Chapter 9: Virtual Memory

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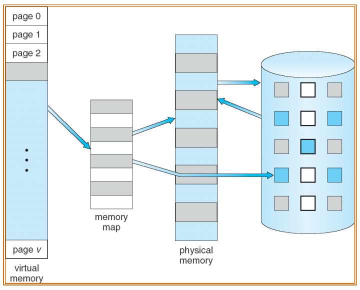
- Background
- Demand Paging
- Process Creation
- Page Replacement
- Allocation of Frames
- Thrashing
- Demand Segmentation
- Operating System Examples

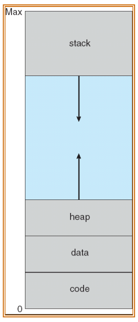
Background

- **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.
- Virtual memory can be implemented via:
  - Demand paging
  - Demand segmentation

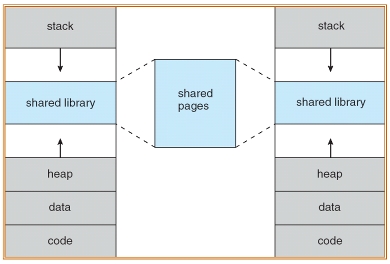
Virtual Memory That is Larger Than Physical Memory



Virtual-address Space



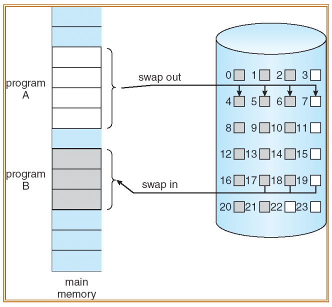
Shared Library Using Virtual Memory



Demand Paging

- Bring a page into memory only when it is needed
  - Less I/O needed
  - Less memory needed
  - Faster response
  - More users
- Page is needed $\Rightarrow$ reference to it
  - invalid reference $\Rightarrow$ abort
  - not-in-memory $\Rightarrow$ bring to memory

Transfer of a Paged Memory to Contiguous Disk Space



Valid-Invalid Bit

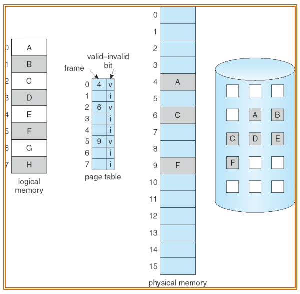
- With each page table entry a valid–invalid bit is associated (1 $\Rightarrow$ in-memory, 0 $\Rightarrow$ not-in-memory)
- Initially valid–invalid but is set to 0 on all entries
- Example of a page table snapshot:

Frame #	valid-invalid bit
	1
	1
	1
	1
	0
⋮	
	0
	0

page table

- During address translation, if valid–invalid bit in page table entry is 0 $\Rightarrow$ page fault

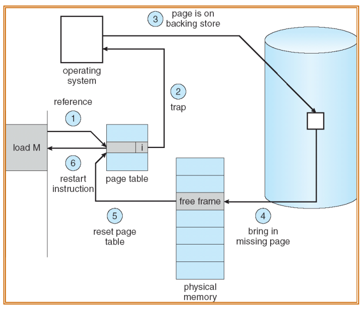
Page Table When Some Pages Are Not in Main Memory



Page Fault

- If there is ever a reference to a page, first reference will trap to OS $\Rightarrow$ page fault
- OS looks at another table to decide:
  - Invalid reference $\Rightarrow$ abort.
  - Just not in memory.
- Get empty frame.
- Swap page into frame.
- Reset tables, validation bit = 1.
- Restart instruction

Steps in Handling a Page Fault



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

Performance of Demand Paging

- Page Fault Rate $0 \leq p \leq 1.0$
  - if $p = 0$ no page faults
  - if $p = 1$, every reference is a fault
- Effective Access Time (EAT)

EAT = (1 – p) x memory access
+ p (page fault overhead
+ [swap page out]
+ swap page in
+ restart overhead)

Process Creation

- Virtual memory allows other benefits during process creation:

  - Copy-on-Write

  - Memory-Mapped Files (later)

Copy-on-Write

- Copy-on-Write (COW) allows both parent and child processes to initially *share* the same pages in memory

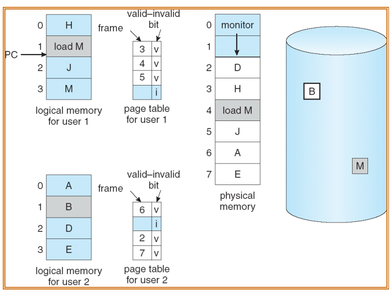
  If either process modifies a shared page, only then is the page copied

- COW allows more efficient process creation as only modified pages are copied

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

Need For Page Replacement



Basic Page Replacement

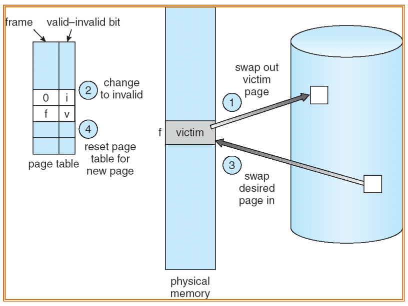
1. Find the location of the desired page on disk

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. Read the desired page into the (newly) free frame. Update the page and frame tables.

4. Restart the process

Page Replacement

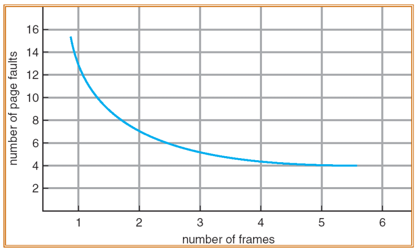


Page Replacement Algorithms

- 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

Graph of Page Faults Versus The Number of Frames



First-In-First-Out (FIFO) Algorithm

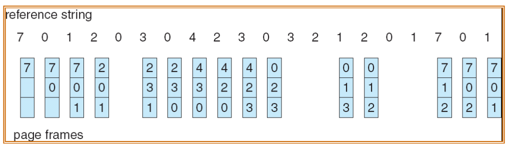
- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
- 3 frames (3 pages can be in memory at a time per process)

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

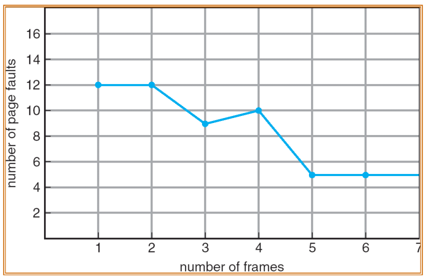
- 4 frames

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

FIFO Page Replacement



FIFO Illustrating Belady's Anomaly



Optimal Algorithm

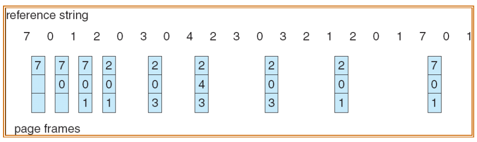
- Replace page that will not be used for longest period of time
- 4 frames example

4

6 page faults

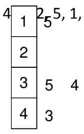
1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5

Optimal Page Replacement



Least Recently Used (LRU) Algorithm

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



- 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

LRU Page Replacement