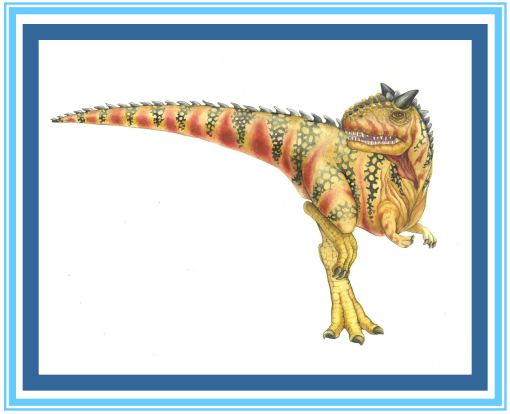
Chapter 9: Virtual Memory
Part 2



Recap

- To understand the virtual memory concept
- Benefits of virtual memory
- Page fault
- Demand Paging
- Copy on Write

Objectives

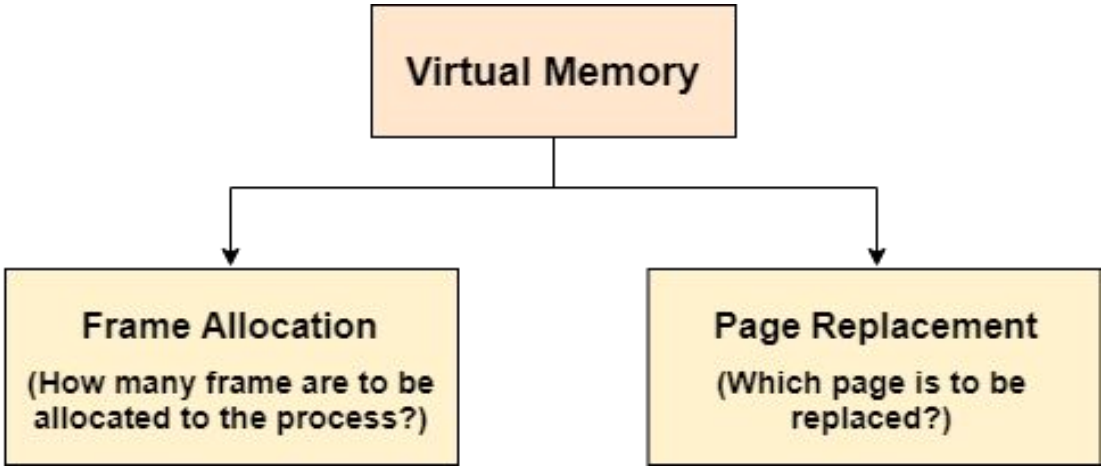
- Page Replacement Algorithms
  - First In First Out (FIFO)
  - Optimal Algorithm
  - Least Recently Used (LRU)

Page Replacement

- In an operating system that uses paging for memory management, a page replacement algorithm is needed to decide which page needs to be replaced when new page comes in.
- **Page Fault –** A page fault happens when a running program accesses a memory page that is mapped into the virtual address space, but not loaded in physical memory.
- Since actual physical memory is much smaller than virtual memory, page faults happen.
- In case of page fault, Operating System might have to replace one of the existing pages with the newly needed page.
- Different page replacement algorithms suggest different ways to decide which page to replace. The target for all algorithms is to reduce the number of page faults.

Page Replacement

- Page replacement is done when the requested page is not found in the main memory (page fault).
- There are two main aspects of virtual memory, Frame allocation and Page Replacement. It is very important to have the optimal frame allocation and page replacement algorithm.

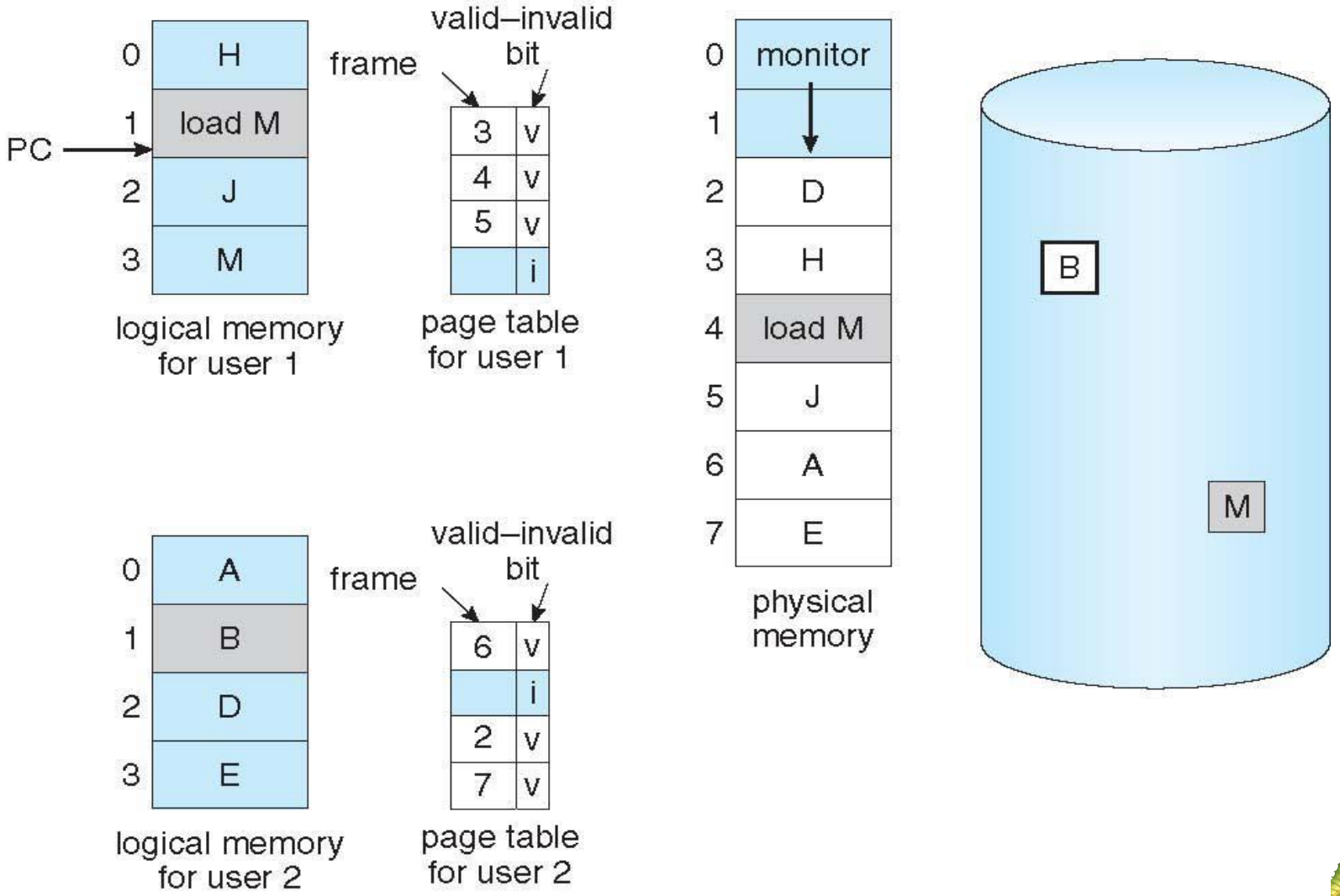


- Frame allocation is all about how many frames are to be allocated to the process while the page replacement is all about determining the page number which needs to be replaced in order to make space for the requested page.

Page Replacement

- Prevent **over-allocation** of memory by modifying page-fault service routine to include page replacement
- Use **modify** (**dirty**) **bit** to reduce overhead of page transfers – only modified pages are written to disk
- Page replacement completes separation between logical memory and physical memory – large virtual memory can be provided on a smaller physical memory

Need For Page Replacement



Basic Page Replacement

1. Find the location of the desired page on disk

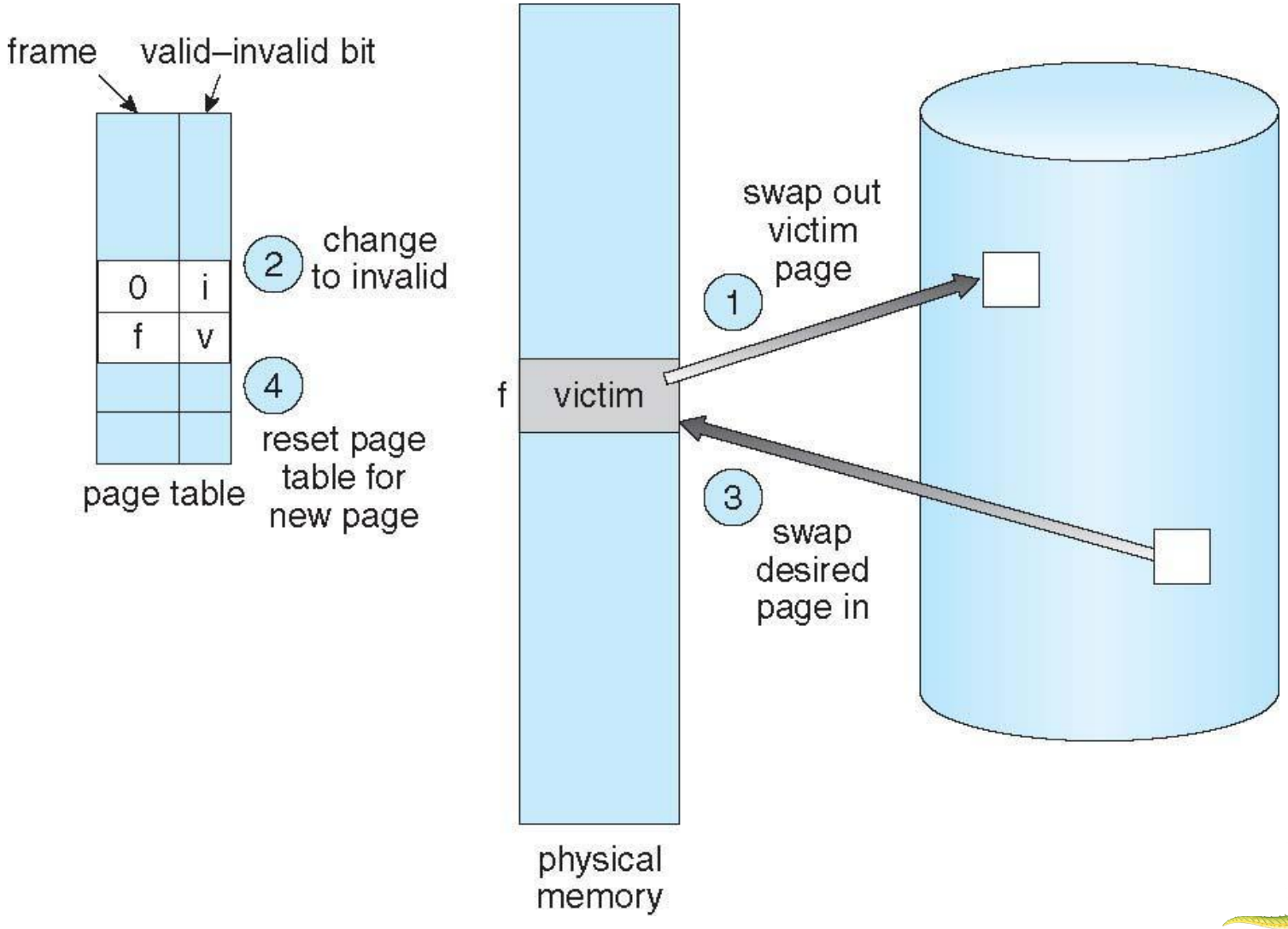
2. Find a free frame:
   - If there is a free frame, use it
   - If there is no free frame, use a page replacement algorithm to select a **victim frame**
   - Write victim frame to disk if dirty

3. Bring the desired page into the (newly) free frame; update the page and frame tables

4. Continue the process by restarting the instruction that caused the trap

Note now potentially 2 page transfers for page fault – increasing EAT

Page Replacement

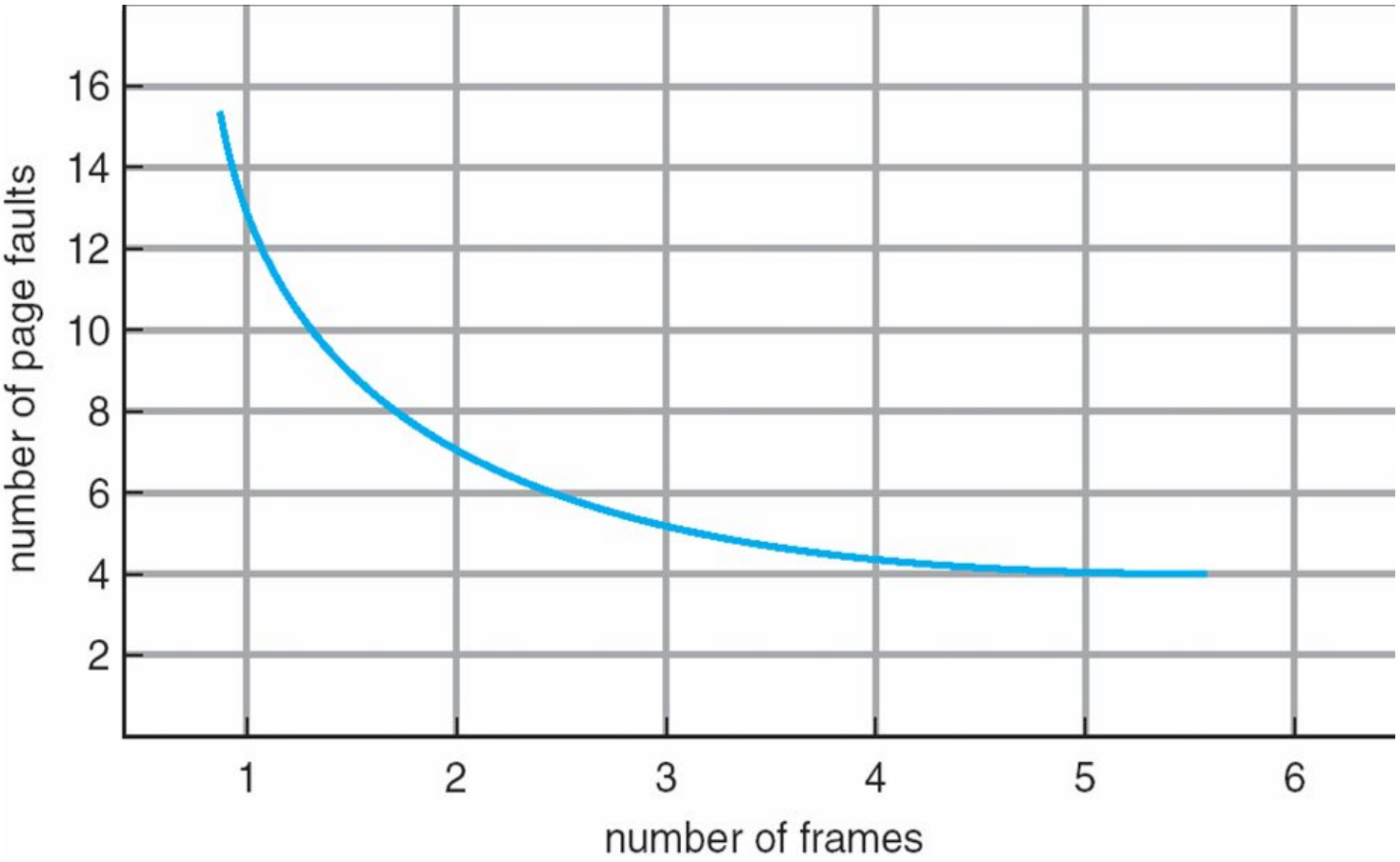


Page and Frame Replacement Algorithms

- **Frame-allocation algorithm** determines
  - How many frames to give each process
  - Which frames to replace
- **Page-replacement algorithm**
  - Want lowest page-fault rate on both first access and re-access
- Evaluate algorithm by running it on a particular string of memory references (reference string) and computing the number of page faults on that string
  - String is just page numbers, not full addresses
  - Repeated access to the same page does not cause a page fault
  - Results depend on number of frames available
- In all our examples, the **reference string** of referenced page numbers is

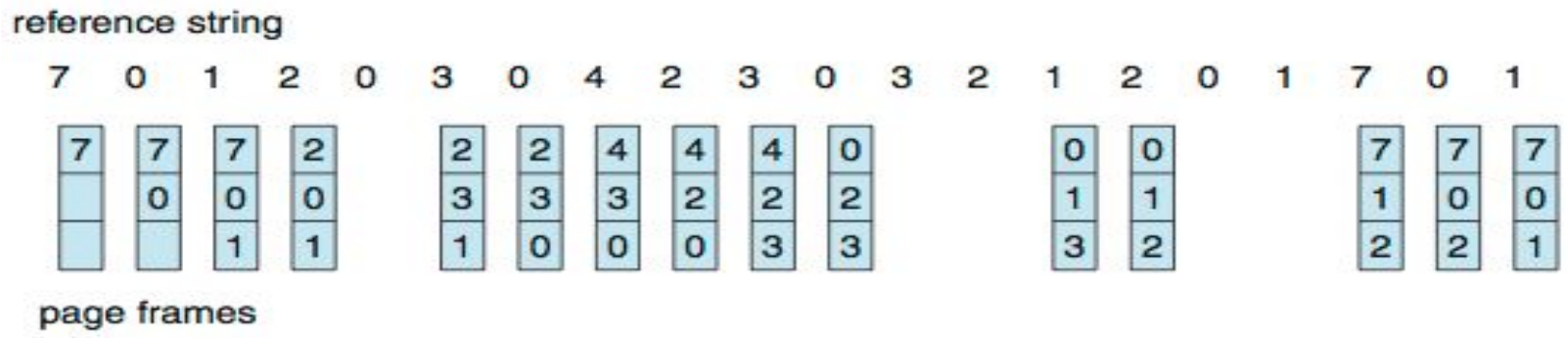
  7,0,1,2,0,3,0,4,2,3,0,3,0,3,2,1,2,0,1,7,0,1

Graph of Page Faults Versus The Number of Frames



First-In-First-Out (FIFO) Algorithm

- Reference string: **7,0,1,2,0,3,0,4,2,3,0,3,0,3,2,1,2,0,1,7,0,1**
- 3 frames (3 pages can be in memory at a time per process)

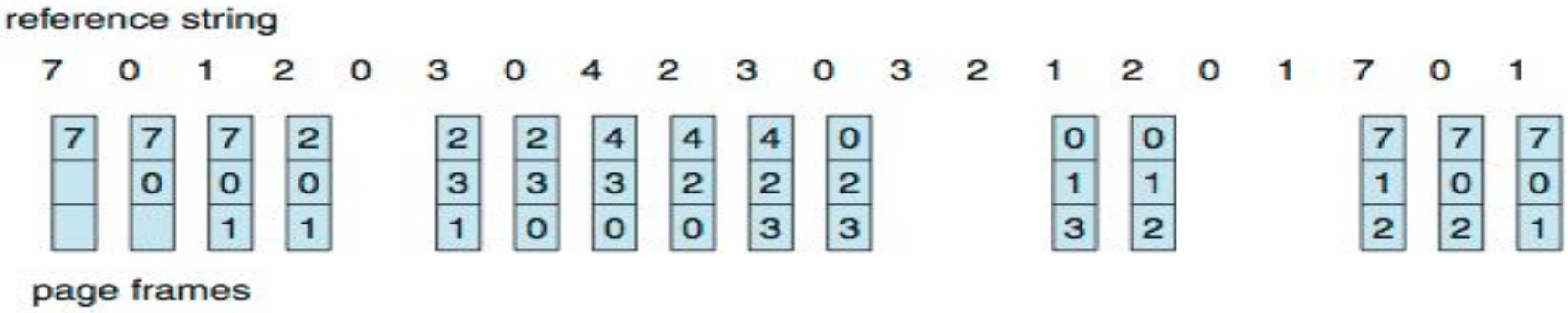


15 page faults

- Can vary by reference string: consider 1,2,3,4,1,2,5,1,2,3,4,5
  - Adding more frames can cause more page faults!
    - **Belady's Anomaly**
- How to track ages of pages?
  - Just use a FIFO queue

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



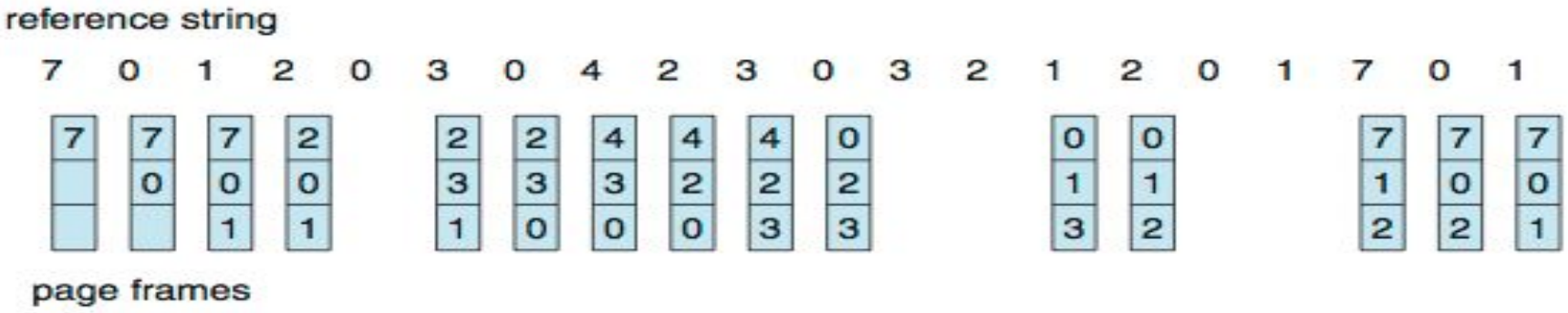
0 1 2 0 3 0 4 2 3 0 3 2 1 2 0 1 7 0 1

M M M

Page Faults = 3

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



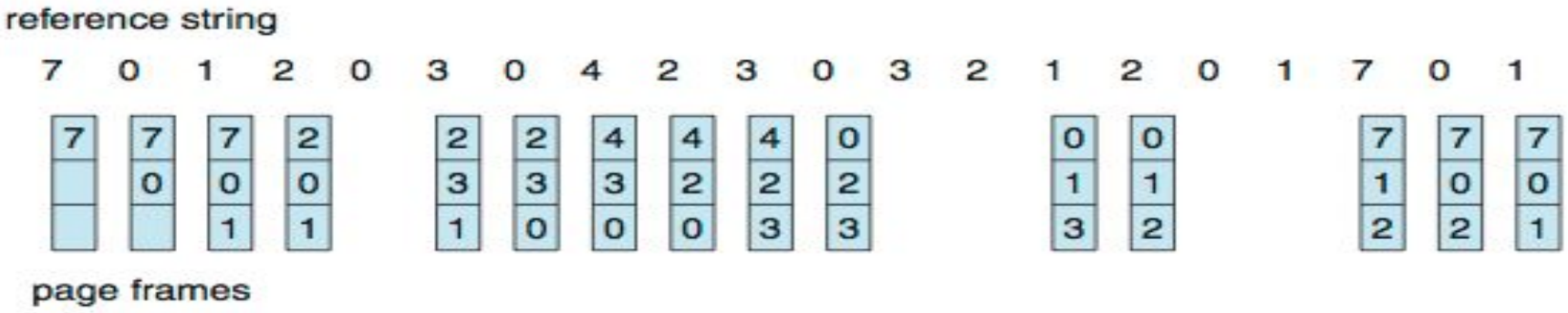
2 0 3 0 4 2 3 0 3 2 1 2 0 1 7 0 1

M M M M

Page Faults = 4 Victim = 7

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



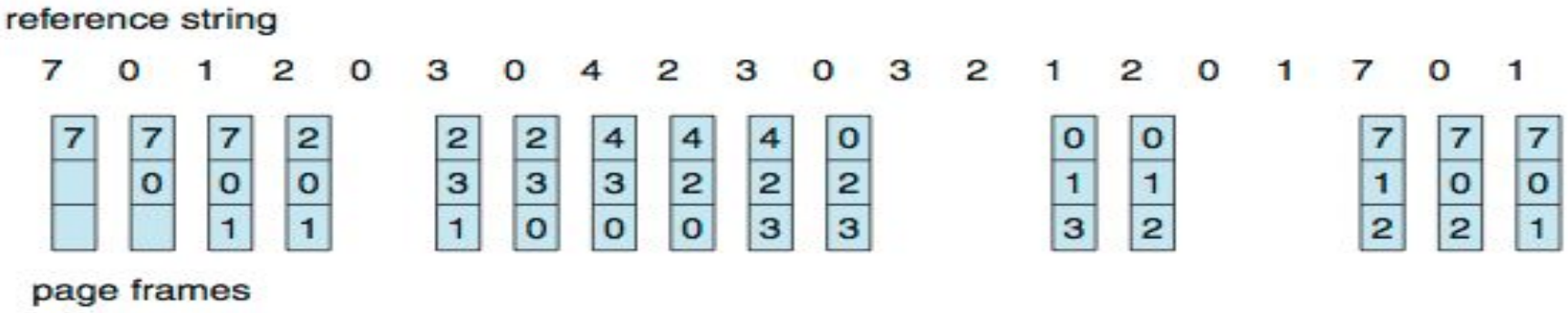
0 3 0 4 2 3 0 3 2 1 2 0 1 7 0 1

M M M M H

Page Faults = 4

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



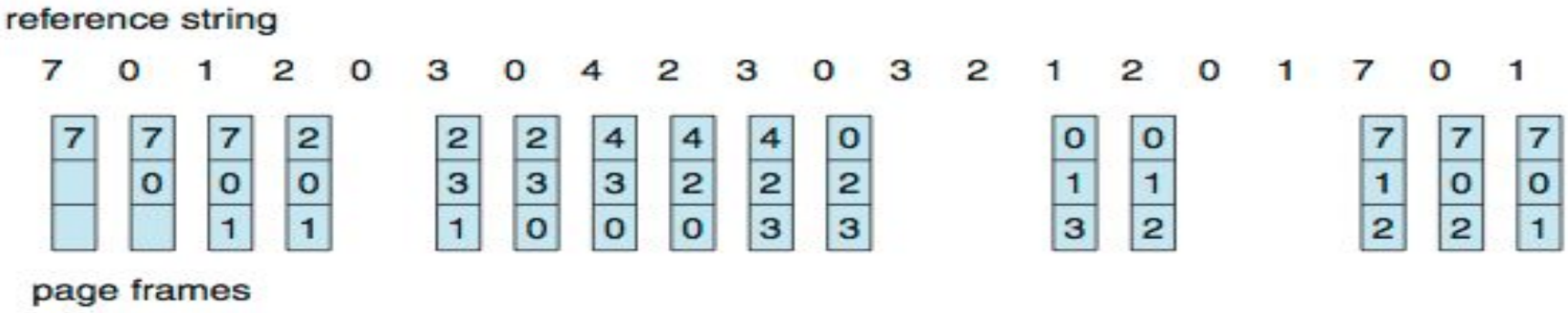
3 0 4 2 3 0 3 2 1 2 0 1 7 0 1

M M M M H M

Page Faults = 5 Victim = 0

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



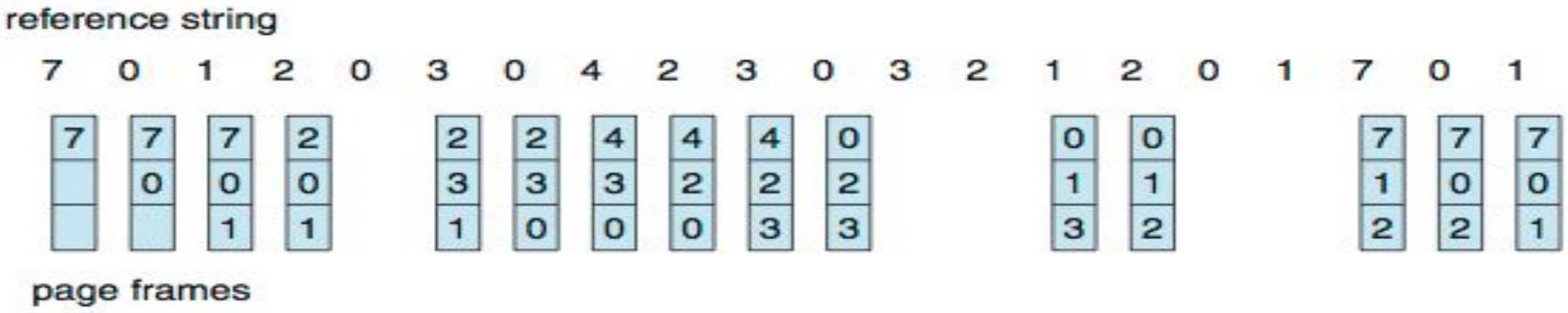
0 4 2 3 0 3 2 1 2 0 1 7 0 1

M M M M H M M

Page Faults = 6 Victim = 1

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



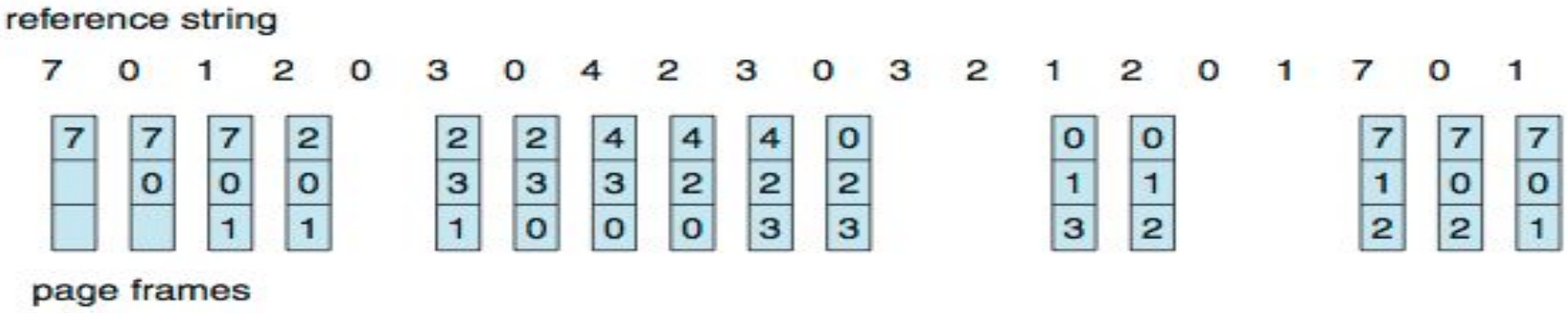
4 2 3 0 3 2 1 2 0 1 7 0 1

M M M M H M M M

Page Faults = 7 Victim = 2

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



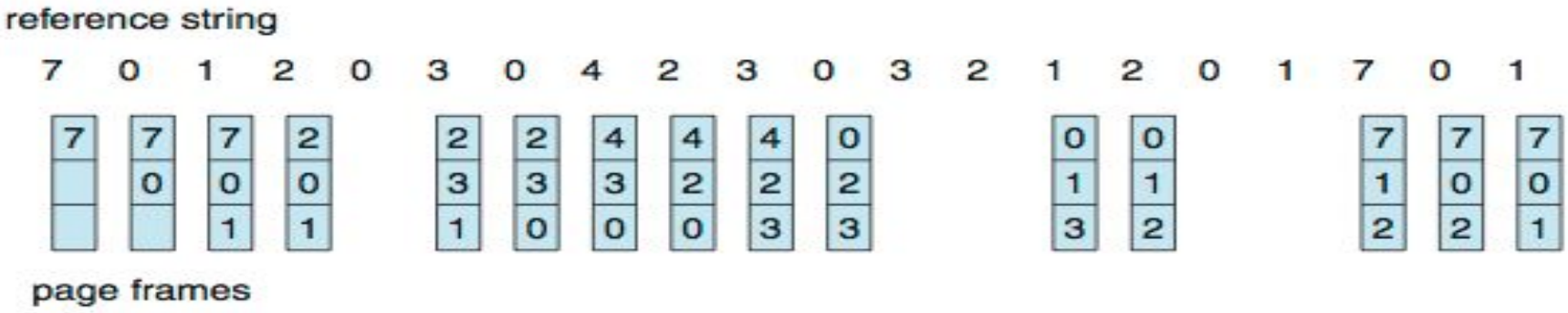
2 3 0 3 2 1 2 0 1 7 0 1

M M M M H M M M M

Page Faults = 8 Victim = 3

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



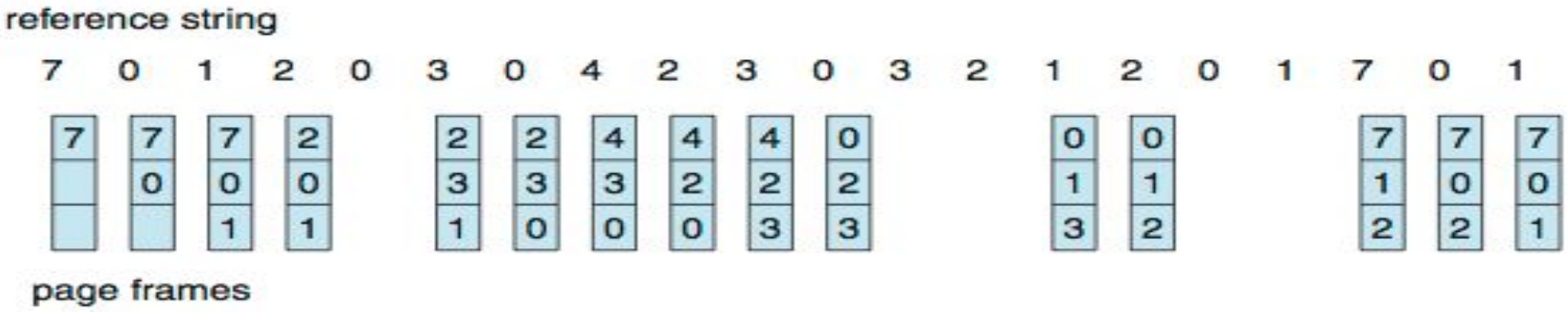
3 0 3 2 1 2 0 1 7 0 1

M M M M H M M M M M

Page Faults = 9 Victim = 0

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



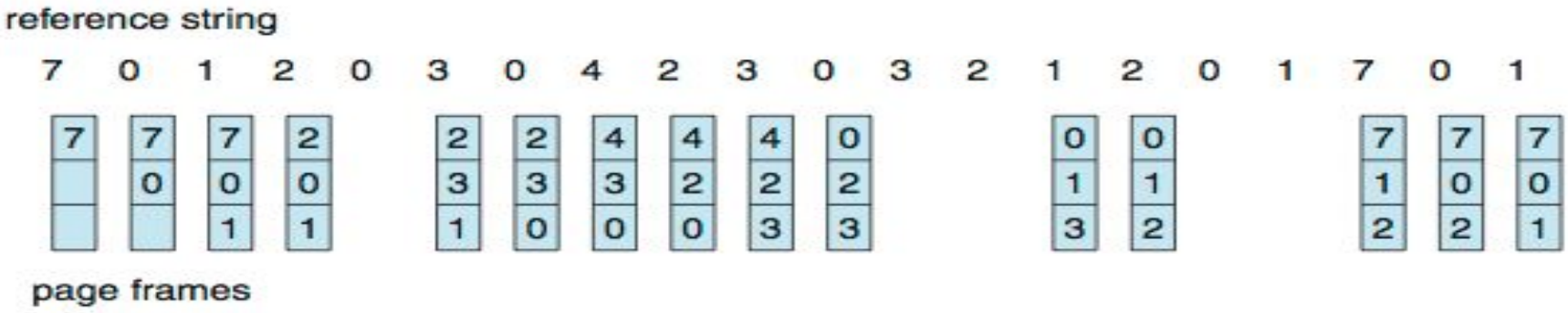
0 3 2 1 2 0 1 7 0 1

M M M M H M M M M M M

Page Faults = 10 Victim = 4

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.

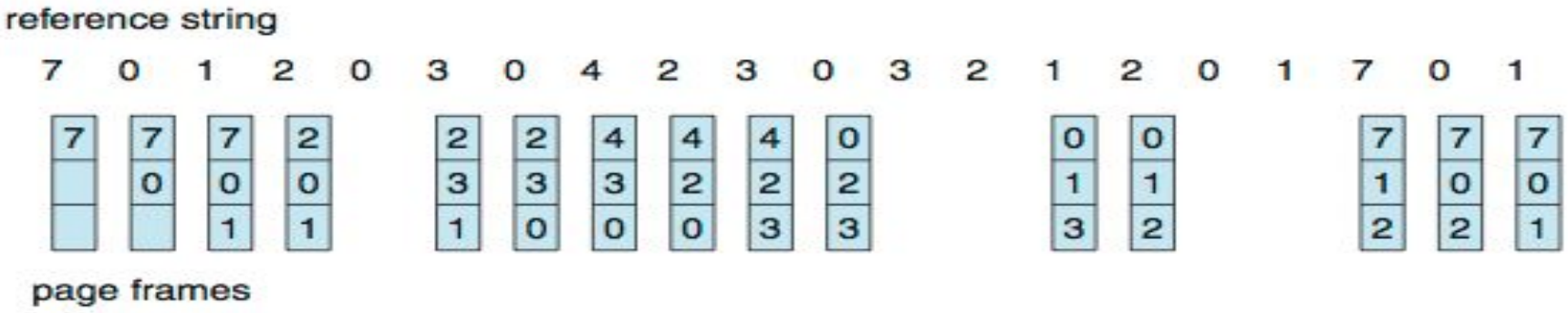


											3	2	1	2	0	1	7	0	1
M	M	M	M	H	M	M	M	M	M	M	H	H							

Page Faults = 10

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



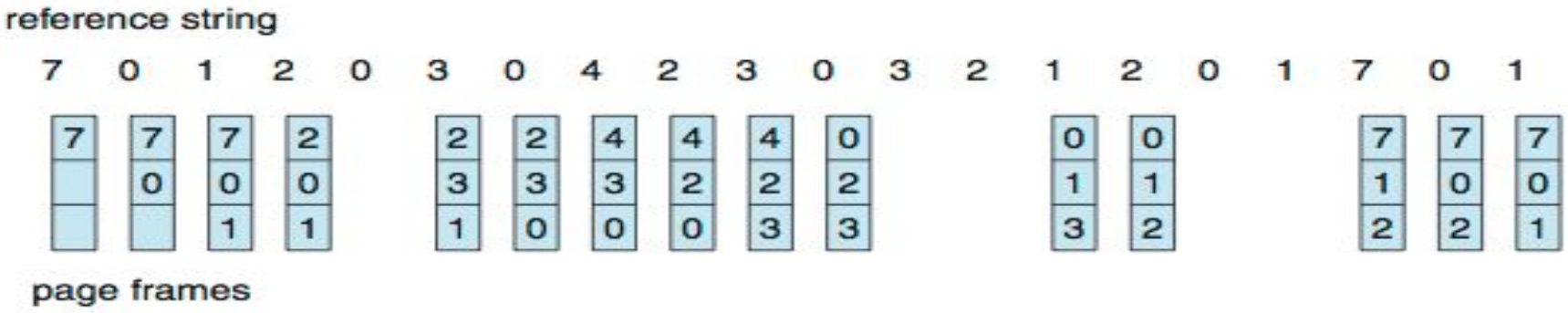
1 2 0 1 7 0 1

M M M M H M M M M M M H H M

Page Faults = 11 Victim = 2

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



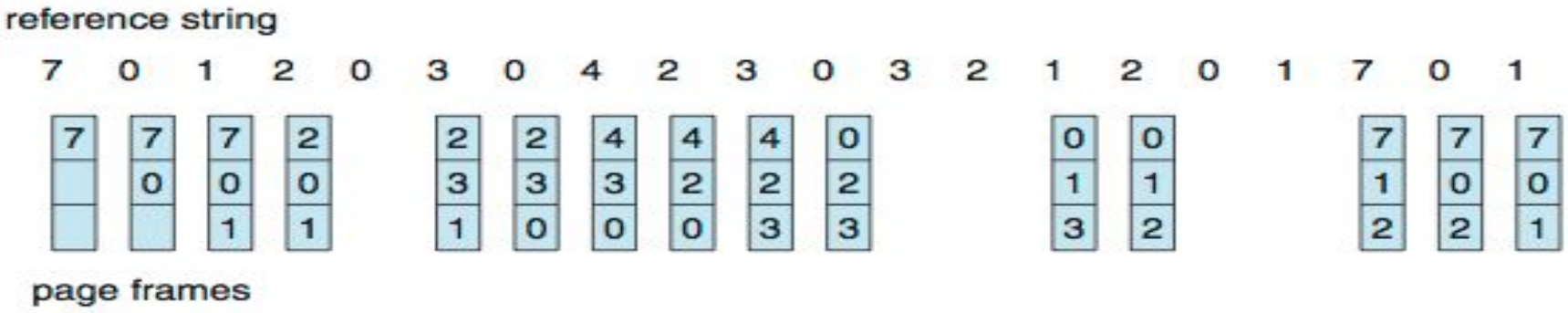
2 0 1 7 0 1

M M M M H M M M M M M H H M M

Page Faults = 12 Victim = 3

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



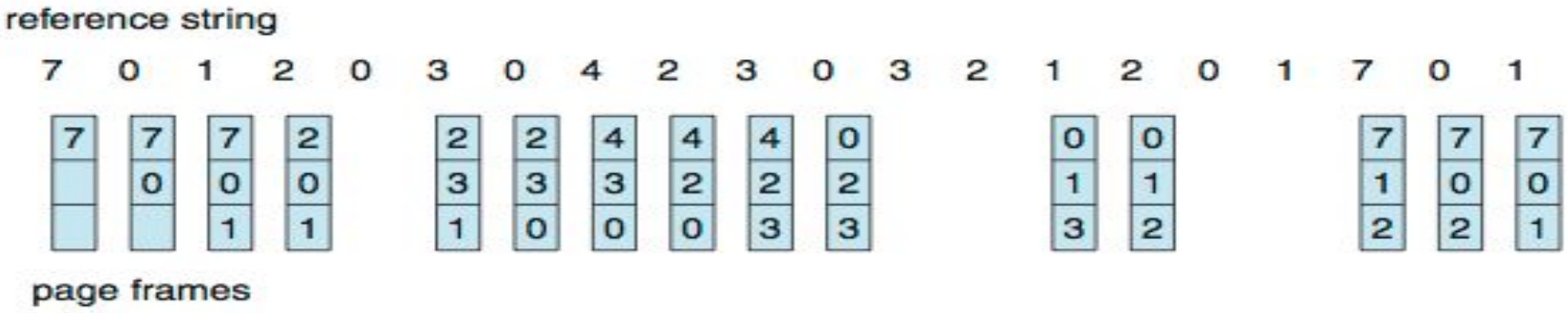
0 1 7 0 1

M M M M H M M M M M M H H M M H H

Page Faults = 12

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



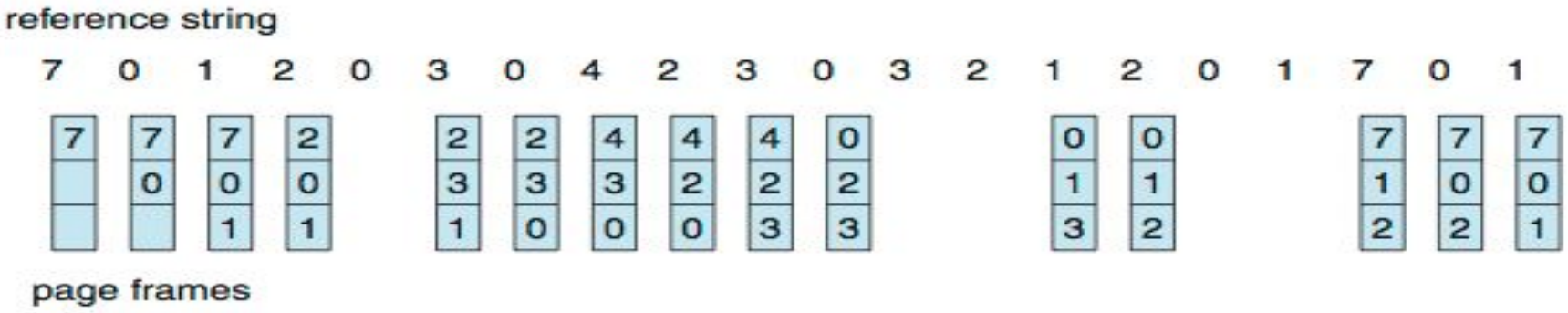
7 0 1

M M M M H M M M M M M H H M M H H M

Page Faults = 13 Victim = 0

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



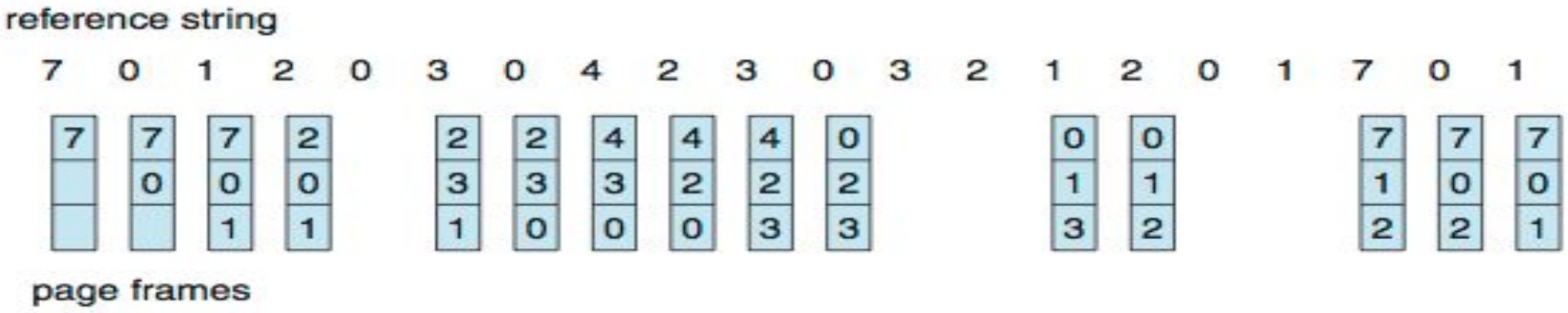
0 1

M M M M H M M M M M M H H M M H H M M

Page Faults = 14 Victim = 1

First-In-First-Out (FIFO) Algorithm

- In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.
- When a page needs to be replaced page in the front of the queue is selected for removal.



1

M M M M H M M M M M M H H M M H H M M M

Page Faults = 15 Victim = 2

FIFO Illustrating Belady's Anomaly