

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

Page fault handler

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, location on disk)
- 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 them from disk & to reduce the page fault rate
 - fully associative mapping between pages & page frames to reduce page faults due to page frame conflicts
 - optimized page replacement algorithms to minimize page fault rate
 - write-back disk update policy (disk writes take too long for write-through)
- 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
 - 32 - 128 entries (if fully associative), up to 4K if direct-mapped
 - 4-8 byte blocks
 - can be separate 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

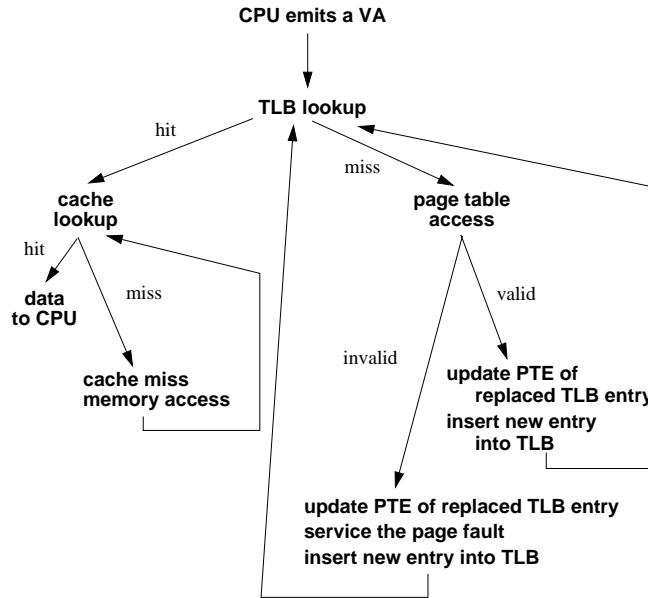
- (1) Access using the virtual page number. Why virtual?
- (2) If a **hit**,
 - concatenate the physical page number & the page offset bits, to form a physical address
 - set the **reference bit**
 - if writing, set the **dirty bit**
- (3) If a **miss**,
 - get the physical address from the page table
 - evict a TLB entry & update its dirty/reference bits in the page table
 - 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