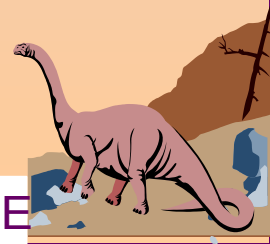
Process Creation

- Virtual memory allows other benefits during process creation:

  - Copy-on-Write

  - Memory-Mapped Files



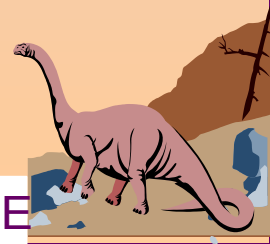
Copy-on-Write

- Copy-on-Write (COW) allows both parent and child processes to initially *share* the same pages in memory.

  If either process modifies a shared page, only then is the page copied.

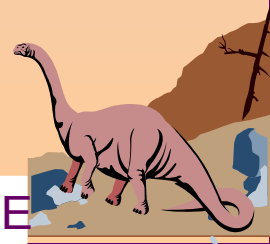
- COW allows more efficient process creation as only modified pages are copied.

- Free pages are allocated from a *pool* of zeroed-out pages.

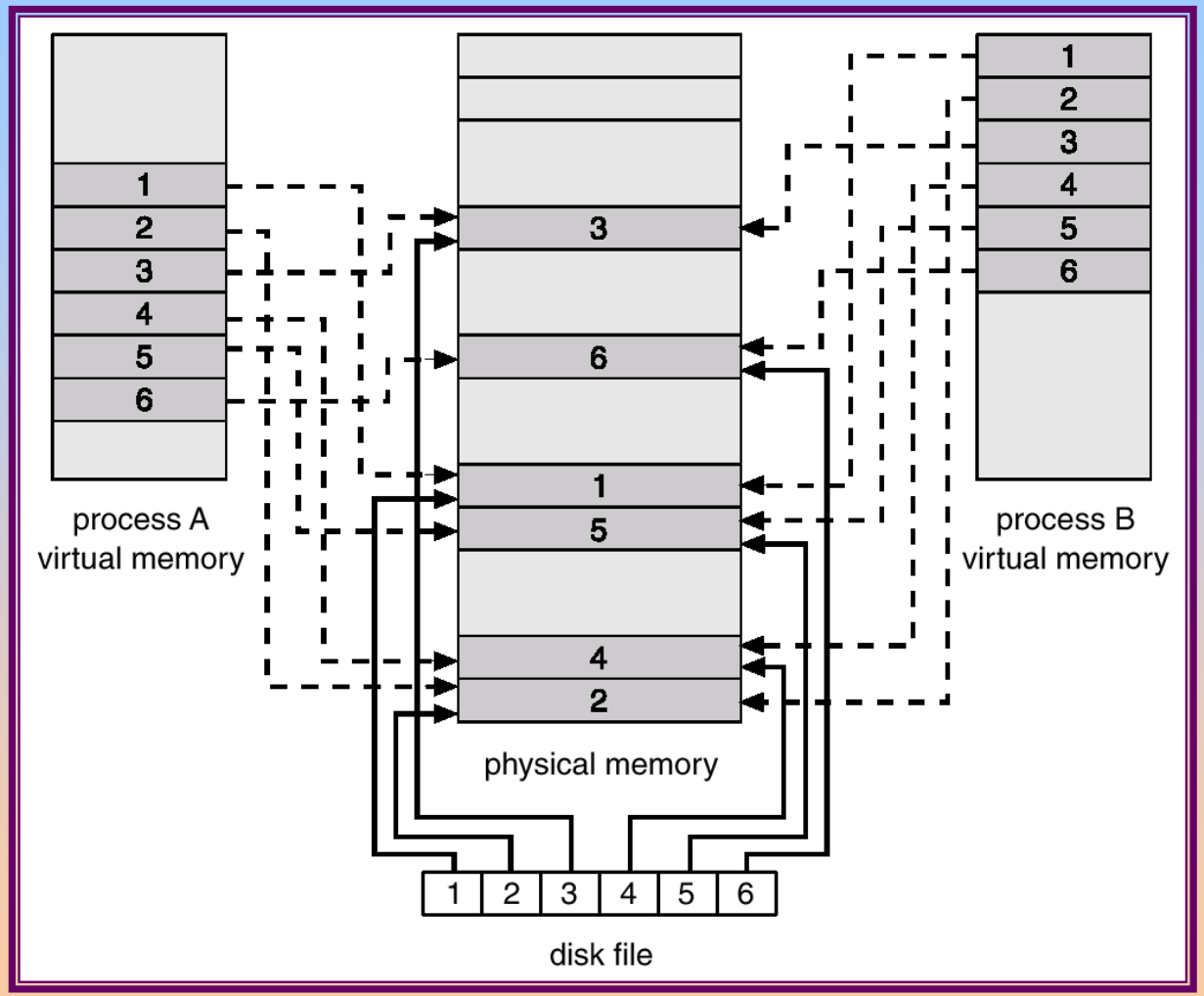


Memory-Mapped Files

- Memory-mapped file I/O allows file I/O to be treated as routine memory access by *mapping* a disk block to a page in memory.
- A file is initially read using demand paging. A page-sized portion of the file is read from the file system into a physical page. Subsequent reads/writes to/from the file are treated as ordinary memory accesses.
- Simplifies file access by treating file I/O through memory rather than **read() write()** system calls.
- Also allows several processes to map the same file allowing the pages in memory to be shared.

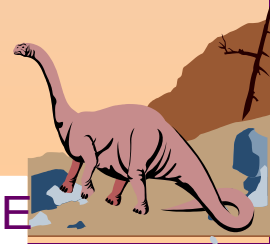


Memory Mapped Files

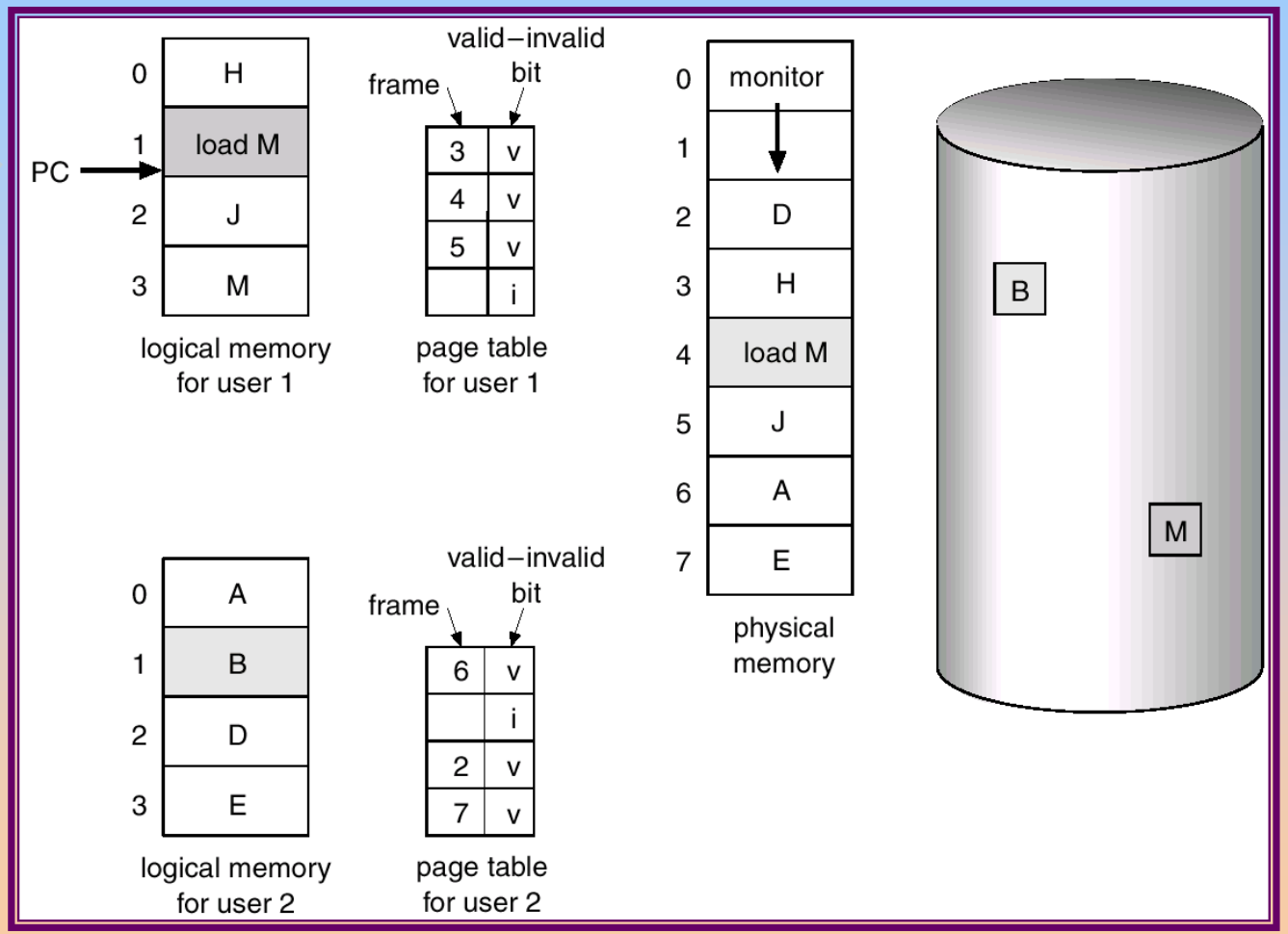


Page Replacement

- 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



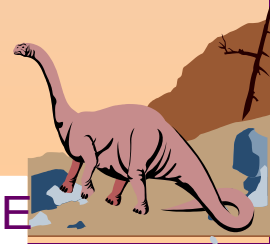
Basic Page Replacement

1. Find the location of the desired page on disk.

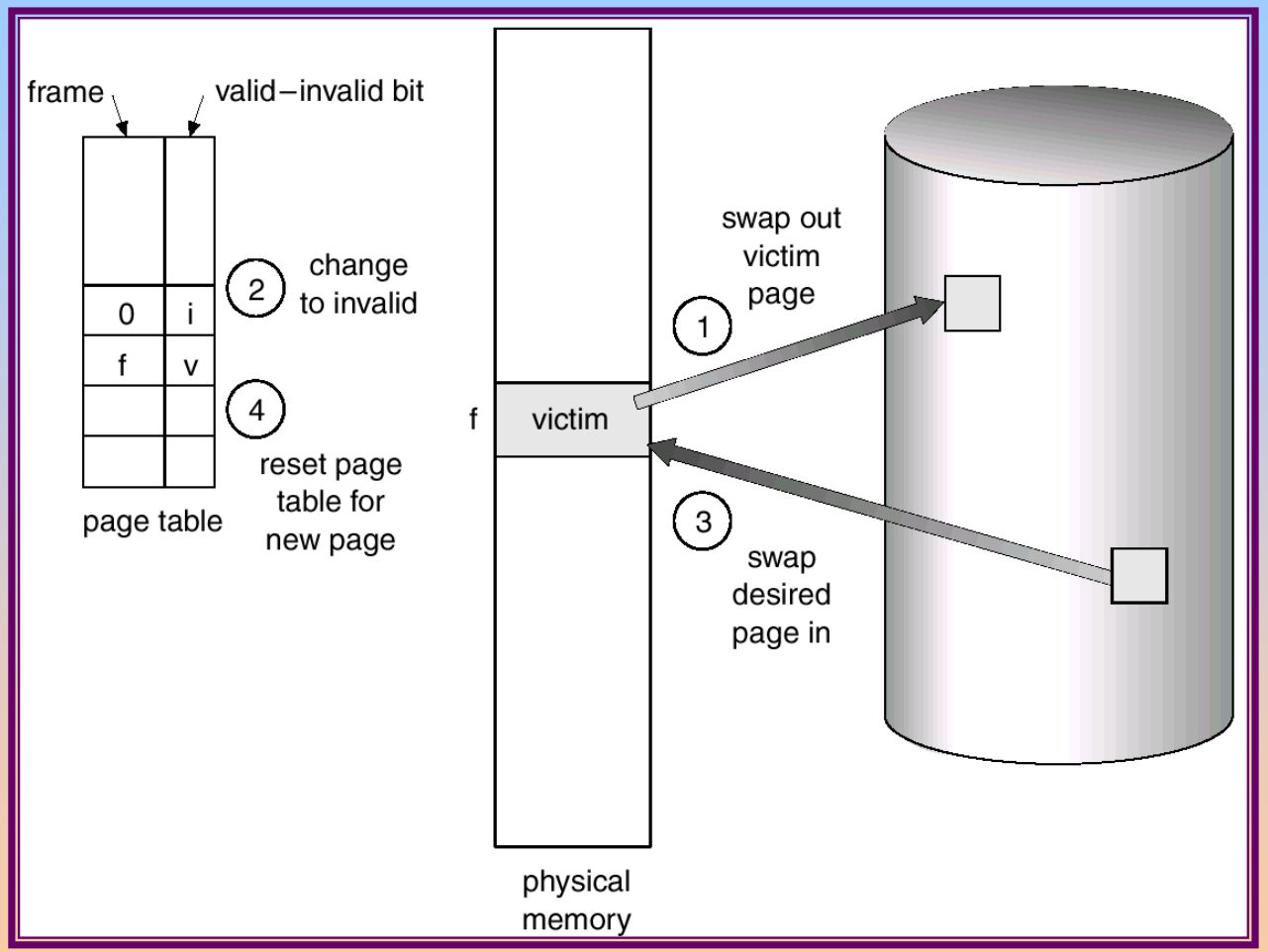
2. Find a free frame:
   - If there is a free frame, use it.
   - If there is no free frame, use a page replacement algorithm to select a *victim* frame.

3. Read the desired page into the (newly) free frame. Update the page and frame tables.

4. Restart the process.



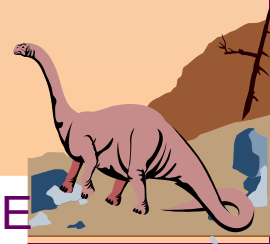
Page Replacement



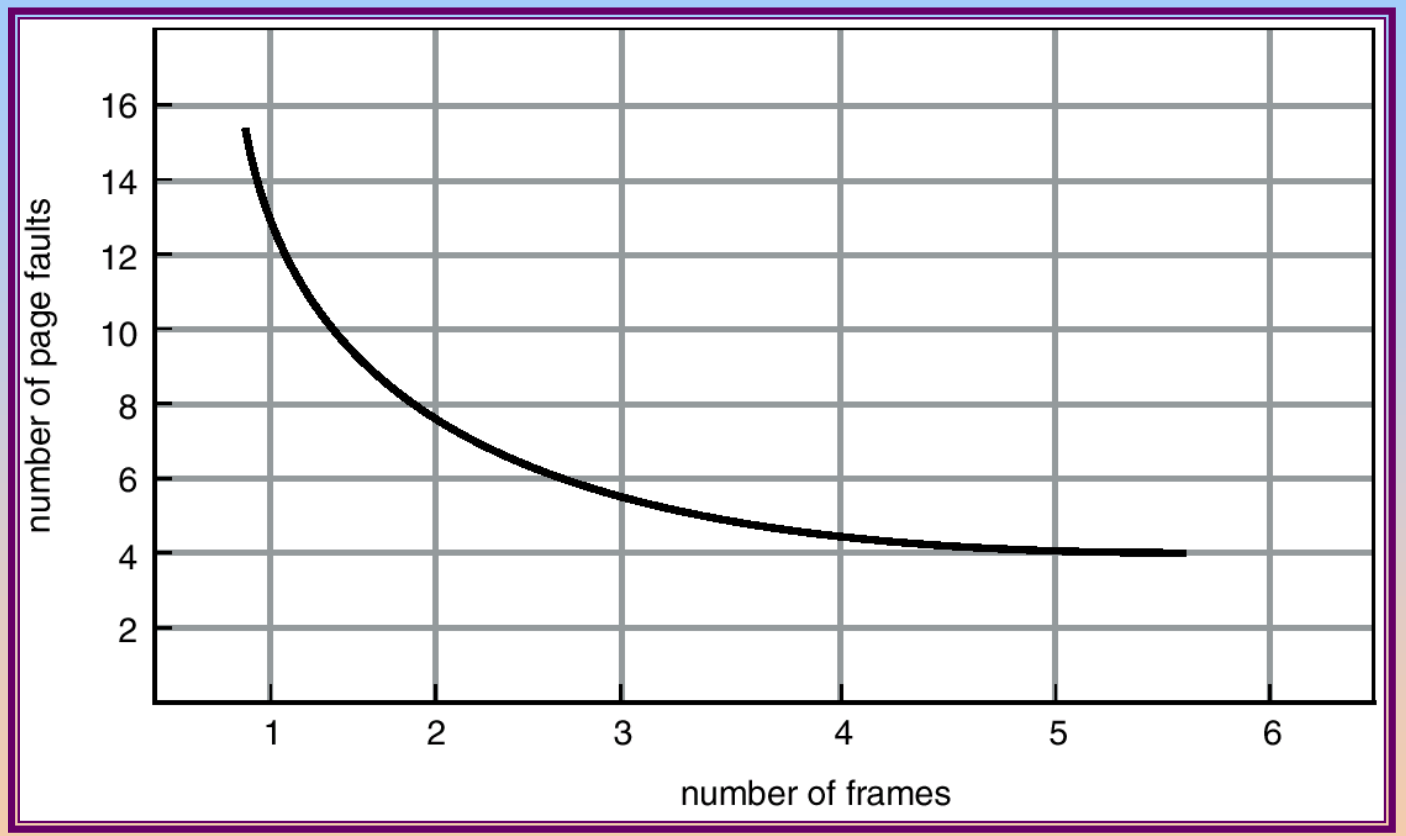
Page Replacement Algorithms

- Want lowest page-fault rate.
- Evaluate algorithm by running it on a particular string of memory references (reference string) and computing the number of page faults on that string.
- In all our examples, the reference string is

  1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5.



Graph of Page Faults Versus The Number of Frames



First-In-First-Out (FIFO) Algorithm

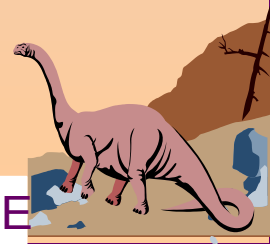
- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
- 3 frames (3 pages can be in memory at a time per process)

1	1	4	5	
2	2	1	3	9 page faults
3	3	2	4	

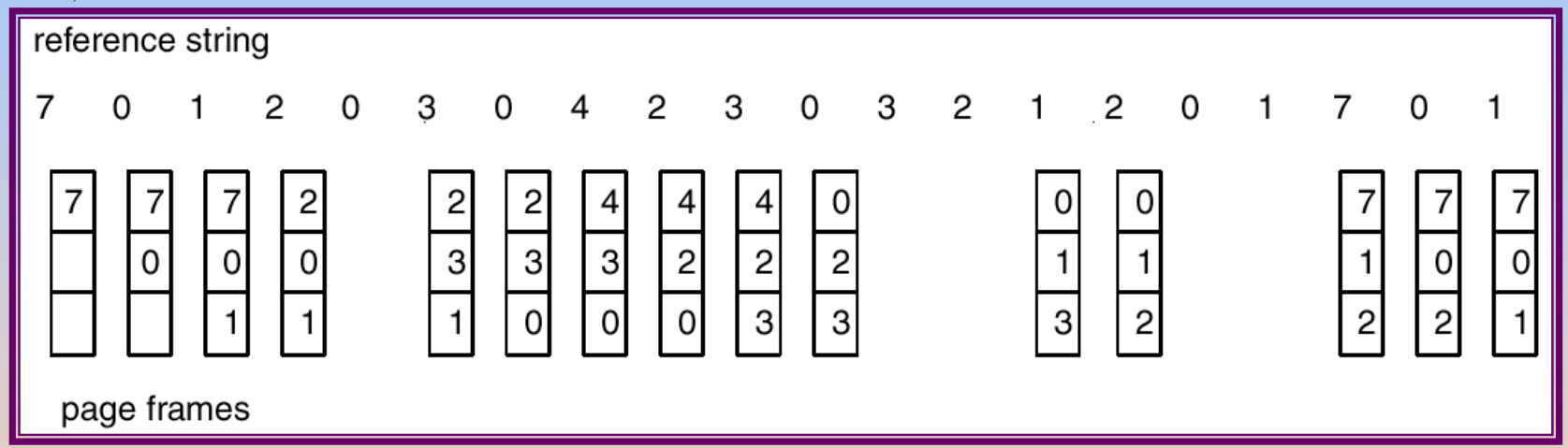
- 4 frames

1	1	5	4	
2	2	1	5	10 page faults
3	3	2		
4	4	3		

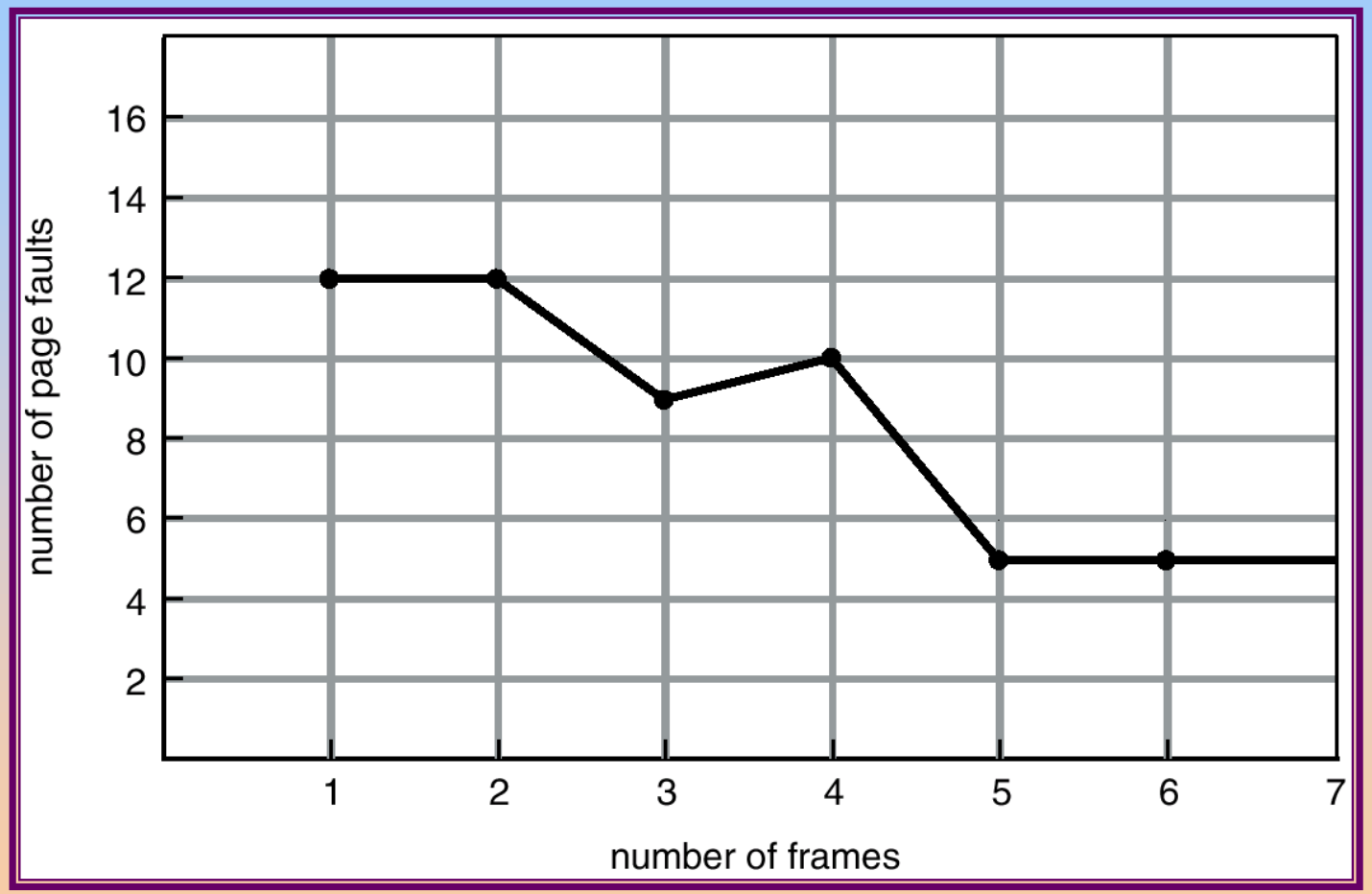
- FIFO Replacement – Belady's Anomaly
  - more frames ⇒ less page faults



FIFO Page Replacement



FIFO Illustrating Belady's Anamoly



Optimal Algorithm

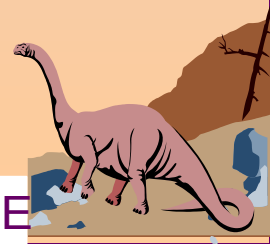
- Replace page that will not be used for longest period of time.
- 4 frames example

1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5

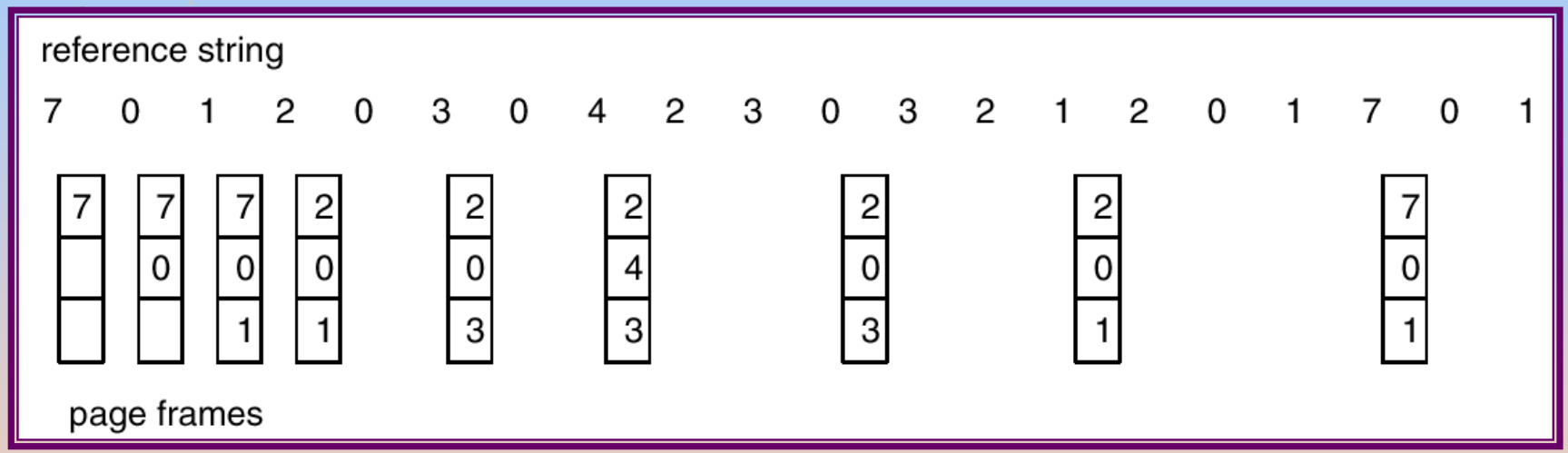
1	4
2	
3	
4	5

6 page faults

- How do you know this?
- Used for measuring how well your algorithm performs.

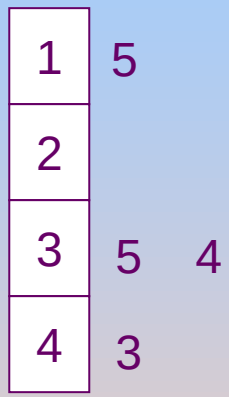


Optimal Page Replacement



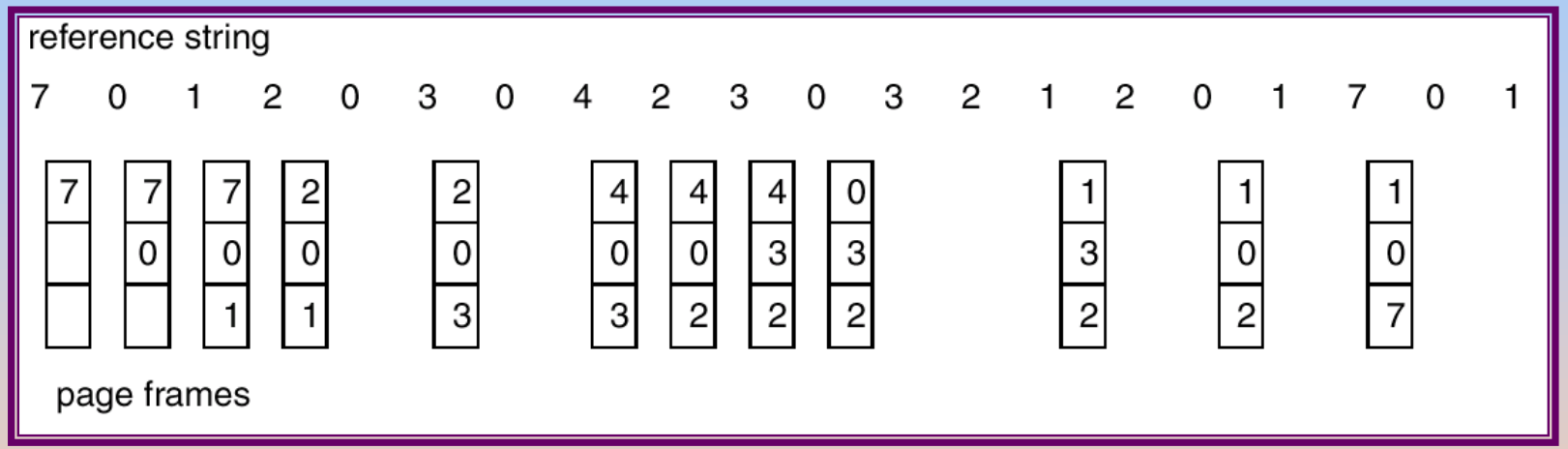
Least Recently Used (LRU) Algorithm

- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5



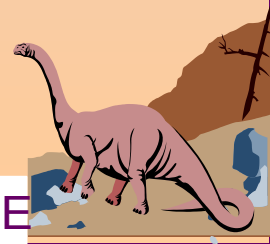
- Counter implementation
  - Every page entry has a counter; every time page is referenced through this entry, copy the clock into the counter.
  - When a page needs to be changed, look at the counters to determine which are to change.

LRU Page Replacement

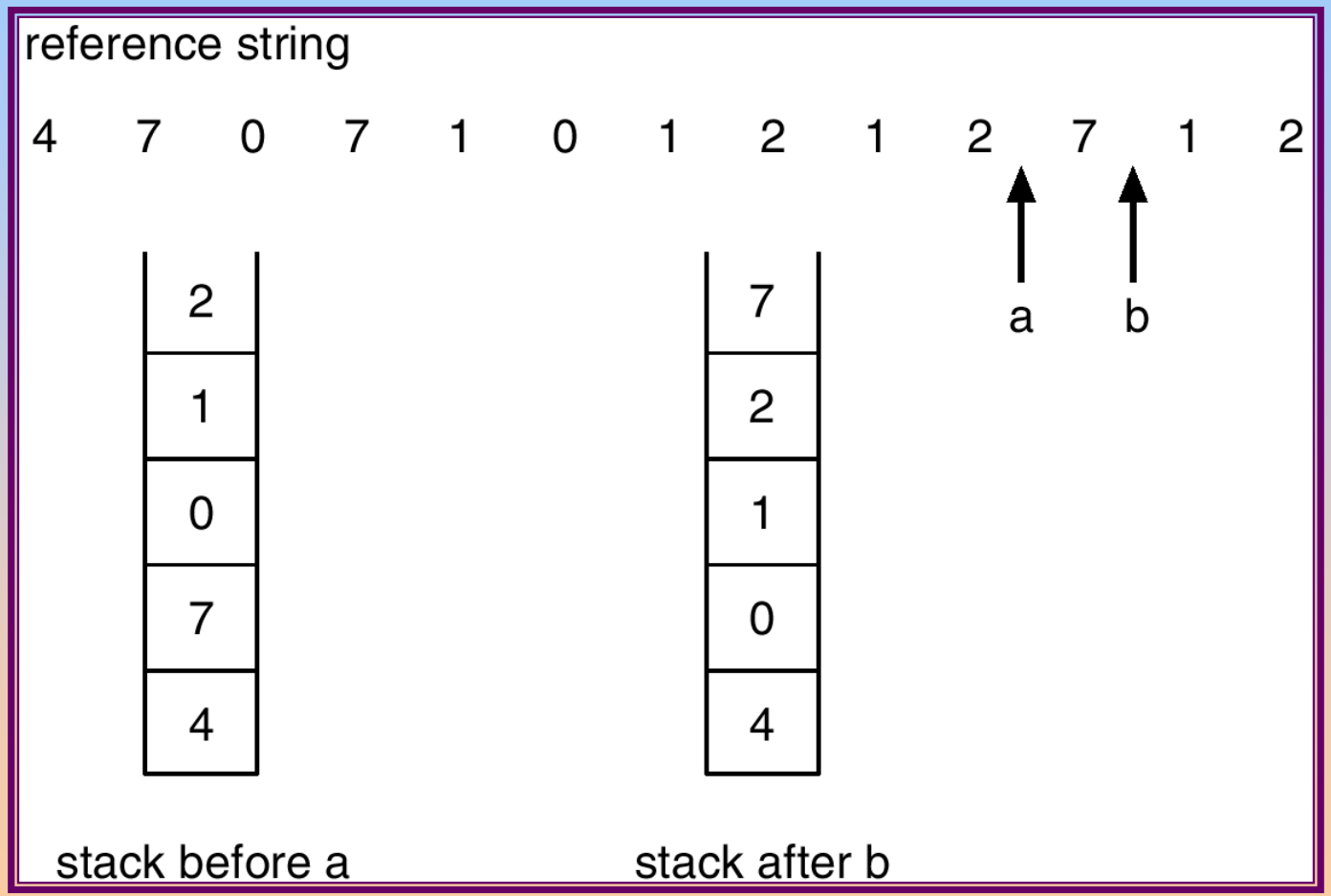


LRU Algorithm (Cont.)

- Stack implementation – keep a stack of page numbers in a double link form:
  - Page referenced:
    - move it to the top
    - requires 6 pointers to be changed
  - No search for replacement

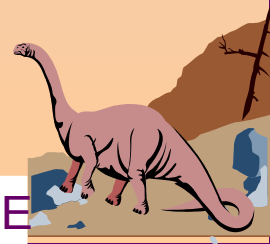


Use Of A Stack to Record The Most Recent Page References

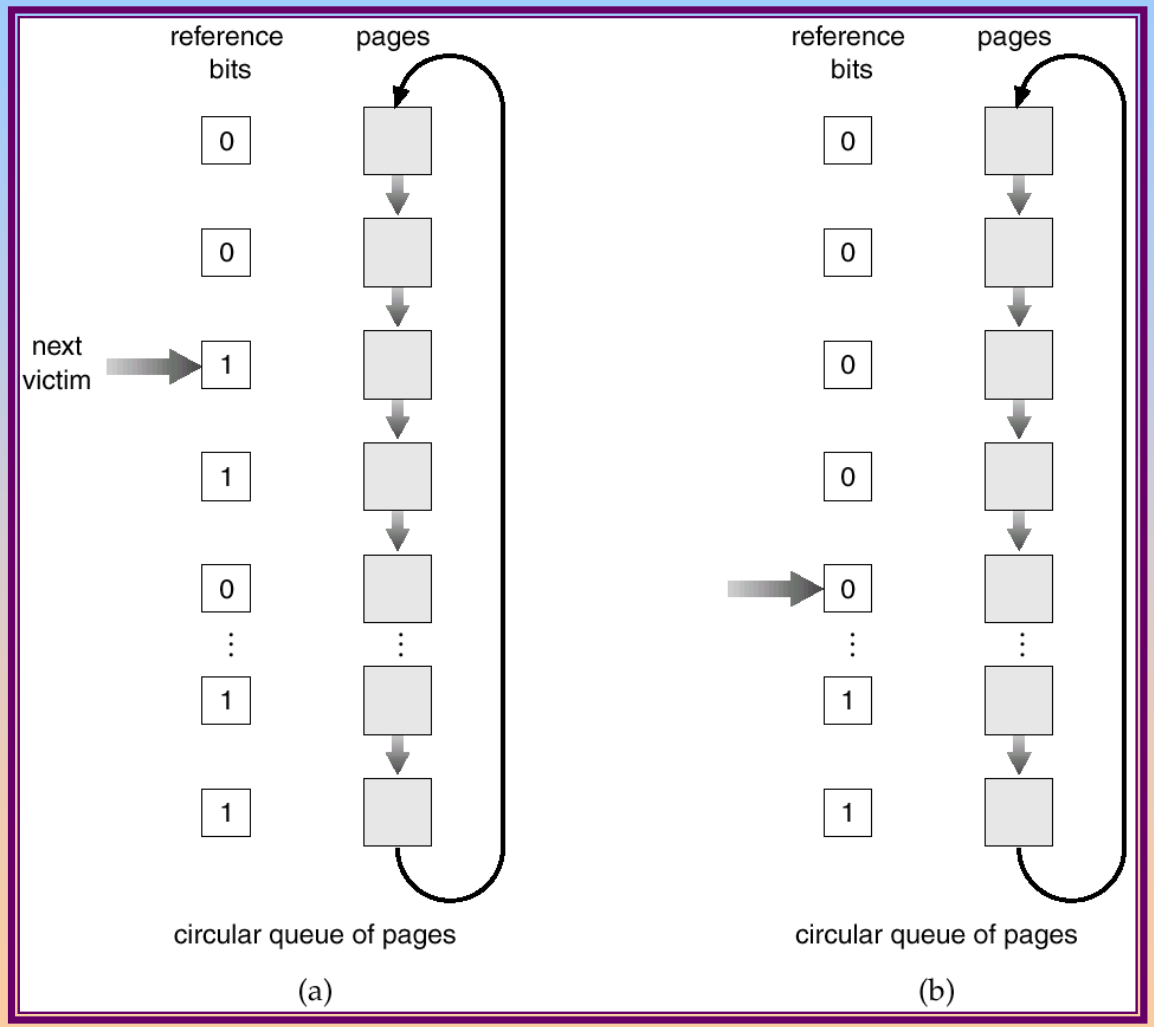


LRU Approximation Algorithms

- Reference bit
  - With each page associate a bit, initially = 0
  - When page is referenced bit set to 1.
  - Replace the one which is 0 (if one exists). We do not know the order, however.
- Second chance
  - Need reference bit.
  - Clock replacement.
  - If page to be replaced (in clock order) has reference bit = 1. then:
    - set reference bit 0.
    - leave page in memory.
    - replace next page (in clock order), subject to same rules.



Second-Chance (clock) Page-Replacement Algorithm



Counting Algorithms

- Keep a counter of the number of references that have been made to each page.
- LFU Algorithm: replaces page with smallest count.
- MFU Algorithm: based on the argument that the page with the smallest count was probably just brought in and has yet to be used.