Memory Management

CSE 410, Spring 2004

Computer Systems

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

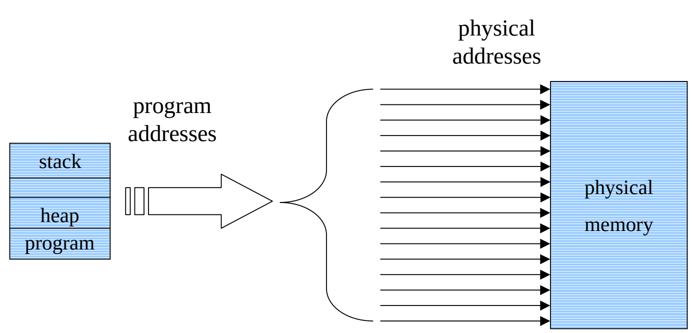
Readings and References

- Reading
  - » Chapter 9, *Operating System Concepts*, Silberschatz, Galvin, and Gagne
- Other References

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

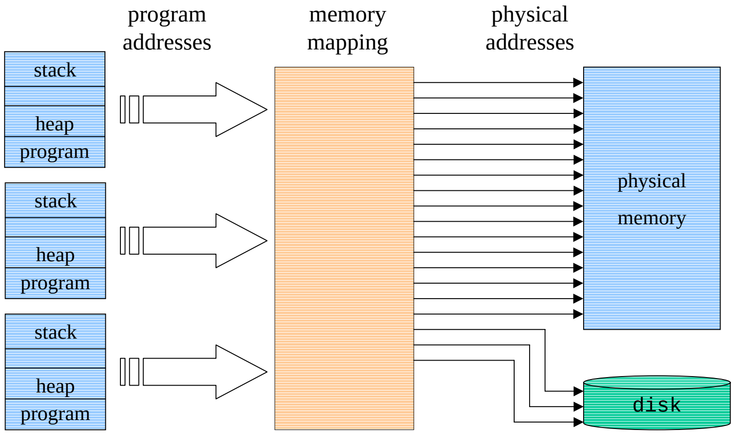
Direct Physical Addressing



Physical Addresses

- 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

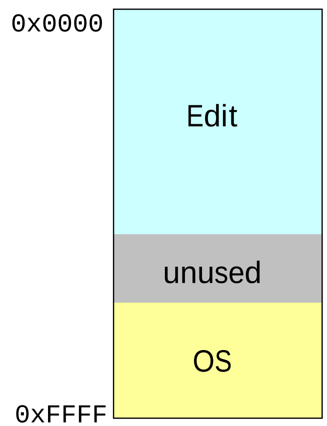
- The program addresses are now considered to be “virtual addresses”
- The memory management unit (MMU) translates the program addresses to the real physical addresses of locations in memory
- This is another of the many interface layers that let us work with abstractions, instead of all details at all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

Physical Memory Layout

- Contiguous Allocation
  - » Each process gets a single range of addresses
  - » Single-partition allocation
    - one process resident at a time
  - » Multiple-partition allocation
    - multiple processes resident at a time
- Noncontiguous allocation
  - » Paging, segmentation, or a combination

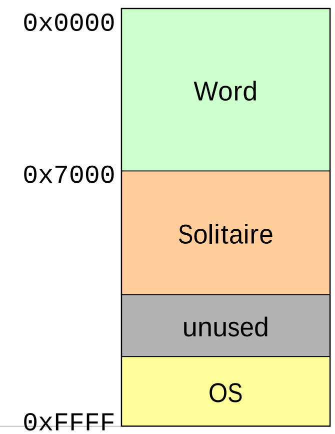
Uniprogramming without Protection

- Application always runs at the same place in physical memory
- Process can access all memory even OS
  - » program bug crashes the machine
- MS-DOS



Multiprogramming without Protection

- When a program is loaded the linker-loader translates a program's memory accesses (loads, stores, jumps) to where it will actually be running in memory
  - » Still no protection
- Once was very common
- Windows 3.1

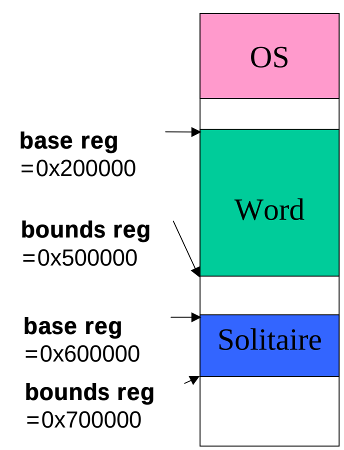


Multiprogramming with Protection

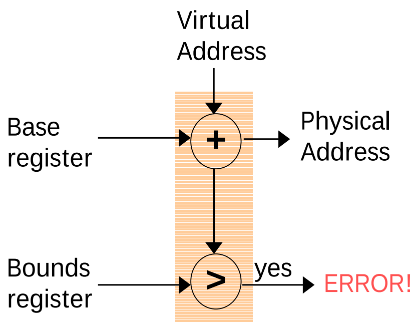
- Restrict what a program can do by restricting what it can touch
- User process is restricted to its own memory space
  - » can't crash OS
  - » can't crash other process
- How?
  - » "All problems can be solved with another level of indirection"

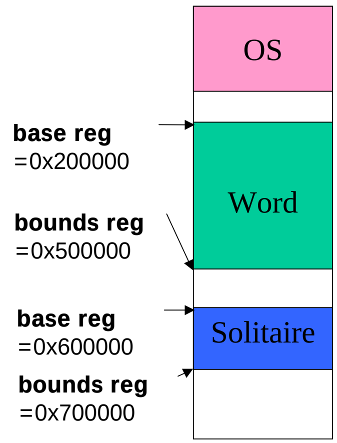
Simple Translation: Base/Bounds

- Each process has a **base register**
  - » added to every memory reference
- Each process has a **bounds register**
  - » no memory reference allowed beyond here



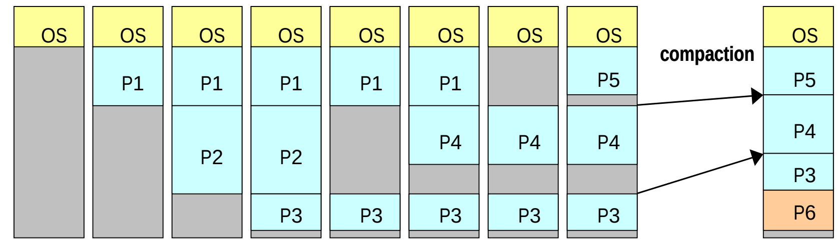
Base/Bounds





- Word references 0x004FF00 - valid
- Solitaire references 0x1100C0 - error

Fragmentation



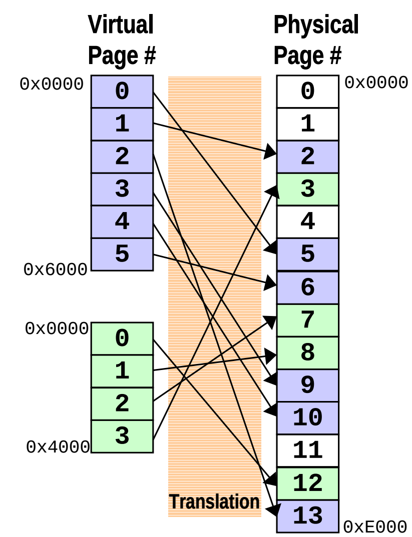
- Over time unused memory is spread out in small pieces
  » external fragmentation
- Rearrange memory to make room for the next program
  » compaction = lots of copying (expensive)
  » change base/bounds registers for moved programs

Base/bounds Evaluation

- Advantages of base/bounds
  » process can't crash OS or other processes
  » can move programs around and change base register
  » can change program memory allocation by changing bounds register
- Problems with base/bounds
  » external fragmentation
  » can't easily share memory between processes
  » programs are limited to amount of physical memory
  » doesn’t improve support for sparse address spaces

Paging

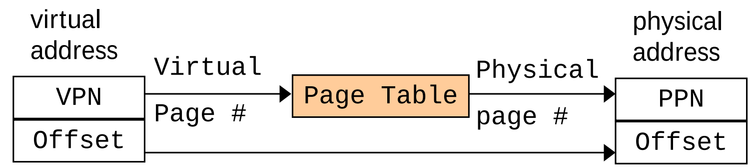
- Divide a process's virtual address space into fixed-size chunks (called **pages**)
- Divide physical memory into pages of the same size
- **Any virtual page can be located at any physical page**
- Translation box converts from virtual pages to physical pages



Paging and Fragmentation

- No **external fragmentation** because all pages are the same size
  - » don’t have to rearrange pages
- Sometimes there is **internal fragmentation** because a process doesn’t use a whole page
  - » some space wasted at the end of a page
  - » better than external fragmentation

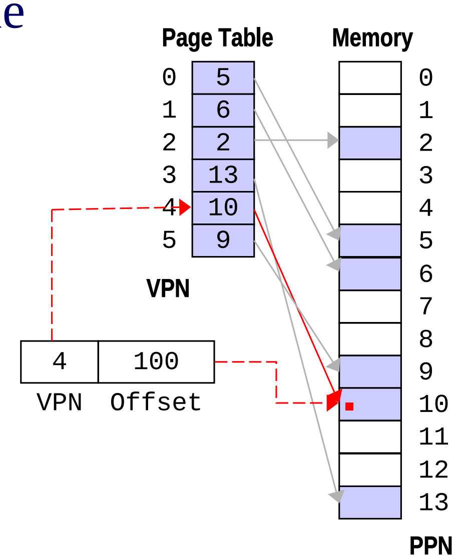
Page Tables



- A page table maps virtual page numbers to physical page numbers
- Lots of different types of page tables
  - » arrays, lists, hashes

Flat Page Table

- A flat page table uses the VPN to index into an array
- What's the problem? (Hint: how many entries are in the table?)



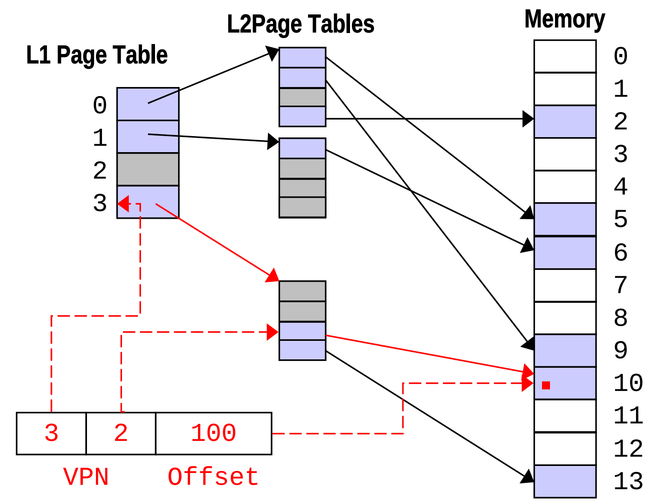
Flat Page Table Evaluation

- Very simple to implement
- Don't work well for sparse address spaces
  - » code starts at 0x00400000, stack starts at 0x7FFFFFFF
- With 4K pages, this requires 1M entries per page table
  - » must be kept in main memory (can't be put on disk)
- 64-bit addresses are a nightmare (4 TB)
- Addressing page tables in kernel virtual memory reduces the amount of physical memory used

Multi-level Page Tables

- Use multiple levels of page tables
  - » each page table entry points to another page table
  - » the last page table contains the physical page numbers (PPN)
- The VPN is divided into
  - » Index into level 1 page
  - » Index into level 2 page
  - » …

Multi-level Page Tables



Multi-Level Evaluation

- Only allocate as many page tables as we need--works with the sparse address spaces
- Only the top page table must be in pinned in physical memory
- Each page table usually fills exactly 1 page so it can be easily moved to/from disk
- Requires multiple physical memory references for each virtual memory reference

Inverted Page Tables

- Inverted page tables **hash** the VPN to get the PPN
- Requires O(1) lookup
- Storage is proportional to number of physical pages being used **not** the size of the address space