Amirkabir University of Technology
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Operating Systems

Virtual Memory

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Chapter 10: Virtual Memory

- Background
- Demand Paging
- Copy-on-Write
- Page Replacement

Objectives

- Define virtual memory and describe its benefits.
- Illustrate how pages are loaded into memory using demand paging.
- Apply the FIFO, optimal, and LRU page-replacement algorithms.

Background

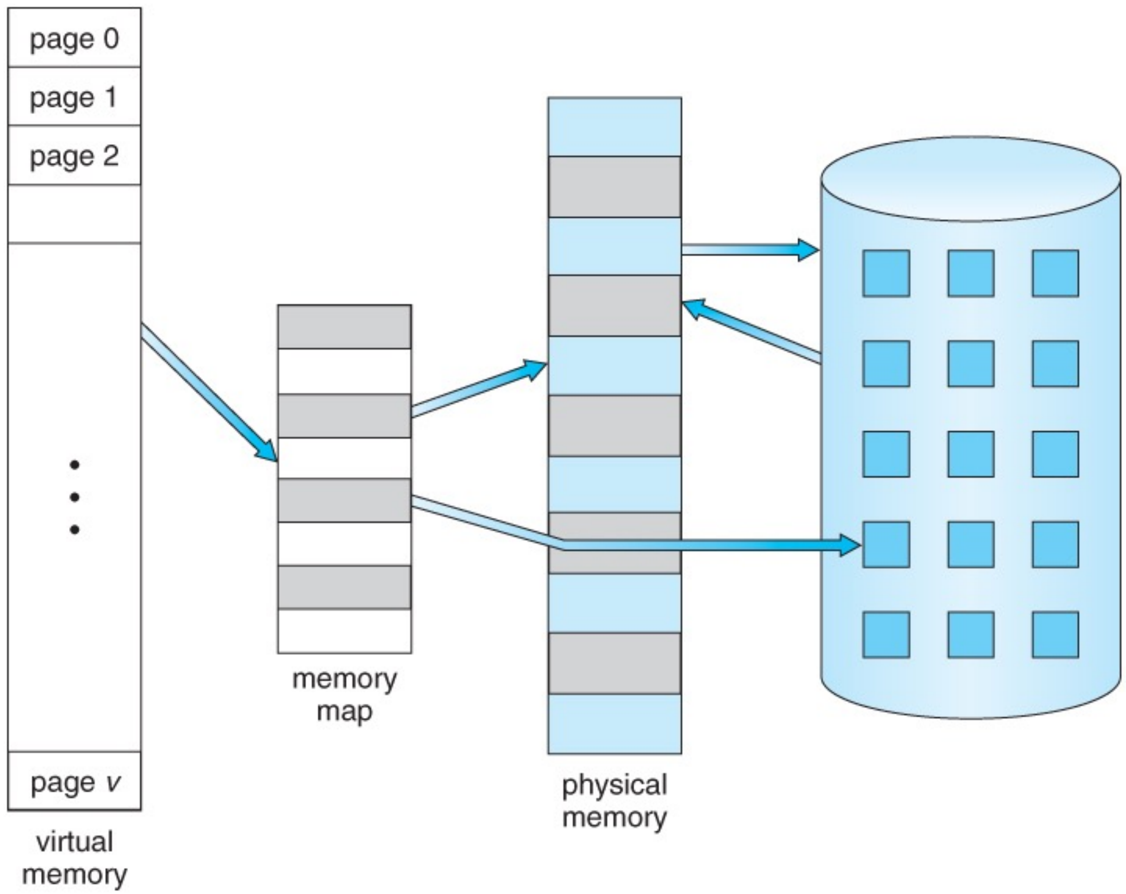
- Code needs to be in memory to execute, **but entire program rarely used**
  - Error code, unusual routines, large data structures

```
try {

  //code may cause exception
}

catch (Exception e) {

  // code that handles an exception

}

finally {

   // default piece of code

}
```

- Entire program code not needed at same time

Benefits of Executing Partially-load Programs

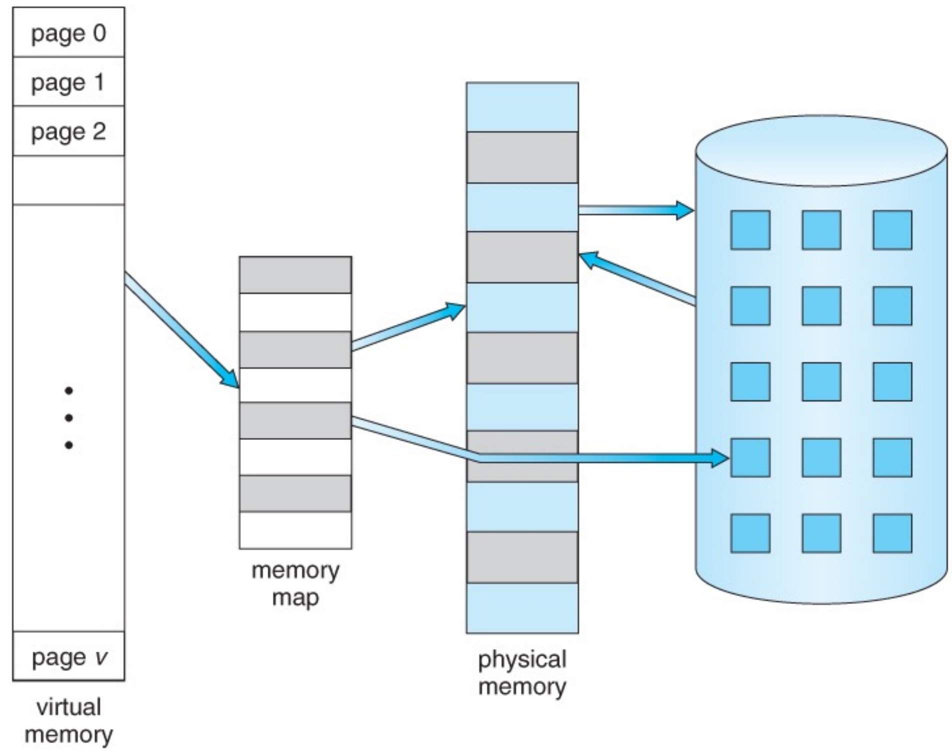
- Program no longer constrained by limits of physical memory



https://www.cs.uic.edu/~jbell/CourseNotes/OperatingSystems/9_VirtualMemory.html

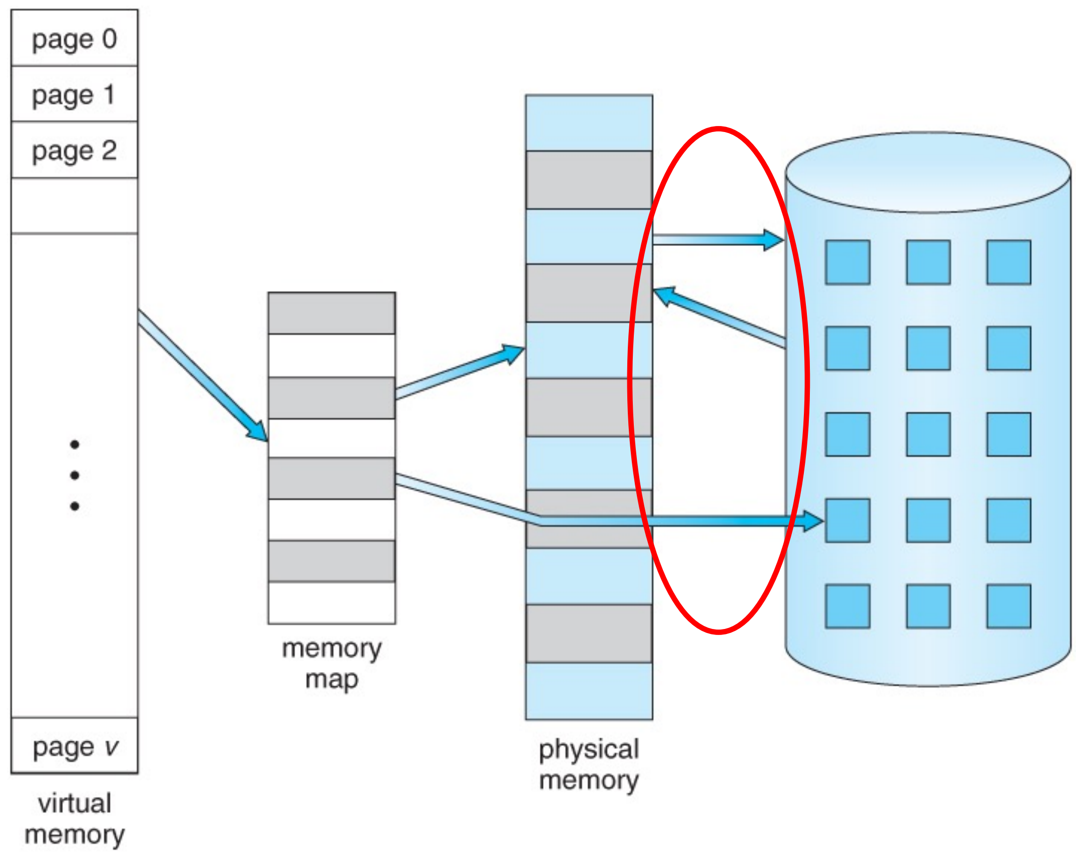
Benefits of Executing Partially-load Programs

- Each program takes less memory while running -> **more programs run at the same time.**
  - Increased CPU utilization and throughput with no increase in response time or turnaround time.



Benefits of Executing Partially-load Programs

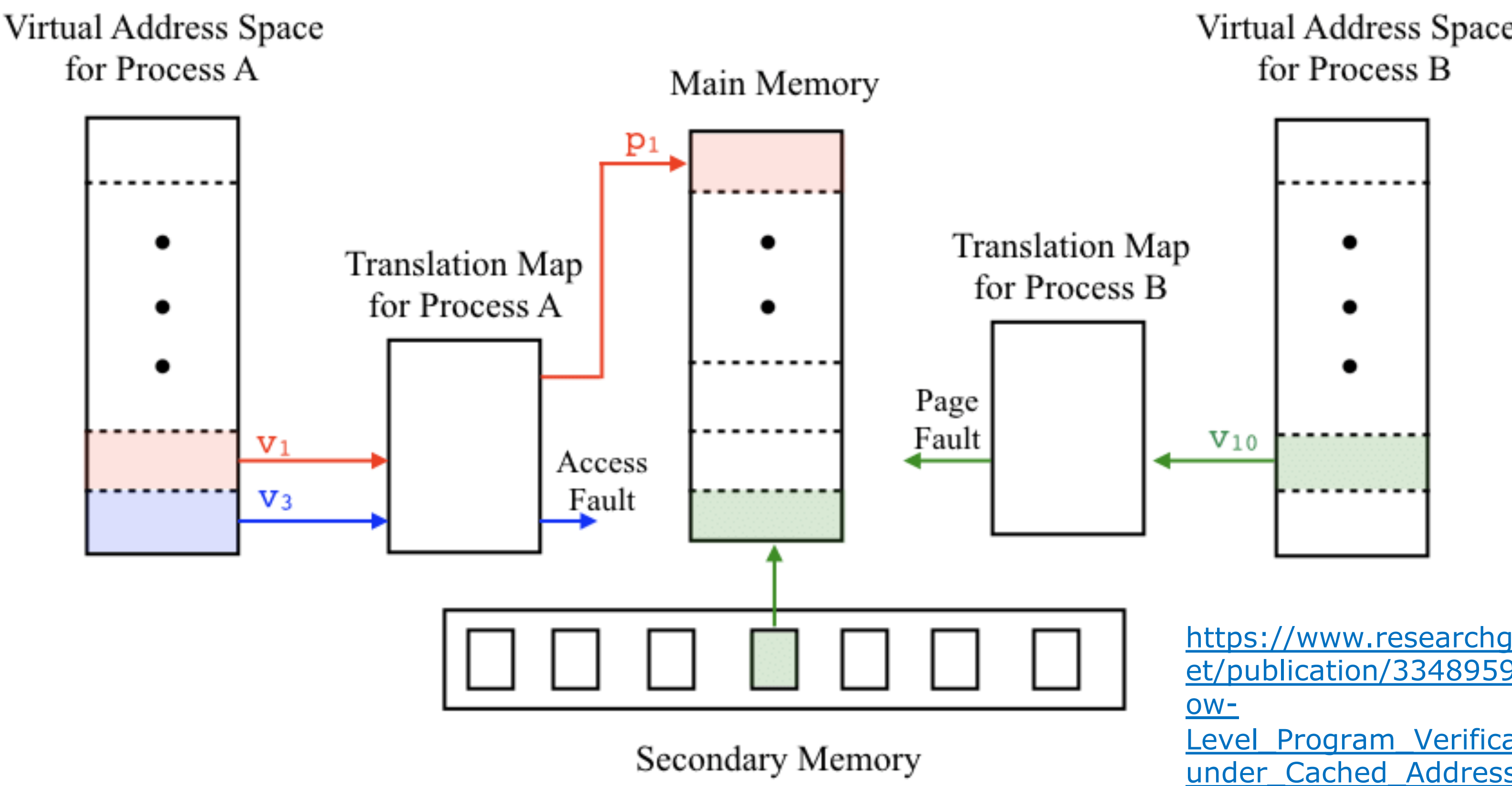
- Less I/O needed to load or swap programs into memory -> **each user program runs faster.**



Virtual memory

separation of user logical memory from physical memory

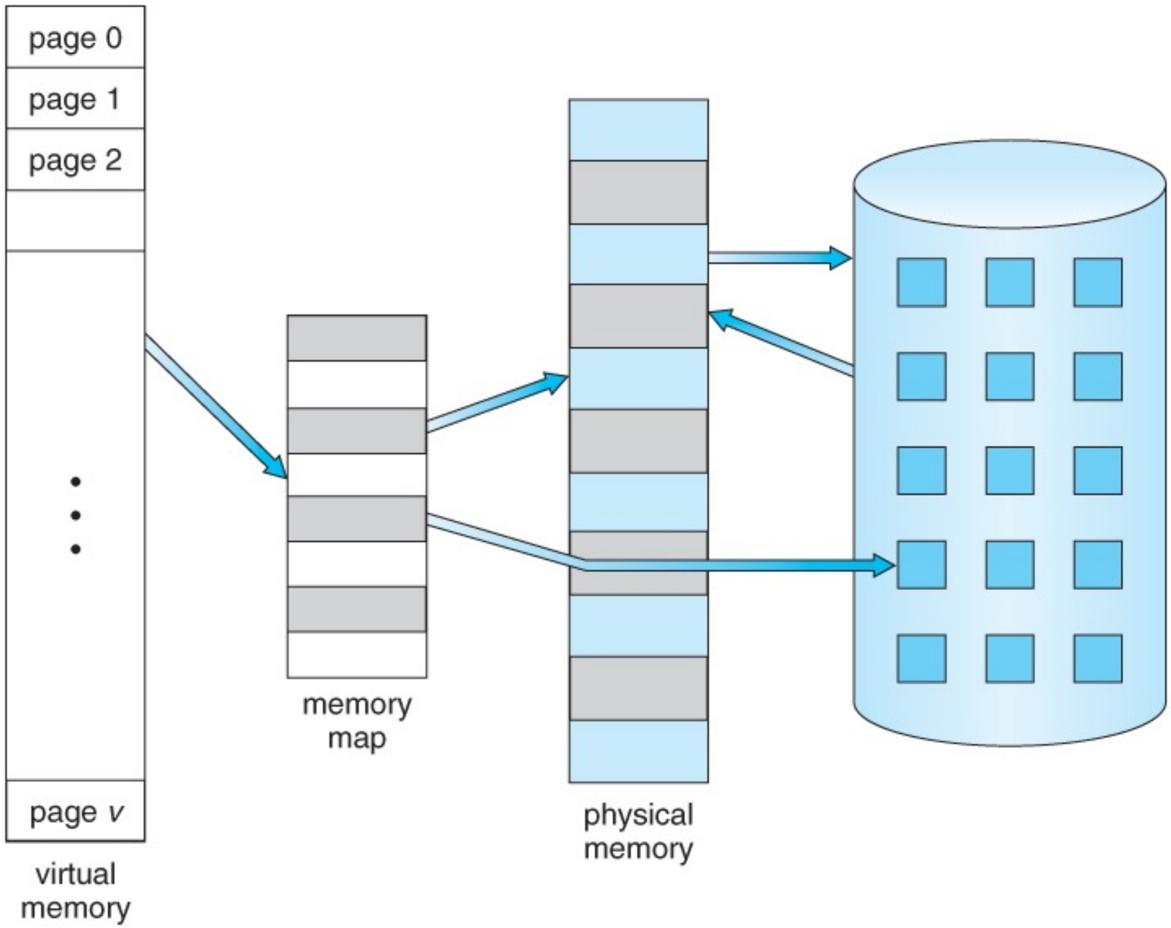
Only part of the program needs to be in memory for execution



https://www.researchgate.net/publication/334895925_Low-Level_Program_Verification_under_Cached_Address_Translation/figures?lo=1

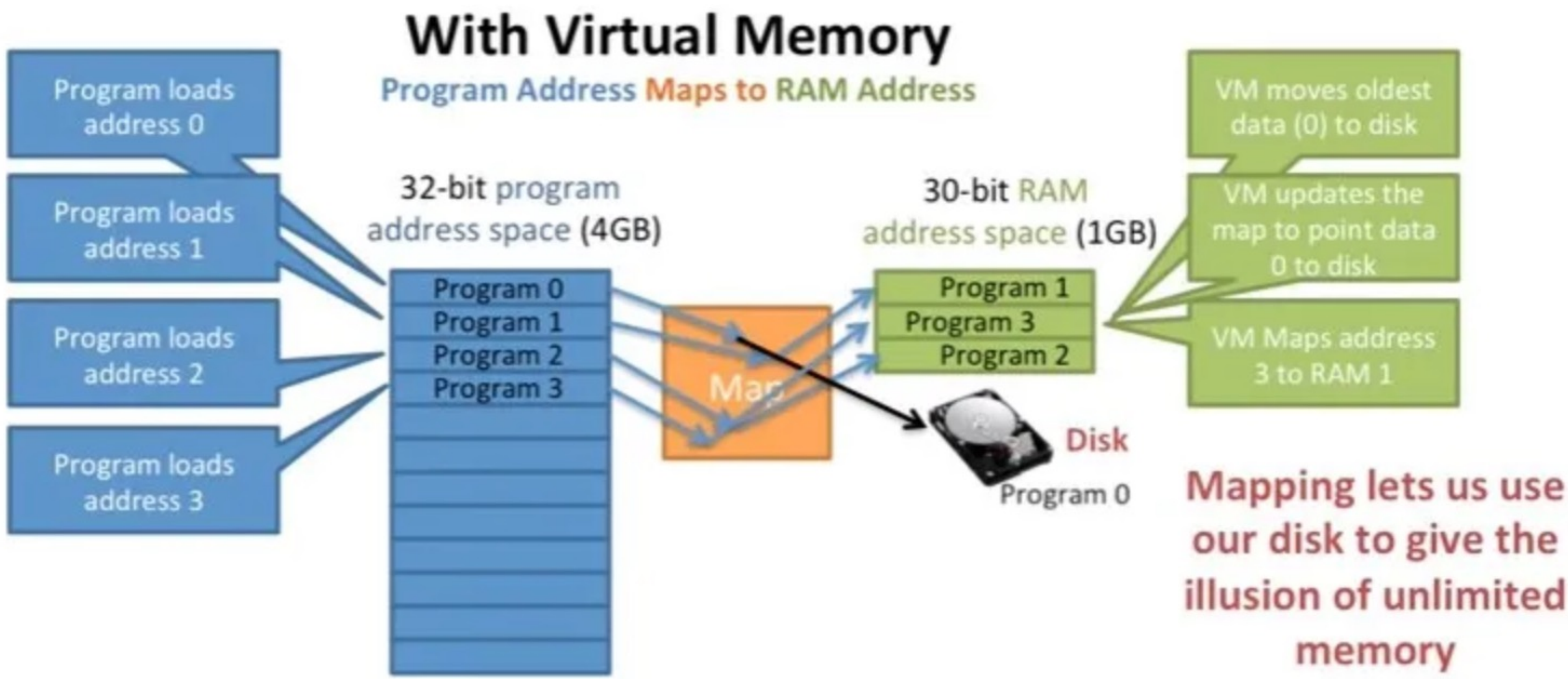
Benefits of Virtual memory

- Logical address space can be much larger than physical address space



Benefits of Virtual memory

- Allows address spaces to be shared by several processes



Benefits of Virtual memory

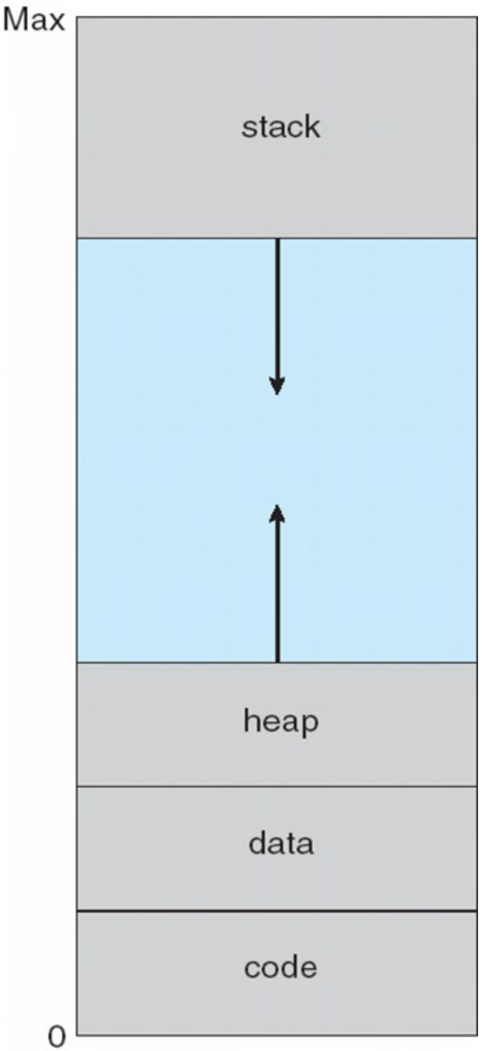
- Allows for more efficient process creation
- More programs running concurrently
- Less I/O needed to load or swap processes

Virtual memory (cont.)

- **Virtual address space:**
  - Logical view of how process is stored in memory
  - Usually start at address 0, contiguous addresses until end of space
  - Meanwhile, physical memory organized in page frames
  - MMU must map logical to physical
- Virtual memory can be implemented via:
  - Demand **paging**
  - Demand **segmentation**

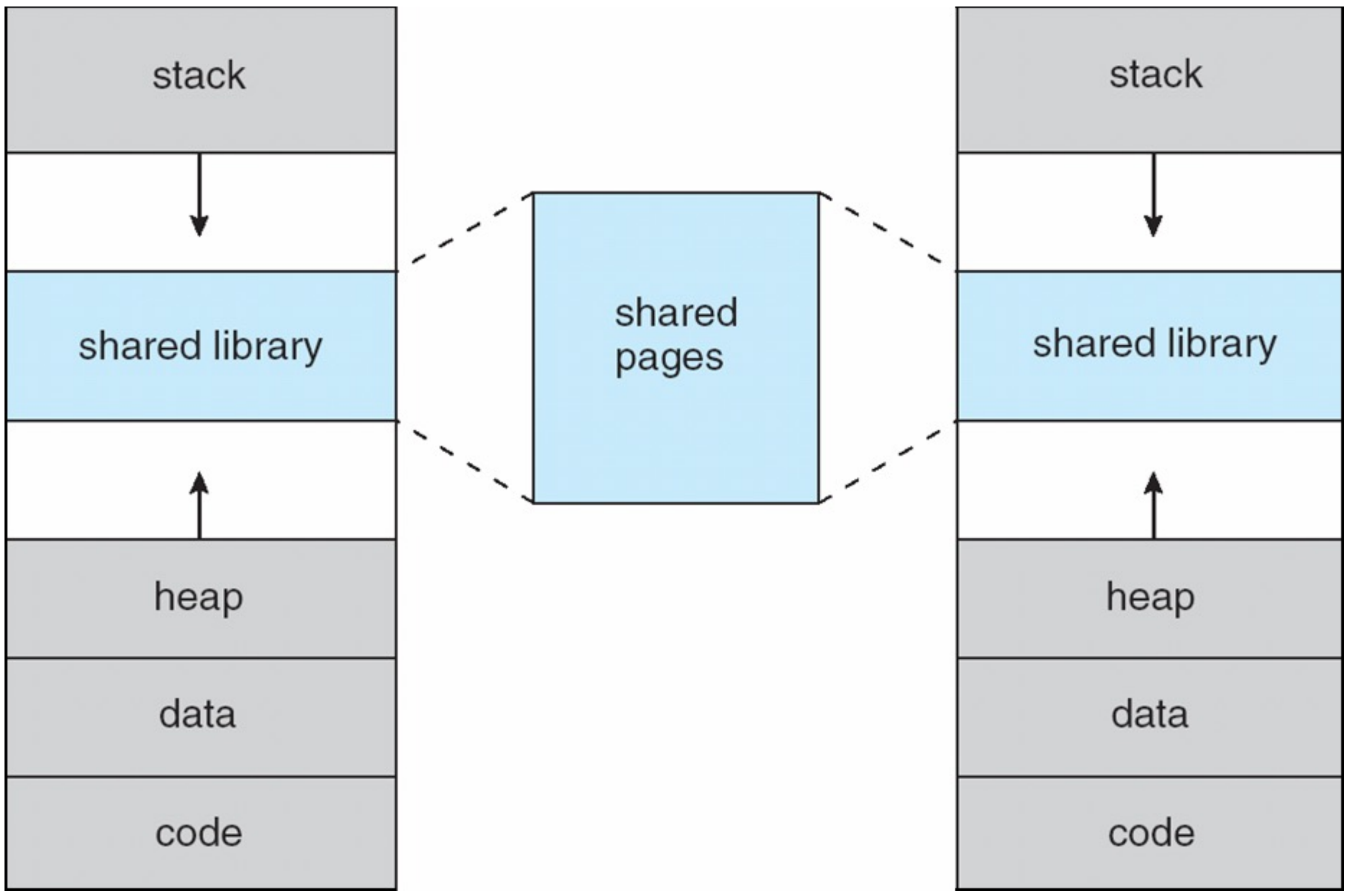
Virtual-address Space

- Usually design logical address space for stack to start at Max logical address and grow “down” while heap grows “up”
  - Maximizes address space use
  - Unused address space between the two is hole
  - No physical memory needed until heap or stack grows to a given new page



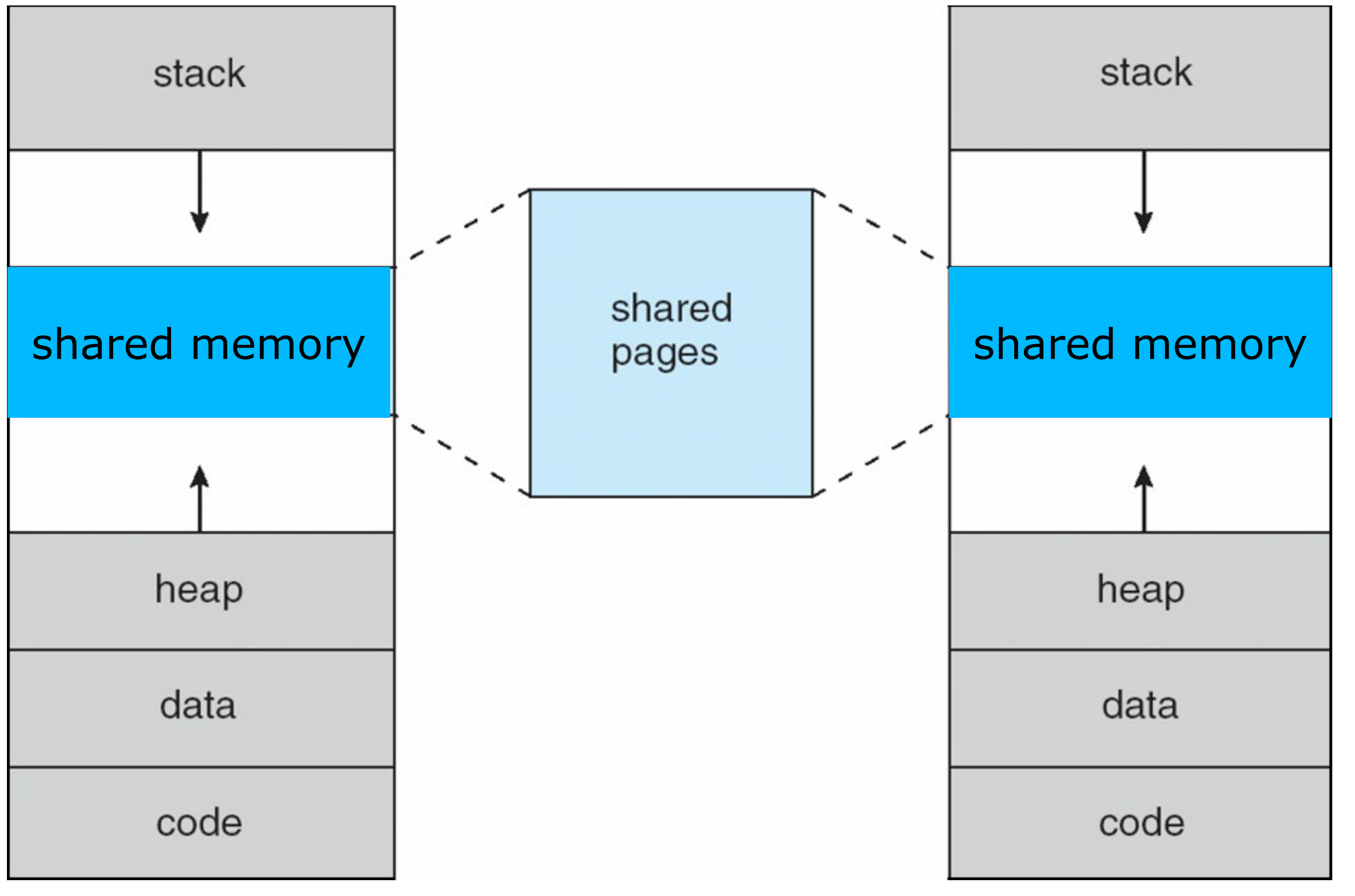
Virtual-address Space (cont.)

- System libraries shared via mapping into virtual address space



Virtual-address Space (cont.)

- Shared memory by mapping pages read-write into virtual address space



Virtual-address Space (cont.)

- Pages can be shared during `fork()`, speeding process creation
- How?

Demand Paging

- Could bring entire process into memory at load time

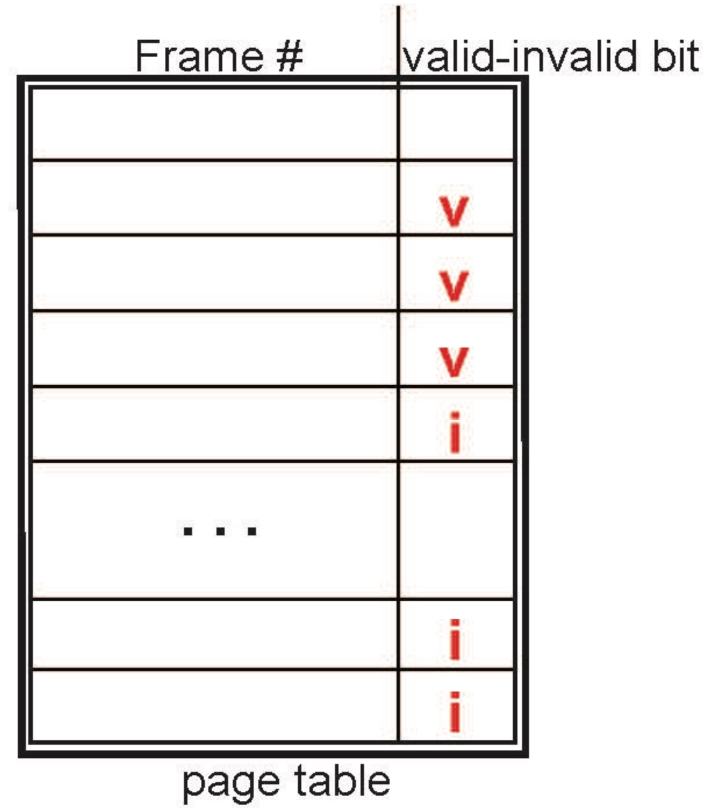
- Or bring **a page into memory only when it is needed**
  - Less I/O needed, no unnecessary I/O
  - Less memory needed
  - Faster response
  - More users

Basic Concepts

- If pages needed are already **memory resident**
  - No difference from non demand-paging
- If page needed and not memory resident
  - Need to detect and load the page into memory from storage
    - Without changing program behavior
    - Without programmer needing to change code

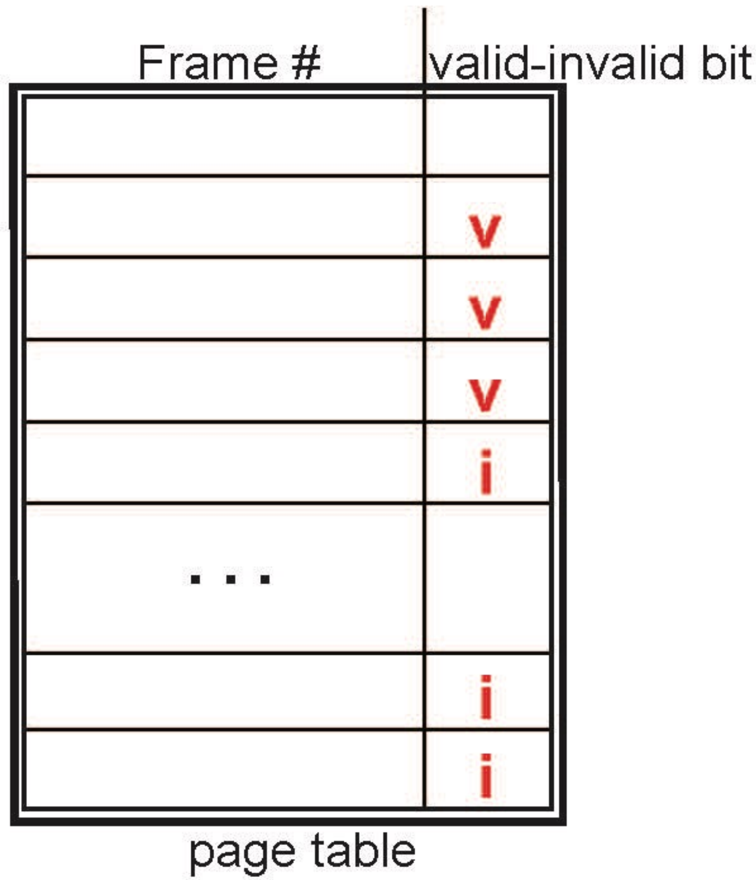
Valid-Invalid Bit

- With each page table entry a valid–invalid bit is associated
  ($v \Rightarrow$ in-memory – memory resident, $i \Rightarrow$ not-in-memory)
- Initially valid–invalid bit is set to **i** on all entries
- Example of a page table snapshot:

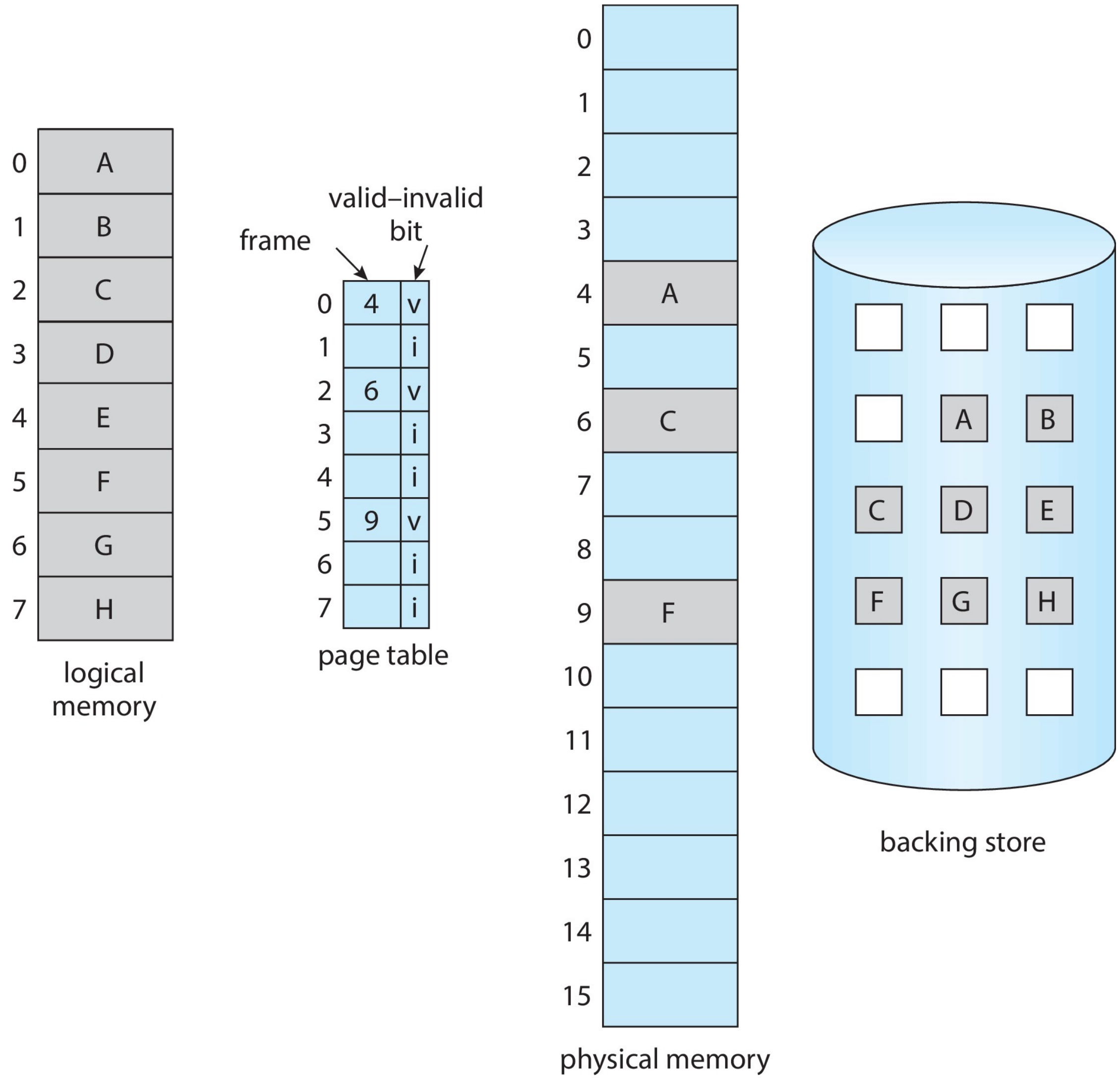


Valid-Invalid Bit

- During MMU address translation, if valid–invalid bit in page table entry is **i** ⇒ **page fault**



Page Table When Some Pages Are Not in Main Memory



Steps in Handling Page Fault

1. If there is a reference to a page, first reference to that page will trap to operating system
   - Page fault

2. Operating system looks at another table to decide:
   - Invalid reference $\Rightarrow$ abort
   - Just not in memory

...

Steps in Handling Page Fault

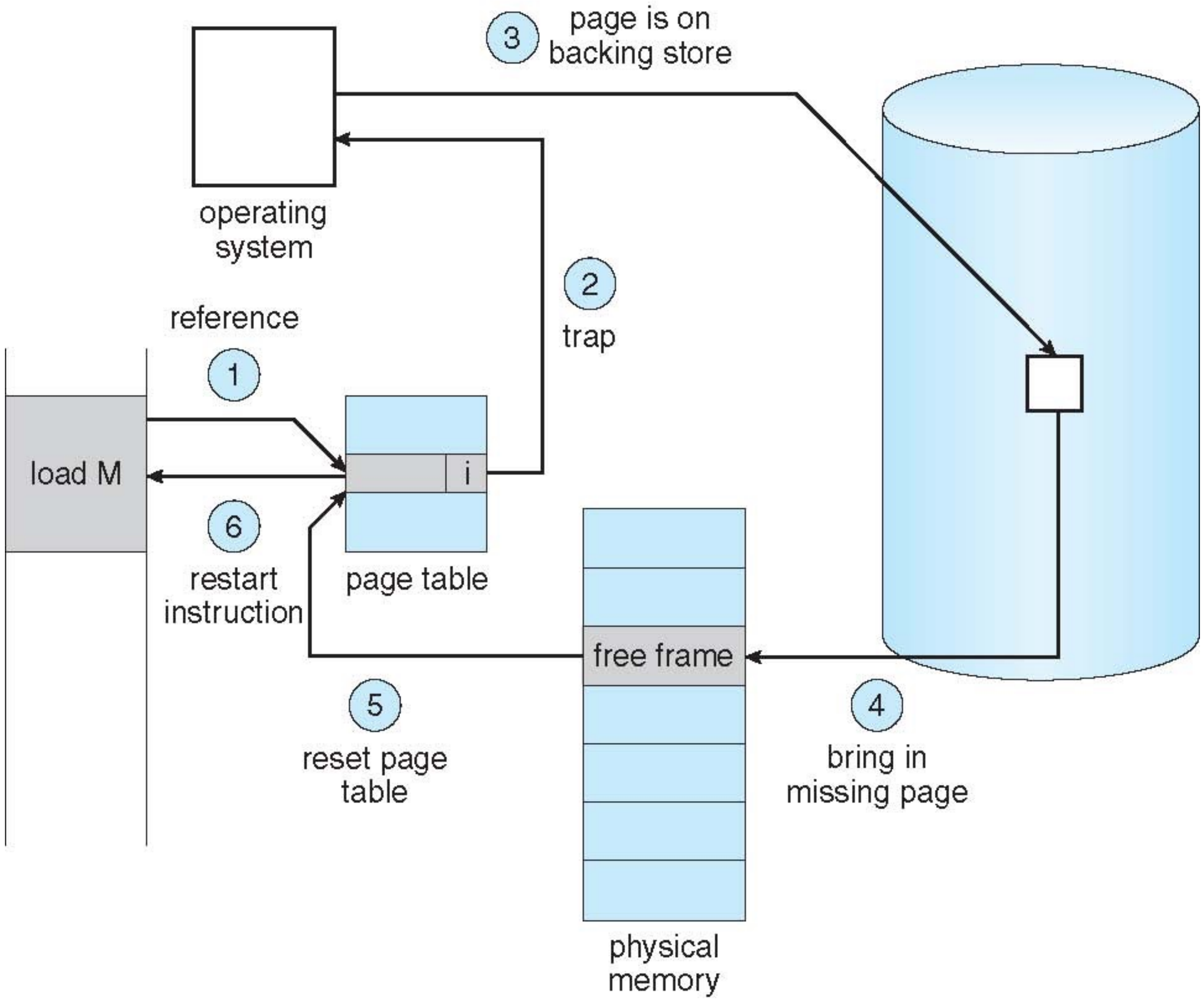
…

3. Find free frame
4. Swap page into frame via scheduled disk operation
5. Reset tables to indicate page now in memory

   Set validation bit = v

6. Restart the instruction that caused the page fault

Steps in Handling a Page Fault (cont.)



Aspects of Demand Paging

- Extreme case – start process with ***no* pages in memory**
  - OS sets instruction pointer to first instruction of process:

    non-memory-resident -> page fault

  - And for every other process pages on first access
  - **Pure demand paging**

Aspects of Demand Paging (cont.)

- …
- Actually, a given instruction could access multiple pages -> multiple page faults
  - Consider fetch and decode of instruction which adds 2 numbers from memory and stores result back to memory
  - Pain decreased because of **locality of reference**

Locality of reference

- Page faults are expensive!
- Thrashing: Process spends most of the time paging in and out instead of executing code.
- Most programs display a pattern of behavior called the principle of locality of reference.

Locality of Reference: A program that references a location *n* at some point in time is likely to reference the same location *n* and locations in the immediate vicinity of *n* in the near future.

Source: https://people.engr.tamu.edu/bettati/Courses/410/2017A/Slides/virtmemory.pdf

Aspects of Demand Paging

- …
- …
- Hardware support needed for demand paging
  - Page table with valid / invalid bit
  - …

Performance of Demand Paging

- Three major activities
  - **Service the interrupt** – careful coding means just several hundred instructions needed
  - **Read the page** – lots of time
  - **Restart the process** – again just a small amount of time

Performance of Demand Paging (cont.)

- ...
- Page Fault Rate $0 \le p \le 1$
  - if $p = 0$ no page faults
  - if $p = 1$, every reference is a fault
- Effective Access Time (EAT)

  EAT = $(1 - p)$ x memory access + p (page fault overhead)

Demand Paging Example

- Memory access time = 200 nanoseconds
- Average page-fault service time = 8 milliseconds
- EAT = (1 – p) x 200 + p (8 milliseconds)

  = (1 – p) x 200 + p x 8,000,000

  = 200 + p x 7,999,800
- If one access out of 1,000 causes a page fault, then

  EAT = 8.2 microseconds.

  This is a slowdown by a factor of 40!!

Demand Paging Example (cont.)

- ....
- If want performance degradation < 10 percent
  - 220 > 200 + 7,999,800 x p

    20 > 7,999,800 x p
  - p < .0000025
  - < one page fault in every 400,000 memory accesses