Operating Systems Design
10. Memory Management: Paging

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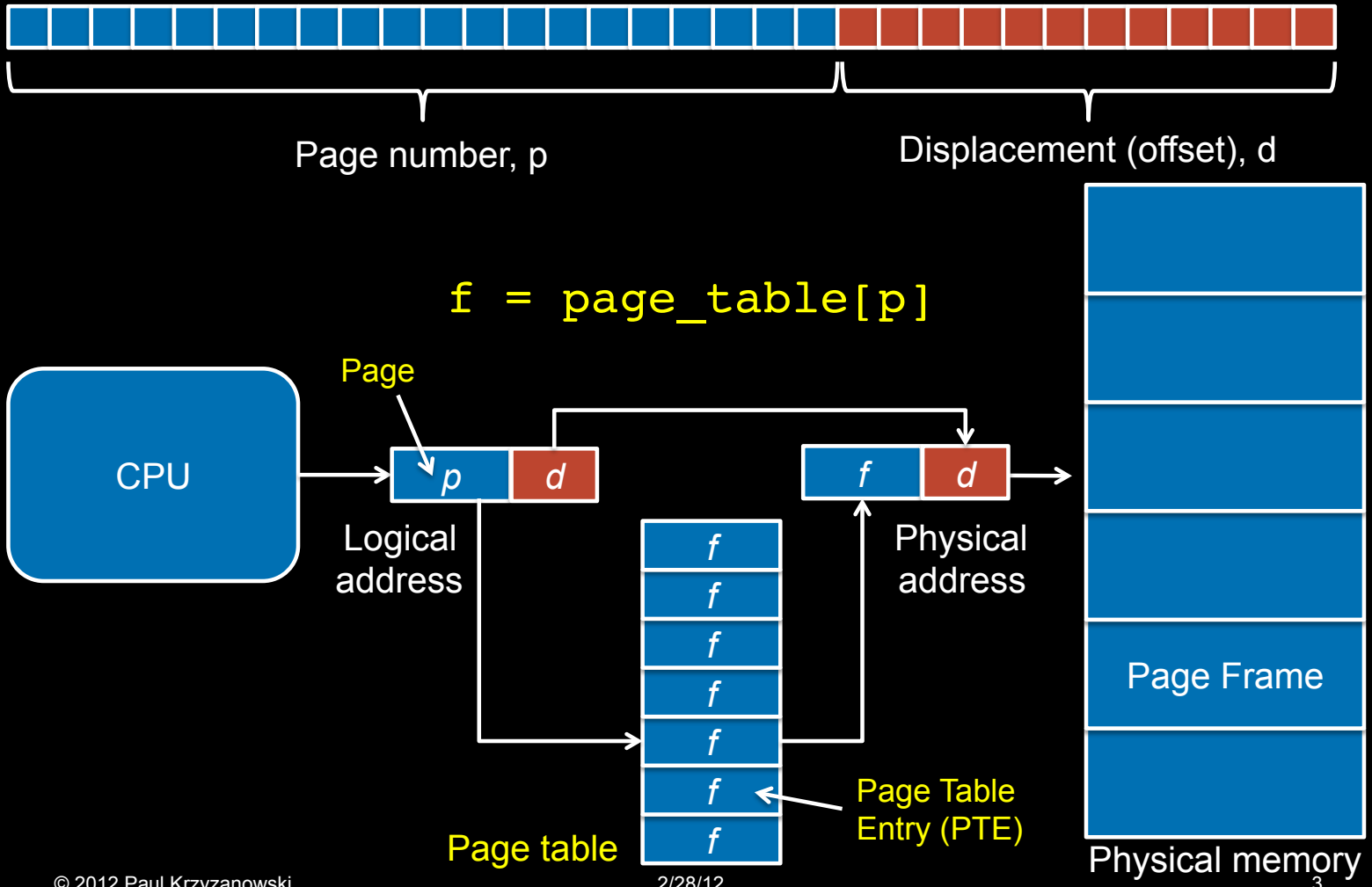
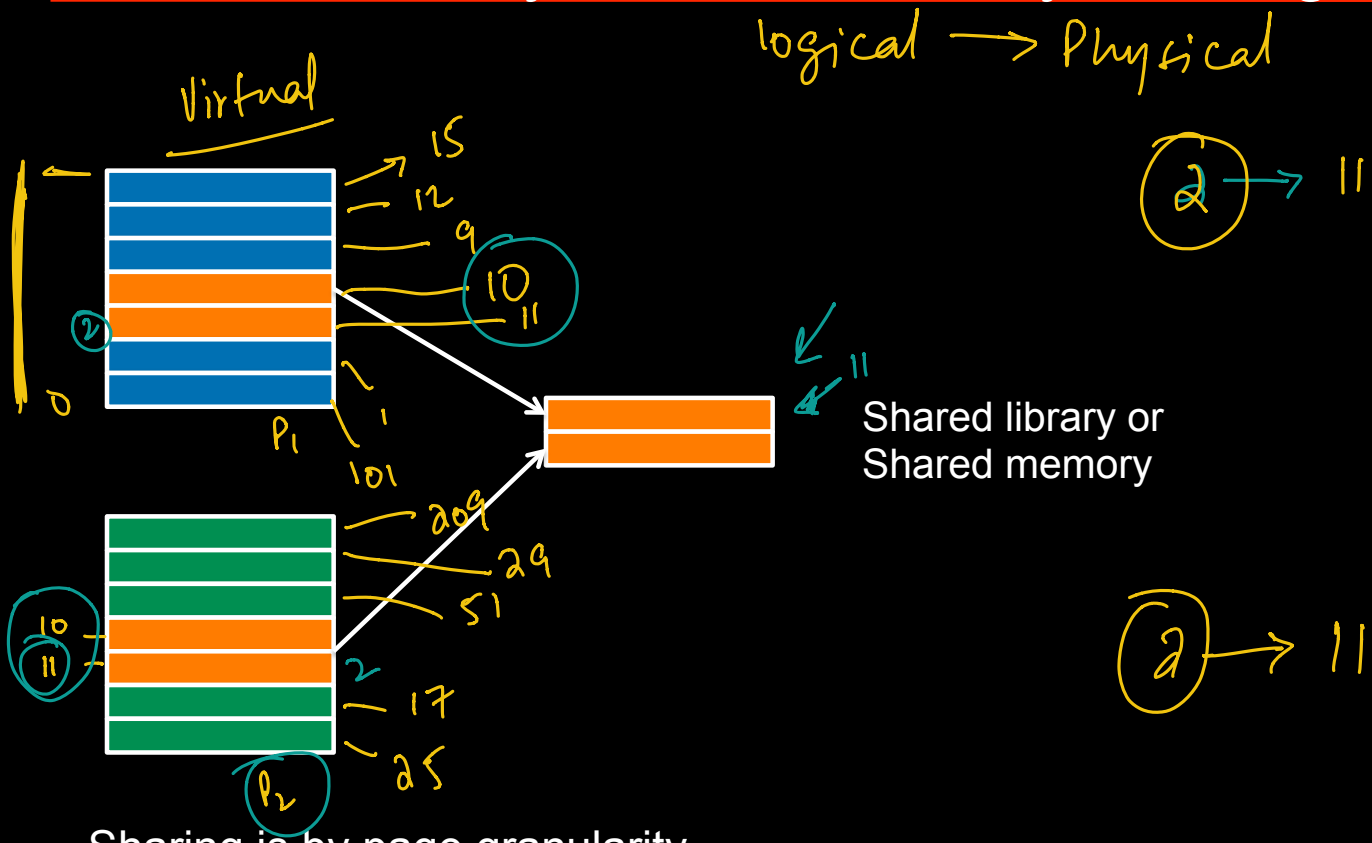
Page translation

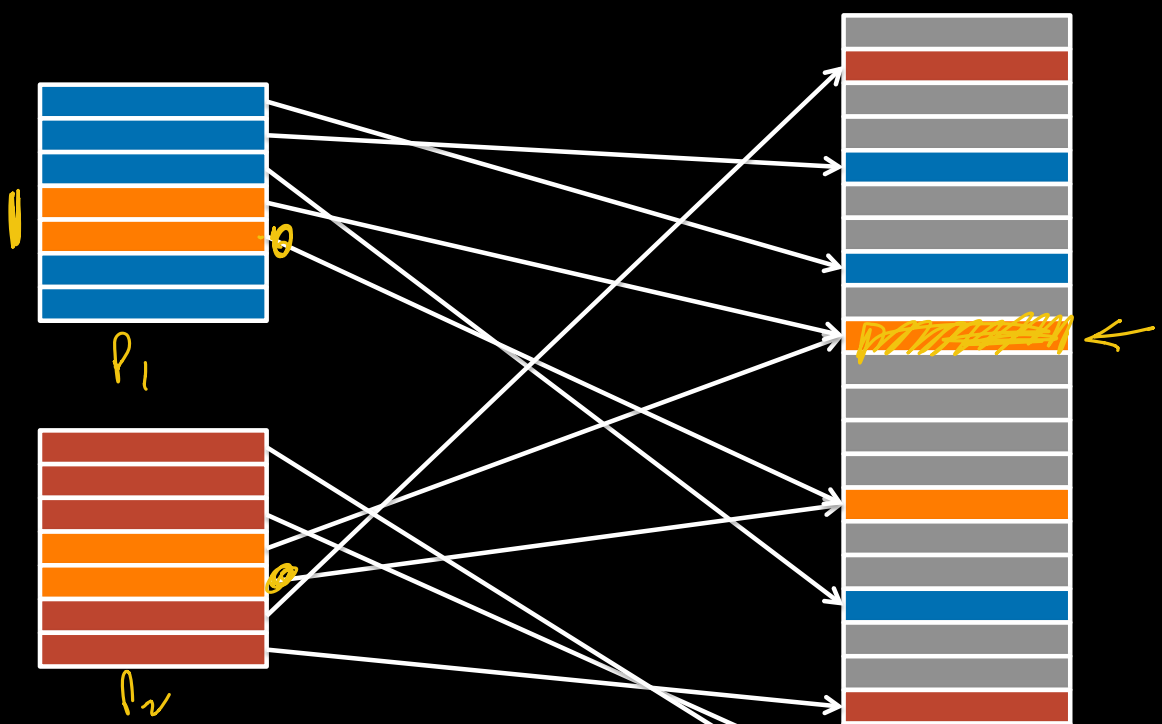


Virtual memory makes memory sharing easy



Sharing is by page granularity.

Virtual memory makes memory sharing easy

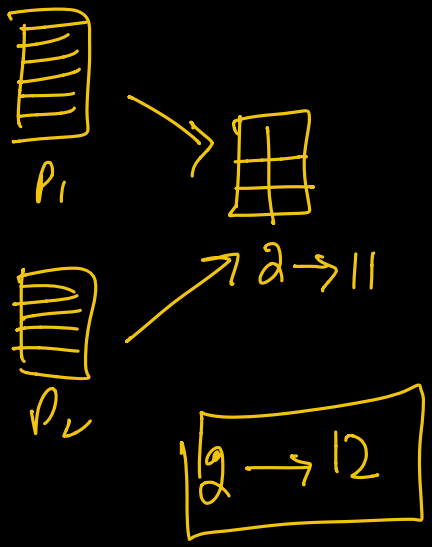


Sharing is by page granularity.

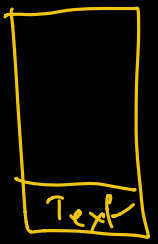
Keep reference counts!

Copy on write

- Share until a page gets modified
- Example: fork()
  - Set all pages to read-only
  - Trap on write
  - If legitimate write
    - Allocate a new page and copy contents



Q: Do we keep the whole process image in RAM?



Demand Paging

Executing a program

- Allocate memory + stack and load the entire program from memory (including linked libraries)
- Then execute it

Executing a program

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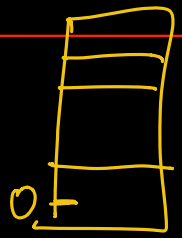
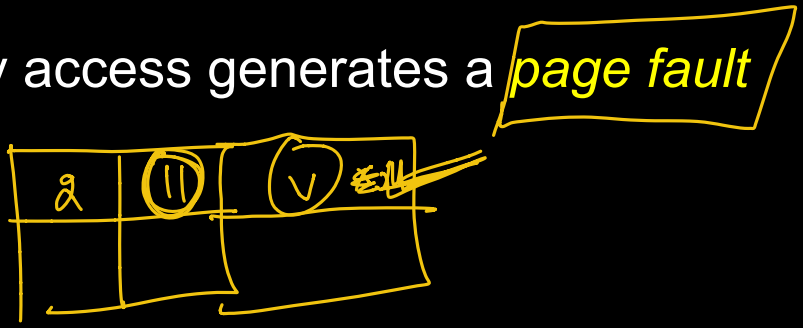
We don’t need to do this!

Demand Paging

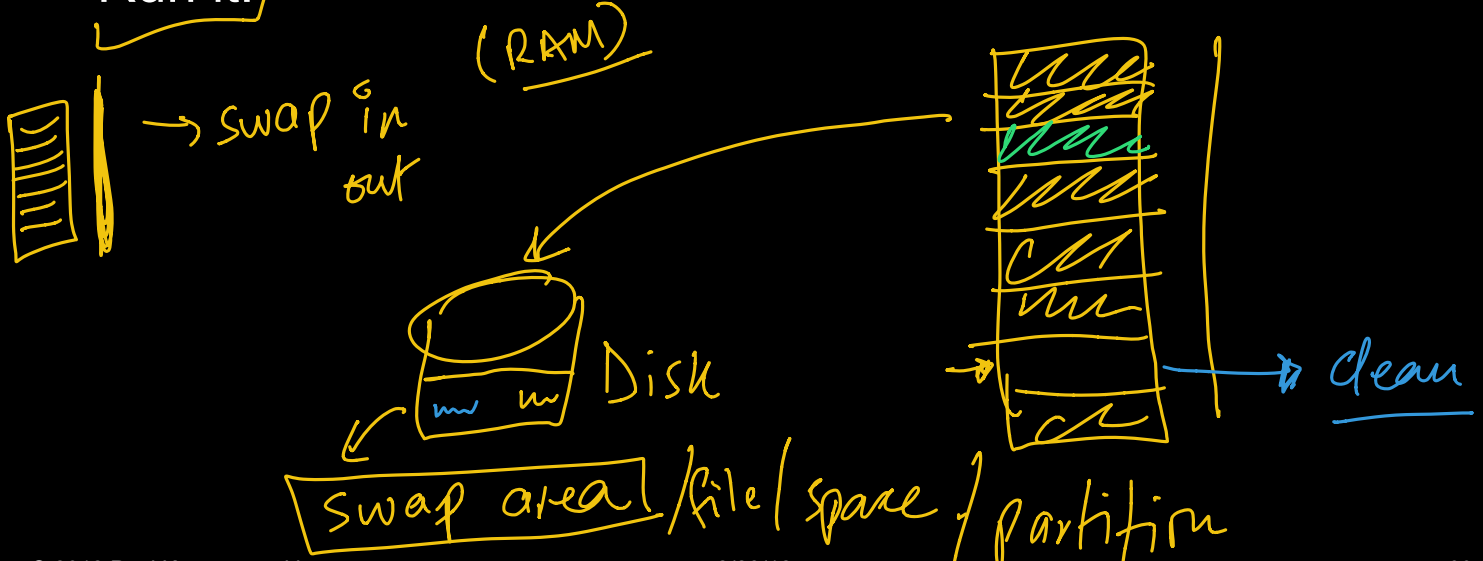


- Load pages into memory only as needed
  - On first access
  - Pages that are never used never get loaded
- Use valid/invalid bit in page table entry
  - Valid: the page is in memory ("valid" mapping)
  - Invalid: out of bounds access or page is not in memory
    - ~~Have to check the process' memory map in the PCB to find out~~
- Invalid memory access generates a *page fault*



Demand Paging: At Process Start

- Open executable file
- Set up memory map (stack & text/data/bss)
  - But don't load anything!
- Load first page & allocate initial stack page
- Run it!



Demand Paging: Page Fault Handling

- Soon the process will access an address without a valid page
  - OS gets a page fault from the MMU
- What happens?
  - Kernel searches a tree structure of memory allocations for the process to see if the faulting address is valid
    - If not valid, send a SEGV signal to the process
  - Is the type of access valid for the page?
    - Send a signal if not
  - We have a valid page but it's not in memory
  - Bring page in, mark as valid. ← restart instruction

Page Replacement

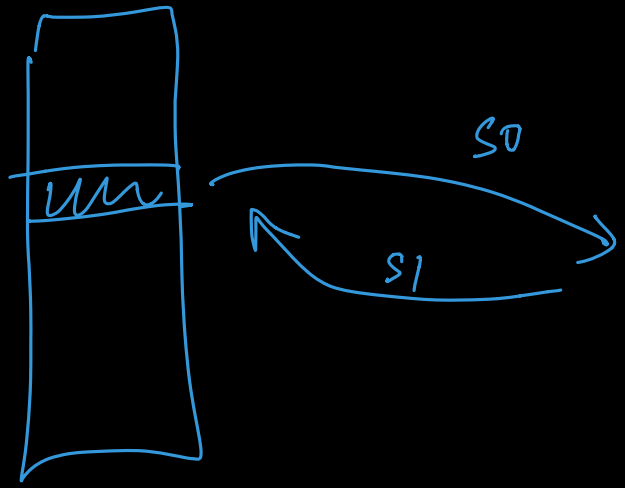
- A process can run without having all of its memory allocated
  - It's allocated on demand
- If the
  {address space used by all processes + OS} ≤ physical memory
  then we're ok
- Otherwise:
  - Make room: discard or store a page onto the disk
  - If the page came from a file & was not modified
    - Discard … we can always get it
  - If the page is dirty, it must be saved in a swap file
  - Swap file: a file (or disk partition) that holds excess pages

Cost

- Handle page fault exception: ~ 400 usec
- Disk seek & read: ~ 10 msec
- Memory access: ~ 100 ns
- Page fault degrades performance by around 100,000!!
- Avoid page faults!
  - If we want < 10% degradation of performance, we can have just one page fault per 1,000,000 memory accesses

Page replacement

- We need a good replacement policy for good performance



FIFO Replacement

- First In, First Out
- Good
  - May get rid of initialization code or other code that's no longer used
- Bad
  - May get rid of a page holding frequently used global variables

Least Recently Used (LRU)

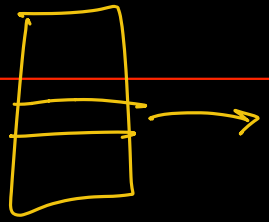
- Timestamp a page when it is accessed
- When we need to remove a page, search for the one with the oldest timestamp

- Nice algorithm but…
  - Timestamping is a pain – we can't do it with the MMU!

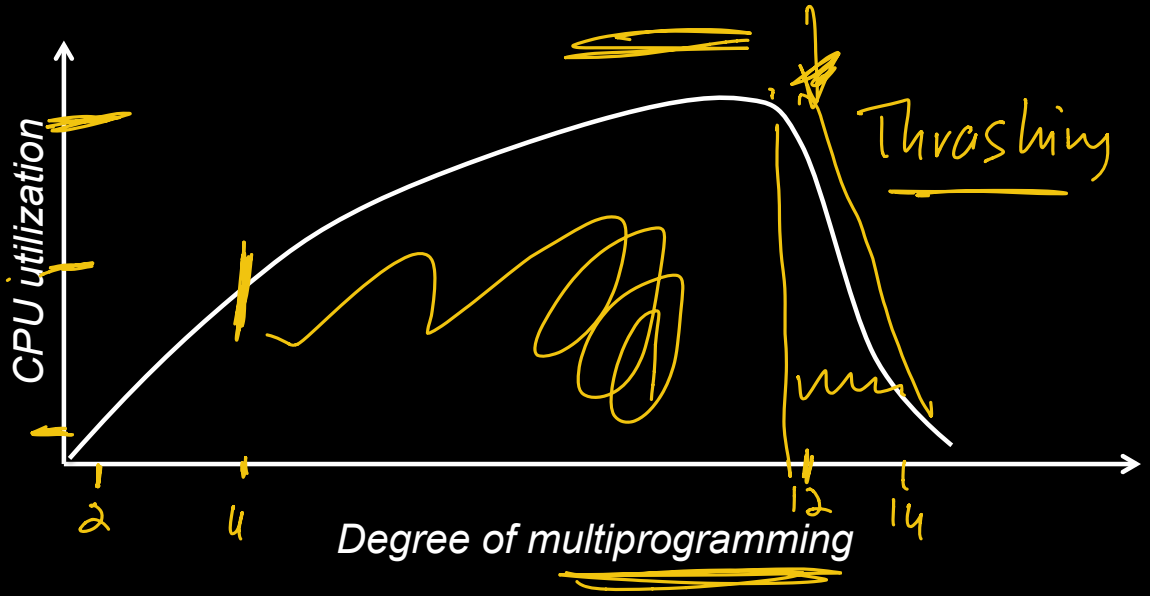
Not Frequently Used Replacement

- Approximate LRU
- Each PTE has a reference bit
- Keep a counter for each page frame
- At each clock interrupt:
  - Add the reference bit of each frame to its counter
  - Clear reference bit
- To evict a page, choose the frame with the lowest counter
- Problem
  - No sense of time: a page that was used a lot a long time ago may still have a high count
  - Updating counters is expensive

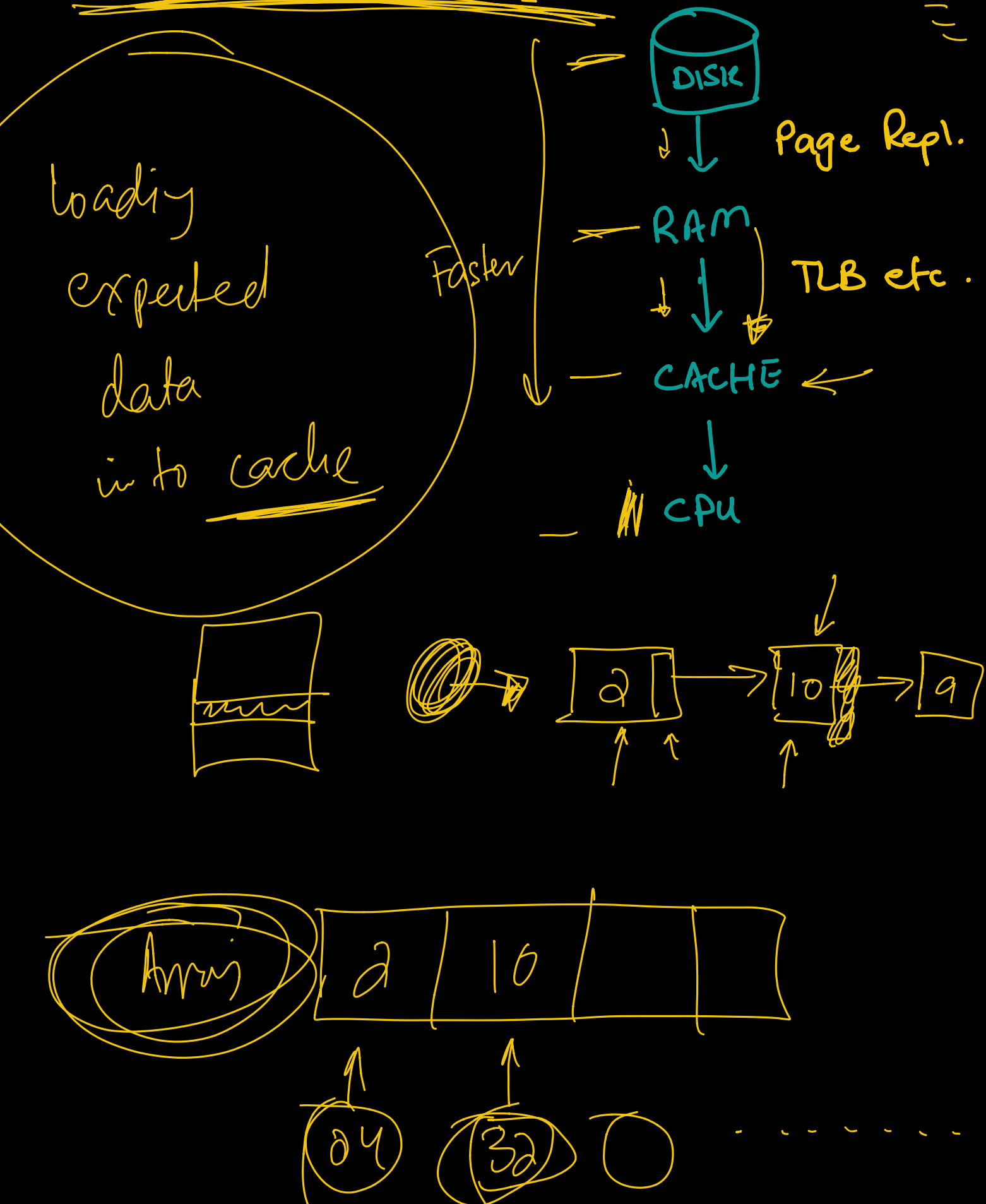
Thrashing



- Locality
  - Process migrates from one locality (working set) to another
- Thrashing
  - Occurs when sum of all working sets > total memory



Cache Coherence



The End