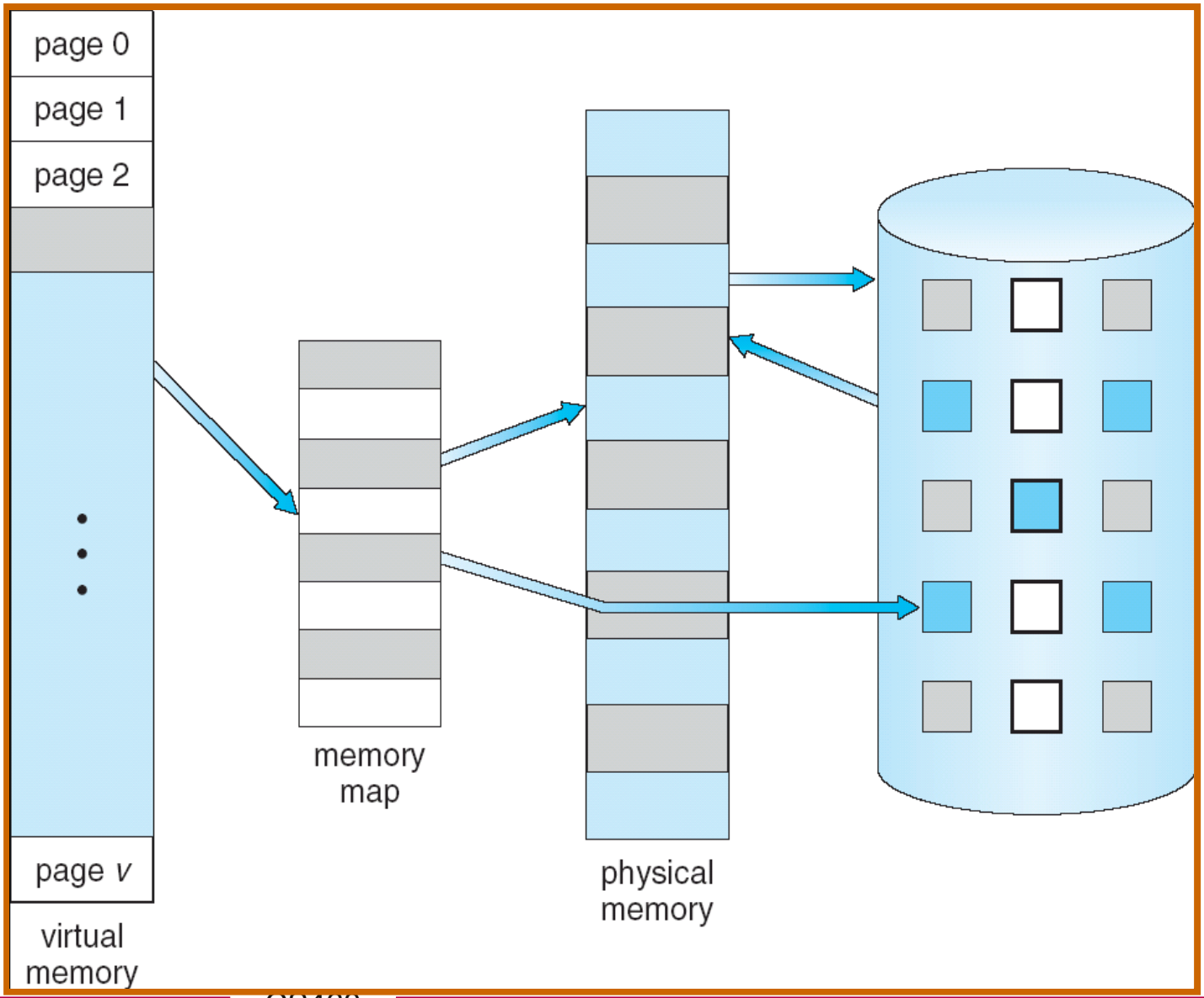
Chapter 9
Virtual Memory

Images from Silberschatz

Virtual Memory

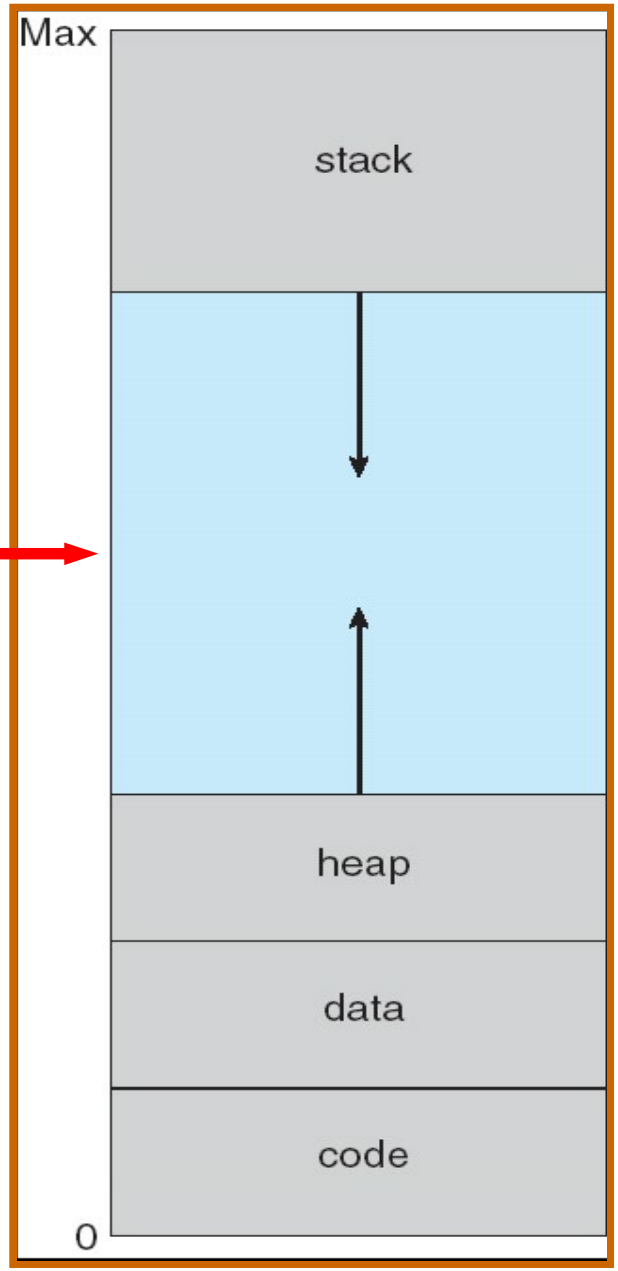
- Processes do not need to be completely in memory to execute
  - data
  - code
  - data set can be larger than physical memory
- Demand Paging



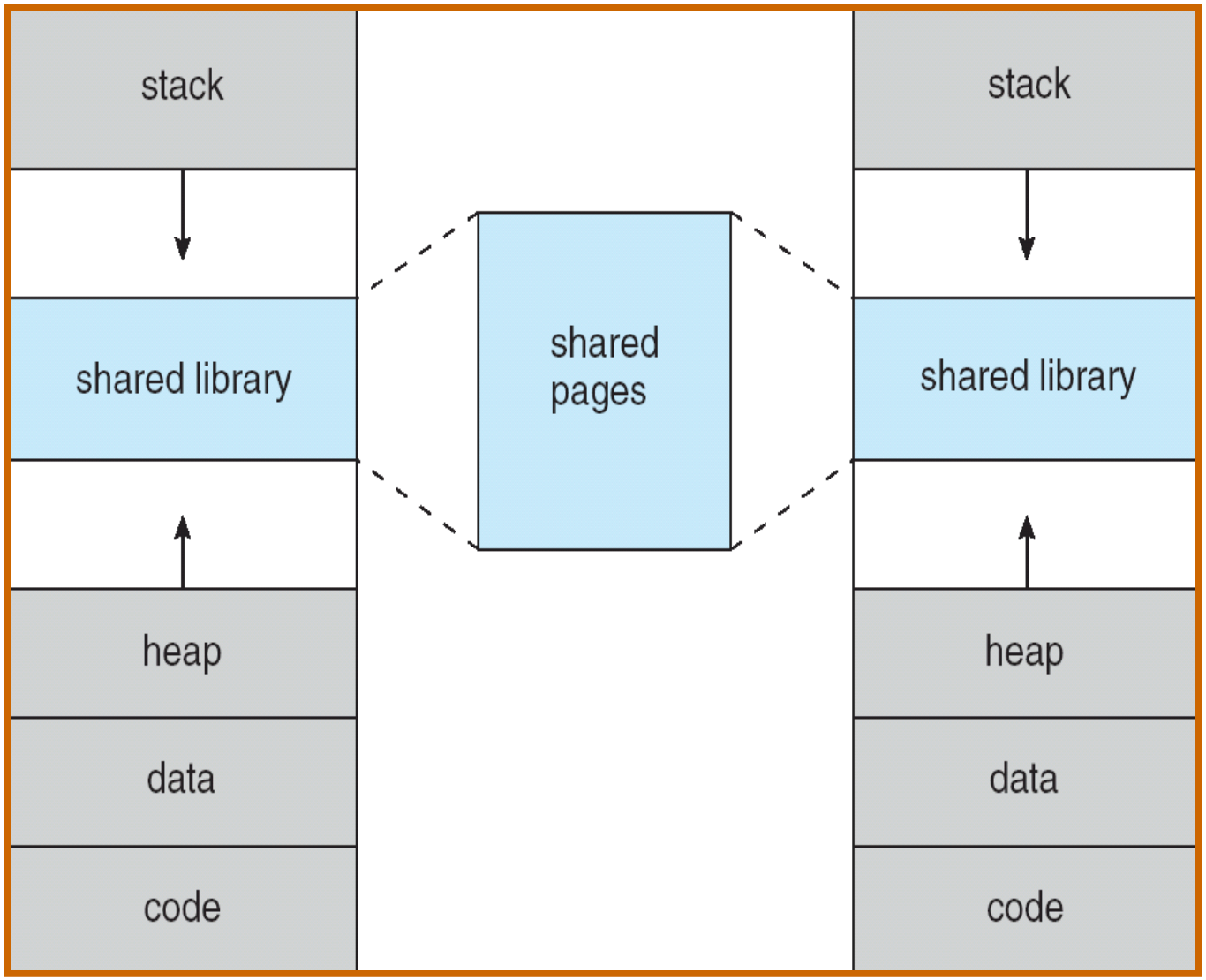
Process View

- Big Virtual Memory space
- Only allocated needed pages
- Empty pages are ignored

Empty Until Needed



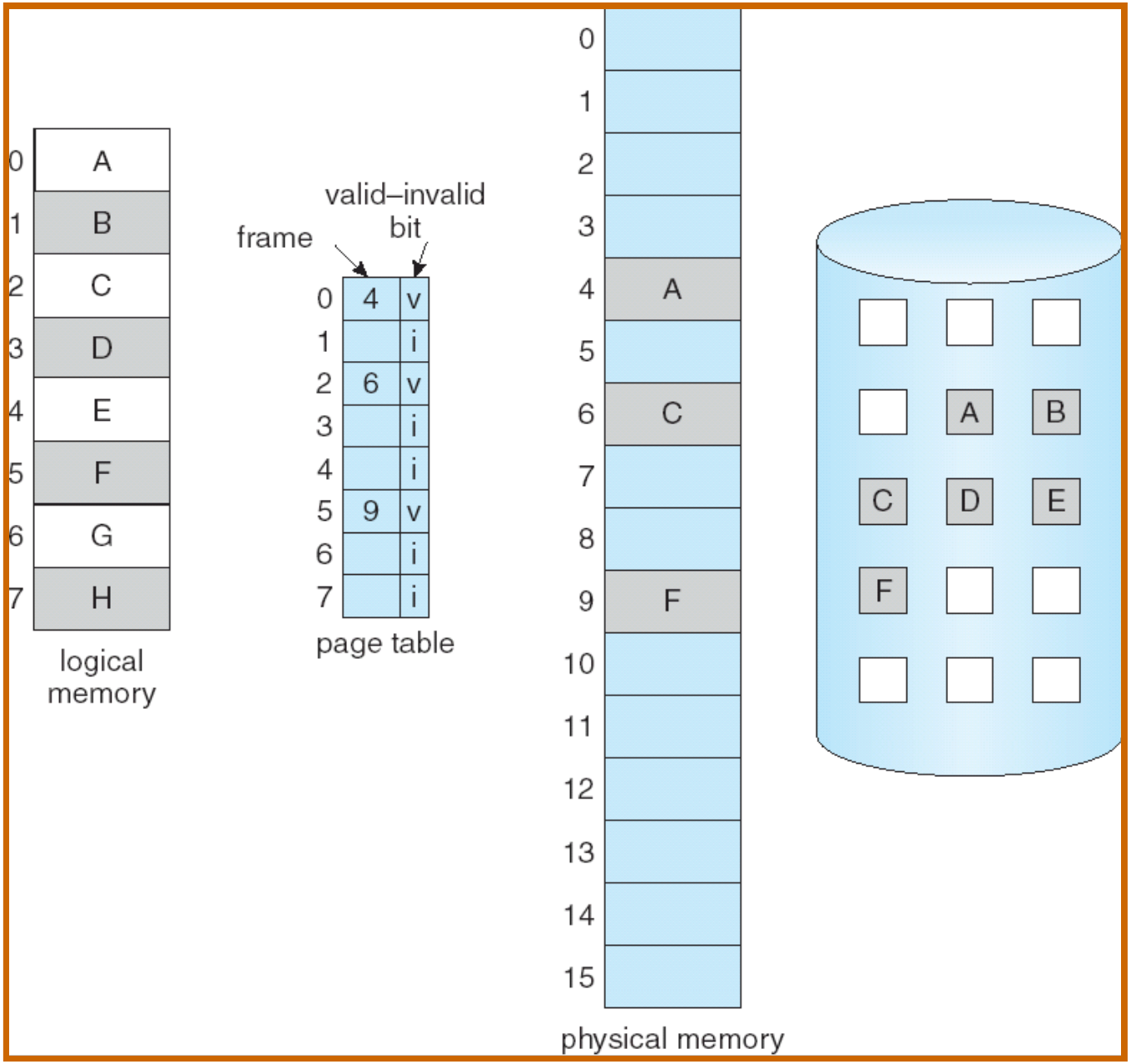
Sharing Memory



Demand Paging

- Load pages as they are needed
  - lazy swapping (pager)
  - less I/O (up front)
  - less memory used at once
  - faster response
  - more processes fit into memory
  - mark pages as in memory or not (similar to valid/invalid)

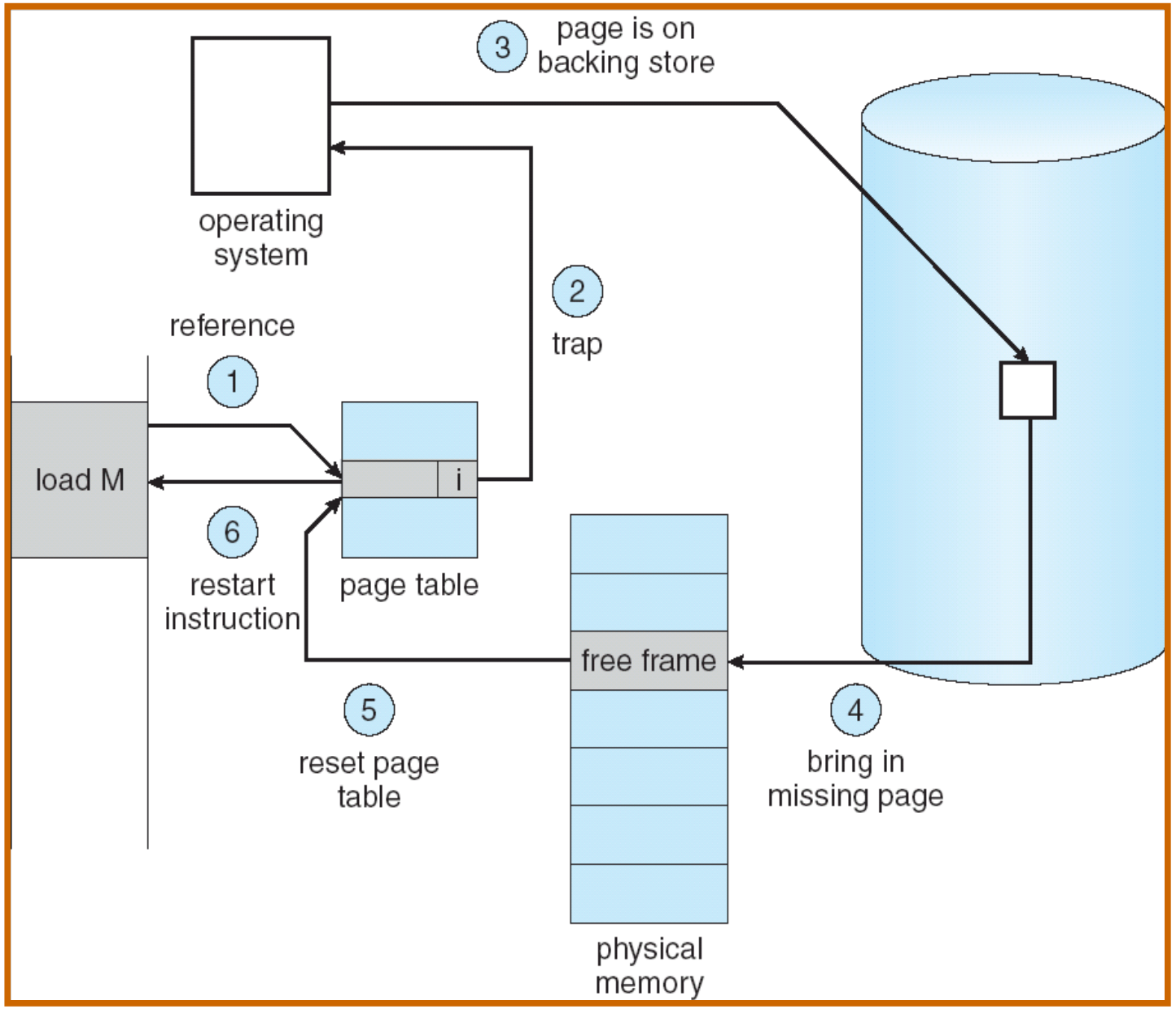
New Page Table



Hardware Support

- Accessing an out-of-memory page causes a page fault trap
- OS handles this and brings the page into memory
- Also must check for invalid address
- Pure Demand Paging
  - Locality of reference
- Page fault may occur anywhere in an instruction
  - may backup and rerun something

Page Fault!


3
page is on
backing store
operating
system
2
trap
reference
1
load M
i
6
restart
instruction
page table
free frame
5
reset page
table
4
bring in
missing page
physical
memory

Copy-on-Write

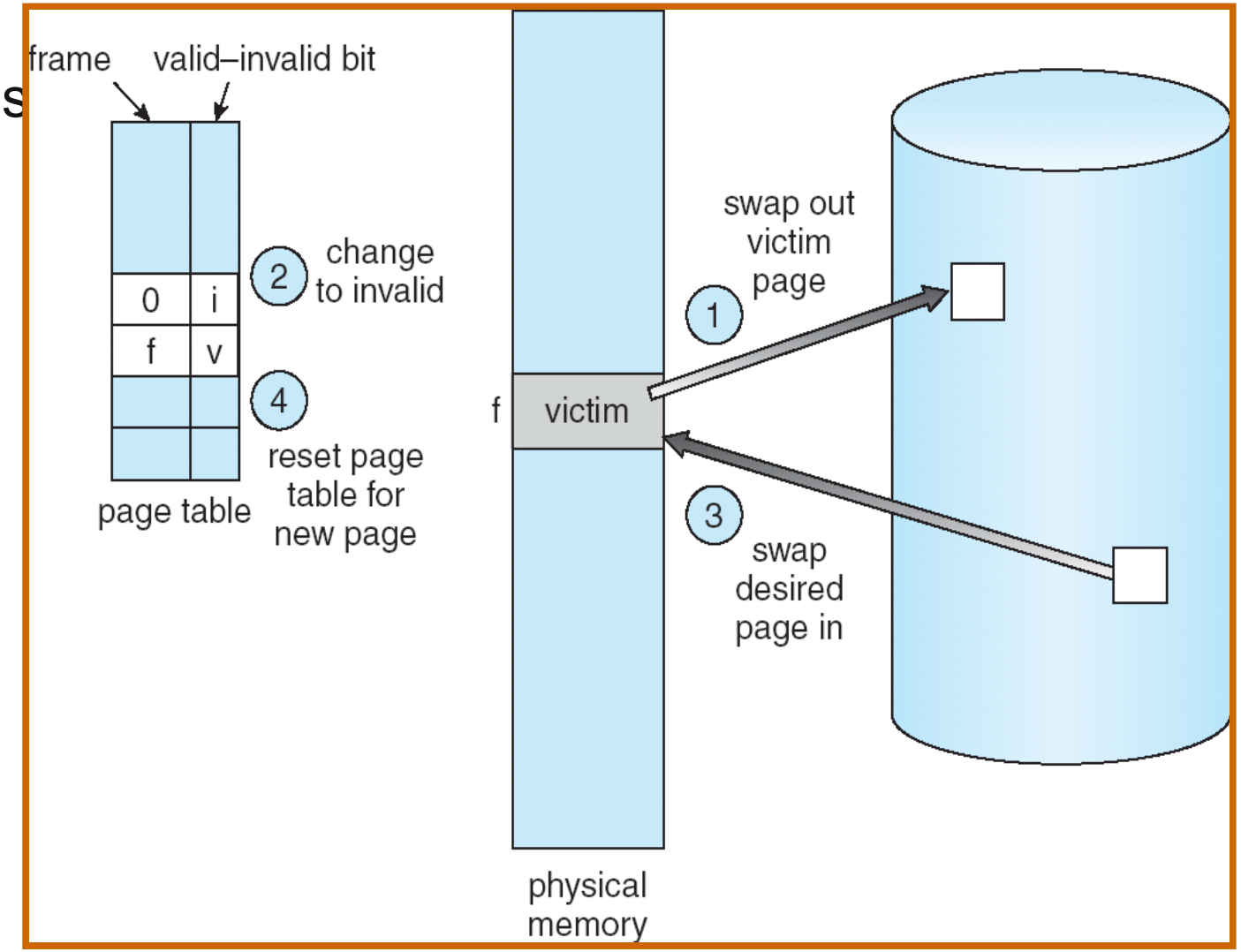
- When do processes share pages?

- Only copy (create a new page) when one process writes to a shared page
  - faster

- vfork()/exec()

Page Replacement

- Remove page from physical memory to make room
  - swap out a process/frame
- Two I/O operations
  - out then in
  - time consuming
  - page may still be on disk
  - dirty bit!



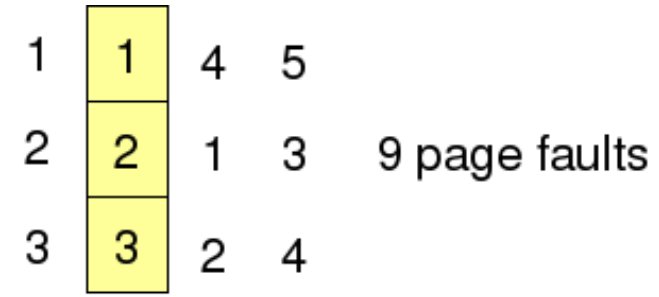
Algorithms

- Goal: Few page faults
- Frame Allocation

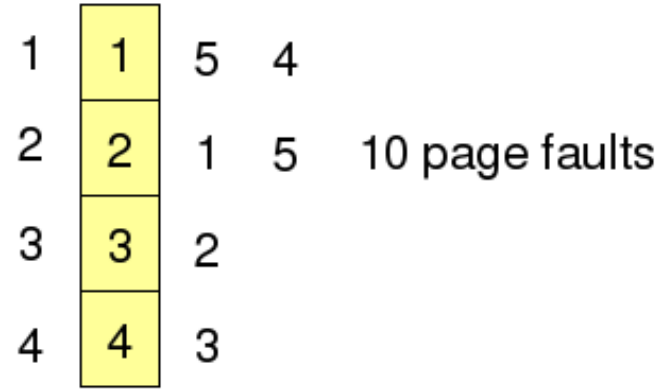
- Page Replacement

FIFO

- First In, First Out
- Ref String: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5



- Belady's Anomaly:
  - more frames, more faults



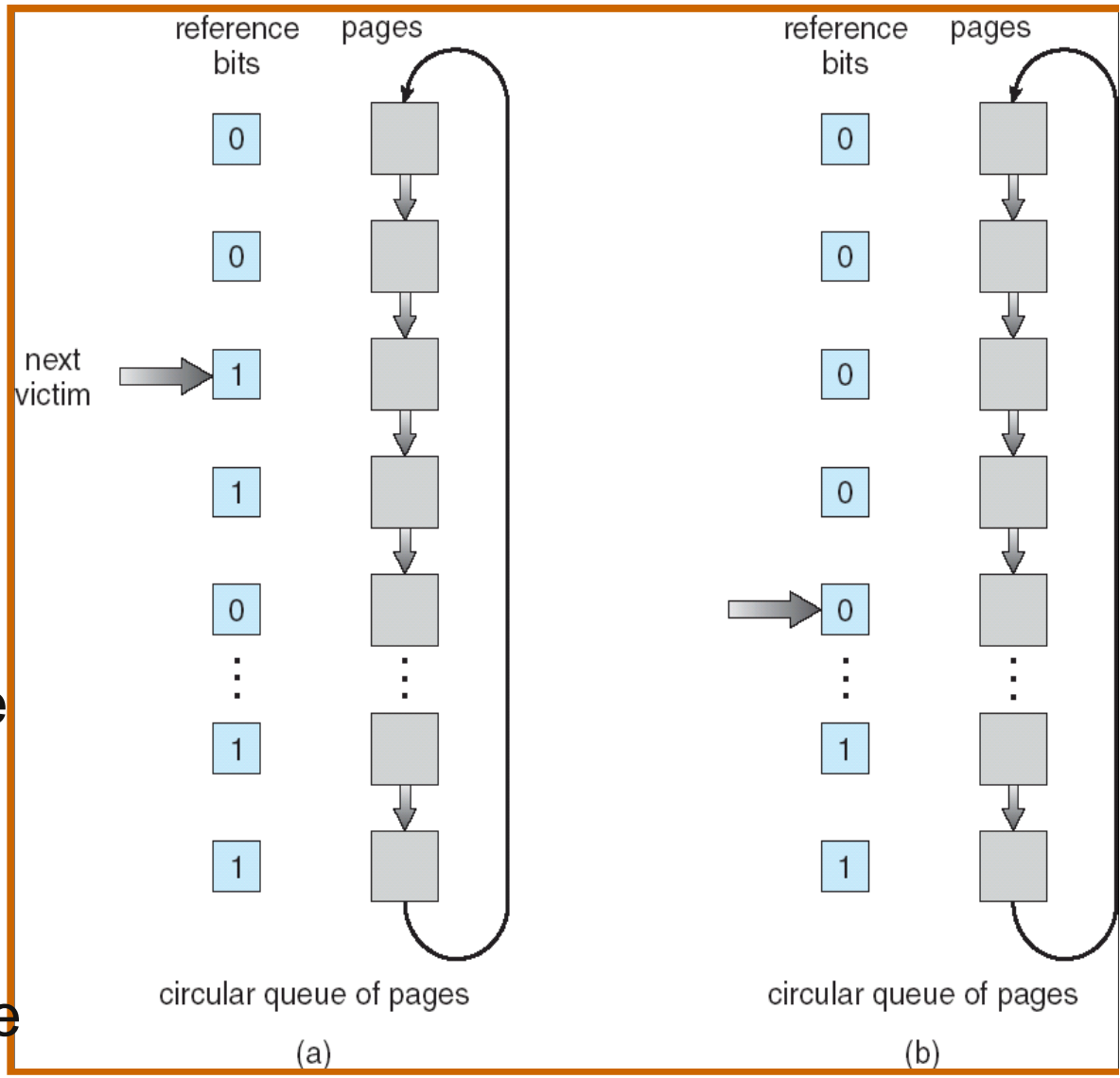
Optimal Replacement Algo

- “Replace the page that will not be used for the longest period of time”

- Problems with this?

Approximate Optimal

- LRU
- LRU-Approximate
  - reference bit
  - may be also FIFO (second chance)
- LRU-Additional-Reference-Bits
  - many (8?) bits
- Enhanced Second Chance
  - referenced, modified bits



Counting Algorithms

- Count references per page
  - rarely used in real world
- Least Frequently Used
- Most Frequently Used

Global vs Local

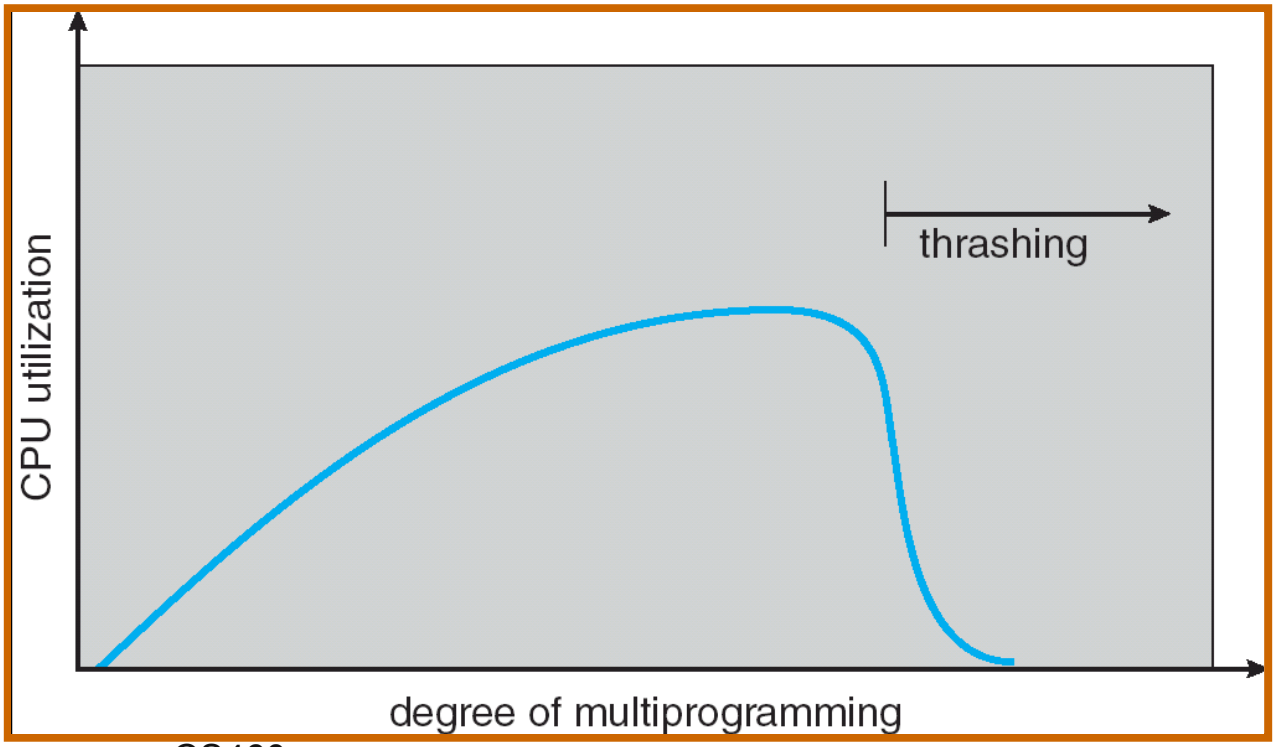
- Global replacement

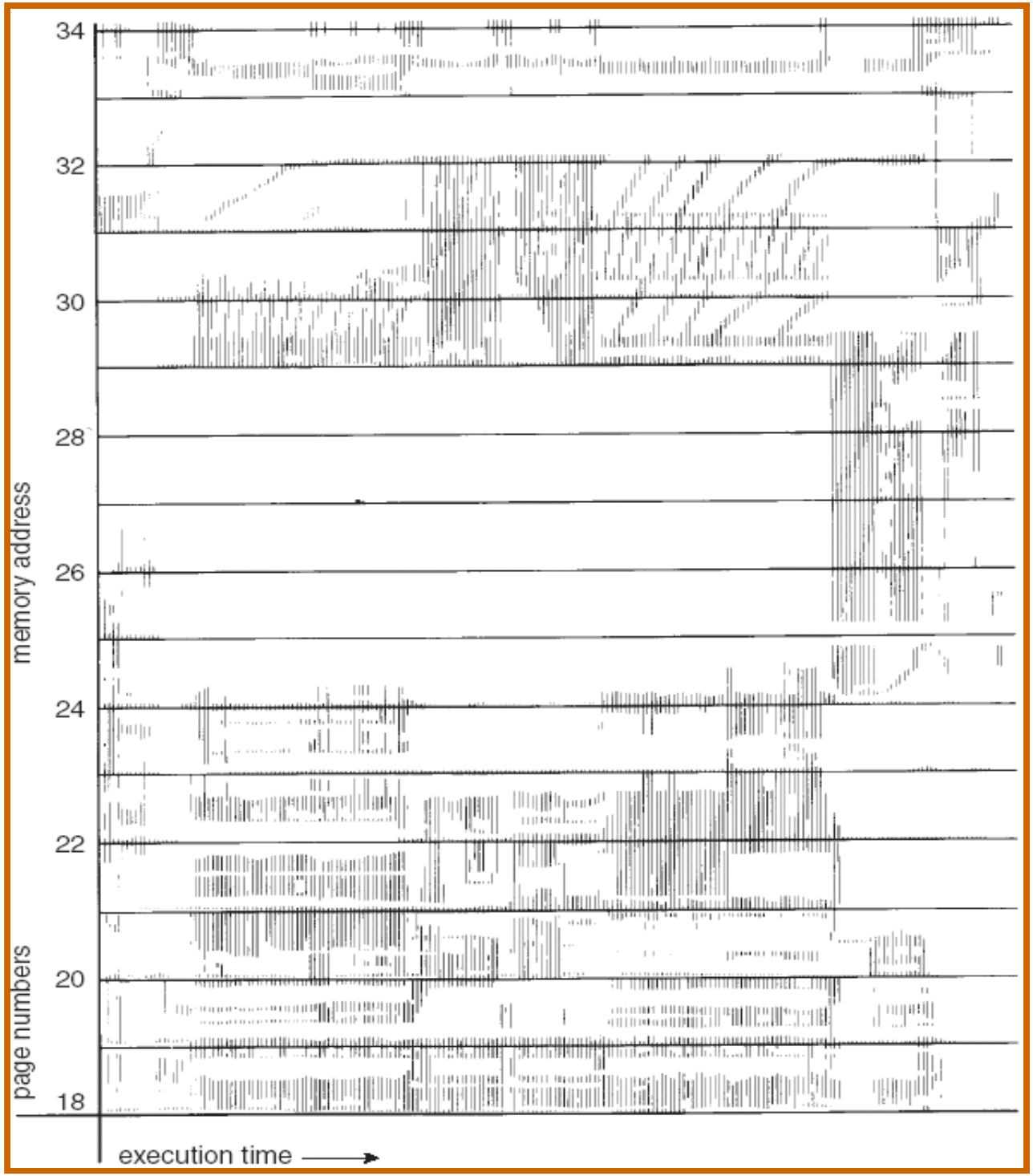
- Local replacement

Thrashing

- Furiously swapping pages in and out
- Problems?

- CPU utilization is low, so OS adds more processes
  - more frames are used
- Poor data layout in your application




34
32
30
28
26
24
22
20
18
memory address
page numbers
execution time