Design and Analysis of Operating Systems CSCI 3753

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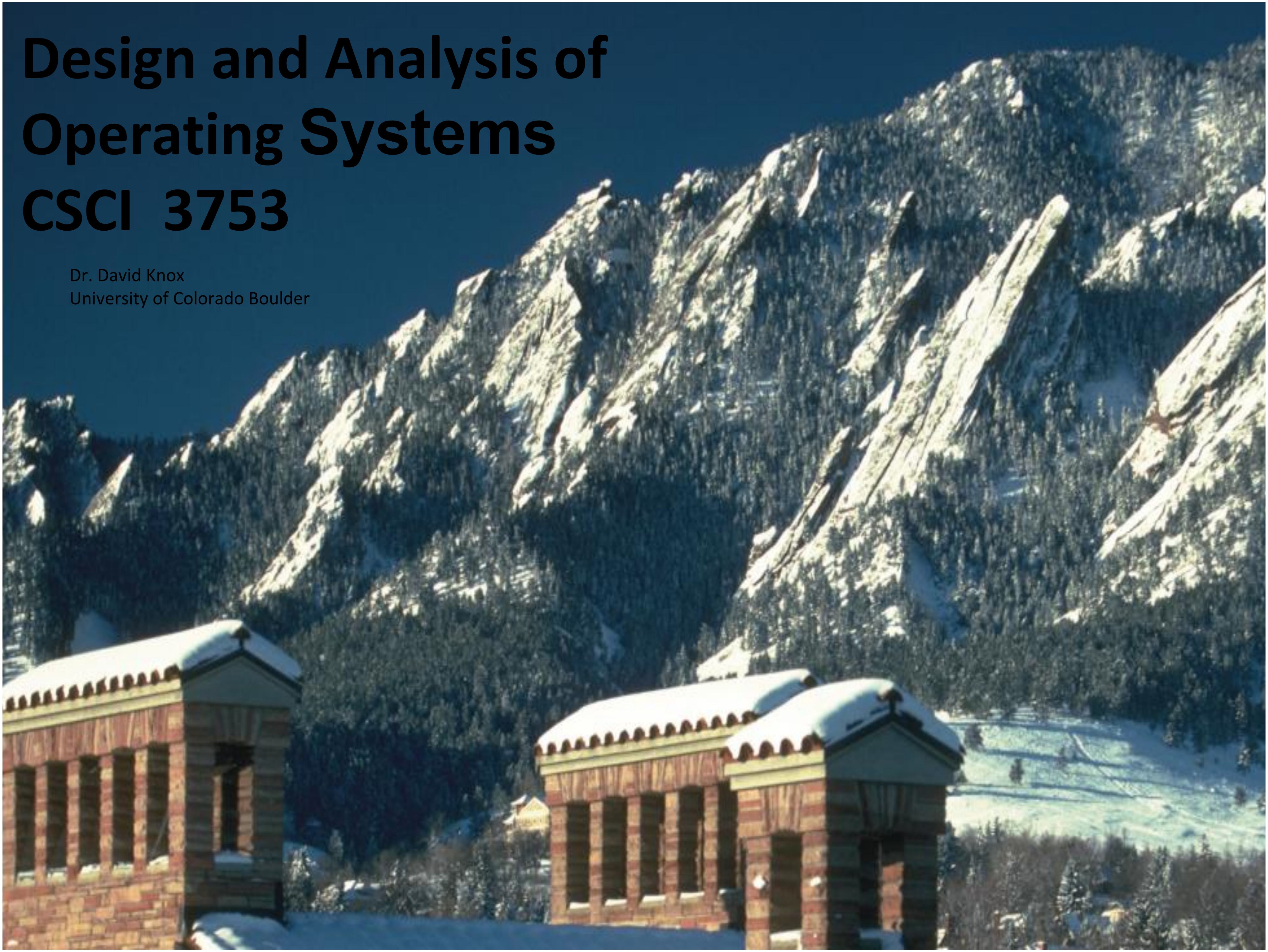

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Memory Management
Virtual Memory

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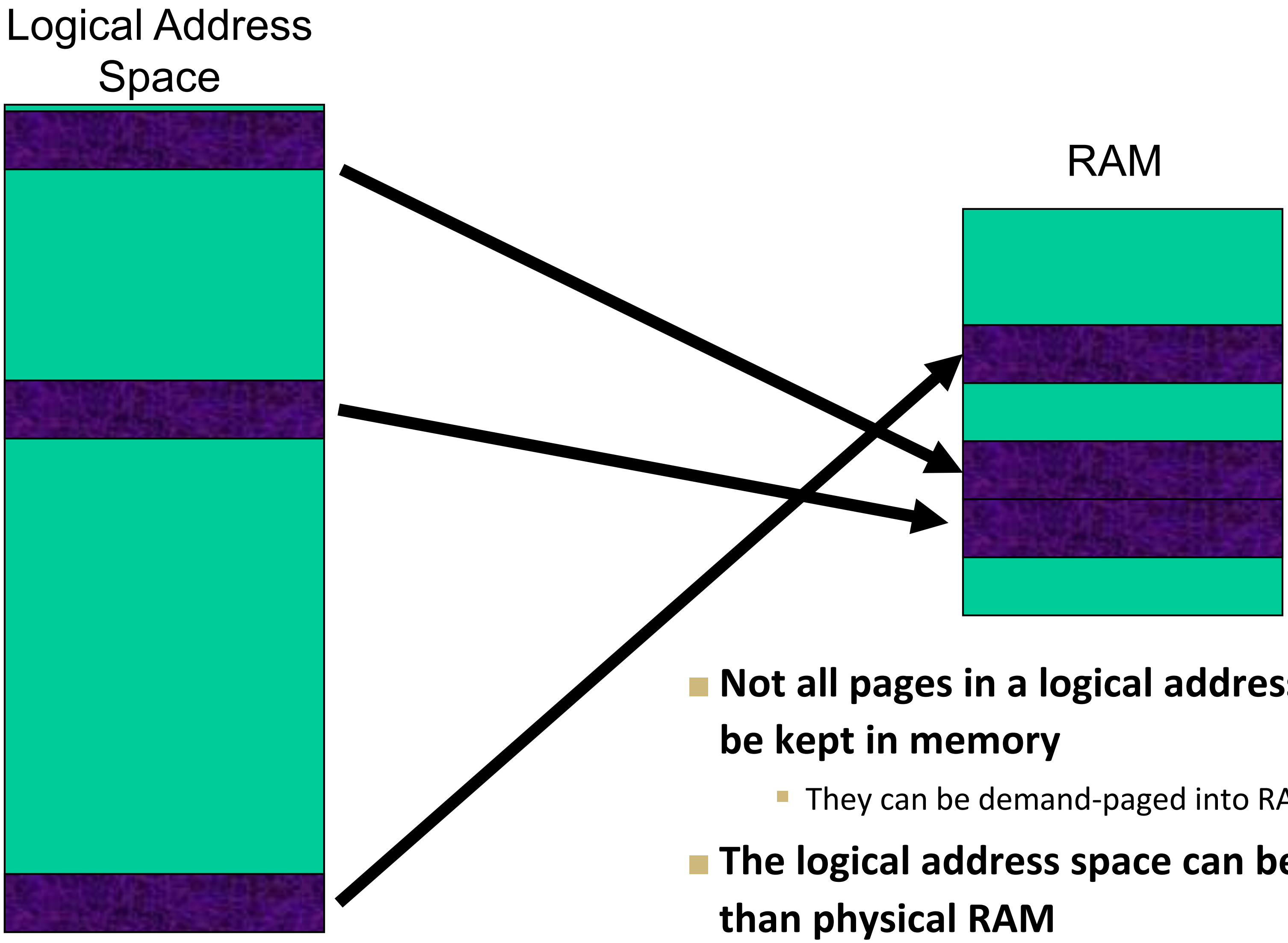


- **Not all pages in a logical address space need to be kept in memory**
  - They can be demand-paged into RAM
- **The logical address space can be much larger than physical RAM**
  - *Swap in the pages needed, when needed*

On-Demand Paging

- **Page tables may be large, consuming much RAM**

- **Key observation: not all pages in a logical address space need to be kept in memory**
  - in the simplest case, just keep the current page where the PC is executing

  - all other pages could be on disk

  - when another page is needed, retrieve the page from disk and place in memory before executing
    - this would be costly and slow, because it would happen every time that a page different from the current one is needed

On-Demand Paging

- **Instead of just keeping one page, keep a *subset* of a process's pages in memory**
  - Load just what you need, not the entire address space
  - use memory as a cache of frequently or most recently used pages
  - rely on a program's behavior to exhibit locality of reference
    - if an instruction or data reference in a page was previously invoked, then that page is likely to be referenced again in the near future

On-Demand Paging

- **Most programs exhibit some form of locality**
  - looping locally through the same set of instructions
  - branching through the same code
  - executing linearly, the next instruction is typically the next one immediately after the previous instruction, rather than some random jump
- **Thus process execution revisits pages already stored in memory**
  - so you don't have to go to disk each time the program counter (PC) jumps to a different page

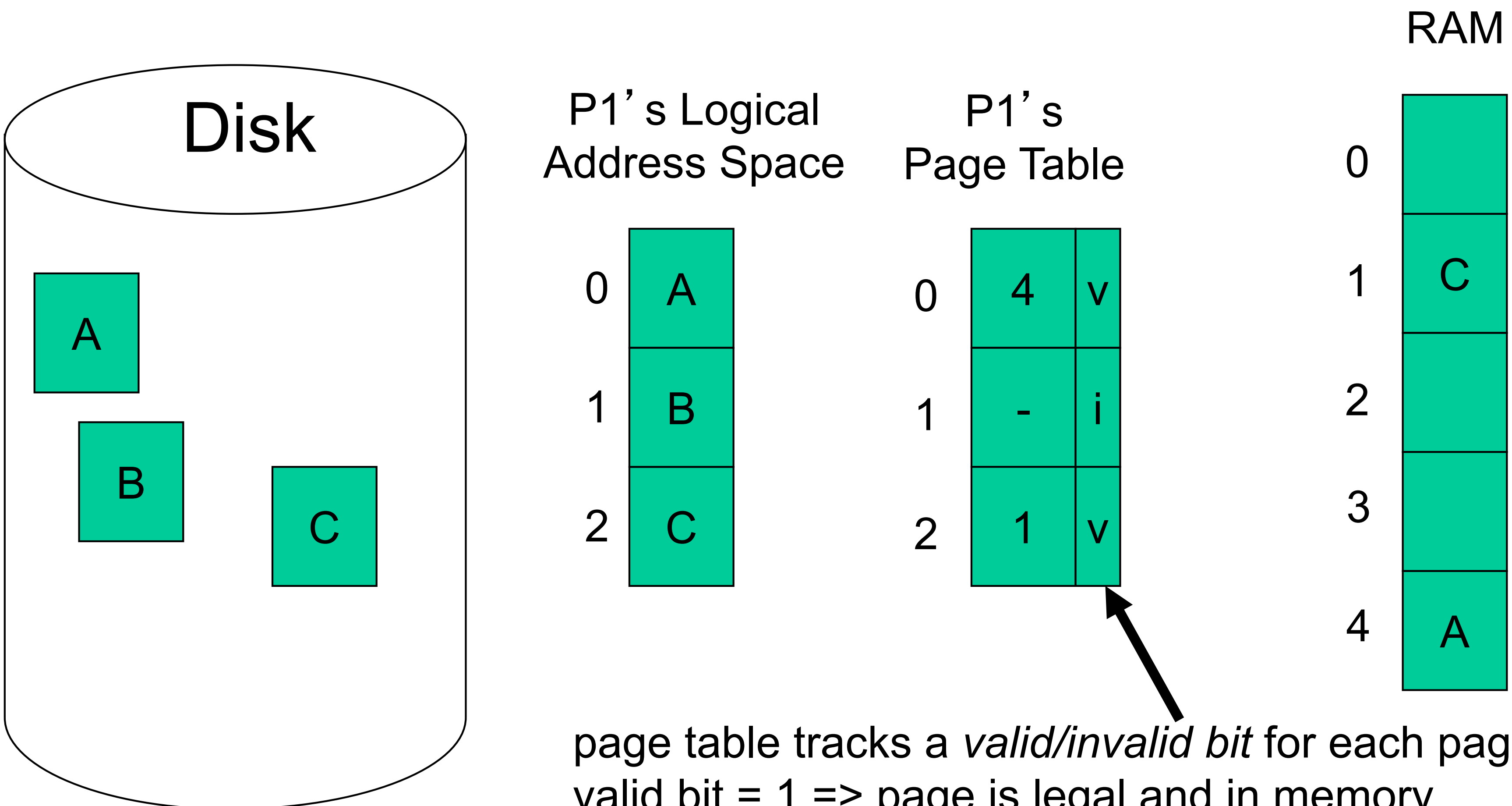
On-Demand Paging

- **On-demand paging is used to page in new pages from disk to RAM**
  - only when a page is needed is it loaded into memory from disk

- **Can page in an entire process on demand:**
  - starting with “zero” pages
  - the reference to the first instruction causes the first page of the process to be loaded on demand into RAM.
  - Subsequent pages are loaded on demand into RAM as the process executes.

On-Demand Paging

- **On-demand paging loads a page from disk into RAM only when needed**
  - in the example below, pages A and C are in memory, but page B is not



page table tracks a *valid/invalid bit* for each page
valid bit = 1 => page is legal and in memory

Virtual Memory Advantages

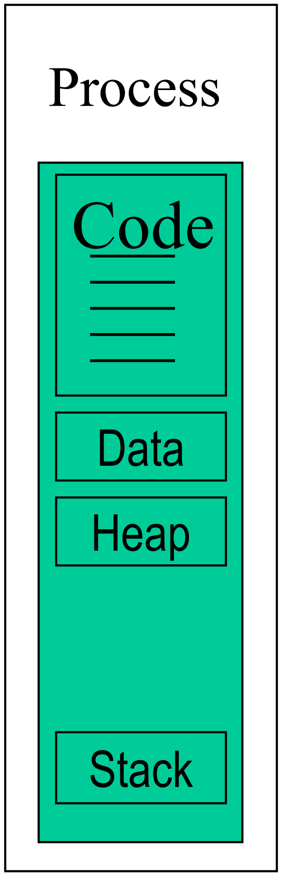
1. **Virtual address space can now exceed physical RAM**
   - Only a subset (most demanded) of pages are kept in RAM
   - We have decoupled virtual memory from physical memory
2. **Fit many more processes in memory**

Virtual Memory Advantages

3. **Decreases swap time**

   – there is less to swap

4. **Can have large sparse address spaces**
   - most of the address space is unused
   - does not taking up physical RAM
   - a large heap and stack that is mostly unused/empty won't take up any actual RAM until needed



On-Demand Paging

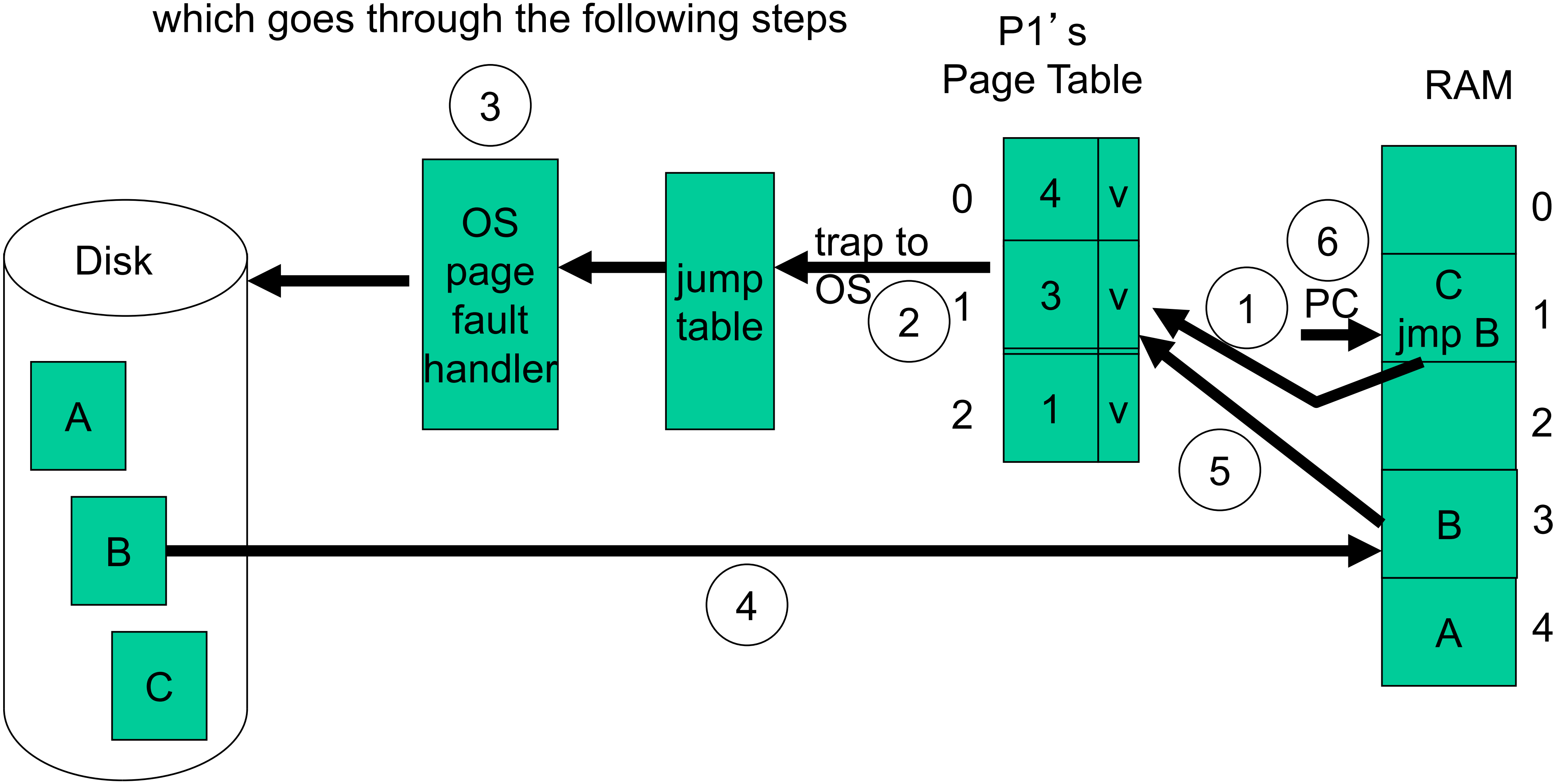
- **Open questions to be answered:**
  - how is a needed page loaded into memory from disk?
  - how many pages in memory should be allocated to a process?
  - if the # of pages allocated to a process is exceeded, i.e. the cache is full, then how do you choose which page to replace?

Virtual Memory

- **Page-fault steps to load a page into RAM:**
  1. MMU detects a page is not in memory (invalid bit set) which causes a *page-fault trap* to OS
  2. OS saves registers and process state. Determines that the fault was due to demand paging and jumps to page fault handler
  3. *Page fault handler*
     a) If reference to page not in logical A.S. then seg fault.
     b) Else if reference to page in logical A.S., but not in RAM, then load page
     c) OS finds a free frame
     d) OS schedules a disk read. Other processes may run in meantime.
  4. Disk returns with interrupt when done reading desired page. OS writes desired page into free frame
  5. OS updates page table, sets valid bit of page and its physical location
  6. Restart interrupted instruction that caused the page fault

Virtual Memory

On-demand paging causes a page fault, which goes through the following steps



Virtual Memory

- **OS can retrieve the desired page from**
  - file system
  - swap space/backing store
    - faster, avoids overhead of file system lookup
- **pages can be in swap space because:**
  - the entire executable file was copied into swap space when the program was first started.
    - Avoids file system, but also allows the copied executable to be laid out contiguously on disk's swap space, for faster access to pages (no seek time)

Virtual Memory

- **pages can be in swap space because:**
  - as pages have to be replaced in RAM, they are written to swap space instead of the file system’s portion of disk.
    - The next time they’re needed, they’re retrieved quickly from swap space, avoiding a file system lookup.

Performance of On-Demand Paging

- **Want to limit the number/frequency of page faults, which cause a read from disk, which slows performance**
  - disk read is about 10 ms
  - memory read is about 10 ns
- **What is the average memory access time?**
  - average access time = p*10 ms + (1-p)*10 ns where p = probability of a page fault.
  - if p=.001, then average access time = 10 μs >> 10 ns (1000 X greater!)
  - to keep average access time within 10% of 10 ns, would need a page fault rate lower than $p<10^{-7}$
  - Reducing page fault frequency improves performance in a big way

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