Virtual Memory

CS 256/456

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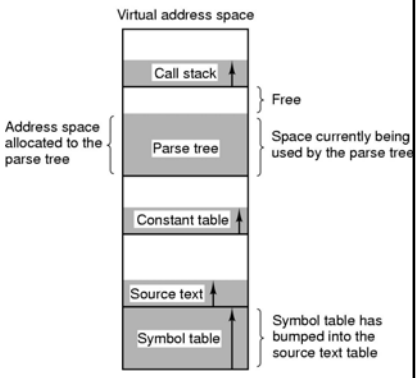
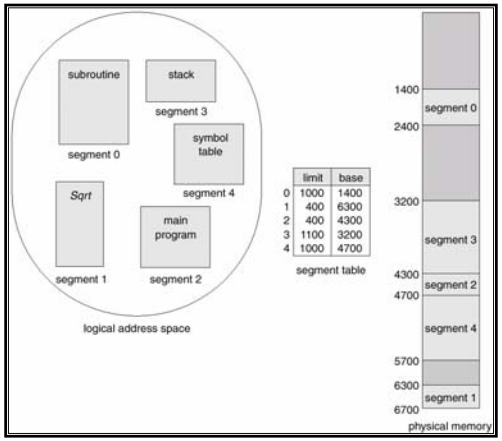
Segmentation

- One-dimensional address space with growing pieces
- At compile time, one table may bump into another
- Segmentation:
  - generate segmented logical address at compile time
  - segmented logical address is translated into physical address at execution time

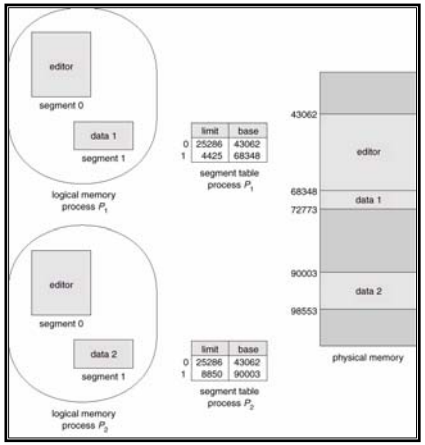


Example of Segmentation



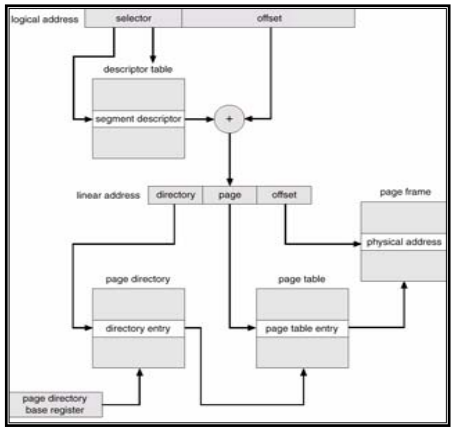
Sharing of Segments

- Convenient sharing of libraries



Segmentation & Paging – Intel x86

- Segmentation and paging with a two-level paging scheme.



Virtual Memory

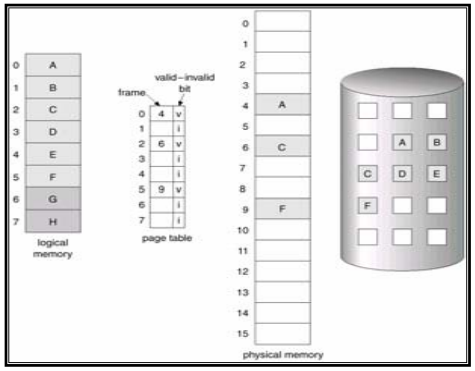
- **Virtual memory** – separation of user logical memory from physical memory.
  - Allows address spaces to be shared by several processes.
  - Copy-on-write: allows for more efficient process creation.
  - Only part of the program needs to be in memory for execution.
  - Logical address space can therefore be much larger than physical address space.
- Demand paging
  - Make a physical instance of a page in memory only when needed.

Backing Store

- With virtual memory, the whole address space of each process has a copy in the backing store (i.e., disk)
  - program code
  - data/stack
- Consider the whole program actually resides on the backing store, only part of it is cached in memory.
- With each page table entry a valid–invalid bit is associated (1 ⇒ in-memory, 0 ⇒ not-in-memory or invalid logical page)

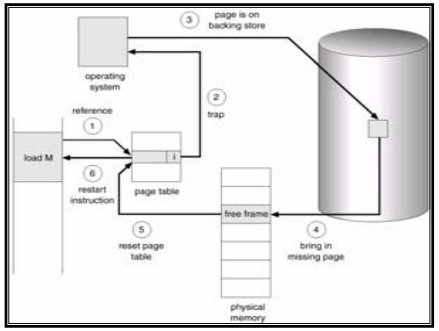
Page Table with Virtual Memory

- With each page table entry a valid–invalid bit is associated (1 ⇒ in-memory, 0 ⇒ not-in-memory or invalid logical page)



Page Fault

- A reference to a page with the valid bit set to 0 will trap to OS ⇒ page fault
- Invalid logical page:
  - ⇒ abort.
- Just not in memory:
  - Get a free frame.
  - Swap page into the free frame.
  - Reset the page table entry, valid bit = 1.
  - Restart the program from the fault instruction.



- What if there is no free frame?

Performance of Demand Paging

- Page Fault Rate $0 \le p \le 1.0$
- Effective Access Time (EAT)

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

Memory-Mapped Files

- Memory-mapped file I/O allows file I/O to be treated as routine memory access by *mapping* a disk block to a page in memory.
- At page fault:
  - A certain portion of the file is read from the file system into physical memory.
  - Subsequent reads/writes to/from the file are like ordinary memory accesses.
- Simplifies file access by treating file I/O through memory rather than **read() write()** system calls.

Page Replacement

- Page replacement is necessary when no physical frames are available for demand paging
  - a victim page would be selected and replaced
- A dirty bit for each page
  - indicating if a page has been changed since last time loaded from the backing store
  - indicating whether swap-out is necessary for the victim page.
  - Should this bit be in page table or not?

Page Replacement Algorithms

- Page replacement algorithm: the algorithm that picks the victim page.
- Metric:
  - low page-fault rate.
  - implementation cost/feasibility.
- For the page-fault rate:
  - Evaluate an algorithm by running it on a particular string of memory references (reference string) and computing the number of page faults on that string.

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)

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

- 4 frames

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

- Anomaly for the FIFO Replacement
  - more frames not necessarily leading to less page faults

Optimal Algorithm

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

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

1	4	
2		6 page faults
3		
4	5	

Least Recently Used (LRU) Algorithm

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

1	5	
2		
3	5	4
4	3	

- Not always better than FIFO, but more frames always lead to less or equal page faults
  - imagine a virtual stack (infinite size) of pages
  - each page is moved to the top after being accessed
  - this virtual stack is independent of the number of frames
  - page fault number when there are N frames:
    - the number of accesses that do not hit the top N pages in the virtual stack.

Implementations

- FIFO implementation
- Time-of-use LRU implementation:
  - Every page entry has a time-of-use filed; every time page is referenced through this entry, copy the clock into the field.
  - When a page needs to be changed, look at the time-of-use fields to determine which are to change.
- Stack LRU implementation – keep a stack of page numbers in a double link form:
  - Page referenced: move it to the top
  - Always replace at the bottom of the stack

Feasibility of the Implementations

- FIFO implementation.
- LRU implementations:
  - Time-of-use implementation
  - Stack implementation
- What needs to be done at each memory reference?
- What needs to be done at page loading or page replacement?

LRU Approximation Algorithms

- LRU approximation with a little help from the hardware.
- Reference bit
  - With each page associate a bit, initially = 0
  - When page is referenced, the bit is set to 1 by the hardware.
  - Replace a page whose reference bit is 0 (if one exists). We do not know the order, however.
- Second chance
  - Combining the reference bit with FIFO replacement
  - If page to be replaced (in FIFO order) has reference bit = 1. then:
    - set reference bit 0.
    - leave page in memory.
    - replace next page (in FIFO order), subject to same rules.

LRU Approximation Algorithms

- Enhancing the reference bit algorithm:
  - it would be nice if there is more information about the reference history than a single bit.
  - with some help from software.
- Maintain more reference bits in software:
  - at every N-th clock interrupt, the OS moves each hardware page reference bit into a page reference history word (with more than one bit).

Counting-based Page Replacement

- Least frequently used page-replacement algorithm
  - the page with smallest access count (within a period of time) is replaced
- Implementation?

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