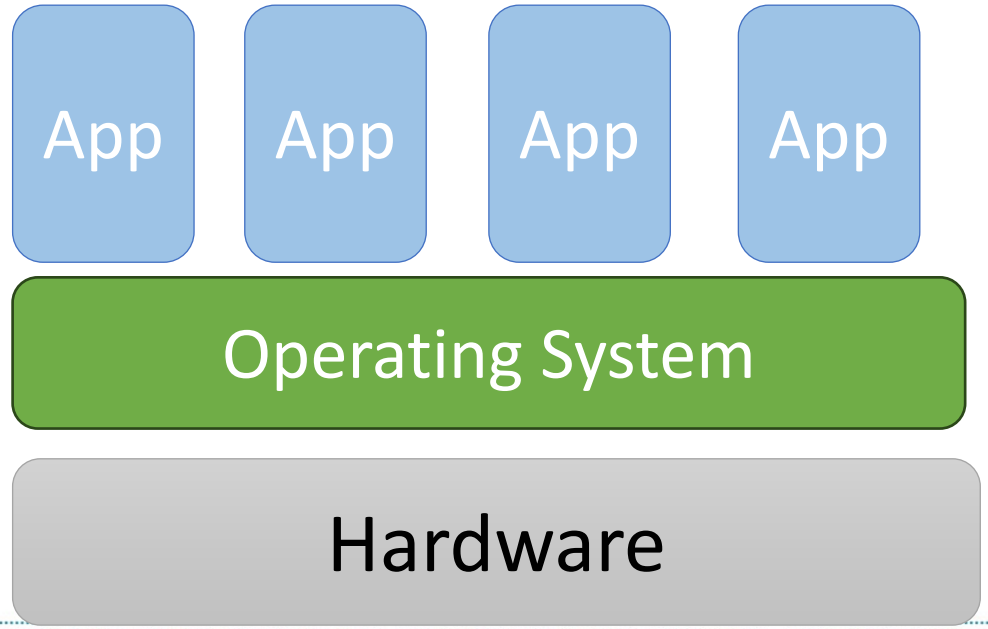
Quick refresher on Modern Operating Systems & CPUs

Introduction

What is an Operating System ?

- An OS is a program
- It seats between hardware and other programs
- It provides services to other programs
- It hides the hardware complexity
- It manages access to resources

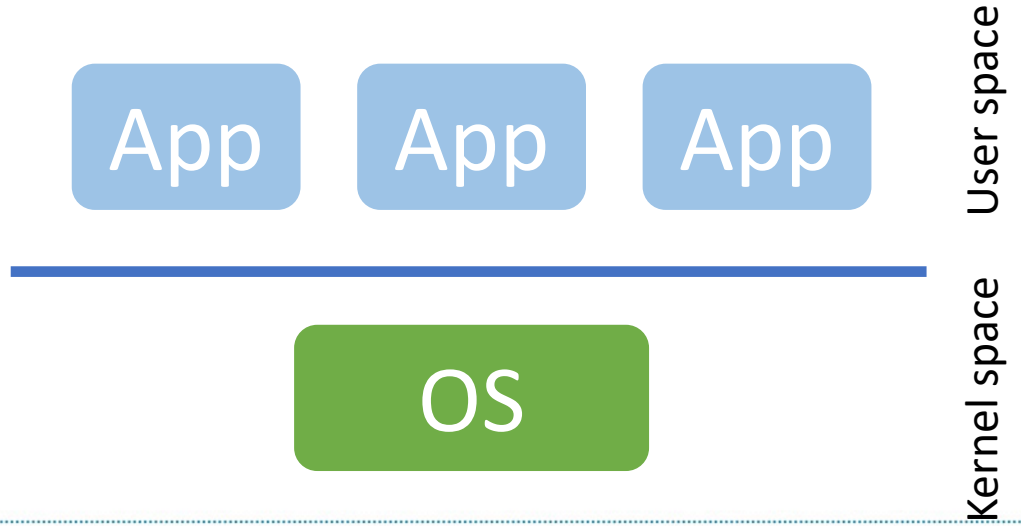


A special program

- The OS is the first program to be executed
  - It has a privileged access to the processor
- The OS can execute special instructions
  - If a standard app tries to call them, the CPU will generate errors
- The OS is not monolithic
  - Kernel
  - Drivers/Modules

Kernel space vs User space

- When the kernel executes, it’s in a privileged mode
  - Called kernel space
- An application executes in a standard mode
  - User space



Access to resources

- A program cannot access resources directly
  - It must ask the OS to do it on its behalf (system call)
- Examples of resources access
  - Memory allocation
  - I/O on devices
  - Display
- For each request, the OS checks
  - The program is allowed (security)
  - The resource is free or can be shared
  - Access is fair

CPU-OS interaction

Process

- A process is a program being executed
  - It's a service offered by the OS
- A process has
  - Its instructions
  - Its data (variables, open files…)
  - A process-specific CPU state
- A process always need at least 2 resources
  - CPU and Memory
- Multiple processes have to be isolated
  - Memory protection

CPU Sharing

- Multitasking when multiple processes
  - Each process needs the CPU to be executed
  - But so does the OS?!
- Consider the CPU as a resource
  - Give each process some time on the CPU
  - Alternate processes rapidly, feeling of continuous execution
- Giving the CPU to another process is called **Context Switch**
  - It’s a costly operation

Preemptive multitasking

- General idea
  - Allow a process to execute for at most x milliseconds on CPU
  - If process doesn't need CPU anymore before x, it gives it back
  - If not, process is kicked from the CPU and replaced by OS
- But how can this be done?
- It can't ☹
  - Unless we get help from the CPU

Interrupt

- An interrupt is a signal requiring an immediate action
- Software vs Hardware interrupt
- An interrupt is first processed by the CPU
  - It routes it to the correct interrupt handler (function)
- Who registers interrupt handlers to the CPU ?
  - The OS !
- Workflow
  1. An interrupt is raised
  2. CPU finds the matching interrupt handler
  3. Interrupt handler (OS) is given the CPU (executed)

Preemptive multitasking – 2

- The OS registers an interrupt handler for clock interruptions
  - Every 15-50ms (depending on OS), a clock raises an interrupt
  - So even if a process keeps the CPU, the OS will get it back after 15-50ms
- How can a process not need the CPU ?
  - After all it needs it to execute….
  - Many reasons actually
    - Wait for an I/O
    - Wait for another process…

Memory management

Memory as a resource

- Memory is a resource
  - All processes and OS need some
- Memory is sensitive
  - A process should not be able to
    - read memory from another process
    - Read memory from the OS
- Memory is scarce
  - Limited amount so has to be shared fairly
- General idea
  - Allocate parts of memory to processes/OS
- 3 point of view
  - Processes, OS and CPU

Memory management

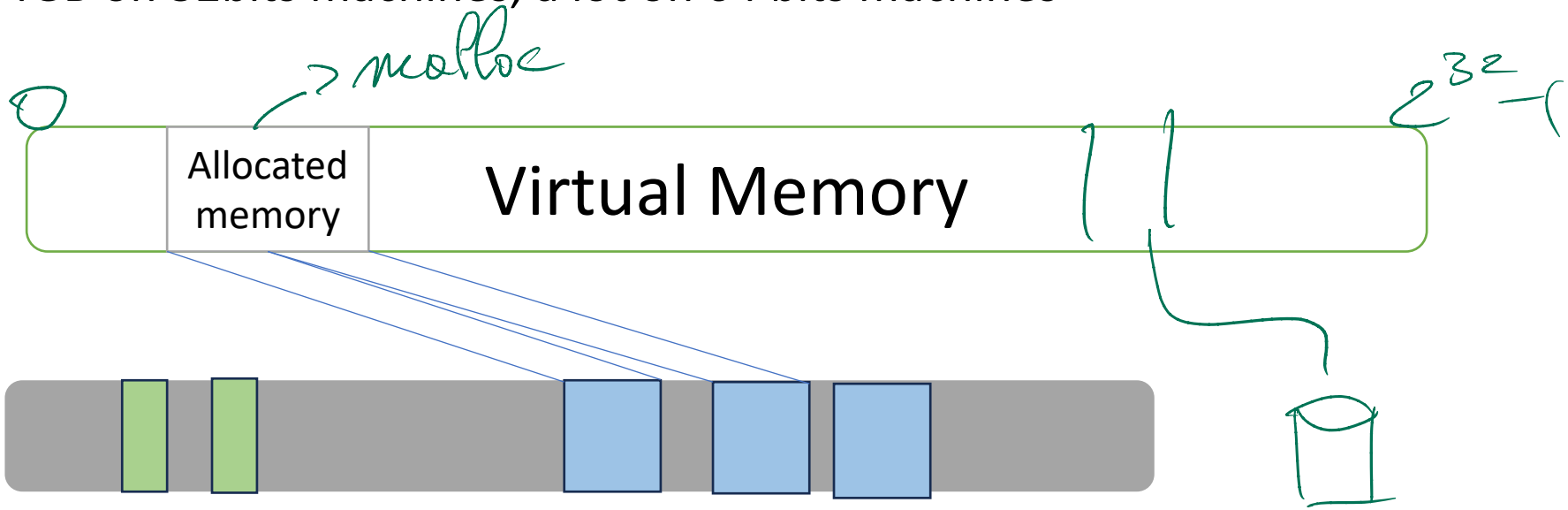
From the process's point of view

Process's point of view

- A process needs memory to execute
  - Needs may vary during its lifetime
- New memory needed
  - At creation
  - When executing (malloc())
  - When accessing files, communicating with other processes…
- Problem — hardware
  - Physical memory might be fragmented
  - Non contiguous memory addresses are hard for programmer !
- Solution
  - Use of virtual memory

Virtual Memory

- Each process has the illusion that it can address the whole memory
  - Logical address space
  - 4GB on 32bits machines, a lot on 64 bits machines



Memory management

From the CPU point of view

Managing physical memory

- The CPU manages access to physical memory
  - Different strategies depending on CPU family
- Memory Management Unit (MMU)
  - Dedicated unit on the CPU to help with memory management
- Pagination / Paging
  - Main strategy
  - Physical memory is divided in chunk called pages
    - 4KB or 4MB on x86, can be mixed!

why chunks of Memory

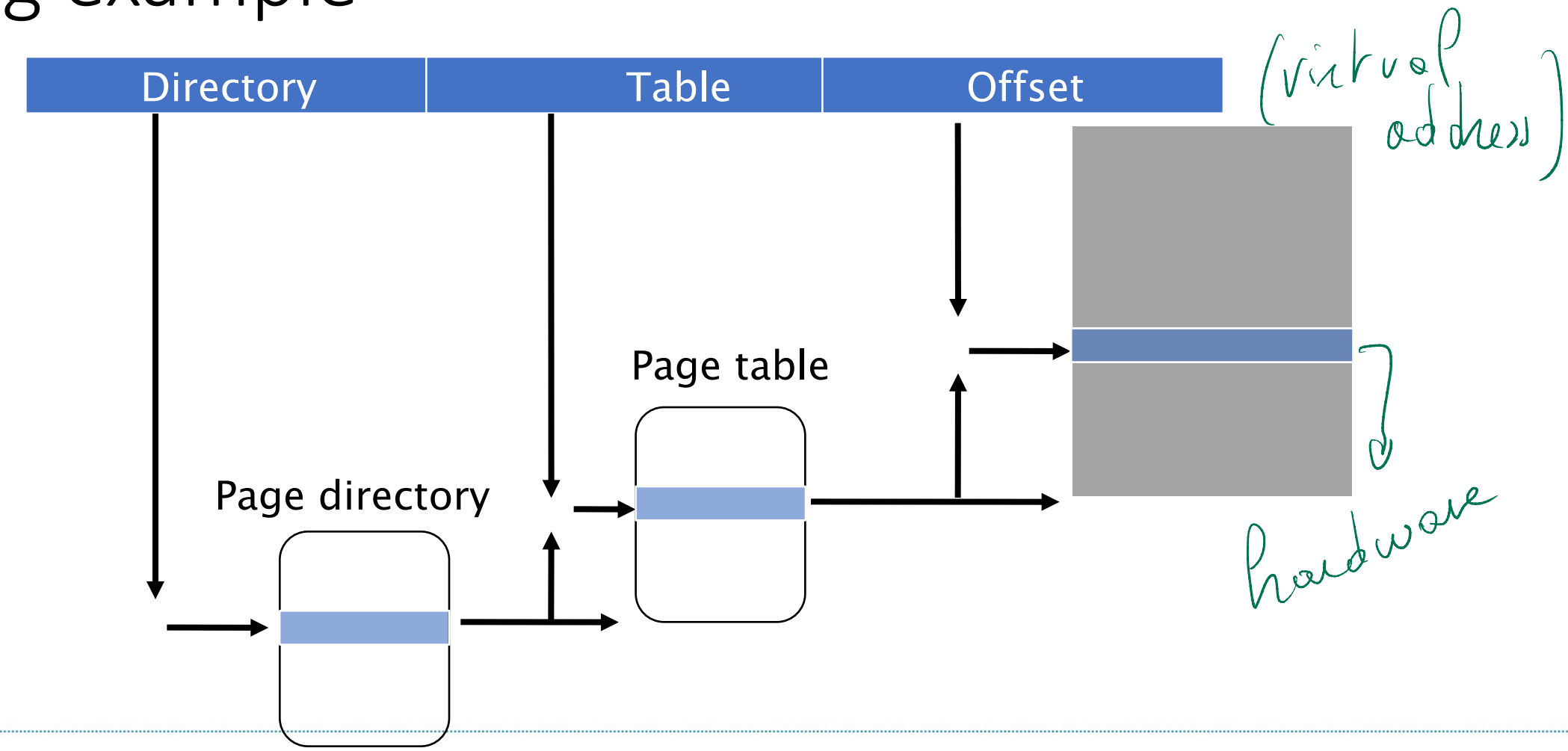
- Each time a process asks for memory it will get $\alpha \times 4kB$

Because overhead

Paging

- General idea
  - Divide a linear address in parts : directory, table, offset
- Maintain 2 data structures (simplified version)
    - Page Directory
    - Page Table
- Conversion from linear to physical in 2 steps
  - Use directory part in Page Directory to get Page Table address
  - Use table part in Page Table to get physical address of page
  - Use offset to get data
- Easy 😅

Paging example



Paging - 2

- Each memory access (process or kernel) has to go through these steps
  - Need to be implemented in hardware
  - But not fast enough
    - Use of a caching mechanism called Translation Lookaside Buffer (TLB)
- But this cannot work !!
  - What about 2 processes using the same virtual address (allowed)?
  - Surely they will end up on the same physical address, unless…
- Unless the Page Directory is process dependent !

Memory management

From the OS point of view

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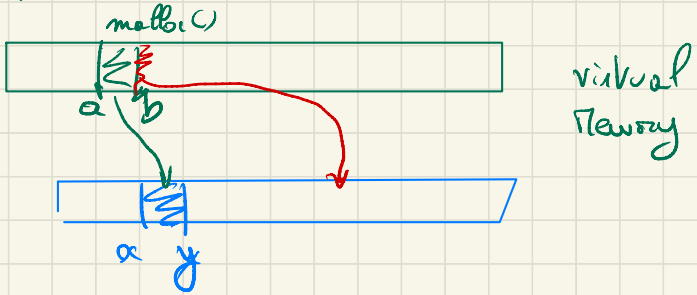
OS and memory

- The OS needs memory for itself
  - High priority, not really notion of fairness
- The OS allocates manages memory for processes
  - Keeps track of mapping virtual memory with physical memory with help of CPU → MMU
  - Decide whether page should be in memory or on disk (swap)
- The OS handles memory errors
  - CPU error if a process tries to access an unallocated memory page
  - OS will take action depending on situation
    - Kill the process (SegFault)
    - Allocate memory…

SegFault



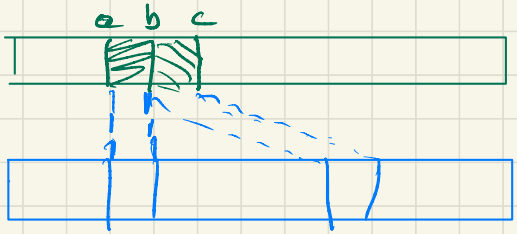
virtual a → physical a

virtual b → physical y

what happens when your process access b+1

1) Error if b+1 is translated to physical address not belonging to process

2) Sometimes b+1 is translated to a physical address which belongs to the process



ISA

Instruction Set Architecture (ISA)

- An abstract model of a computer
  - Describes how the CPU is controlled by the software
- The ISA defines
  - Supported data types and Registers
  - How the hardware manages main memory (e.g. virtual memory)
  - Which instructions a microprocessor can execute
  - The input/output model
- ISA essentially describes what the computer can do and how it does it

Typical ISA : instructions + HW archi

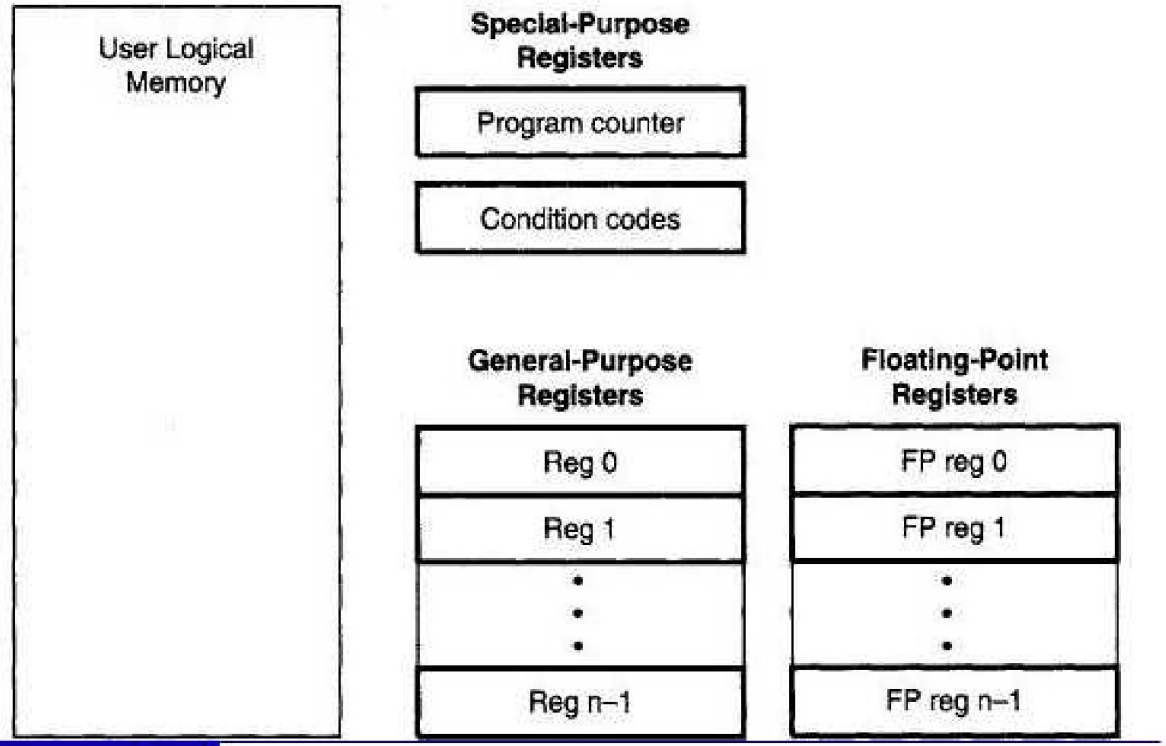


Figure A.6 Key Architected User State of a Typical ISA. *This includes a logical (virtual) memory space, a special-purpose register, general-purpose registers, and floating-point registers.*

Registers

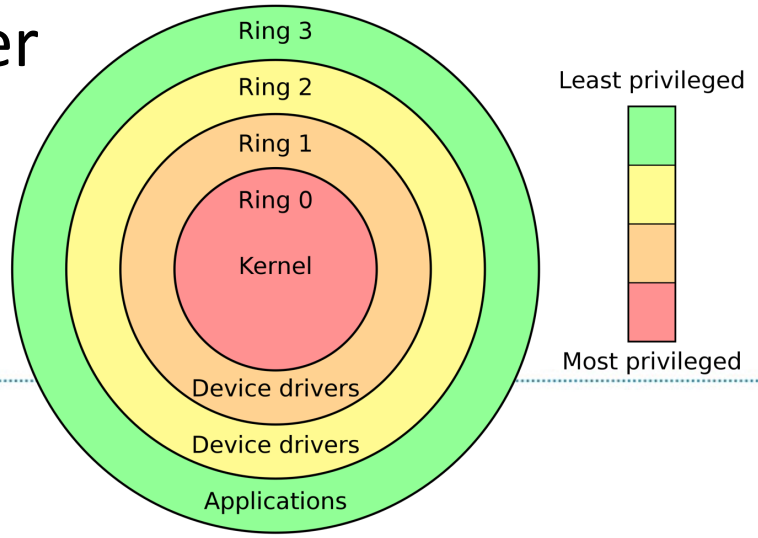
- Generic registers
  - Can hold different types of values
- Typed registers for specific operands
  - ISA dependent
  - Ex : pointer to a memory segment in Intel IA-32 ISA
- Specific registers
  - Program counters (PC) address of the next instruction
  - Condition

User ISA

- Part of the ISA instructions for user applications
- 4 categories
  - Load/store memory <-> registers
  - Integer/logical operations and bit shifting
  - Floating point operations
  - Branching and jumps

System ISA

- Processors features several executions modes
  - Numbered from 0 to 3 in general
    - Intel/AMD has 4, ARM v7 has 3, ARM v8 has 4
- Used to protect data and functionality from faults
  - Hierarchical, lower is higher privilege
- Current execution mode stored in specific register



Source: wikipedia

System registers

- Time register
  - E.g. Time stamp counter on x86
- Traps and interruptions registers
- Traps and interruptions masking registers
- Page directory pointer
  - E.g. CR3 on Intel (Control Register 3 or PDBR for Page Directory Base Register)

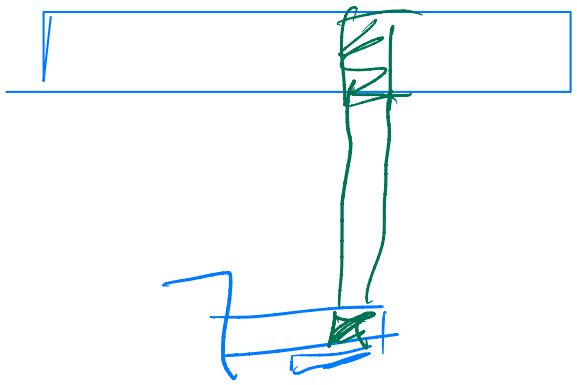
Traps and interruptions

- Traps and interruptions
  - Transfer of control to the OS
- Interruption
  - Clock
  - Request from an I/O device
- Trap
  - Error during execution of an instruction (page fault, division by 0)
  - Explicit call from a program

System ISA : processor management

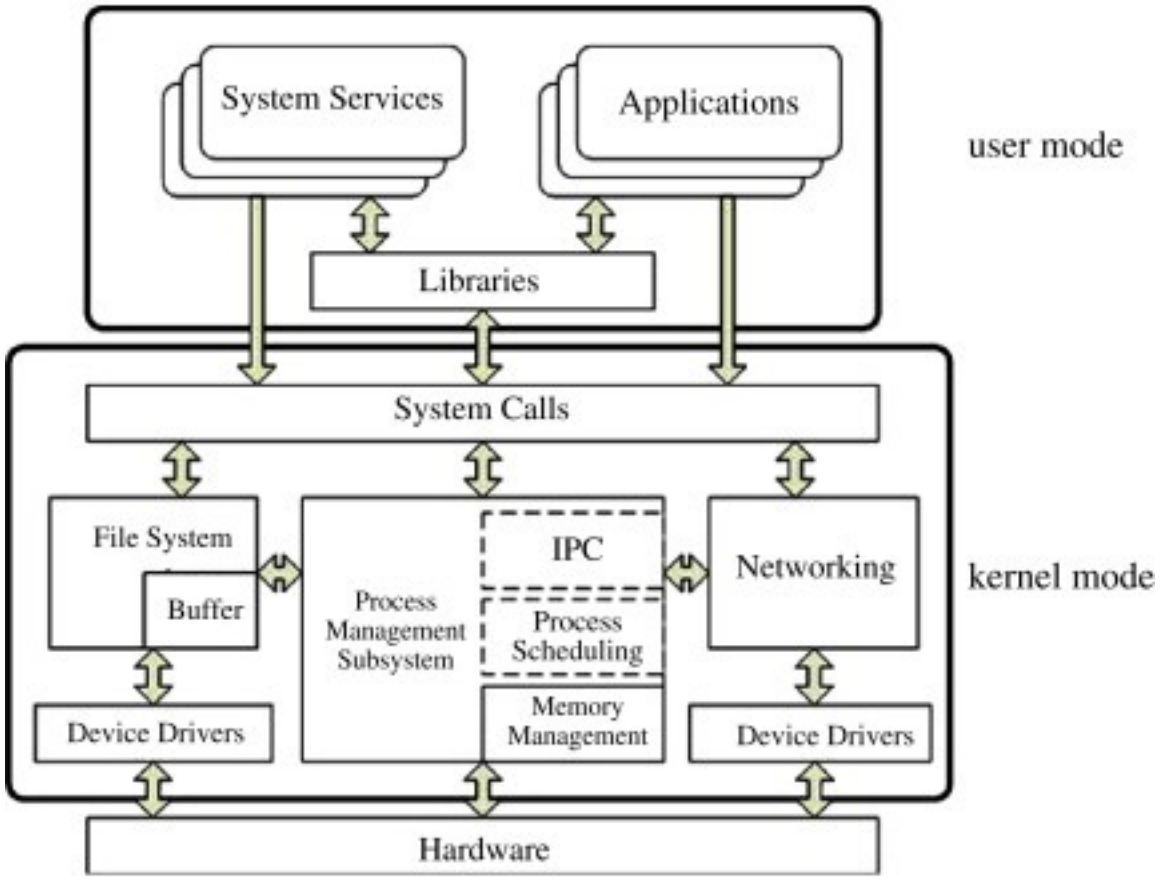
- OS must be able to hand over control of the processor to processes
  - Jump to an instruction of the user program
  - Modification of CPU registers
- And regain control later
  - Use of interrupts

System ISA : I/O Management



- 3 models
- Memory Mapped I/O
  - Peripheral device's memory is mapped to CPU's memory
  - Transfer between memory and device uses memory transfer instructions
- Instruction based I/O
  - Special instruction to access I/O ports
- DMA I/O
  - Direct Memory Access
  - Peripheral can access main memory directly without CPU

Linux kernel schematic view



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Source : https://www.sciencedirect.com/science/article/pii/S0895717709003409

Conclusion

Conclusion

- The OS
  - Is a program
  - Provides services to other programs (processes)
- Some services require collaborating with the CPU
  - Multitasking
  - Memory management (safety)
- Different CPUs can have similar behaviour
  - Described in ISA
  - ISA specifies how the OS should interract