Memory Management

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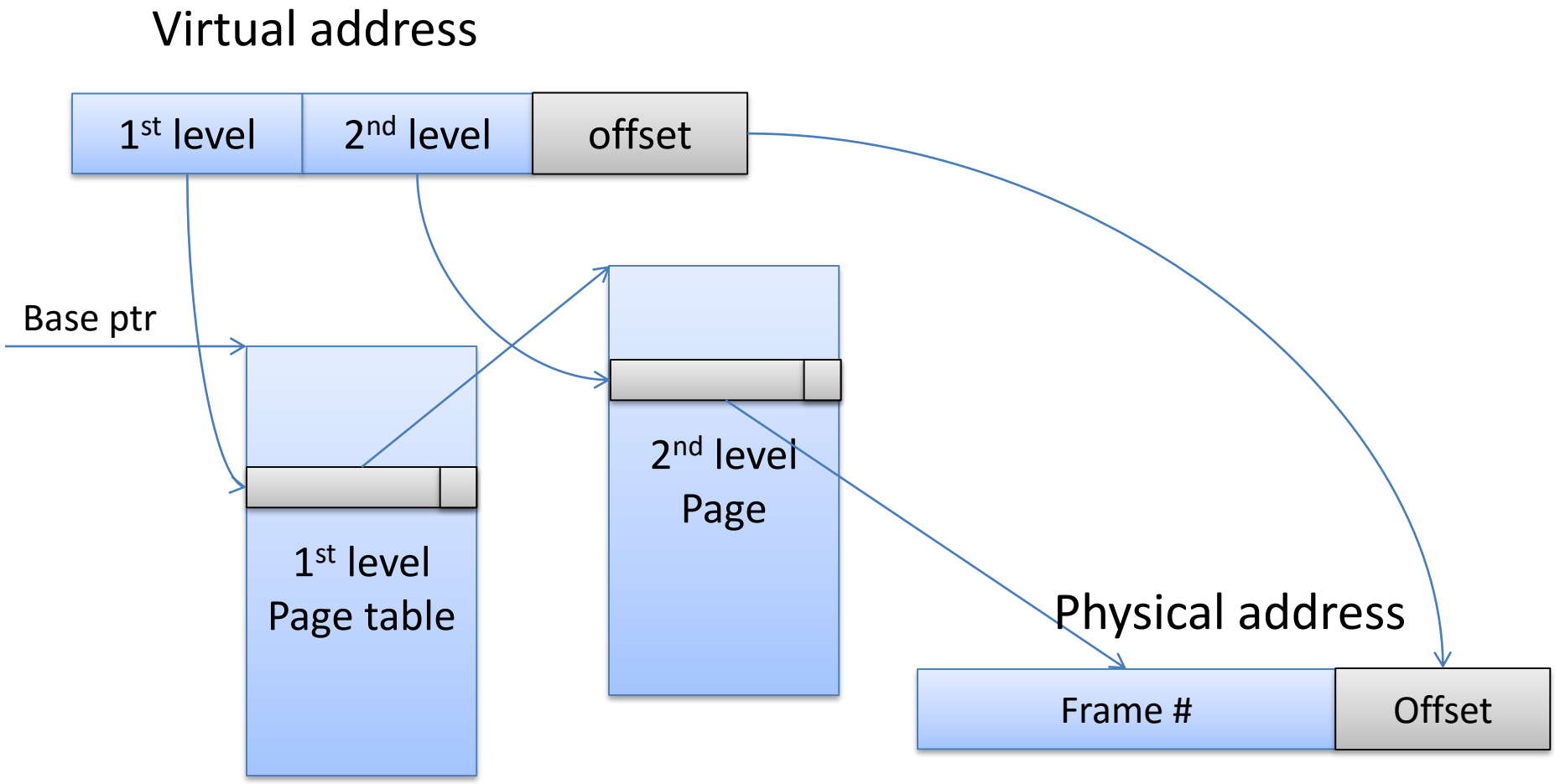
Recap: Two Level Paging



Quiz

- What is the page table size for a process that only uses 8MB memory?
  - Common: 32bit address space, 4KB page size
  - Case 1) 1-level page table
    - Assume each page table entry is 4 bytes
    -
  - Case 2) two-level page table
    - Assume first 10 bits are used as the index of the first-level page table, next 10 bits are used as the index of the second-level page table. In both-levels, single page table entry size is 4 bytes
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Quiz

- What is the page table size for a process that only uses 8MB memory?
  - Common: 32bit address space, 4KB page size
  - Case 1) 1-level page table
    - Assume each page table entry is 4 bytes
    - Answer: 2^20 x 4 byte = 4MB
  - Case 2) two-level page table
    - Assume first 10 bits are used as the index of the first-level page table, next 10 bits are used as the index of the second-level page table. In both-levels, single page table entry size is 4 bytes
    - Answer: 2^10 x 4 + 2 x (2^10 x 4) = 4KB + 8KB = 12KB

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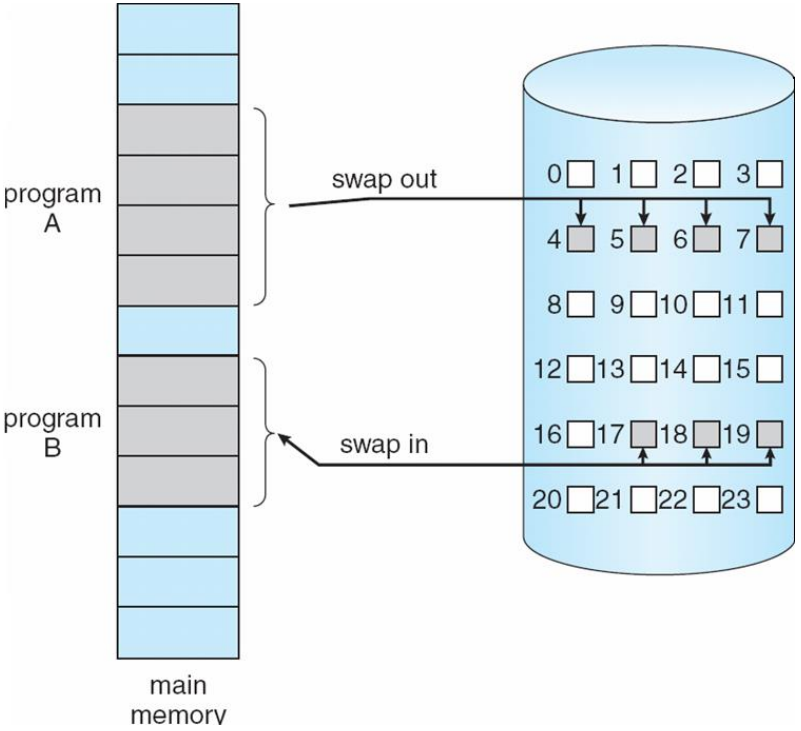
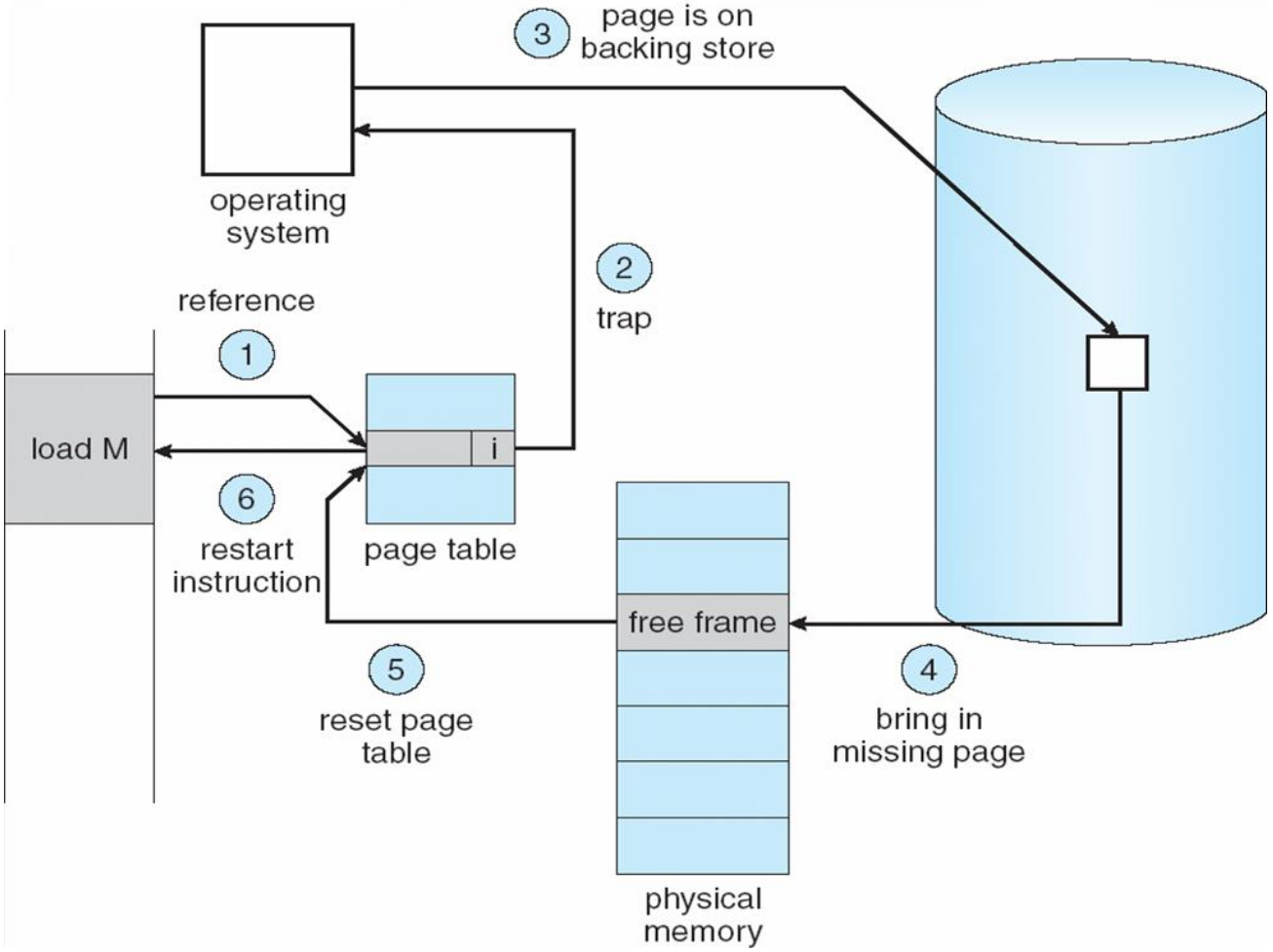
Recap: Demand Paging

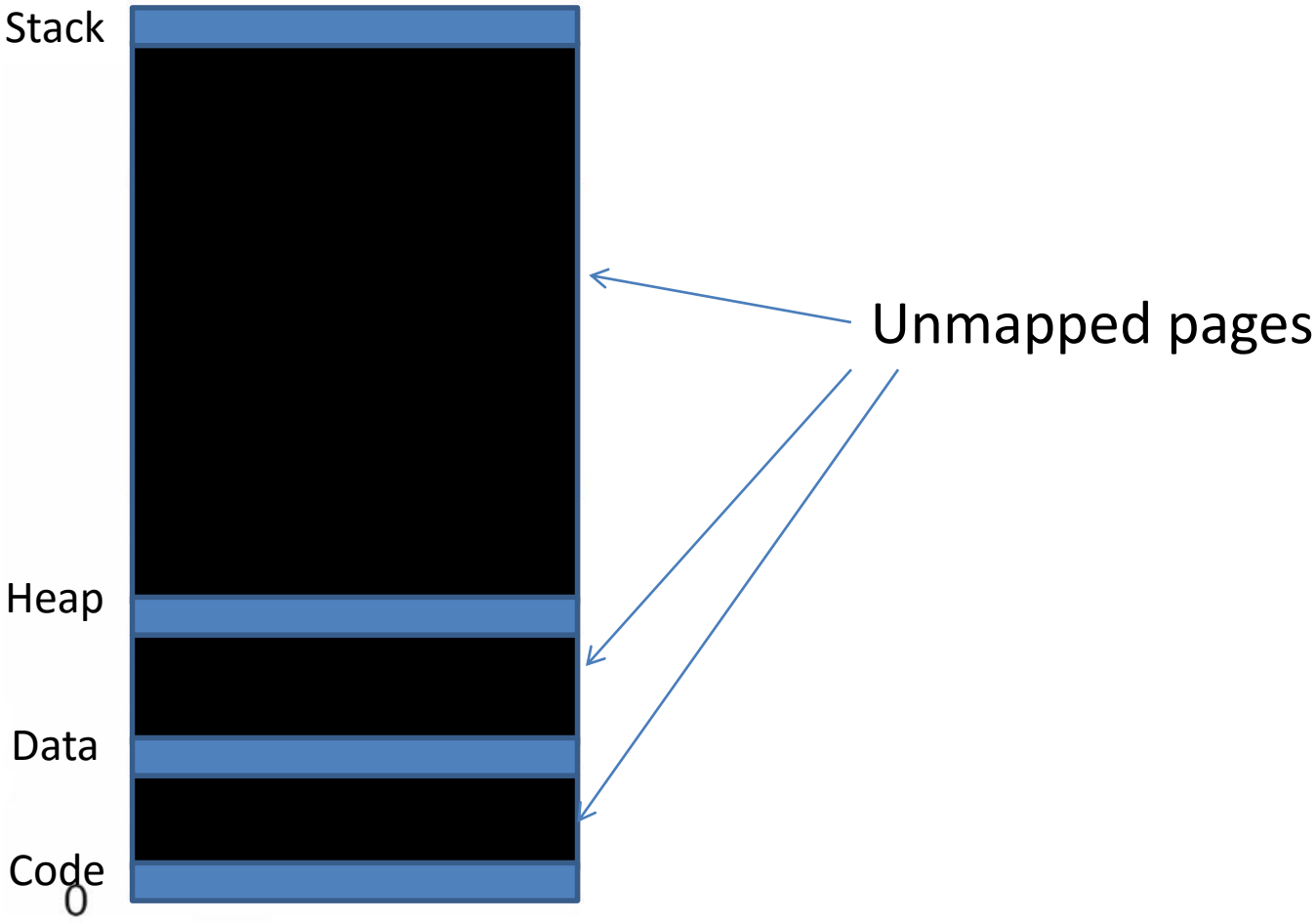
- Idea: instead of keeping the entire memory pages in memory all the time, keep only part of them on a on-demand basis



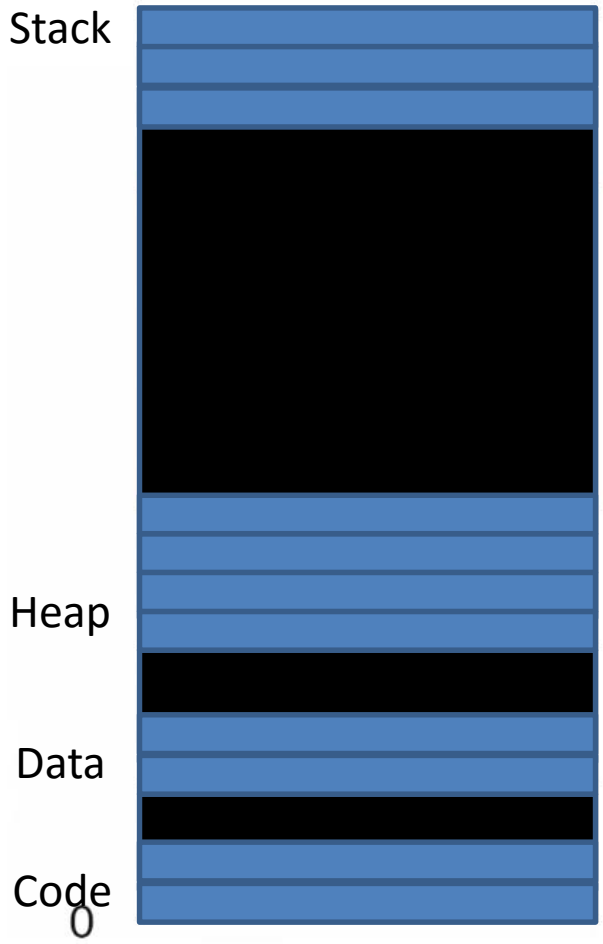
Recap: Page Fault Handling



Recap: Starting Up a Process



Recap: Starting Up a Process

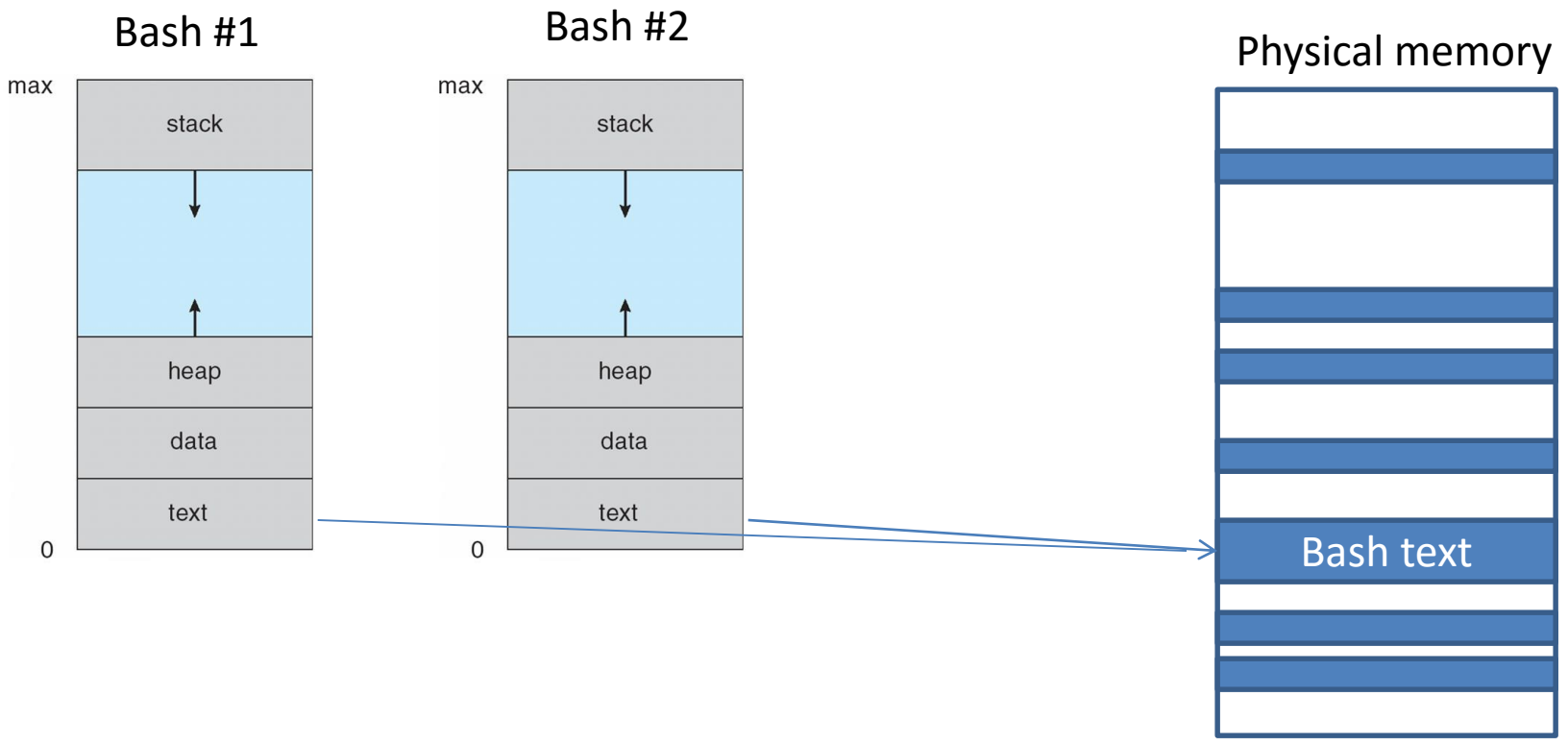


Over time, more pages are mapped as needed

Anonymous Page

- An executable file contains code (binary)
  - So we can read from the executable file
- What about heap?
  - No backing storage (unless it is swapped out later)
  - Simply map a new free page (anonymous page) into the address space

Program Binary Sharing



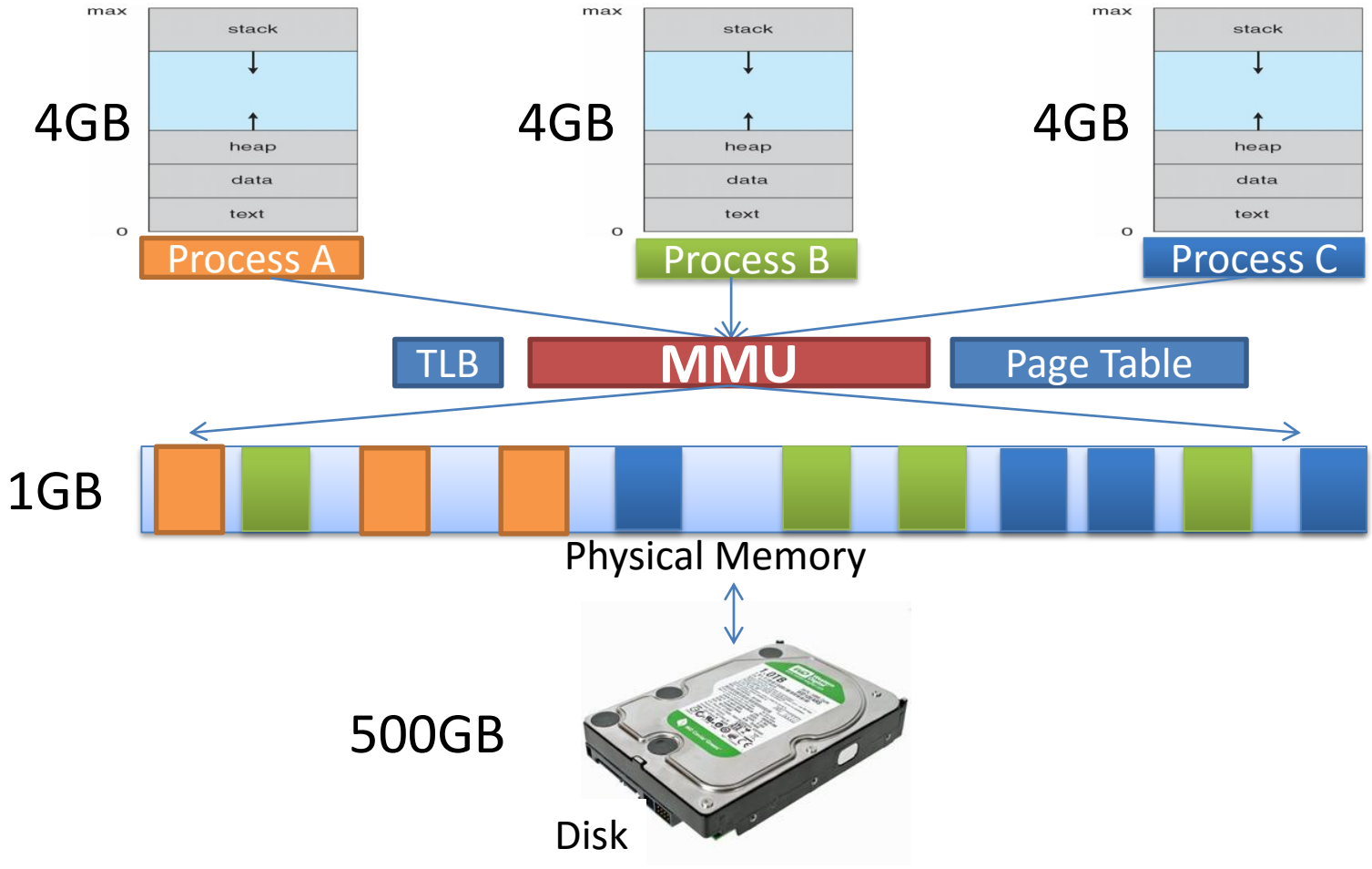
- Multiple instances of the same program
  - E.g., 10 bash shells

Concepts to Learn

- Page replacement/swapping
- Thrashing

Memory Size Limit?

- Demand paging → **illusion of infinite memory**



Illusion of Infinite Memory

- Demanding paging
  - Allows more memory to be allocated than the size of physical memory
  - Uses memory as **cache** of disk

- What to do when memory is full?
  - On a page fault, there's no free page frame
  - Someone (page) must go (be evicted)

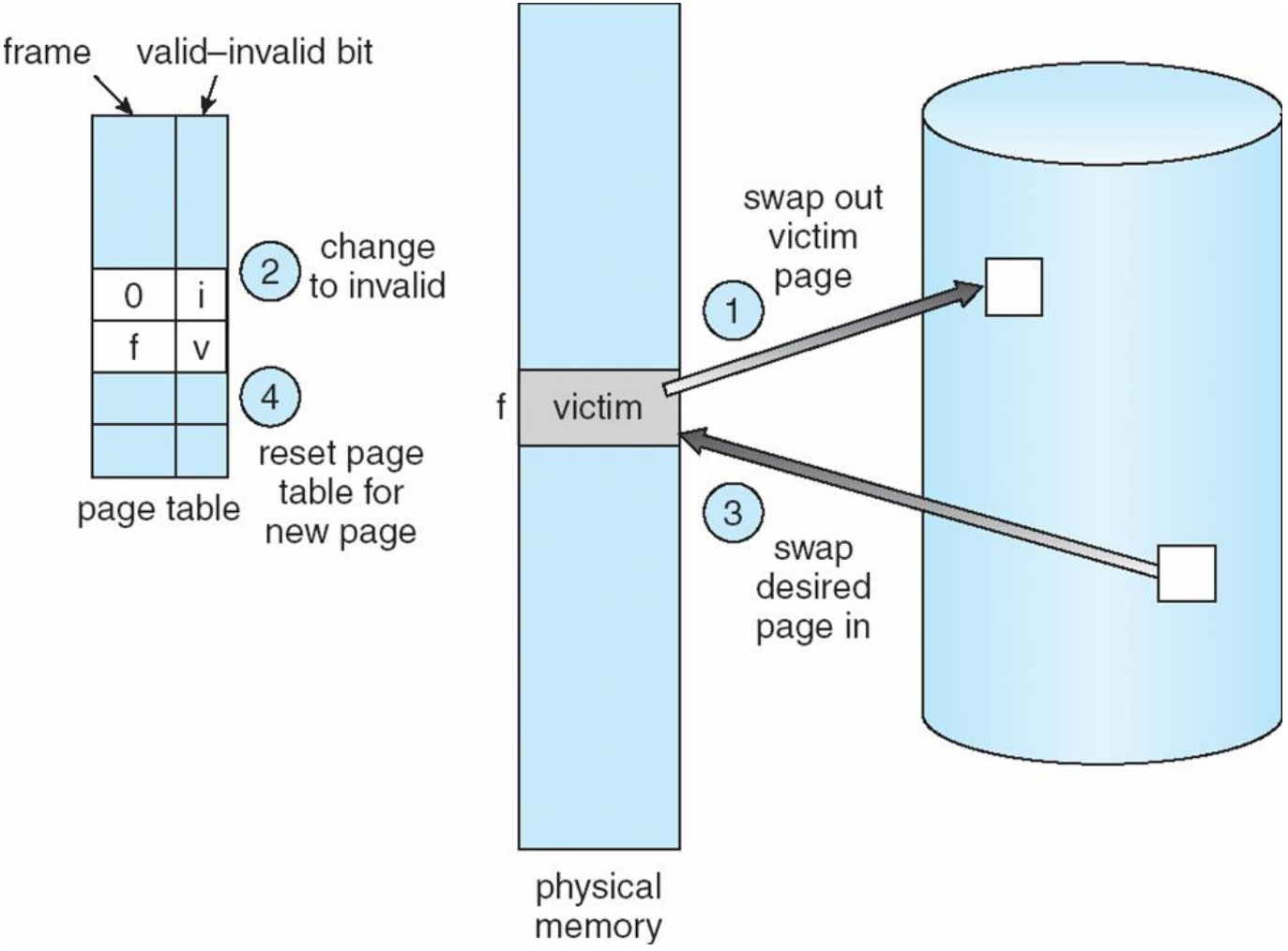
Recap: Page Fault

- On a page fault
  - Step 1: allocate a free page frame
  - Step 2: bring the stored page on disk (if necessary)
  - Step 3: update the PTE (mapping and valid bit)
  - Step 4: restart the instruction

Page Replacement Procedure

- On a page fault
  - Step 1: allocate a free page frame
    - If there's a free frame, use it
    - If there's no free frame, choose a **victim frame** and evict it to disk (if necessary) → **swap-out**
  - Step 2: bring the stored page on disk (if necessary)
  - Step 3: update the PTE (mapping and valid bit)
  - Step 4: restart the instruction

Page Replacement Procedure



Page Replacement Policy

- Which page (a.k.a. victim page) to go?
  - What if the evicted page is needed soon?
    - A page fault occurs, and the page will be re-loaded
  - Important decision for performance reason
    - The cost of choosing wrong page is very high: disk accesses

Page Replacement Policies

- FIFO (First In, First Out)
  - Evict the oldest page first.
  - Pros: fair
  - Cons: can throw out frequently used pages
- Optimal
  - Evict the page that will not be used for the longest period
  - Pros: optimal
  - Cons: you need to know the future

Page Replacement Policies

- Random
  - Randomly choose a page
  - Pros: simple. TLB commonly uses this method
  - Cons: unpredictable
- LRU (Least Recently Used)
  - Look at the past history, choose the one that has not been used for the longest period
  - Pros: good performance
  - Cons: complex, requires h/w support