Virtual Memory

Virtual Memory - separation of user logical memory from physical memory.
Virtual address space – logical view of how a 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.
Frame - Divide physical memory into fixed-sized blocks called frames.
Page - Divide logical memory into blocks of the same size called pages.

* To run a program of size \( N \) pages, need to find \( N \) free frames and load program.

Example - Paging

Assuming a 64KB virtual address space and 32KB physical address space. If the page size is 4KB, calculate:
A. Frame size
B. Number of pages
C. Number of frames

Answer:
frame size = 4KB (same as page size)
# of pages = 16 (64KB / 4KB)
# of frames = 8 (32KB / 4KB)

Address translation
The address generated by CPU is split into:

- **page number** \( (p) \) – used as an index into a page table which contains a base address of the corresponding frame in physical memory.
- **page offset** \( (d) \) – combined with base address to define the physical memory address that is sent to the memory unit.

Page Table - Set up a page table to translate logical to physical addresses.
The address generated by CPU is divided into:
- Page number \( (p) \) – used as an index into a page table which contains a base address of each page in physical memory.
- Page offset \( (d) \) – combined with a base address to define the physical memory address that is sent to the memory unit.
- Example setup:
  - n=2 and m=4 (p and d are each 2-bits)
  - 32-bytes of physical memory and
  - 4-byte pages (8 pages can fit in physical memory space)

- Example:
  - Logical address 10 is in page 2 at offset 2
  - According to the page table, page 2 is located in frame 1
  - Physical memory address is: (Frame # * Page size) + Offset
  - Physical memory address for logical address 10 is: (1 * 4 bytes) + 2 byte offset = 6
Multiple Choice
1. An address generated by a CPU is referred to as a ____.
   A) physical address
   B) logical address
   C) post-relocation register address
   D) Memory-Management Unit (MMU) generated’s address.

2. Suppose a program is operating with execution-time binding and the physical address generated is 300. The relocation register is set to 100. What is the corresponding logical address? 
   (Pavol’s Slide - Slide 10 of Memory)
   A) 100
   B) 200
   C) 300
   D) 400

3. The mapping of a logical address to a physical address is done in hardware by the ________.
   A) memory-management-unit (MMU)
   B) memory address register
   C) relocation register
   D) dynamic loading register.

4. _____ is the dynamic storage-allocation algorithm which results in the smallest leftover hole in the memory.
   A) First fit
   B) Best fit
   C) Worst fit
   D) Next fit

5. Consider a logical address with a page size of 8 KB. How many bits must be used to represent the page offset in the logical address?
   A) 10
   B) 8
   C) 13
   D) 12
6. Assume a system has a TLB hit ratio of 90%. It requires 15 nanoseconds to access the TLB, and 85 nanoseconds to access the main memory. What is the effective memory access time in nanoseconds for this system? (Pavol Slide - Slide 23 of Virtual Memory)
   A) 108.5
   B) 100
   C) 22
   D) 176.5

7. Given the logical address 0xAEF9 (in hexadecimal) with a page size of 256 bytes, what is the page number? (Pavol Slide - Slide 10 of Virtual Memory)
   A) 0xAE
   B) 0xF9
   C) 0xA
   D) 0x00F9

8. Consider a 32-bit address for a two-level paging system with an 8 KB page size. The outer page table has 1024 entries. How many bits are used to represent the second-level page table? (Pavol Slide - Slide 29 of Virtual Memory)
   A) 10
   B) 8
   C) 12
   D) 9

9. With segmentation, a logical address consists of _____.
   A) segment number and offset
   B) segment name and offset
   C) segment number and page number
   D) segment table and segment number

10. Assume the value of the base and limit registers are 1200 and 350 respectively. Which of the following addresses is legal?
    A) 355
    B) 1200
    C) 1551
    D) all of the above
11. In systems that support virtual memory, ____.
A) virtual memory is separated from logical memory.
B) virtual memory is separated from physical memory.
C) physical memory is separated from secondary storage.
D) physical memory is separated from logical memory.

12. _____ is the dynamic storage-allocation algorithm which results in the largest leftover hole in the memory.
A) First fit
B) Best fit
C) Worst fit
D) None of the above

13. Consider a logical address with 18 bits used to represent an entry in a conventional page table. How many entries are in the conventional page table?
A) 262144
B) 1024
C) 1048576
D) 18

14. Given the logical address 0xAEF9 (in hexadecimal) with a page size of 256 bytes, what is the page offset?
A) 0xAE
B) 0xF9
C) 0xA
D) 0xF900

15. Distinguish between internal and external fragmentation.

Ans: Fragmentation occurs when memory is allocated and returned to the system. As this occurs, free memory is broken up into small chunks, often too small to be useful. External fragmentation occurs when there is sufficient total free memory to satisfy a memory request, yet the memory is not contiguous, so it cannot be assigned. Some contiguous allocation schemes may assign a process more memory than it actually requested (i.e. they may assign memory in fixed-block sizes). Internal fragmentation occurs when a process is assigned more memory than it has requested and the wasted memory fragment is internal to a process.
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