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This *cooperative* approach needs something extra

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Similarly, interrupts from peripherals like terminals or disks pass control to the OS

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Always mediated by the OS, of course

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When a key is hit, an interrupt happens, the OS takes over, schedules and runs the appropriate program to deal with the keystroke

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My PC is running at about 150 interrupts per second (timers and other stuff)

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This means the OS will continue to schedule the same program over many timer interrupts

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We shall return to scheduling later

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We shall start by looking at general hardware protection mechanisms

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- Unprivileged operations. Like arithmetic operations, loads, stores, jumps and so on. Any program can execute these
- Privileged operations. Like access peripherals, reboot the machine. Only certain privileged programs can run these

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- Privileged. For systems operation, called *kernel mode*

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The latest Intel and AMD architectures added a Ring -1 (for OS virtualisation)

History

Exercise And it doesn't stop there. Read about rings -2 and -3

Exercise The ARM architecture has 3 levels. Read about this

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For example, the OS may decide to disallow the operation, and kill the program (i.e., not run it any more)

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And the user program can never manage to get into privileged mode as every transition to privileged mode is tied by the hardware to a jump to the OS

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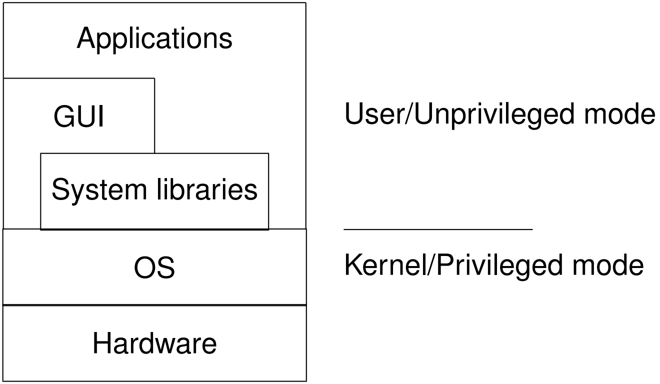

There is a strict divide between kernel (OS) code and user code, controlled by the hardware

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The `open` system library function simply hides these details from the programmer

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In user mode, only “safe” things are possible

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This was because the earliest PC hardware did not support such things (no rings)

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Incidentally, Microsoft's need for backwards compatability with these early systems is a major reason why they have so many problems with security

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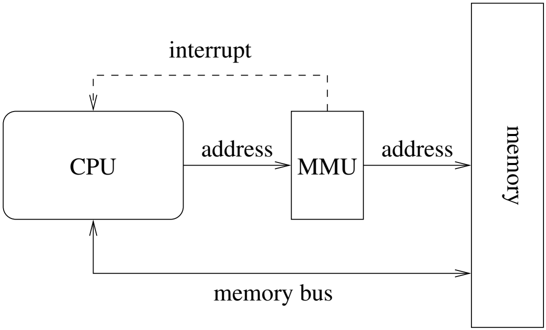
There is a table of flags in a special piece of hardware: the *memory management unit* (MMU). These flags say whether the *currently running* (user mode) program can read or write a given area of memory

History



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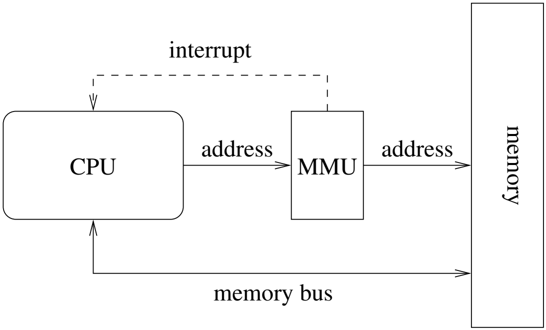

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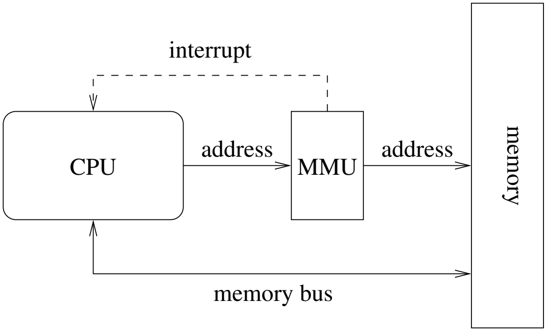

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It is often useful to separate ability to read from ability to write

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And if an unprivileged program tries to read or write to an area of memory for which it does not have the required permission (say some other program's or the OS's memory) the MMU raises an interrupt and the OS takes control again

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A page is just a contiguous area of memory: 4096 bytes is popular on modern machines, though current hardware can support 4MB pages

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There is usually also an *executable* flag: can you execute code from this memory address?

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This we shall cover later, but it builds on the ideas above and provides a much more flexible method of protection

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An interrupt is raised if the program tries to read or write memory that is not allocated to it

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- MacOS. MacOS X is a Unix derivative (BSD), from 1999 onwards. Earlier systems (MacOS 9 and earlier) were completely different, with no preemption, only cooperative

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- OS/2. Initially from Microsoft and IBM (1997), then just IBM as Microsoft went off to do its own thing. Intended to be the followup to DOS. Multitasking when the hardware could support it: OS/2 2.0 (1992) could run multiple copies of DOS/Windows simultaneously. Previously used a lot in bank ATMs (until IBM ended support in 2006). OS/2 3.0 became Windows NT

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All PC-level OSs have MMU protection (and more); while embedded systems have it if required, otherwise not (so not to have the cost of the MMU hardware)