CSE 421/521 - Operating Systems
Fall 2011

Lecture - XV

Memory Management & Virtual Memory

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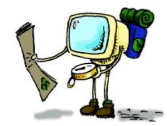
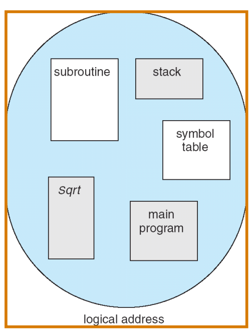
Roadmap

- Main Memory Management
  - Segmentation
- Virtual Memory
  - Demand Paging
  - Page Faults
  - Page Replacement
  - Page Replacement Algorithms
  - Performance of Demand Paging



User's View of a Program

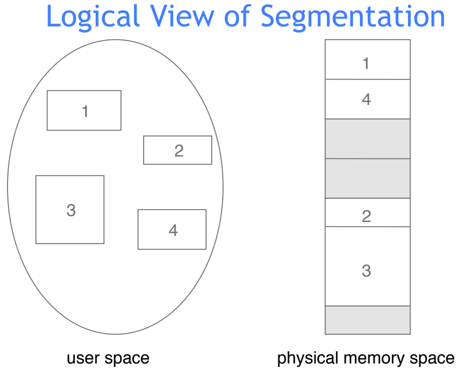


Segmentation

- Memory-management scheme that supports user view of memory
- A program is a collection of segments. A segment is a logical unit such as:

  main program,
  procedure,
  function,
  method,
  object,
  local variables, global variables,
  common block,
  stack,
  symbol table, arrays

Logical View of Segmentation



Segmentation Architecture

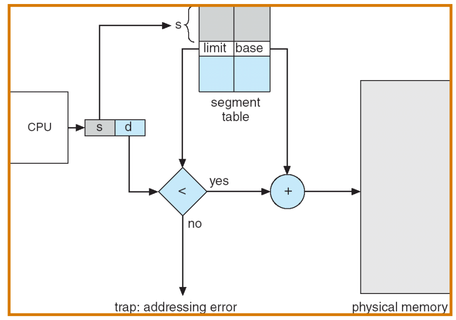
- Logical address consists of a two tuple:

  <segment-number, offset>,
- Segment table – maps two-dimensional physical addresses; each table entry has:
  - base – contains the starting physical address where the segments reside in memory
  - *limit* – specifies the length of the segment
- *Segment-table base register (STBR)* points to the segment table's location in memory
- *Segment-table length register (STLR)* indicates the length (limit) of the segment
- segment addressing is d (offset) < STLR

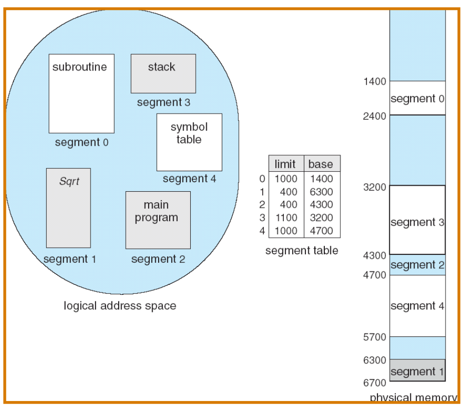
Segmentation Architecture (Cont.)

- Protection. With each entry in segment table associate:
  - validation bit = 0 ⇒ illegal segment
  - read/write/execute privileges
- Protection bits associated with segments; code sharing occurs at segment level
- Since segments vary in length, memory allocation is a dynamic storage-allocation problem
- A segmentation example is shown in the following diagram

Address Translation Architecture



Example of Segmentation



Exercise

- Consider the following segment table:

Segment	Base	Length
0	219	600
1	2300	14
2	90	100
3	1327	580
4	1952	96

What are the physical addresses for the following logical addresses?

a. 1, 100

b. 2, 0

c. 3, 580

Solution

- Consider the following segment table:

Segment	Base	Length
0	219	600
1	2300	14
2	90	100
3	1327	580
4	1952	96

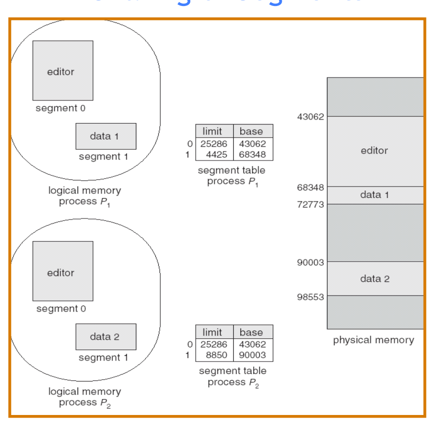
What are the physical addresses for the following logical addresses?

a. 1, 100
illegal reference (2300+100 is not within segment limits)

b. 2, 0
physical address = 90 + 0 = 90

c. 3, 580
illegal reference (1327 + 580 is not within segment limits)

Sharing of Segments



Virtual Memory

Background

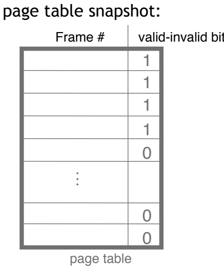
- **Virtual memory** – separation of user logical memory from physical memory.
  - Only part of the program needs to be in memory for execution.
  - Logical address space can therefore be much larger than physical address space.
  - Allows address spaces to be shared by several processes.
  - Allows for more efficient process creation.
- Virtual memory can be implemented via:
  - Demand paging
  - Demand segmentation

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 ⇒ reference to it
  - invalid reference ⇒ abort
  - not-in-memory ⇒ bring to memory

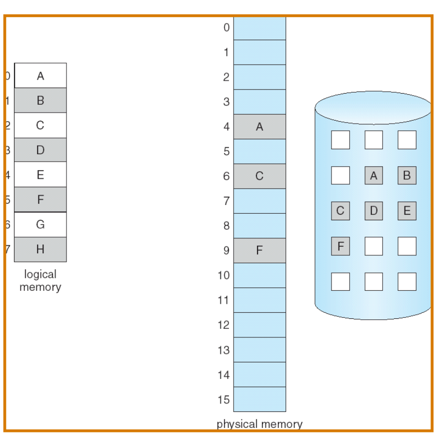
Valid-Invalid Bit

- With each page table entry a valid–invalid bit is associated (1 ⇒ in-memory and legal, 0 ⇒ not-in-memory or invalid)
- Initially valid–invalid bit is set to 0 on all entries
- Example of a page table snapshot:

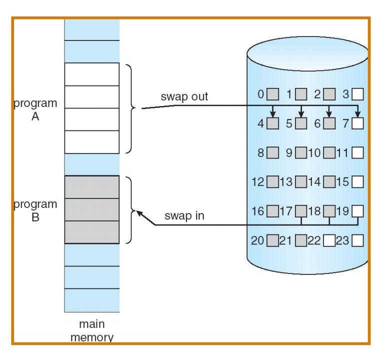


- During address translation, if valid–invalid bit in page table entry is 0 ⇒ page fault

Page Table When Some Pages Are Not in Main Memory



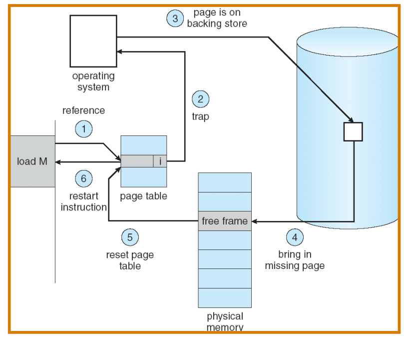
Transfer of a Paged Memory to Contiguous Disk Space



Page Fault

- If there is ever a reference to a page not in memory, first reference will trap to OS ⇒ page fault
- OS looks at another table (in PCB) to decide:
  - Invalid reference ⇒ abort.
  - Just not in memory. ==> page-in
- Get an empty frame.
- Swap (read) page into the new frame.
- Set 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
  - Algorithms (FIFO, LRU ..)
  - performance – want an algorithm which will result in minimum number of page faults
- Same page may be brought into memory several times

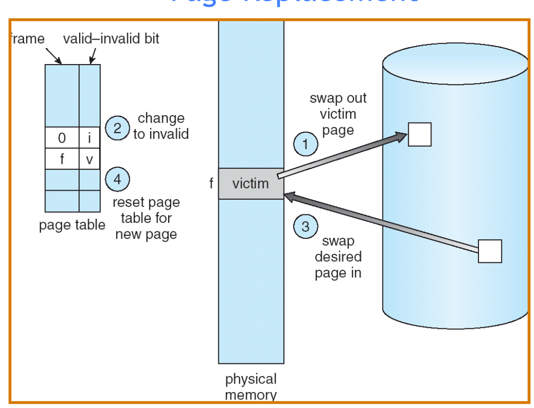
Page Replacement

- 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

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

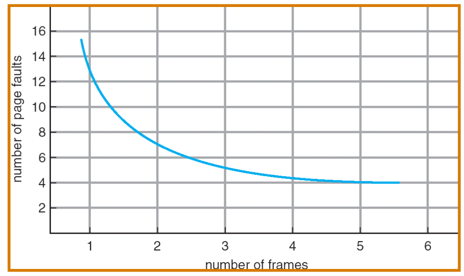


Page Replacement Algorithms

- 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)

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

-

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First-In-First-Out (FIFO) Algorithm

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- 3 frames (3 pages can be in memory at a time per process)

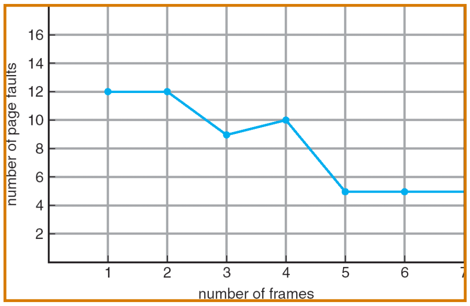
1	1	4	5	
2	2	1	3	9 page faults
3	3	2	4	

- 4 frames

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

- FIFO Replacement - Belady's Anomaly
  - more frames $\Rightarrow$ more page faults

FIFO Illustrating Belady's Anomaly



Performance of Demand Paging

- Page Fault Rate $0 \le p \le 1.0$
  - 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 x (page fault overhead
  + [swap page out]
  + swap page in
  + restart overhead)

Demand Paging Example

- Memory access time = 1 microsecond
- 50% of the time the page that is being replaced has been modified and therefore needs to be swapped out
- Swap Page Time = 10 msec = 10,000 microsec
- EAT = ?

Demand Paging Example

- Memory access time = 1 microsecond
- 50% of the time the page that is being replaced has been modified and therefore needs to be swapped out
- Swap Page Time = 10 msec = 10,000 microsec
- EAT = (1 - p) x 1 + p x (10,000 + 1/2 x 10,000)

  = 1 + 14,999 x p (in microsec)
- What if 1 out of 1000 memory accesses cause a page fault?
- What if we only want 30% performance degradation?

Summary

- Main Memory Management
  - Segmentation
- Virtual Memory
  - Demand Paging
  - Page Faults
  - Page Replacement
  - Page Replacement Algorithms
  - Performance of Demand Paging

- Next Lecture: Virtual Memory - II
- Reading Assignment: Chapter 9 from Silberschatz.

Acknowledgements

- "Operating Systems Concepts" book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne
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