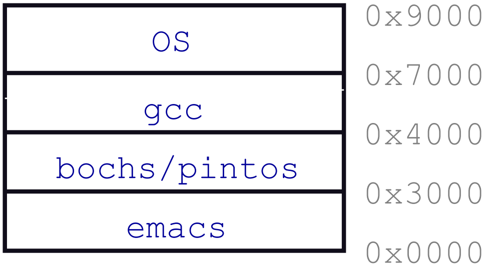
Want processes to co-exist

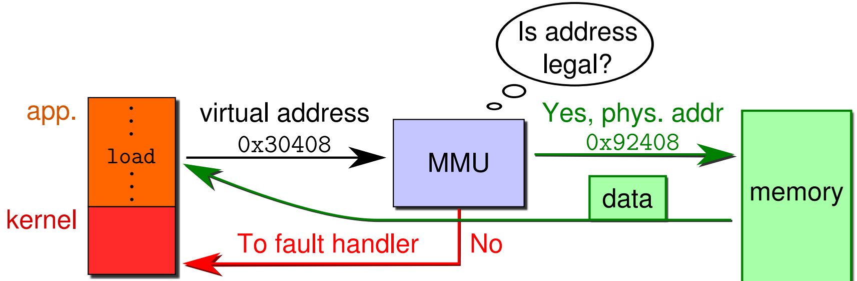


- **Consider multiprogramming on physical memory**
  - What happens if pintos needs to expand?
  - If emacs needs more memory than is on the machine??
  - If pintos has an error and writes to address 0x7100?
  - When does gcc have to know it will run at 0x4000?
  - What if emacs isn't using its memory?

Issues in sharing physical memory

- **Protection**
  - A bug in one process can corrupt memory in another
  - Must somehow prevent process *A* from trashing *B*'s memory
  - Also prevent *A* from even observing *B*'s memory (ssh-agent)
- **Transparency**
  - A process shouldn't require particular physical memory bits
  - Yes processes often require large amounts of contiguous memory (for stack, large data structures, etc.)
- **Resource exhaustion**
  - Programmers typically assume machine has "enough" memory
  - Sum of sizes of all processes often greater than physical memory

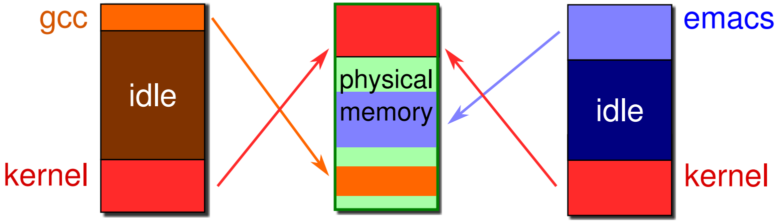
Virtual memory goals



- **Give each program its own "virtual" address space**
  - At run time, Memory-Management Unit relocates each load, store to actual memory… App doesn't see physical memory
- **Also enforce protection**
  - Prevent one app from messing with another's memory
- **And allow programs to see more memory than exists**
  - Somehow relocate some memory accesses to disk

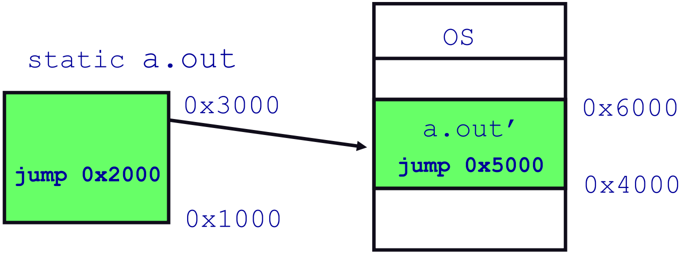
Virtual memory advantages

- **Can re-locate program while running**
  - Run partially in memory, partially on disk
- **Most of a process's memory will be idle (80/20 rule).**



  - Write idle parts to disk until needed
  - Let other processes use memory of idle part
  - Like CPU virtualization: when process not using CPU, switch (Not using a memory region? switch it to another process)
- **Challenge: VM = extra layer, could be slow**

Idea 1: load-time linking



- *Linker* **patches addresses of symbols like** `printf`
- **Idea: link when process executed, not at compile time**
  - Determine where process will reside in memory
  - Adjust all references within program (using addition)
- **Problems?**

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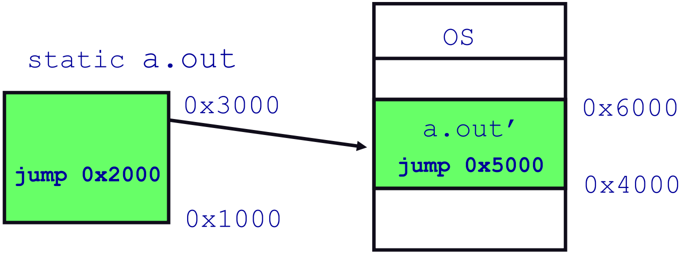

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- **Idea: link when process executed, not at compile time**
  - Determine where process will reside in memory
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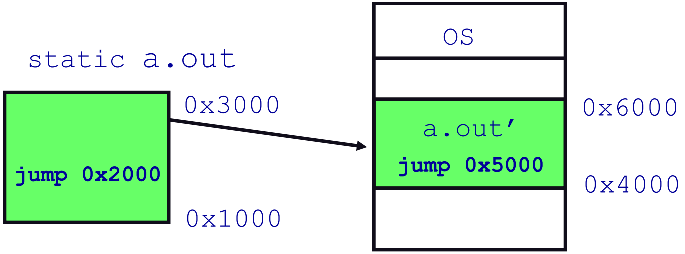
- **Problems?**
  - How to enforce protection
  - How to move once in memory (Consider: data pointers)
  - What if no contiguous free region fits program?

Idea 2: base + bound register



- **Two special privileged registers: base and bound**
- **On each load/store:**
  - Physical address = virtual address + base
  - Check $0 \leq$ virtual address $<$ bound, else trap to kernel
- **How to move process in memory?**
- **What happens on context switch?**

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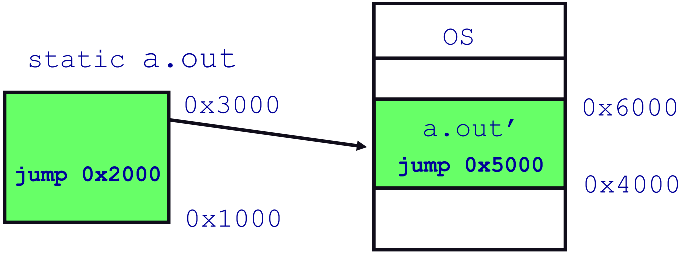

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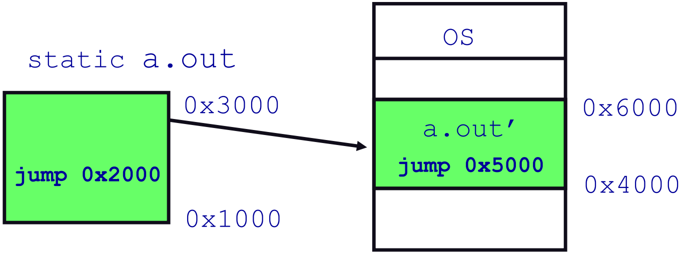

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- **How to move process in memory?**
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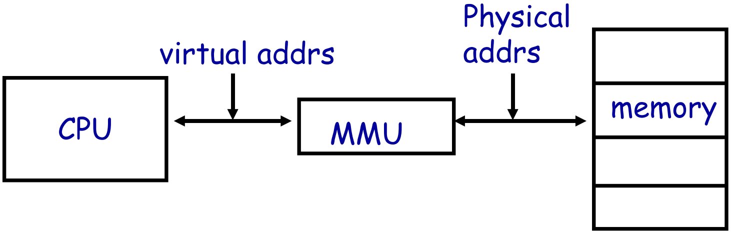
- **What happens on context switch?**
  - OS must re-load base and bound register

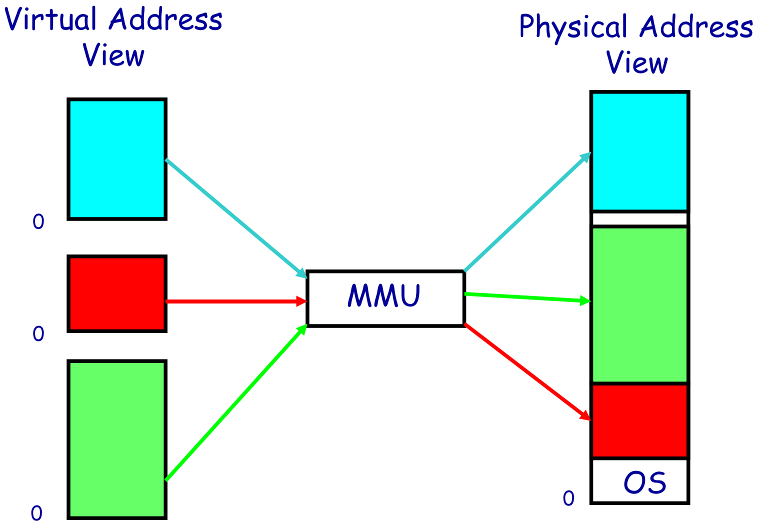
Definitions

- **Programs load/store to virtual (or logical) addresses**
- **Actual memory uses physical (or real) addresses**
- **VM Hardware is Memory Management Unit (MMU)**



  - Usually part of CPU
  - Accessed w. privileged instructions (e.g., load bound reg)
  - Translates from virtual to physical addresses
  - Gives per-process view of memory called address space

Address space



Base+bound trade-offs

- **Advantages**
  - Cheap in terms of hardware: only two registers
  - Cheap in terms of cycles: do add and compare in parallel
  - Examples: Cray-1 used this scheme

- **Disadvantages**

Base+bound trade-offs

- **Advantages**
  - Cheap in terms of hardware: only two registers
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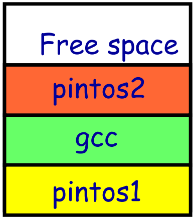
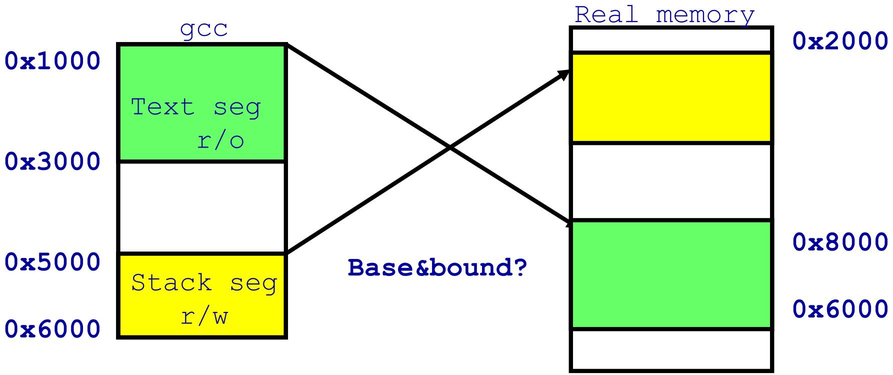
- **Disadvantages**
  - Growing a process is expensive or impossible
  - No way to share code or data (E.g., two copies of bochs, both running pintos)



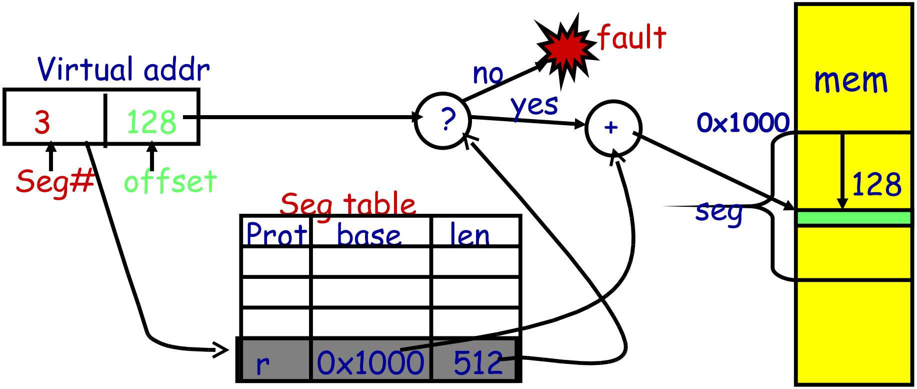
- **One solution: Multiple segments**
  - E.g., separate code, stack, data segments
  - Possibly multiple data segments

Segmentation



- **Let processes have many base/bound regs**
  - Address space built from many segments
  - Can share/protect memory at segment granularity
- **Must specify segment as part of virtual address**

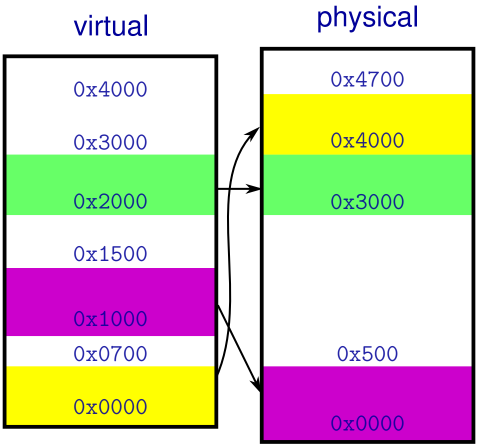
Segmentation mechanics



- **Each process has a segment table**
- **Each VA indicates a segment and offset:**
  - Top bits of addr select segment, low bits select offset (PDP-10)
  - Or segment selected by instruction or operand (means you need wider “far” pointers to specify segment)

Segmentation example

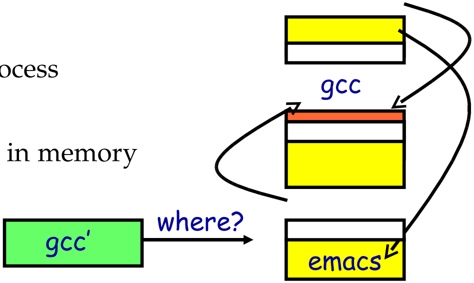
Seg	base	bounds	rw
0	0x4000	0x6ff	10
1	0x0000	0x4ff	11
2	0x3000	0xfff	11
3			00



- **2-bit segment number (1st digit), 12 bit offset (last 3)**
  - Where is 0x0240? 0x1108? 0x265c? 0x3002? 0x1600?

Segmentation trade-offs

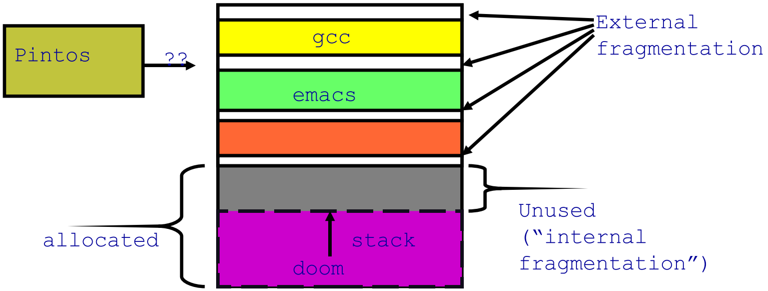
- **Advantages**
  - Multiple segments per process
  - Allows sharing! (how?)
  - Don't need entire process in memory



- **Disadvantages**
  - Requires translation hardware, which could limit performance
  - Segments not completely transparent to program (e.g., default segment faster or uses shorter instruction)
  - *n* byte segment needs *n contiguous* bytes of physical memory
  - Makes *fragmentation* a real problem.

Fragmentation

- **Fragmentation $\Longrightarrow$ Inability to use free memory**
- **Over time:**
  - Variable-sized pieces = many small holes (external fragmentation)
  - Fixed-sized pieces = no external holes, but force internal waste (internal fragmentation)


Pintos
??
gcc
emacs
External fragmentation
allocated
stack
doom
Unused ("internal fragmentation")