



Memory Protection

Lecture 9



Memory Protection

- Memory Protection Unit
- Memory Management Unit



Memory Protection

ARM: MPU, RISC-V: PMP





Memory Management

MMU



Bibliography

for this section

1. Andrew Tanenbaum, *Modern Operating Systems (4th edition)*

- Chapter 3 - *Memory Management*
 - Subchapter 3.3 - *Virtual Memory*

2. Philipp Oppermann, *Writing an OS in Rust*

- *Introduction to Paging*
- *Paging Implementation*



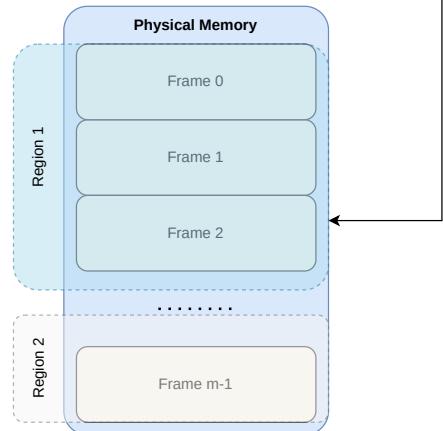
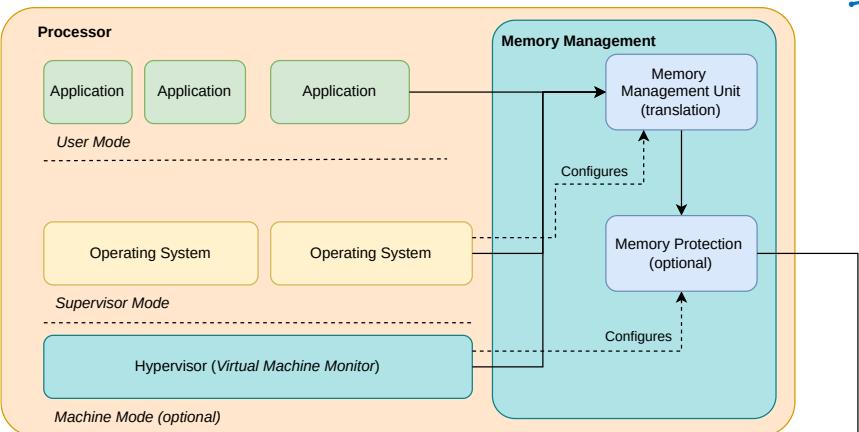
Memory Management

memory access defined page by page

- uses *logical addresses*
- **translates** to *physical addresses*

The processor works in at least two modes:

- **supervisor mode**
 - restricts access to some registers
 - accesses virtual addresses through Memory Protection (*if machine mode exists*)
- **user mode**
 - allows only ALU and memory load and store
 - accesses memory access through the Memory Management Unit (*MMU*)





Paging

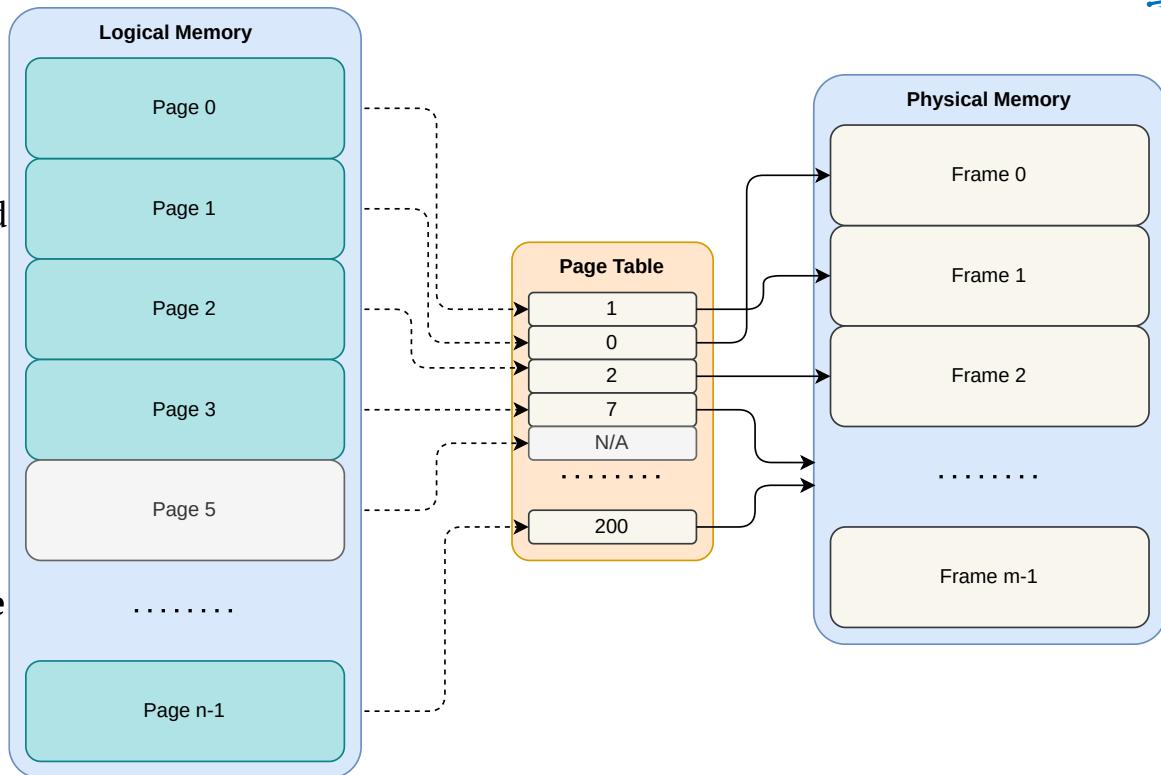
the memory *unit* is the page

- Physical Memory (*RAM*) is divided in **frames**
- Logical Memory is divided in **pages**
- **page = frame = 4 KB** (usually)

logical addresses are translated to *physical addresses* using a **page table**

the **page table** is located in the **physical memory**

- each memory access requires at least 2 memory accesses





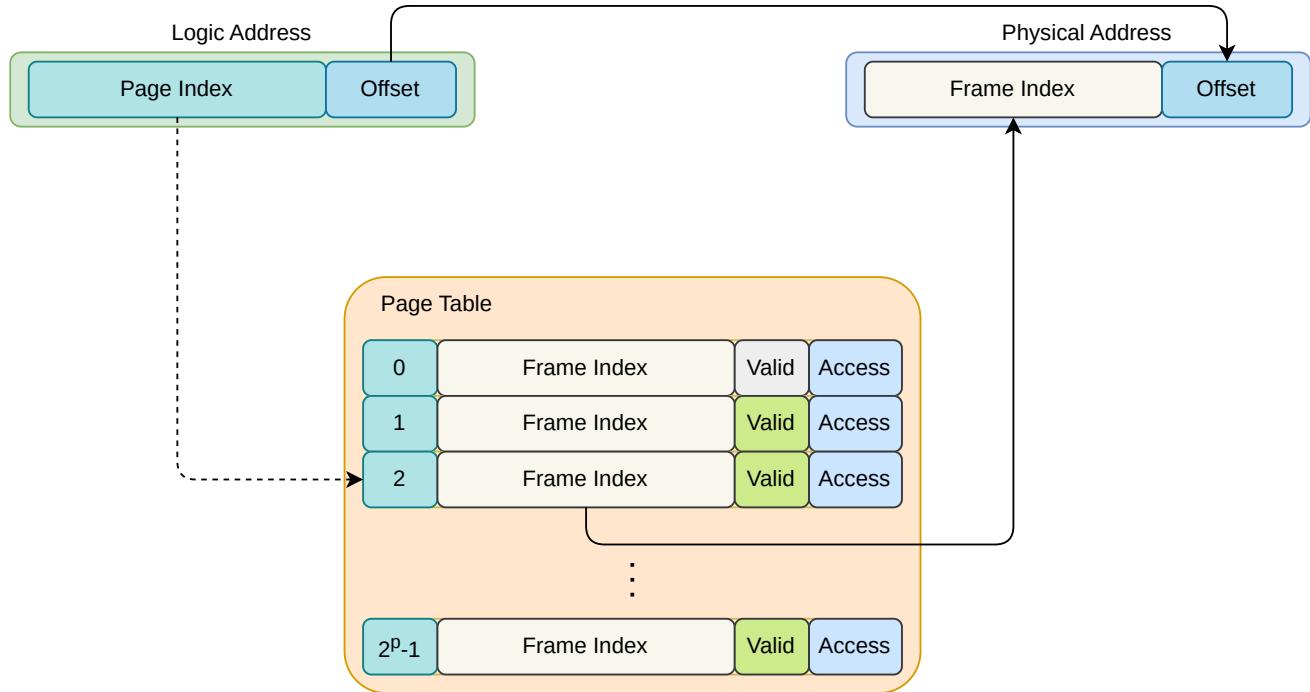
Address Translation

page to frame

the logic address is divided
in two parts:

- *page index*
- *offset* within the page

the MMU translates every
logic address into a
physical address using a
page table





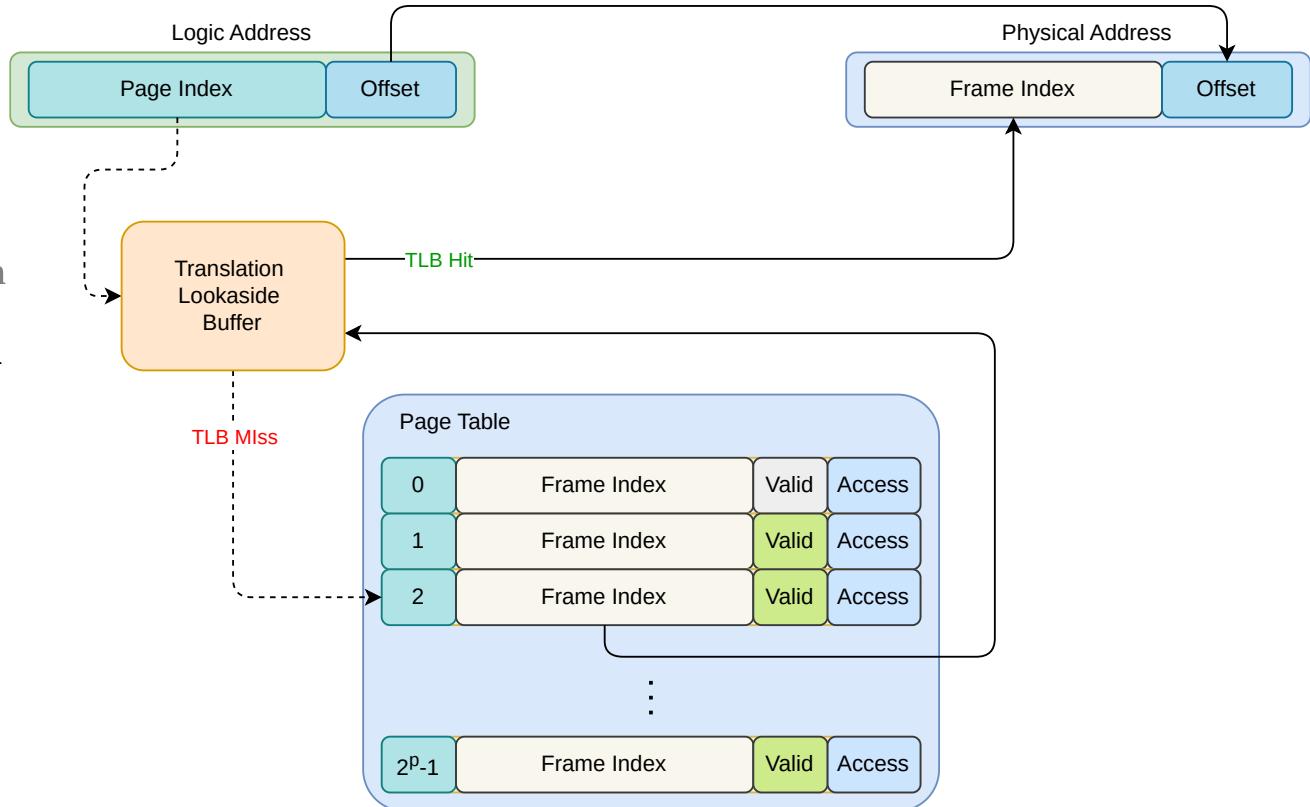
Translation Lookaside Buffer (TLB)

caching address translation

the **page table** is stored in RAM

each memory access requires 2 accesses

1. read the page table entry to translate the address
2. the requested access





Page Directory

caching address translation

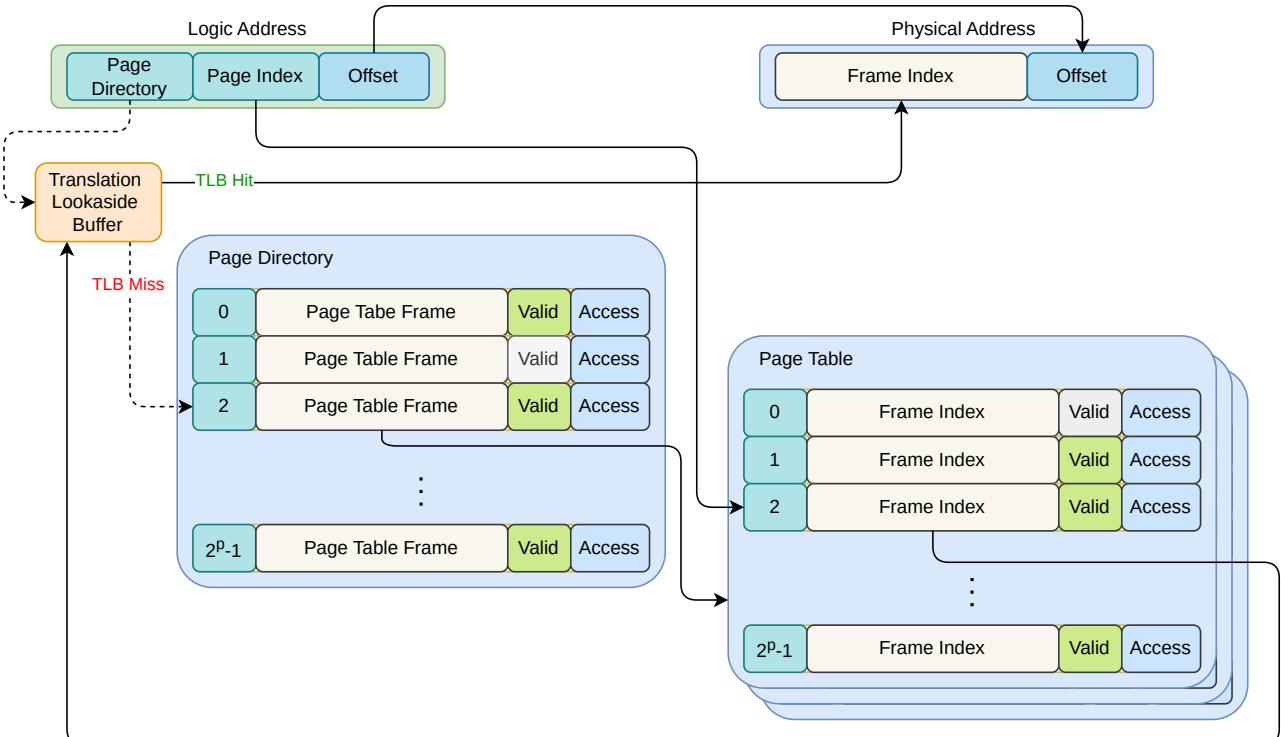
$$size_{table} = \frac{size_{ram}}{size_{page}}$$

- each table entry is 4B
- the address space is 4GB
(for 32 bits processors)

$$size_{table_32_bits} = \frac{2^{32}}{4 \times 2^{10}}$$

$$size_{table_32_bits} = 4MB$$

RAM was counted in MB
when paging started being
used



two levels, page directory and table, usually used for 32 bits systems



Page Table Entry

for x86 - 32 bits

this is one entry of the page table

- **P** - is the page's frame present in RAM?
- **R/W** - read only or read write access
- **U/S** - can the page be accessed in user mode?
- **D** and **A** - has this page been written since the OS has reset these bits?
- **AVL** - bits available for the OS to use, ignored by MMU

Frame Number															
15	12	11	9	8	7	6	5	4	3	2	1	0			
Frame Number	AVL	G	PAT	D	A	PCD	PWT	U/S	R/W	P					
available for OS	Global	Attributes	Dirty	Accessed	Cache	0 - W Back 1 - W Through	0: User 1: Super	0: User 1: Super	0 - R 1 - RW	0: Invalid 1: Valid					

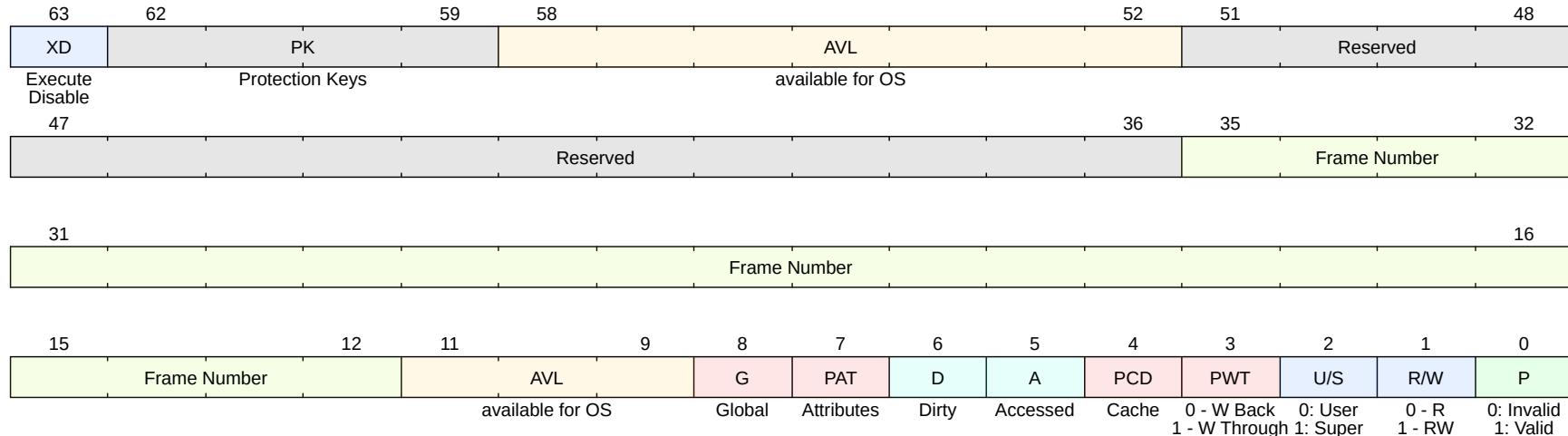


Page Table Entry

for x86 - 32 bits with PAE

this is one entry of the page table using Physical Address Extension (*PAE*)

- **XD** - eXecute Disable (aka *DEP*), if set triggers a fault if an instruction is read from the page
- **PK** - Protection Keys, allows user mode to set protection (64 bit only)





Microcontroller (MCU)

Integrated in embedded systems for certain tasks

- low operating frequency (MHz)
- a lot of I/O ports
- controls hardware
- does not require an Operating System
- costs \$0.1 - \$25
- uses **Memory Protection Unit**



Microprocessor (CPU)

General purpose, for PC & workstations

- high operating frequency (GHz)
- limited number of I/O ports
- usually requires an Operating System
- costs \$75 - \$500
- uses **Memory Management Unit**





Conclusion

we talked about

- Memory Protection Unit
- Memory Management Unit