CSE 4/521 Introduction to Operating Systems

Lecture 18 – Virtual Memory IV

(Allocation of Frames, Thrashing, Operating System Examples)

Summer 2018

Overview

- Allocation of Frames
- Thrashing
- Operating System Examples

Recap

- Page Replacement Algorithms
  - FIFO, Belady’s Anomaly, Optimal Algorithm, LRU Algorithm, Second Chance Algorithms, Counting Algorithms

Questions

1. You have devised a new page-replacement algorithm that you think may be optimal. In some test cases, Belady's anomaly occurs. Is the new algorithm optimal? (Medium)

2. In which circumstances would LFU produce less page-faults than LRU? (Medium)

3. In which circumstances would MFU produce less page-faults than LRU? (Medium)

Overview

- Allocation of Frames
- Thrashing
- Operating System Examples

Allocation of Frames

- Each process needs minimum number of frames
- Example: IBM 370 – 6 pages to handle SS MOVE instruction:
  - instruction is 6 bytes, might span 2 pages
  - 2 pages to handle *from*
  - 2 pages to handle *to*
- *Maximum* allocation is total frames in the system
- Two major allocation schemes
  - Fixed allocation
  - Priority allocation
- Many variations

Allocation of Frames : Fixed Allocation

- Equal allocation – For example, if there are 100 frames (after allocating frames for the OS) and 5 processes, give each process 20 frames
  - Keep some as free frame buffer pool

- Proportional allocation – Allocate according to the size of process
  - Dynamic as degree of multiprogramming, process sizes change

$s_i = \text{size of process } p_i$

$S = \sum s_i$

$m = \text{total number of frames}$

$a_i = \text{allocation for } p_i = \frac{s_i}{S} \times m$

$m = 62$

$s_1 = 10$

$s_2 = 127$

$a_1 = \frac{10}{137} \times 62 \approx 4$

$a_2 = \frac{127}{137} \times 62 \approx 57$

Allocation of Frames : Priority Allocation

- Use a proportional allocation scheme using priorities rather than size

- If process P_i generates a page fault,
  - select for replacement one of its frames
  - select for replacement a frame from a process with lower priority number

Allocation of Frames : Global vs. Local Allocation

- Global replacement – process selects a replacement frame from the set of all frames; one process can take a frame from another
  - But then process execution time can vary greatly
  - But greater throughput so more common
- Local replacement – each process selects from only its own set of allocated frames
  - More consistent per-process performance
  - But possibly underutilized memory

Allocation of Frames : Non-Uniform Memory Access

- So far all memory accessed equally
- Many systems are NUMA – speed of access to memory varies
- Optimal performance comes from allocating memory "close to" the CPU on which the thread is scheduled
  - Solved by Solaris by creating lgroups
    - Structure to track CPU / Memory low latency groups
    - When possible, schedule all threads of a process and allocate all memory for that process within the lgroup

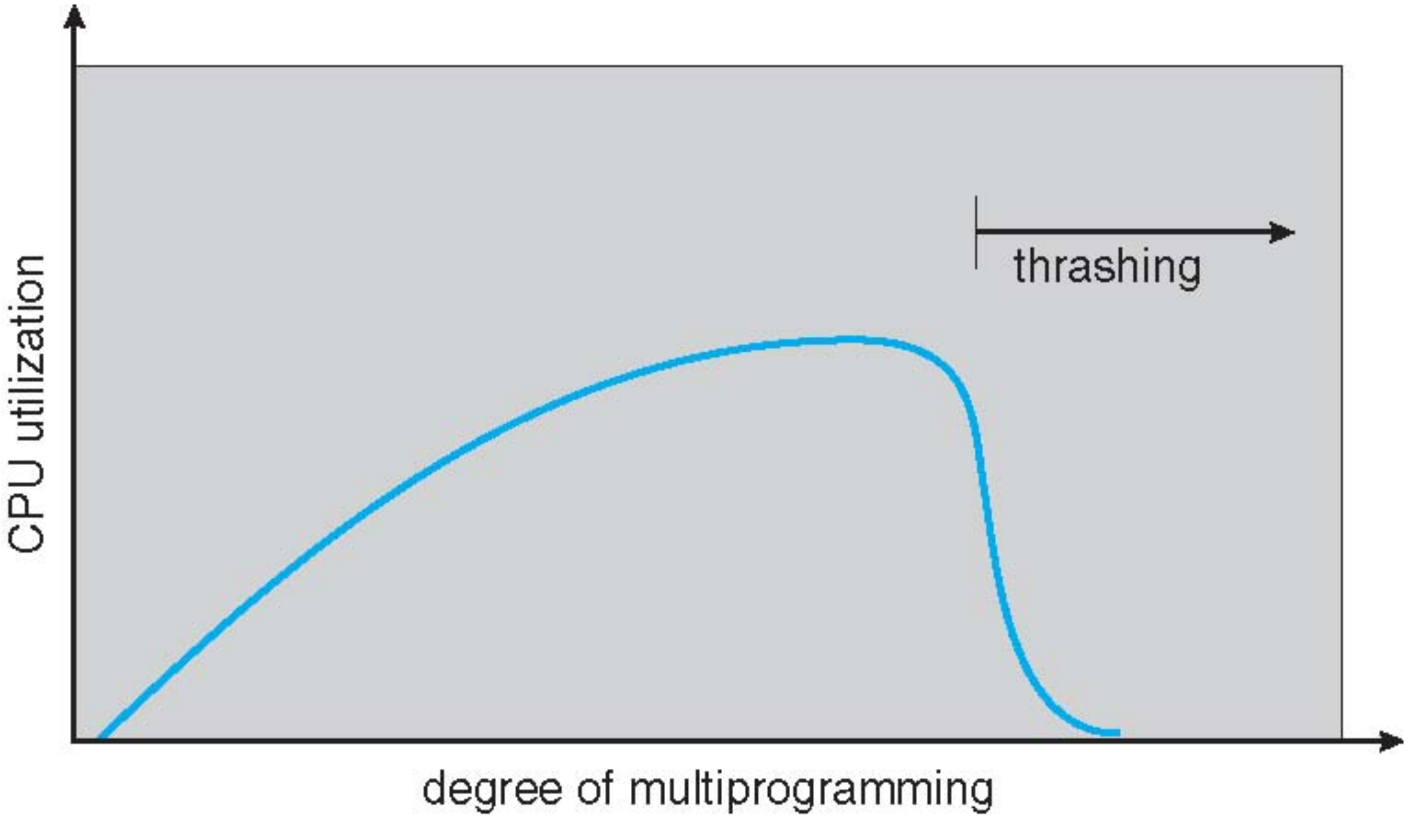
Overview

- Allocation of Frames
- Thrashing
- Operating System Examples

Thrashing

- If a process does not have "enough" pages, the page-fault rate is very high
  - Page fault to get page
  - Replace existing frame
  - But quickly need replaced frame back
  - This leads to:
    - Low CPU utilization
    - Operating system thinking that it needs to increase the degree of multiprogramming
    - Another process added to the system
- Thrashing ≡ a process is busy swapping pages in and out

Thrashing



Thrashing : Demand Paging and Thrashing

- Why does demand paging work?

Locality model

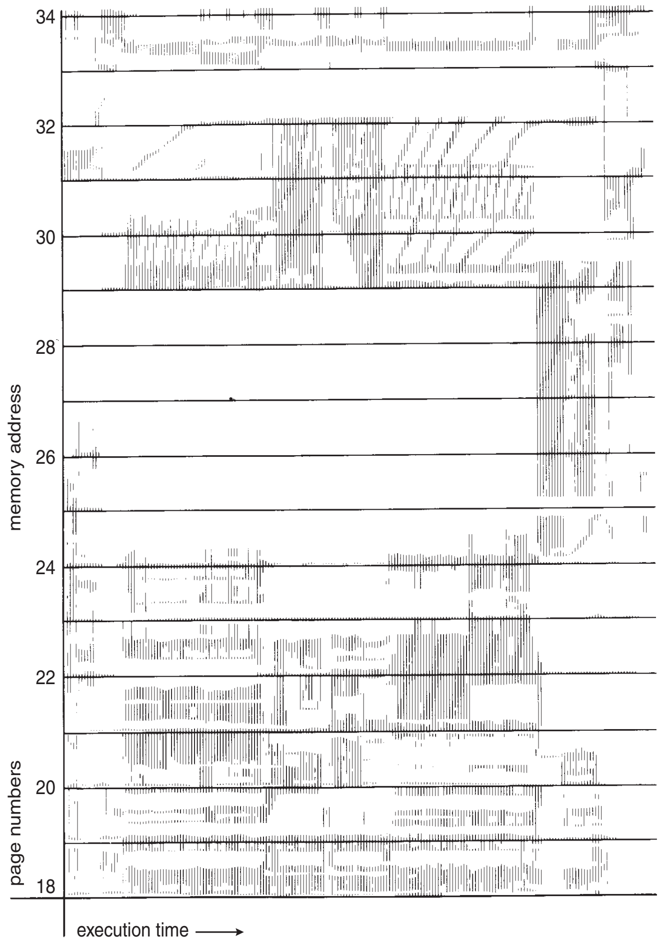
  - Process migrates from one locality to another
  - Localities may overlap

- Why does thrashing occur?

$$\Sigma \text{ size of locality} > \text{total memory size}$$

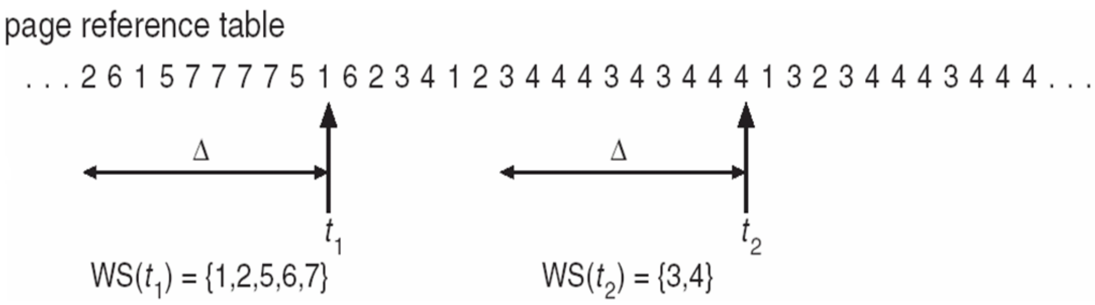
Limit effect of thrashing by using local or priority page replacement

Thrashing : Locality in a Memory-Reference Pattern



Thrashing : Working-Set Model

- $\Delta \equiv$ working-set window $\equiv$ a fixed number of page references (Example: 10,000 instructions)
- WSS_i (working set of Process P_i) =
  total number of pages referenced in the most recent Δ (varies in time)
  - if Δ too small will not encompass entire locality
  - if Δ too large will encompass several localities
  - if $\Delta = \infty \Rightarrow$ will encompass entire program
- $D = \Sigma\, WSS_i \equiv$ total demand for frames
  - Approximation of locality
- if $D > m \Rightarrow$ Thrashing (m is total number of available frames)
- Policy: If $D >$ m, then suspend or swap out one of the processes

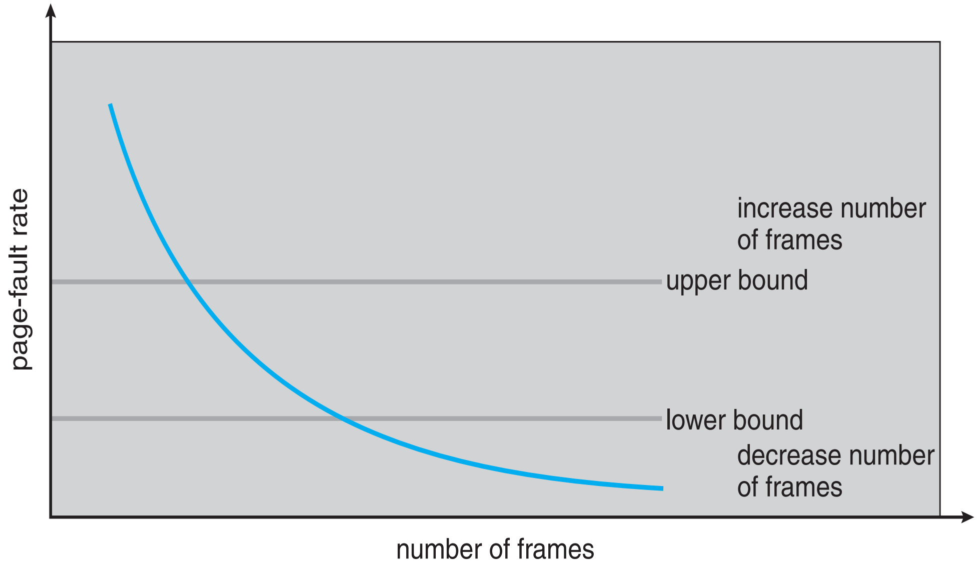


Thrashing : Keeping Track of the Working Set

- Approximate with interval timer + a reference bit
- Example: $\Delta = 10{,}000$
  - Timer interrupts after every 5000 time units
  - Keep in memory 2 bits for each page
  - Whenever a timer interrupts, copy and set the values of all reference bits to 0
  - If one of the bits in memory = 1 $\Rightarrow$ page in working set
- It is not completely accurate though.
- Possible Improvement : 10 bits and interrupt every 1000 time units

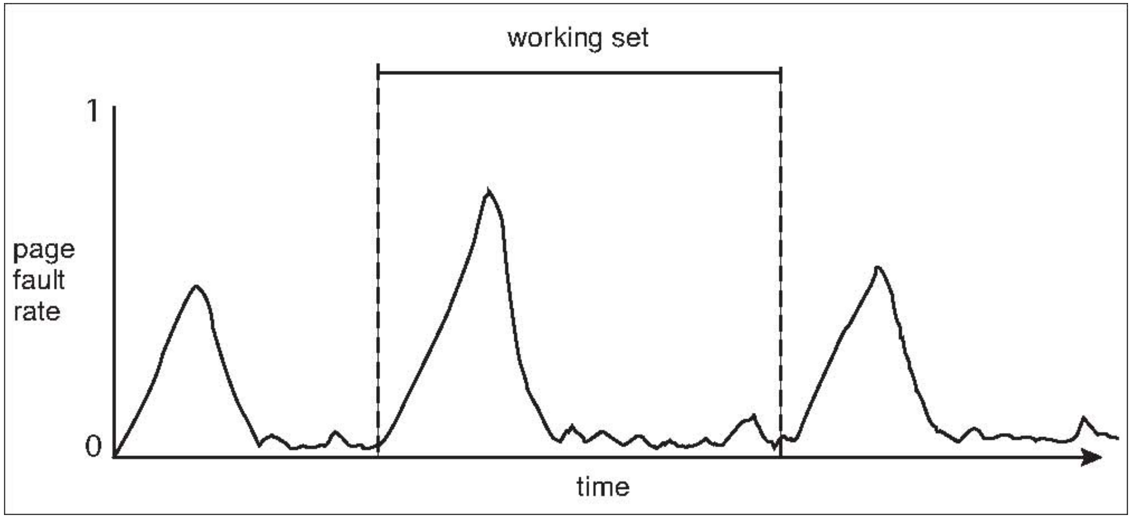
Thrashing : Page-Fault Frequency

- More direct approach than WSS
- Establish "acceptable" page-fault frequency (PFF) rate and use local replacement policy
  - If actual rate too low, process loses frame
  - If actual rate too high, process gains frame



Thrashing : Working Sets and Page Fault Rates

- Direct relationship between working set of a process and its page-fault rate
- Working set changes over time
- Peaks and valleys over time



Overview

- Allocation of Frames
- Thrashing
- Operating System Examples

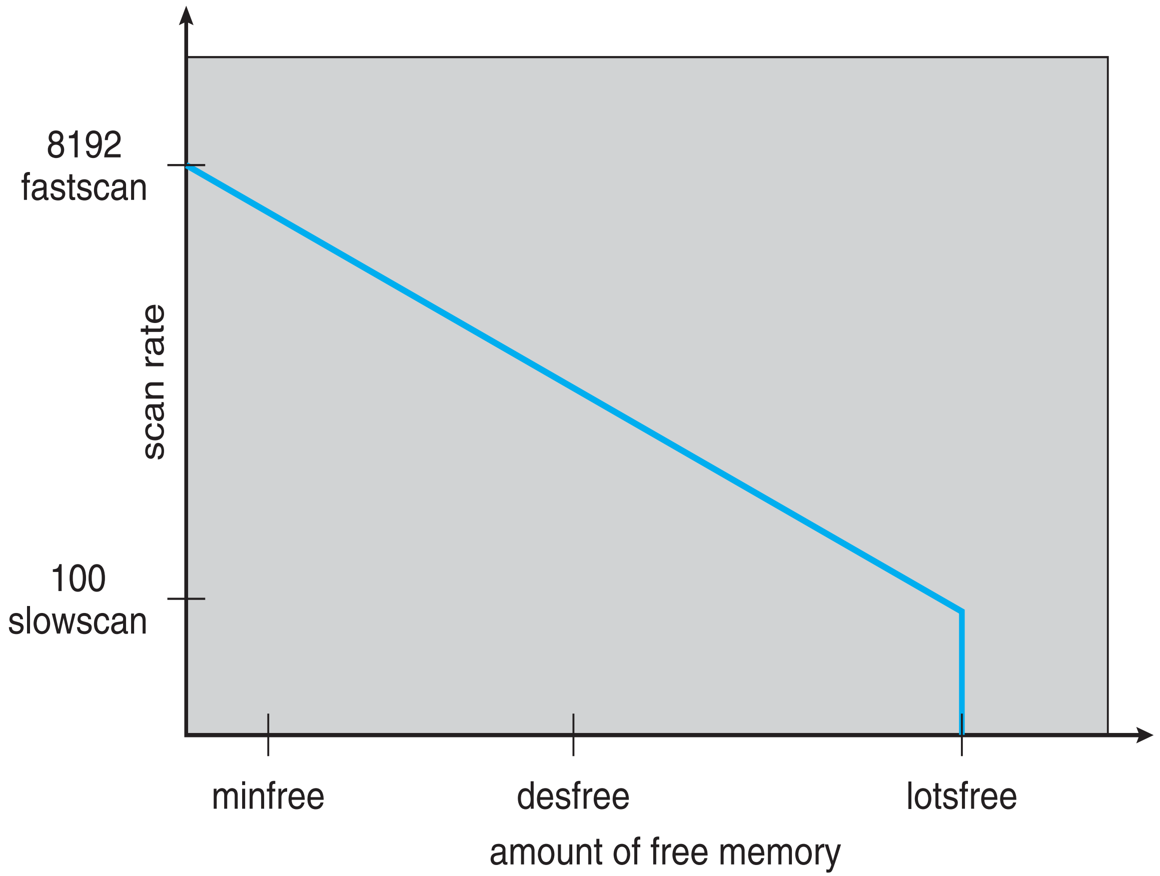
Operating System Examples : Windows

- Uses demand paging with clustering. Clustering brings in pages surrounding the faulting page
- Processes are assigned working-set minimum and working-set maximum
- Working set minimum is the minimum number of pages the process is guaranteed to have in memory
- A process may be assigned as many pages up to its working set maximum
- When the amount of free memory in the system falls below a threshold, automatic working set trimming is performed to restore the amount of free memory
- Working set trimming removes pages from processes that have pages in excess of their working set minimum

Operating System Examples : Solaris

- Maintains a list of free pages to assign faulting processes
- `Lotsfree` – threshold parameter (amount of free memory) to begin paging
- `Desfree` – threshold parameter to increasing paging
- `Minfree` – threshold parameter to being swapping
- Paging is performed by `pageout` process
- `Pageout` scans pages using modified clock algorithm
- `Scanrate` is the rate at which pages are scanned. This ranges from `slowscan` to `fastscan`
- `Pageout` is called more frequently depending upon the amount of free memory available
- Priority paging gives priority to process code pages

Operating System Examples : Solaris 2 Page Scanner



Credits for slides

Silberschatz, Galvin and Gagne