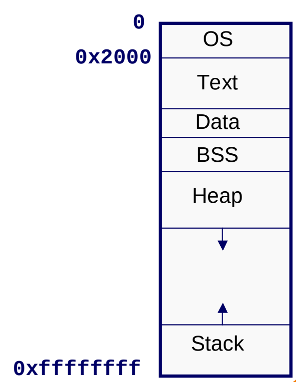
Virtual Memory

CS 217

Memory Management

- Problem 1:
  - Two programs can't control all of memory simultaneously
- Problem 2:
  - One program shouldn't be allowed to access/change the memory of another program
- Problem 3:
  - Machine may have only 256MB of memory, while virtual address space is 4GB



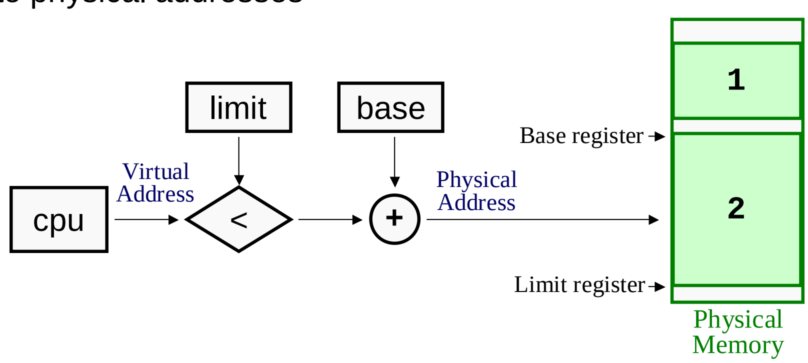
Operating system must manage sharing of physical memory between many processes

Virtual Memory

- Basic idea
  - Programs don't (and can't) name physical addresses
  - Instead, they name virtual addresses (each process has own address space)
  - The kernel translates each virtual address into a physical address before the operation is carried out
- Advantages
  - Can run many programs at once, without them worrying that they will use the same physical memory
  - Kernel controls access to physical memory, so one program can't access or modify the memory of another
  - Can run a program that uses more virtual memory than the computer has available in physical memory

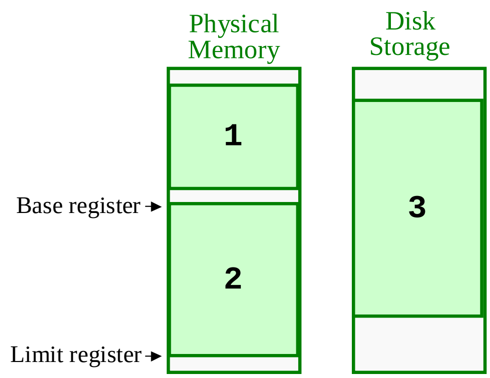
Segmentation

- Allocate memory for segments
  - Provide mapping from addresses in segments to physical memory
- Use base and limit registers to translate virtual addresses to physical addresses



Segmentation

- Allocate memory for segments
  - Provide mapping from addresses in segments to physical memory
- Problems:
  - Segments may grow
  - Fragmentation
  - Large processes
  - Swapping efficiency

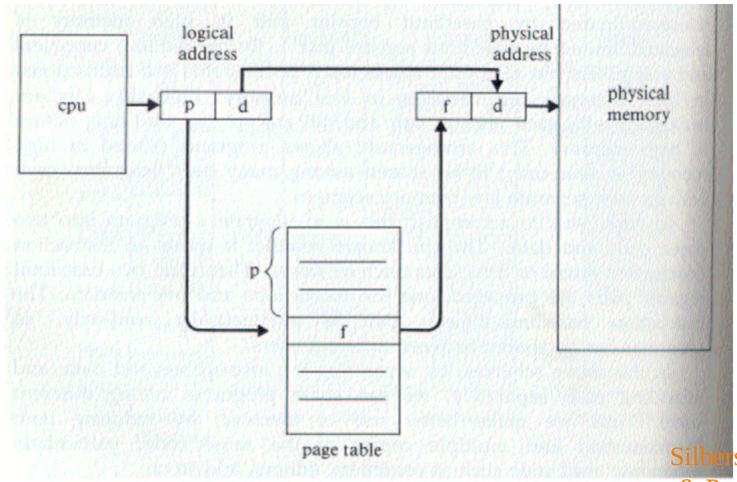


Paging

- Motivation
  - Mapping entire segments is too coarse granularity
  - Mapping individual bytes is too fine granularity
- Pages
  - Divide up memory into blocks, called pages (~4KB)
  - Each virtual page can be mapped to any physical page
  - Each translation involves two steps:
    - Decide which physical page holds the virtual address
    - Decide a what offset the virtual address is inside the page
  - The physical address is formed by gluing together
    the physical page number and the offset within the page

Paging

- Page table maps virtual addresses to physical addresses



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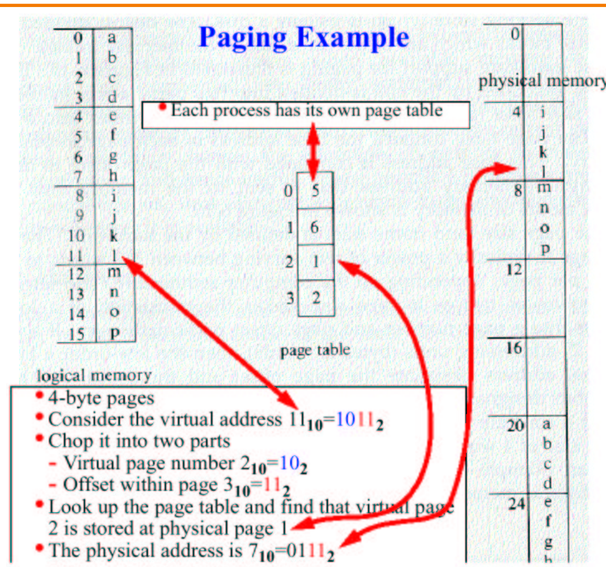
Paging (cont)



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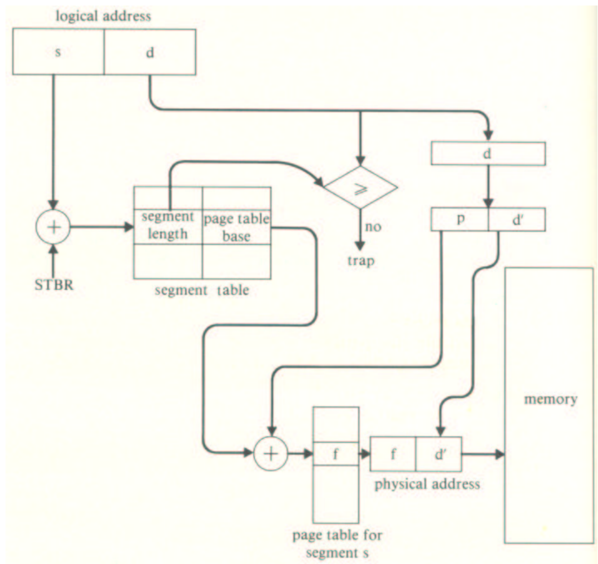
Paged Segmentation



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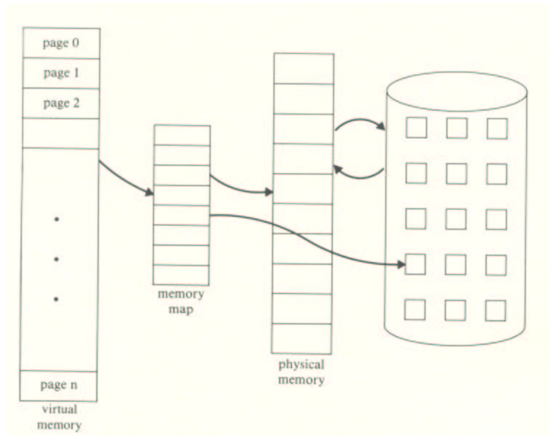
Swapping

- What happens if cumulative sizes of segments exceeds physical memory?

Swapping to Disk

- If all the virtual memory can't fit in physical memory, the OS can temporarily stash some pages on disk
  - Can support virtual memory bigger than physical memory



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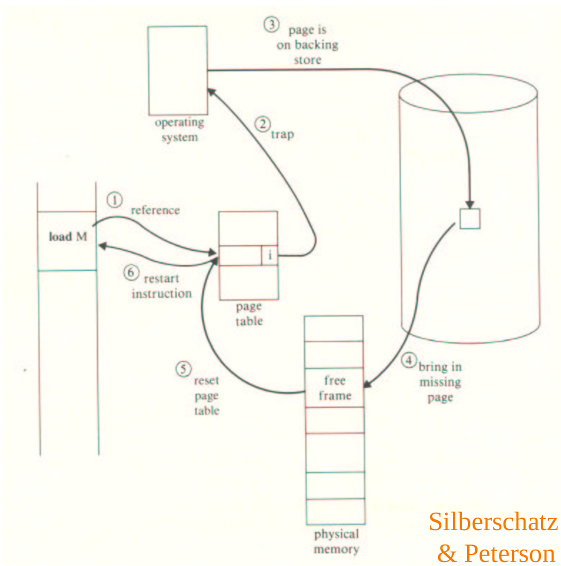
Page Table

- The OS stores for each page ...
  - Physical page number (24 bits)
  - Cacheable bit (C)
  - Modified bit (M)
  - Referenced bit (R)
  - Access permissions (Read only, Read/write)
  - Valid/invalid (V)

Page Faults

- If process accesses virtual address that maps to a page not in memory, then the OS must fetch that page from disk
- Since most references follow others on same page, the cost of reading from disk is amortized across many references



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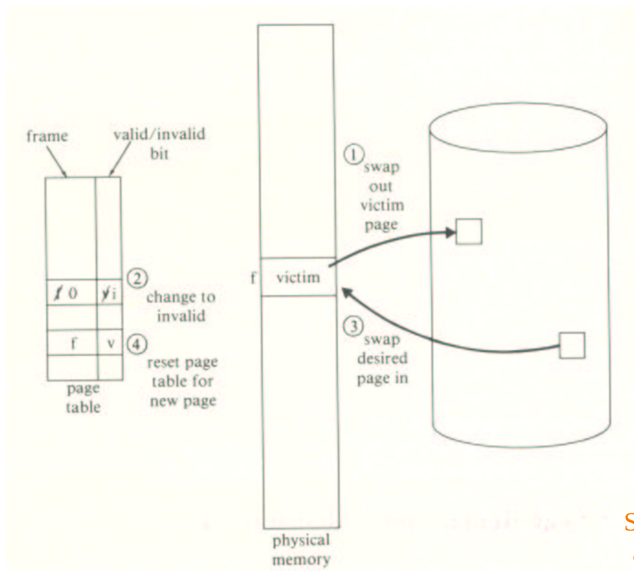
Page Replacement

- When read one page from disk, another page must be evicted?
- Which page should be replaced?
  - Ideal:
    - One that will be accessed furthest in future
  - Practical heuristics:
    - Least recently used
    - Least frequently used
    - Etc.

```
void StringArray_read(StringArray_T s, FILE *fp)
{
  char string[MAX_STRING_LENGTH];

  s->nstrings = 0;
  while (fgets(string, MAX_STRING_LENGTH, fp)) {
    StringArray_grow(nstrings+1);
    s->strings[(s->nstrings)++] = strdup(string);
  }
}
```

Page Replacement (cont)



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Working Sets

- Locality of reference
  - Most memory references are nearby previous ones
- Working set
  - At any point in a program's execution, usually a small region of memory is accessed frequently
  - The region of memory (working set) changes during the course of execution

```
int main()
{
  Array_T *strings;
  strings = ReadStrings(stdin);
  SortStrings(strings);
  WriteStrings(strings, stdout);

  return 0;
}
```

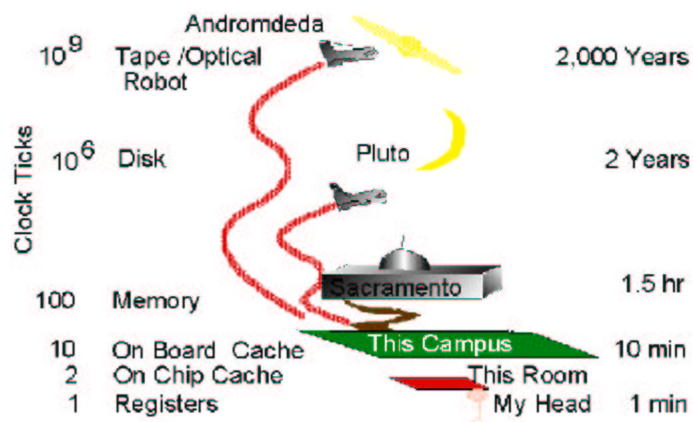
Thrashing

- What happens when cumulative size of working sets exceeds capacity of physical memory?

Storage Hierarchy

- Registers
  - ~128, 1-5ns access time (CPU cycle time)
- Cache
  - 1KB – 4MB, 20-100ns (multiple levels)
- Memory
  - 64MB – 2GB, 200ns
- Disk
  - 1GB – 100GB, 10ms
- Long-term Storage
  - 1TB, 1-10s

Storage Hierarchy Latency



- And the "universe" is expanding -- farther things are getting farther faster!

Jim Gray

Summary

- Memory management
  - Important function of operating system
  - Understanding how it works is critical to effective system development
- Virtual memory
  - OS & Hardware support for mapping virtual addresses to physical addresses
  - Mapping is usually at page granularity, which facilitates ...
    - Relocation
    - Swapping to disk
    - Protection
    - Fragmentation
    - Sharing