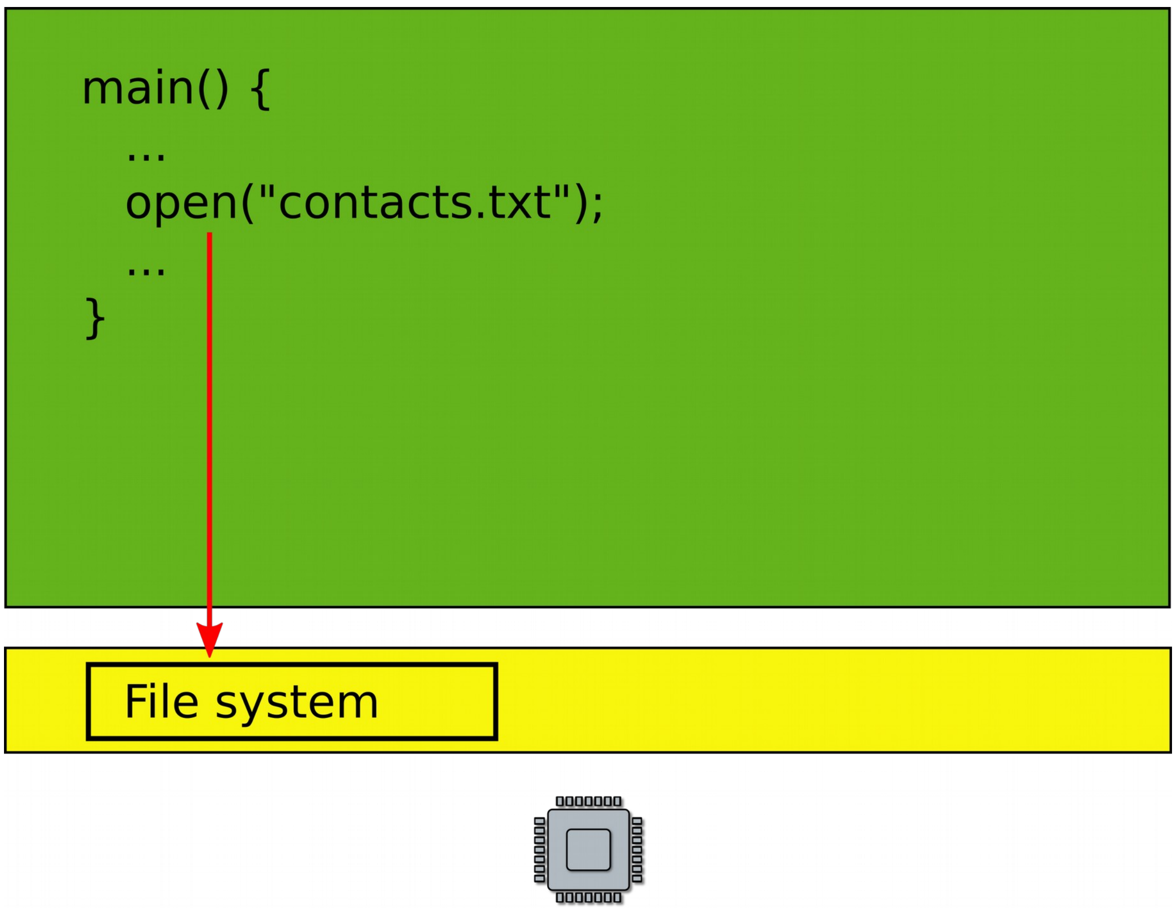
Files and network

- Want to save some data to a file?

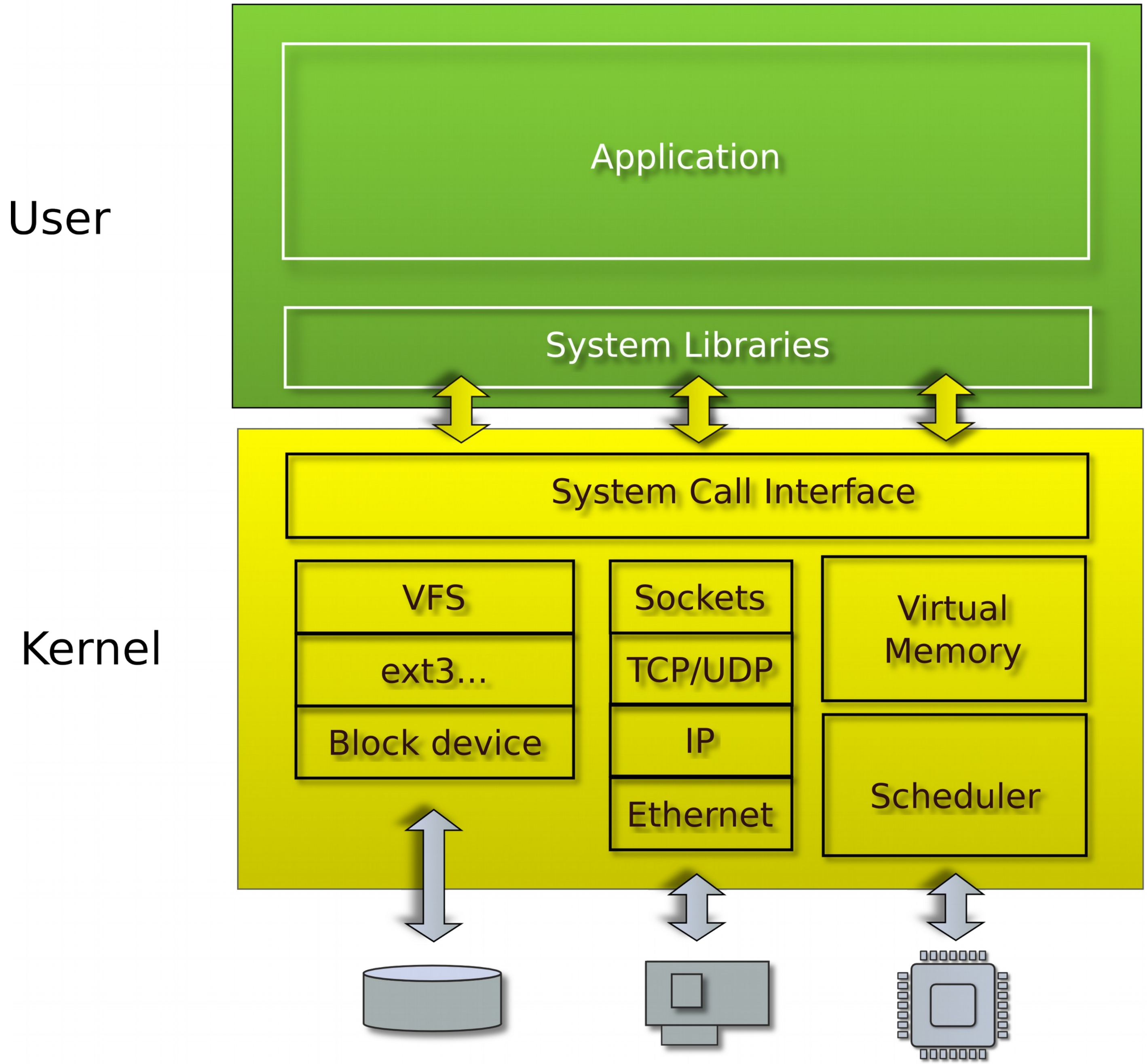
- Want to save some data in a file?
- Permanent storage
  - E.g., disks
- Disks are just arrays of blocks
  - write(block_number, block_data)

- File system and block device provide similar abstractions
- Permanent storage
  - E.g., disks
- Disks are just arrays of blocks
  - write(block_number, block_data)
- Files
  - High level abstraction for saving data
  - fd = open(“contacts.txt”);
  - fpritnf(fd, “Name:%s\n”, name);

File system



- Linux/Windows/Mac



Recap

- Run multiple programs
  - Each has illusion of a private memory and CPU
    - Context switching
    - Isolation and protection
  - Management of resources
    - Scheduling (management of CPU)
    - Memory management (management of physical memory)
- High-level abstractions for I/O
  - File systems
    - Multiple files, concurrent I/O requests
    - Consistency, caching
  - Network protocols
    - Multiple virtual network connections

Questions?

How hard it is to boot into main and print something on the screen?

- If you want to run this demo

  https://github.com/mars-research/hello-os.git

```
printf("Hello world\n");
```