Lecture 21
Virtual Memory

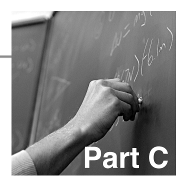
Suggested reading:
(HP Chapter 5.4-5.5)

RELATIVE SIZES

Page Table Size

page table size
- example #1: 32-bit VA, 4KB pages, 4-byte PTE
  - 1M pages (32 bits = 4 GB address space / 4 KB page = 1M pages)
  - 1M pages*4bytes = 4MB page table (bad, but could be worse)
- example #2: 64-bit VA, 4KB pages, 4-byte PTE
  - 4P pages, 16PB page table (not a viable option)
- upshot: can't have page tables of this size in memory

techniques for reducing page table size
- multi-level page tables
- inverted page tables



Block replacement

- **Which block should be replaced on a virtual memory miss?**
  - **Again, we'll stick with the strategy that it's a good thing to eliminate page faults**
  - **Therefore, we want to replace the LRU block**
    - **Many machines use a "use" or "reference" bit**
    - **Periodically reset**
    - **Gives the OS an estimation of which pages are referenced**

Writing a block

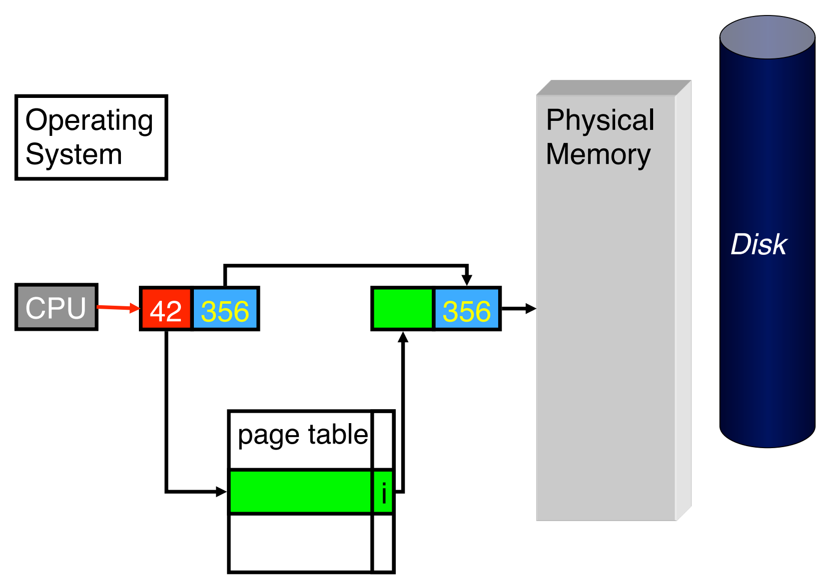
- What happens on a write?
  - We don't even want to think about a write through policy!
    - Time with accesses, VM, hard disk, etc. is so great that this is not practical
  - Instead, a write back policy is used with a dirty bit to tell if a block has been written

INTRODUCTION TO TLBS

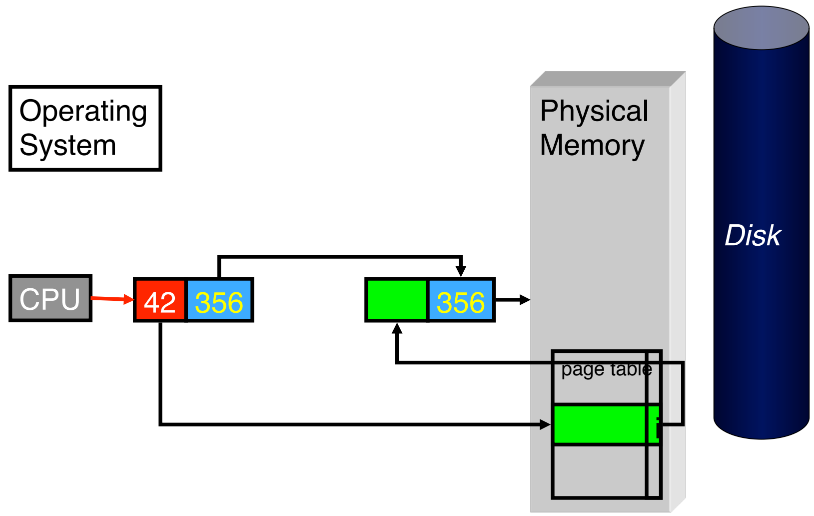
Page tables and lookups…

- 1. Its slow! Weve turned every access to memory into two accesses to memory
  - solution: add a specialized "cache" called a "translation lookaside buffer (TLB)" inside the processor
- 2. its still huge!
  - even worse: we're ultimately going to have a page table for every *process*. Suppose 1024 processes, that's 4GB of page tables!

Paging/VM

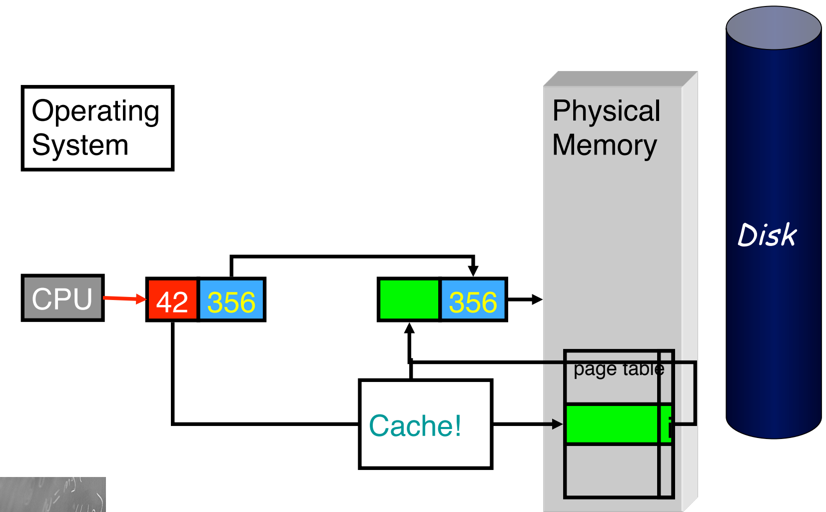


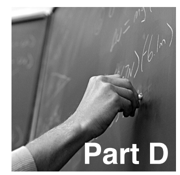
Paging/VM



Place page table in physical memory
However: this doubles the time per memory access!!

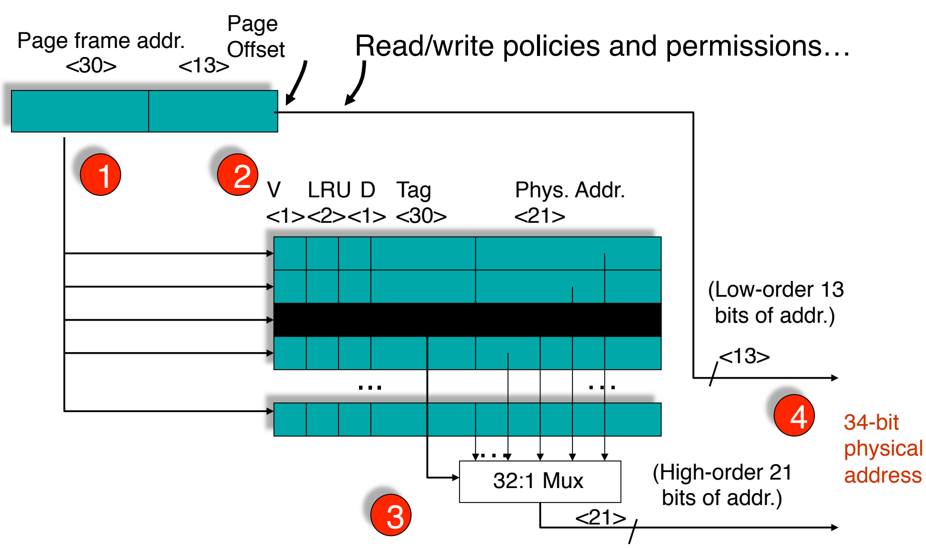
Paging/VM





Special-purpose cache for translations
Historically called the TLB: Translation Lookaside Buffer

An example of a TLB



Review: Translation Cache

A way to speed up translation is to use a special cache of recently used page table entries -- this has many names, but the most frequently used is *Translation Lookaside Buffer* or *TLB*

Virtual Page #	Physical Frame #	Dirty	Ref	Valid	Access

tag

Really just a cache (a special-purpose cache) on the page table mappings

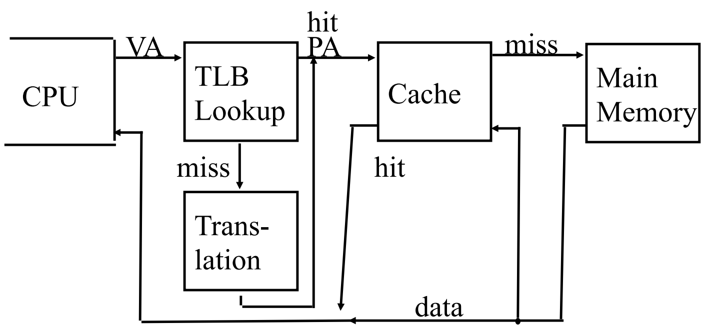
TLB access time comparable to cache access time
(much less than main memory access time)

Review: Translation Cache

Just like any other cache, the TLB can be organized as fully associative, set associative, or direct mapped

TLBs are usually small, typically not more than 128 - 256 entries even on high end machines. This permits fully associative lookup on these machines. Most mid-range machines use small n-way set associative organizations.

Translation with a TLB

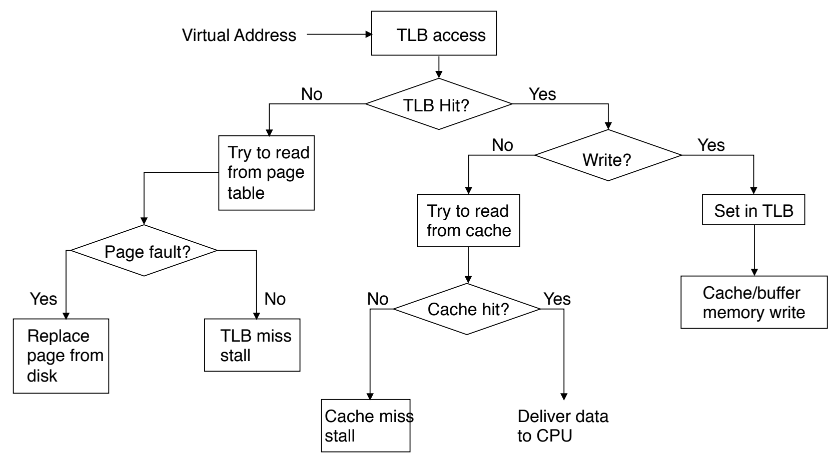


A FULL ADDRESS TRANSLATION

The "big picture" and TLBs

- **Address translation is usually on the critical path…**
  - **…which determines the clock cycle time of the μP**
- **Even in the simplest cache, TLB values must be read and compared**

The "big picture" and TLBs



Examples