9.5 Given memory partitions of 100K, 500K, 200K, 300K, and 600K (in order), how would each of the First-fit, Best-fit, and Worst-fit algorithms place processes of 212K, 417K, 112K, and 426K (in order)? Which algorithm makes the most efficient use of memory?

Answer:

a. First-fit:

b. 212K is put in 500K partition

c. 417K is put in 600K partition

d. 112K is put in 288K partition (new partition 288K = 500K - 212K)

e. 426K must wait

f. Best-fit:

g. 212K is put in 300K partition

h. 417K is put in 500K partition

i. 112K is put in 200K partition

j. 426K is put in 600K partition

k. Worst-fit:

l. 212K is put in 600K partition

m. 417K is put in 500K partition

n. 112K is put in 388K partition

o. 426K must wait

In this example, Best-fit turns out to be the best.

9.8 Consider a logical address space of eight pages of 1024 words each, mapped onto a physical memory of 32 frames.

a. How many bits are there in the logical address?

b. How many bits are there in the physical address?

Answer:

a. Logical address: 13 bits

b. Physical address: 15 bits

9.10 Consider a paging system with the page table stored in memory.

a. If a memory reference takes 200 nanoseconds, how long does a paged memory reference take?

b. If we add associative registers, and 75 percent of all page-table references are found in the associative registers, what is the effective memory reference time? (Assume that finding a page-table entry in the associative registers takes zero time, if the entry is there.)

Answer:

a. 400 nanoseconds; 200 nanoseconds to access the page table and 200 nanoseconds to access the word in memory.

b. Effective access time = 0.75 $\times$ (200 nanoseconds) + 0.25 $\times$ (400 nanoseconds) = 250 nanoseconds.

9.16 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. 0,430

b. 1,10

c. 2,500

d. 3,400

e. 4,112

Answer:

a. 219 + 430 = 649

b. 2300 + 10 = 2310

c. illegal reference, trap to operating system

d. 1327 + 400 = 1727

e. illegal reference, trap to operating system

10.2 Assume a page reference string for a process with m frames (initially all empty). The page reference string has length p with n distinct page numbers occurring in it. For any page-replacement algorithms,

a. What is a lower bound on the number of page faults?

b. What is an upper bound on the number of page faults?

Answer:

a. n

b. p

10.3 A certain computer provides its users with a virtual-memory space of 2^{32} bytes. The computer has 2^{18} bytes of physical memory. The virtual memory is implemented by paging, and the page size is 4096 bytes. A user process generates the virtual address 11123456. Explain how the system establishes the corresponding physical location. Distinguish between software and hardware operations.

Answer: The virtual address in binary form is

0001 0001 0001 0010 0011 0100 0101 0110

Since the page size is 2^{12}, the page table size is 2^{20}. Therefore the low-order 12 bits "0100 0101 0110" are used as the displacement into the page, while the remaining 20 bits "0001 0001 0001 0010 0011" are used as the displacement in the page table.

10.5 Assume we have a demand-paged memory. The page table is held in registers. It takes 8 milliseconds to service a page fault if an empty page is available or the replaced page is not modified, and 20 milliseconds if the replaced page is modified. Memory access time is 100 nanoseconds.

Assume that the page to be replaced is modified 70 percent of the time. What is the maximum acceptable page-fault rate for an effective access time of no more than 200 nanoseconds?

Answer:

$$\begin{aligned} 0.2\ \mu\text{sec} &= (1-P) \times 0.1\ \mu\text{sec} + (0.3P) \times 8\ \text{millisec} + (0.7P) \times 20\ \text{millisec} \\ 0.1 &= -0.1P + 2400\,P + 14000\,P \\ 0.1 &\simeq 16{,}400\,P \\ P &\simeq 0.000006 \end{aligned}$$

10.6 Consider the following page-replacement algorithms. Rank these algorithms on a five-point scale from "bad" to "perfect" according to their page-fault rate. Separate those algorithms that suffer from Belady's anomaly from those that do not.

a. LRU replacement

b. FIFO replacement

c. Optimal replacement

d. Second-chance replacement

Answer:

Rank	Algorithm	Suffer from Belady's anomaly
1	Optimal	no
2	LRU	no
3	Second-chance	yes
4	FIFO	yes

10.8 An operating system supports a paged virtual memory, using a central processor with a cycle time of 1 microsecond. It costs an additional 1 microsecond to access a page other than the current one. Pages have 1000 words, and the paging device is a drum that rotates at 3000 revolutions per minute and transfers 1 million words per second. The following statistical measurements were obtained from the system:

- 1 percent of all instructions executed accessed a page other than the current page.
- Of the instructions that accessed another page, 80 percent accessed a page already in memory.
- When a new page was required, the replaced page was modified 50 percent of the time.

Calculate the effective instruction time on this system, assuming that the system is running one process only, and that the processor is idle during drum transfers.

Answer:

$$\begin{aligned} \text{effective access time} &= 0.99 \times (1\ \mu\text{sec} + 0.008 \times (2\ \mu\text{sec}) \\ &\quad + 0.002 \times (10{,}000\ \mu\text{sec} + 1{,}000\ \mu\text{sec}) \\ &\quad + 0.001 \times (10{,}000\ \mu\text{sec} + 1{,}000\ \mu\text{sec}) \\ &= (0.99 + 0.016 + 22.0 + 11.0)\ \mu\text{sec} \\ &= 34.0\ \mu\text{sec} \end{aligned}$$

10.11 Consider the following page reference string:

1, 2, 3, 4, 2, 1, 5, 6, 2, 1, 2, 3, 7, 6, 3, 2, 1, 2, 3, 6.

How many page faults would occur for the following replacement algorithms, assuming one, two, three, four, five, six, or seven frames? Remember all frames are initially empty, so your first unique pages will all cost one fault each.

- LRU replacement
- FIFO replacement
- Optimal replacement

Answer:

Number of frames	LRU	FIFO	Optimal
1	20	20	20
2	18	18	15
3	15	16	11
4	10	14	8
5	8	10	7
6	7	10	7
7	7	7	7

10.16 A page-replacement algorithm should minimize the number of page faults. We can do this minimization by distributing heavily used pages evenly over all of memory, rather than having them compete for a small number of page frames. We can associate with each page frame a counter of the number of pages that are associated with that frame. Then, to replace a page, we search for the page frame with the smallest counter.

a. Define a page-replacement algorithm using this basic idea. Specifically address the problems of (1) what the initial value of the counters is, (2) when counters are increased, (3) when counters are decreased, and (4) how the page to be replaced is selected.

b. How many page faults occur for your algorithm for the following reference string, for four page frames?

$$1, 2, 3, 4, 5, 3, 4, 1, 6, 7, 8, 7, 8, 9, 7, 8, 9, 5, 4, 5, 4, 2.$$

c. What is the minimum number of page faults for an optimal page-replacement strategy for the reference string in part b with four page frames?

Answer:

a. Define a page-replacement algorithm addressing the problems of:
   i. Initial value of the counters—0.
   ii. Counters are increased—whenever a new page is associated with that frame.
   iii. Counters are decreased—whenever one of the pages associated with that frame is no longer required.
   iv. How the page to be replaced is selected—find a frame with the smallest counter. Use FIFO for breaking ties.

b. 14 page faults

c. 11 page faults

10.17 Consider a demand-paging system with a paging disk that has an average access and transfer time of 20 milliseconds. Addresses are translated through a page table in main memory, with an access time of 1 microsecond per memory access. Thus, each memory reference through the page table takes two accesses. To improve this time, we have added an associative memory that reduces access time to one memory reference, if the page-table entry is in the associative memory.

Assume that 80 percent of the accesses are in the associative memory and that, of the remaining, 10 percent (or 2 percent of the total) cause page faults. What is the effective memory access time?

Answer:

$$\begin{aligned} \text{effective access time} &= (0.8) \times (1\ \mu\text{sec}) \\ &\quad + (0.1) \times (2\ \mu\text{sec}) + (0.1) \times (5002\ \mu\text{sec}) \\ &= 501.2\ \mu\text{sec} \\ &= 0.5\ \text{millisec} \end{aligned}$$

10.18 Consider a demand-paged computer system where the degree of multiprogramming is currently fixed at four. The system was recently measured to determine utilization of CPU and the paging disk. The results are one of the following alternatives. For each case, what is happening? Can the degree of multiprogramming be increased to increase the CPU utilization? Is the paging helping?

a. CPU utilization 13 percent; disk utilization 97 percent

b. CPU utilization 87 percent; disk utilization 3 percent

c. CPU utilization 13 percent; disk utilization 3 percent

Answer:

a. Thrashing is occurring.

b. CPU utilization is sufficiently high to leave things alone, an increase degree of multiprogramming.

c. Increase the degree of multiprogramming.