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Exercises „Operating Systems and Distributed Systems 2“
2019/20

Management of the Storage Hierarchy – Solutions

Exercise 1: Replacement Strategies

- Given:
  - A "reference string" of a process: `1 2 3 4 1 2 5 1 2 3 4 5`

    = sequence of virtual page numbers
    in the order by which they are accessed by the process
  - Replacement strategies:

    i.) FIFO ii.) LRU
  - Main memory sizes:

    a.) 3 page frames b.) 4 page frames

    Main memory is empty when the process starts.
- Determine, for all four combinations of replacement strategy and main memory size separately (i.e. FIFO with 3 and with 4 page frames, LRU with 3 and with 4 page frames):
  - The contents of main memory immediately before each page access
  - The instants of the page faults
    (i.e. accesses to pages that are currently not present in main memory)
  - The total number of page faults
- Proceed as shown in:
  - http://www.nt.th-koeln.de/vogt/bs/animationen/FIFOvsLRU_engl.pdf
  - http://www.nt.th-koeln.de/vogt/bs/videos/BVS2_7334.mp4 (from minute 6:55)
- What do you observe regarding the page fault numbers for the different memory sizes?

Solution: Main memory contents and page faults see next page

Observation: When increasing the size of main memory, the number of page faults for FIFO increases here, too. This means that having installed additional hardware we may get a worse performance with FIFO! This undesirable behaviour is called the "FIFO anomaly". LRU does not have this behaviour (which can be even proven for the general case).

p.t.o.

FIFO, 3 Page Frames

* = Page Fault

```
 *   *   *   *   *   *   *           *   *

 1   2   3   4   1   2   5   1   2   3   4   5

∅   1   2   3   4   1   2   5   5   5   3   4
        1   2   3   4   1   2   2   2   5   3
            1   2   3   4   1   1   1   2   5
```

9 Page Faults

FIFO, 4 Page Frames

```
 *   *   *   *           *   *   *   *   *   *

 1   2   3   4   1   2   5   1   2   3   4   5

∅   1   2   3   4   4   4   5   1   2   3   4
        1   2   3   3   3   4   5   1   2   3
            1   2   2   2   3   4   5   1   2
                1   1   1   2   3   4   5   1
```

10 Page Faults

LRU, 3 Page Frames

```
 *   *   *   *   *   *   *           *   *   *

 1   2   3   4   1   2   5   1   2   3   4   5

∅   1   2   3   4   1   2   5   1   2   3   4
        1   2   3   4   1   2   5   1   2   3
            1   2   3   4   1   2   5   1   2
```

10 Page Faults

LRU, 4 Page Frames

```
 *   *   *   *           *           *   *   *

 1   2   3   4   1   2   5   1   2   3   4   5

∅   1   2   3   4   1   2   5   1   2   3   4
        1   2   3   4   1   2   5   1   2   3
            1   2   3   4   1   2   5   1   2
                1   2   3   4   4   4   5   1
```

8 Page Faults

p.t.o.

Exercise 2: Allocation of Fixed Amounts of Main Memory Space

- Assumptions:
  - Static allocation of main memory
    (i.e. a process gets a fixed number of page frames in main memory when it starts)
  - Main memory is initially empty
  - LRU page replacement
- Given: A reference string of a process

  `1 2 1 2 1 2 1 2 1 2 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4`

  - I.e. there are two phases:
    - 1st phase: Only pages 1 and 2 are accessed
    - 2nd phase: All pages 1-4 are accessed
- Determine:

  a.) For a static allocation of 4 main memory page frames

  b.) For a static allocation of 2 main memory page frames

  - The pages stored in main memory during phase 1 and during phase 2
  - The utilization of main memory (in percent) during phase 1 and during phase 2
  - The instants of the page faults
- What drawbacks do you see for a.) and for b.)?

Solution:

a.) 4 page frames:
The first phase starts with two page faults to load pages 1 and 2. After this there are no more page faults during this phase. Pages 1 and 2 remain in main memory during the whole phase. The utilization of main memory in this phase is 50% because only two of the four main memory page frames are needed.
The second phase starts with two further page faults to load pages 3 and 4. After this there are no more page faults during this phase. All pages remain in main memory during the whole phase. The utilization of main memory in this phase is 100% because all four main memory page frames are needed.
→ Drawback: Underutilization of main memory during the first phase.

a.) 2 page frames:
The first phase starts with two page faults to load pages 1 and 2. After this there are no more page faults during this phase. Pages 1 and 2 remain in main memory during the whole phase. The utilization of main memory in this phase is 100% because both two main memory page frames are needed.
The second phase loads page 3 evicting page 1, then loads page 4 evicting page 2, then loads page 1 evicting page 3 etc. Each page access causes a page fault and main memory contents changes continuously. The utilization of main memory in this phase is 100%.
→ Drawback: The process "thrashes" (i.e. is severely slowed down) due to the page faults.

p.t.o.

Exercise 3: Working Set Strategy

- Given:
  - A reference string of a process:

```
1212121212...121234123412341234...12343434343434...34
     ↑                     ↑                ↑
     t1                    t2               t3
```

  - Window sizes:

    a.) $\delta = 2$ b.) $\delta = 4$

- Determine for both window sizes and each of the instants t_1, t_2, t_3:
  - The Working Set $WS(t_i,\delta)$
  - The amount of main memory space allocated to the process
- What drawback do you see for the smaller window size $\delta = 2$?

Solution: (as explained in http://www.nt.th-koeln.de/vogt/bs/videos/BVS2_7334.mp4, from minute 22:00)

- $WS(t_1,2) = \{ 1, 2 \}$ → 2 page frames $WS(t_1,4) = \{ 1, 2 \}$ → 2 page frames
- $WS(t_2,2) = \{ 3, 4 \}$ → 2 page frames $WS(t_2,4) = \{ 1, 2, 3, 4 \}$ → 4 page frames
- $WS(t_3,2) = \{ 3, 4 \}$ → 2 page frames $WS(t_3,4) = \{ 3, 4 \}$ → 2 page frames
- Obviously, the window size δ=2 is too small to find the current locality (= the set of pages used) at instance t_2. Therefore, the amount of memory space allocated to the process will be too small with this window size (and the process will thrash, as in exercise 2). Window size δ=4 does better.