Sistemi Operativi I

Corso di Laurea in Informatica

2025-2026

SAPIENZA
UNIVERSITÀ DI ROMA

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Where Do We Stand?

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  - Processes and Threads
  - CPU Scheduling
  - Synchronization and Deadlock

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  - Synchronization and Deadlock
- Today, we will be talking about:
  - Memory Management
- … Later on:
  - File Systems and I/O Storage
  - Advanced Topics (?)

Part IV: Memory Management

Goals of Memory Management

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- Allocate memory resources among multiple competing processes
  - maximizing memory utilization and system throughput
- Guarantee isolation between processes
  - addressability and protection
- Provide a convenient abstraction to the programmer
  - illusion of unlimited amount of memory

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  1) **Translated** from source code to binary executable and stored on disk
  2) **Loaded** from disk into main memory (RAM)

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NOTE:
In case of purely-interpreted language implementations, translation from source code to executable is done "on-the-fly" by the loaded interpreter

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How?

Generating Memory Addresses: Example

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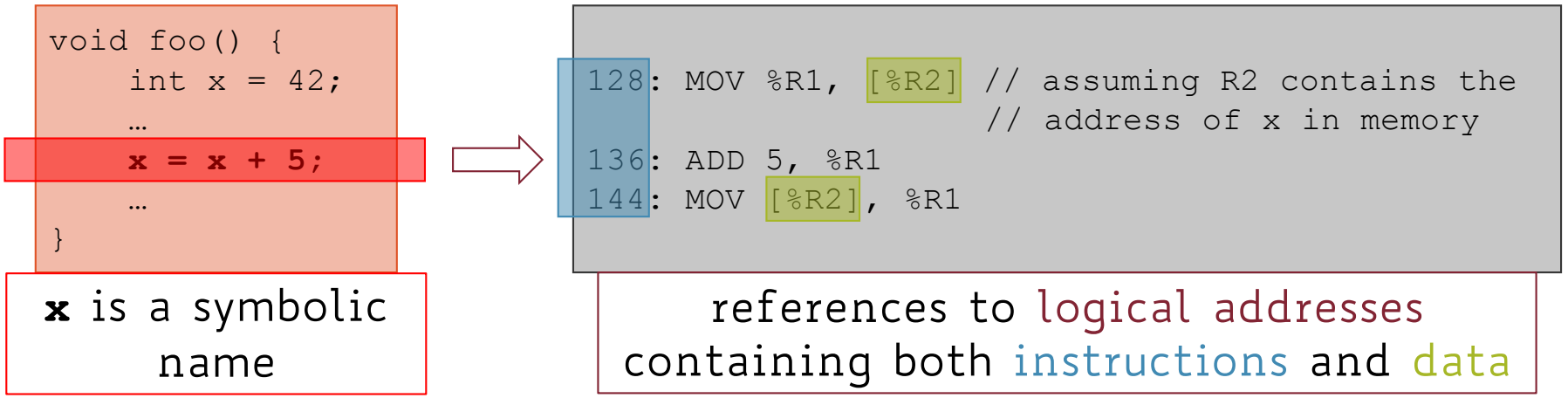

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1. Fetch instruction at address `128`
2. Execute istruction: load from address `[%R2]` (e.g., `1234`)
3. Fetch instruction at address `136`
4. Execute instruction: addition (no memory reference)
5. Fetch instruction at address `144`
6. Execute instruction: store to address `[%R2]` (`1234`)

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physical address: actual memory address which memory chip operates on

Address Binding

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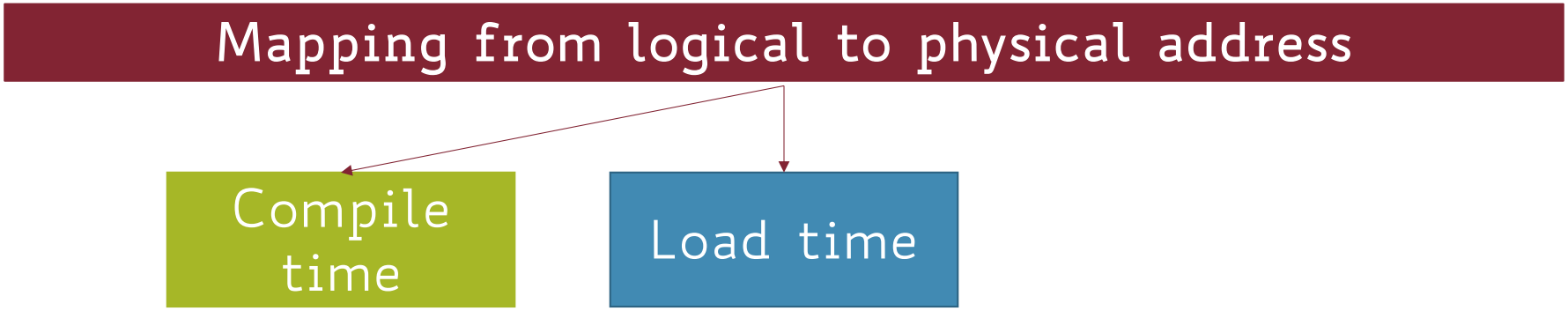

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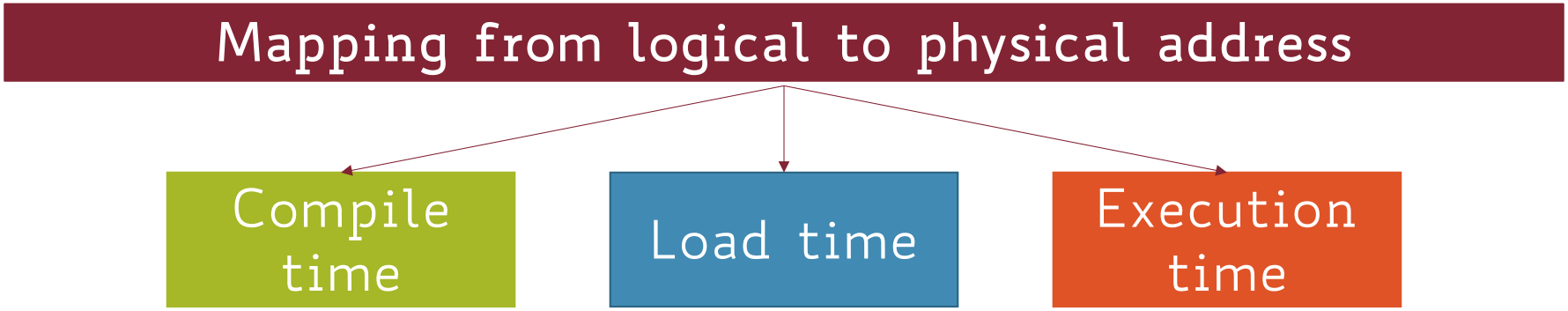

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The program must be recompiled!

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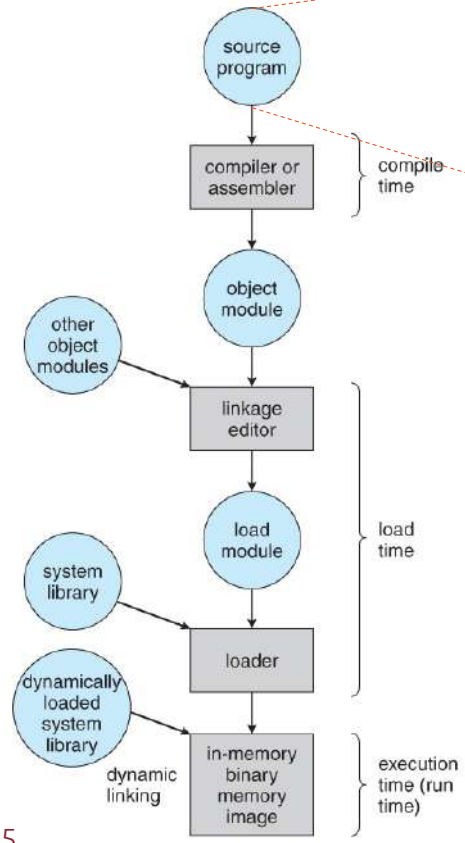


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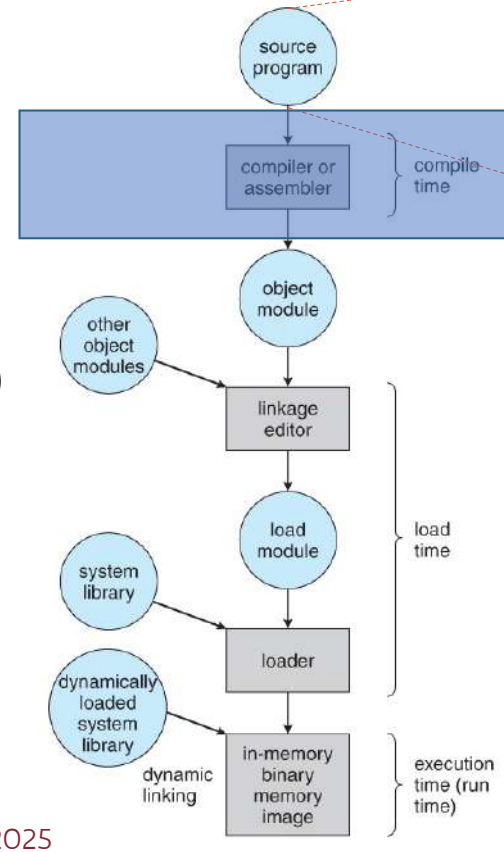


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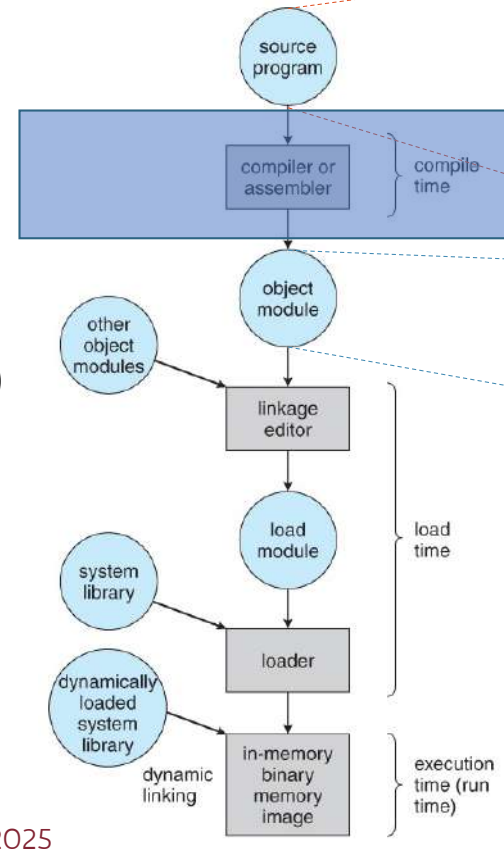


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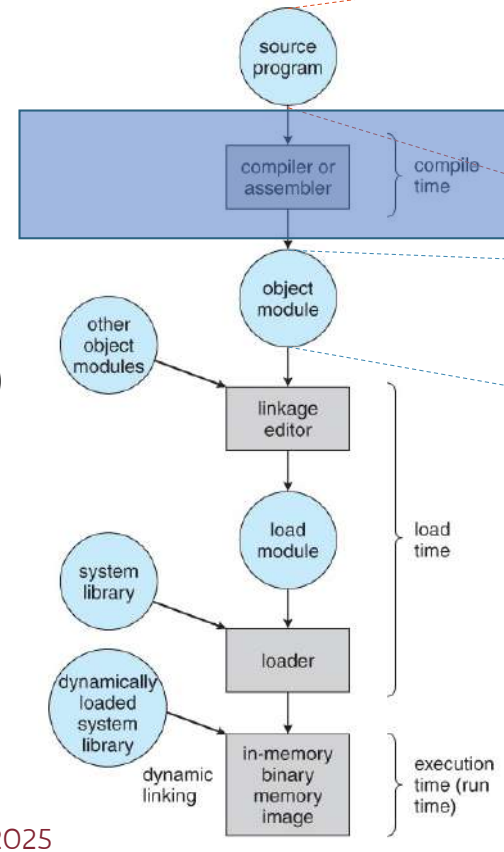


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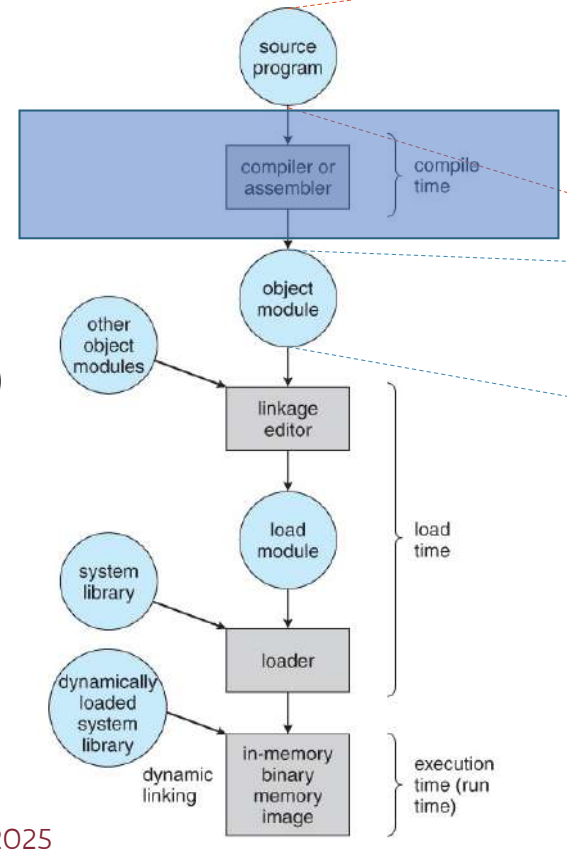


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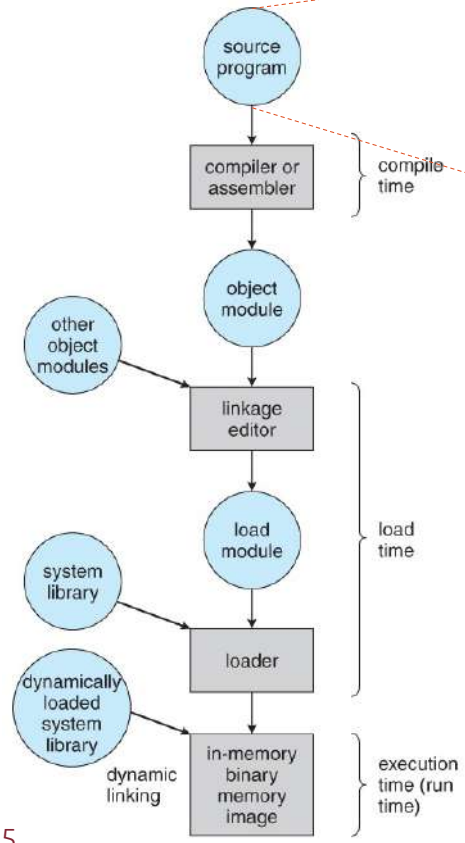


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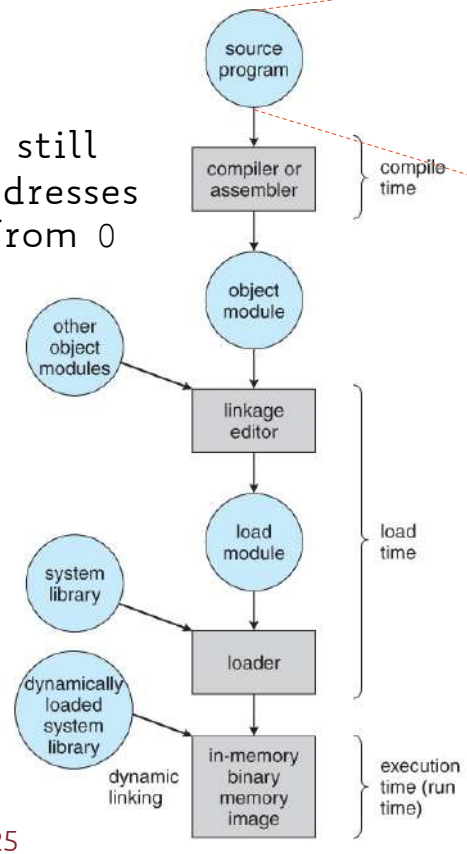


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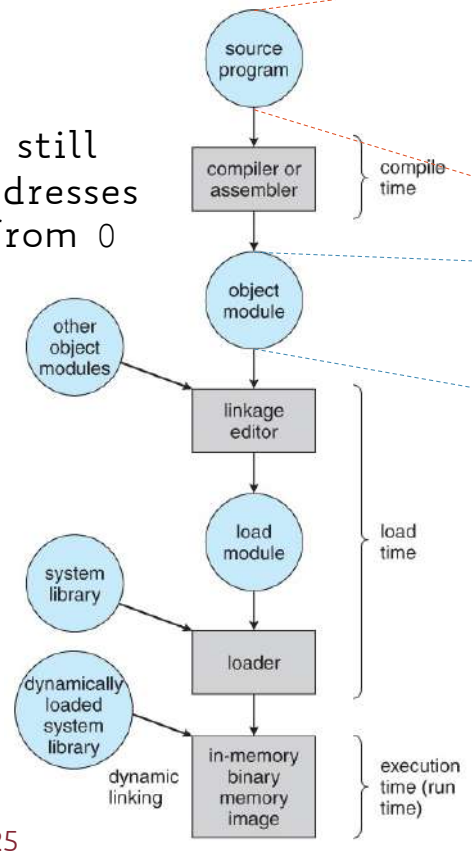


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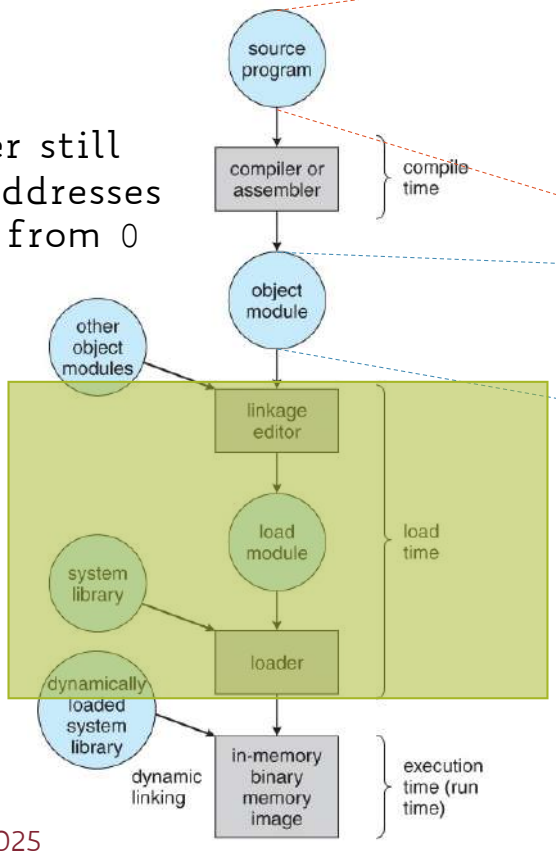


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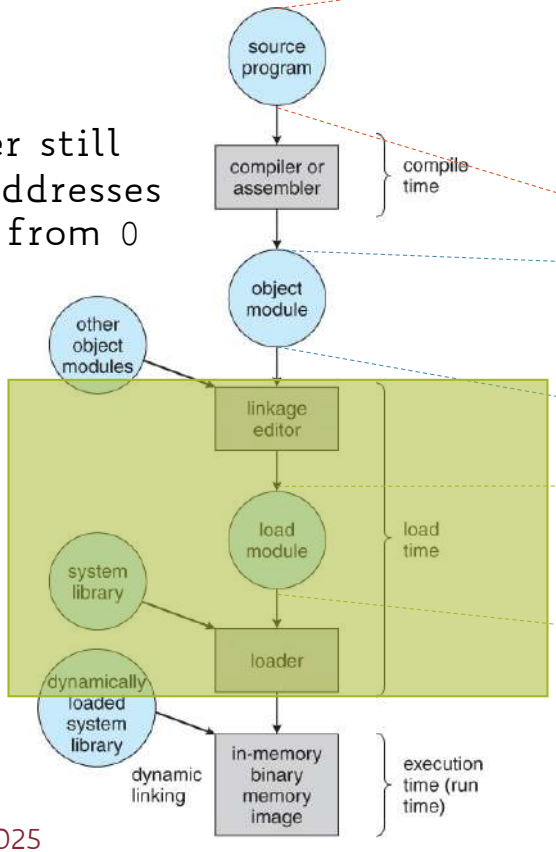


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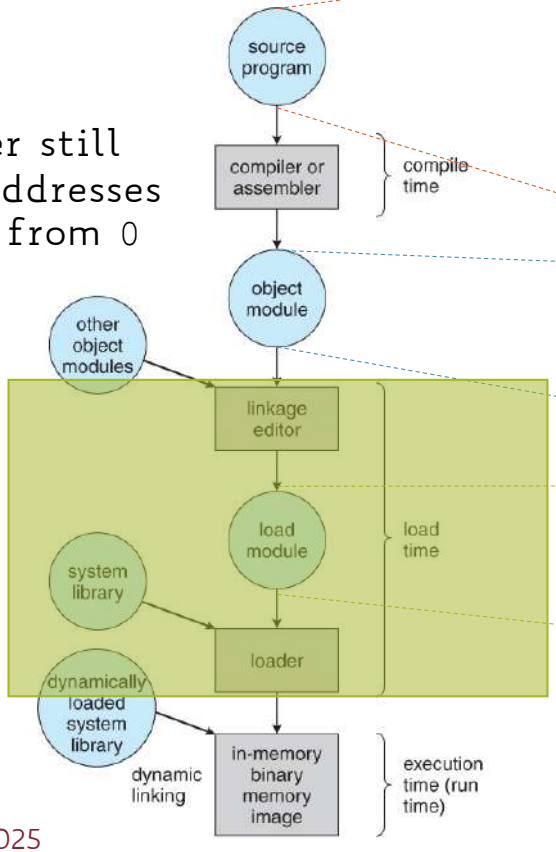


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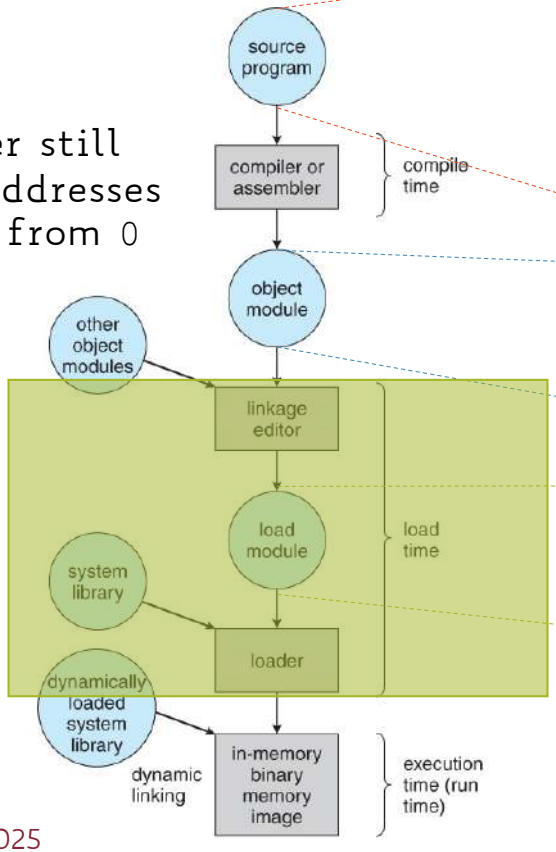


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Most flexible solution implemented by the majority of modern OSs

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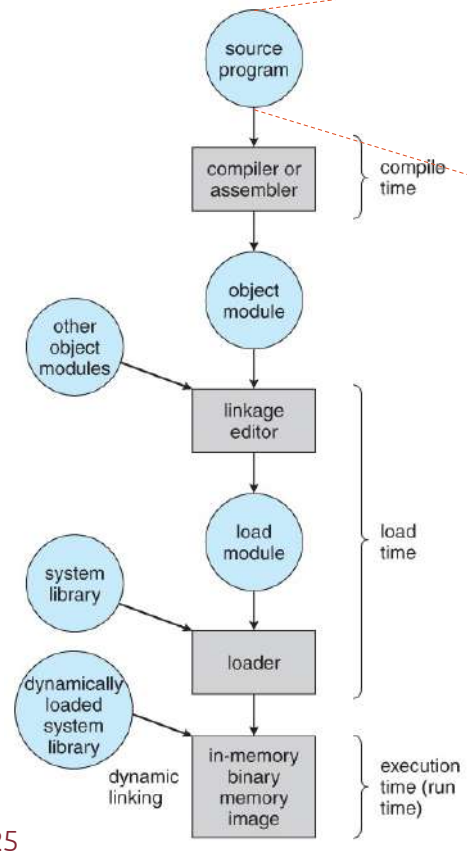


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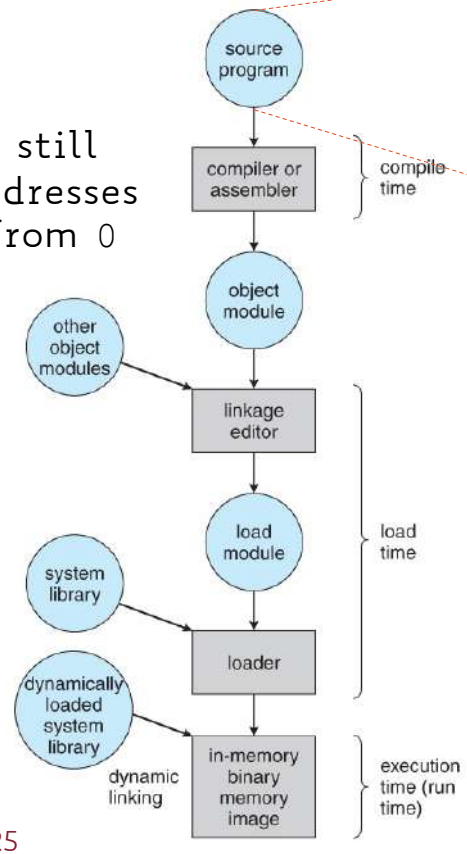


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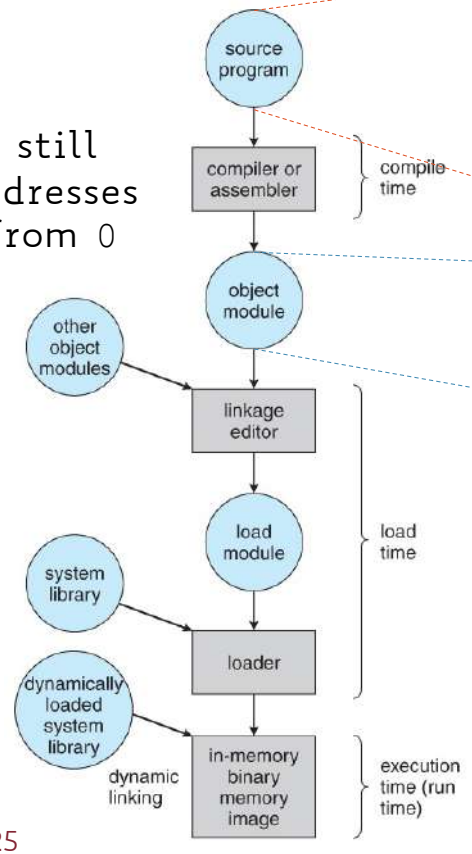


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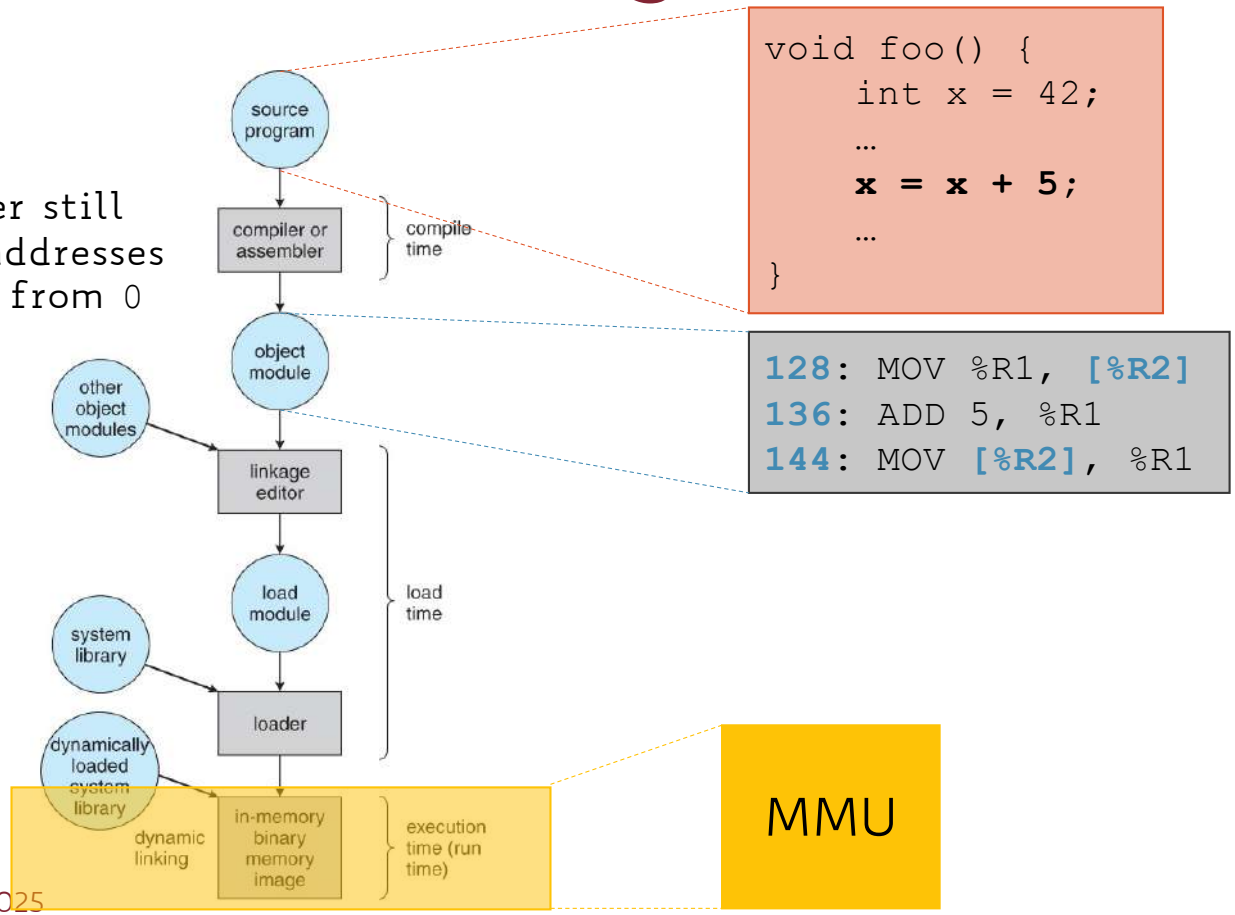


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MMU

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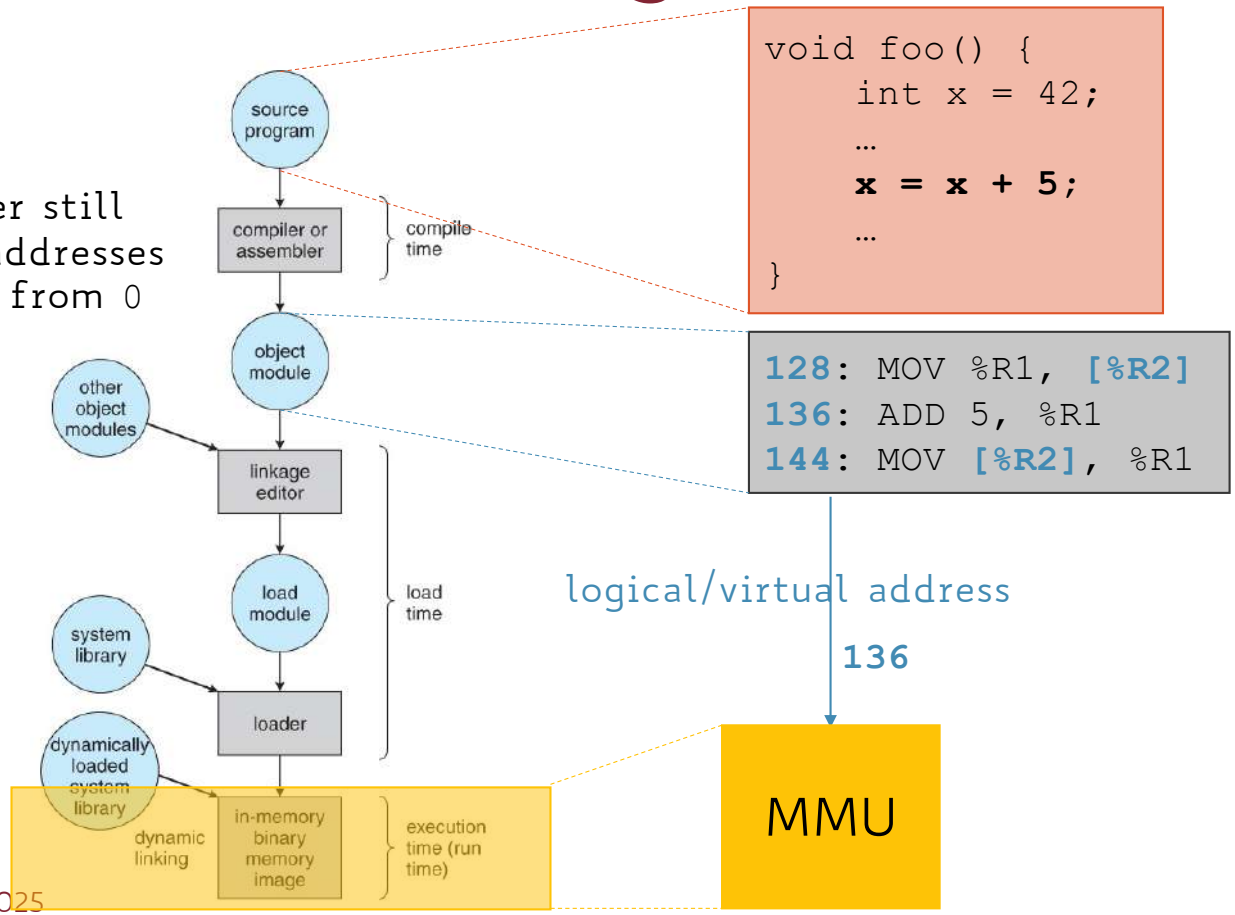

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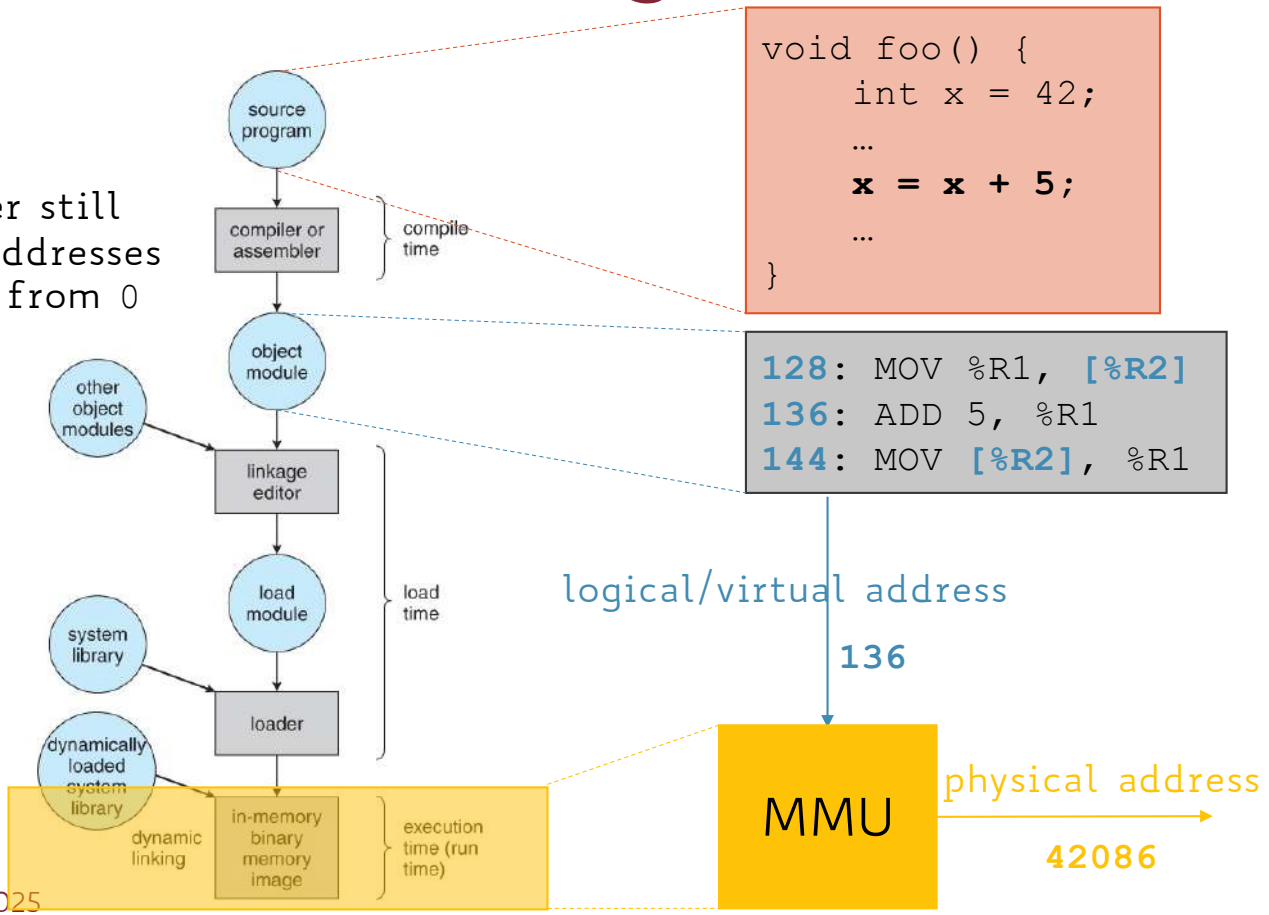

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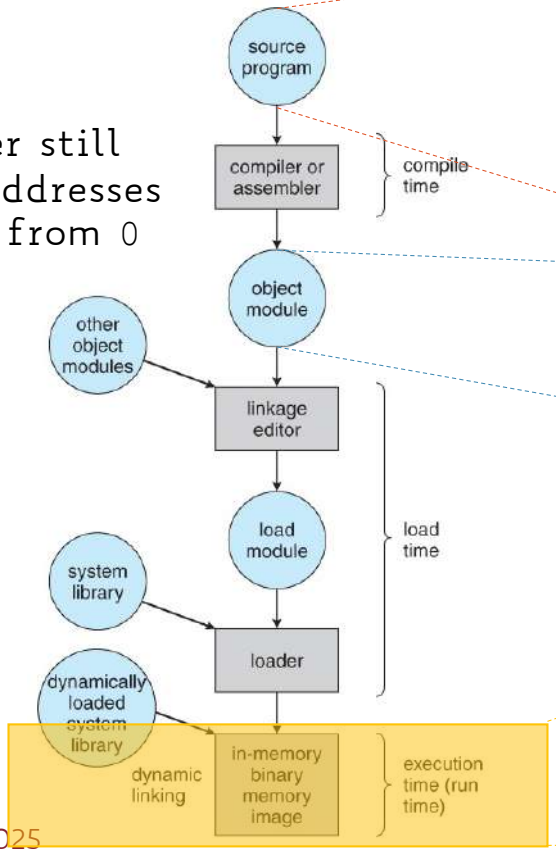


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logical/virtual address

136

MMU

physical address

42086

Every logical address referenced by the CPU is translated by HW at run time

physical addresses != logical addresses

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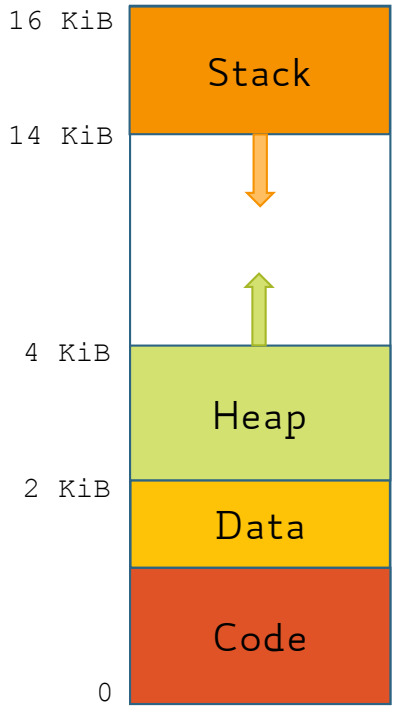
Don't worry! We will soon relax those assumptions

Managing Memory: VAS

`virtual address space = 16 KiB`



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  - Processes should not be aware of which portions of physical memory they are assigned to

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  - CPU and memory performance should not degrade badly due to sharing
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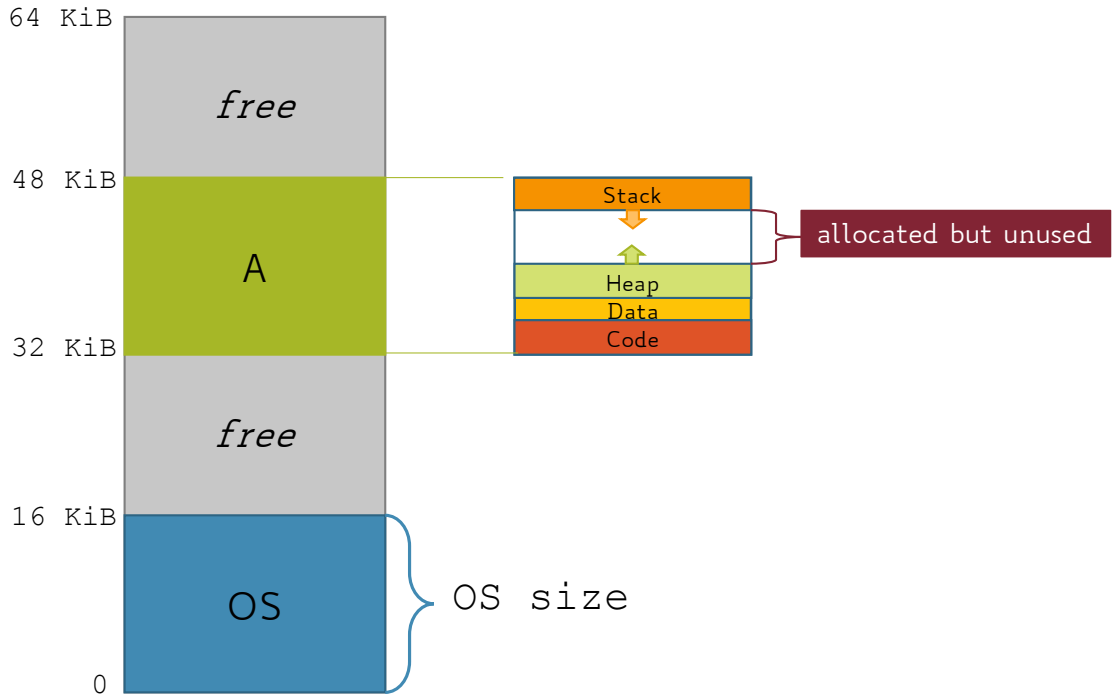
- Allow transparent sharing of memory: each process' address space may be placed anywhere in memory

Managing Memory: VAS Relocation

RAM size = 64 KiB

OS size = 16 KiB



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- CONs:
  - No protection/privacy → processes can corrupt the OS or other processes
  - Address space must be entirely allocated contiguously → free space between stack and heap can be huge and wasted!
  - The OS cannot move a process (address space) once allocated in memory

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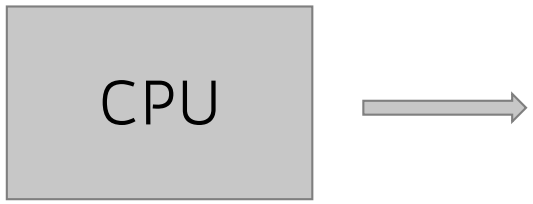

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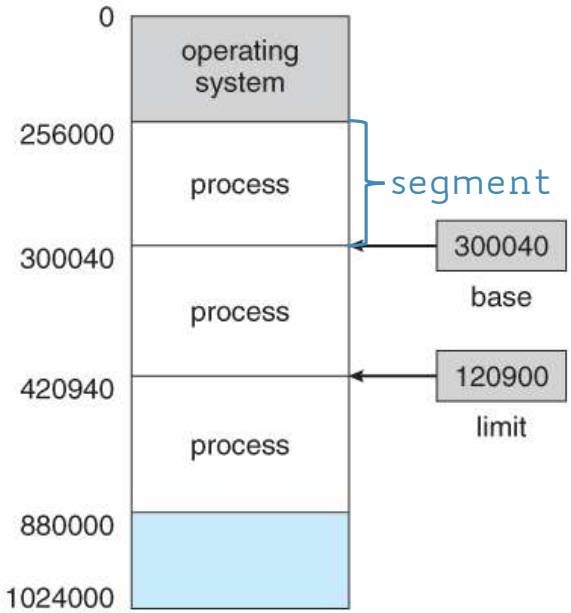
    - while executing process instructions on the CPU

Base and Limit Registers: Idea



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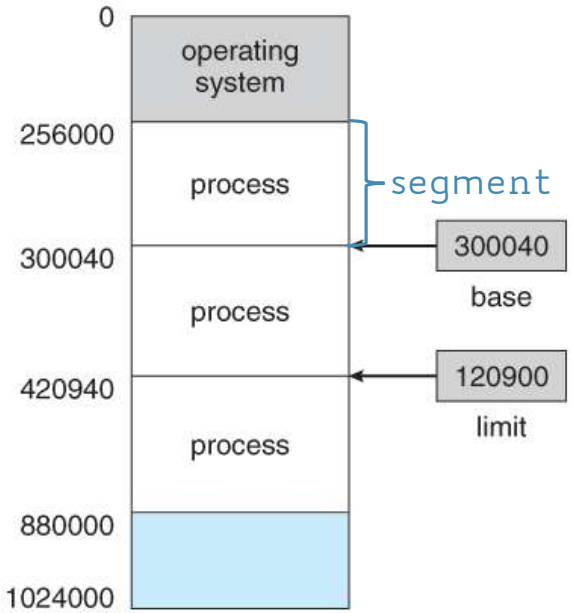

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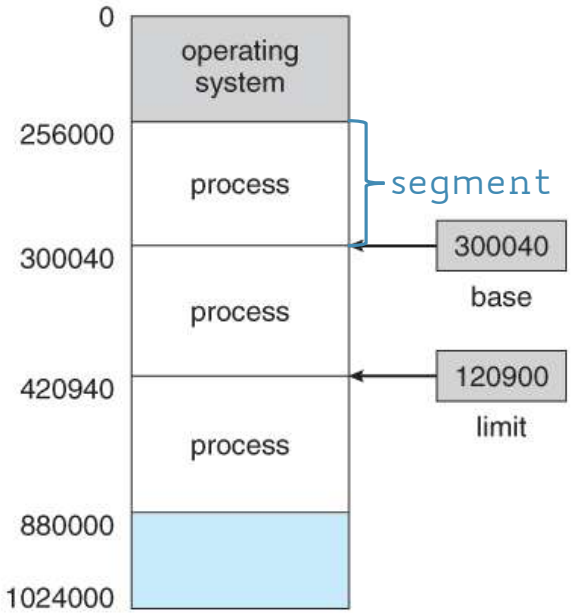

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Protection implemented using two MMU registers: base and limit

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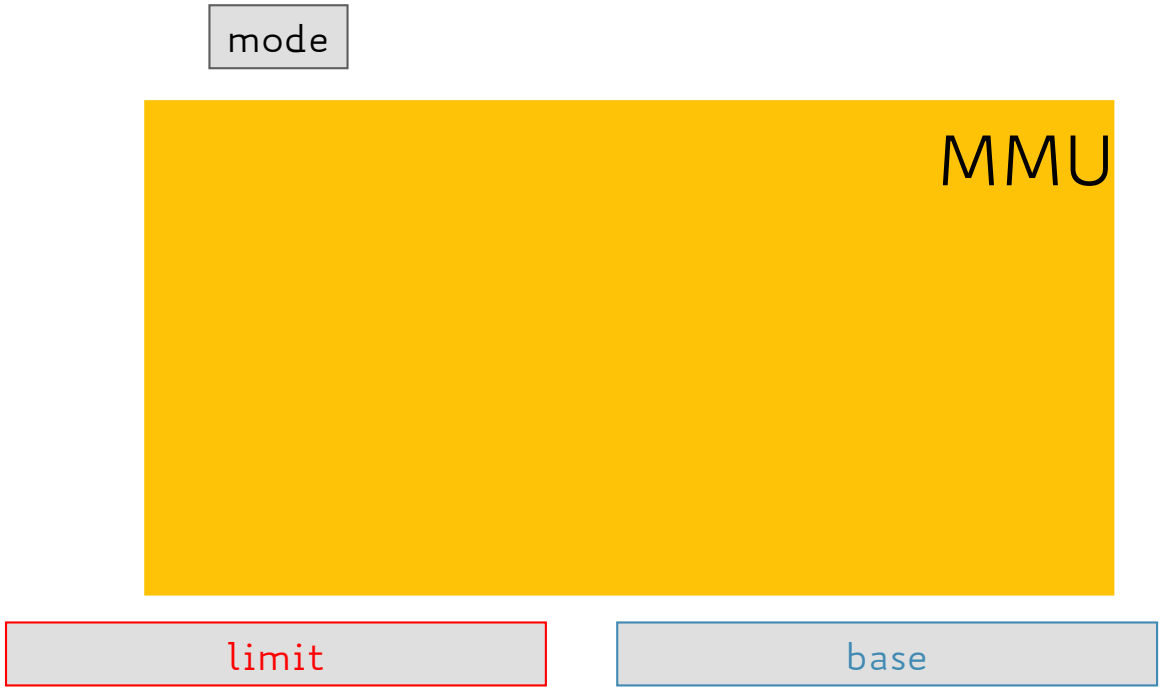

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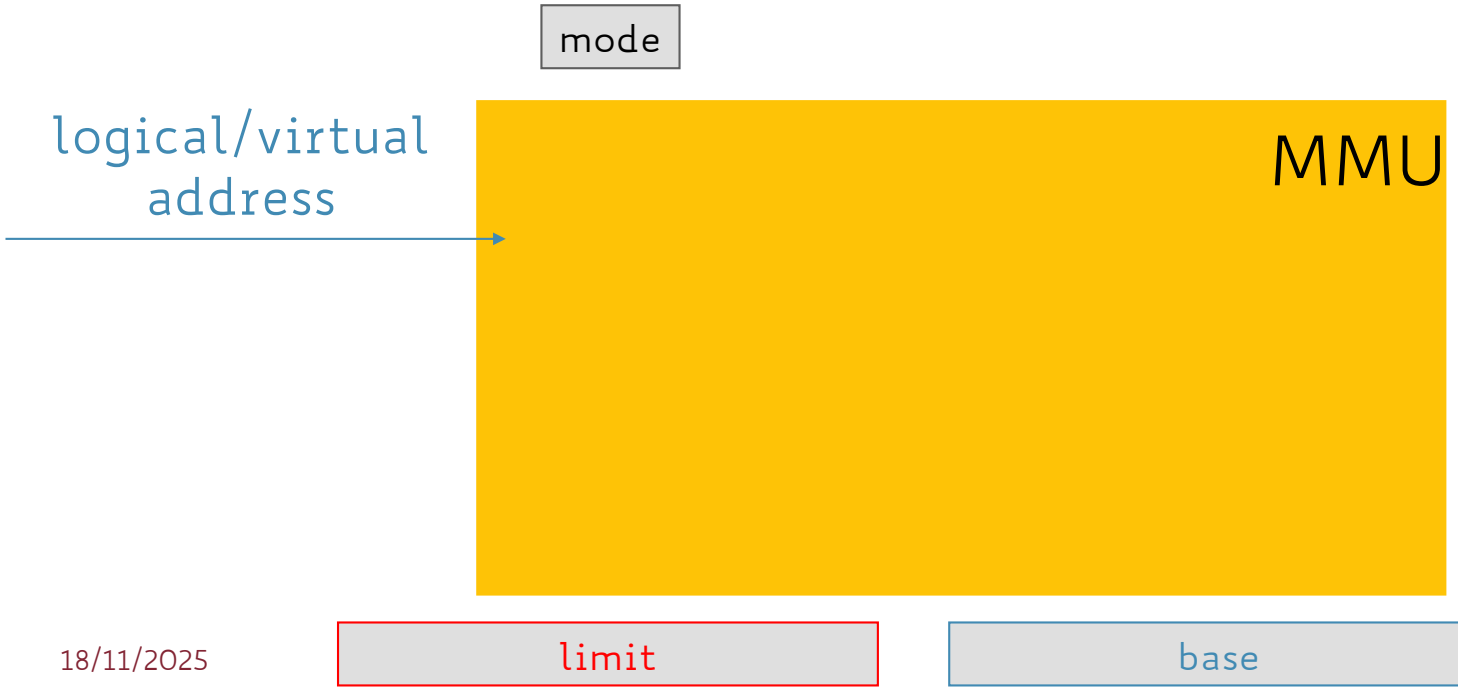

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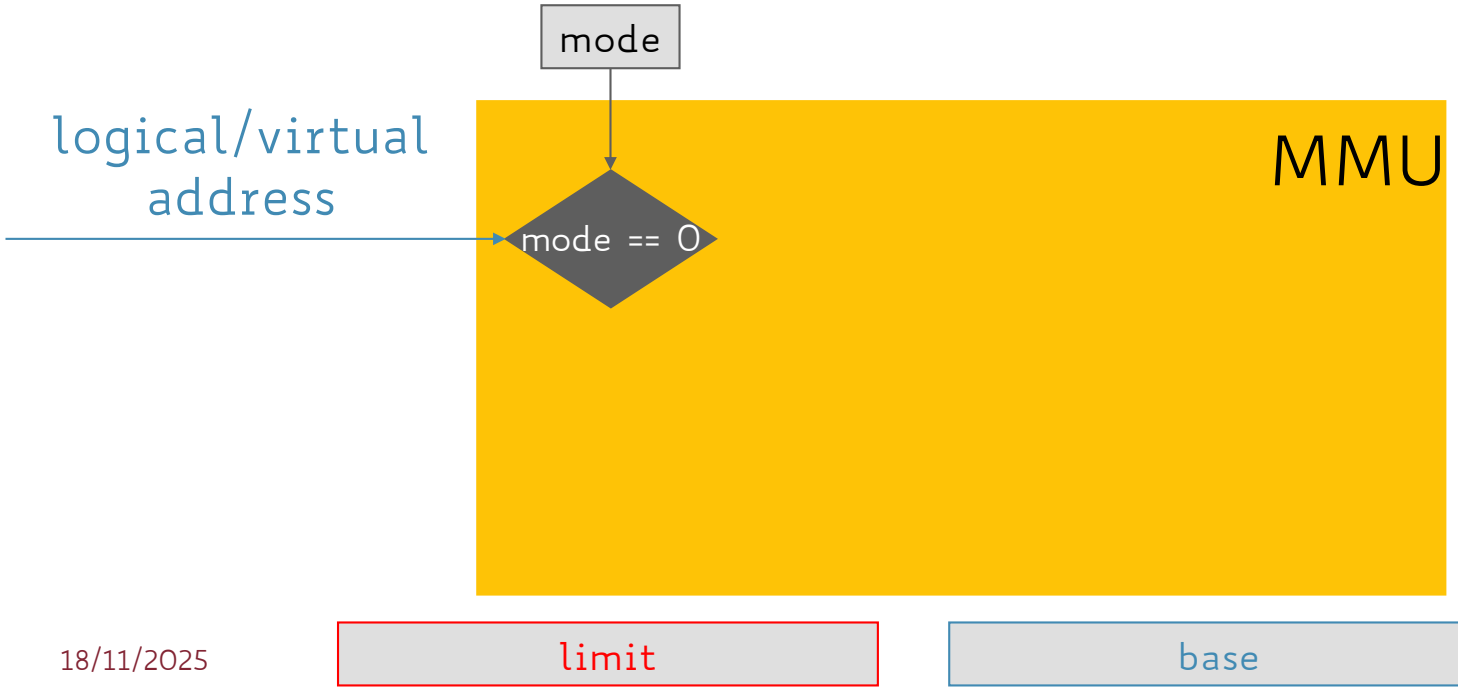

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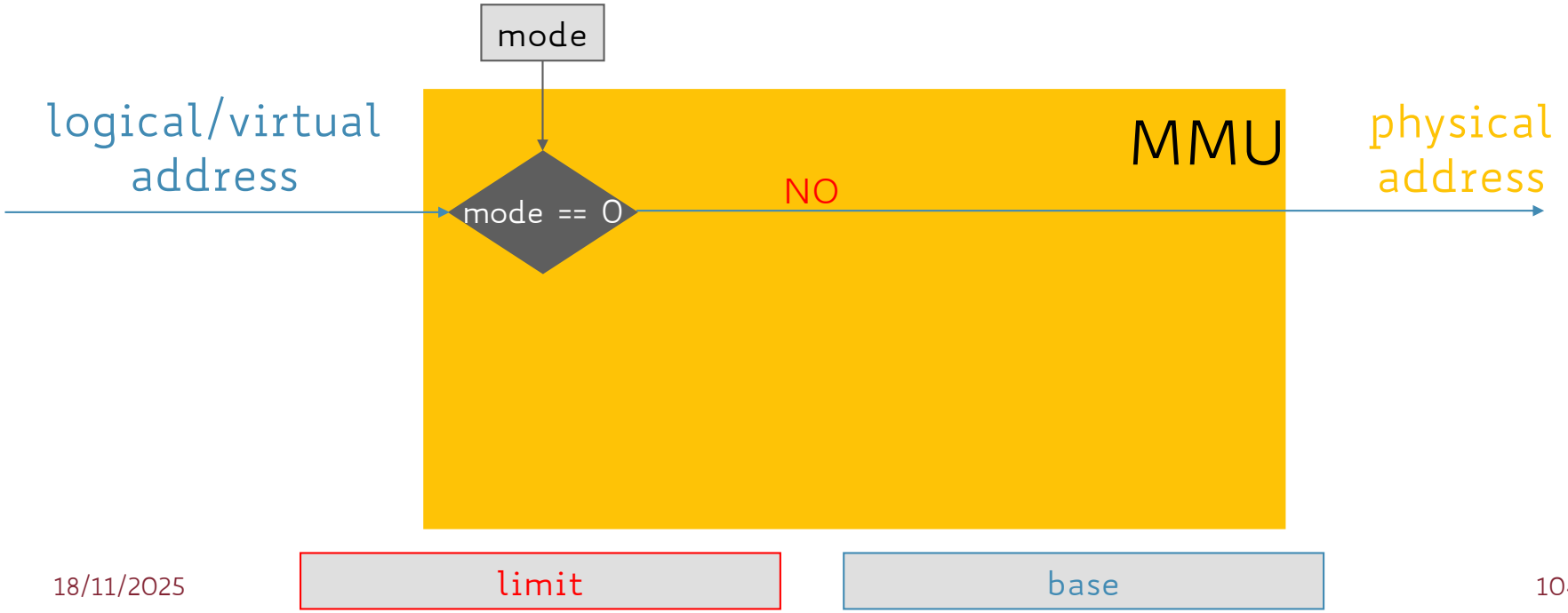

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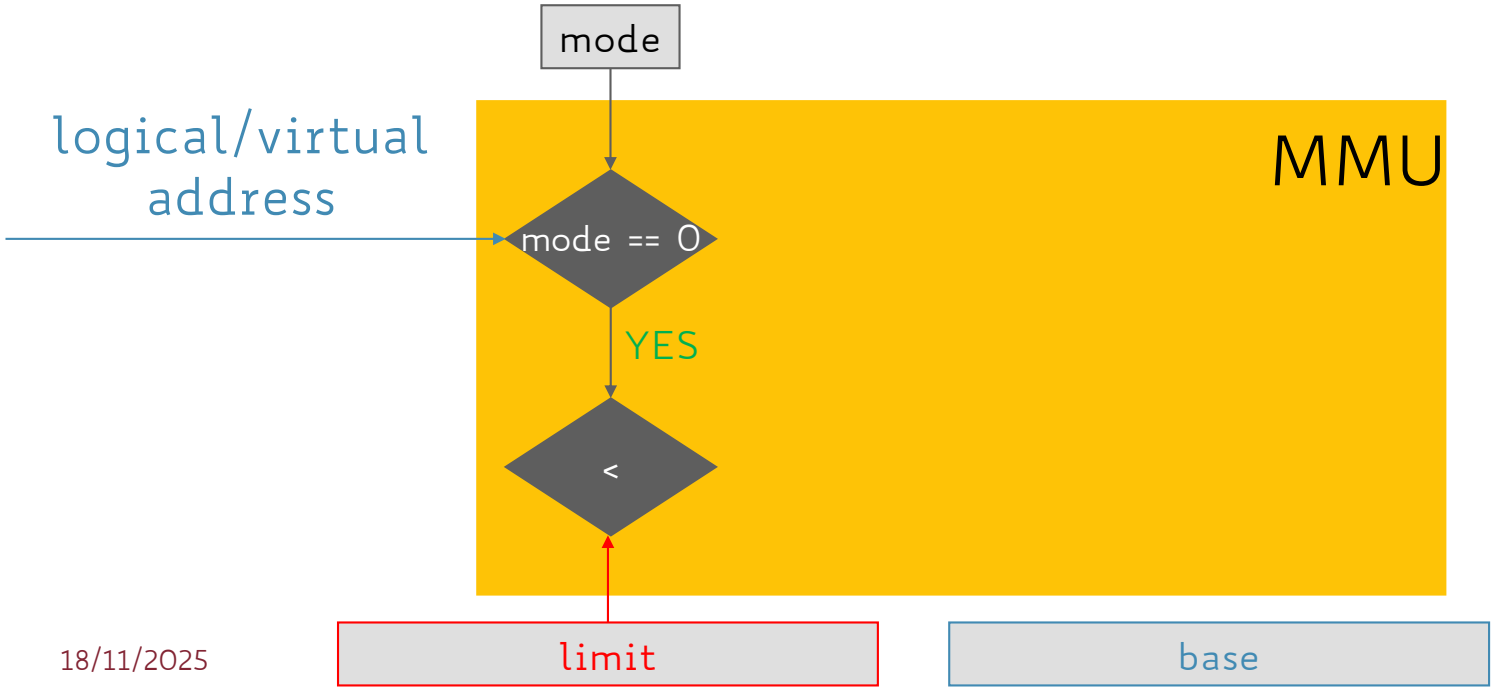

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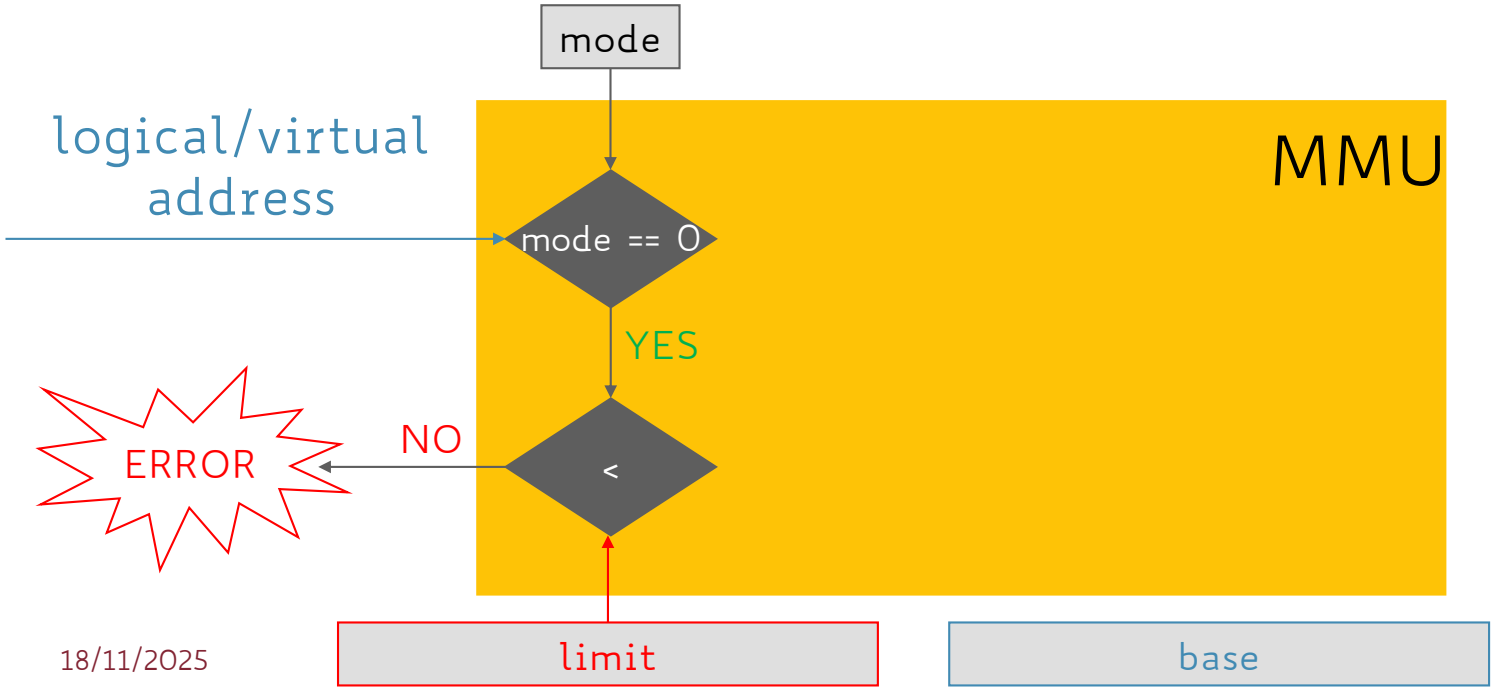

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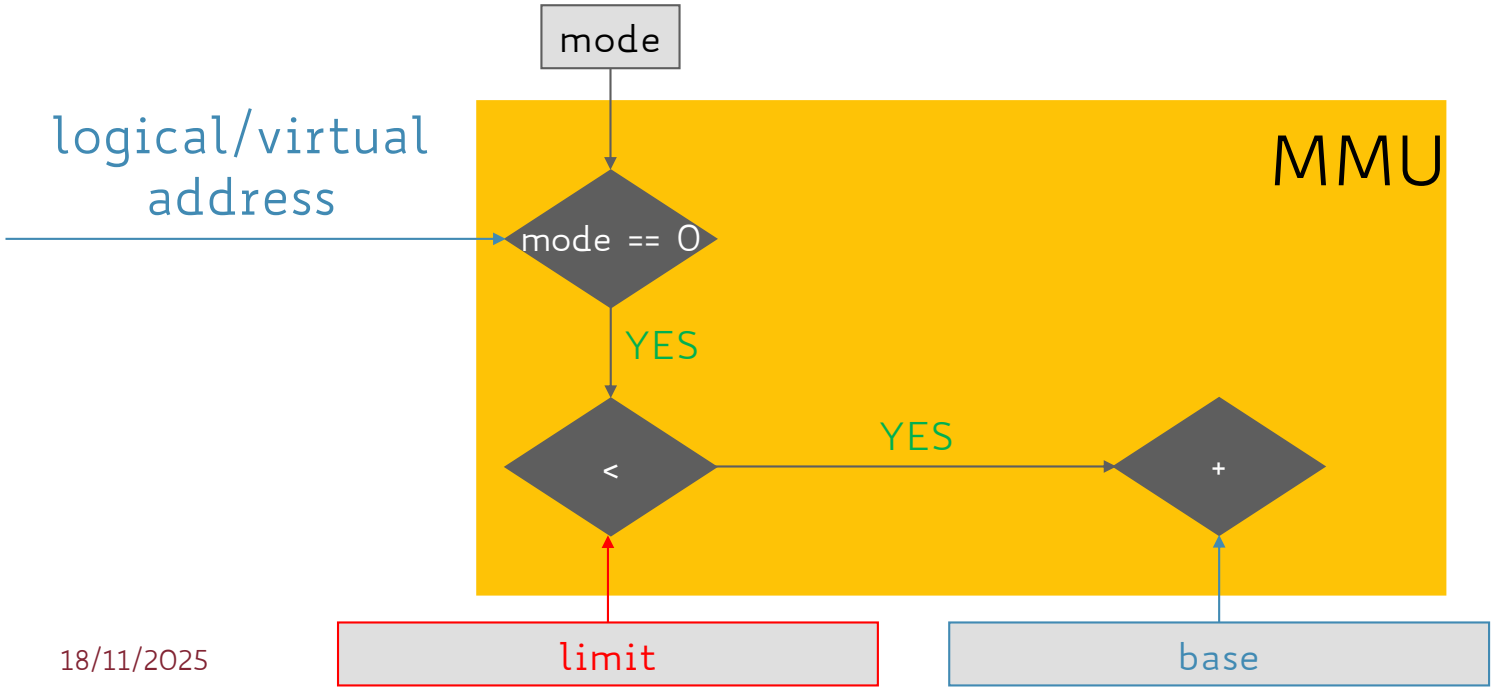

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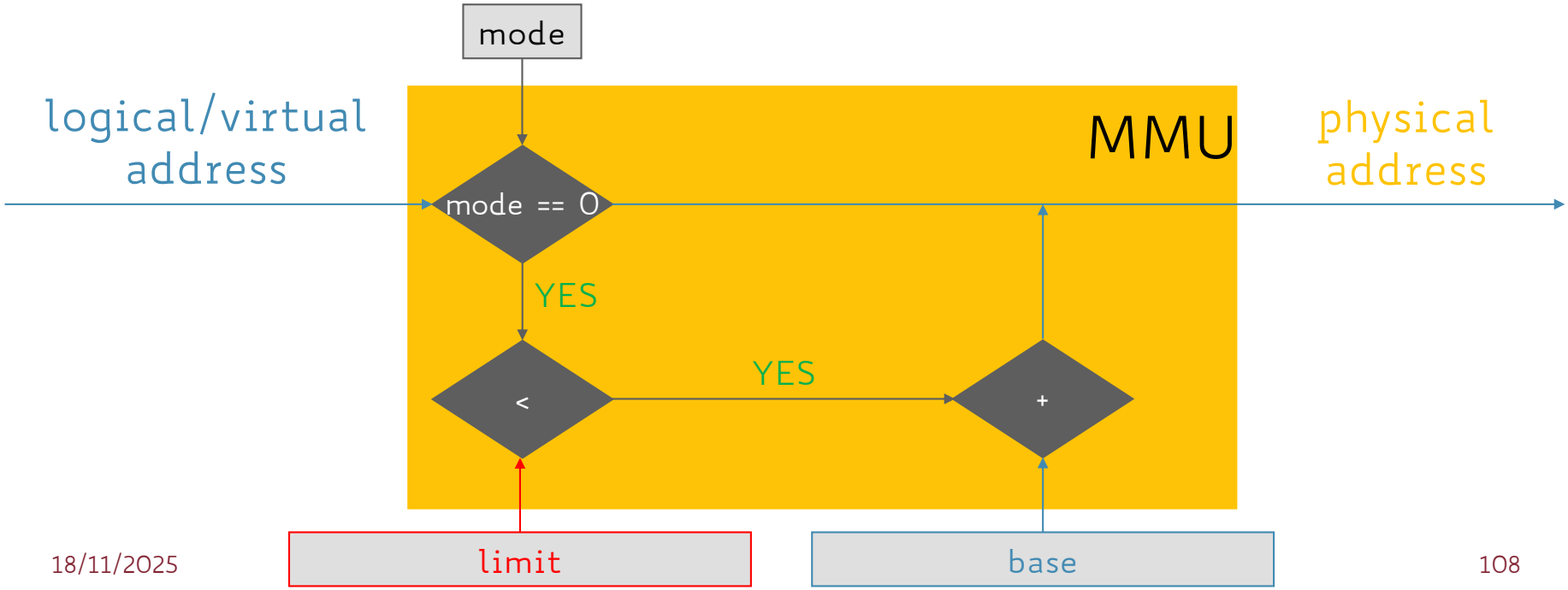

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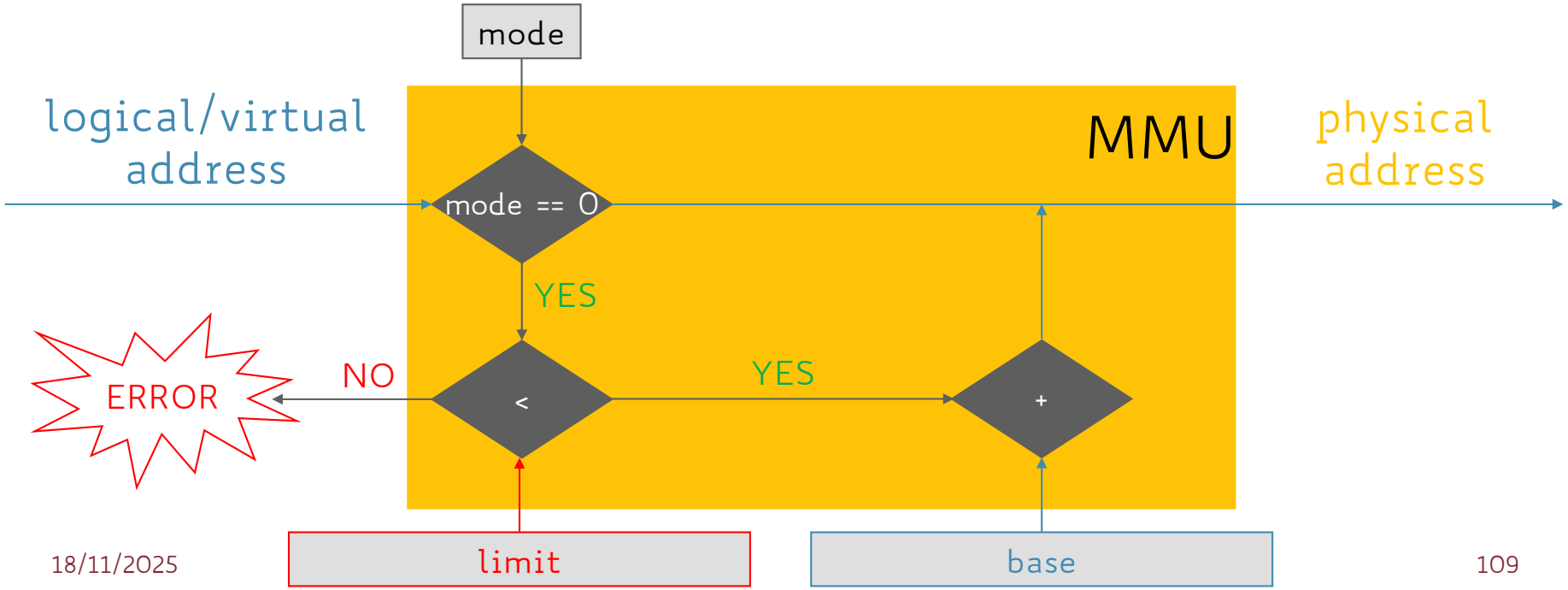

Dynamic Relocation

- PROs:
  - Provides protection (both read and write) across address spaces
  - OS can easily move a process during execution
  - OS can allow process to dynamically grow over time
  - Simple, fast hardware implementation (MMU):
    - 2 special registers, one add and one compare operation (can be done in parallel)

Dynamic Relocation

- CONs:
  - Little hardware overhead to pay at each memory reference
  - Each VAS of a process must still be allocated contiguously in physical memory (possible memory waste, e.g., stack/heap) → **segmentation**
  - Degree of multiprogramming is bound since all VAS of all active processes must fit entirely in memory → **paging**
  - Process is still limited to physical memory size → **virtual memory**

To Wrap Up

- Modern OSs manage memory ensuring:
  - Transparency → logical/virtual vs. physical address space
  - Protection/Flexibility → dynamic relocation
  - Efficiency → hardware support (e.g., MMU)
- We are still assuming the whole virtual address space of a process is fully and contiguously loaded in main memory → **serious limitation!**

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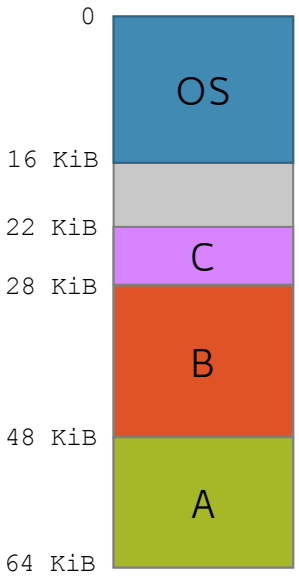

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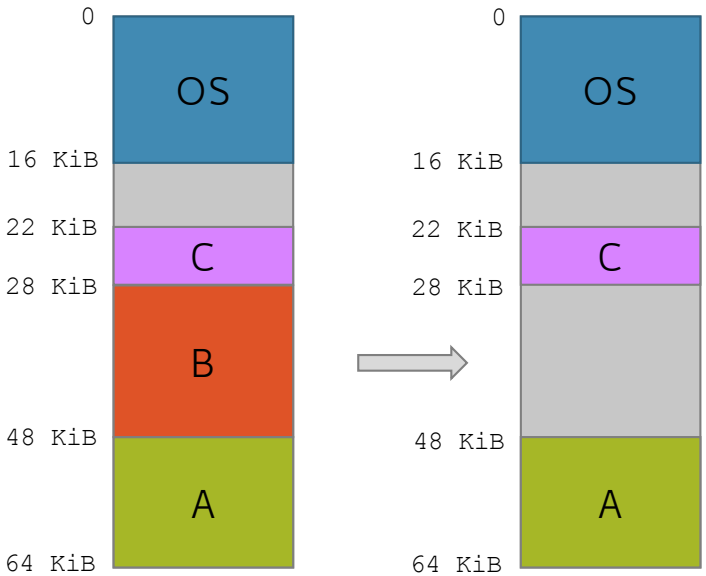

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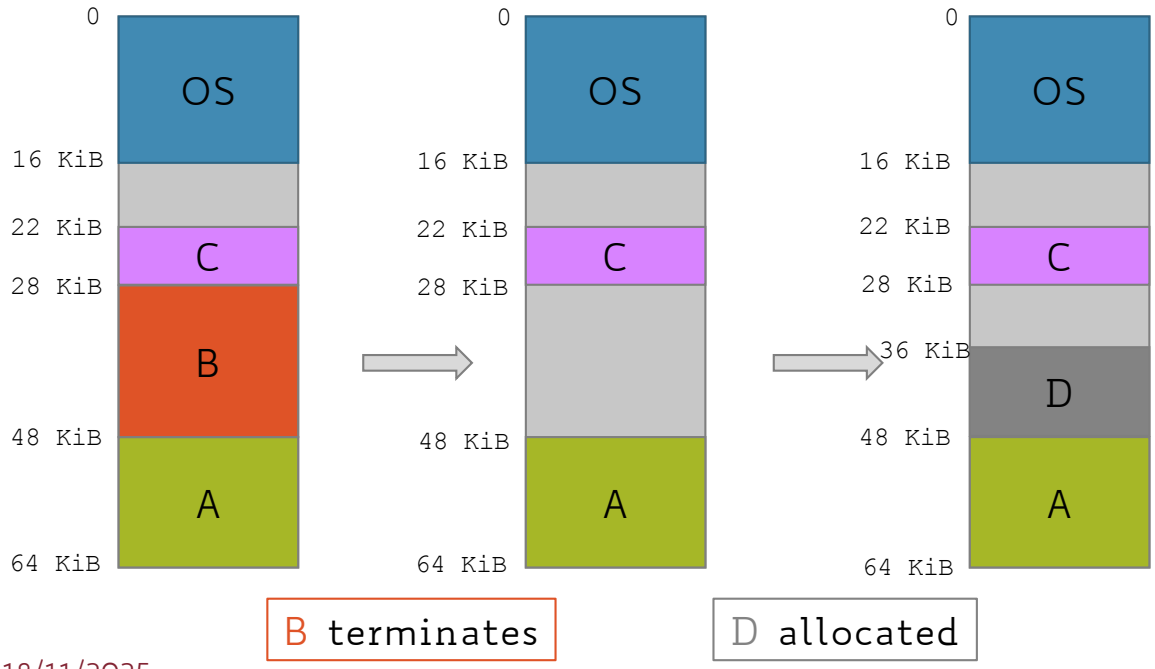

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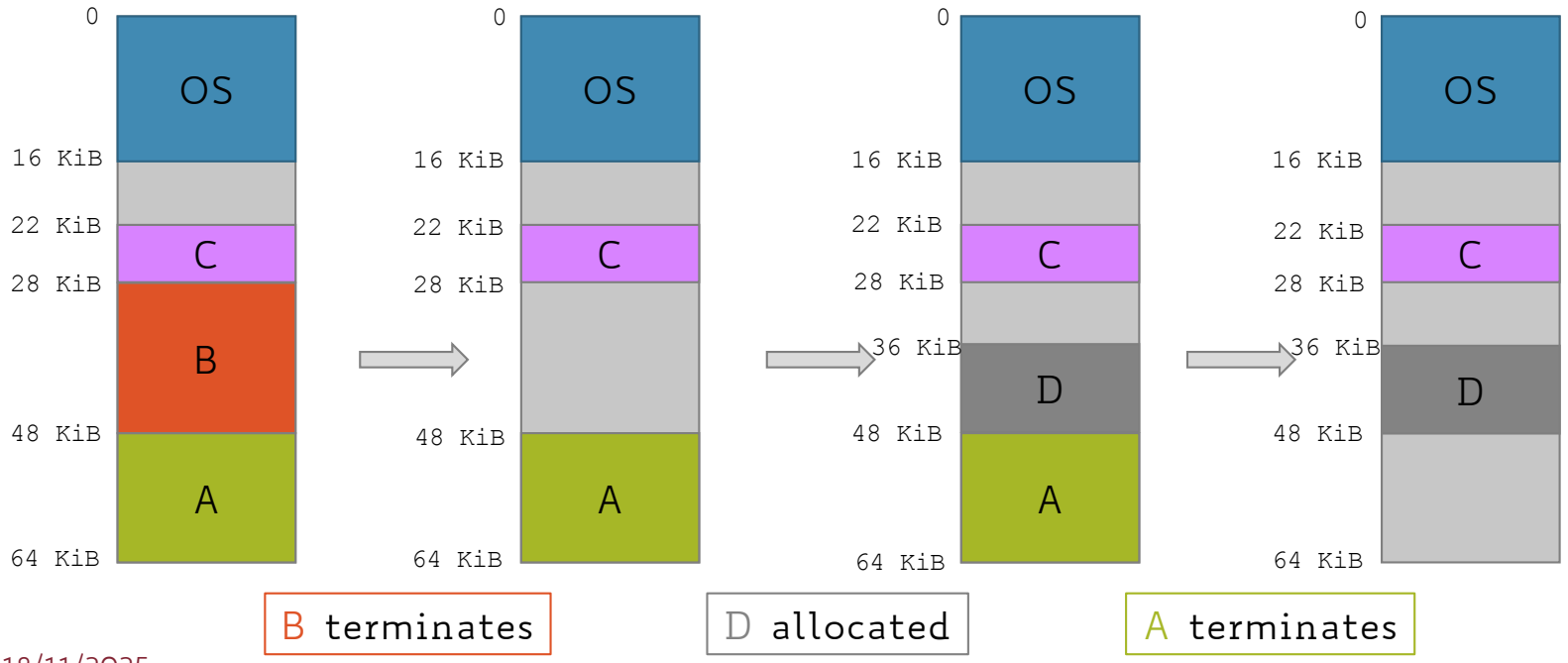

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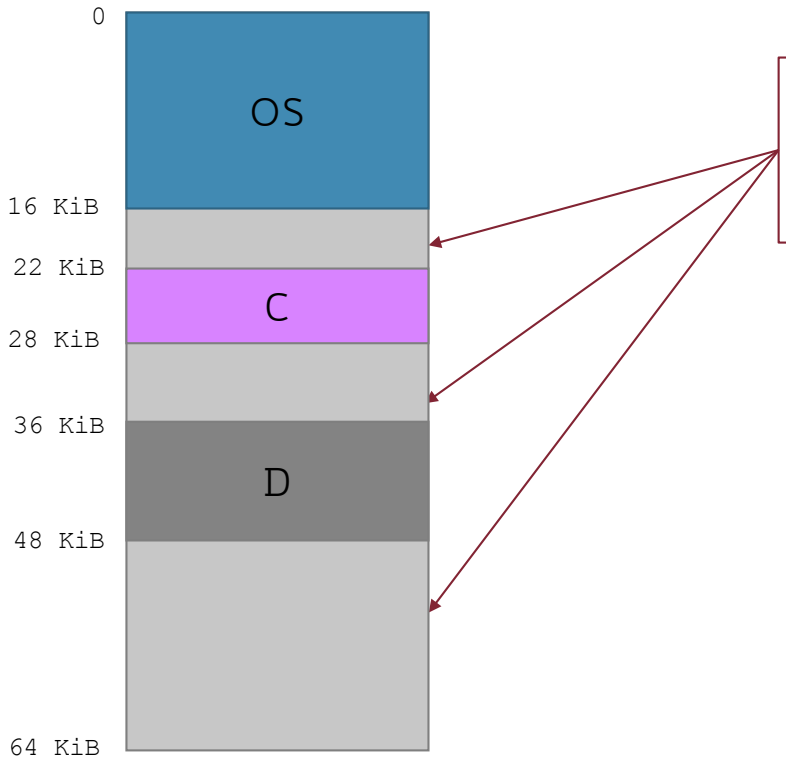

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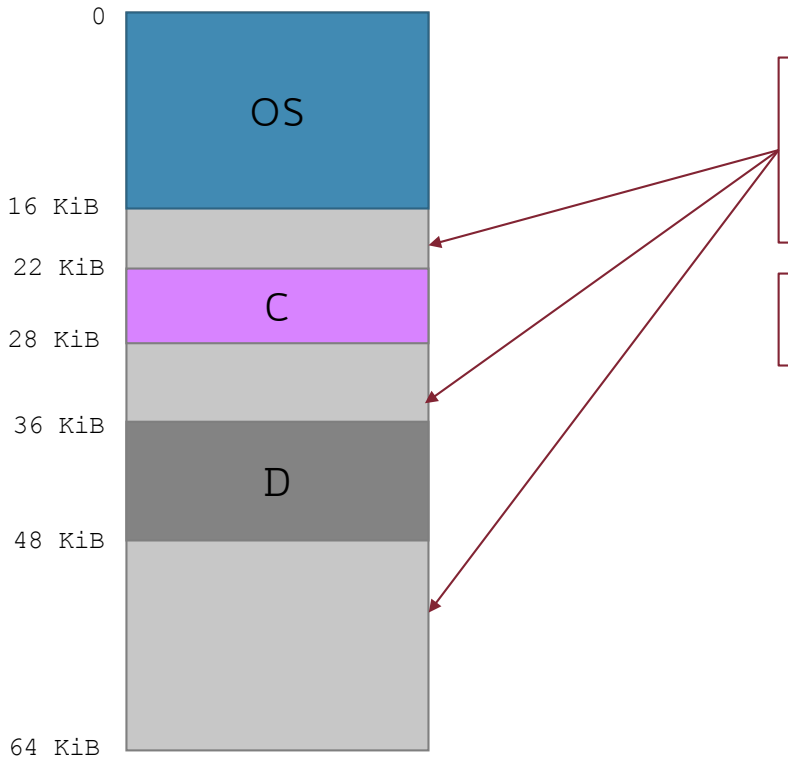

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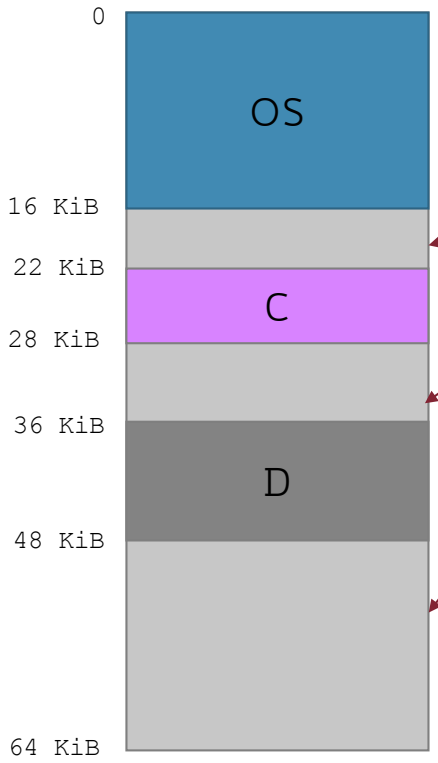

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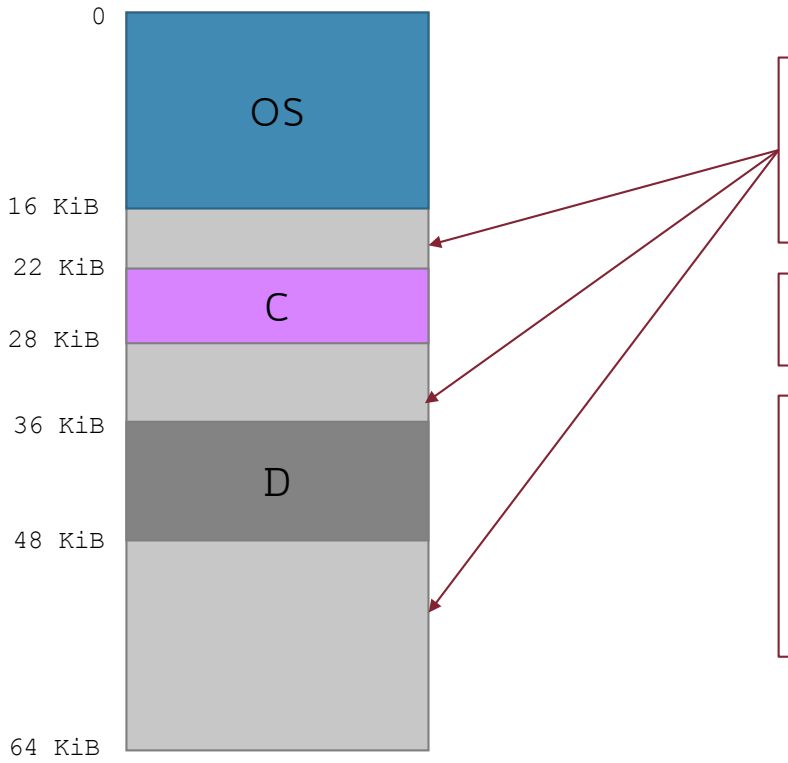

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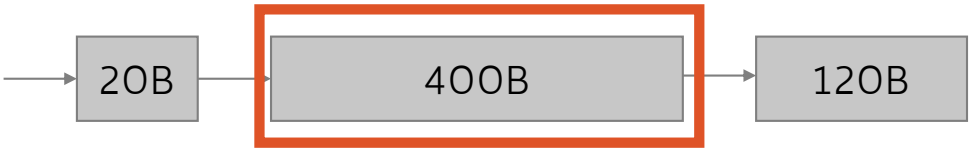

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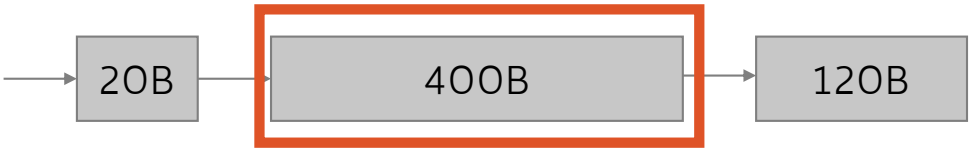

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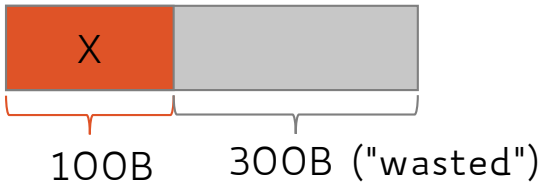

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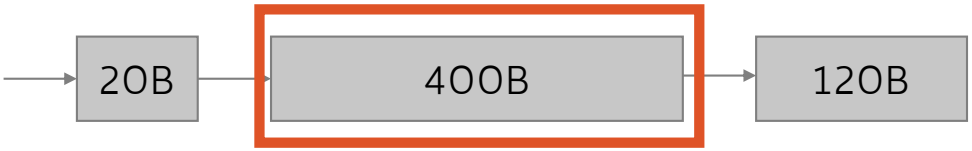

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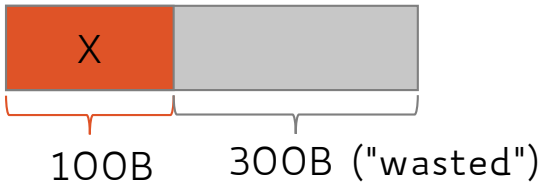

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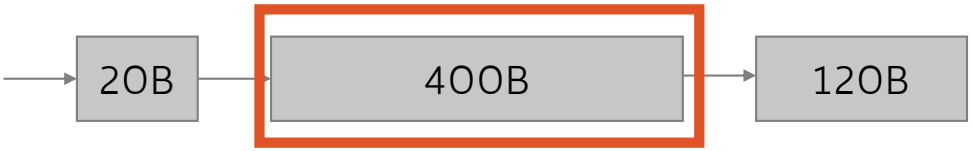

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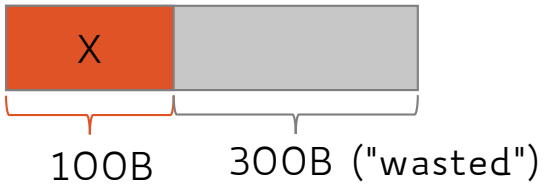

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We will not be able to satisfy this request even if theoretically we could

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Binary Search Tree (BST)

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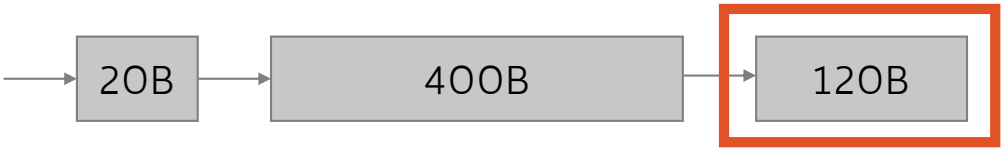

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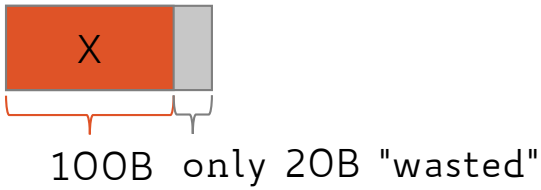

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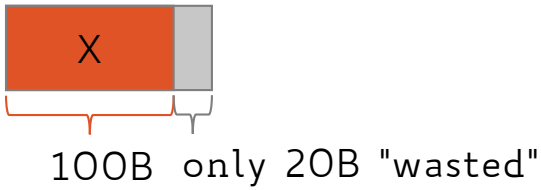

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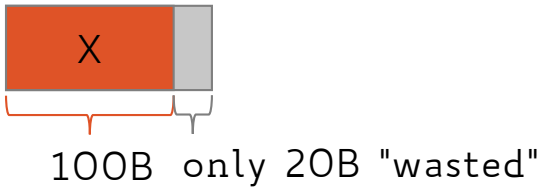

What if afterwards process Y requires 350B?

We can now assign it the second available hole segment (400B)

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Individual holes may be too small to serve a process request but they can be large enough if combined together

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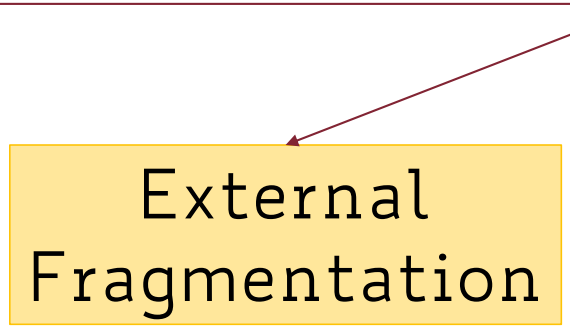

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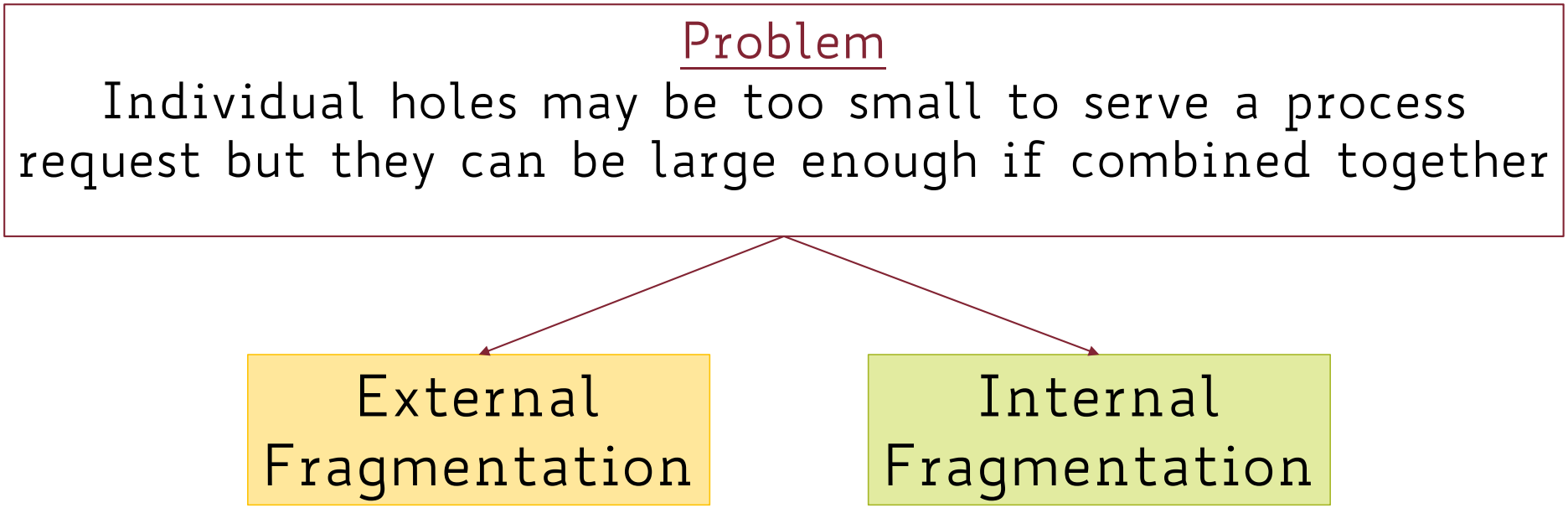

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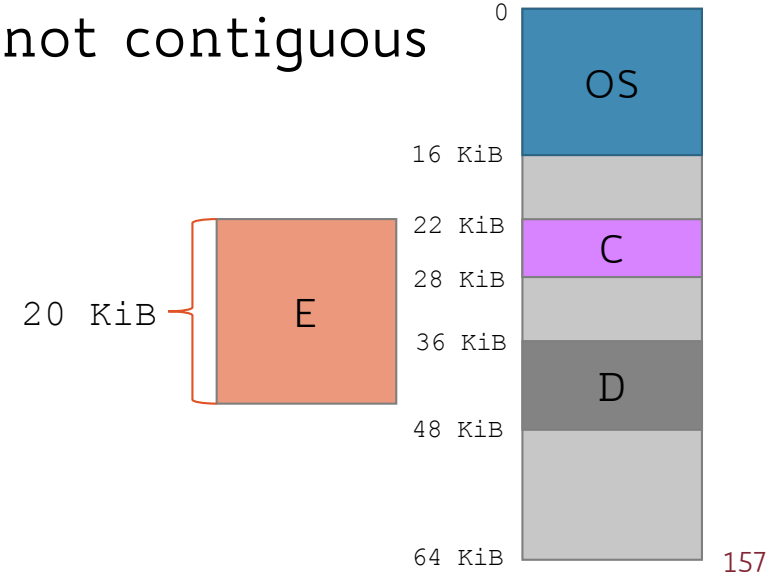

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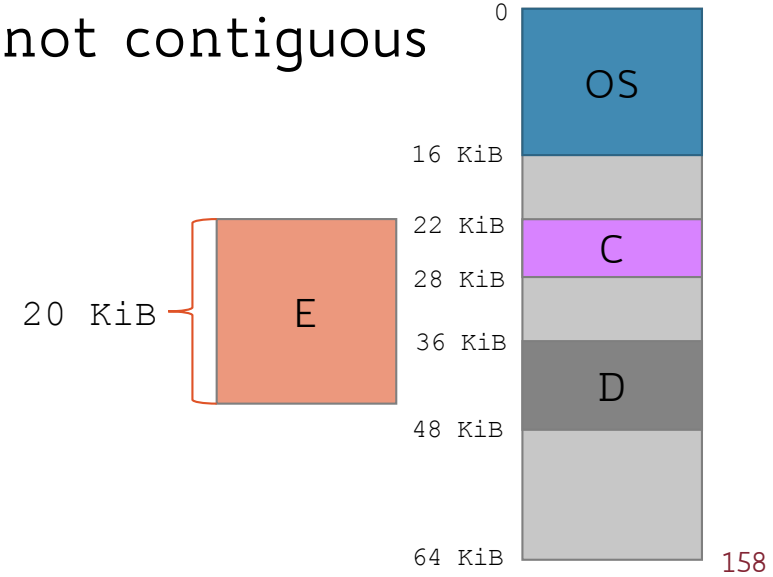

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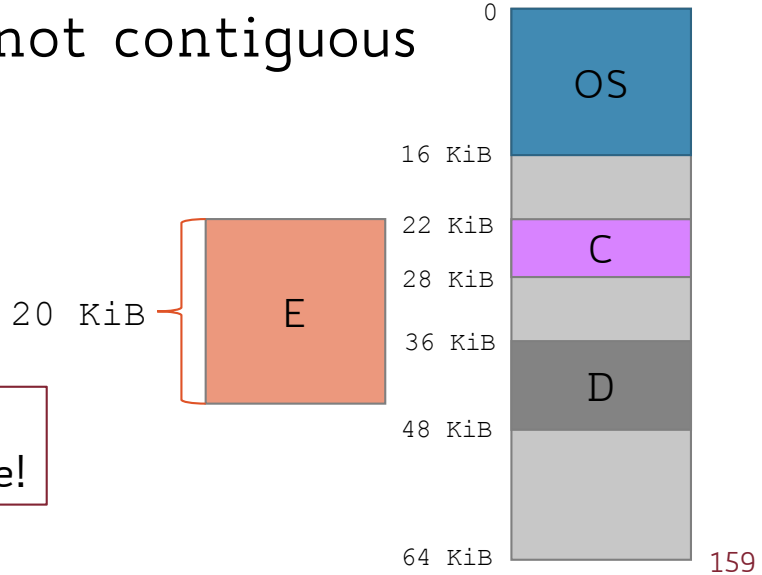
Goal:
Allocation policy that minimizes wasted space!



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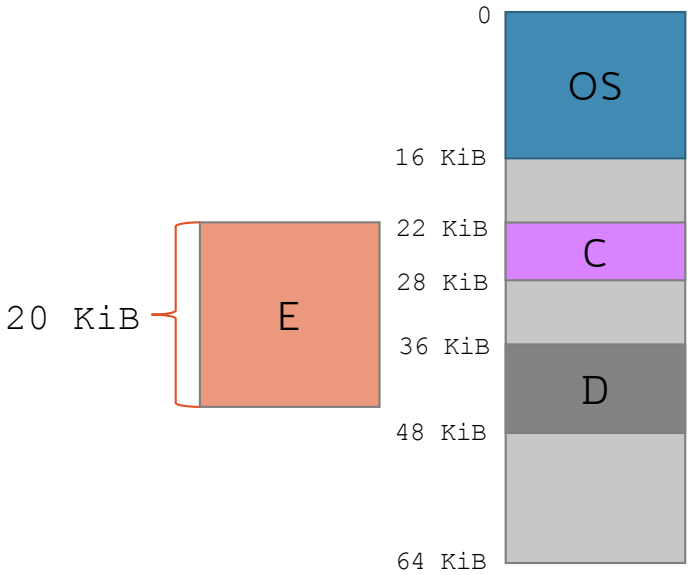
- For example, consider a process whose size is 8,846B and a hole of size 8,848B
- It may be much more efficient to allocate the process the whole block (and waste 2B) rather than keep track of a tiny 2B hole

Solution to Fragmentation: Full Compaction



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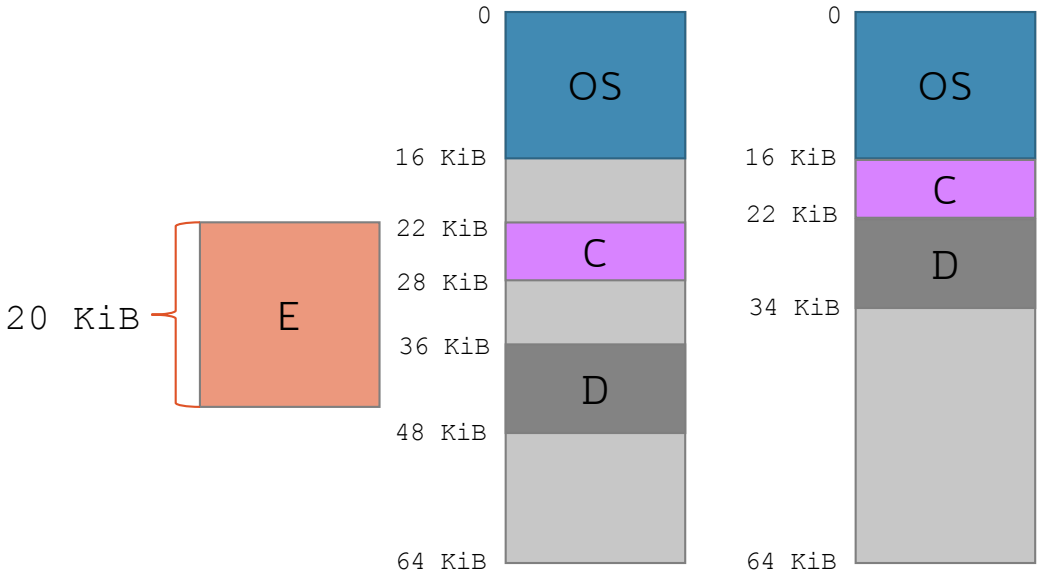

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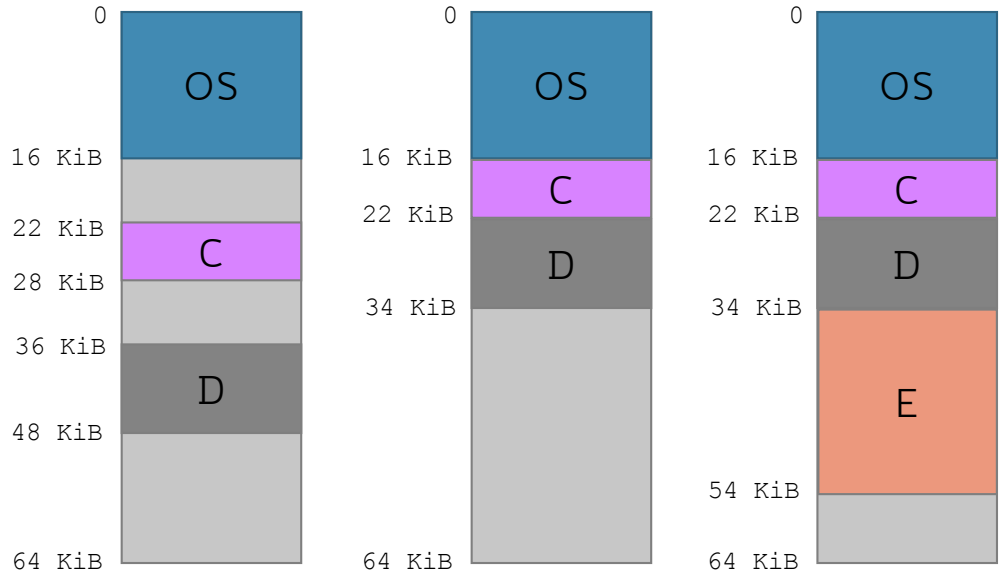

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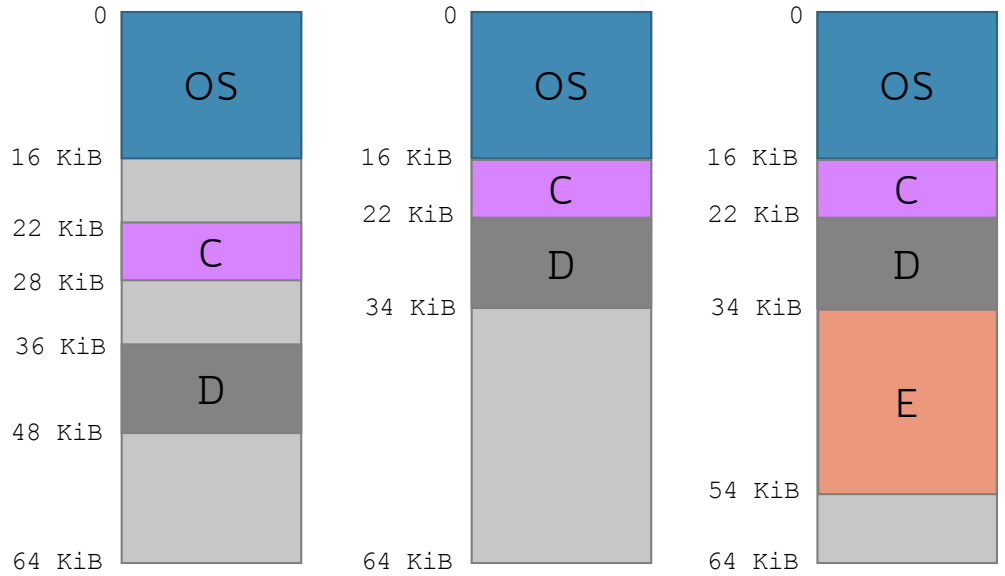

Only one hole is left but two processes need to be moved (C and D)

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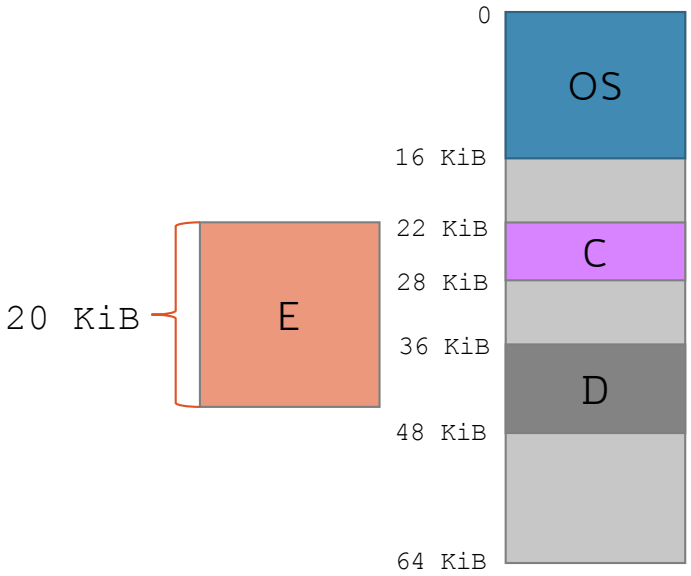

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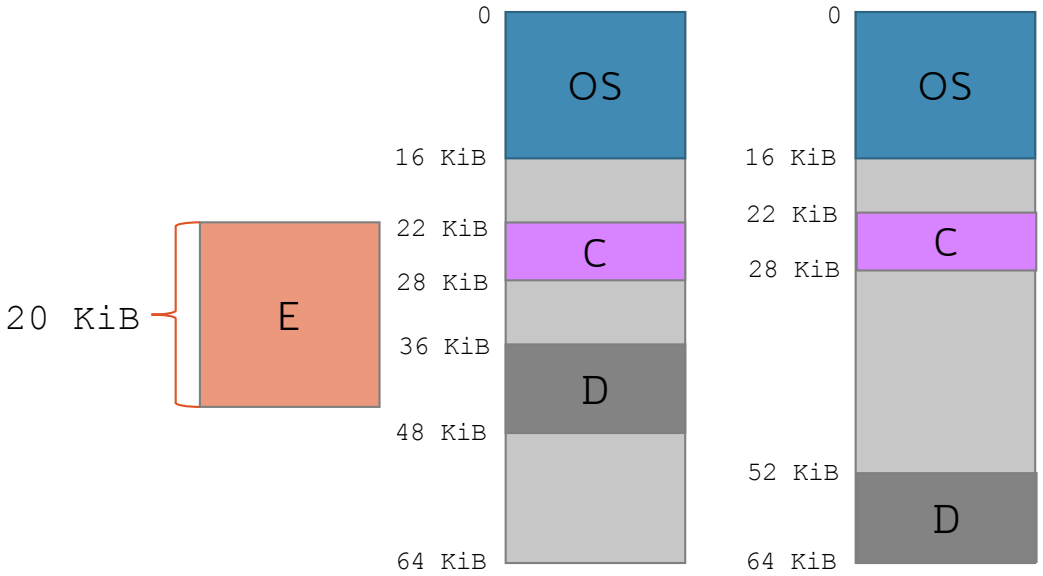

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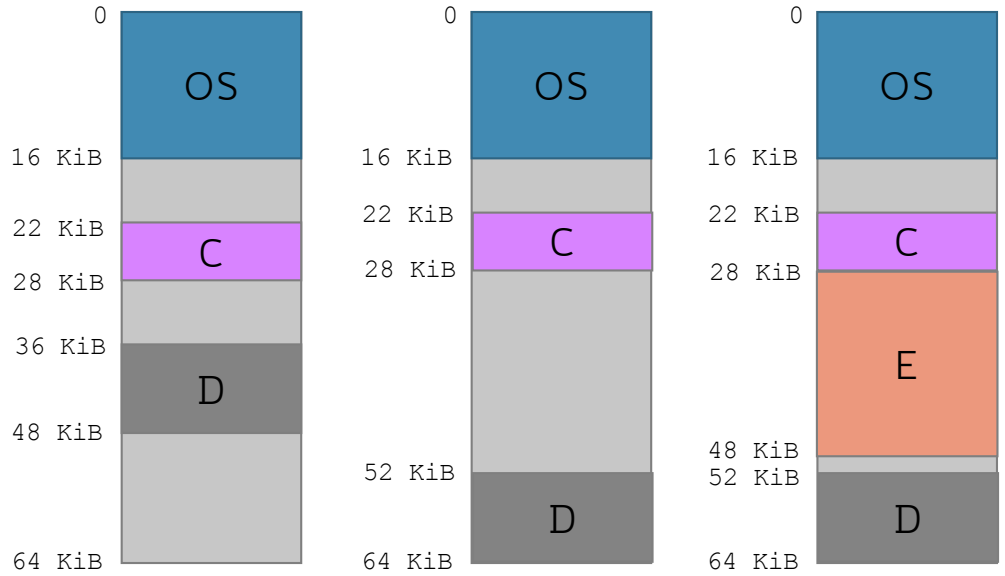

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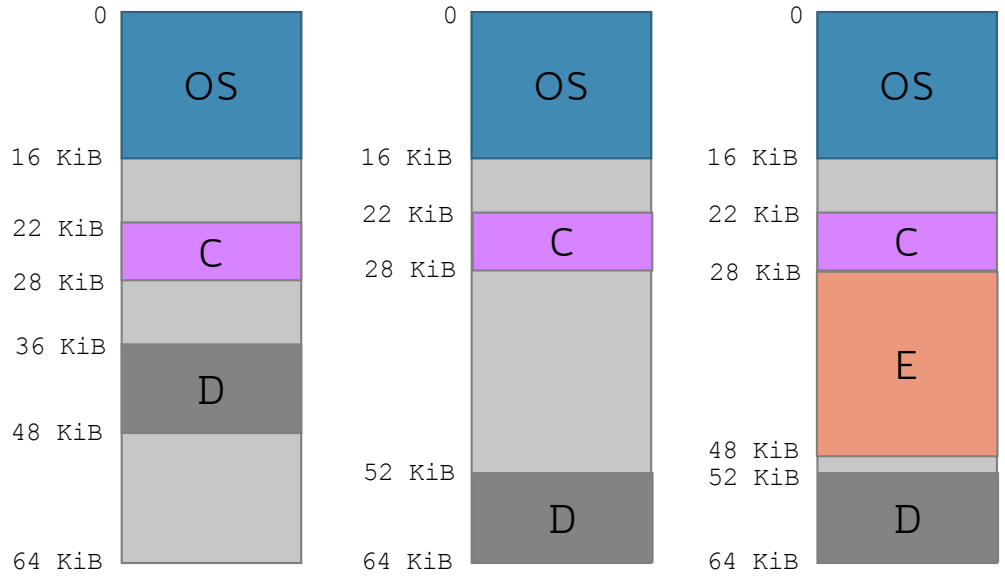

Still some holes left but only one process is moved (D) rather than two

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- That process can be "swapped out" from memory to disk to make room for other processes

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- Using swapping, fragmentation can be tackled easily
  - Just run compaction before swapping-in a process

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- Time slice is usually way smaller than that!

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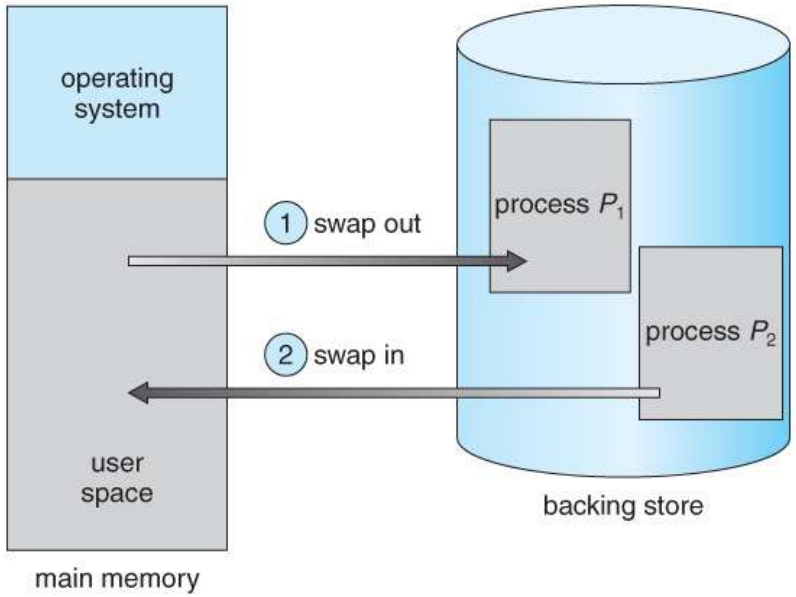

Most modern OSs no longer use swapping, because it is too slow and there are faster alternatives available (e.g., paging)

Summary

- Contiguous memory allocation may cause fragmentation
  - External vs. Internal Fragmentation
- Existing countermeasures (compaction) exist but they are costly
- We may want to relax the constraint on having an entire process loaded in main memory
- Paging solves all these issues!