

Part 1: (39 points - 3 points for each problem)

- (D) 1. Which statement about inverted paging is false?
(A) There is one entry per page frame.
(B) It must search the entire inverted page table for an entry.
(C) There is one global page table sorted by the frame number.
(D) None of the above
- (B) 2. With paging, the internal fragmentation is possible when:
(A) The page does not quite fit the frame.
(B) The last page of the program is less than maximum page size.
(C) There are too many programs to fit in the memory.
(D) There is no such thing as internal fragmentation with paging.
- (B) 3. Which of the memory allocation schemes is not subject to internal fragmentation?
(A) Multiple Contiguous Fixed Partitions (B) Segmentation (C) Paging (D) None of above
- (D) 4. A machine has 512 MB memory. Each memory word is 32 bits. What is the length of the physical address?
(A) 24 bits (B) 29 bits (C) 32 bits (D) None of the above
- (X) 5. The time to read or write a 32-bit memory word is 10 nsec. Assume the total holes take one fourth of the 512 MB memory. What is the time needed to eliminate holes by compaction?
(A) 83.886 ms (B) 167.772 ms (C) 251.658 ms (D) 335.544 ms
- (D) 6. A computer with virtual address space of 2^{36} words has the page size of 4096 (2^{12}) words. If the hexadecimal virtual address is 123456789, the offset in hexadecimal would be:
(A) 123456 (B) 6789 (C) 123 (D) 789
- (B) 7. If there are 64 pages, and the page size is 4096 words, the length of logical address is:
(A) 16 bits (B) 18 bits (C) 20 bits (D) 22 bits
- (D) 8. A machine with 256 (2^8) MB memory has a 32-bit memory word. The frame size is 128 (2^7) words. How many bits are used to indicate the frame number?
(A) 24 bits (B) 20 bits (C) 16 bits (D) None of the above
- (B) 9. A system with a 32-bit virtual address. It uses the first 20 bits to indicate the page number. Each table entry takes 2 bytes. What is the size of the page table?
(A) 1 MB (B) 2 MB (C) 4 MB (D) 8 MB
- (A) 10. Which page-replacement algorithm suffers from Belady's anomaly?
(A) Clock (B) Least recently used (LRU) (C) Not recently used (NRU) (D) None of the above
- (C) 11. Working set model is:
(A) Used to find out the average number of frames a job will need in order to run smoothly without causing thrashing
(B) Used to determine whether page replacement is needed
(C) Used for finding the minimum number of frames necessary for a job, so that jobs can run without "thrashing"
(D) None of the above.
- (A) 12. Locking a page in memory is often called:
(A) pinning (B) fixing (C) nailing (D) sticking
- (D) 13. Which statement about paging daemon is false?
(A) It sleeps most of the time. (B) It periodically inspects the state of memory.
(C) If too few page frames are free, it begins selecting pages to evict. (D) None of the above

Part 2: (61 points)

1. (a) Explain the difference between internal and external fragmentation. (3 points)
 - (b) What is associative memory (translation look-aside buffer, TLB)?
Why do some systems use associative memory in addition to page tables? (4 points)
 - (a) Internal fragmentation is the wasted memory (hole) that is internal to a allocated memory partition. External fragmentation is the wasted memory (hole) that is external to a allocated memory partitions.
 - (b) Associative memory is a special, small, fast-lookup hardware cache which stores page tables. Accessing page tables in memory is slow. Using associative memory can reduce effective access time.
2. What is the cause of thrashing? How does the system detect thrashing? Once it detects thrashing, what can the system do to eliminate this problem? (6 points)
 - Thrashing is caused by under-allocation of the minimum number of pages read required by a process, forcing it to continuously page fault.
 - The system can detect thrashing by evaluating the level of CPU utilization as compared to the level of multiprogramming.
 - It can be eliminated by reducing the level of multiprogramming.
 3. Consider a swapping system in which memory consists of 540K as shown below:

xxx	P3	xxxx	P5	xxxxxx	P7	xx	
0	60	140	220	320	420	500	540

where xx.. indicates the unused memory.

Note that P3, P5, and P7 are processes in memory. Assume that process P5 was just swapped in memory and that new processes arrive in the order P8, P9, P10, and are of size 50K, 80K, and 60K, respectively. How would each of the first-fit, next-fit, best-fit, and worst-fit algorithms place processes of P8, P9, and P10? If a process won't fit, write 'out of memory' in the appropriate slot. (10 points)

first fit:

P8	x	P3	P9	P5	P10	xx	P7	xx	
0	50	60	140	220	320	380	420	500	540

next fit:

P10	P3	P9	P5	P8	xxx	P7	xx	
0	60	140	220	320	370	420	500	540

best fit:

P8	x	P3	P9	P5	P10	xx	P7	xx	
0	50	60	140	220	320	380	420	500	540

worst fit:

P10	P3	P9	P5	P8	xxx	P7	xx	
0	60	140	220	320	370	420	500	540

4. The time required to read a word in memory (including the time to access associative memory) is 110 nanoseconds when the page number is not in the associative memory. The access time of associative memory is 10 nanoseconds. (10 points)

(a) Find a formula that expresses the effective access time as a function of the hit ratio.

(b) What hit ratio is needed to reduce the effective access time to 60 nanoseconds?

(a) Let e and t be the access time to associative memory and ordinary memory respectively. Assume the hit ratio be h .

$$e + 2 \times t = 110, 10 + 2 \times t = 110, t = 50$$

$$\text{Effective Access Time} = h \times (10 + 50) + (1 - h) \times 110 = 60h + 110 - 110h = 110 - 50h$$

(b) $110 - 50h \leq 60, 50h \geq 50, h \geq 100\%$ The hit ratio should be 100%.

5. Suppose there are 8 virtual pages and 4 page frames. Determine the number of page faults that will occur with the reference string 0 1 4 2 3 2 6 5 1 0 2 3 4 7 1 3, if the page frames are initially empty, using each of the following page replacement algorithms: (a) FIFO (b) LRU (c) Optimal. (12 points)

(a) FIFO - 14

0	1	4	2	3	2	6	5	1	0	2	3	4	7	1	3
0	1	4	2	3	3	6	5	1	0	2	3	4	7	1	1
	0	1	4	2	2	3	6	5	1	0	2	3	4	7	7
		0	1	4	4	2	3	6	5	1	0	2	3	4	4
			0	1	1	4	2	3	6	5	1	0	2	3	3
P	P	P	P	P		P	P	P	P	P	P	P	P	P	

(b) LRU - 14

0	1	4	2	3	2	6	5	1	0	2	3	4	7	1	3
0	1	4	2	3	2	6	5	1	0	2	3	4	7	1	3
	0	1	4	2	3	2	6	5	1	0	2	3	4	7	1
		0	1	4	4	3	2	6	5	1	0	2	3	4	7
			0	1	1	4	3	2	6	5	1	0	2	3	4
P	P	P	P	P		P	P	P	P	P	P	P	P	P	

(c) Optimal - 10

0	1	4	2	3	2	6	5	1	0	2	3	4	7	1	3
0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		4	4	3	3	6	5	5	5	5	5	4	7	7	7
			2	2	2	2	2	2	2	2	2	2	2	2	2
P	P	P	P	P		P	P				P	P	P		

6. A small computer has five page frames. At the first clock tick, the R bits are 10011 (page 1 and 2 are 0). A subsequent clock ticks, the values are 10100, 10101, 00101, 01100, 01011, 10101, 11001, and 11011. (8 points)

- (a) If the aging algorithm is used with an 8-bit counter, give the values of the counters after the last tick.
- (b) Which page would be selected to be removed from memory?

(a)

R bits	Page 0	Page 1	Page 2	Page 3	Page 4
10011	10000000	00000000	00000000	10000000	10000000
10100	11000000	00000000	10000000	01000000	01000000
10101	11100000	00000000	11000000	00100000	10100000
00101	01110000	00000000	11100000	00010000	11010000
01100	00111000	10000000	11110000	00001000	01101000
01011	00011100	11000000	01111000	10000100	10110100
10101	10001110	01100000	10111100	01000000	11011010
11001	11000111	10110000	01011110	00100000	11101101
11011	11100011	11011000	00101111	10010000	11110110

- (b) Page 2 has the smallest value. It will be evicted.

7. A computer has four page frames. The time of loading, time of last access, and the R and M bits for each page are as shown below (the times are in clock ticks): (8 points)

Page	Loaded	Last Referenced	R M
0	126	280	1 0
1	230	270	0 1
2	140	265	1 1
3	162	285	0 0

- (a) Which page will NRU replace?
- (b) Which page will FIFO replace?
- (c) Which page will LRU replace?
- (d) Which page will second chance replace?

- (a) Page 3 because R and M bits are 0.
- (b) Page 0 because it is oldest (loaded at 126).
- (c) Page 2 because is least recently referenced (referenced at 265).
- (d) Page 3 because it is oldest and not referenced (loaded at 162 and R = 0).