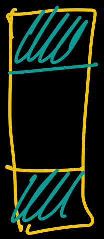
Operating Systems Design

8. Memory Management



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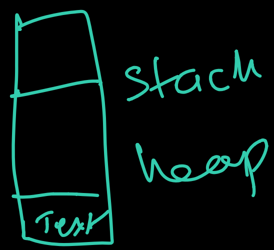
CPU Memory Access

CPU reads instructions and reads/write data from/to memory

Functional interface:

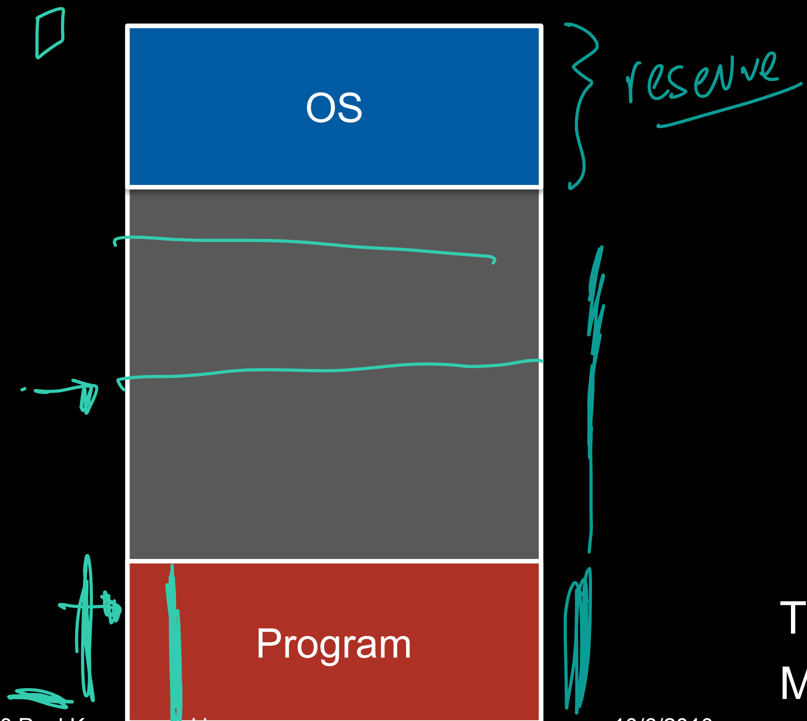
value = read(address)

write(*address*, *value*)



Monoprogramming

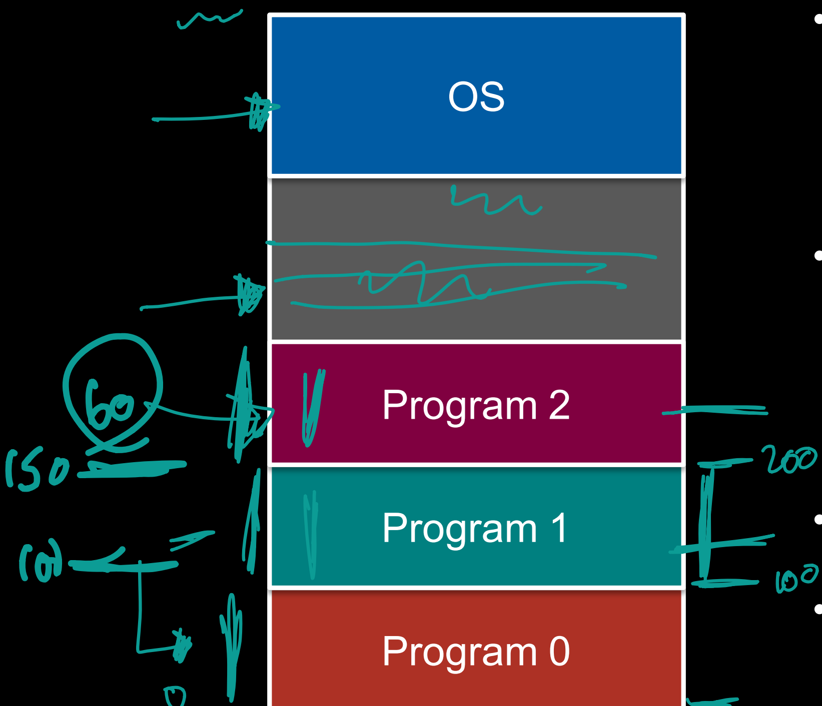
- Run one program at a time
- Share memory between the program and the OS



This was the model in old MS-DOS systems

Multiprogramming

- Keep more than one process in memory
- More processes in memory improves CPU utilization



- If a process spends 20% of its time computing, then would switching among 5 processes give us 100% CPU utilization?
- Not quite. For n processes, if
  p = *% time a process is blocked* on I/O
  then:

  probability all are blocked = p^n

- CPU is not idle for $(1-p^n)$ of the time
- 5 processes: 67% utilization

How do you access memory?

- **Absolute code**

  if you know where the program gets loaded (any relocation is done at link time)

.data

- **Position independent code**

  all addresses are relative

- ~~**Dynamically relocatable code**~~

  ~~relocated at load time~~

0x29ACD9 → RAM

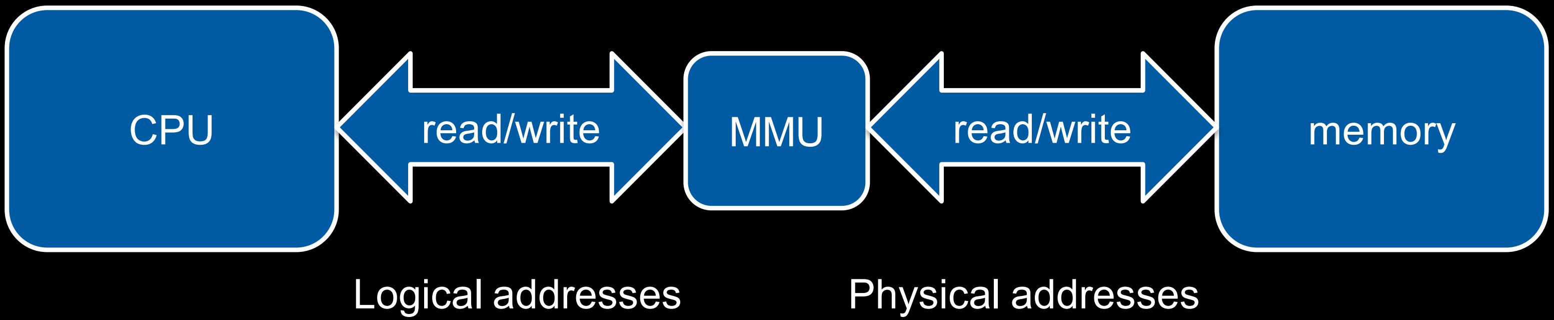
- Or … use **logical addresses**

  absolute code with with addresses translated at runtime

Logical addressing

- Memory management unit (MMU):

  Real-time, on-demand translation between *logical* and *physical* addresses



CS register

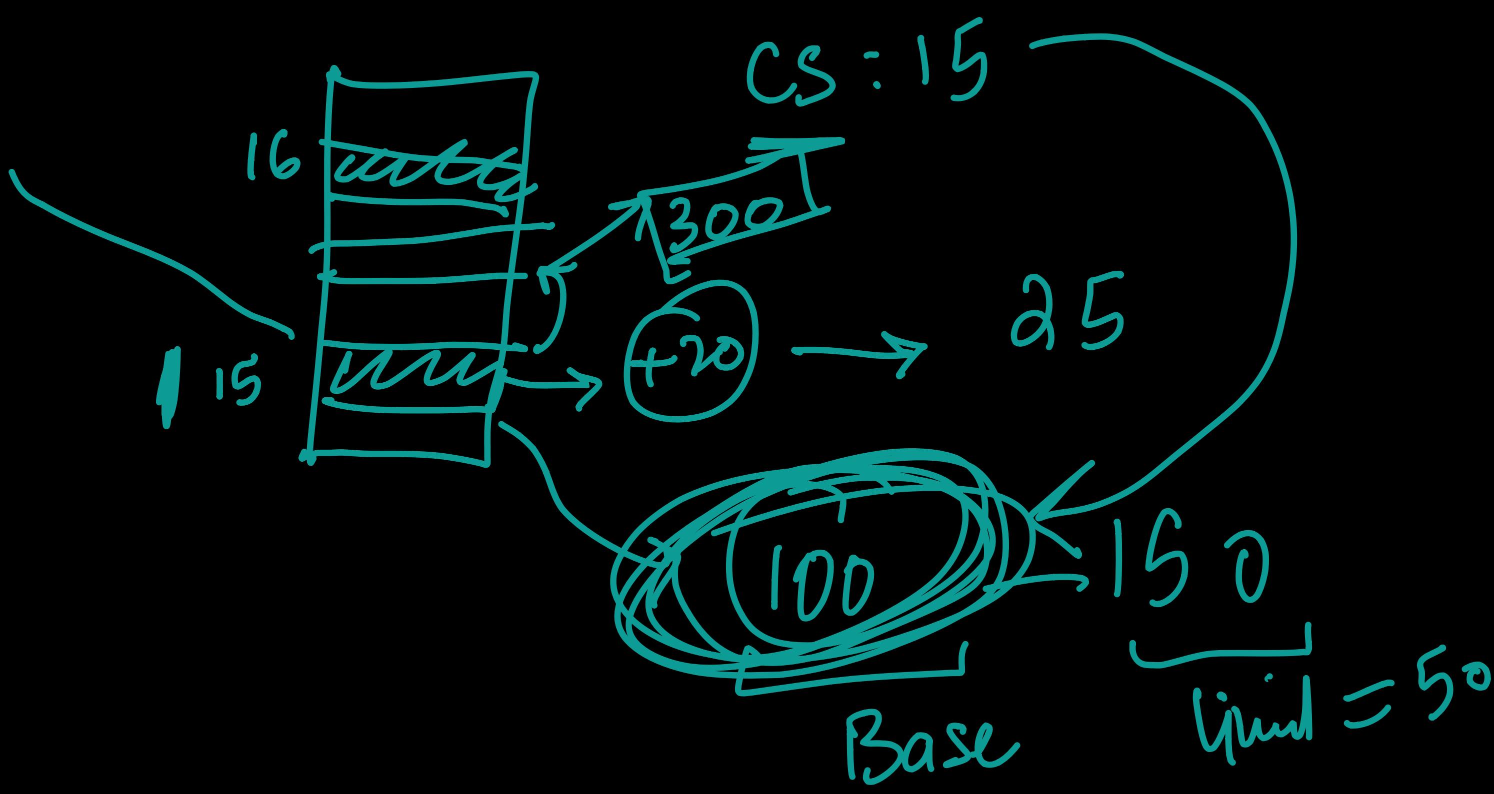
DS register

mov [ESI] , 25

mov [$\underbrace{DS}_{}$: $\underbrace{ESI}_{}$] , 25

15 20

100 + 20 = 120



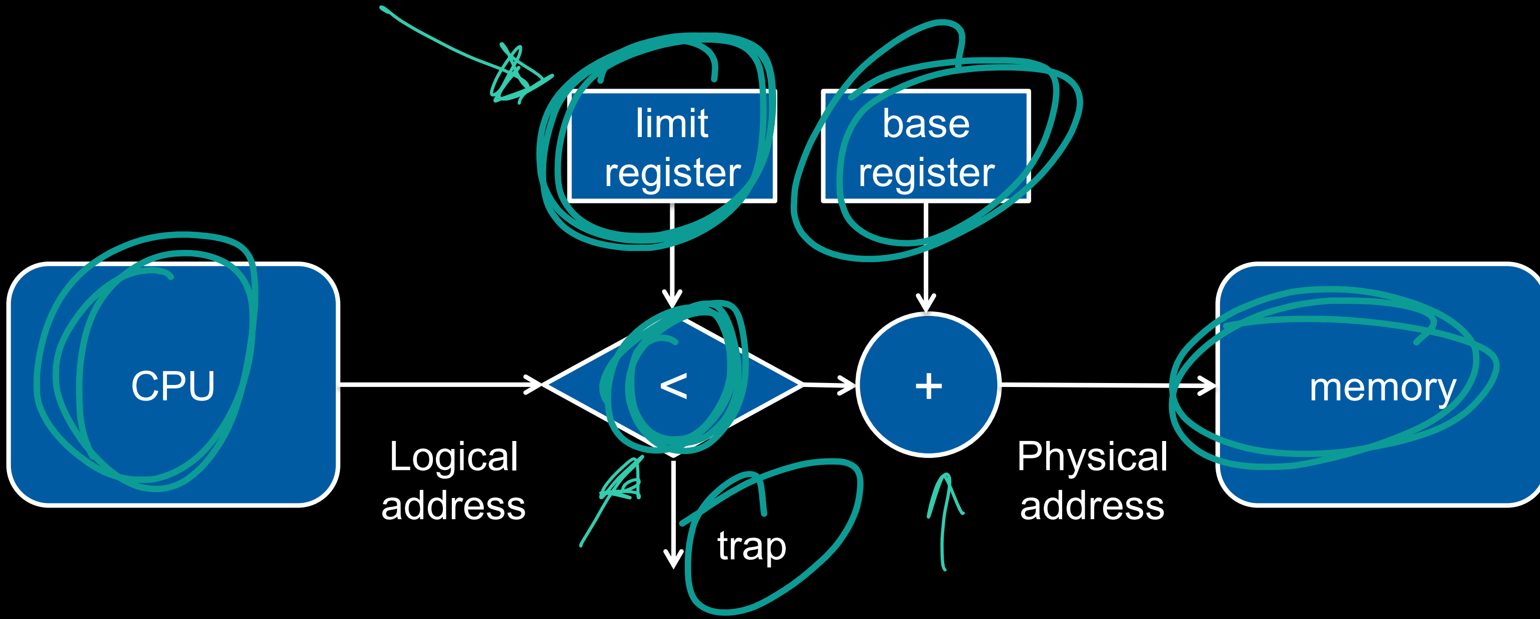
Relocatable addressing

15 : 20 25

100 + 20 = 120

- Base & limit
  - *Physical address = logical address + base register*
  - But first check that: *logical address < limit*

120 25

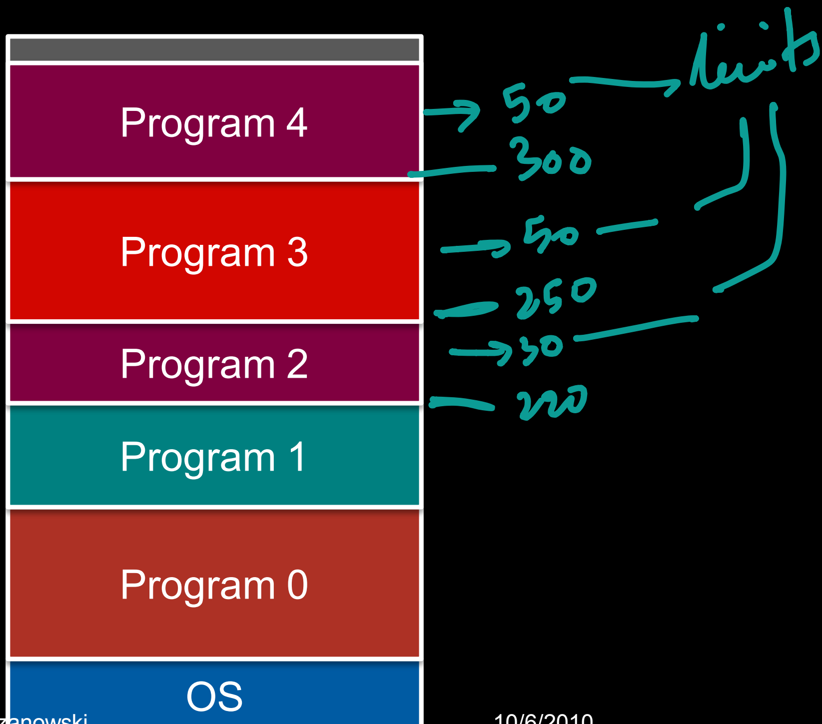


Multiple Fixed Partitions

- Divide memory into predefined partitions (segments)
  - Partitions don't have to be the same size
  - For example: a few big partitions and many small ones
- New process gets queued for a partition that can hold it
- Unused memory in a partition goes unused

Variable partition multiprogramming

- Create partitions as needed
- New process gets queued
- OS tries to find a hole for it



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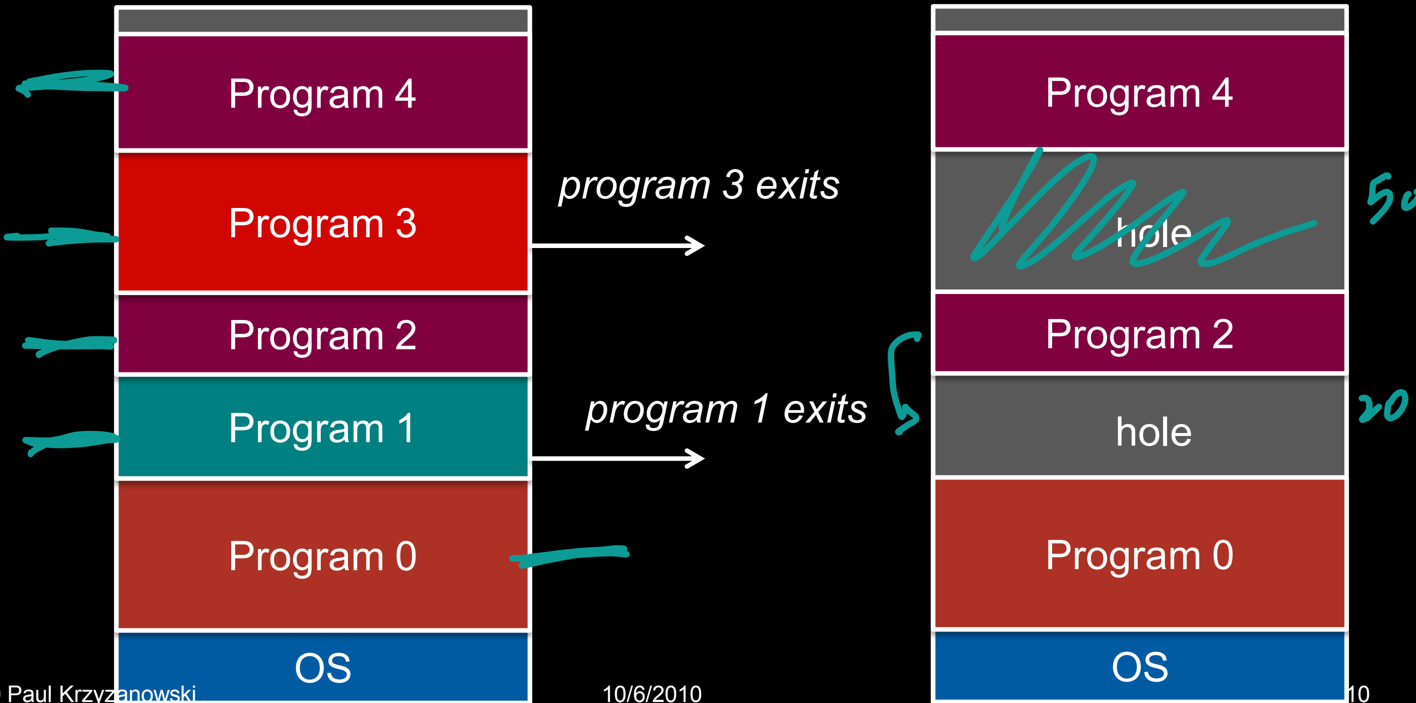
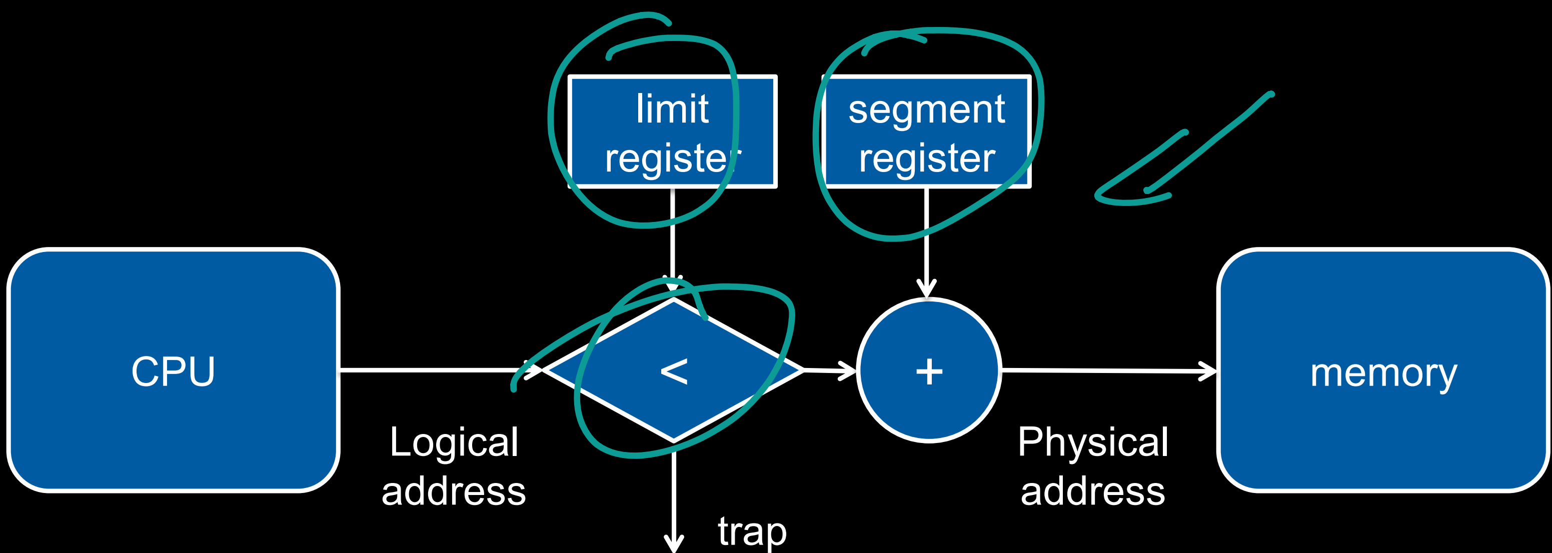


Variable partition multiprogramming

- What if a process needs more memory?
  - Always allocate some extra memory just in case
  - Find a hole big enough to relocate the process
- Combining holes
  - Memory compaction
  - Usually not done because of CPU time to move a lot of memory

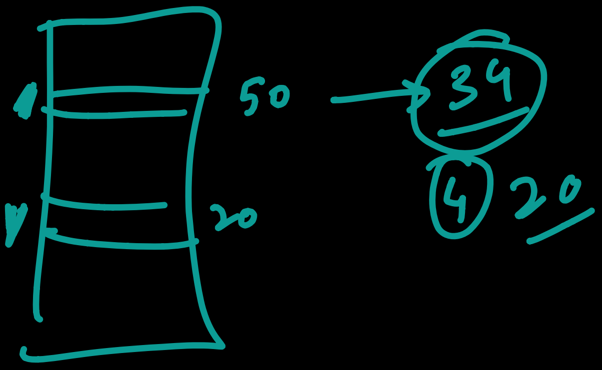
Segmentation hardware

- Divide a process into segments and place each segment into a partition of memory
  - Code segment, data segment, stack segment, etc.



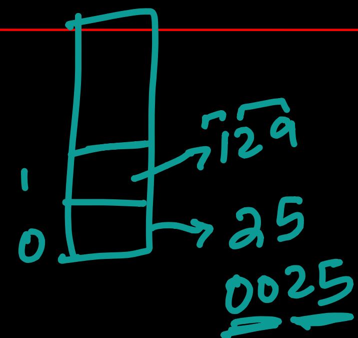
Allocation algorithms

- First fit: find the first hole that fits
- Best fit: find the hole that best fits the process
- Worst fit: find the largest available hole
  - *Why?* Maybe the remaining space will be big enough for another process. In practice, this algorithm does not work well.

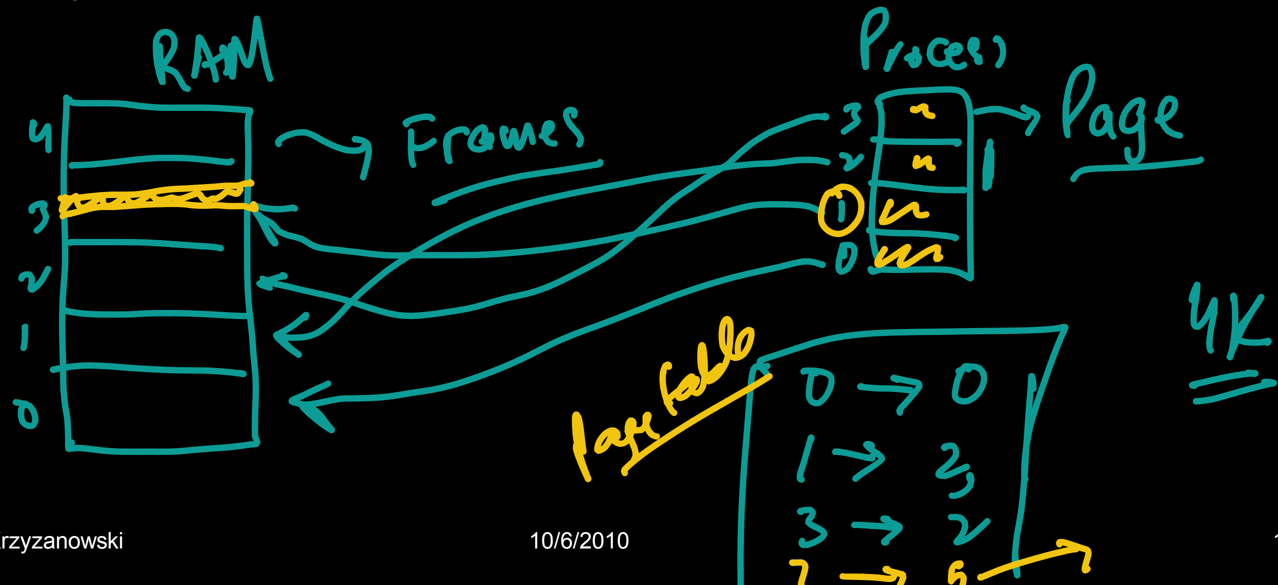


Paging

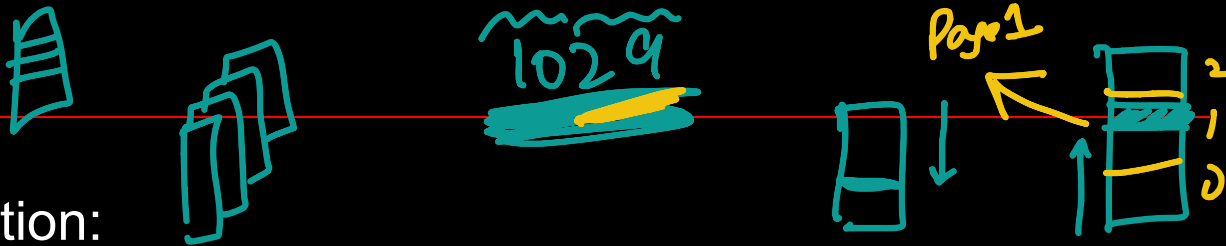
- Memory management scheme
  - Physical space can be non-contiguous
  - No fragmentation problems
  - No need for compaction



- Paging is implemented by the Memory Management Unit (MMU) in the processor

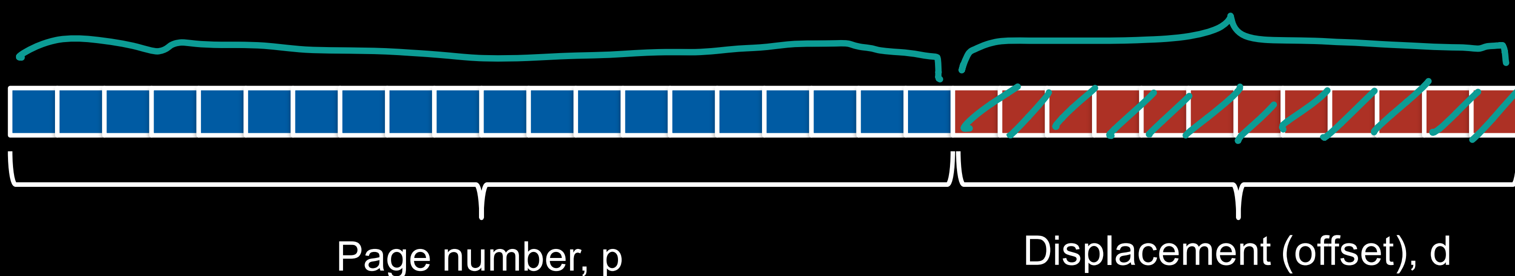


Paging

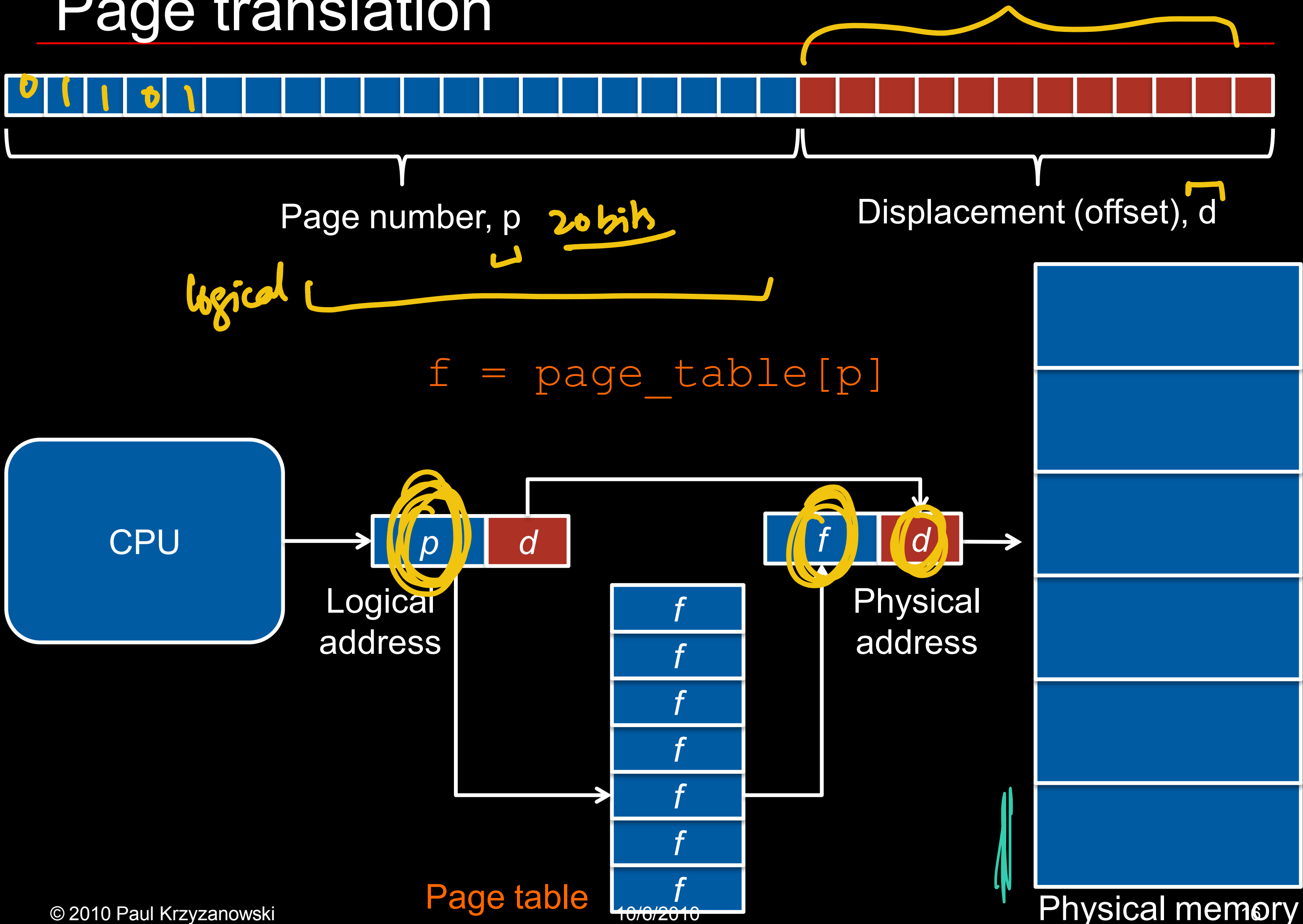


- Translation:
  - Divide physical memory into fixed-size blocks: page frames
  - A logical address is divided into blocks of the same size: pages
  - All memory accesses are translated: page → page frame
  - A page table maps pages to frames
- Example:
  - 32-bit address, 4 KB page size:
    - Top 20 bits identify the page number
    - Bottom 12 bits identify offset within the page/frame

12-bits
=4096



Page translation



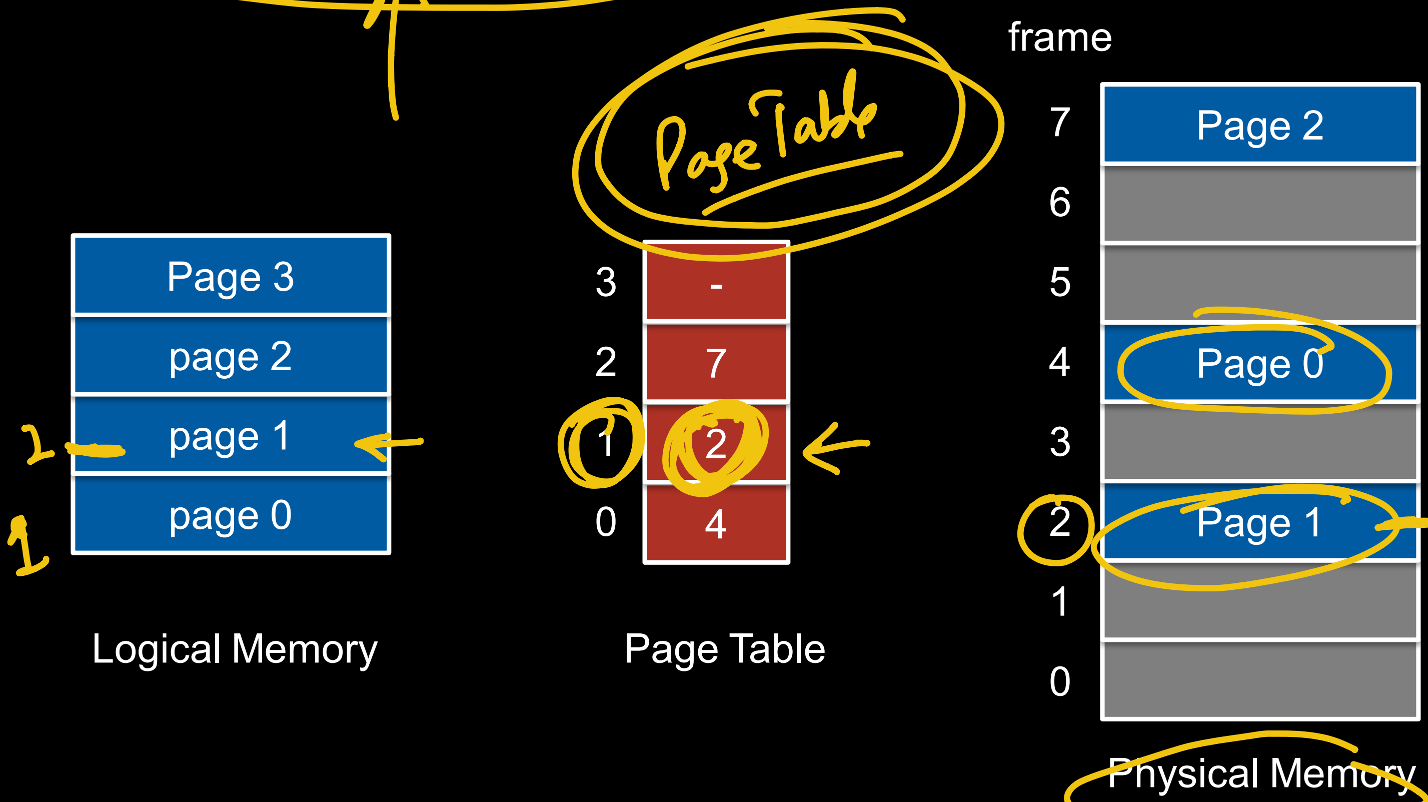
Logical vs. physical views of memory

0 01 000000000010

20 bits 12-bits.

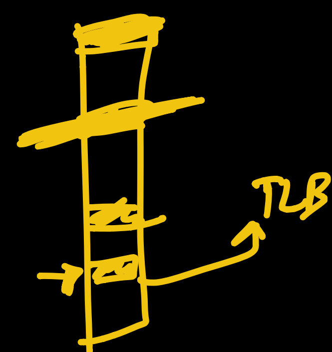
00 — 01000 — 10

32-bit



Hardware Implementation

- Where do you keep the page table? *In memory*
- Each process gets its own virtual address space
  - Each process has its own page table
  - Change the page table by changing a *page table base register*
- Memory translation is now slow!
  - To read a byte of memory, we need to read the page table first
  - Each memory access is now 2x slower!

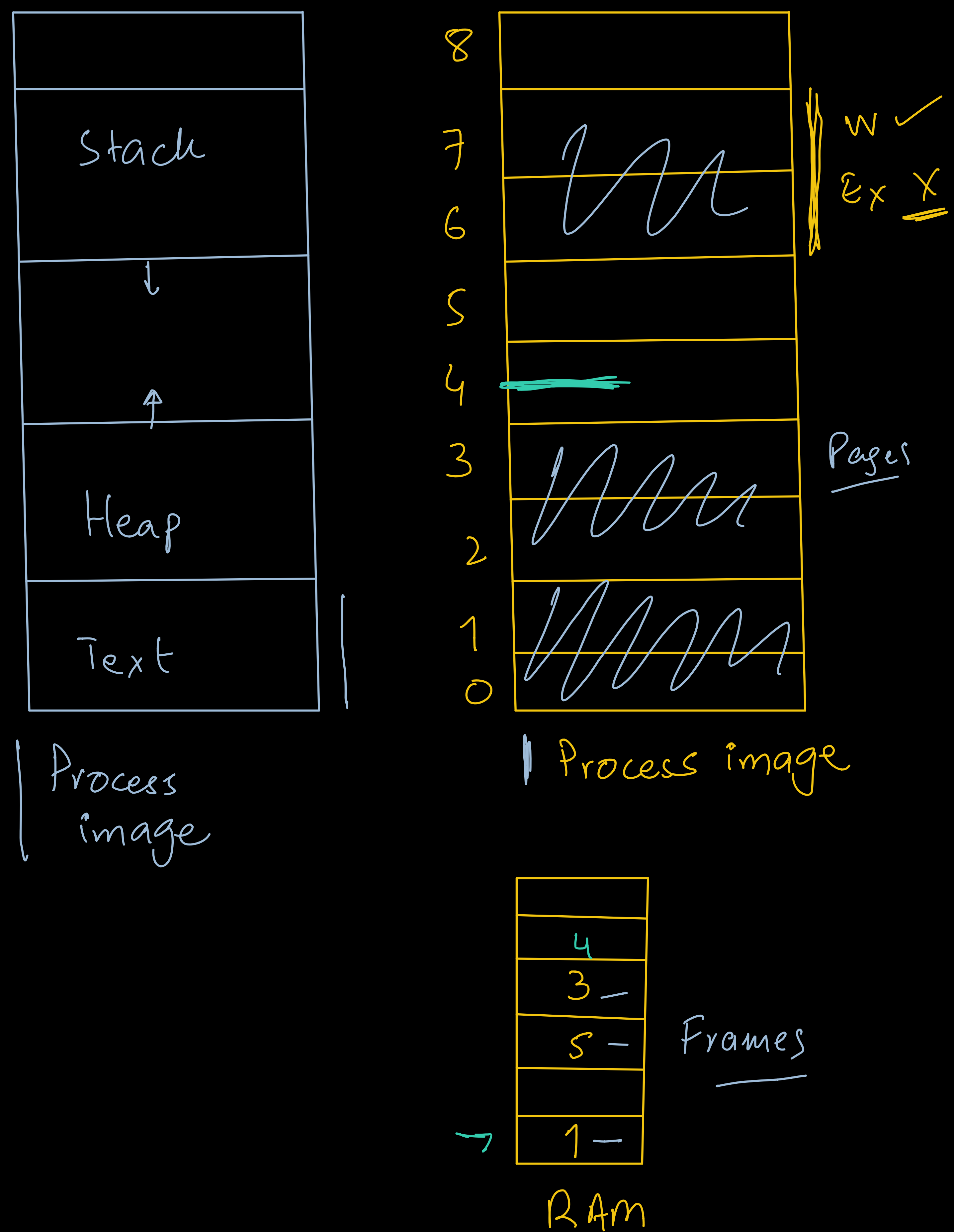


Hardware Implementation: TLB

- Cache frequently-accessed pages
  - Translation lookaside buffer (TLB)
  - Associative memory: key (page #) and value (frame #)

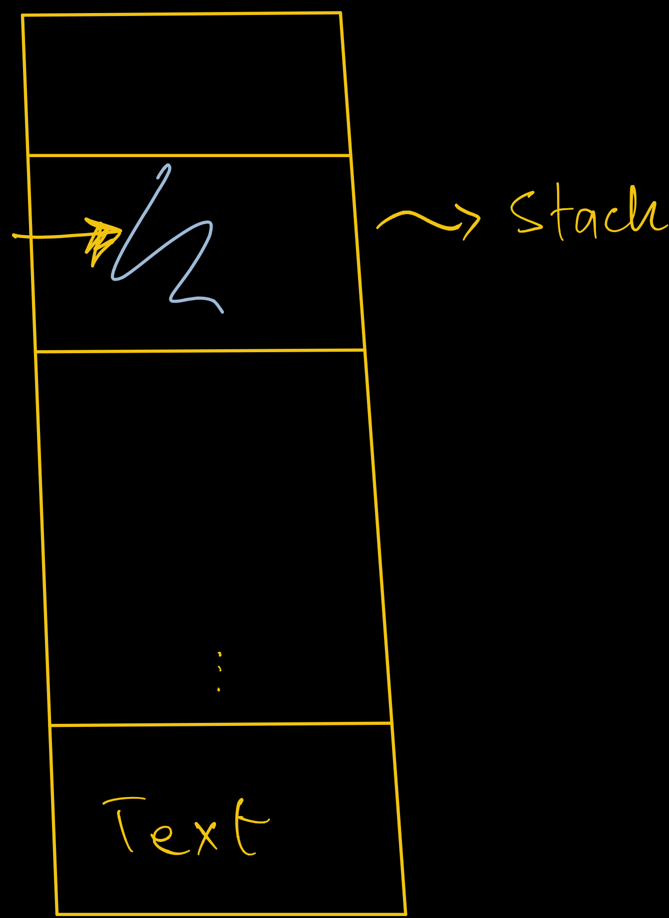
- TLB is on-chip & fast … but small (64-1,024 entries)
- TLB miss: result not in the TLB
  - Need to do page table lookup in memory
- Hit ratio = % of lookups that come from the TLB

- Issue when we context switch

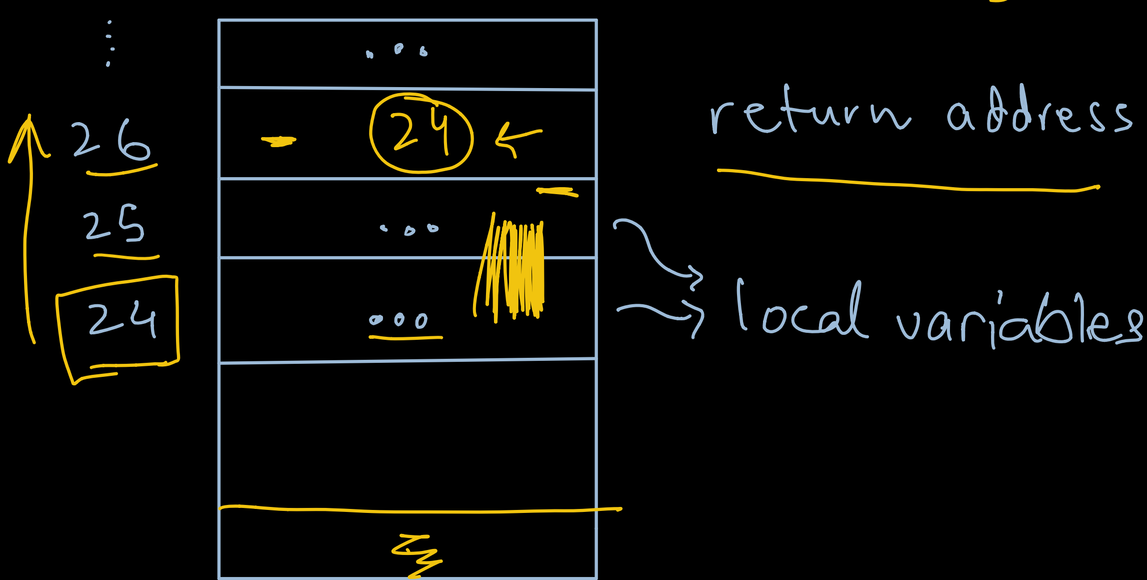


Stack
Heap
Text
Process image
8
7
6
5
4
3
2
1
0
W ✓
Ex X
Pages
Process image
4
3
5
1
Frames
RAM

How does malware work?



1. Writing
2. Executing



Protection

- An MMU can enforce memory protection
- Page table stores protection bits per frame
  - Valid/invalid: is there a frame mapped to this page?
  - Read-only
  - No execute
  - Dirty

The End