Virtual Memory

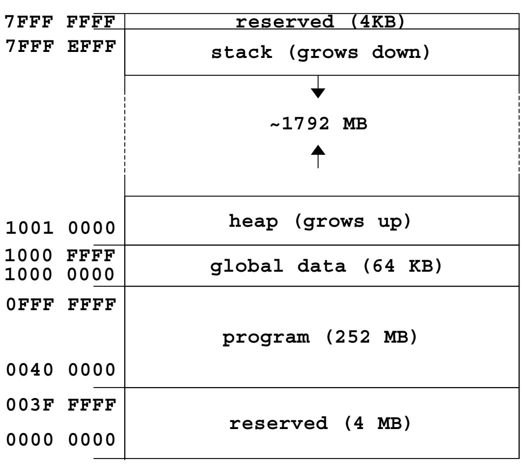
CSE 410, Spring 2004
Computer Systems

http://www.cs.washington.edu/education/courses/410/04sp/

Reading and References

- Reading
  - » Section 7.4-7.5*, Computer Organization and Design, Patterson and Hennessy*
- Reference
  - » Chapter 4, Caches for MIPS, *See MIPS Run*, D. Sweetman

Layout of program memory

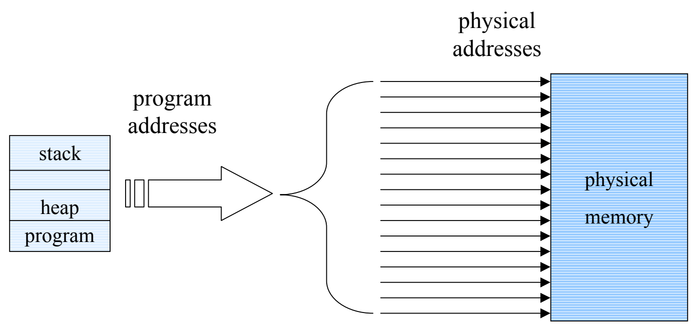


Not to Scale!

Program Memory Addresses

- Program addresses are fixed at the time the source file is compiled and linked
- Small, simple systems can use program addresses as the physical address in memory
- Modern systems usually much more complex
  - » program address space very large
  - » other programs running at the same time
  - » operating system is in memory too

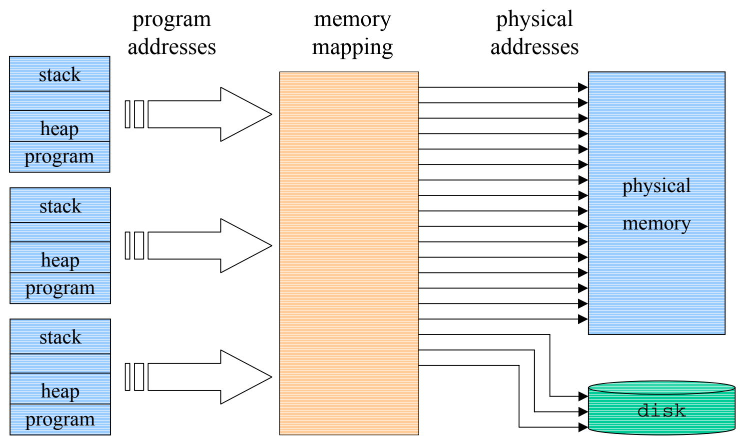
Direct Physical Addressing



Physical Addressing

- Address generated by the program is the same as the address of the actual memory location
- Simple approach, but lots of problems
  - » Only one process can easily be in memory at a time
  - » There is no way to protect the memory that the process isn't supposed to change (ie, the OS or other processes)
  - » A process can only use as much memory as is physically in the computer
  - » A process occupies all the memory in its address space, even if most of that space is never used
    - 2 GB for the program and 2 GB for the system kernel

Memory Mapping

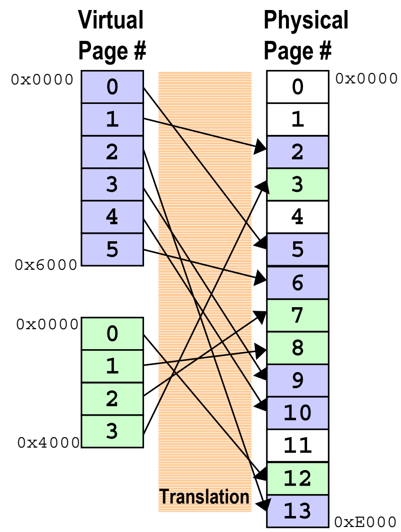


Virtual Addresses

- The program addresses are now considered to be "virtual addresses"
- The memory management unit (MMU) translates the program addresses to the real physical addresses of locations in memory
- This is another of the many interface layers that let us work with *abstractions*, instead of all details at all levels

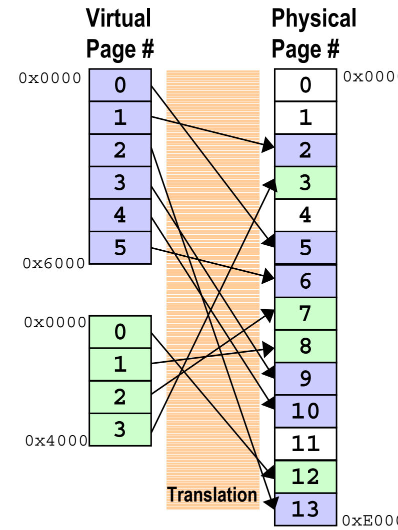
Paging

- Divide a process's virtual address space into fixed-size chunks (called **pages**)
- Divide physical memory into pages of the same size
- **Any virtual page can be located at any physical page**
- Translation box converts from virtual pages to physical pages



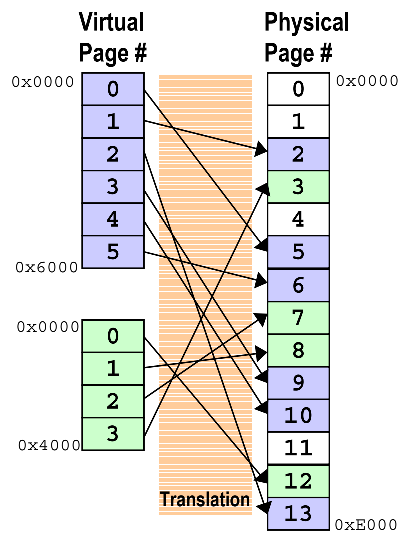
Multiple Processes Share Memory

- Each process thinks it starts at address 0x0000 and has all of memory
- A process doesn't know anything about physical addresses and doesn't care



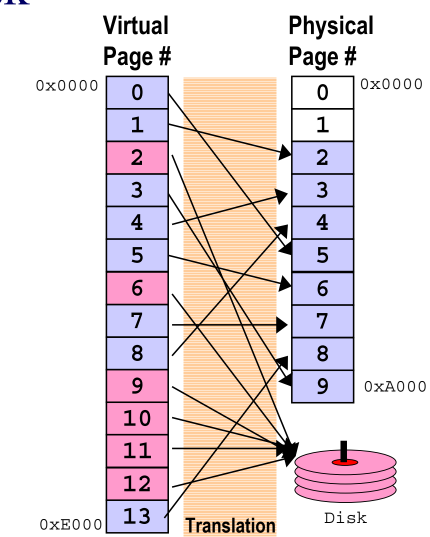
Protection

- A process can only use virtual addresses
- A process can't corrupt another process's memory
  - » It has no address to refer to it
- How can Blue write to Greens's page 2?
  - » needs an address to refer to physical page 7, but it doesn't have one



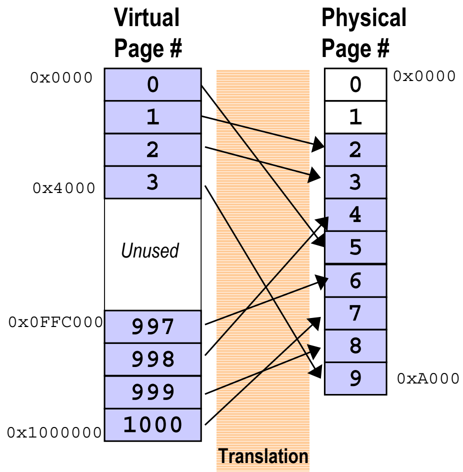
Store Memory on Disk

- Memory that isn't being used can be saved on disk
  - » swapped back in when it is referenced via page fault
- **Programs can address more memory than is physically available**
- This is an important reason for virtual memory
  - » too hard for programs to do this on their own (using overlays, for example)



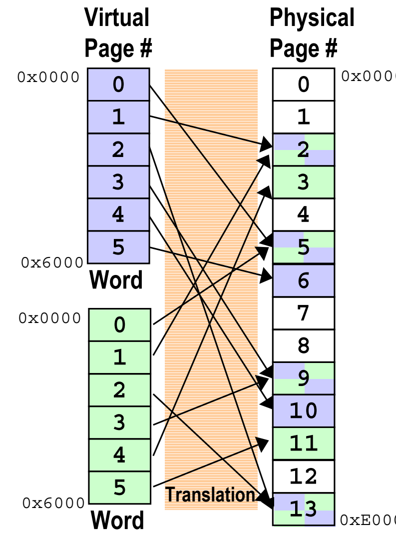
Sparse Address Spaces

- Memory addresses that aren't being used at all don't have to be in memory or on disk
  - » Code can start at a very low logical address
  - » Stack can start at a very high logical address
  - » No physical pages allocated for unused addresses in between

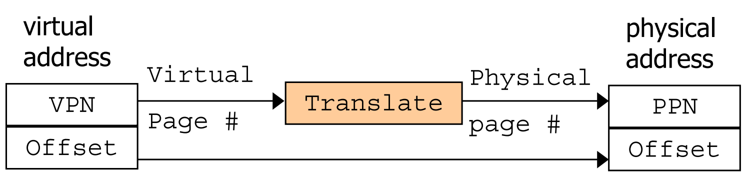


Sharing Memory

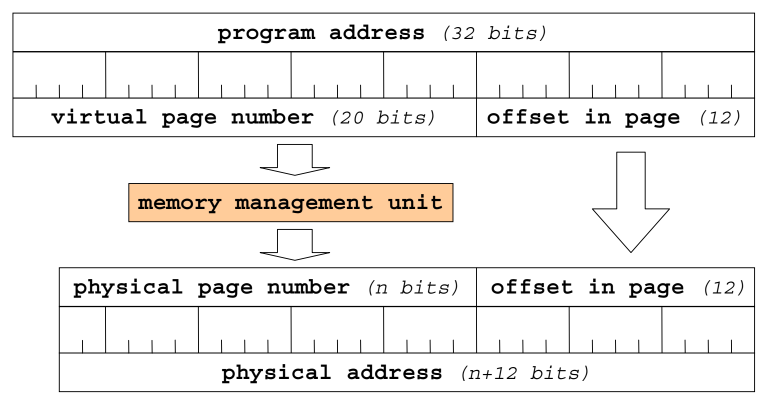
- Two processes can share memory by mapping two virtual pages to the same physical page
- The code for Word can be shared for two Word processes
  - » code pages are read only
- Each process has its own data pages
  - » possible to share data pages too, but less common



Virtual Address Translation



program -> virtual -> physical



Page Tables

- Offset field is 12 bits
  - » so each page is 2^{12} bytes = 4096 bytes = 4KB
- Virtual Page Number field is 20 bits
  - » so 2^{20} = 1 million virtual pages
- Page table is an array with one entry for each virtual page
  - » 1 million entries
  - » entry includes physical page number and flags

Gack!

- Each process has a page table with 1 Million entries - *big*
  - » no memory left to store the actual programs
- Each page table must be referenced for every address reference in a program - *slow*
  - » no time left to do any useful work
- But wait, system designers are clever kids

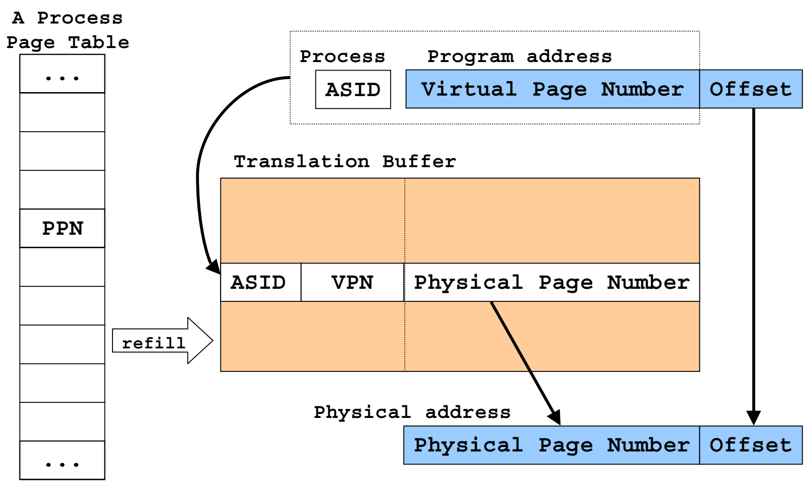
Page tables - size problem

- The page tables are addressed using virtual addresses in the kernel
- Therefore they don't need physical memory except for the parts that are actually used
  - » see "Sparse Address Spaces" diagram
- Operating System manages these tables in its own address space
  - » kernel address space

Page Tables - speed problem

- Use special memory cache for page table entries - Translation Lookaside Buffer
- Each TLB entry contains
  - » address space ID number (part of the tag)
  - » virtual page number (rest of the tag)
  - » flags (read only, dirty, etc)
  - » associated physical page number (the data)
- TLB is a fully associative cache

Using the TLB



Classifying Memory Management

- Where can a block be placed?
  - » Direct mapped, N-way Set or Fully associative
- How is a block found?
  - » Direct mapped: by index
  - » Set associative: by index and search
  - » Fully associative: by search or table lookup
- Which block should be replaced?
  - » Random
  - » LRU (Least Recently Used)
- What happens on a write access?
  - » Write-back or Write-through