CS 3204
Operating Systems

Lecture 20

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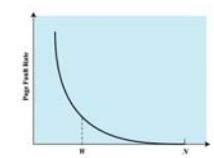
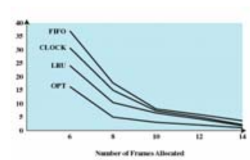
Announcements

- Project 3 milestone feedback was sent out
- Project 1 grades were sent out
- Project 3 due November 8
- Reading assignment:
  - Chapter 8 & 9
    - full readthrough is highly recommended!

VM Design Issues & Techniques

of Page Faults vs Frame Allocation





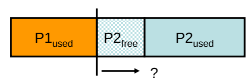
- Desired behavior of paging algorithm: reduce page fault rate below “acceptable level” as number of available frames increases
- Q.: does increasing number of physical frames always reduce page fault rate?
  - A.: usually yes, but for some algorithms not guaranteed (“Belady’s anomaly”)

Page Buffering

- Select victim (as dictated by page replacement algorithm – works as an add-on to any algorithm we discussed)
- But don’t evict victim – put victim on tail of victim queue. Evict head of that queue instead.
- If victim page is touched before it moves to head of victim queue, simply reuse frame
- Further improvement: keep queue of unmodified victims (for quick eviction – aka *free page list*) and separate queue of modified pages (aka *modified list* - allows write-back in batch)
- Related issue: when should you write modified pages to disk?
  - Options: demand cleaning vs pre-cleaning (or pre-flushing)

Local Replacement

- So far, considered global replacement algorithms
  - Most widely used
- But could also divide memory in pools
  - Per-process or per-user
- On frame allocation, requesting process will evict pages from pool to which it belongs
- Advantage: Isolation
  - No between-process interference



- Disadvantage: Isolation
  - Can’t temporarily “borrow” frames from other pools
- Q.: How big should pools be?
  - And when should allocations change?

When Virtual Memory works well

- Locality
  - 80% of accesses are to 20% of pages
  - 80% of accesses are made by 20% of code
- Temporal locality:
  - Page that's accessed will be accessed again in near future
- Spatial locality:
  - Prefetching pays off: if a page is accessed, neighboring page will be accessed
- If VM works well, average access to all memory is about as fast as access to physical memory

VM Access Time & Page Fault Rate

access time = p * memory access time
+ (1-p) * (page fault service time + memory access time)

- Consider expected access time in terms of fraction p of page accesses that don't cause page faults.
- Then 1-p is page fault frequency
- Assume p = 0.99, assume memory is 100ns fast, and page fault servicing takes 10ms – how much slower is your VM system compared to physical memory?
- access time = 99ns + 0.01*(10000100) ns ≈ 100,000ns or 0.1ms
  - Compare to 100ns or 0.0001ms speed ≈ about 1000x slowdown
- Conclusion: even low page fault rates lead to huge slowdown

Thrashing: When Virtual Memory Does Not Work Well

- System accesses a page, evicts another page from its frame, and next access goes to just-evicted page which must be brought in
- Worst case a phenomenon called Thrashing
  - leads to constant swap-out/swap-in
  - 100% disk utilization, but no process makes progress
    - CPU most idle, memory mostly idle

When does Thrashing occur?

- Process does exhibit locality, but is simply too large
  - Here: (assumption of) locality hurts us
- Process doesn't exhibit locality
  - Does not reuse pages
- Processes individually fit & exhibit locally, but in total are too large for the system to accommodate all

What to do about Thrashing?

- Buy more memory
  - ultimately have to do that
  - increasing memory sizes ultimately reason why thrashing is nowadays less of a problem than in the past – still OS must have strategy to avoid worst case
- Ask user to kill process
- Let OS decide to kill processes that are thrashing
  - Linux has an option to do that
- In many cases, still: reboot only time-efficient option
  - But OS should have reasonable strategy to avoid it if it can

OS Strategies to prevent thrashing

- Or contain its effects
- Define: "working set" (1968, Denning)
- Set of pages that a process accessed during some window/period of length T in the past
  - Hope that it'll match the set accessed in the future
- Idea: if we can manage to keep working set in physical memory, thrashing will not occur

Working Set

- Suppose we know or can estimate working set – how could we use it?
- Idea 1: give each process as much memory as determined by size of its WS
- Idea 2: preferably evict frames that hold pages that don't seem to be part of WS
- Idea 3: if WS cannot be allocated, swap out entire process (and exclude from scheduling for a while)
  - "medium term scheduling", "swap-out scheduling"
  - (Suspended) inactive vs active processes
  - Or don't admit until there's enough frames for their WS ("long term scheduling")

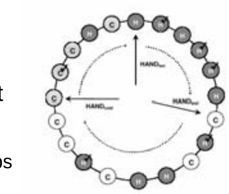
Estimating Working Set

- Compute "idle time" for each page
  - Amount of CPU time process received since last access to page
- On page fault, scan resident pages
  - If referenced, set idle time to 0
  - If not referenced, idle_time += time since last scan
  - If idle_time > T, consider to not be part of working set
- This is known as working set replacement algorithm [Denning 1968]
- Variation is WSClock [Carr 1981]
  - treats working set a circular list like global clock does, and updates "time of last use" (using a process's CPU use as a measure) – evicting those where T_last < T_current - T

Page Fault Frequency

- Alternative method of working set estimation
  - PFF: # page faults/instructions executed
  - Pure CPU perspective vs memory perspective provided by WSClock
- Below threshold – can take frames away from process
- Above threshold – assign more frames
- Far above threshold – suspect thrashing & swap out
- Potential drawback: can be slow to adopt to periods of transition

Clock-PRO

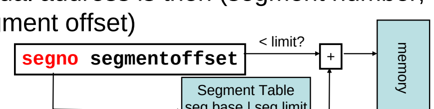


- Clock and algorithms like it try to approximate LRU:
  - LRU does not work well for:
  - Sequential scans, large loops
- Alternative:
  - Reuse distance: should replace page with large reuse distance
- Clock-PRO: Idea – extend our focus by remembering information about pages that were evicted from frames previously
- See [Jiang 2005]

Segmentation

Segmentation

- Historical alternative to paging
- Instead of dividing virtual address space in many small, equal-sized pages, divide into a few, large segments
- Virtual address is then (segment number, segment offset)



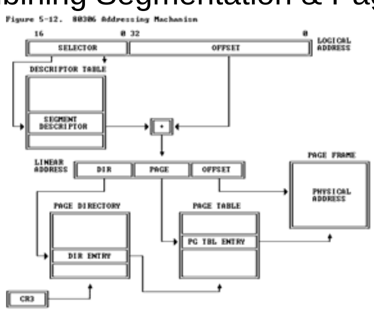
Segmentation (2)

- Advantages:
  - little internal fragmentation “segments can be sized just right”
  - easy sharing – can share entire code segment
  - easy protection – only have to set access privileges for segment
  - small number of segments means small segment table sizes
- Disadvantages:
  - external fragmentation (segment requires physically contiguous addresses!)
  - if segment is partially idle, can’t swap out

Segmentation (3)

- Pure segmentation is no longer used
  - (Most) RISC architectures don’t support segmentation at all
  - Other architectures combine segmentation & paging
- Intel x86 started out with segmentation, then added paging
  - Segment number is carried in special set of registers (GS, ES, FS, SS), point to “selectors” kept in descriptor tables
  - Instruction opcode determines with segment is used
  - Today: segmentation unit is practically unused (in most 32-bit OS, including Pintos): all segments start at 0x00000000 and end at 0xFFFFFFFF
  - Do not confuse with Pintos’s code/data segments, which are linear subregions of virtual addresses spanning multiple virtual pages
- Note: superpages are somewhat of a return to segmentation

Combining Segmentation & Paging



Memory Management Wrap-Up

Mem Mgmt Without Virtual Memory

- Book discusses this as motivation
  - Historically important, and still important for VM-less devices (embedded devices, etc.)
- Imagine if we didn’t have VM, it would be hard or impossible to
  - Retain the ability to load a program anywhere in memory
  - Accommodate programs that grow or shrink in size
  - Use idle memory for other programs quickly
  - Move/relocate a running program in memory
- VM *drastically* simplifies systems design

User-level Memory Management

- Goals:
  - Minimize fragmentation
  - Speed
  - Maximize locality
  - Provide for some error detection
- Typical algorithms:
  - First-fit, best-fit
  - No universally best algorithm: can always construct worst case sequence
- Conservative heap growth
  - “wilderness preservation”