Sistemi Operativi I

Corso di Laurea in Informatica

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Problems Seen So Far

- Contiguous allocation
  - Hard to grow or shrink process memory
- Fragmentation
  - Frequent compaction needed
- Process entirely loaded
  - Swapping helps but it may be too inefficient

Paging

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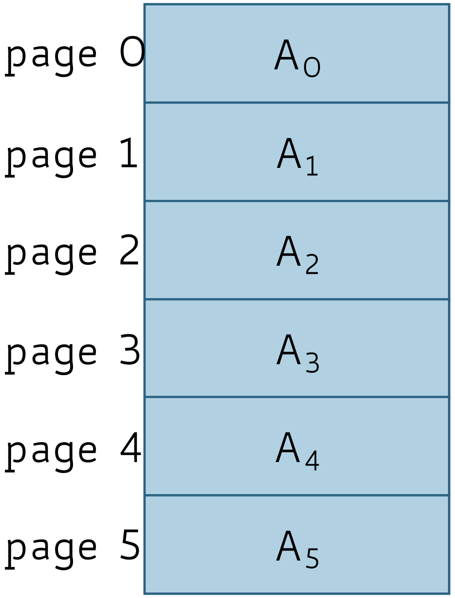
90/10 Rule

Processes spend 90% of their time accessing only 10% of their allocated memory space

Paging: The Big Picture



Logical/Virtual Address Space
of process A

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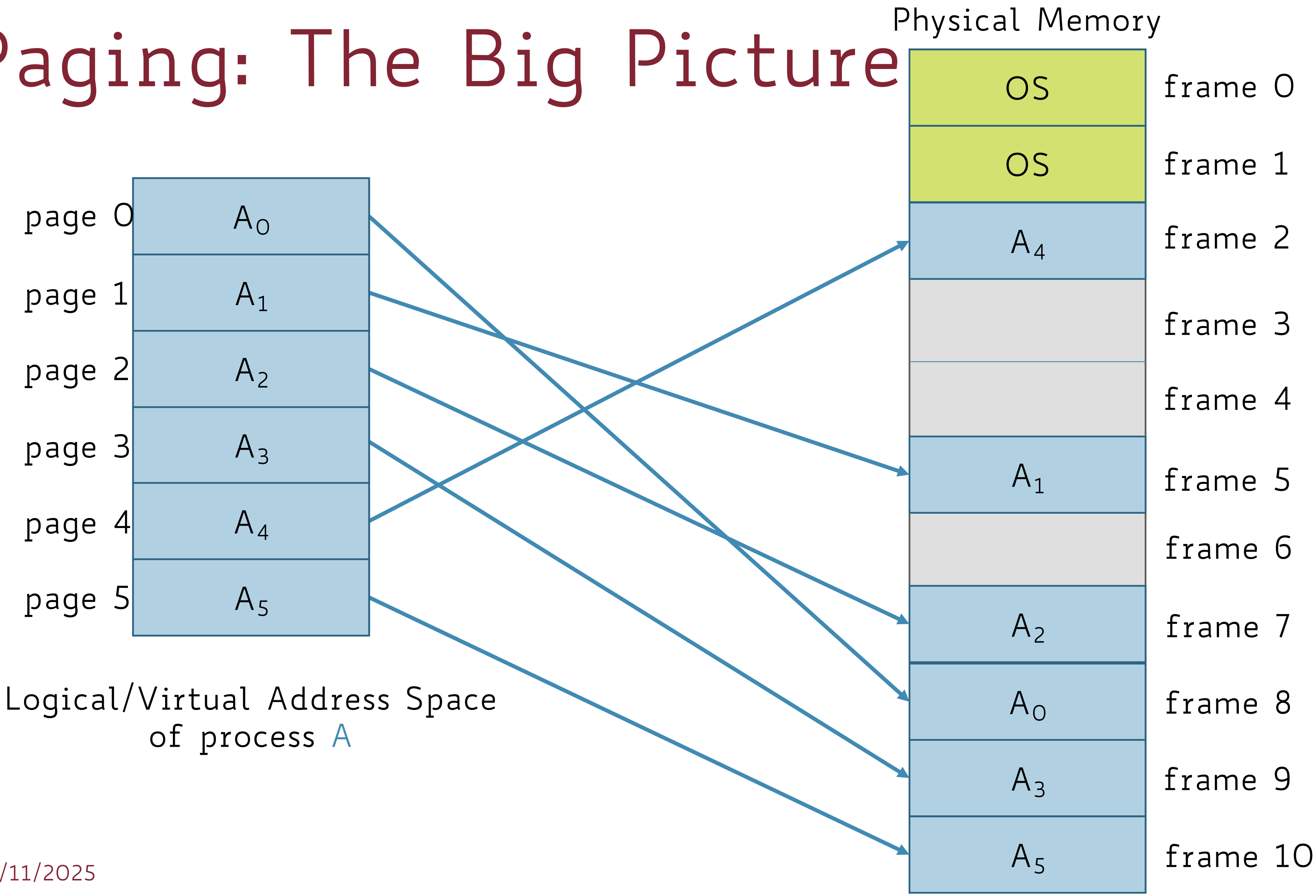

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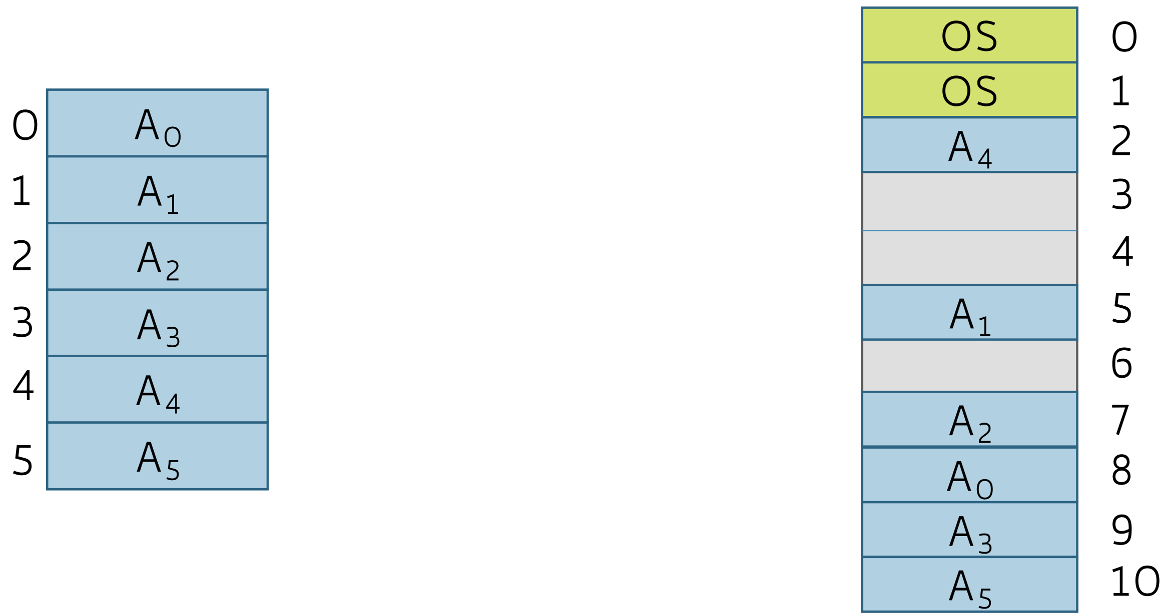
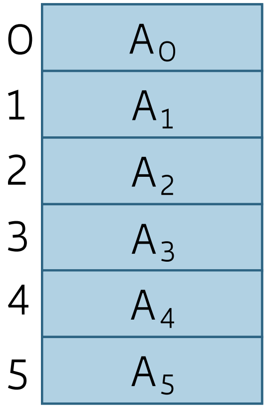
- All of this must be done efficiently!
  - Remember, memory addresses are referenced all the time
- OS needs dedicated support for doing it → **Page Table**

Page Table: Mapping Pages to Frames

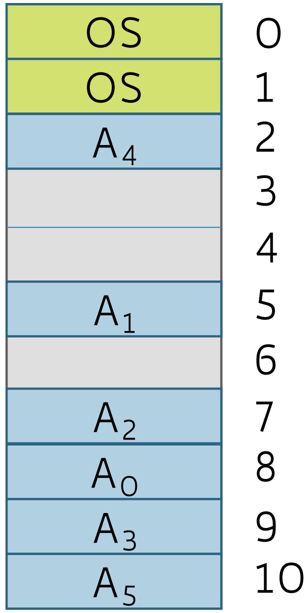


Page Table: Mapping Pages to Frames

Lookup table to retrieve what frame a page is stored in



Page	Frame
0	8
1	5
2	7
3	9
4	2
5	10



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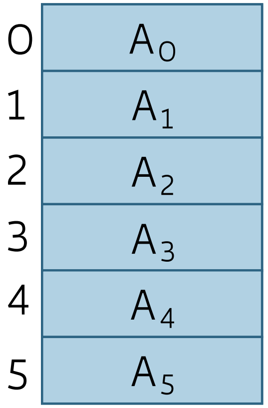

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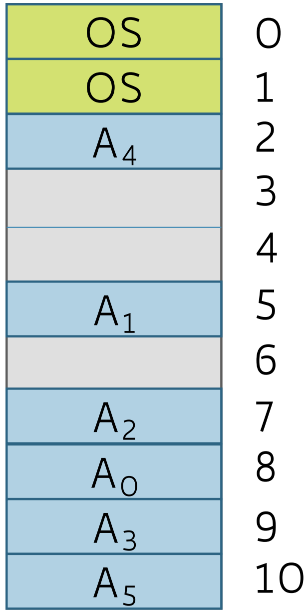

We have assumed all pages of a process are mapped to physical frames, but this is not always the case

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- Page table must ultimately translate virtual address to physical address

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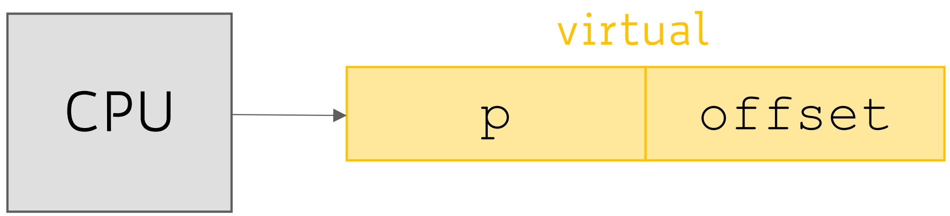
virtual address consists of 2 parts:
- `p`: page number where the address resides
- `offset`: relative from the beginning of the page



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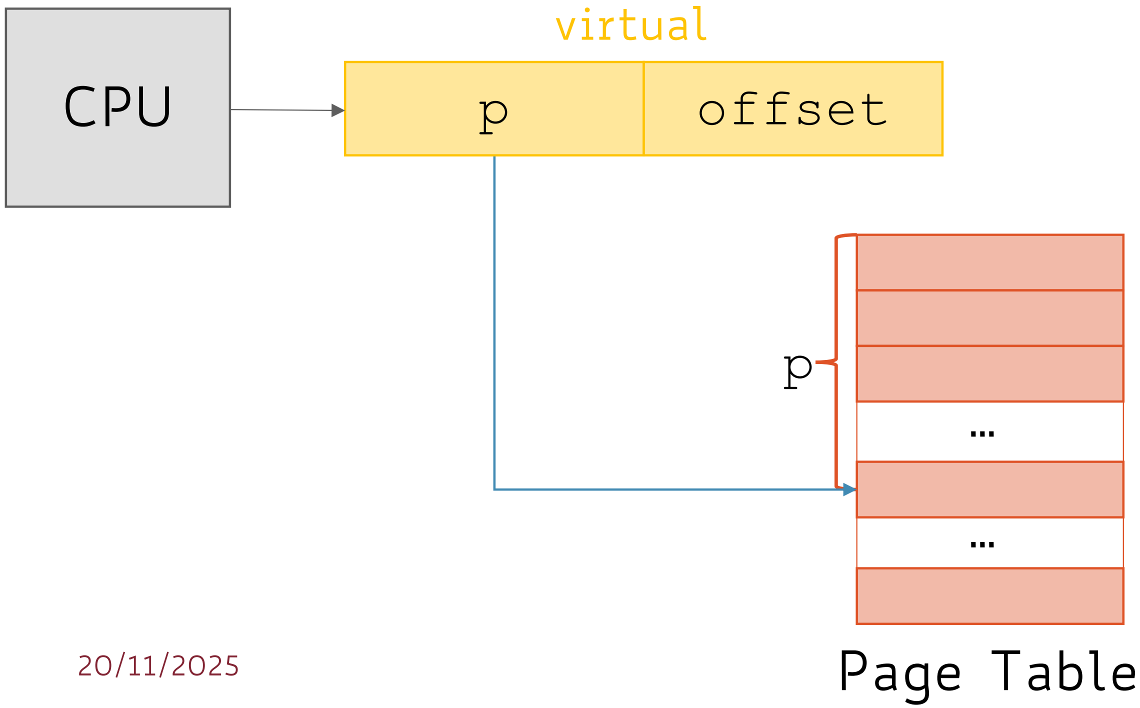

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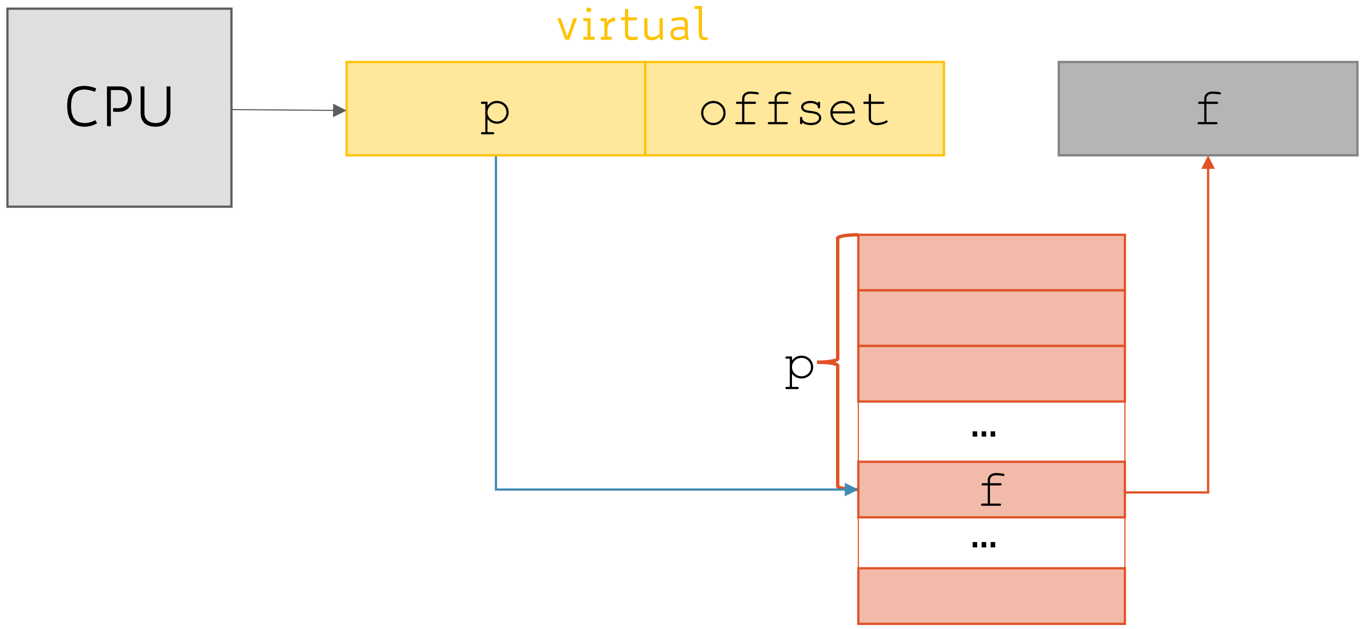

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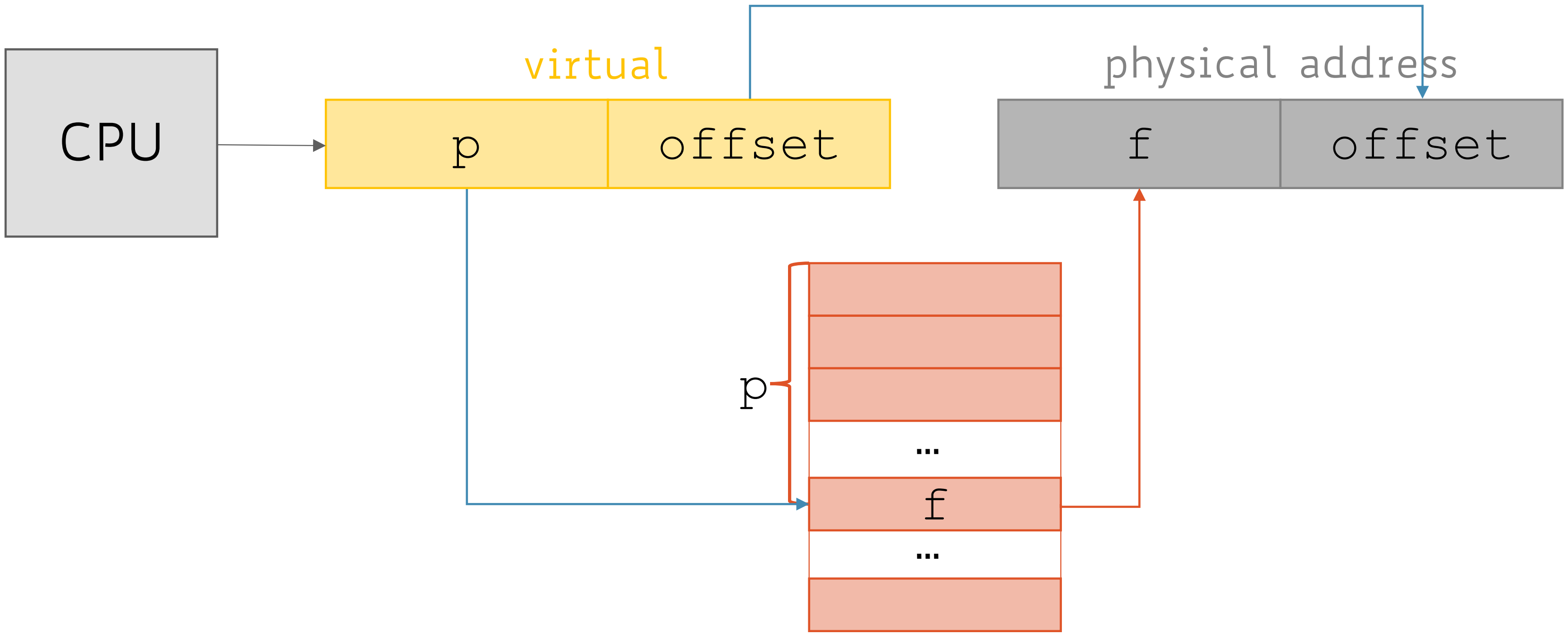

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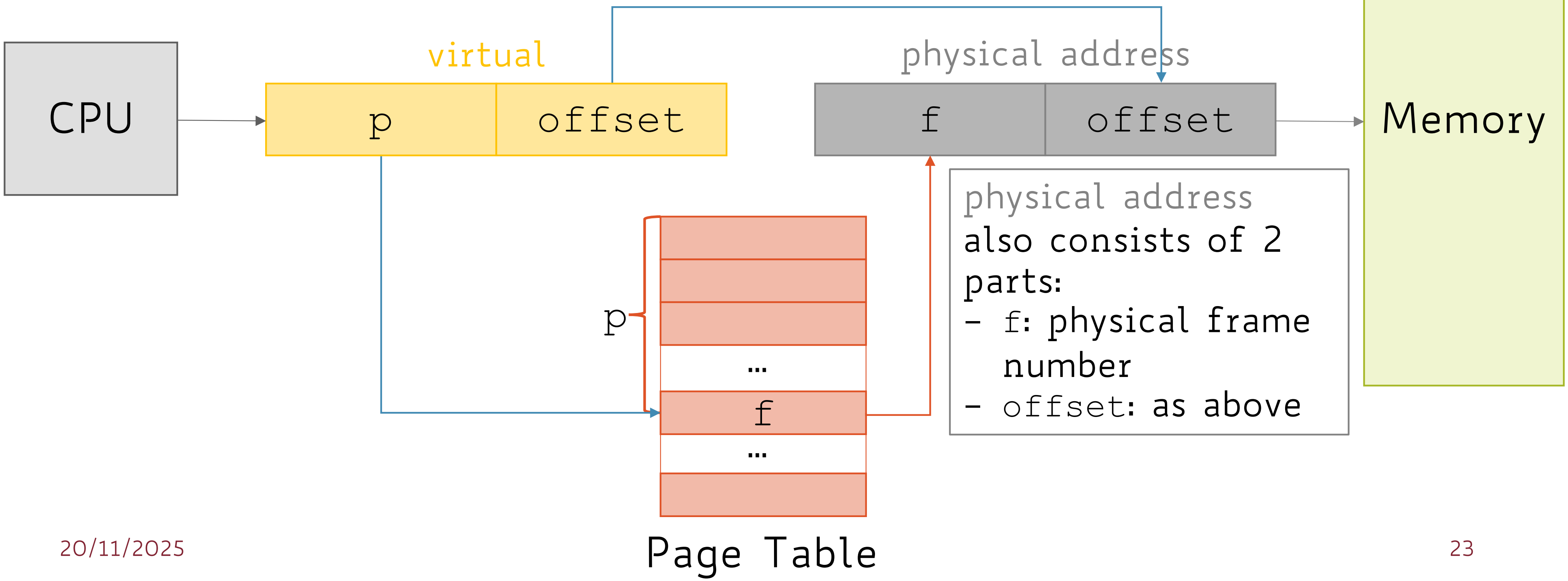
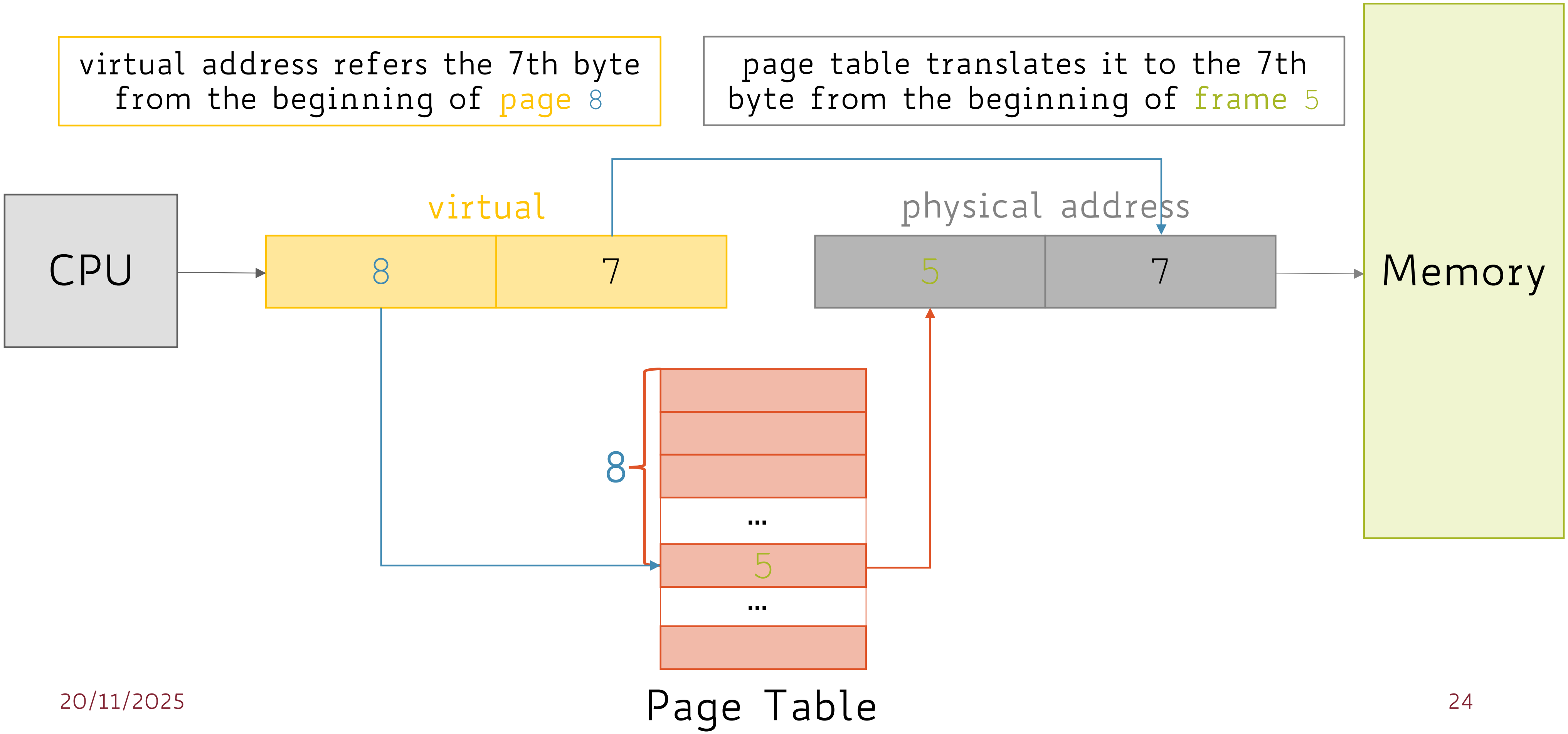


Page Table: Example of Address Translation



Paging as Dynamic Relocation

- Paging is an advanced form of dynamic relocation
- Each virtual address is bound by the page table to a physical address
- Page table can be seen just as a set of base (relocation) registers, one for each frame
- Mapping is invisible to the user process: the OS maintains the page table and translation happens in hardware (via the MMU)
- Protection is provided similarly to dynamic relocation (limit register)

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3. Combine **`f`** with **`offset`** to obtain the physical address **`y`**

Paging: Get `p` and `offset` from `x`

Suppose we have **`50B`** of physical memory available for user processes

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Address translation requires a **div** and a **mod** operation

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- The low order n bits represent the **offset**

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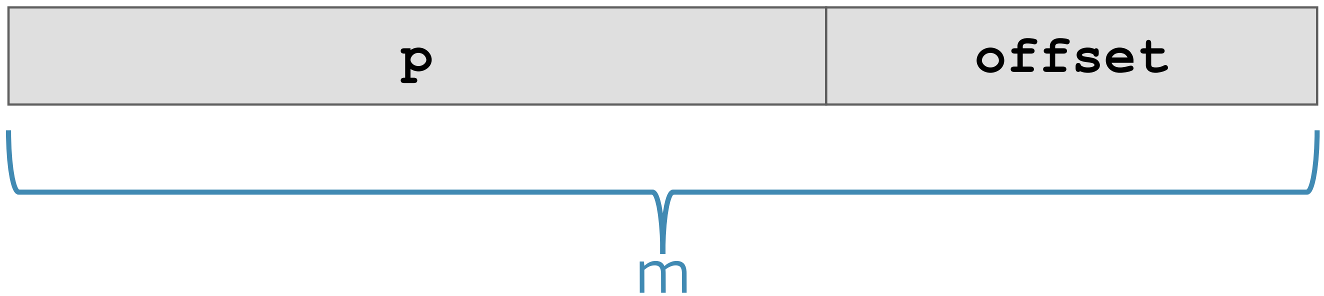

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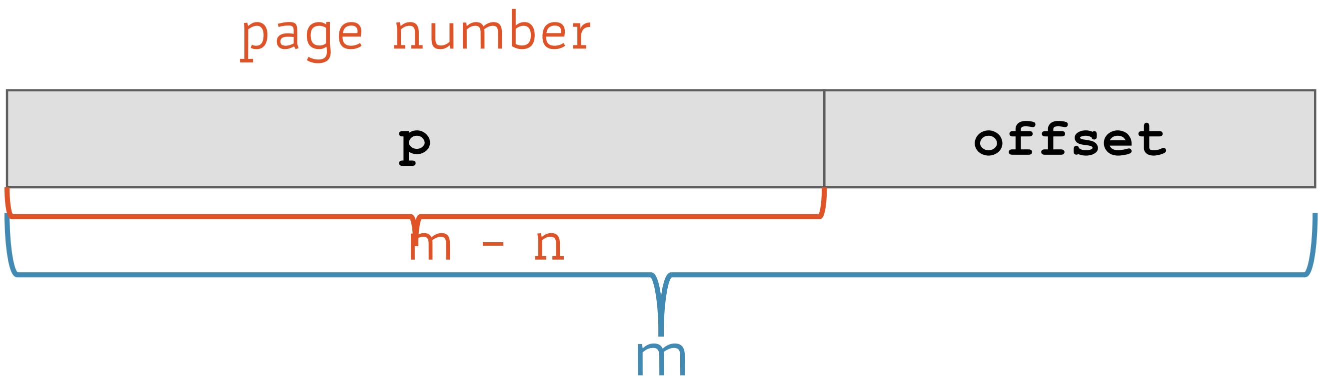

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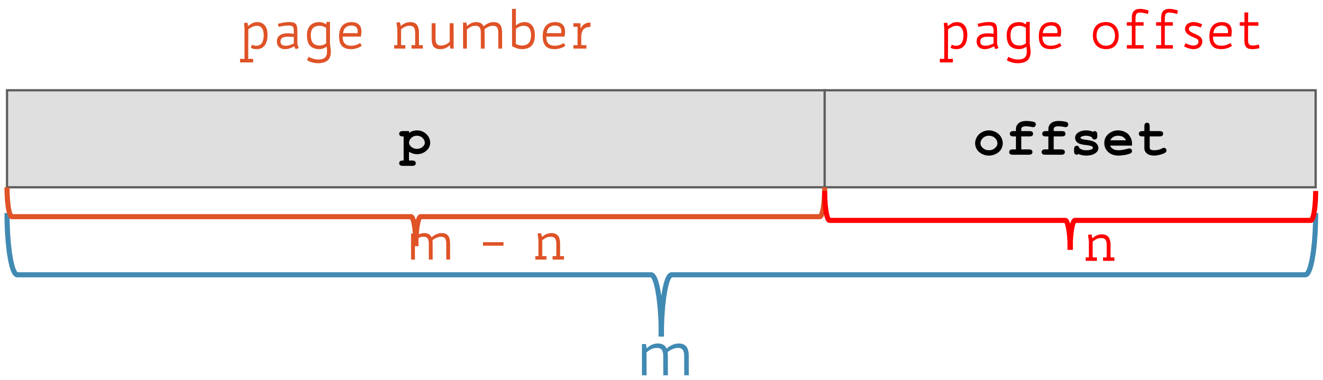
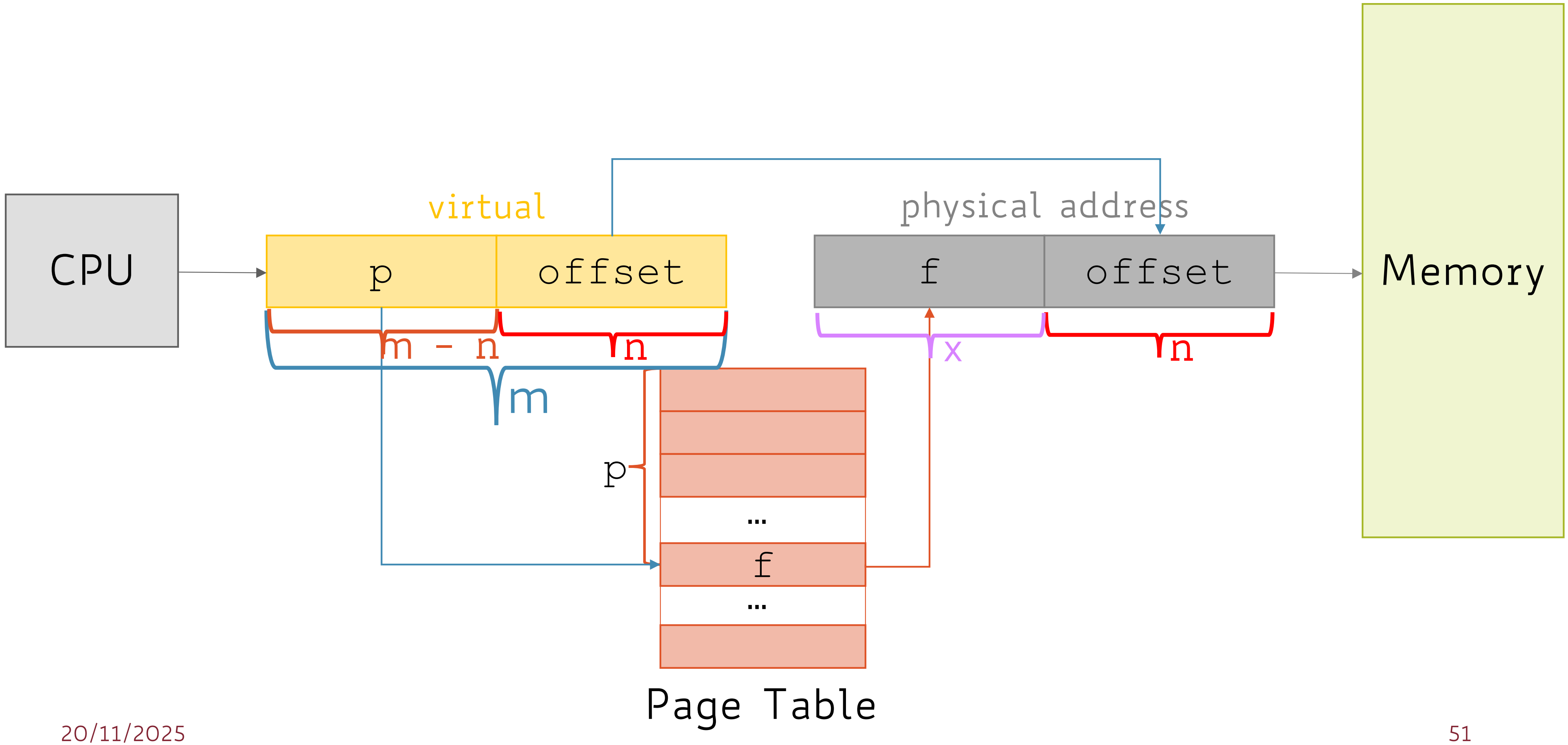


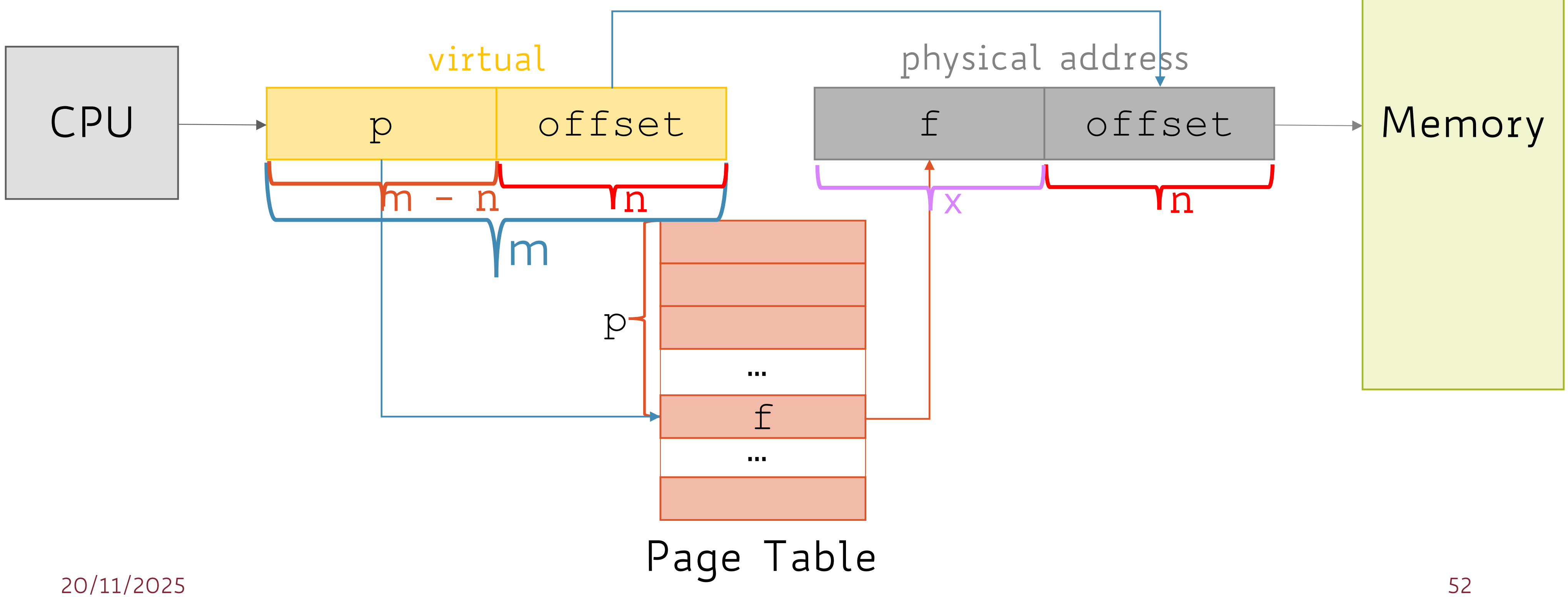
Paging: Practical Details



Paging: Practical Details

NOTE

m-n doesn't necessarily have to be equal to x



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  - The virtual address space is 2^{32} = 4GiB or 2^{64} = 16EiB
- Typical values of page/frame sizes is n = 12 bits
  - Each page/frame is 2^{12} = 4KiB
- Assuming m = 32 bits, there are $2^{m-n} = 2^{20}$ = ~1M pages/frames
  - The page table has 2^{20} entries (i.e., one for each page/frame)

Paging: Practical Example

Suppose we have a virtual memory and a physical memory, both of size M = 1024B (1KiB)

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10 bits to address M = 1024 bytes (both for virtual and physical address)

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Q2

How big is the page table? (i.e., how many pages/entries does it have to index?)

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T = M / S = 1024 memory bytes / 16 bytes per page = 64 pages

Paging: Practical Example

Q3

What is `p` and `offset` (i.e., how many bits for `p` and `offset`?)

Paging: Practical Example

Q3

What is `p` and `offset` (i.e., how many bits for `p` and `offset`?)

R3

Our logical address is made of $m = 10$ bits

$n = 4$ bits are used to represent the `offset`, as each page/frame is $S = 16$ bytes

$m-n = 6$ bits are used to represent page number `p`, as there are $T = 64$ pages

Paging: Practical Example

Q4

Translate the virtual address $x = 42$, assuming the following page table

page	frame
0	12
1	5
2	37
3	0
…	..
63	29

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R4

p = x **div** S = 42 **div** 16 = **2**

offset = x **mod** S = 42 **mod** 16 = **10**

10th byte from the beginning of frame 37

Paging: Practical Example 2

Suppose we still have a virtual memory and a physical memory, both of size $M = 1024B$

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Modern computers however operate natively on multiple of bytes (i.e., words) rather than single-byte. Typical values of word length is: 16, 32 or 64 bits.
If we assume 32-bit architecture (i.e., word = 32 bits = 4 bytes), virtual addresses refer to words instead of bytes

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R1
8 bits to address M = 1024/4 = 256 4-byte words

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Q3

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Q3

What is p and offset (i.e., how many bits for p and offset?)

R3

Our logical address is now made of m = 8 bits

n = 2 bits are used to represent the offset, as each page/frame is:

S = 16 bytes = 4 * 4-byte words

m-n = 6 bits are used to represent page number p, as there are still

T = 64 pages

Paging: Practical Example 2

Q4

Translate the virtual address $x = 7$, assuming the following page table

page	frame
0	12
1	5
2	37
3	0
…	..
63	29

Paging: Practical Example 2

Q4

Translate the virtual address $x = 7$, assuming the following page table

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Remember: now virtual address refers to a 4-byte word!

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S = 16 bytes = 4 * 4-byte words
Must be expressed in terms of number of words

R4
p = x **div** S = 7 **div** 4 = **1**

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R4

p = x **div** S = 7 **div** 4 = **1**

offset = x **mod** S = 7 **mod** 4 = **3**

3rd word from the beginning of frame 5

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- An advanced form of dynamic relocation that requires OS intervention (**Page Tables**)
- Standard paging alone can be inefficient…