Chapter 8: Virtual-Memory Management

1

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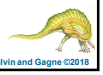
- Background
- Demand Paging
- Page Replacement
- Allocation of Frames



2

Objectives

- To describe the benefits of a virtual memory system
- To explain the concepts of demand paging, page-replacement algorithms, and allocation of page frames

3

Background

- Code needs to be in memory to execute, but entire program rarely used
  - Error code, unusual routines, large data structures
- Entire program code not needed at same time
- Consider ability to execute partially-loaded program
  - Program no longer constrained by limits of physical memory
  - Each program takes less memory while running -> more programs run at the same time
    - Increased CPU utilization and throughput with no increase in response time or turnaround time
  - Less I/O needed to load or swap programs into memory -> each user program runs faster

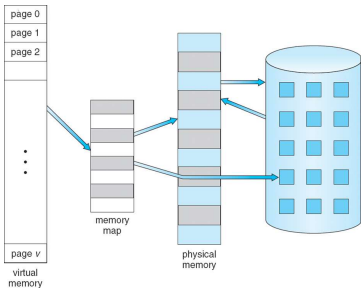
4

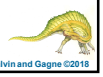
Background

- **Virtual memory** – separation of user logical memory from physical memory.
  - Only part of the program needs to be in memory for execution
  - Logical address space can therefore be much larger than physical address space
  - Allows address spaces to be shared by several processes
  - Allows for more efficient process creation
  - More programs running concurrently
  - Less I/O needed to load or swap processes
- **Virtual address space** – logical view of how process is stored in memory
  - Usually start at address 0, contiguous addresses until end of space
  - Meanwhile, physical memory organized in page frames
  - MMU must map logical to physical
- Virtual memory can be implemented via:
  - Demand paging
  - Demand segmentation

5

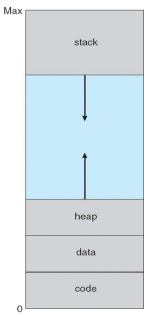
Virtual Memory That is Larger Than Physical Memory





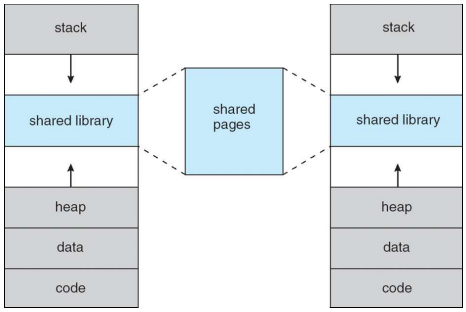
6

Virtual-address Space



7

Shared Library Using Virtual Memory



8

Demand Paging

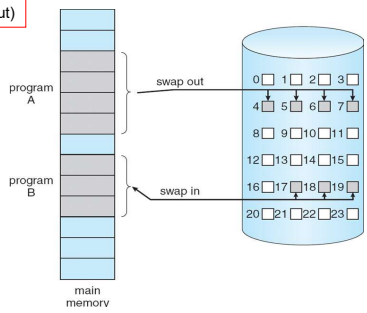
(การจัดสรร **Paging** ตามความต้องการที่ร้องขอ)

- Bring a page into memory only when it is needed
  - Less I/O needed
  - Less memory needed
  - Faster response
  - More users
- Page is needed ⇒ reference to it (หากต้องการใช้ page ให้อ้างตำแหน่งถึง page ที่ต้องการ)
  - invalid reference ⇒ abort (หากอ้างตำแหน่งไม่ถูกต้องให้ยกเลิก)
  - not-in-memory ⇒ bring to memory (หากอ้างแล้วไม่มีใน memory ให้นำเข้ามาไว้ใน memory)
- **Lazy swapper** – never swaps a page into memory unless page will be needed
  - Swapper that deals with pages is a **pager**

9

Transfer of a Paged Memory to Contiguous Disk Space

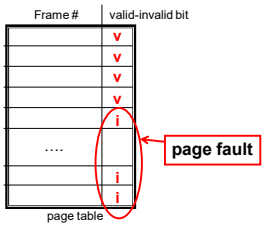
มี pager เป็นตัวย้าย page
เข้า (swap in) หรือออก (swap out)



10

Valid-Invalid Bit

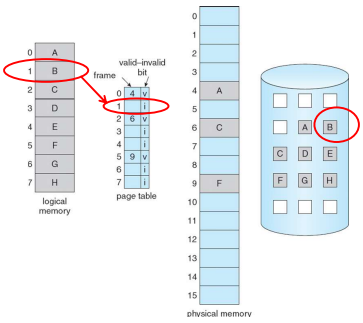
- With each page table entry a valid–invalid bit is associated (**v** ⇒ in-memory, **i** ⇒ not-in-memory)
- Initially valid–invalid bit is set to **i** on all entries
- Example of a page table snapshot:



- During address translation, if valid–invalid bit in page table entry is **i** ⇒ **page fault** (การอ้างอิงผิดหน้าหรือไม่พบหน้าที่ต้องการ)

11

Page Table When Some Pages Are Not in Main Memory



12

Page Fault

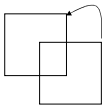
เมื่อมีการอ้างอิงมิดหน้าหรือไม่พบหน้าที่ต้องการในหน่วยความจำหลัก **(page fault)** จะมีขั้นตอนดำเนินการดังนี้

- If there is a reference to a page, first reference to that page will trap to operating system:
  - page fault
1. Operating system looks at another table to decide:
   - Invalid reference ⇒ abort
   - Just not in memory
2. Get empty frame
3. Swap page into frame
4. Reset tables
5. Set validation bit = **v**
6. Restart the instruction that caused the page fault

13

Page Fault (Cont.)

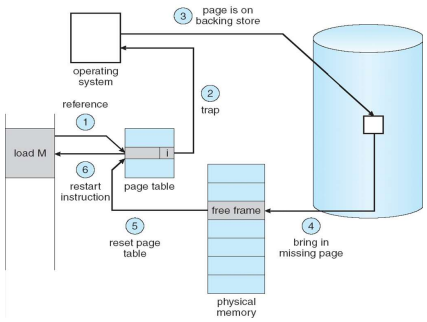
- Restart instruction (ทำต่อจากจุดที่ได้ทำมาแล้วล่าสุด หรือ ทำต่อจากจุดที่เกิด page fault ขึ้น)
  - block move



  - auto increment/decrement location

14

Steps in Handling a Page Fault



15

What happens if there is no free frame?

- **Page replacement** – find some page in memory, but not really in use, swap it out
  - algorithm
  - performance – want an algorithm which will result in minimum number of page faults
- Same page may be brought into memory several times

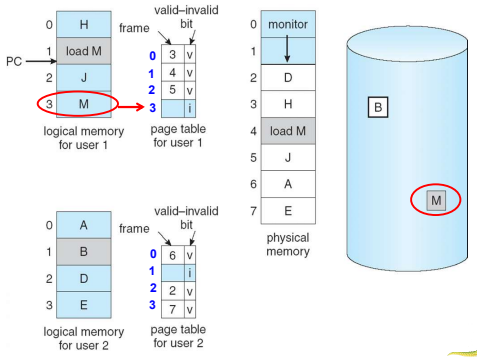
16

Page Replacement

- **Prevent over-allocation of memory** by modifying page-fault service routine to include page replacement
- Use **modify (dirty) bit** to reduce overhead of page transfers – only modified pages are written to disk
- Page replacement completes separation between logical memory and physical memory – large virtual memory can be provided on a smaller physical memory

17

Need For Page Replacement



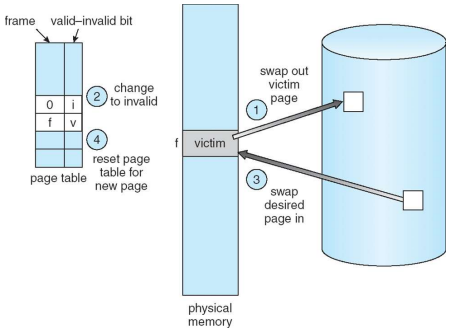
18

Basic Page Replacement

1. Find the location of the desired page on disk
2. Find a free frame:
   - If there is a free frame, use it
   - If there is no free frame, use a page replacement algorithm to select a **victim** frame
3. Bring the desired page into the (newly) free frame; update the page and frame tables
4. Restart the process

19

Page Replacement



20

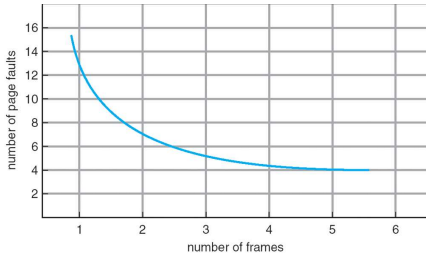
Page Replacement Algorithms

- **Want lowest page-fault rate**
- Evaluate algorithm by running it on a particular string of memory references (reference string) and computing the number of page faults on that string
- In all our examples, the reference string is

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

21

Graph of Page Faults Versus The Number of Frames



22

First-In-First-Out (FIFO) Algorithm

- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
- 3 frames (3 pages can be in memory at a time per process)

1	1	4	5	
2	2	1	3	เกิด 9 page faults
3	3	2	4	

- 4 frames

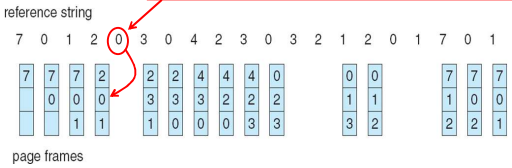
1	1	5	4	
2	2	1	5	เกิด 10 page faults
3	3	2		
4	4	3		

- Belady's Anomaly: more frames ⇒ more page faults

23

FIFO Page Replacement

มี 0 อยู่แล้วใน memory จึงไม่ต้องไปดึงข้อมูลมาใหม่อีก จึงไม่เกิด page fault สำหรับ page 0

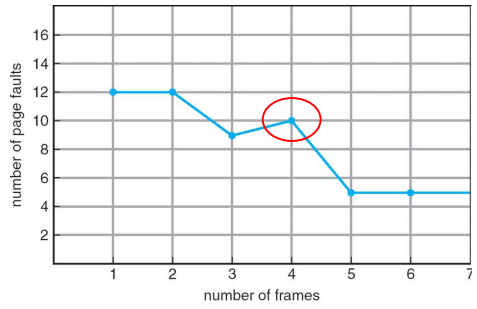


เมื่อ physical memory 3 frames และใช้ reference string ตามที่กำหนดให้ จะเกิด page fault ทั้งหมด 15 page faults

- ครั้งแรกไม่มี page อยู่ใน Physical Memory จะเกิด page fault

24

FIFO Illustrating Belady's Anomaly



Belady's Anomoly : เป็นเหตุการณ์ที่เมื่อมี Physical Memory เพิ่มขึ้น แต่จะเกิด page fault เพิ่มขึ้นด้วย (เป็นข้อยกเว้นสำหรับ FIFO Algorithm)

25

Optimal Algorithm

- Replace page that will not be used for longest period of time

(มองใน list ของ reference string ถัดไปในอนาคตว่า page ใดอีกนานที่จะถูกใช้งาน จะโดน replace)

- 4 frames example

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

1	4
2	
3	
4	5

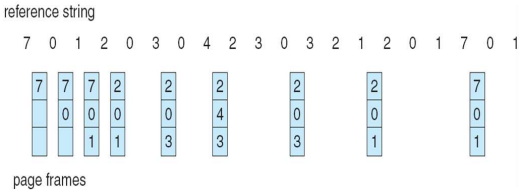
เกิด 6 page faults

ไม่ **make sence** เราไม่สามารถรู้อนาคตได้

- How do you know this?
- Used for measuring how well your algorithm performs

26

Practice: Optimal Page Replacement

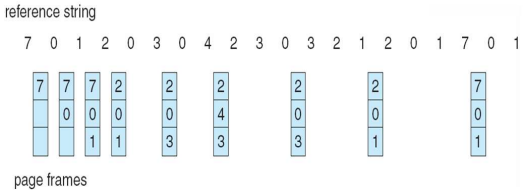


เกิดกี่ page faults ???

27

Practice: Optimal Page Replacement

Answer!!



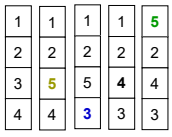
เกิด **9** page faults

28

Least Recently Used (LRU) Algorithm

(มองย้อนกลับไปในอดีตว่า **page** ใดไม่ได้ถูกใช้มานานที่สุดจะถูก **replace**)

- Reference string: 1, 2, 3, 4, 1, 2, **5**, 1, 2, **3**, **4**, **5**

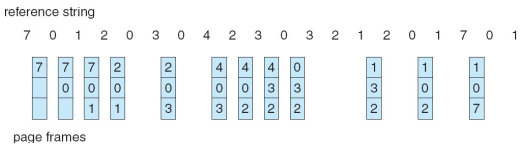


เกิด **8** page faults

- Counter implementation
  - Every page entry has a counter; every time page is referenced through this entry, copy the clock into the counter
  - When a page needs to be changed, look at the counters to determine which are to change

29

Practice: LRU Page Replacement



เกิดกี่ page fault ???

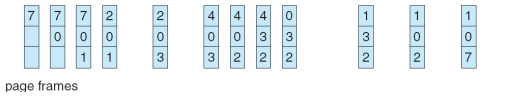
30

Practice: LRU Page Replacement

Answer!!

reference string

7 0 1 2 0 3 0 4 2 3 0 3 2 1 2 0 1 7 0 1



page frames

เกิด **12** page faults

- Better than FIFO but worse than Optimal Algorithm

31

Counting Algorithms

- Keep a counter of the number of references that have been made to each page
- **LFU Algorithm**: replaces page with smallest count
- **MFU Algorithm**: based on the argument that the page with the smallest count was probably just brought in and has yet to be used

LFU : Least Frequently Used (ความถี่ในการถูกใช้น้อยที่สุด)
MFU: Most Frequently Used (ความถี่ในการถูกใช้มากที่สุด)

32

Allocation of Frames

- Each process needs *minimum* number of pages
- 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*
- Two major allocation schemes
  - fixed allocation
  - priority allocation

33

Fixed Allocation

- Equal allocation – For example, if there are 100 frames and 5 processes, give each process 20 frames. (ได้จาก (frame / process) = (100 /5)
- Proportional allocation – Allocate according to the size of process
  - s_i = size of process p_i
  - $S = \sum s_i$
  - m = total number of frames
  - a_i = allocation for $p_i = \frac{s_i}{S} \times m$

$m = 64$
$s_i = 10$ ← P_i
$s_2 = 127$ ← P_2

P_i ได้ **5 frames** $a_1 = \frac{10}{137} \times 64 \approx 5$

P_2 ได้ **59 frames** $a_2 = \frac{127}{137} \times 64 \approx 59$

34

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

35

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
- **Local replacement** – each process selects from only its own set of allocated frames

36

End of Chapter 8