Page Faults

Page fault:

- occurs when a page is not in memory
  - valid bit in its PTE is clear
- trap to the operating system to service the page fault
- **page fault handler**: the software that handles the page fault (*next slide*)

Demand paging: bring a page into memory the first time the CPU references a location in it

Page Faults

What happens on a page fault (high-level view):

- choose a page frame to free (page replacement):
  - the algorithm approximates LRU replacement
  - reference bit is set on an access to the page
  - cleared every once in awhile
  - pick a page with a cleared reference bit
- if the dirty bit is set, write the replaced page to disk
- update its PTE (valid bit, dirty bit)
- read the faulting page from disk
- update its PTE

Page Faults

Disk overhead is large (milliseconds)

The implications:

- want to reduce the page fault rate because servicing the page fault is expensive
- mechanisms for maintaining a low page fault rate:
    - pages are at least 4KB to amortize the overhead of accessing it from disk & to reduce the page fault rate
    - fully associative mapping between pages & page frames to reduce page faults due to page frame conflicts
    - write-back disk update policy (disk writes take too long for write-through)
    - optimized page replacement algorithms to minimize page fault rate
- have lots of time during a page fault because of the long disk latency
    - page fault can be handled in software
    - page replacement algorithms can be optimized (i.e., take time)
    - the program that incurred the page fault is descheduled & another program is scheduled to execute:
      called a **context switch**

Translation Lookaside Buffer

Translation lookaside buffer (TLB)

- is a cache
- contains the most recent virtual-to-physical translations
- HW looks for the physical address in the TLB before checking the page table
    - if it's there, avoid the memory reference to the page table
    - because of locality of reference, it probably will be there!

- TLB configuration
    - usually fully-associative or large set-associative
    - 4-8 byte blocks
    - 32 - 128 entries (if fully associative),
      up to 4K if direct-mapped
    - can be instruction & data (today) or unified (more in the past)
    - write back
    - .5 - 1 cycle hit time, tens of cycles miss penalty
    - TLB misses handled in software or hardware or software with hardware assists

Using a TLB

(1) Access using the virtual page number. Why?

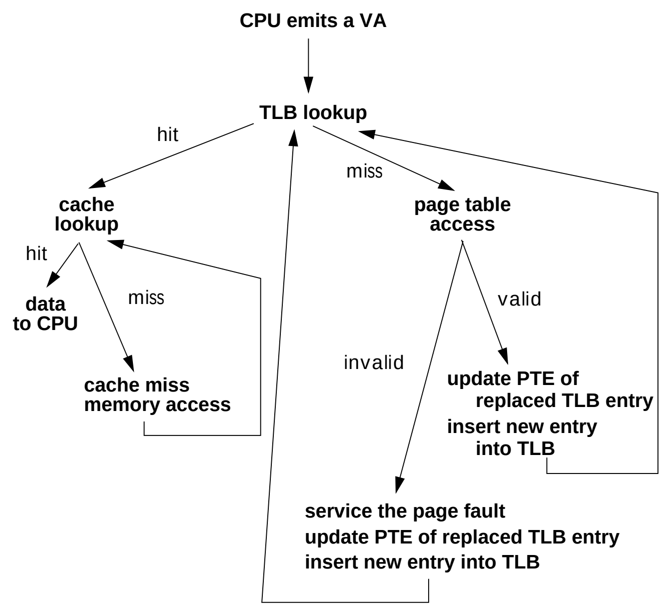
(2) If a **hit**,
- concatenate the physical page number & the page offset bits, to form a physical address
- set the **reference bit**
- if writing, set the **dirty bit**

(3) If a **miss**,
- get the physical address from the page tables
- evict a TLB entry & update dirty/reference bits in the page tables
- update the TLB with the new mapping

Using a TLB

TLB (physical) components:
- TLB entry (cache data)
  - contents of the PTE: physical page number, dirty bit, reference bit, protection bits
- TLB tags are **process identifiers (PIDs)** & virtual page numbers
  - PID prevents one process from accessing a TLB entry of another process
  - PID of the currently executing process is stored in a special register
  - TLB tag match: PID register & virtual address tag are compared to PID & virtual address in TLB tag
  - if a PID is not part of the tag match, how else can we prevent one process from accessing another process's pages via the TLB?
- TLB state (valid, dirty bits)

Handling a Memory Reference



Handling a Memory Reference

Special situations

- cannot hit in the TLB & have a page fault
  - TLB entry is invalidated when its page is paged out to disk
- cannot hit in the cache when there is a TLB miss and a page fault
  - blocks from the page are flushed from the cache when a paged is paged out to disk
- all other combinations are possible
  - see Figure 7.27

Pros & Cons of Paging

Advantages of paging:

- provides a simple memory location model to the programmer

  ⟹ users do not have to do manual overlays
- not all pages have to be in memory during execution (demand paging)

  ⟹ lower program start-up time
- program (virtual) space can be larger than the physical memory

  ⟹ allows larger programs or lower memory cost
- allows flexible page relocation; pages do not have to be contiguous (fully-associative)

  ⟹ low page fault rate
- allows co-location of programs in physical memory without (external) fragmentation

  ⟹ full utilization of memory
- allows programs to share pages

  ⟹ better use of memory
- provides protection of one program from another on a page basis

Pros & Cons of Paging

Disadvantages of paging:

- address translation via page tables takes time
- paging takes time