Question 1

(a)(i) FIFO (3 frames)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| 0 | 0 | 0 | 0 | 2 | 2 | 2 | 6 | 6 | 6 | 0 | 0 | 0 | 5 | 5 | 5 | 2 | 2 | 2 | 3 |
| - | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 6 | 6 | 6 | 4 | 4 | 4 |
| - | - | 1 | 1 | 1 | 1 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 0 | 0 | 0 | 1 | 1 |
| M | M | M | H | M | M | M | M | M | M | M | M | M | M | M | M | M | M | M | M |

Page Hits = 1, Page Fault = 19

Hit Radio = (1/20)\*100 = 5%, Miss Radio = (19/20)\*100 = 95%

(a)(ii) FIFO (4 frames)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 6 | 6 | 6 | 6 | 1 | 1 |
| - | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 3 |
| - | - | 1 | 1 | 1 | 1 | 1 | 6 | 6 | 6 | 6 | 6 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| - | - | - | - | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 4 |
| M | M | M | H | M | M | M | M | H | M | M | M | M | M | M | M | M | M | M | M |

Page Hits = 2, Page Fault = 18

Hit Radio = (2/20)\*100 = 10%, Miss Radio = (18/20)\*100 = 90%

(b)(i) Optimal (3 frames)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| 0 | 0 | 0 | 0 | 0 | 3 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 2 | 4 | 1 | 3 |
| - | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| - | - | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| M | M | M | H | M | M | M | M | H | H | M | M | M | M | H | H | M | M | M | M |

Page Hits = 5, Page Fault = 15

Hit Radio = (5/20)\*100 = 25%, Miss Radio = (15/20)\*100 = 75%

(b)(ii) Optimal (4 frames)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 3 |
| - | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 1 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| - | - | 1 | 1 | 1 | 3 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| - | - | - | - | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| M | M | M | H | M | M | M | M | H | H | H | M | M | M | H | H | H | M | M | M |

Page Hits = 7, Page Fault = 13

Hit Radio = (7/20)\*100 = 35%, Miss Radio = (13/20)\*100 = 65%

(c)(i) LRU (3 frames)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| 0 | 0 | 0 | 0 | 2 | 2 | 2 | 6 | 6 | 6 | 0 | 0 | 0 | 5 | 5 | 5 | 2 | 2 | 2 | 3 |
| - | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 0 | 0 | 0 | 1 | 1 |
| - | - | 1 | 1 | 1 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 6 | 6 | 6 | 4 | 4 | 4 |
| M | M | M | H | M | M | M | M | M | M | M | M | M | M | M | M | M | M | M | M |

Page Hits = 1, Page Fault = 19

Hit Radio = (1/20)\*100 = 5%, Miss Radio = (19/20)\*100 = 95%

LRU stack content

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| - | 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 |
| - | - | 0 | 0 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 |

(c)(ii) LRU (4 frames)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 4 |
| - | 4 | 4 | 4 | 4 | 4 | 4 | 6 | 6 | 6 | 6 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 3 |
| - | - | 1 | 1 | 1 | 1 | 5 | 5 | 5 | 5 | 0 | 0 | 0 | 0 | 6 | 6 | 6 | 6 | 1 | 1 |
| - | - | - | - | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| M | M | M | H | M | M | M | M | H | M | M | M | M | M | M | M | M | M | M | M |

Page Hits = 1, Page Fault = 19

Hit Radio = (1/20)\*100 = 5%, Miss Radio = (19/20)\*100 = 95%

LRU stack content

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| - | 0 | 4 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 |
| - | - | 0 | 0 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 |
| - | - | - | - | 0 | 1 | 4 | 2 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 |

(d)

Insert 1 item in the reference string (FIFO)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 4 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 6 | 6 | 6 | 0 | 0 | 0 | 5 | 5 | 5 | 2 | 2 | 2 | 3 |
| - | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 6 | 6 | 6 | 4 | 4 | 4 |
| - | - | 1 | 1 | 1 | 1 | 1 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 0 | 0 | 0 | 1 | 1 |
| M | M | M | H | M | H | M | M | M | M | M | M | M | M | M | M | M | M | M | M | M |

Page Hits = 2, Page Fault = 19

Hit Radio = (2/21)\*100 = 9.52%, Miss Radio = (19/21)\*100 = 90.48%

Insert 1 item in the reference string (LRU)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 4 | 1 | 4 | 2 | 4 | 3 | 5 | 6 | 2 | 4 | 0 | 1 | 3 | 5 | 6 | 0 | 2 | 4 | 1 | 3 |
| 0 | 0 | 0 | 0 | 2 | 2 | 2 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 0 | 0 | 0 | 1 | 1 |
| - | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 6 | 6 | 6 | 0 | 0 | 0 | 5 | 5 | 5 | 2 | 2 | 2 | 3 |
| - | - | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 6 | 6 | 6 | 4 | 4 | 4 |
| M | M | M | H | M | H | M | M | M | M | M | M | M | M | M | M | M | M | M | M | M |

Page Hits = 2, Page Fault = 19

Hit Radio = (2/21)\*100 = 9.52%, Miss Radio = (19/21)\*100 = 90.48%

In this case, even after adding an extra reference string, the number of page faults remains at 19. This could be due to Belady’s Anomaly occurring in FIFO, where increasing the number of frames does not necessarily improve the page replacement situation. If using LRU, the unchanged page fault count may indicate that the additional frame did not effectively reduce the necessary page replacements.

Question 2