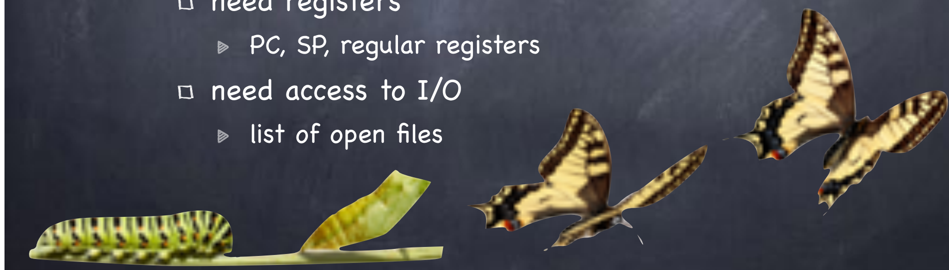
The Process

A running program

From Program to Process

- To make the program's code and data come alive
  - need a CPU
  - need memory — the process' address space
    - for data, code, stack, heap
  - need registers
    - PC, SP, regular registers
  - need access to I/O
    - list of open files

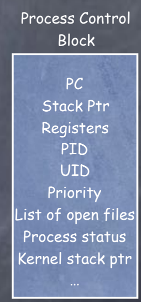


A First Cut at the API

- Create
  - causes the OS to create a new process
- Destroy
  - forcefully terminates a process
- Wait (for the process to end)
- Other controls
  - e.g. to suspend or resume the process
- Status
  - running? suspended? blocked? for how long?

How the OS Keeps Track of a Process

- A process has code
  - OS must track program counter
- A process has a stack
  - OS must track stack pointer
- OS stores state of process in Process Control Block (PCB)
  - Data (program instructions, stack & heap) resides in memory, metadata is in PCB



You'll Never Walk Alone

- Machines run (and thus OS must manage) multiple processes
  - how should the machine's resources be mapped to these processes?
- OS as a referee…

You'll Never Walk Alone

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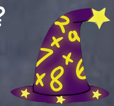
- Enter the illusionist!



  - give every process the illusion of running on a private CPU
    - which appears slower than the machine's

    } Virtualize the CPU

  - give every process the illusion of running on a private memory
    - which may appear larger(??) than the machine's

    } Virtualize memory

Isolating Applications

Reading and writing memory, managing resources, accessing I/O...

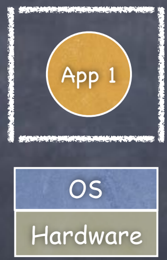
- Buggy apps can crash other apps
- Buggy apps can crash OS
- Buggy apps can hog all resources
- Malicious apps can violate privacy of other apps
- Malicious apps can change the OS

Mechanism and Policy

- Mechanism
  - what the system can do
- Policy
  - what the system should do

Mechanisms should not determine policies!

The Process, Refined



- An abstraction for isolation
  - the execution of an application program with restricted rights
- The enforcing mechanism must not hinder functionality
  - still efficient use of hardware
  - enable safe communication

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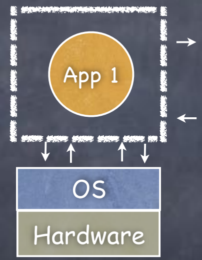

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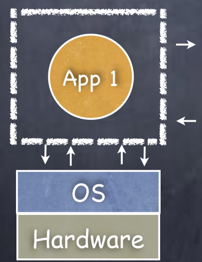
Special

- The process abstraction is enforced by the kernel
  - all kernel is in the OS
  - not all the OS is in the kernel
    - (why not? robustness)
    - widgets libraries, window managers etc

How can the OS Enforce Restricted Rights?

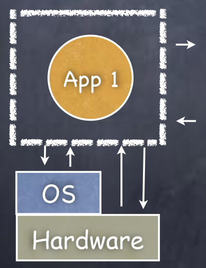
- Easy: kernel interprets each instruction!



  - slow
  - many instructions are safe: do we really need to involve the OS?

How can the OS enforce restricted rights?

Mechanism: Dual Mode Operation



- hardware to the rescue: use a mode bit
  - in user mode, processor checks every instruction
  - in kernel mode, unrestricted rights
- hardware to the rescue (again) to make checks efficient

Amongst our weaponry are such diverse elements as...

- Privileged instructions
  - in user mode, no way to execute potentially unsafe instructions
- Memory isolation
  - in user mode, memory accesses outside a process' memory region are prohibited
- Timer interrupts
  - kernel must be able to periodically regain control from running process

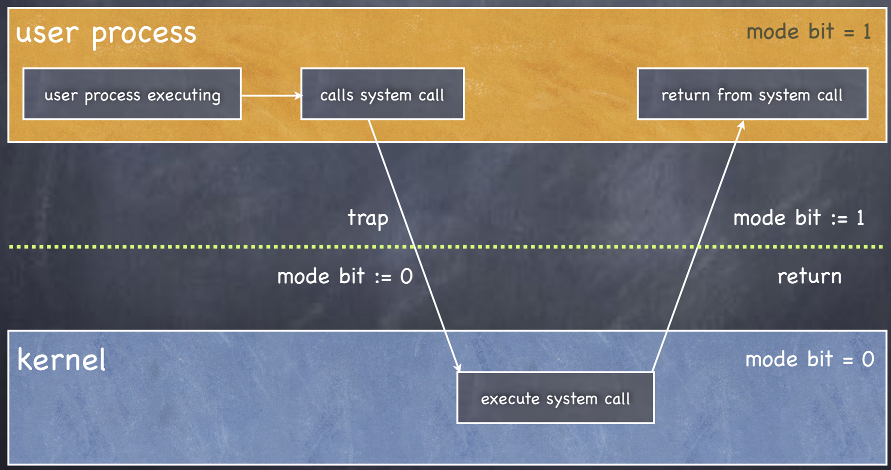
I. Privileged instructions

- Set mode bit
- I/O ops
- Memory management ops
- Disable interrupts
- Set timers
- Halt the processor

I. Privileged instructions

- But how can an app do I/O then?
  - system calls achieve access to kernel mode only at specific locations specified by OS
- Executing a privileged instruction while in user mode (naughty naughty...) causes a processor exception....
  - ...which passes control to the kernel

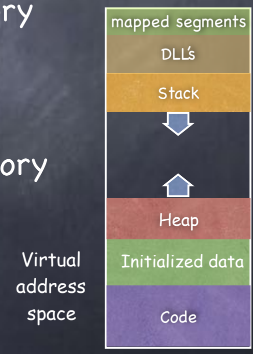
Crossing the line



II. Memory Protection

Step 1: Virtualize Memory

- Virtual address space: set of memory addresses that process can "touch"
  - CPU works with virtual addresses
- Physical address space: set of memory addresses supported by hardware

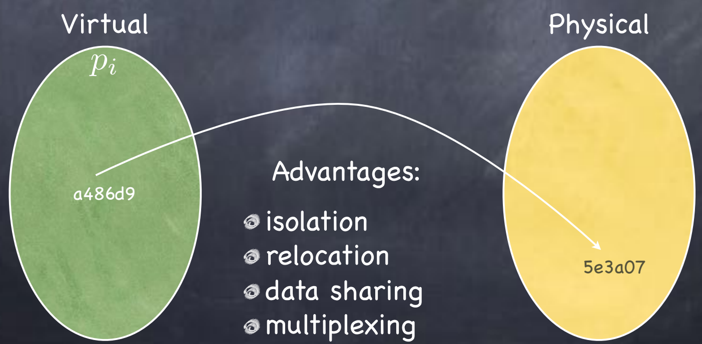


II. Memory Isolation

Step 2: Address Translation

- Implement a function mapping

$\langle pid, virtual\ address \rangle$ into $physical\ address$

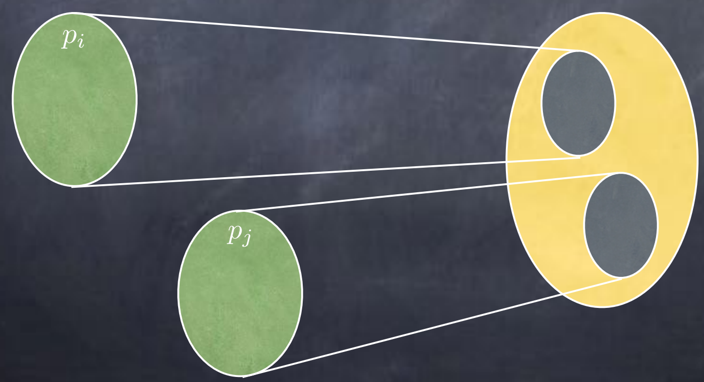


Advantages:

- isolation
- relocation
- data sharing
- multiplexing

Isolation

- At all times, functions used by different processes map to disjoint ranges — aka "Stay in your room!"



Relocation

- The range of the function used by a process can change over time

Relocation

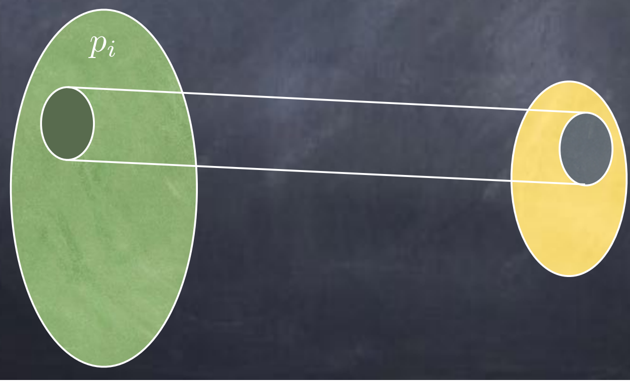
- The range of the function used by a process can change over time — "Move to a new room!"

Data Sharing

- Map different virtual addresses of distinct processes to the same physical address — "Share the kitchen!"

Multiplexing

- Create illusion of almost infinite memory by changing domain (set of virtual addresses) that maps to a given range of physical addresses — ever lived in a studio?



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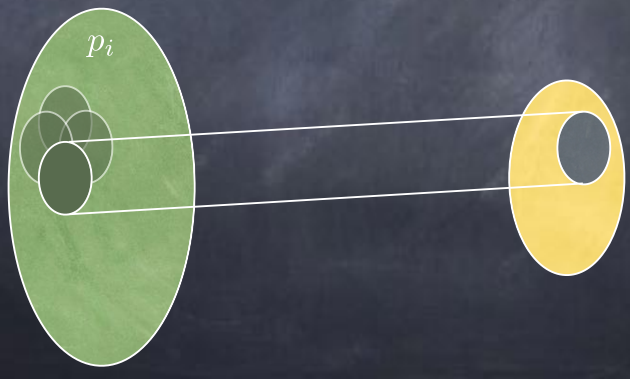

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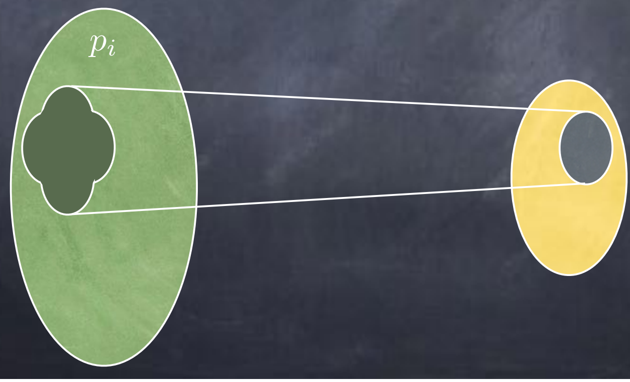
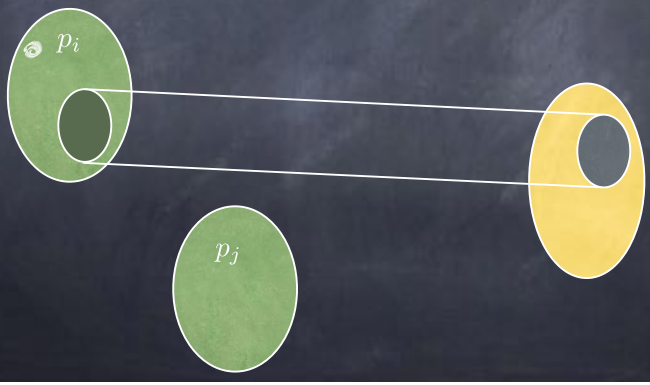


More Multiplexing

- At different times, different processes can map part of their virtual address space into the same physical memory — change tenants!



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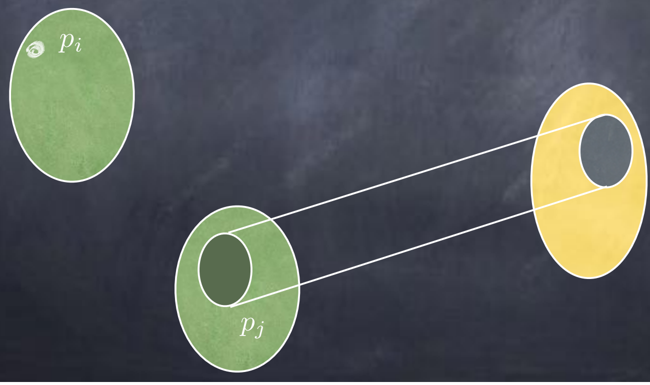
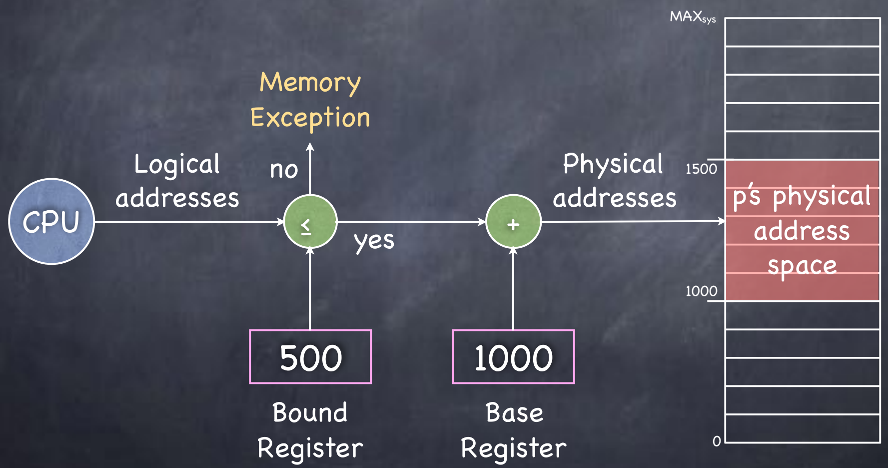


A simple mapping mechanism: Base & Bound



On Base & Limit

- Contiguous Allocation: contiguous virtual addresses are mapped to contiguous physical addresses
- Isolation is easy, but sharing is hard
  - Two copies of emacs: want to share code, but have heap and stack distinct...
- And there is more...
  - Hard to relocate
  - Hard to account for dynamic changes in both heap and stack