OPERATING SYSTEMS CS3500

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VM_ II

PAGE REPLACEMENT

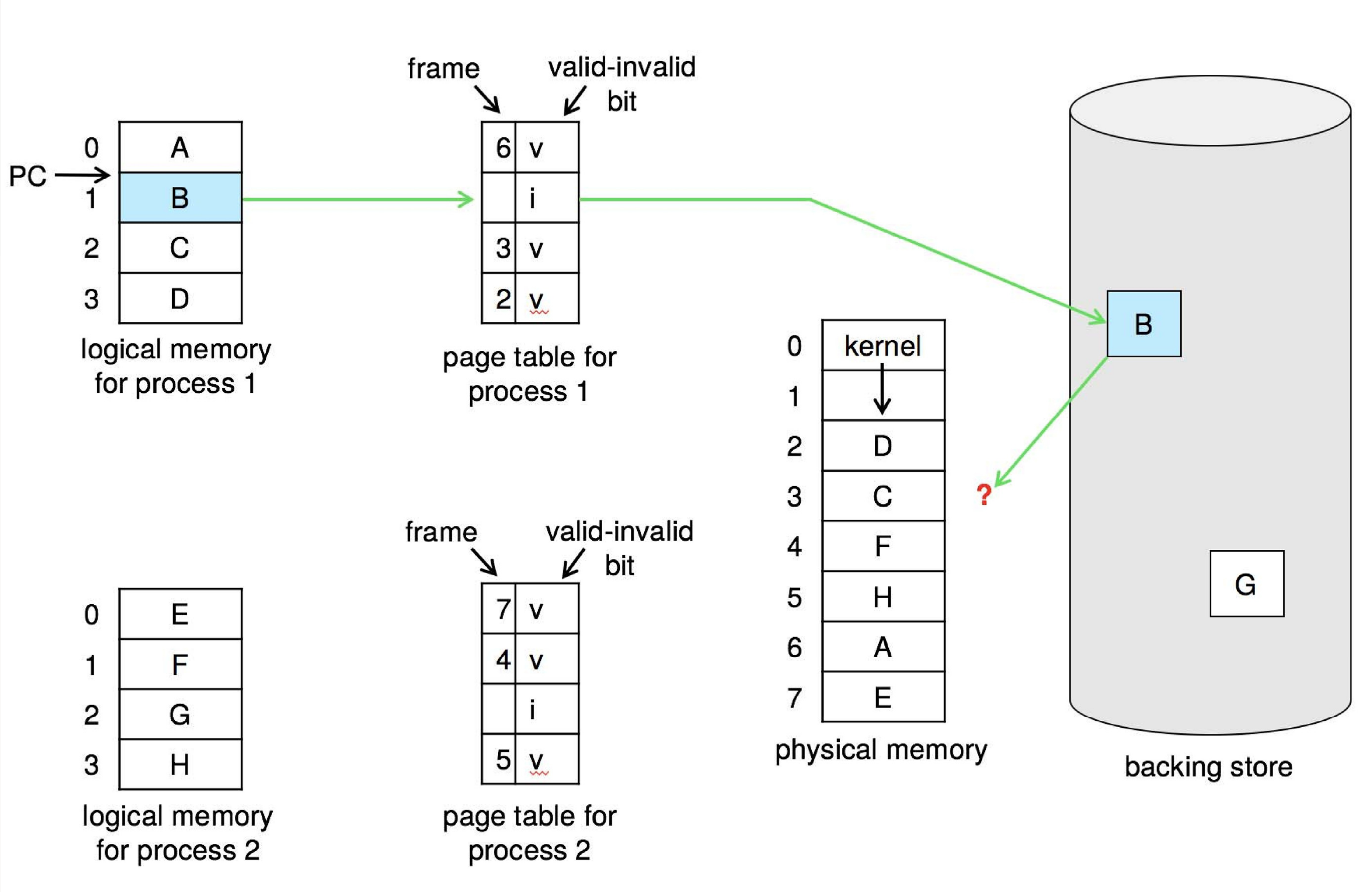
WHAT HAPPENS IF THERE IS NO FREE FRAME?

- Used up by process pages
- Also in demand from the kernel, I/O buffers, etc
- How much to allocate to each?
- Page replacement – find some page in memory, but not really in use, page it out
  - Algorithm – terminate? swap out? replace the page?
  - Performance – want an algorithm which will result in minimum number of page faults
- Same page may be brought into memory several times

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



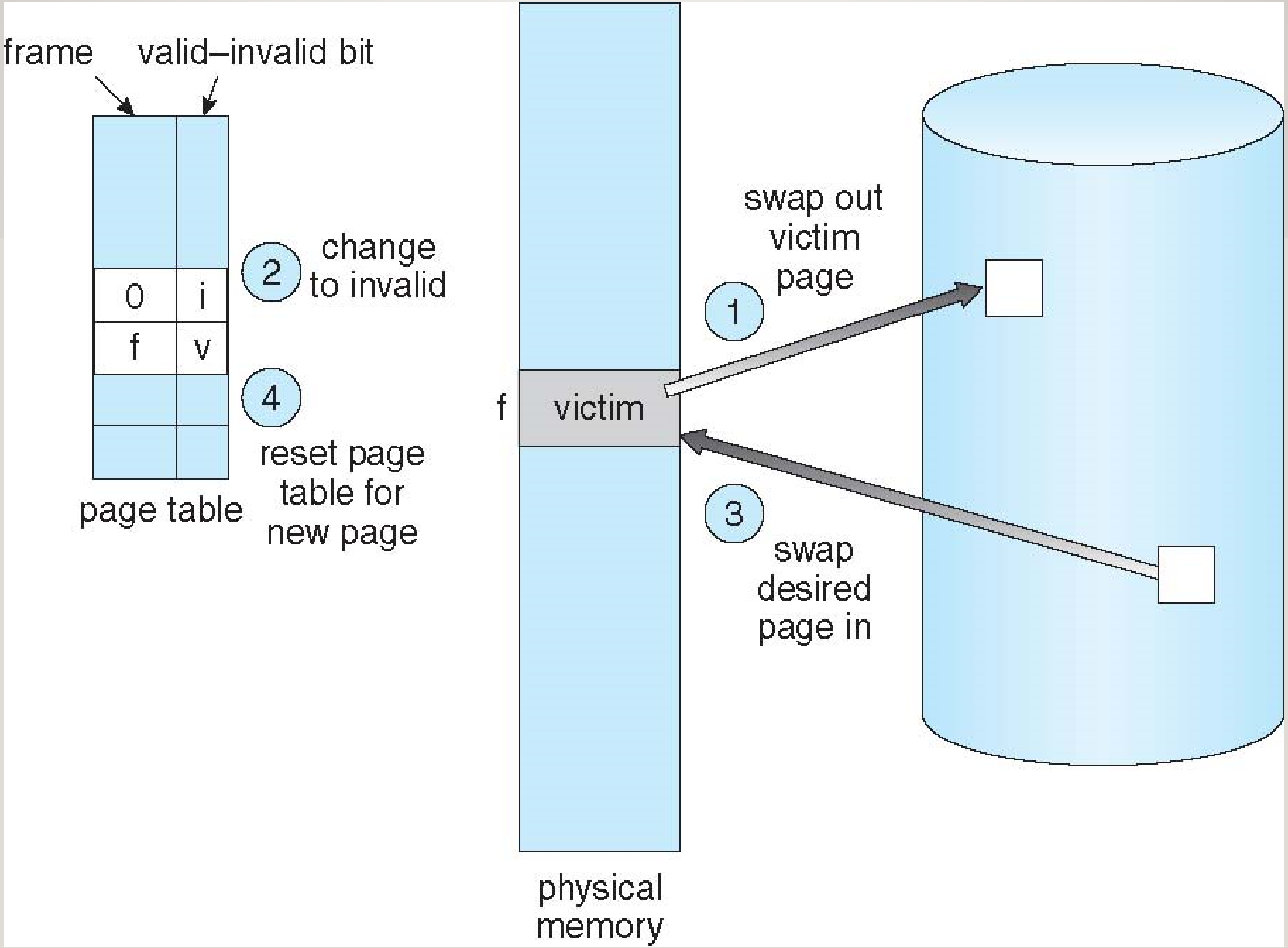
BASIC PAGE REPLACEMENT

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;

Use dirty bit to swap out contents (for code, say ?)

PAGE REPLACEMENT

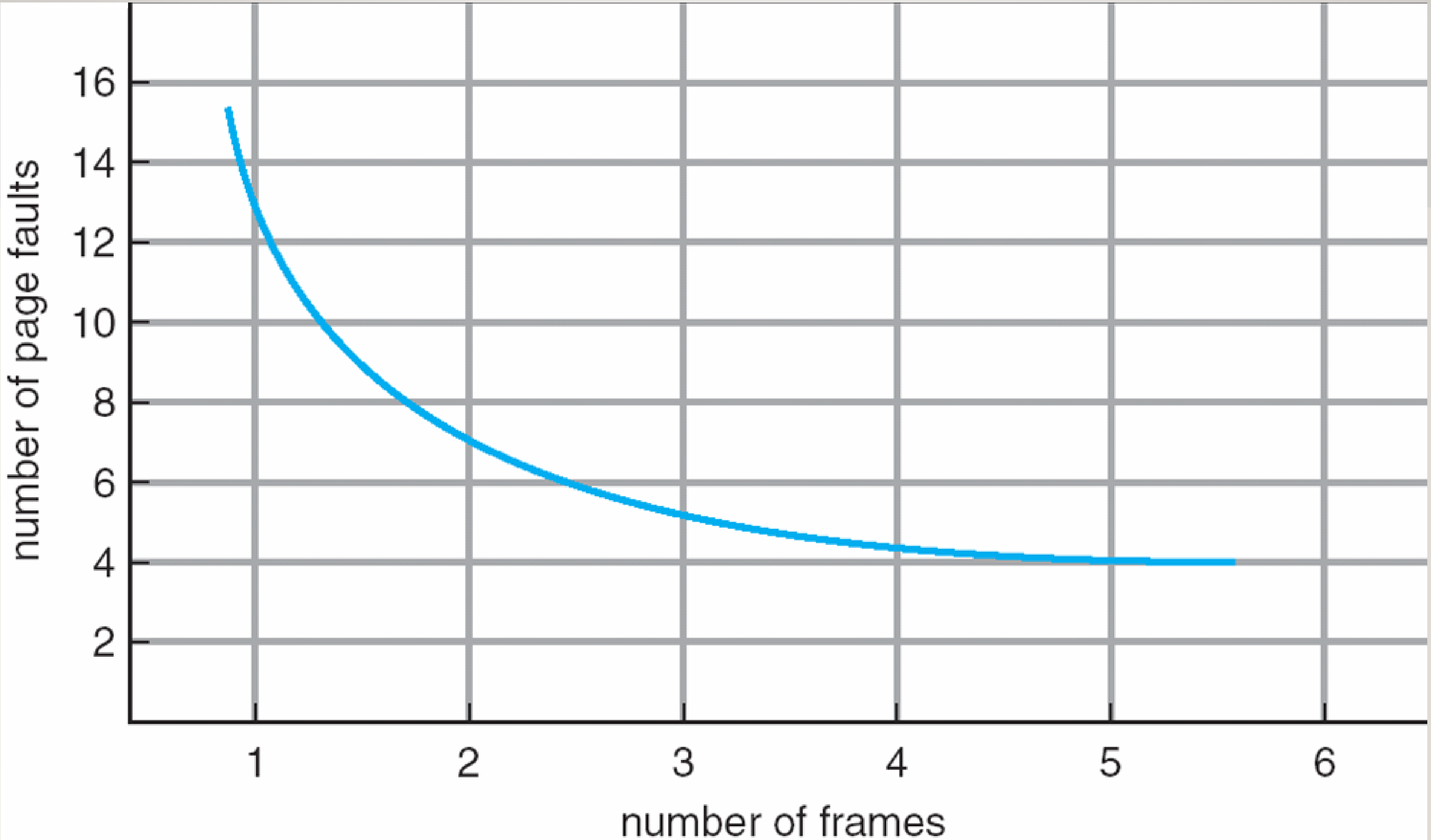


PAGE AND FRAME REPLACEMENT ALGORITHMS

- **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

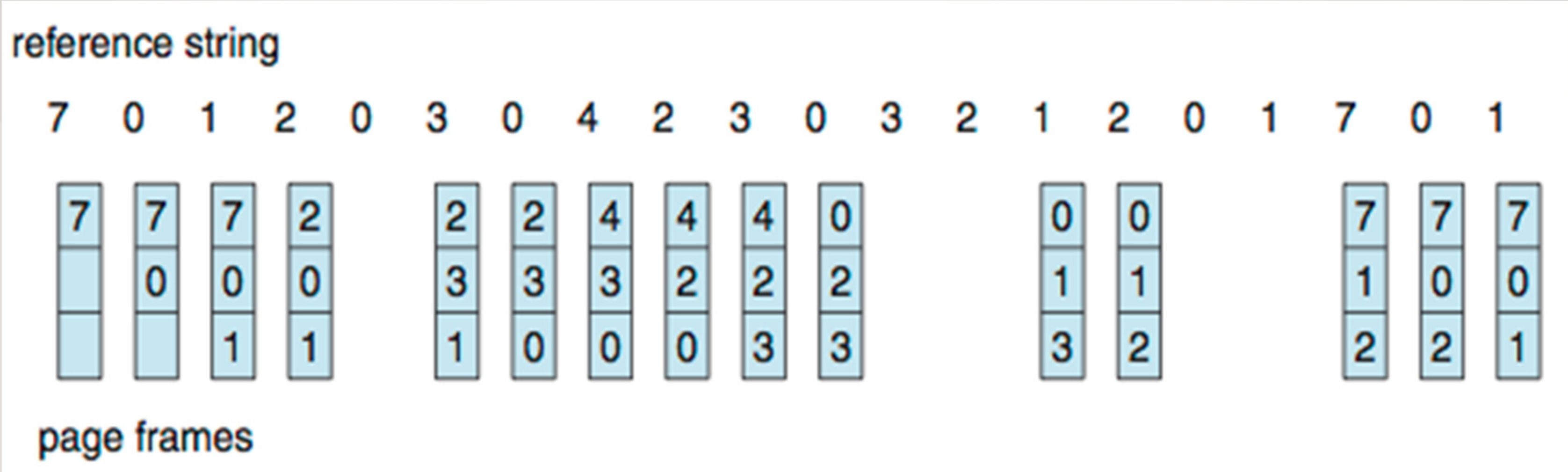
7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 0, 3, 2, 1, 2, 0, 1, 7, 0, 1

GRAPH OF PAGE FAULTS VERSUS THE NUMBER OF FRAMES



FIRST-IN-FIRST-OUT (FIFO) ALGORITHM

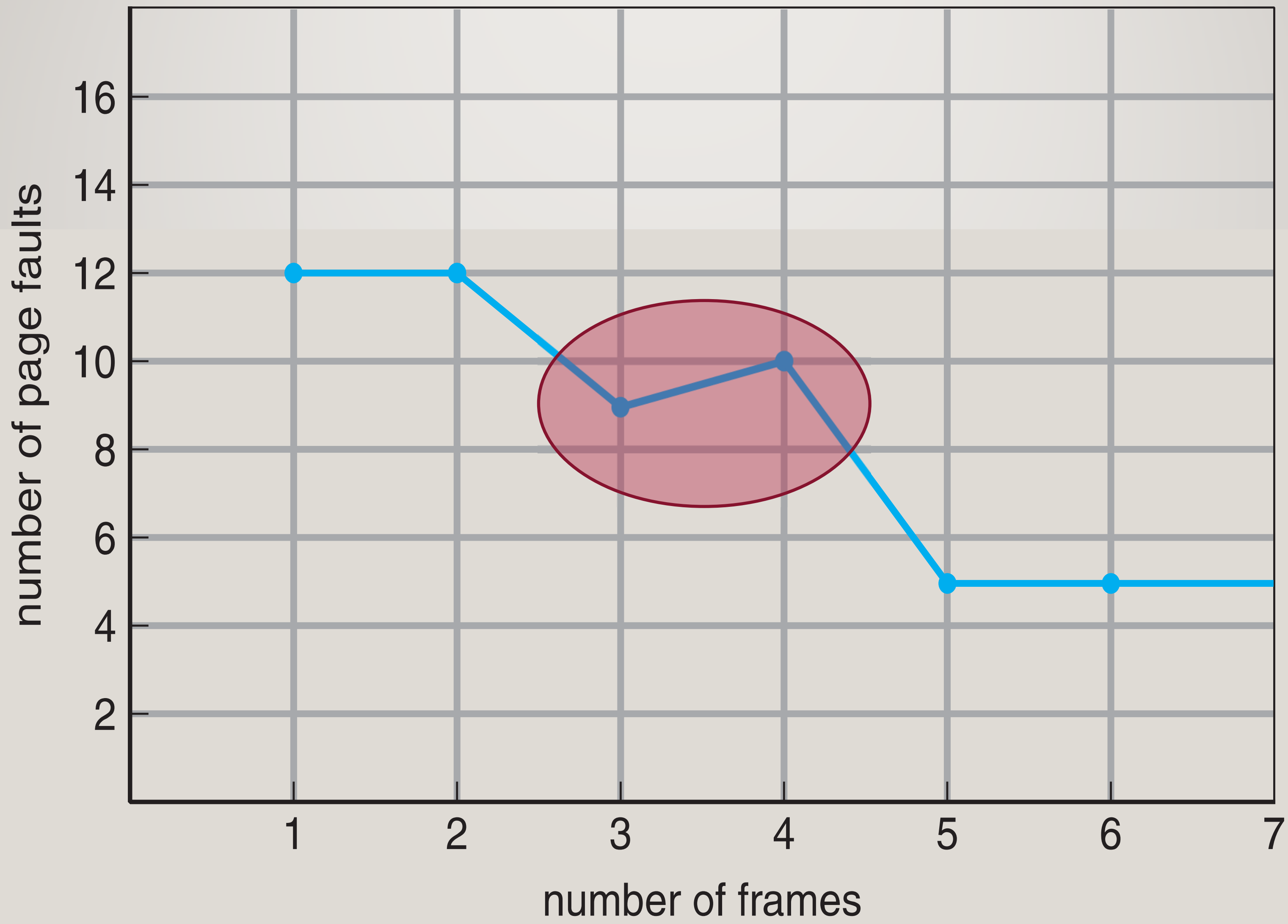
- Reference string: ***7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 0, 3, 2, 1, 2, 0, 1, 7, 0, 1***
- 3 frames (3 pages can be in memory at a time per process)



15 page faults

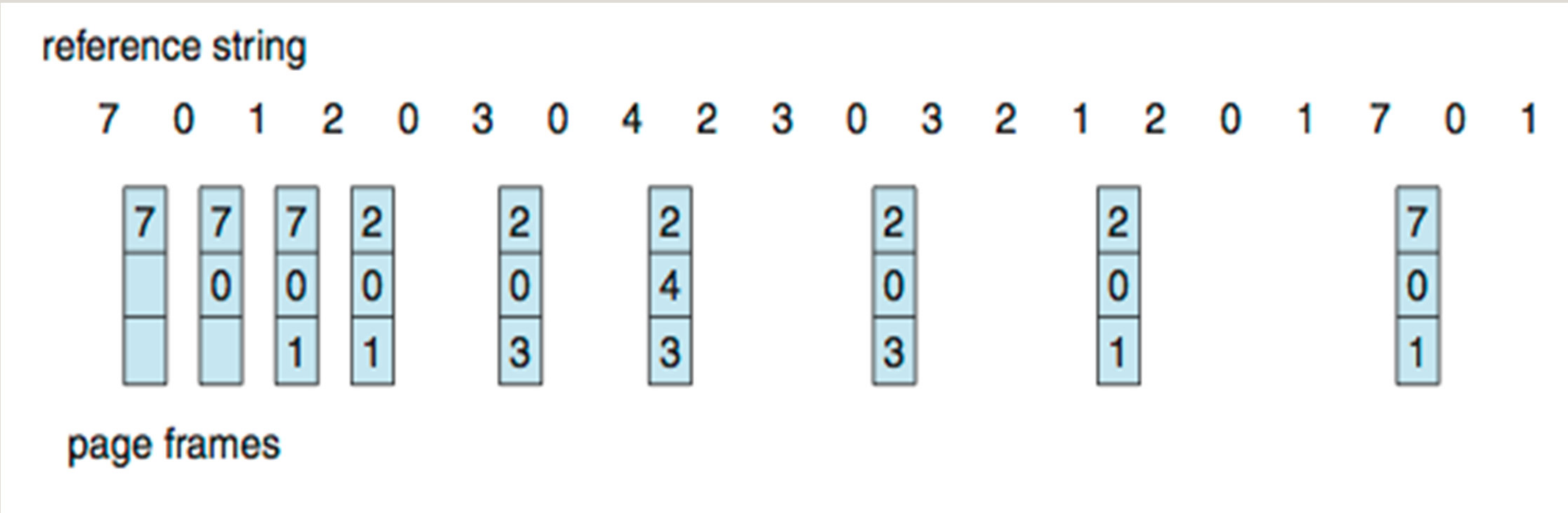
- Can vary by reference string: consider ***1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5***
  - Adding more frames can cause more page faults!
    - **Belady's Anomaly**
- How to track ages of pages?
  - Just use a FIFO queue

FIFO ILLUSTRATING BELADY'S ANOMALY



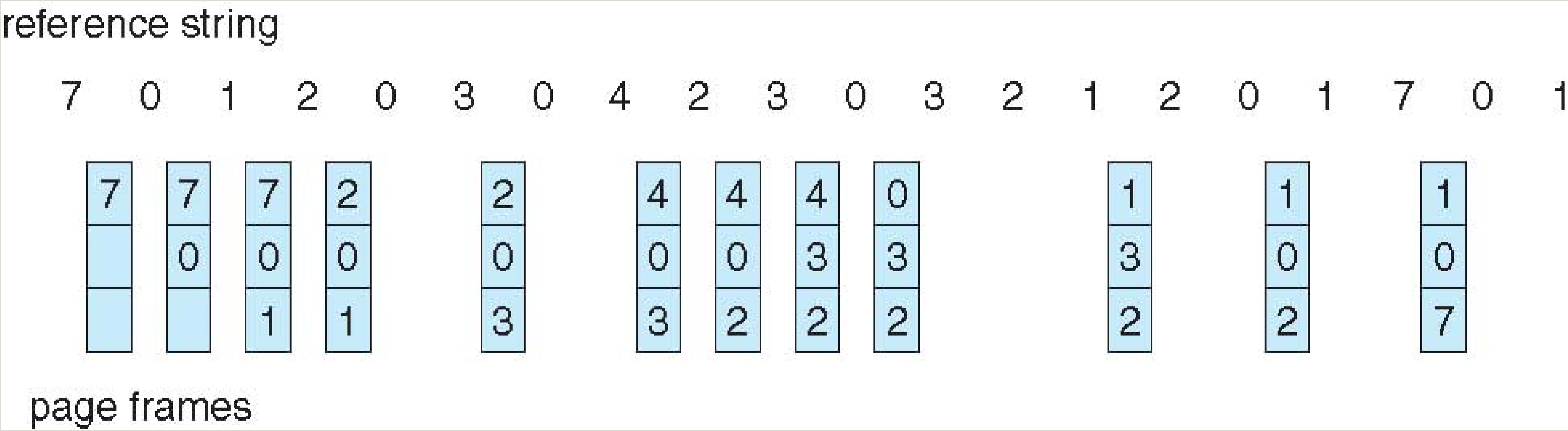
OPTIMAL ALGORITHM

- Replace page that will not be used for longest period of time
  - #page faults = [redacted] ? is optimal for the example, better than FIFO
- How do you know this?
  - Can't read the future
- Used for measuring how well your algorithm performs



LEAST RECENTLY USED (LRU) ALGORITHM

- Use past knowledge rather than future
- Replace page that has not been used in the most amount of time
- Associate time of last use with each page



- faults (?)

  – better than FIFO but worse than OPT

- Generally good algorithm and frequently used
- But how to implement?

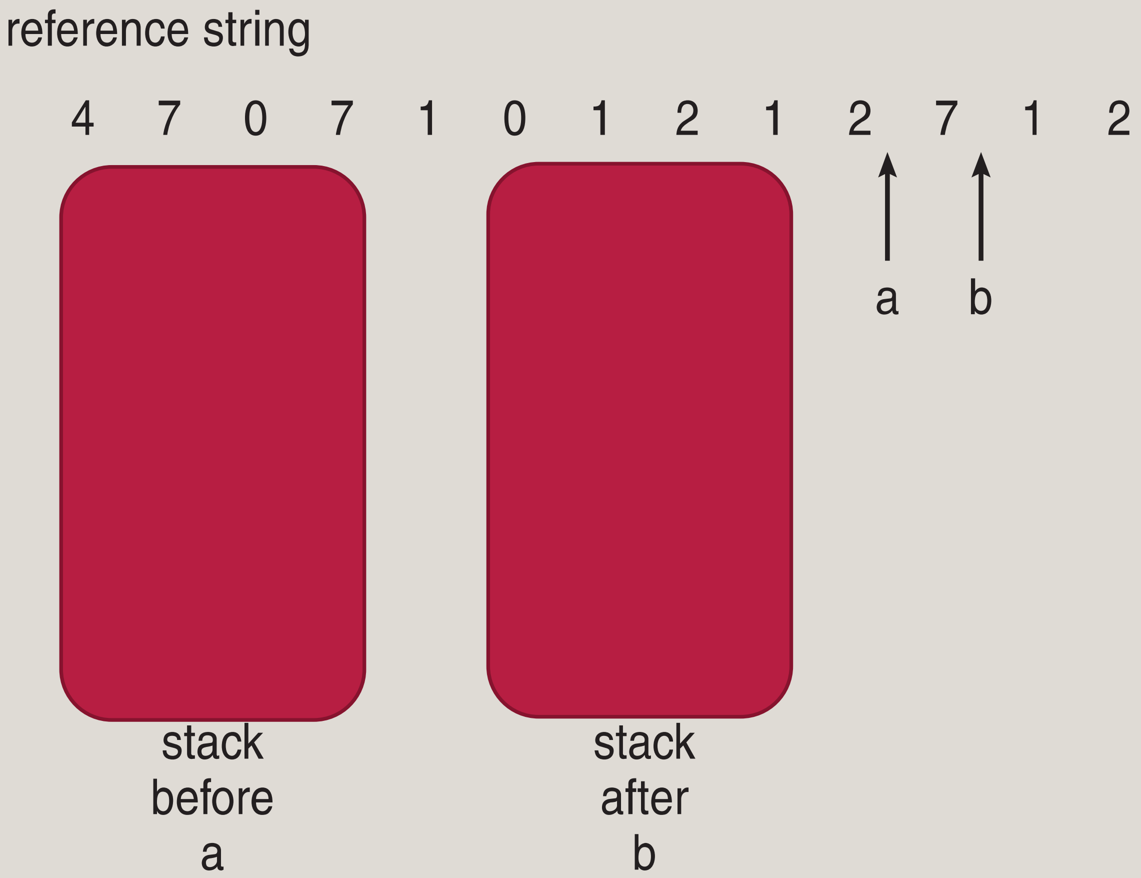
LRU ALGORITHM (CONT.)

- 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 find smallest value
    - Search through table needed

- 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
  - But each update more expensive
  - No search for replacement

LRU ALGORITHM (CONT.)

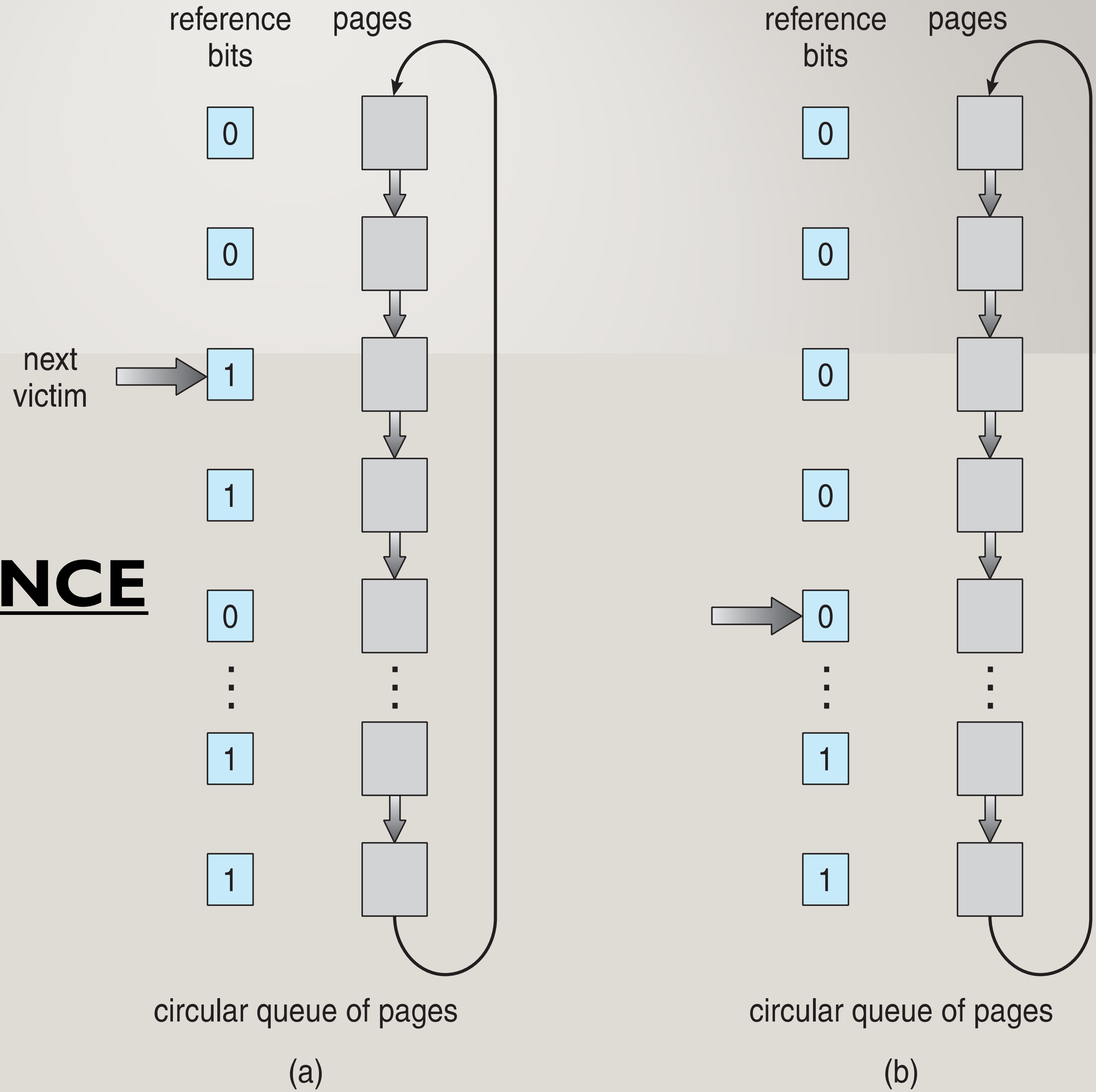
- LRU and OPT are cases of **stack algorithms** that don't have Belady's Anomaly
- Use of A Stack to Record Most Recent Page References



LRU APPROXIMATION ALGORITHMS

- LRU needs special hardware and still slow
- **Reference bit**
  - With each page associate a bit, initially = 0
  - When page is referenced bit set to 1
  - Replace any with reference bit = 0 (if one exists)
    - We do not know the order, however.
    - Additional Reference bits used too – use K-bit Shift Reg; least No. replaced
- **Second-chance algorithm**
  - Generally FIFO, plus hardware-provided reference bit
  - **"Clock"** replacement algo.
  - If page (victim) to be replaced has
    - Reference bit = 0 -> replace it
    - reference bit = 1 then:
      - set reference bit 0, leave page in memory
      - replace next victim page, subject to same rules

SECOND-CHANCE ALGORITHM



ENHANCED SECOND-CHANCE ALGORITHM

- Improve algorithm by using reference bit and modify bit (if available) in concert
- Take ordered pair (reference, modify):
  - (0, 0) neither recently used not modified – best page to replace
  - (0, 1) not recently used but modified – not quite as good, must write out before replacement
  - (1, 0) recently used but clean – probably will be used again soon
  - (1, 1) recently used and modified – probably will be used again soon and need to write out before replacement
- When page replacement called for, use the clock scheme but use the four classes - replace page in lowest non-empty class
  - Might need to search circular queue several times

COUNTING ALGORITHMS

- Keep a counter of the number of references that have been made to each page
  - Not common
- **Lease Frequently Used** (**LFU**) **Algorithm**:
  - Replaces page with smallest count – page heavily used and then idle in memory for a long time; Solution – use SR - exponentially decaying average usage count.
- **Most Frequently Used** (**MFU**) **Algorithm**:
  - Based on the argument that the page with the smallest count was probably just brought in and has yet to be used
  - Both not commonly used

PAGE-BUFFERING ALGORITHMS-

- Typically used as additional measures with PRA, for enhancement of performance.
- Keep a pool of free frames, always
  - Then frame available when needed; But, Page fault forces to locate a free & victim frames
  - Read page into free frame and select victim to evict and add to free pool
  - When convenient, evict victim
- Possibly,   keep list of modified pages
  - When backing store otherwise idle, write pages there and set modify bit to non-dirty
- Possibly, keep free frame contents intact and note what is in them
  - If referenced again before reused, no need to load contents again from disk
  - Generally useful to reduce penalty if wrong victim frame selected

APPLICATIONS AND PAGE REPLACEMENT

- All of these algorithms have OS guessing about future page access
- Some applications have better knowledge – i.e. databases
- Memory intensive applications can cause double buffering
  - OS keeps copy of page in memory as I/O buffer
  - Application keeps page in memory for its own work
- Operating system can given direct access (ie the ability to use a secondary storage partition as a large sequential array of logical blocks) to the disk, getting out of the way of the applications
  - **Raw disk** mode – not like conventional File system access
- Bypasses buffering, locking, etc.