Operating Systems

Lecture 6.1 - Memory management 1

Adrien Krähenbühl

Master of Computer Science
PUF - Hồ Chí Minh

2016/2017

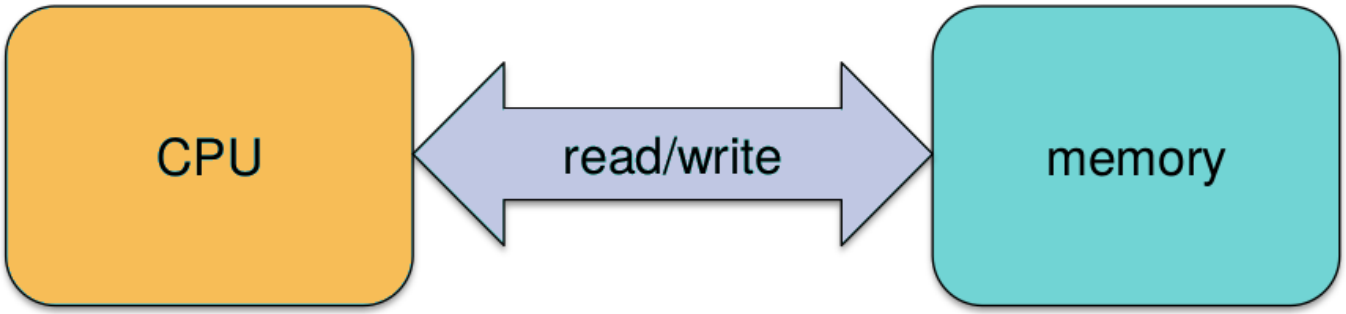
Linking

Allocating memory

Paging overview

CPU access to memory

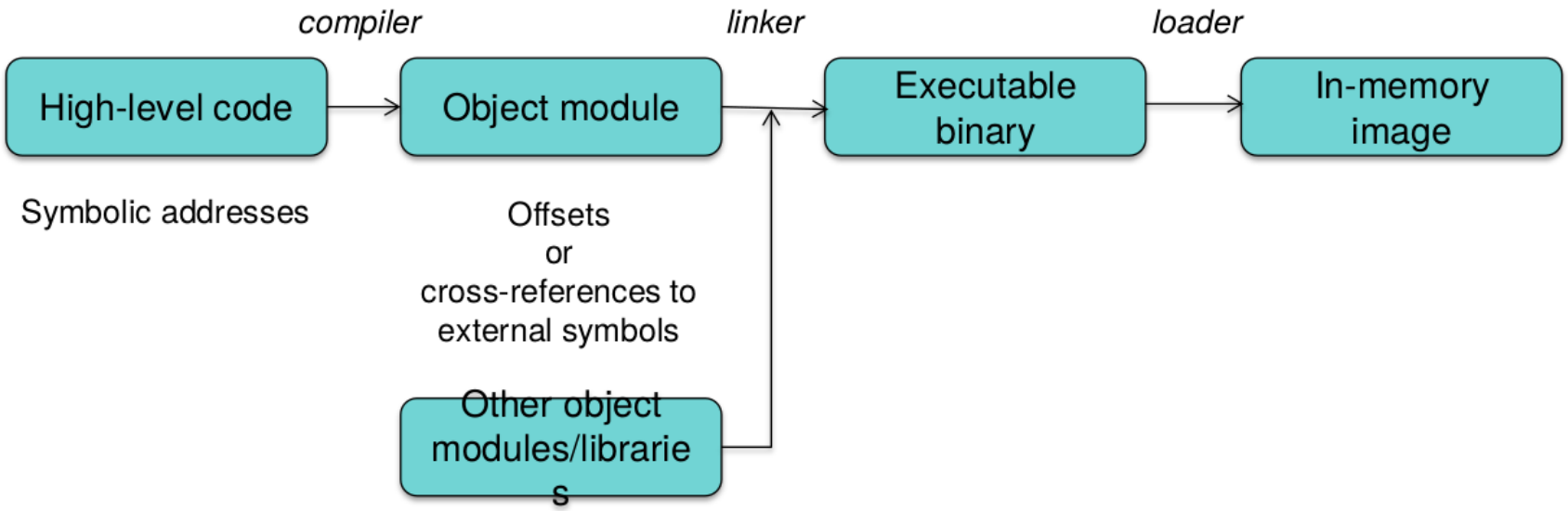
The CPU reads instructions and reads/write data from/to memory.



Functional interface:

```
value = read(address)
write(address, value)
```

Programs have references to memory



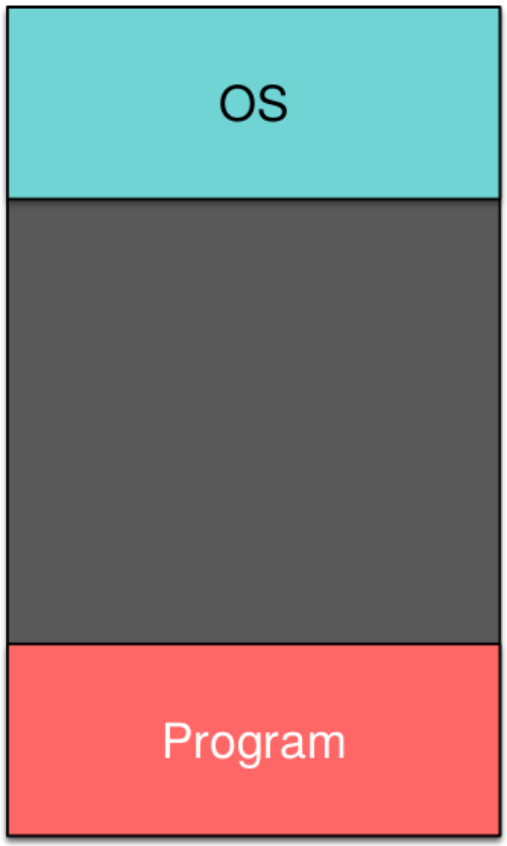
Programs make use of memory addresses

Instruction execution addresses for branching

Data access addresses for reading/writing data

Mono programming

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

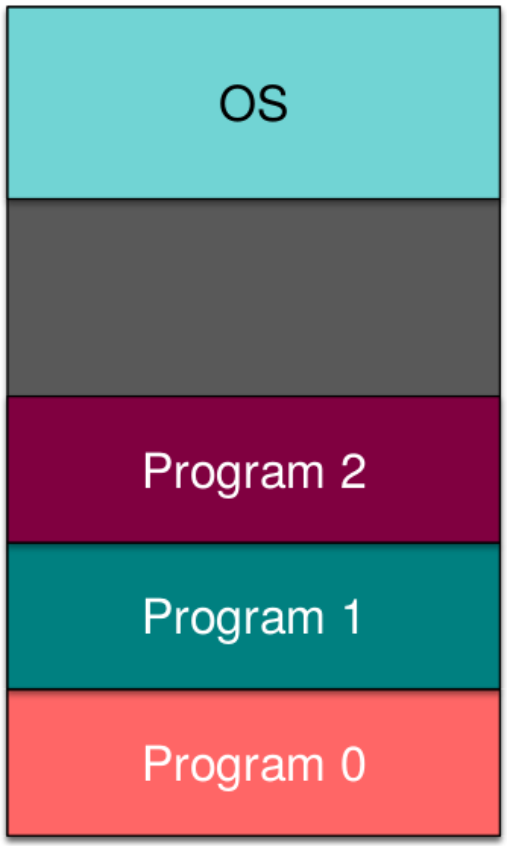


Absolute memory addresses are no problem

This was the model in old MS-DOS (and other) systems.

Multiprogramming

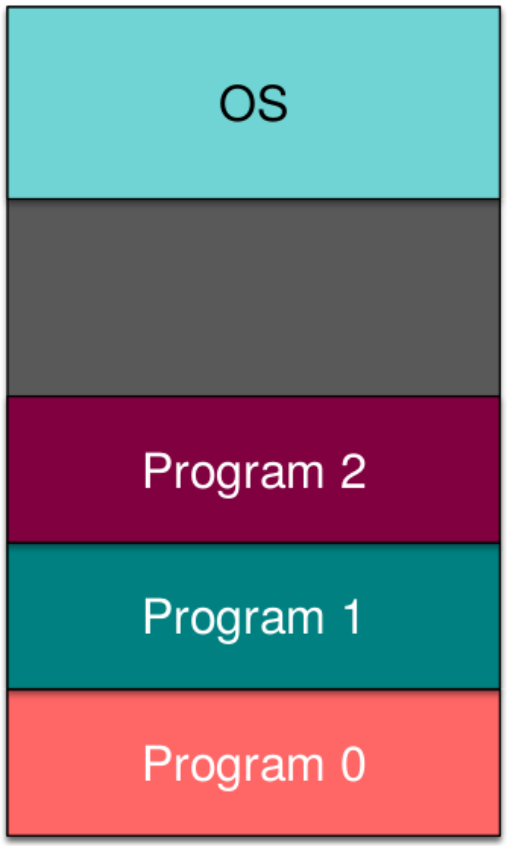
- ✓ Keep more than one process in memory
- ✓ More processes in memory improves CPU utilization



Absolute memory addresses are a problem!!

Justifying Multiprogramming: CPU Utilization

- ✓ 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 programs specify memory access?

Absolute code

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

Position independent code

All addresses are relative (e.g., gcc -fPIC option)

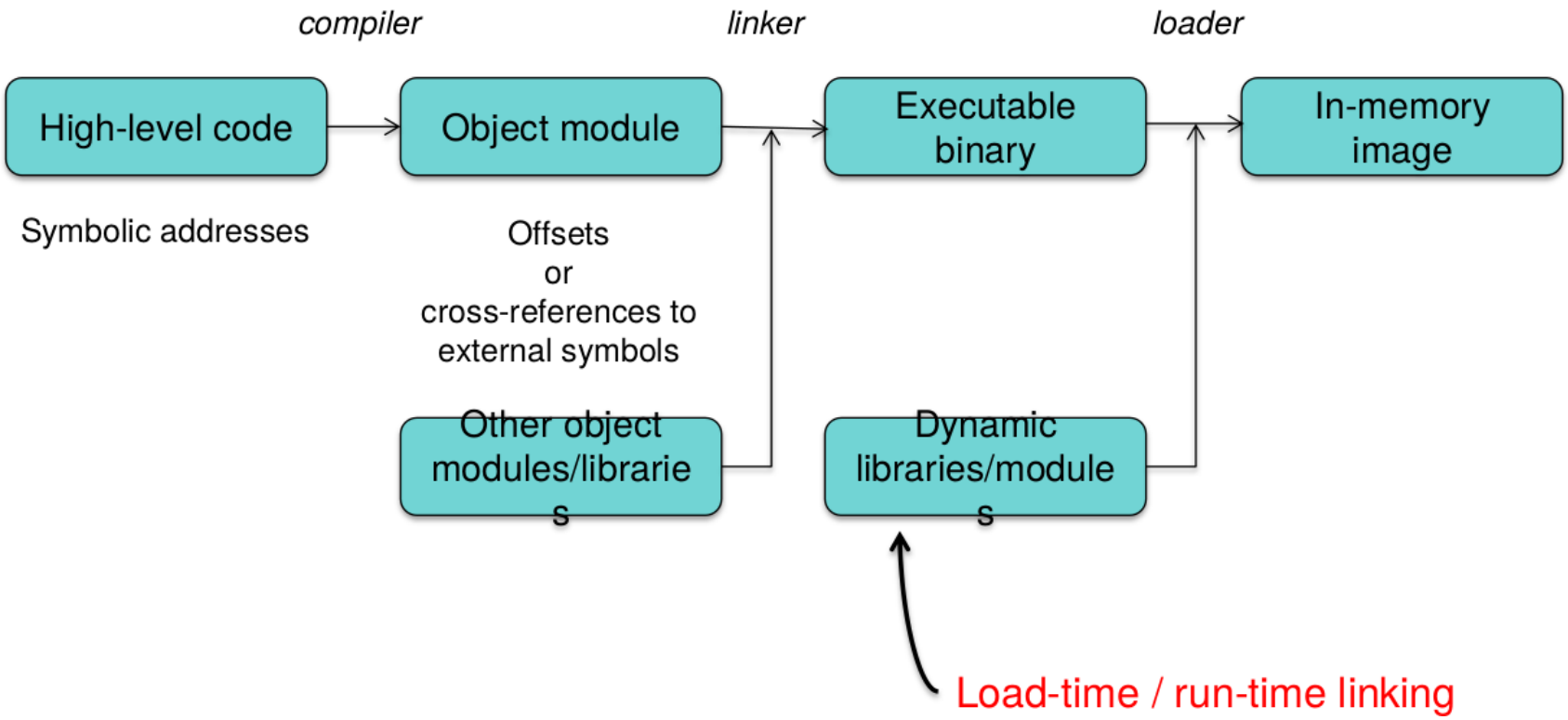
Dynamically relocatable code

Relocated at load time

Or ... use logical addresses

- ✓ Absolute code with with addresses translated at run time
- ✓ Need special memory translation hardware

Dynamic Linking



Dynamic linking

- ✓ A process loads libraries at load time
  - Symbol references are resolved at load time
- ✓ OS loader finds the dynamic libraries and brings them into the process' memory address space

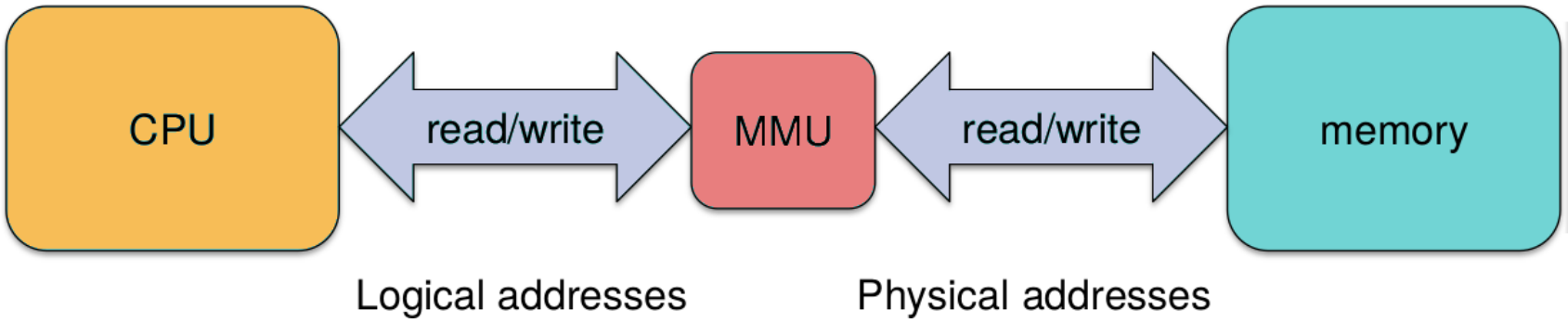
Dynamic loading

- ✓ A process can load a module at runtime on request
  - Similar to dynamic linking
  - Program is written to load a specific library
  - Resolve symbols to get pointers to data & functions
- ✓ The library can be unloaded when not needed

Shared libraries

- ✓ Dynamic linking + sharing
- ✓ Libraries that are loaded by programs when they start
  - All programs that start later use the shared library
  - Program loader searches for needed shared libraries
- ✓ Object code is linked with a stub
  - Stub checks whether the needed library is in memory
  - If not, the stub loads it
  - Stub is then replaced with the address of the library
- ✓ Operating system:
  - Checks if the shared library is already in another process' memory
  - Shares memory region among processes
- ✓ **Need position independent code or pre-mapped code** (reserved regions of memory that processes share)

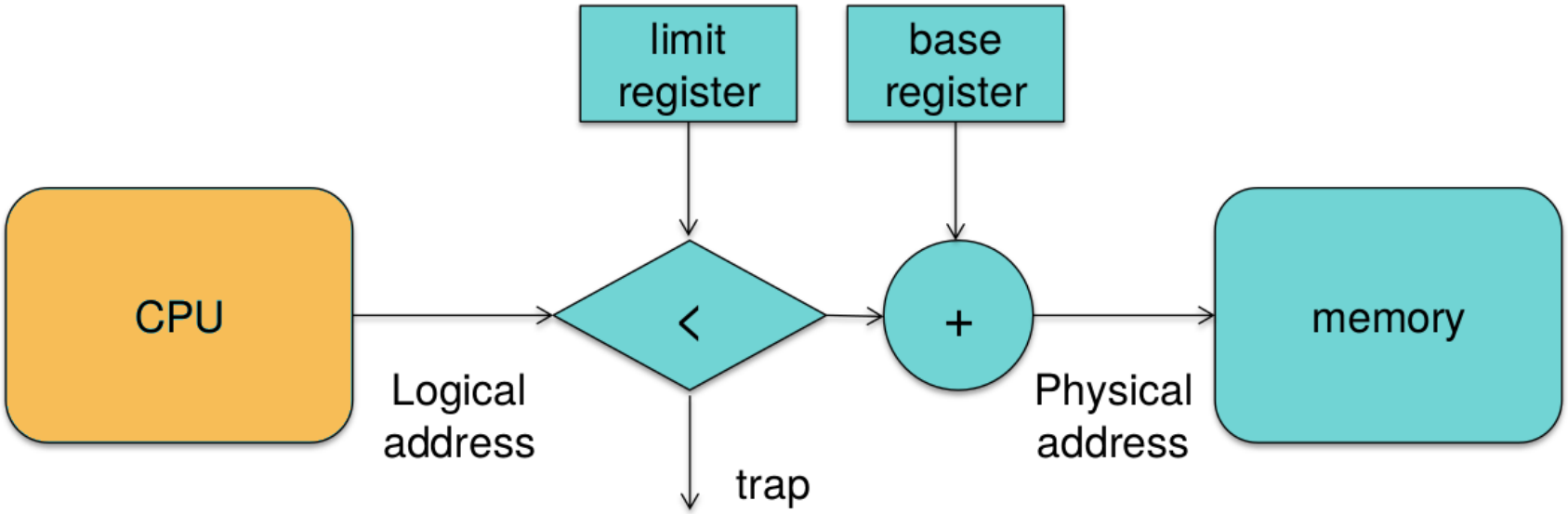
Logical addressing



Memory management unit (MMU)

Real-time, on-demand translation between logical (virtual) and physical addresses

Relocatable addressing



Base & limit

- ✓ Physical address = logical address + base register
- ✓ But first check that: logical address < limit

Linking

Allocating memory

Paging overview

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 is wasted
  - **Internal fragmentation**
  - Unused partitions: **external fragmentation**

Contiguous allocation

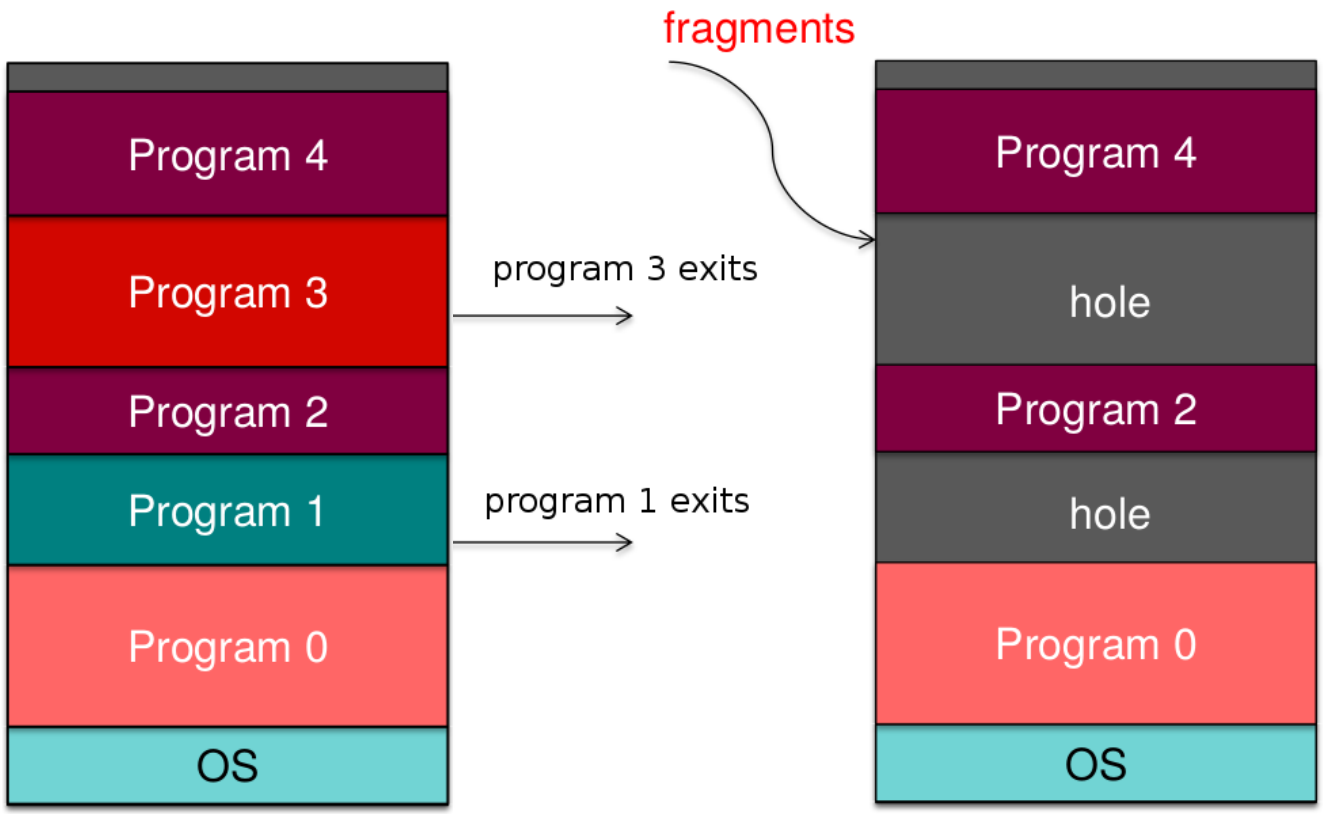
Process takes up a contiguous region of memory

Variable partition multiprogramming

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

Variable partition multiprogramming

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



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.

Variable partition multiprogramming

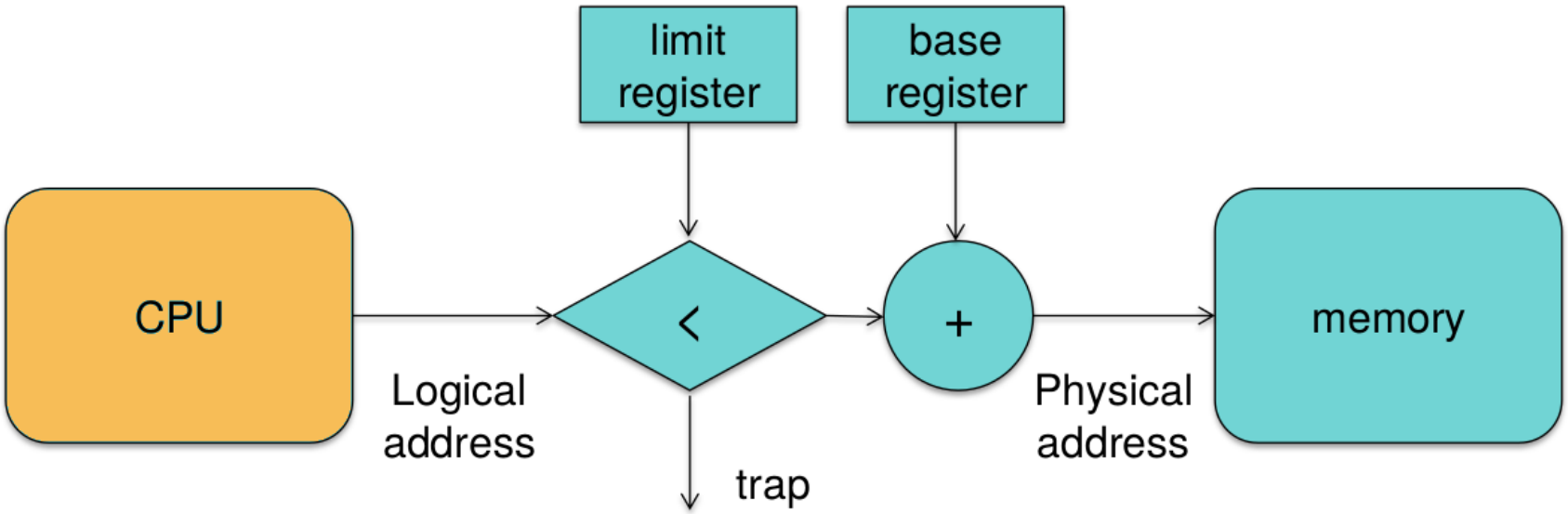
What if a process needs more memory?

- ✓ Always allocate some extra memory just in case
- ✓ Find a hole big enough to relocate the process

Combining holes (fragments)

- ✓ 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.
- ✓ Discontiguous memory allocation

Linking

Allocating memory

Paging overview

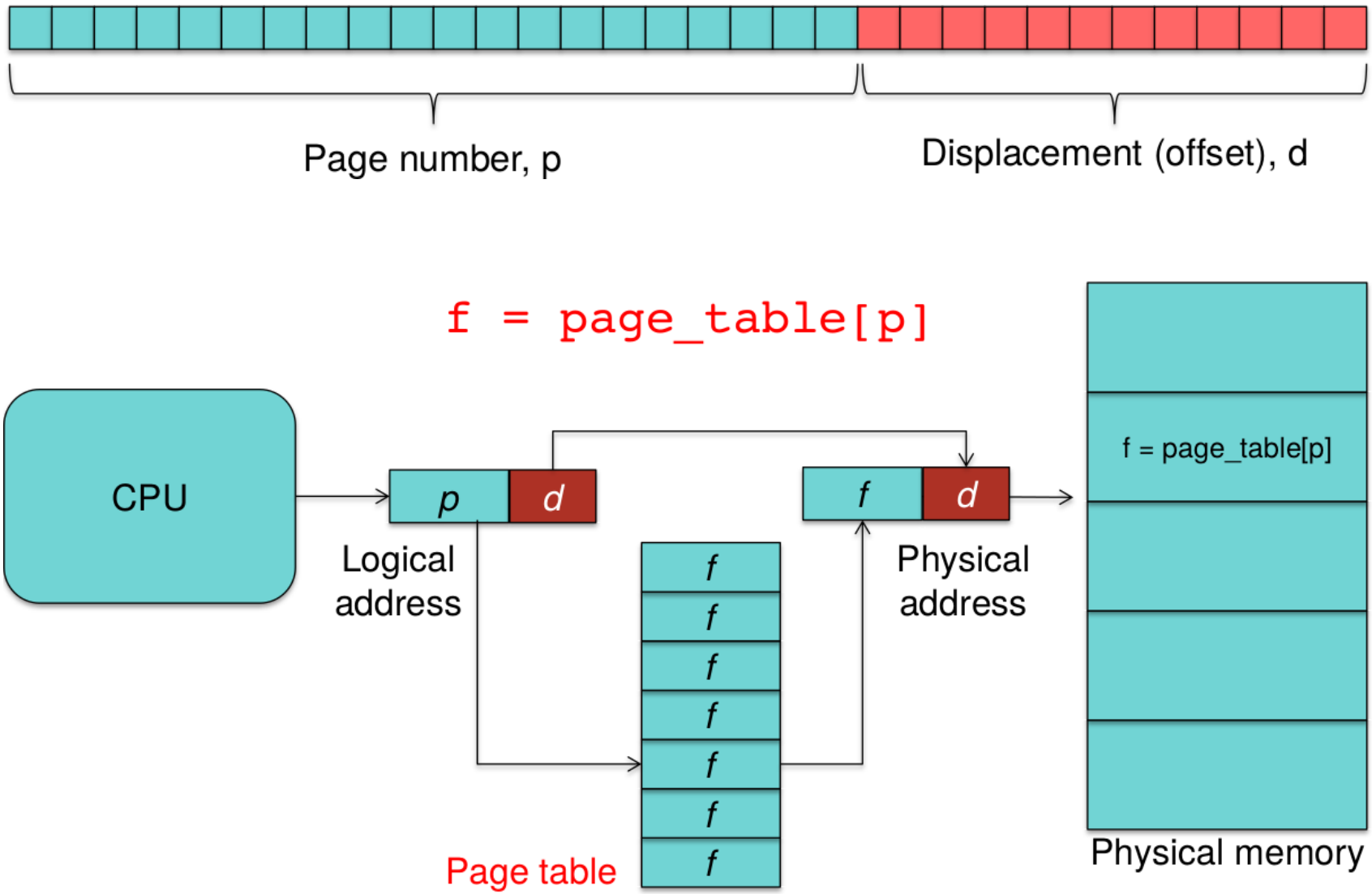
Paging

- ✓ 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

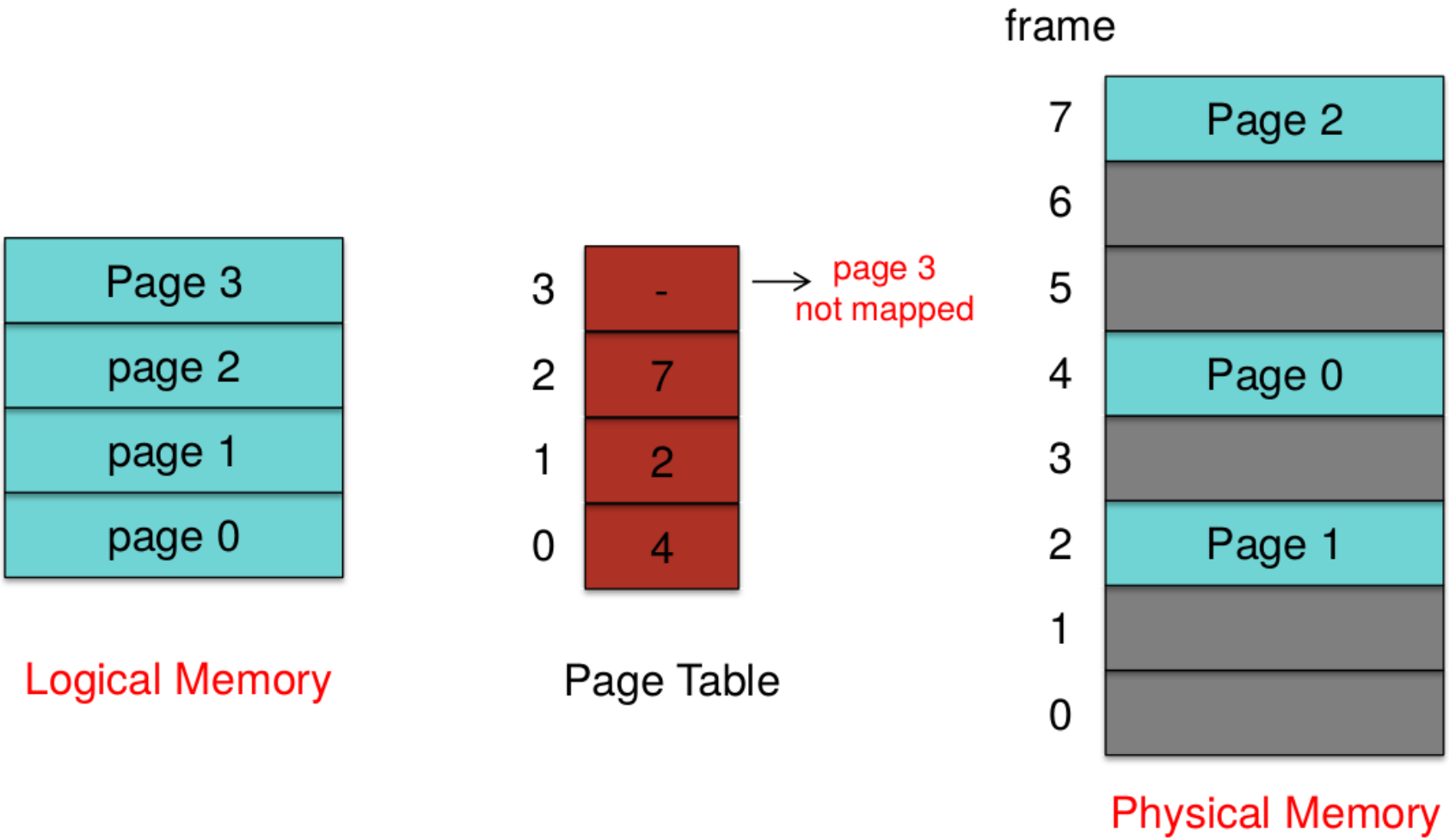
Paging

- ✓ 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
- ✓ Ex: 32-bit address, 4 KB page size
  - Top 20 bits identify the page number
  - Bottom 12 bits identify offset within the page/frame

Page translation



Logical vs. physical views of memory



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**
    → CR3 register on Intel IA-32 and x86-64 architectures
- ✓ 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)
  - Locality in the program ensures lots of repeated lookups
- ✓ **TLB miss** = page # not cached in the TLB
  - Need to do page table lookup in memory
- ✓ **Hit ratio** = % of lookups that come from the TLB

Address Space Identifiers: Tagged TLB

- ✓ There is only one TLB per system
- ✓ When we context switch, we switch address spaces
  - New page table
  - But . . . TLB entries belong to the old address space
- ✓ Either:
  - Flush (invalidate) the entire TLB
  - Have a Tagged TLB with an **Address Space Identifier** (ASID)

Protection

- ✓ An MMU can enforce memory protection
- ✓ Page table stores status & protection bits per frame
  - Valid/invalid: is there a frame mapped to this page?
  - Read-only
  - No execute
  - Kernel only access
  - Dirty: the page has been modified since the flag was cleared
  - Accessed: the page has been accessed since the flag was cleared

Multilevel (Hierarchical) page tables

- ✓ Most processes use only a small part of their address space
- ✓ Keeping an entire page table is wasteful
  - Example: 32-bit system with 4KB pages: 20-bit page table $\rightarrow 2^{20} = 1{,}048{,}576$ entries in the page table

Multilevel page table