CSCE 451/851
Operating Systems Principles

Virtual Memory

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Memory Management
Fundamental problems

- Efficient sharing of physical memory
  - » Protection
  - » Internal fragmentation
  - » External fragmentation
- Execution of programs that require more memory than is physically available
  - » Overlays

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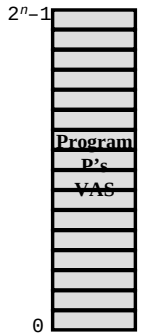
Virtual Memory
Concept

- Hide all physical aspects of memory from users
  - » Memory is a logically unbounded *virtual address space* of 2^n bytes
  - » Only portions of VAS are in physical memory at any one time
- Issues
  - » Placement strategies
  - » Replacement strategies
  - » Load control strategies



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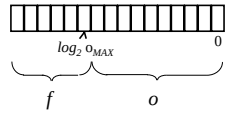
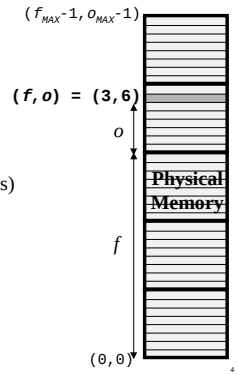
Realizing Virtual Memory
Paging

- Physical memory partitioned into equal sized *page frames*
- Memory address is a pair (f, o)
  - » f — frame number ($2^{f_{MAX}}$ frames)
  - » o — frame offset ($2^{o_{MAX}}$ bytes/frames)
  - » Physical address = $2^{o_{MAX}}f + o$

PA:





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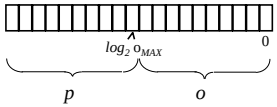
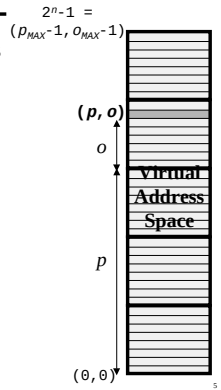
Realizing Virtual Memory

Paging

- A process's virtual address space is partitioned into equal sized *pages*
  - » $|page| = |page\ frame|$
- A virtual address is a pair (p, o)
  - » p— page number ($2^{p_{MAX}}$ pages)
  - » o— page offset ($2^{o_{MAX}}$ bytes/pages)
  - » Virtual address = $2^{o_{MAX}}p + o$

VA:





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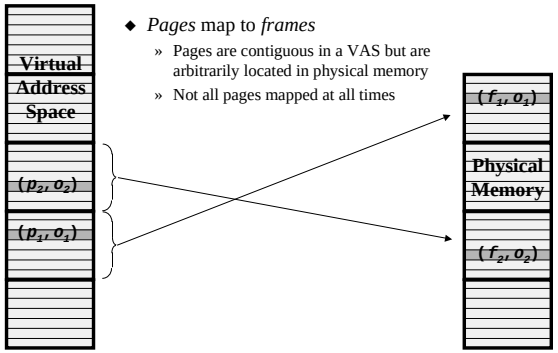
Paging

Mapping virtual addresses to physical addresses



- *Pages* map to *frames*
  - » Pages are contiguous in a VAS but are arbitrarily located in physical memory
  - » Not all pages mapped at all times

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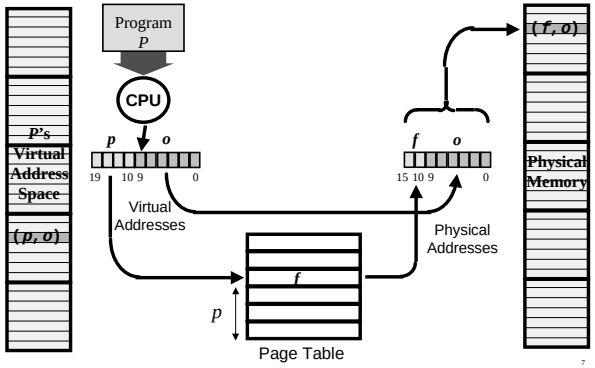
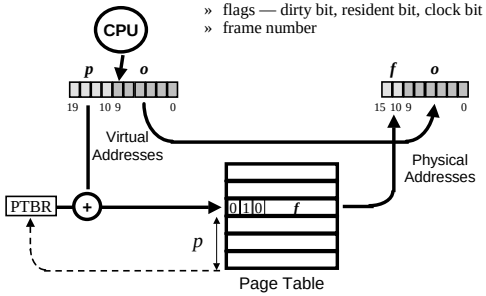
Paging
Virtual address translation



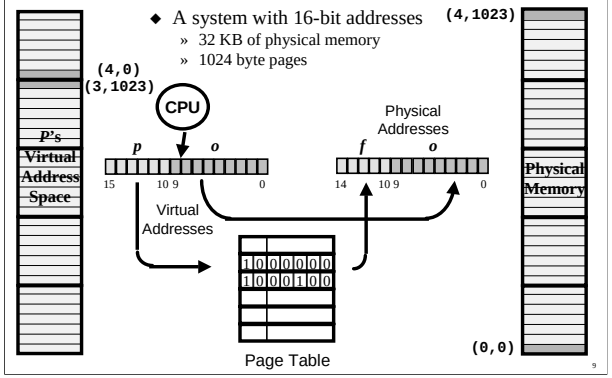
Paging
Page table structure

- 1 table per process
  - » part of process's state
- Contents:
  - » flags — dirty bit, resident bit, clock bit
  - » frame number



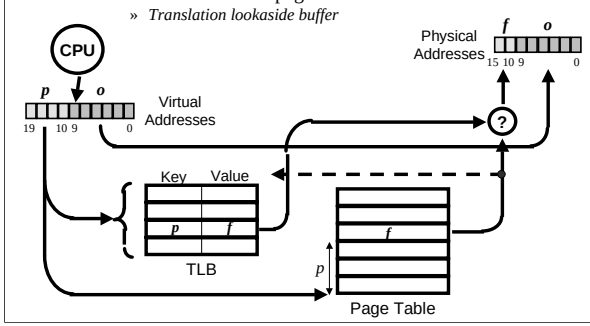
Paging
Example

- A system with 16-bit addresses
  - » 32 KB of physical memory
  - » 1024 byte pages



Virtual Memory Performance
Address translation caching

- Problem — VM reference requires 2 memory references!
- Solution — Cache page-to-frame translations
  - » *Translation lookaside buffer*



Page Fault Handling

- References to non-mapped pages generate a *page fault*
- Page fault handling
  - » Service the fault
  - » Read in the unmapped page
  - » Restart the faulting process

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Virtual Memory Performance
Page fault analysis

- How can VM possible work?!
  - » Memory access time: 20 ns
  - » Disk access time: 25 ms
  - » Effective access time (*EAT*)
    - Let p = the probability of a page fault
    - $EAT = 20(1-p) + 25{,}000{,}000p$
    - For an *EAT* within 5% of minimum, $p \leq 0.000{,}000{,}04$ (less than one fault every 25,000,000 references)
- *Moral*: OS had better do a good job of page replacement!

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