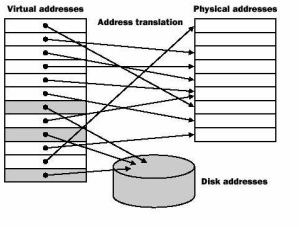
November 9

- 7 classes to go!
- Email questions to me
  - Topics you would like covered
  - Things you don't understand
  - Suggestions for Final Exam questions
- Today: Virtual Memory

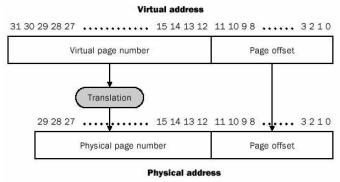
Virtual Memory



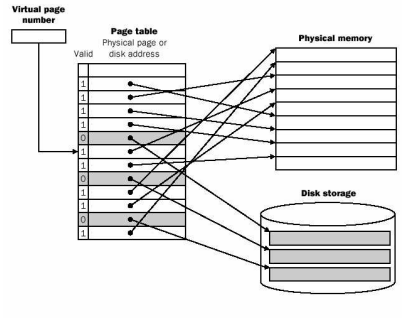
- Main memory is a CACHE for disk
- Advantages:
  - illusion of having more physical memory
  - program relocation
  - protection

Pages: Virtual Memory Blocks

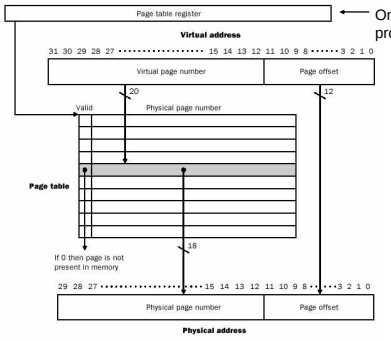
- Page faults: the data is not in memory, retrieve it from disk
  - **huge miss penalty (remember 10 months at human scale)**
    - **Pages should be fairly large (e.g., 4KB)**
    - **Find something else to do while waiting**
  - **reducing page faults is important (LRU is worth the price)**
  - **can handle the faults in software instead of hardware**
  - **using write-through is too expensive so we use writeback**



Page Tables



Page Tables

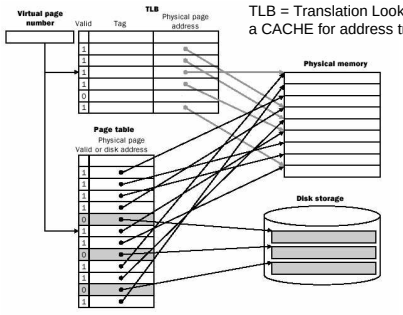


One page table per process!

Where are the page tables?

- Page tables are potentially BIG
  - 4kB page, 4MB program, 1k page table entries per program!
    - Powerpoint 18MB
    - GBMail 32MB
    - SpamFilter 48MB
    - mySQL 40MB
    - iCalMinder 5MB
    - iCal 9MB
    - Explorer 20MB
    - 40 More Processes!
  - Page the page tables!
  - Have to look up EVERY address!

Making Address Translation Fast

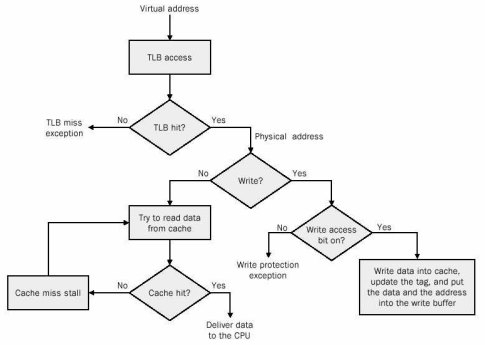


TLB = Translation Lookaside Buffer
a CACHE for address translation

What is in the page table?

- Address = upper bits of physical memory address OR disk address of page if not in memory
- Valid = bit, set if page is in memory
- Use = bit, set when page is accessed
- Protection = bit (or bits) to specify access permissions
- Dirty = bit, set if page has been written

Integrating TLB and Cache



Program Relocation?

We want to run multiple programs on our computer "simultaneously"

To start a new program

Without Virtual Memory:

We have to modify all the address references to correspond to the range chosen. This is "relocation".

With Virtual Memory:

EVERY program can pretend that it has ALL of memory. TEXT segment always starts at 0, STACK always resides a some huge high address (0xfffffff0)

Protection?

We'd like to protect one program from the errors of another

Without Virtual Memory (old Macs, win3-)

One program goes bad (or the programmer makes a mistake) and kills another program or the whole system!

With Virtual Memory (new Macs, win95+)

Every program is isolated from every other. You can't even NAME the addresses in another program.

Each page can have read, write, and execute permissions

Some Issues

- Processor speeds continue to increase
  — much faster than either DRAM or disk access times
- Design challenge: dealing with this growing disparity
- Trends:
  - synchronous SRAMs (provide a burst of data)
  - redesign DRAM chips to provide higher bandwidth or processing
  - restructure code to increase locality
  - use prefetching (make cache visible to ISA)

What these things have in common

Question 1: Where can a block be placed?

Question 2: How is a block found?

Question 3: Which block should be replaced on a cache miss?

Question 4: What happens on a write?

Where can a block be placed?

- Direct Mapped Cache: only 1 place for any block (many blocks map to the same place)
- 2-Way Set Associative: 2 places for any block
- 4-Way Set Associative: 4 places for any block
- Fully Associative: anywhere
- Virtual Memory: anywhere

How is a block found?

- Direct mapped cache: compute the index
- Set associative cache: compute the index, then search
- Fully associative cache: search all cache entries
- Virtual memory: separate lookup table

Which block is replaced on miss?

- Direct mapped cache have no choice
- Others can use:
  - Random replacement
  - Least Recently Used (LRU)
  - Other schemes

What happens on write?

- ***Write-through***: write to both the cache and the next lower level
- ***Write-back***: write only to the cache, remember that we have to write to the lower level on replacement

Misses

- Compulsory misses
- Capacity misses
- Conflict misses

Classes to go

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