# Hệ Điều Hành

(*Nguyên lý các hệ điều hành*)

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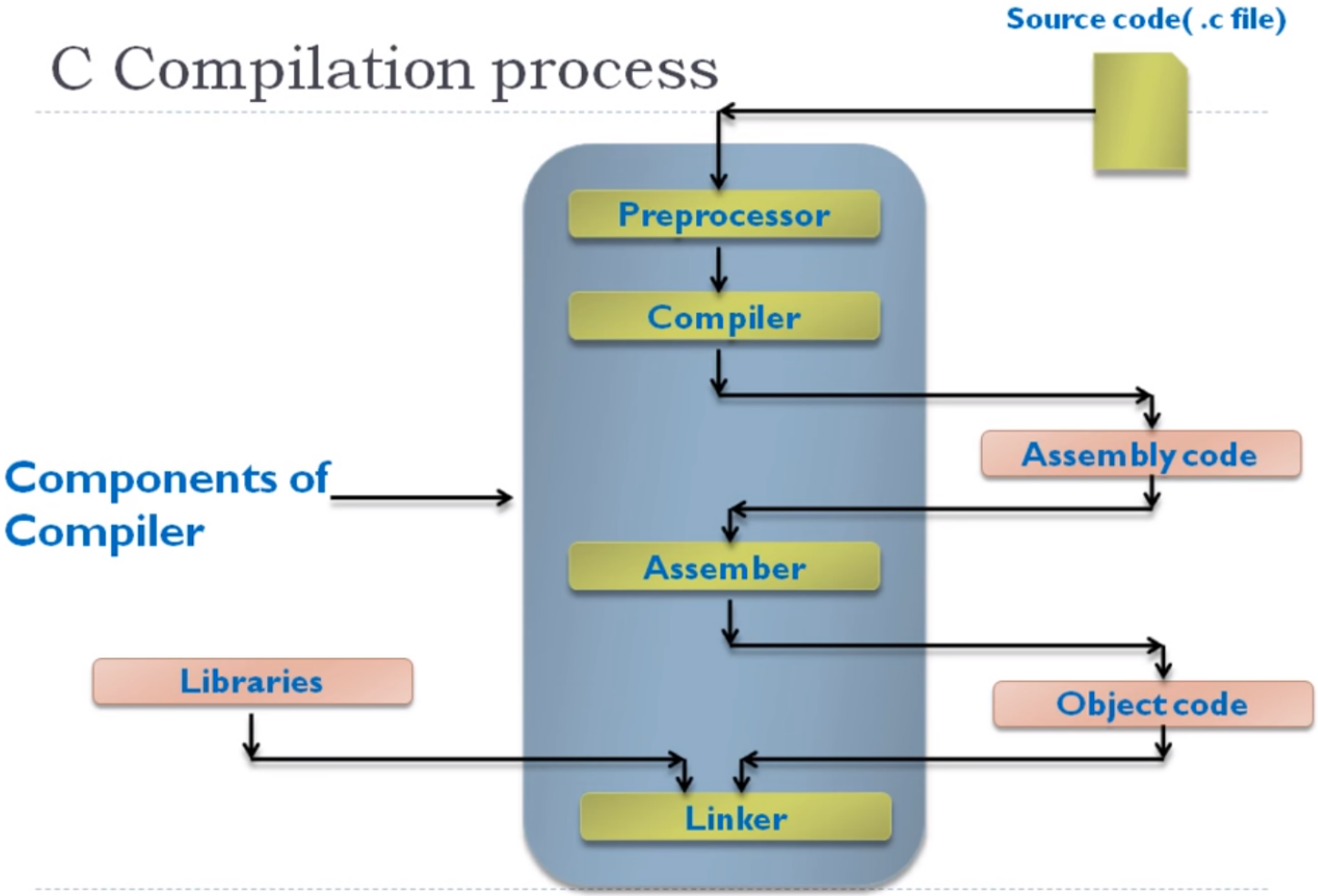
# Chap 3 Memory Management

① Introduction
② Memory management strategies
③ Virtual memory
④ Memory management in Intel's processors family

# Chapter 3 Memory management
## 1. Introduction

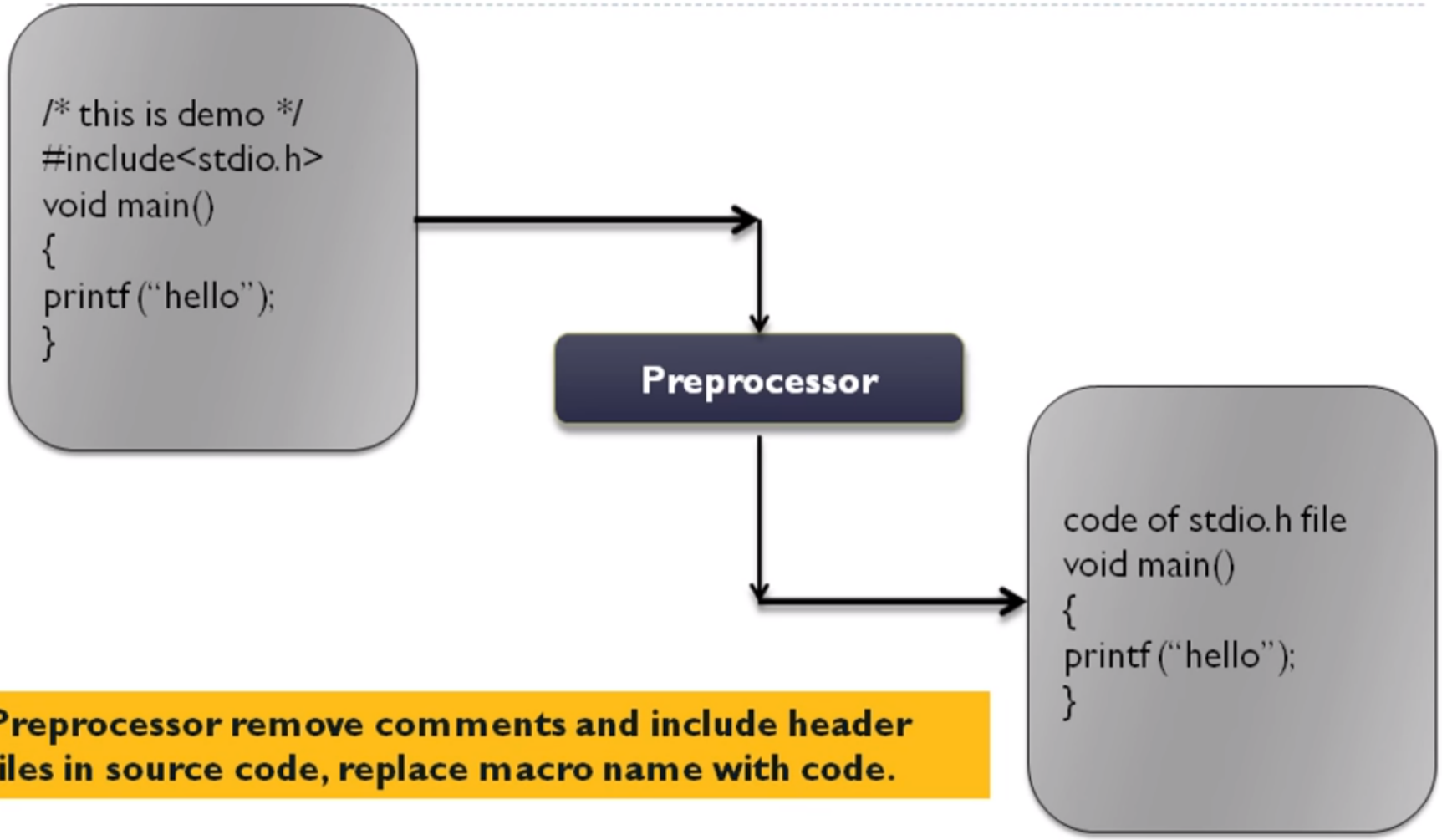
- Example
- Memory and program
- Address binding
- Program’s structures

# C compilation process



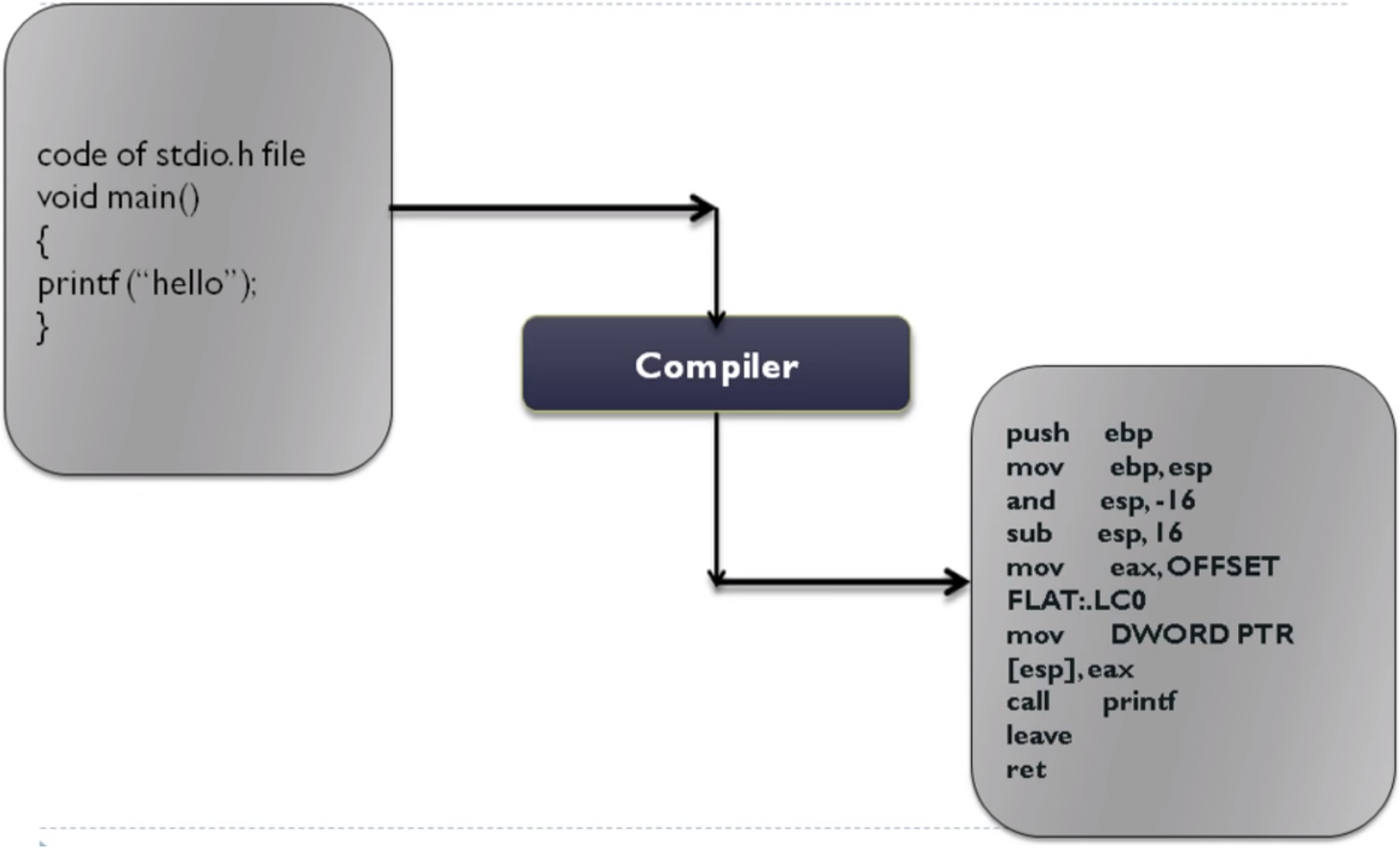
# C compilation process

## Preprocessor




**Preprocessor remove comments and include header files in source code, replace macro name with code.**

# C compilation process



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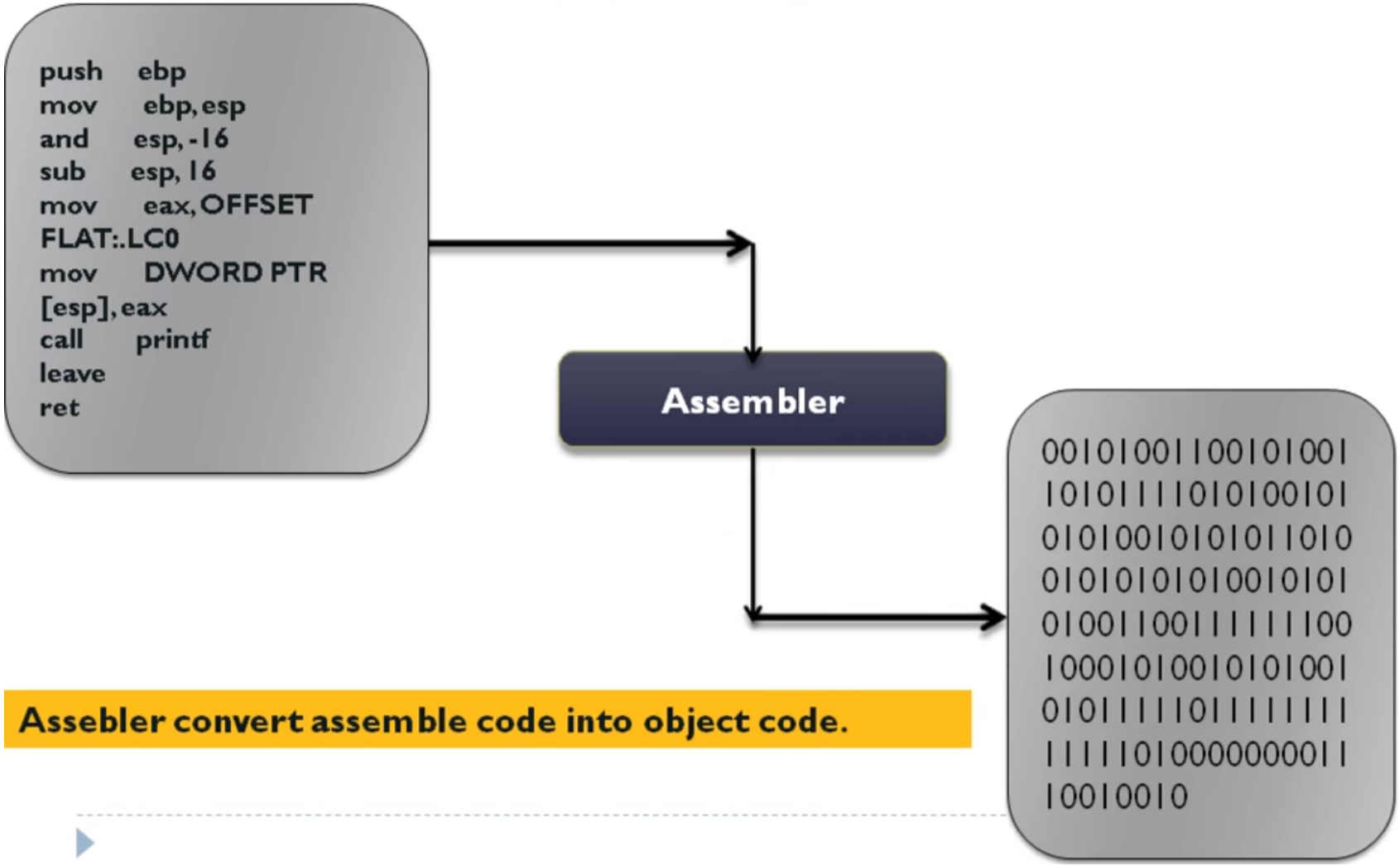
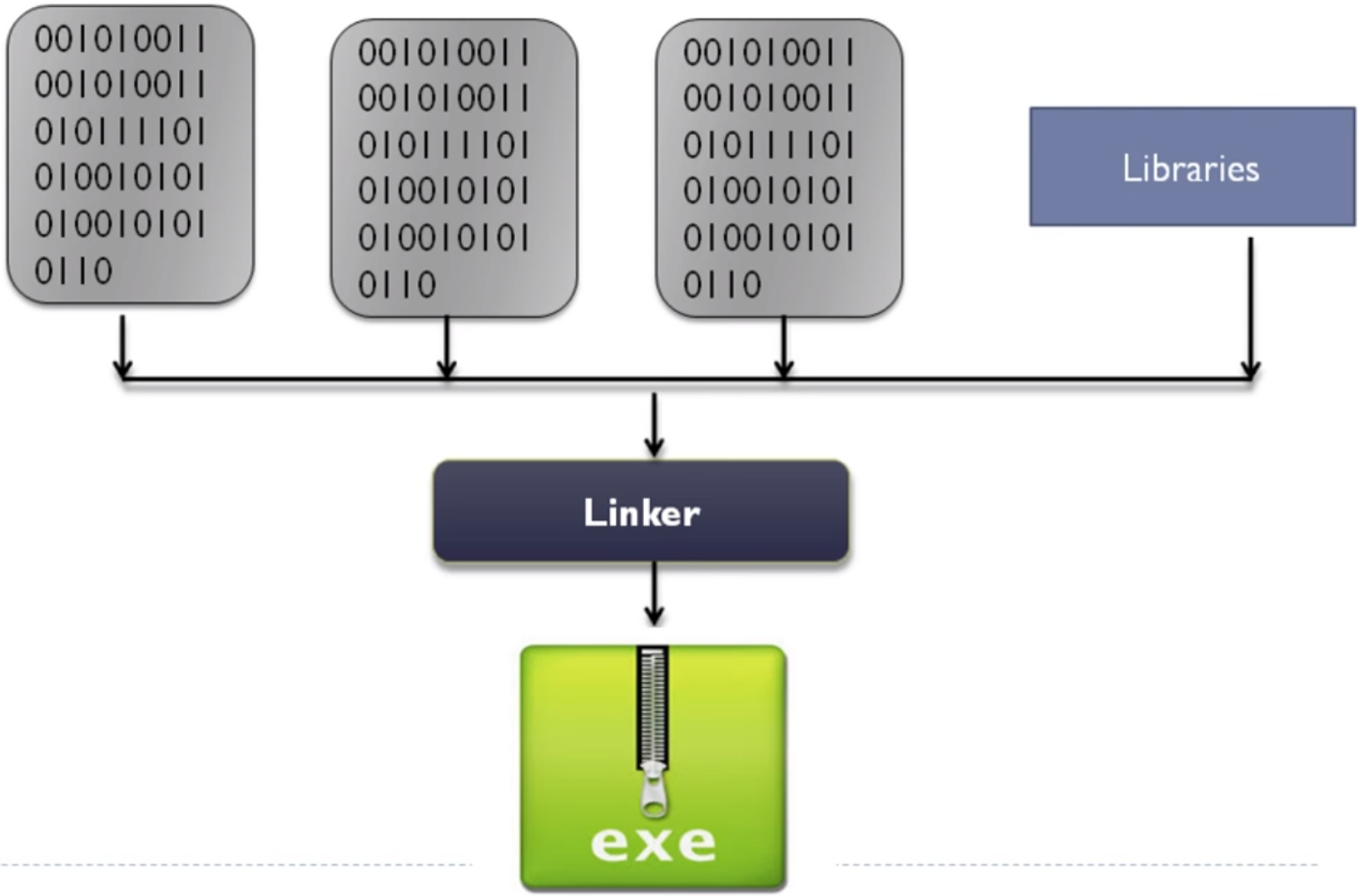



**Assebler convert assemble code into object code.**

# C compilation process



# Example: Generate programs from multi moduls

## Toto project

declared outside main()
⇓
external [pointer]

*file* **main.c**

```
#include <stdio.h>
extern int x, y;
extern void toto();
int main(int argc, char *argv[]){
     toto();
     printf("KQ: %d \n",x * y);
     return 0;
}
```

*file* **M1.c**

```
int y = 10;
```

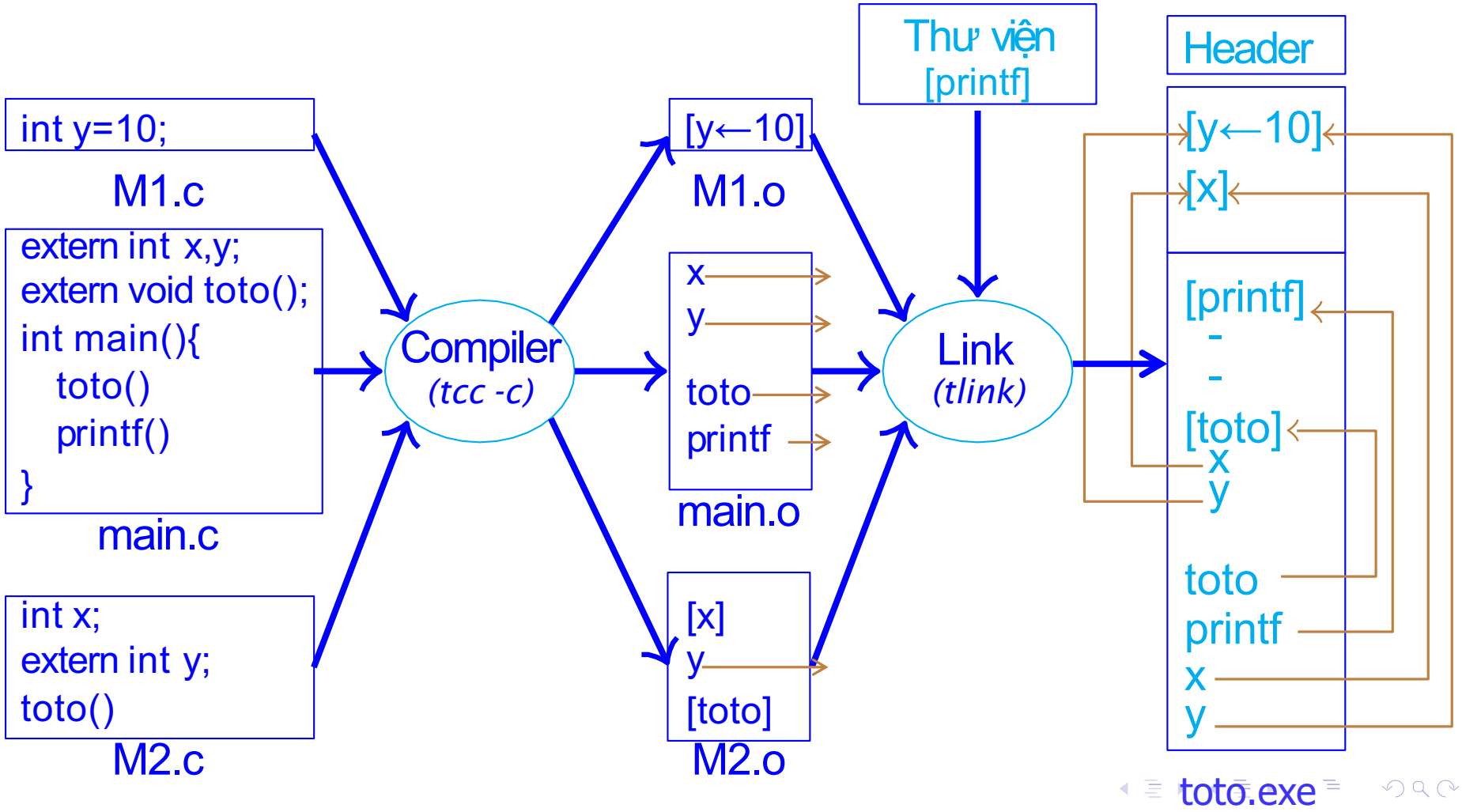
*file* **M2.c**

```
int x;
extern int y;
void toto(){
   x = 10 * y;
}
```

Result

```
KQ: 1000
```

# toto project compilation process



- Example
- Memory and program
- Address binding
- Program's structures

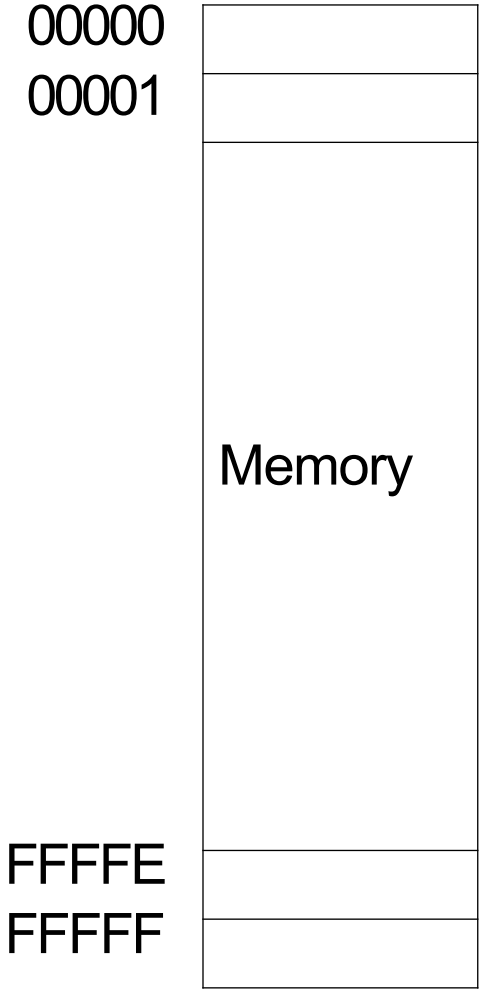
## Memory leveling

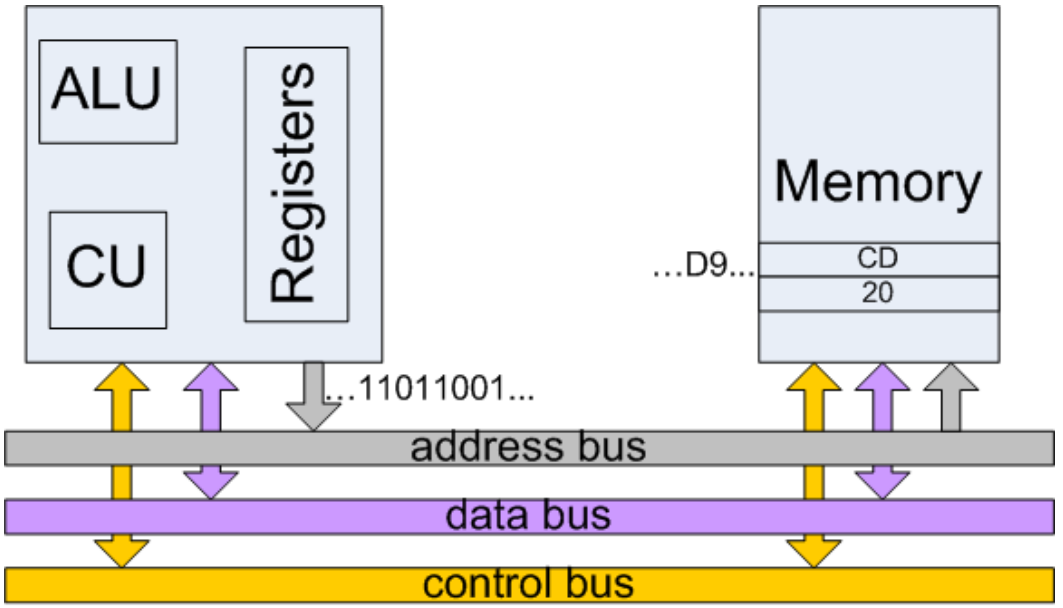
- Memory is an important system's resource
  - Program must be kept inside memory to run

- Memory is characterized by size and access speed
- Memory leveling by access speed

| Memory type | Size | Speed |
|---|---|---|
| Registers | bytes | CPU speed (ηs) 10 |
| Cache on processor | Kilo Bytes | nano seconds |
| Cache level 2 | KiloByte-MegaByte | 100 nanoseconds e |
| Main memory | MegaByte-GigaByte | Micro-seconds |
| Secondary storage(Disk) | GigaByte-Terabytes | Mili-Seconds 10 |
| Tape, optical disk | Unlimit | Seconds |

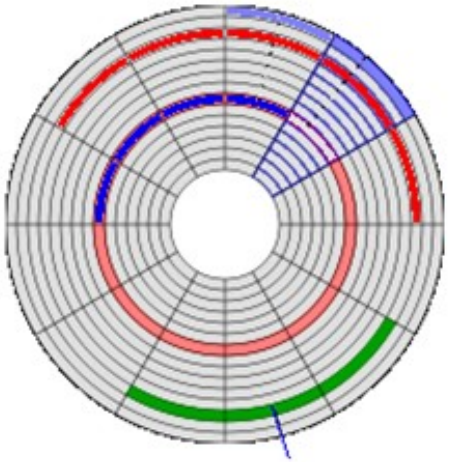
## Main memory




- Used for running program and data
- Array of memory block with size of bytes, words
- Each memory block has an address
  - **Physical address**

# Program




01010110011110010101010101101

| Header | Data | Code |
|---|---|---|

- Store on external storage devices
- Executable binary files
  - File's parameters
  - Machine instruction (binary code),
  - Data area (global variable), . .
- Must be brought into internal memory and put inside a process to be executed (process executes program)
- Input queue
  - Set of processes kept in external memory (*normally: disk*)
  - Wait to be brought into internal memory and execute

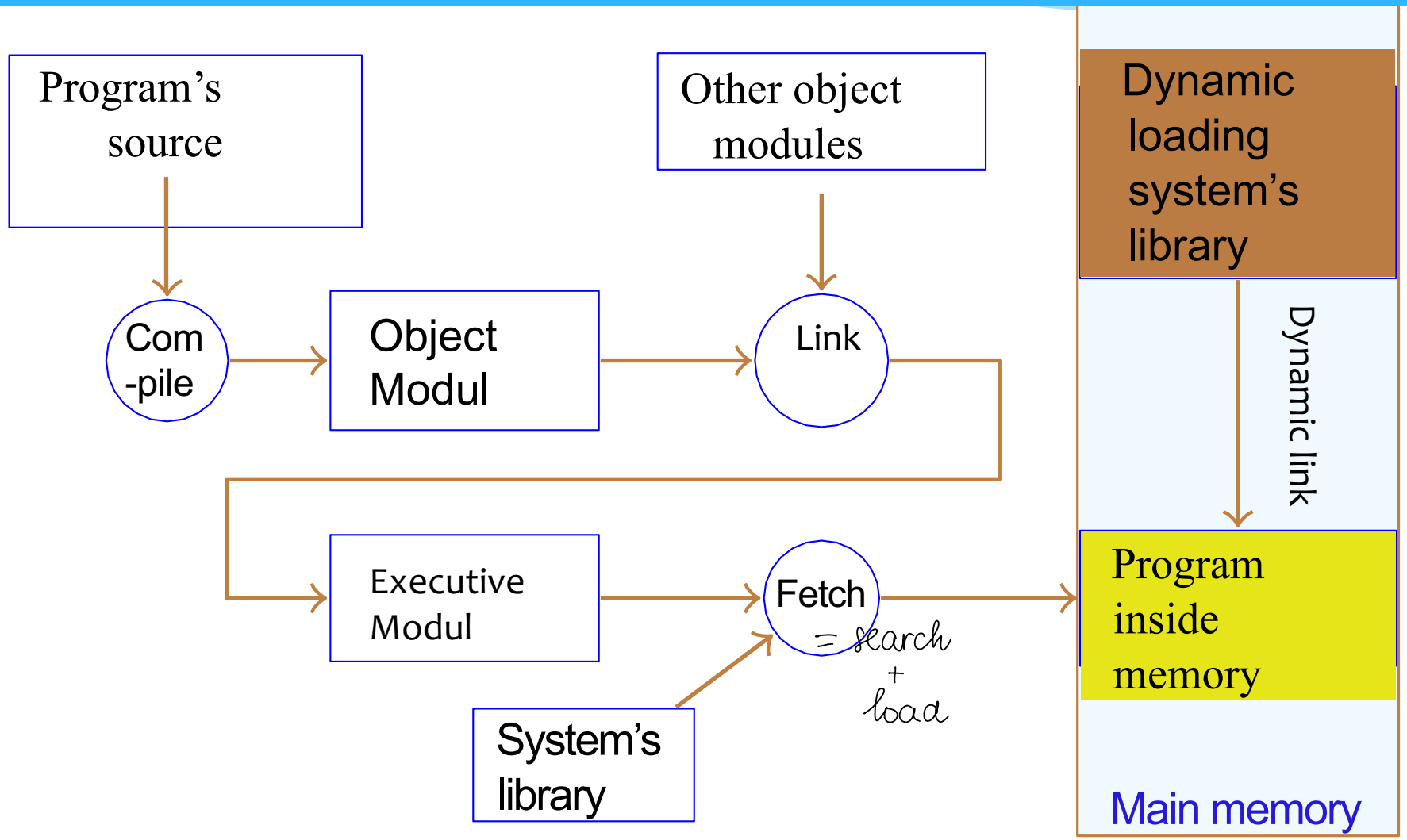
job sched works w/ this!

## Execute a program

- Load the program into main memory
  - Read and analysis executable file (e.g. *.com, file *.exe)
  - Ask for a memory area to load program from disk
  - Set values for parameters, registers to a proper value
- Execute the program
  - CPU reads instructions in memory at location determined by program counter (code segment, instruction pointer (aka. PC))
    - 2 registers CS:IP for Intel's family processor (e.g. : 80x86)
  - CPU decode the instruction
    - May read more operand from memory
  - Execute the instruction with operand
  - If necessary, store the results into memory at a defined location
- Finish executing
  - Free the memory area that allocated to program
- Problem
  - Program may be loaded into any location in the memory
  - When program is executed, a sequence of addresses are generated
- How to access memory?

- Example
- Memory and program
- Address binding
- Program's structures

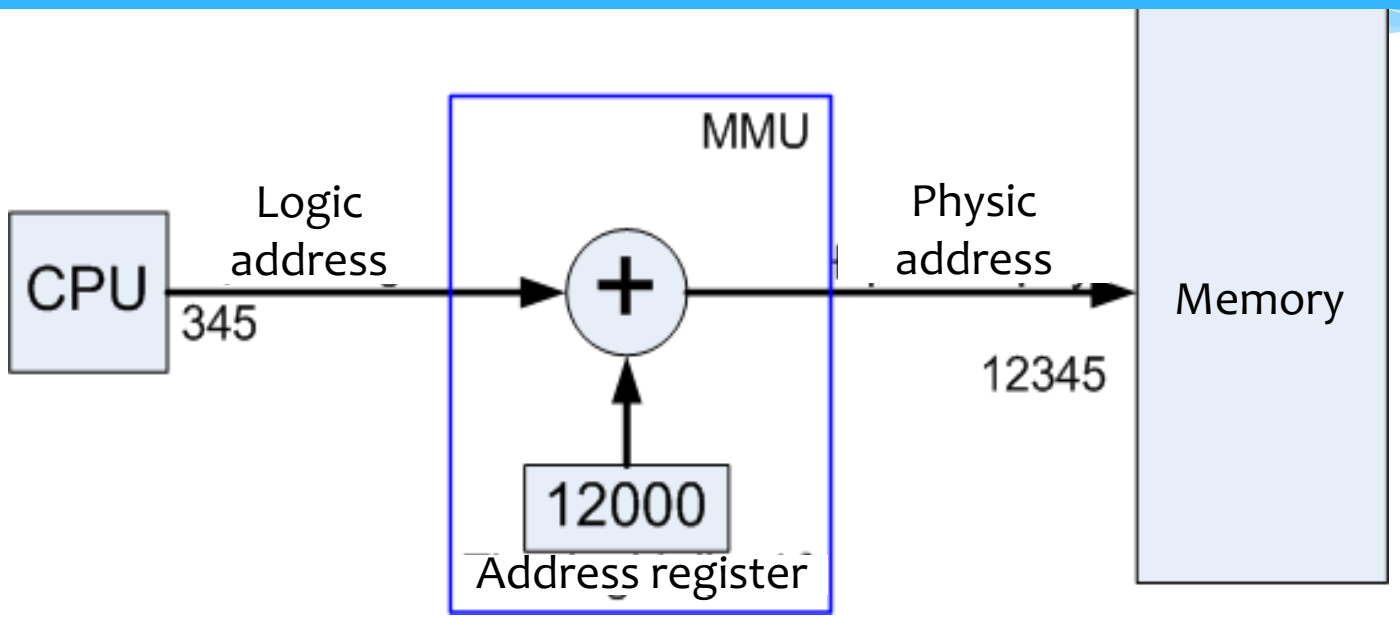
# Application program processing steps



## Types of address

- Symbolic
  - Name of object in the source program
  - Example: counter, x, y,…
- Relative address
  - Generated from symbolic address by compiler
  - Relative position of an object from the module's first position
    - Example: Byte number 10 from the begin of module
- Absolute address
  - Generate from relative address when program is loaded into memory
    - For IBM PC: relative address <Seg :Ofs>→ Seg * 16+Ofs
  - Object's address in physical memory – physical address
  - Example: JMP 010Ah ⇒ jump to the memory block at 010Ah at the same code segment (CS)
    - if CS=1555h, jump to location: 1555h*10h+010Ah =1560Ah

# Physical address-logic address




- Logic address
  - Generate from process, (CPU brings out)
  - Converted to physical address when access to object in the program by the Memory management unit (MMU)
- Physical address
  - Address of an element (byte/word) in main memory
  - Correspond to the logic address bring out by CPU
- Program work with logical address

- Example
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- Program's structures

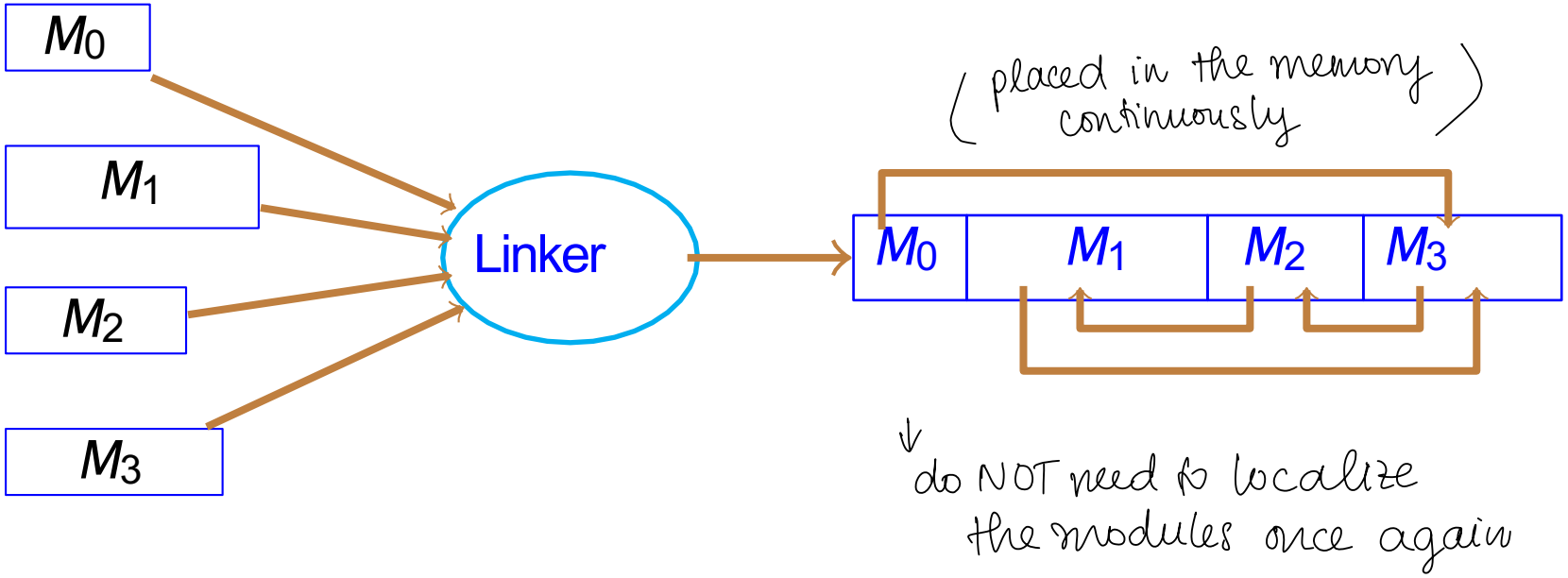
① Linear structure

② Dynamic loading structure

③ Dynamic link structure

④ Overlays structure

# Linear structure




- After linking, modules are merged into a complete program
  - Contain sufficient information to be able to execute
  - External pointers are replaced by defined values
  - To execute, required only one time to fetch into the memory

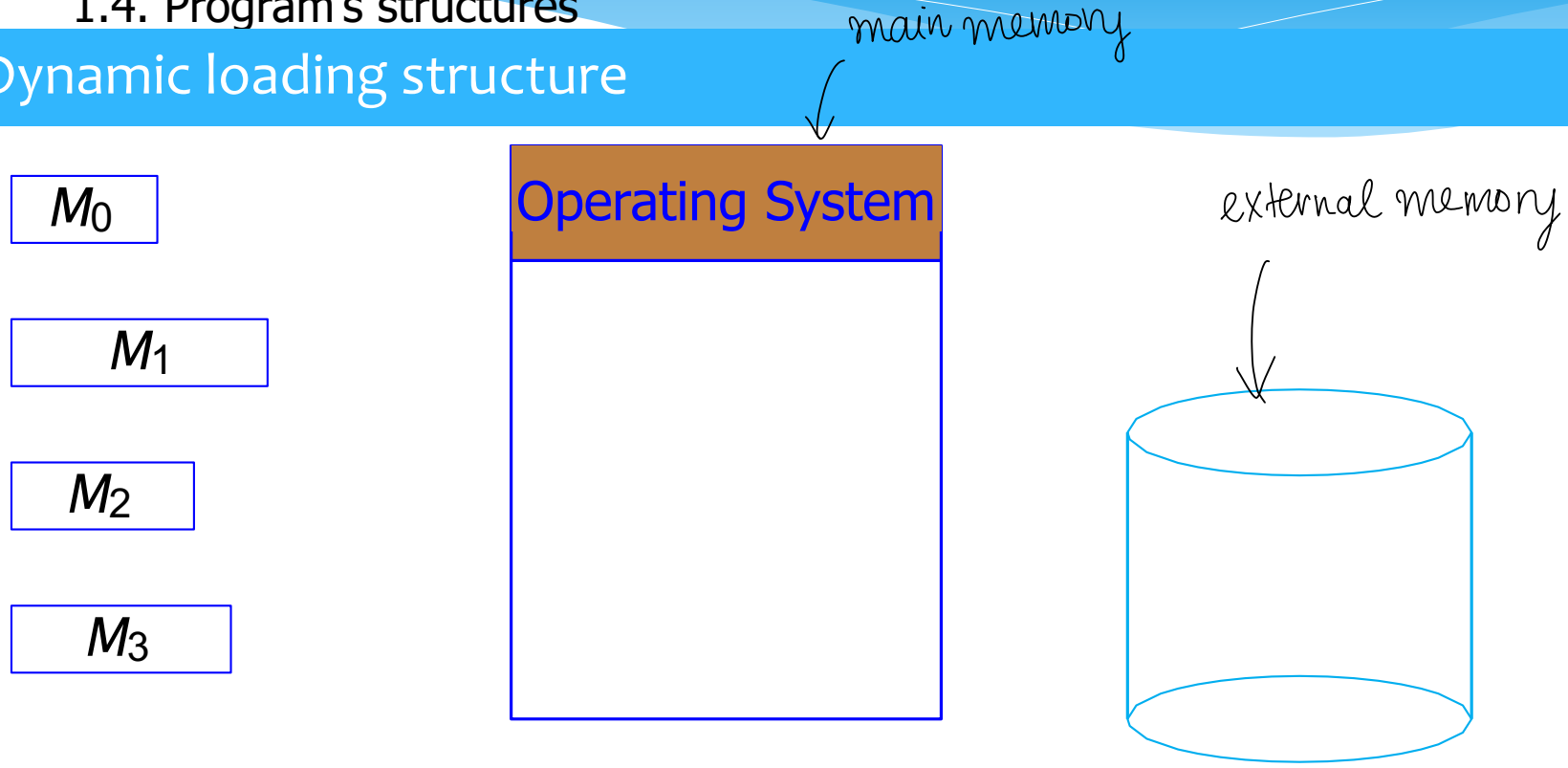
(see TOTO project)
i.e. the variables declared outside main() → then translated into external ptrs

## Linear structure

- Advantages
  - Simple, easy to link and localizing the program
  - Fast to execute (fastest in comparison w/ other structures!)
  - Highly movable (compile once, run everywhere (no need to re-compile))
- Disadvantages
  - Waste of memory (not all modules are needed at 1 time)
    - Not all parts of the program are necessary for the program's execution
  - It's not possible to run the program that larger than physical memory's size

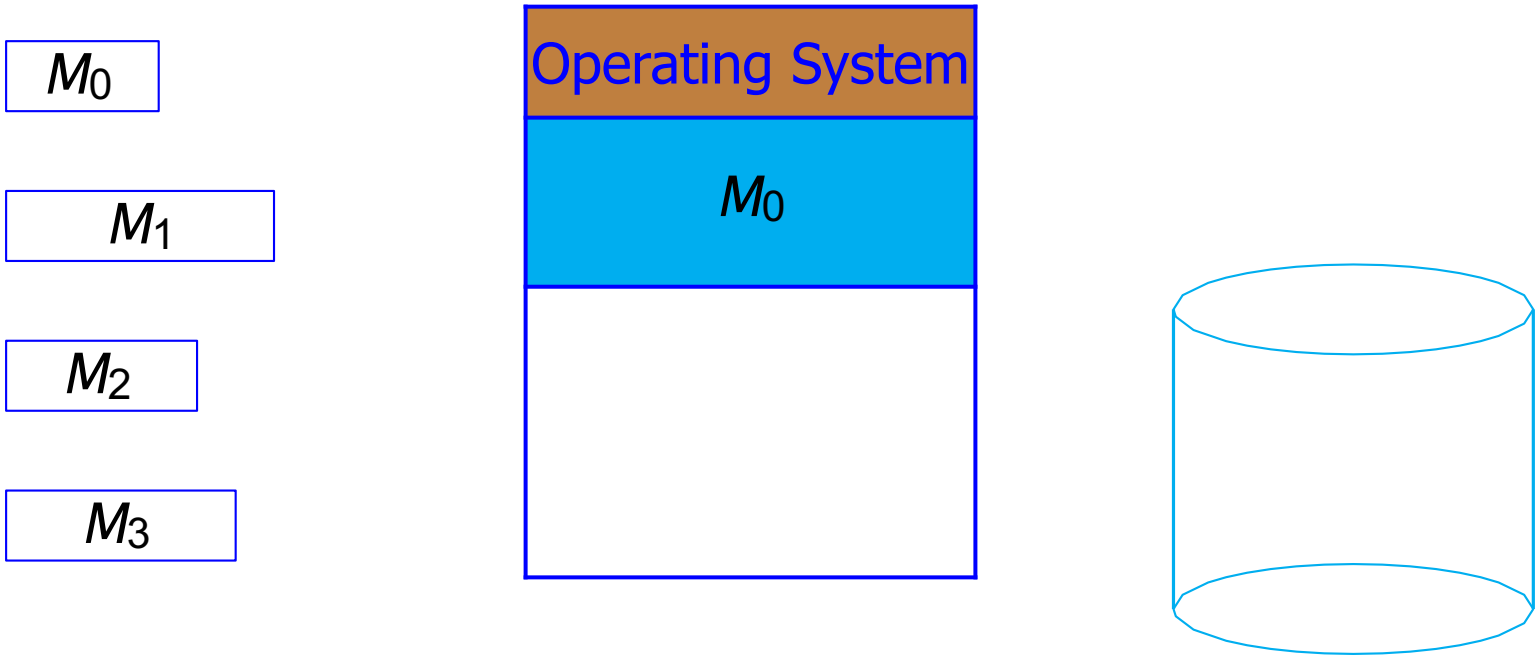
15% - 17% of the modules are really useful for program execution

# Dynamic loading structure



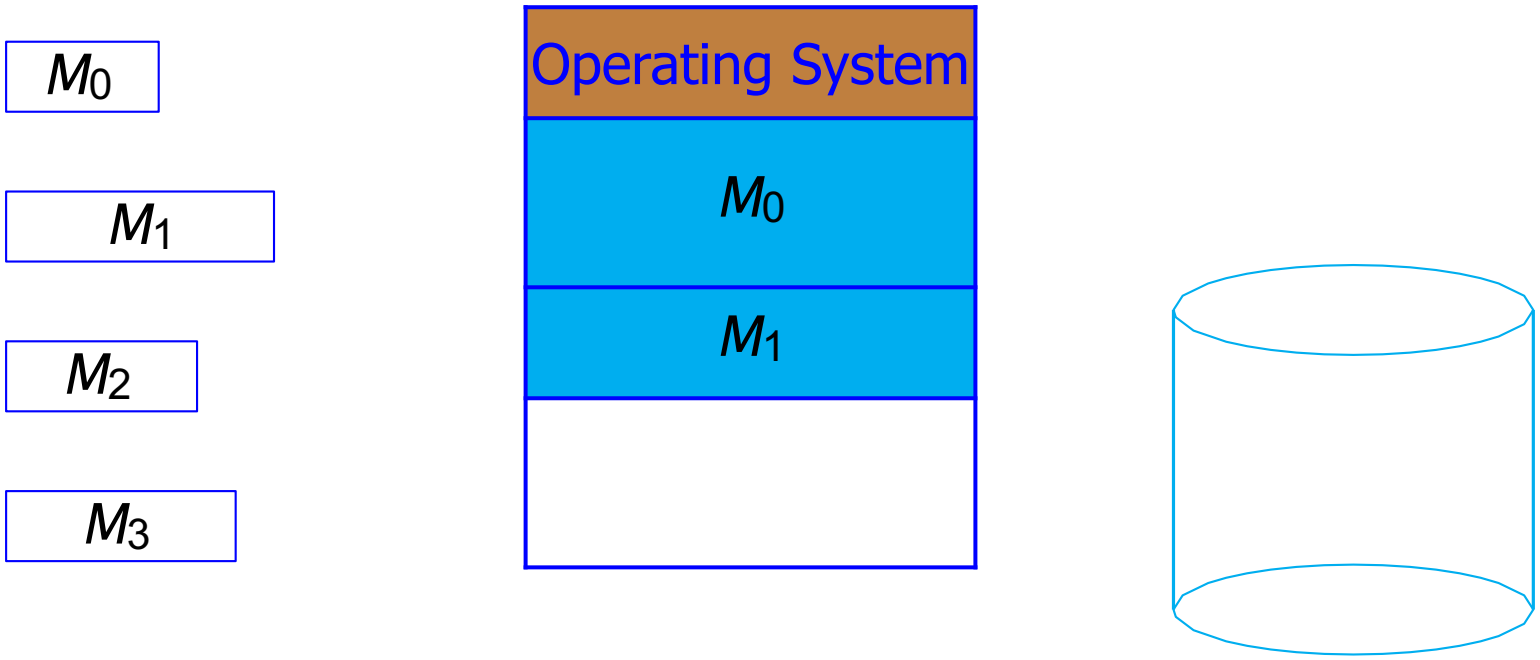

- Each module is edited separately

# Dynamic loading structure




- Each module is edited separately
- When executing, system will load and localize the main module

# Dynamic loading structure

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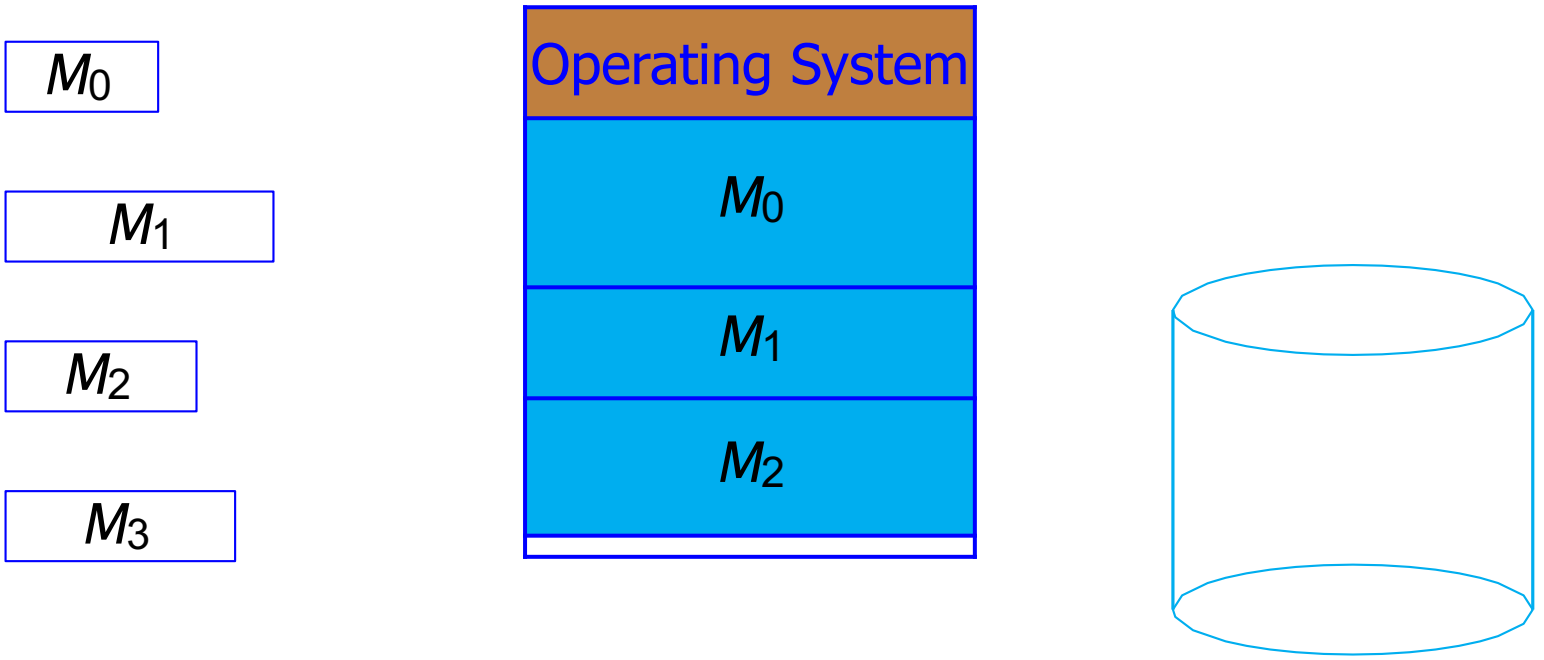
- When module is needed, request for memory and load module into memory

# Dynamic loading structure

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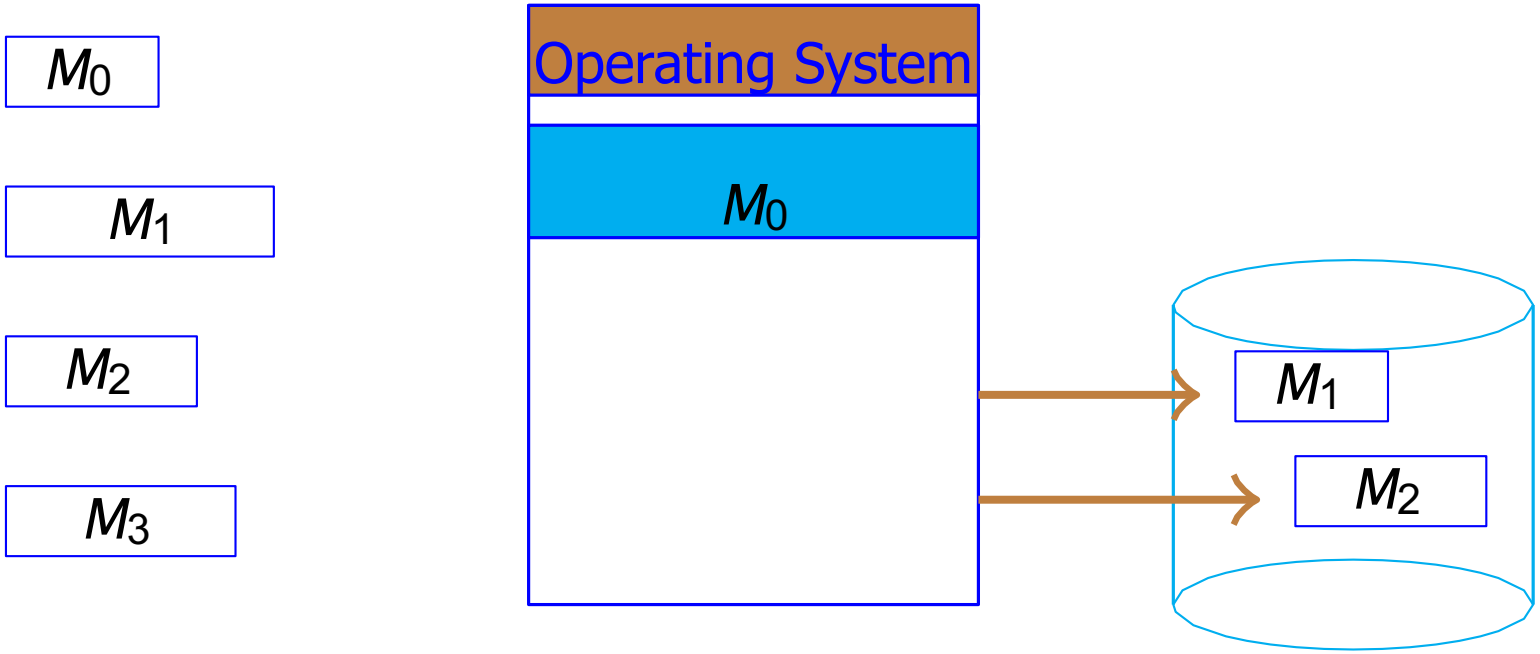


- Each module is edited separately
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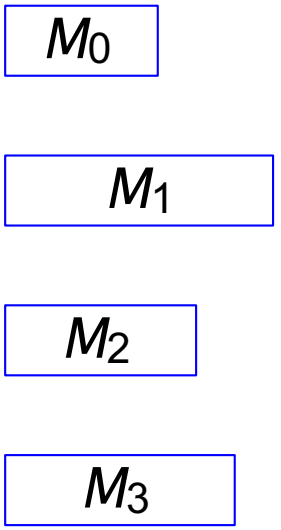
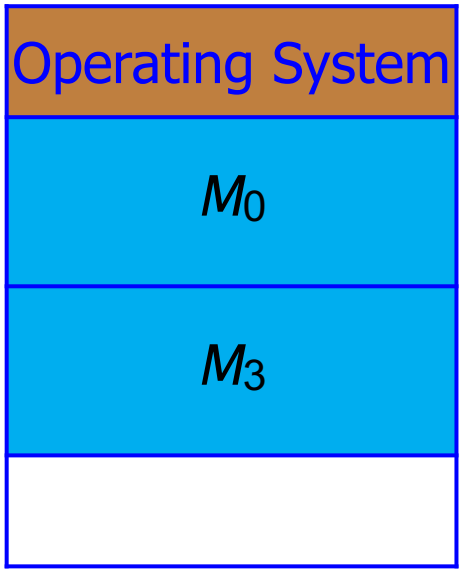
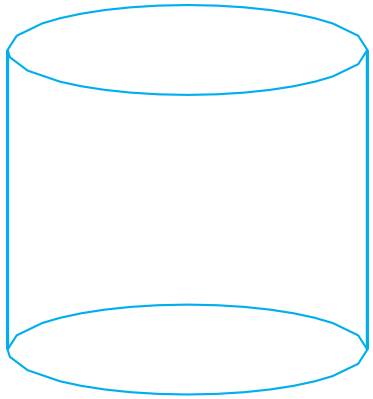
- When a module is finished using or not enough memory, bring unnecessary modules out

# Dynamic loading structure




(With turns of loading & off-load, the address for the same module is DIFFERENT!)



- Each module is edited separately
- When executing, system will load and localize the main module
- When module is needed, request for memory and load module into memory
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# Dynamic loading structure

(≠ dynamic links) Modules belong to your program only
↳ Modules can be shared across programs

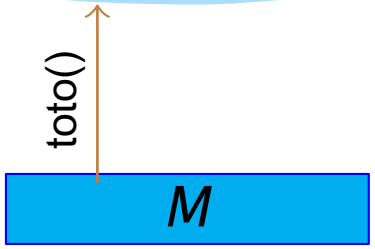
Advantage

- Can use memory are smaller than the program's size
- High memory usage effectiveness if program is managed well

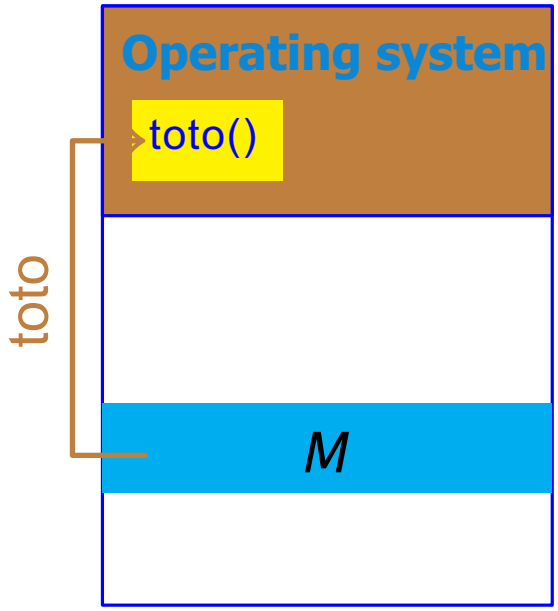
Disadvantage

- Slow when execution (upon offload, in case we need the module again, we'll have to wait for the module to be loaded again and assigned new addresses)
- Mistake may cause waste of memory and increase execution time
- Require user to load and remove modules
  - User must understand clearly about the system
  - Reduce the program's flexible

# Dynamic-link structure

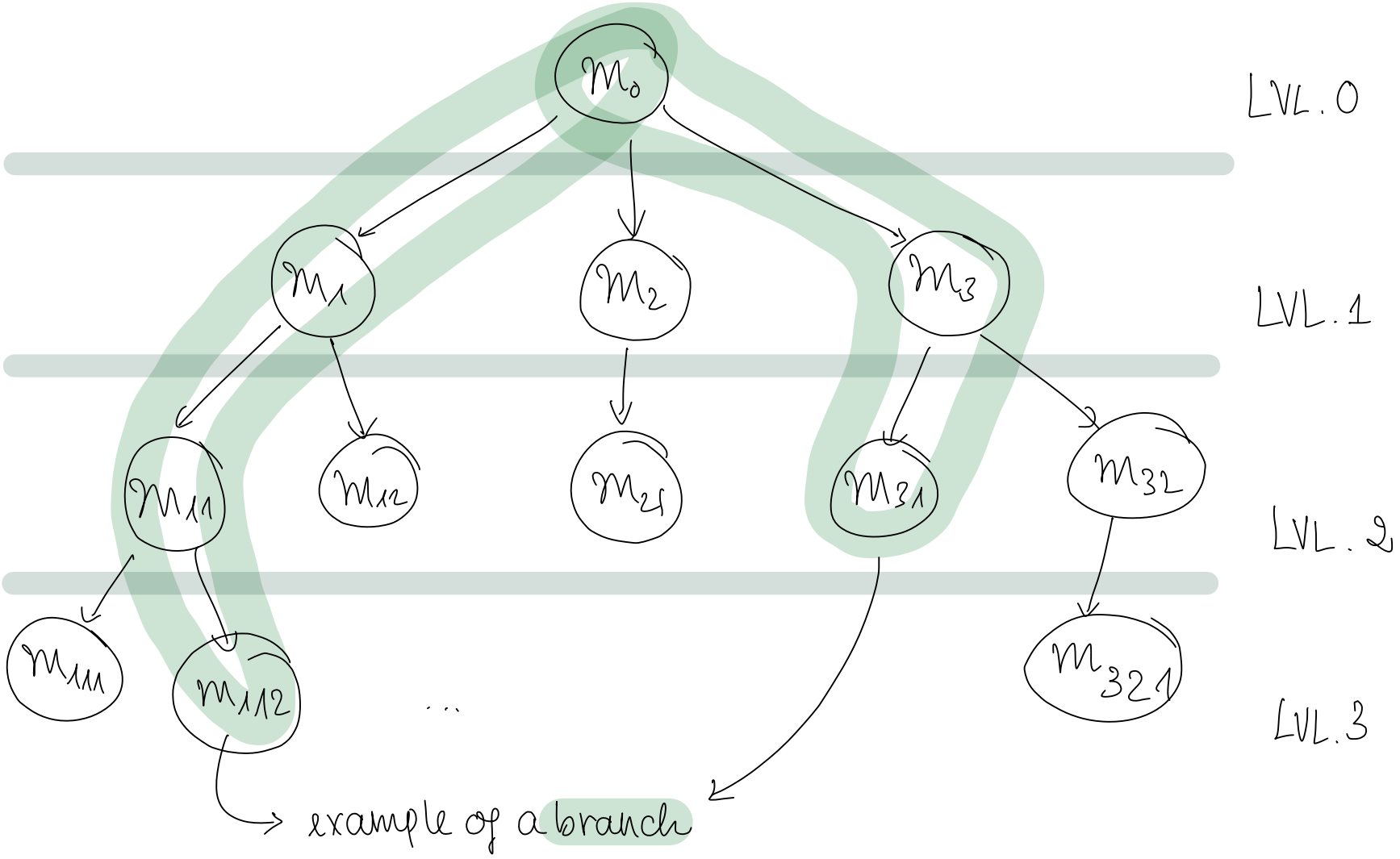



- Links will be postponed when program is executing
- Part of the code segment (stub) is utilized to search for corresponding function in the library in the memory
- When found, stub will be replace by the address of the function and function will be executed
- Useful for constructing library



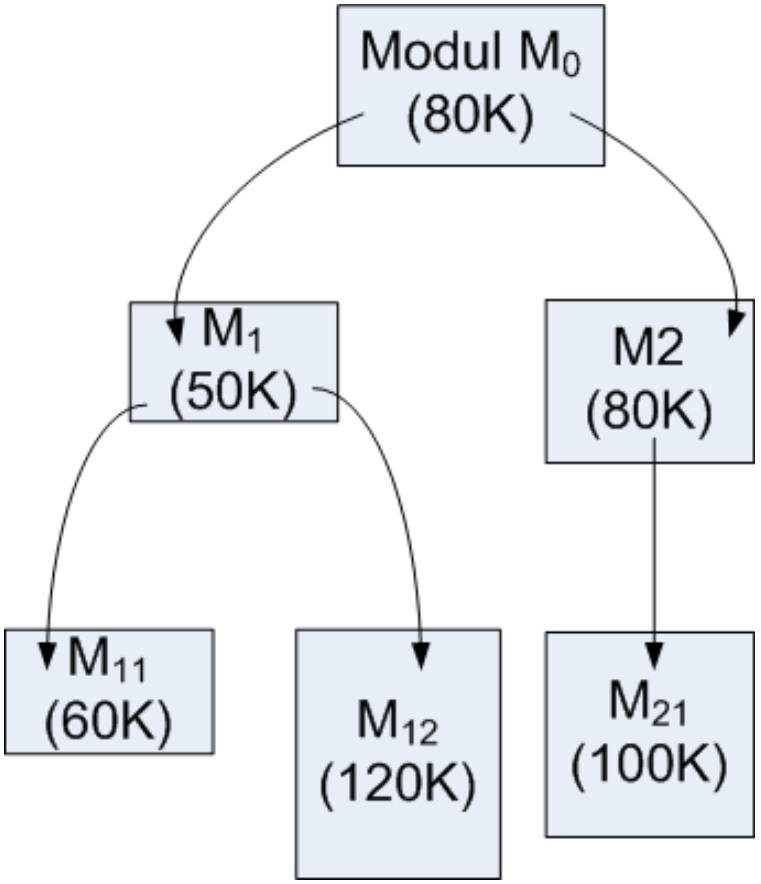
## Overlays structure

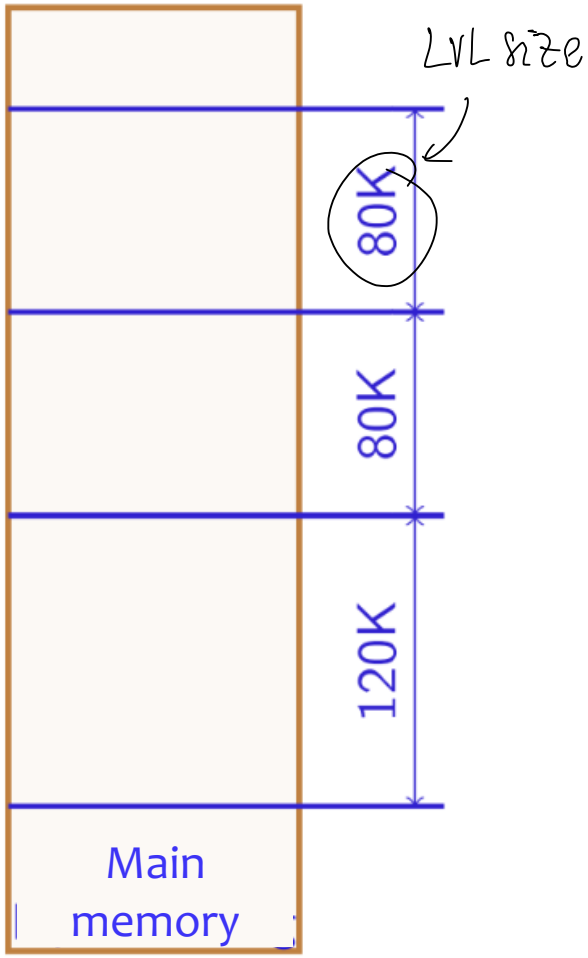
- Modules are divided into different levels
  - Level 0 contains main modul, load and localize the program
  - Level 1 contains modules called from level o's module and these modules do not exist at the same time
  - . . .
- Memory is also divided into levels corresponding to program's levels
  - Size equal to the same level's largest module's size
- Overlay structure requires extra information
  - Program is divided into how many levels, which modules are in each levels
  - Information is stored in a file (overlay map)
- Module at level 0 is edited into an independent executable file
- When program is executed
  - Load level o module similar to a linear structure program
  - When another module is needed, load that module into corresponding memory's level
    - If there are module in the same level exist, bring that module out




- Size of 1 level = size of the largest module in that level
- When running, your program would only need 1 branch to be executable!
- If your program is divided into $n$ levels $\Rightarrow$ Mem for prog is organized into $n$ levels!

## Overlays structure



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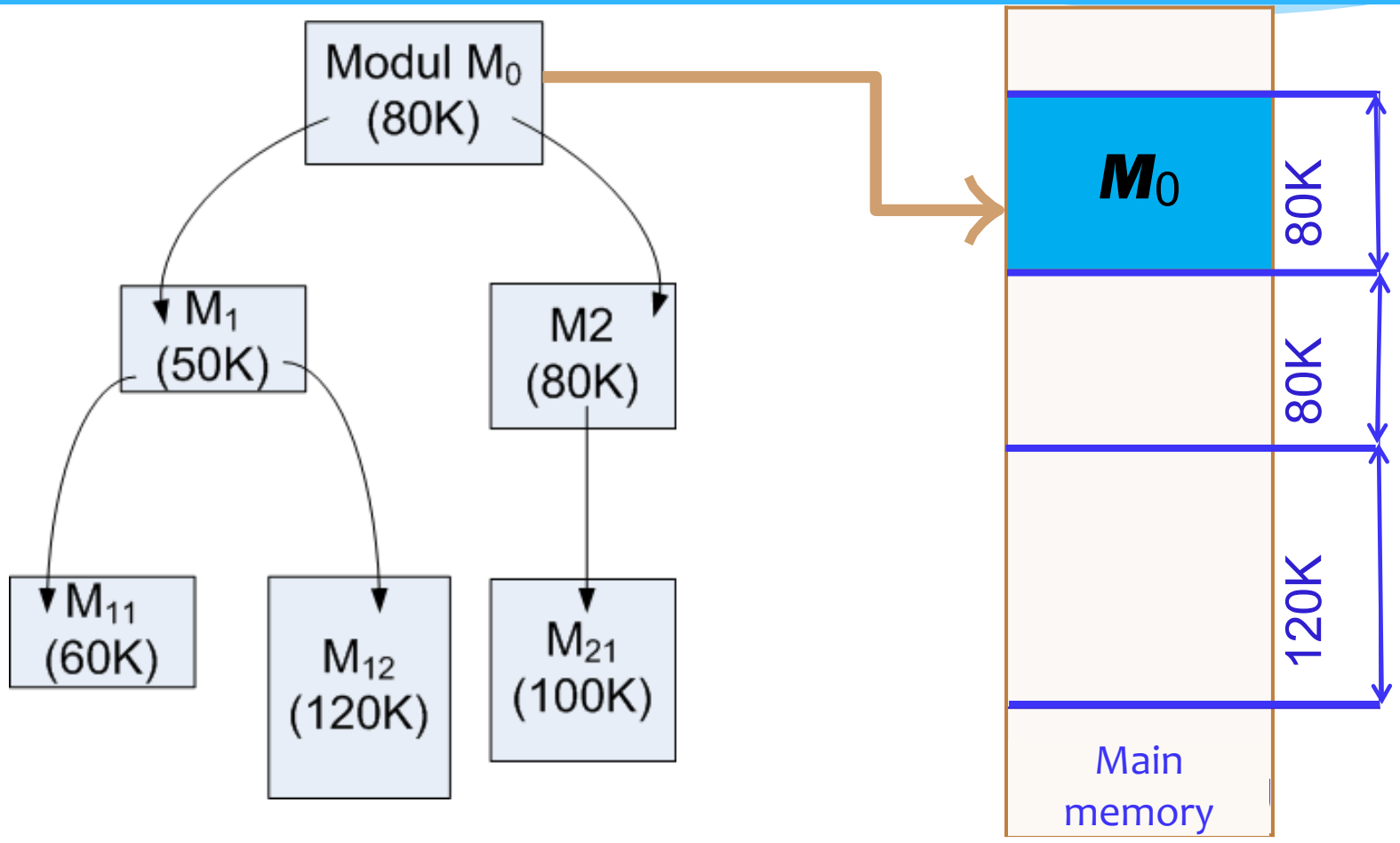

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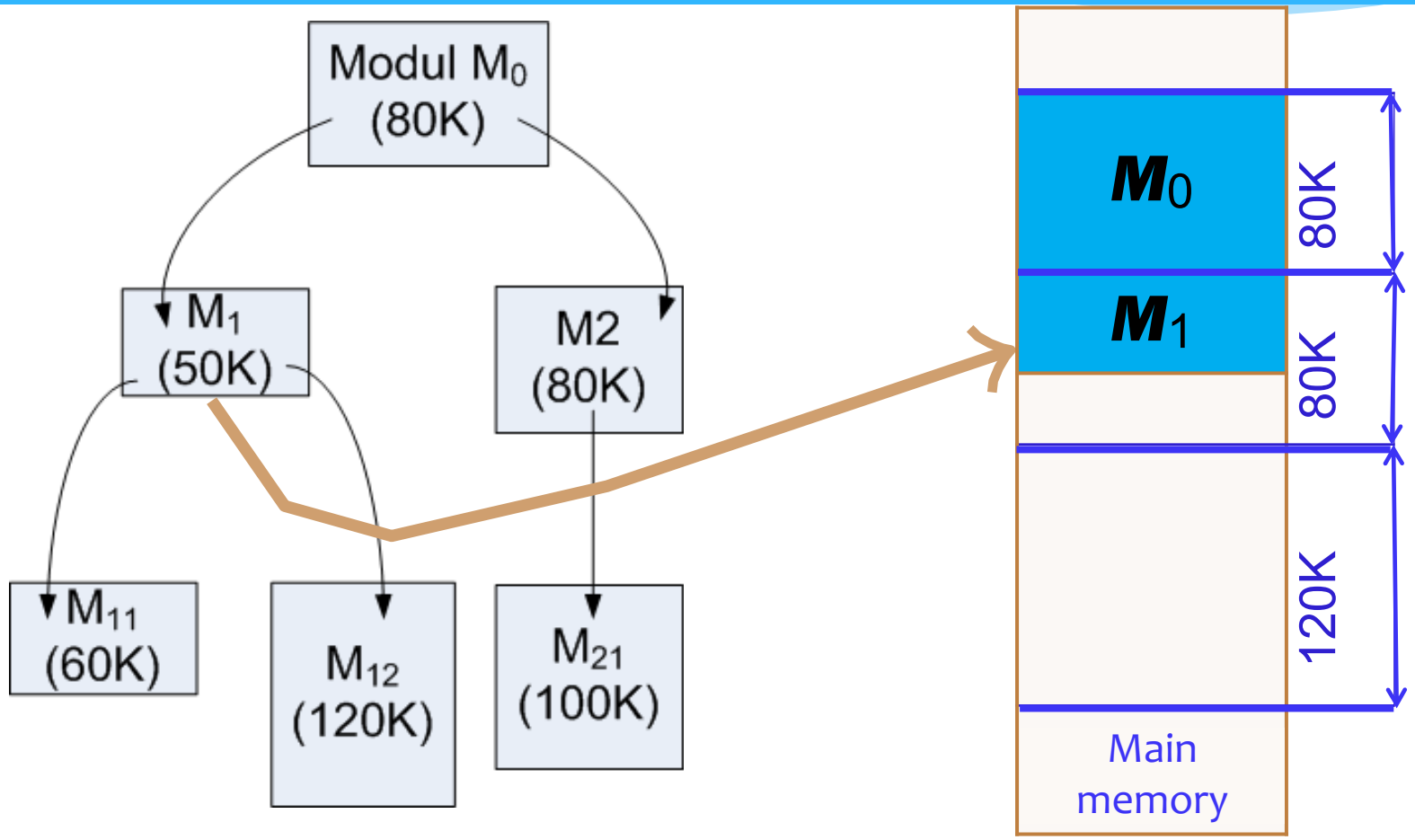

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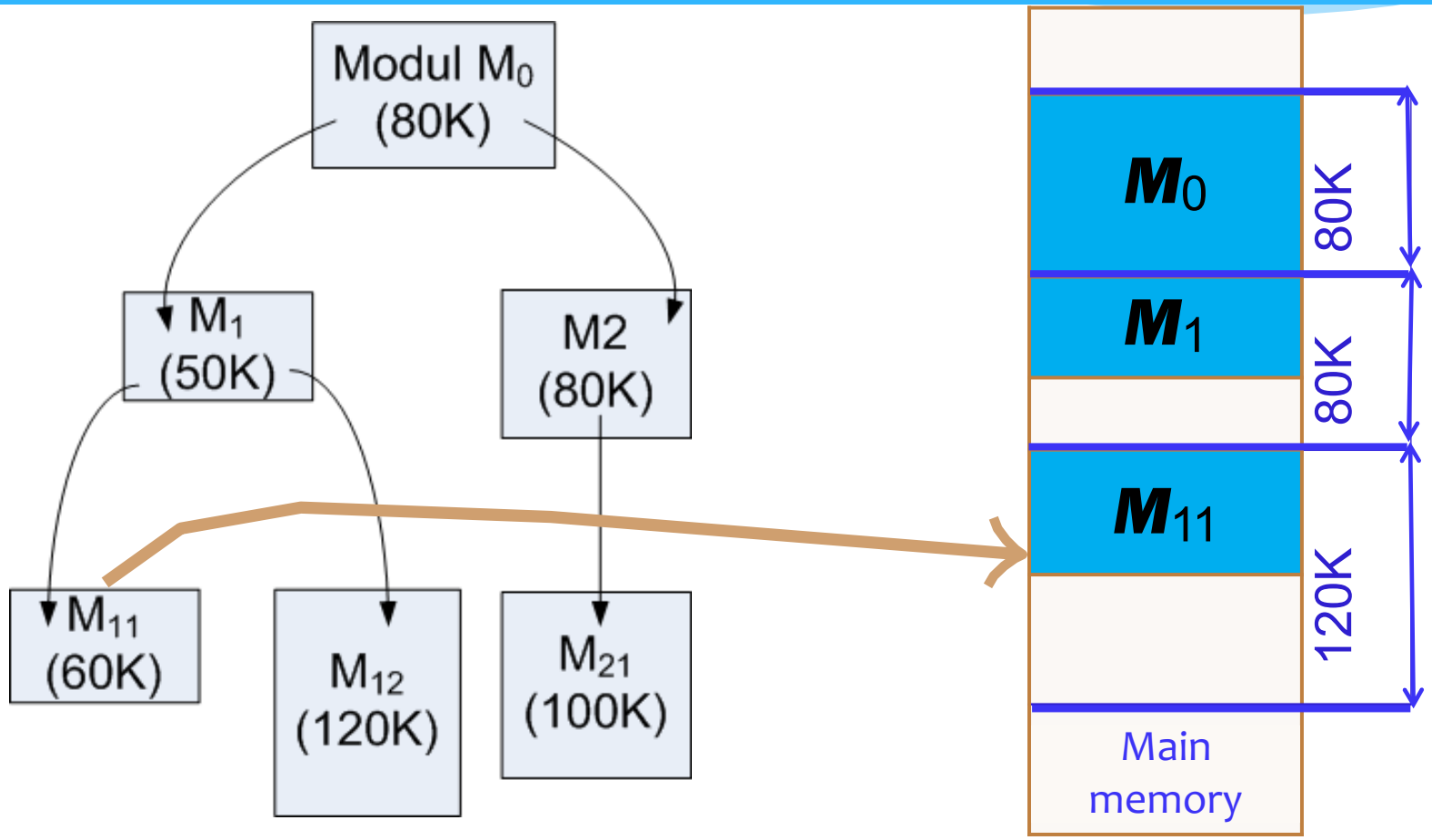

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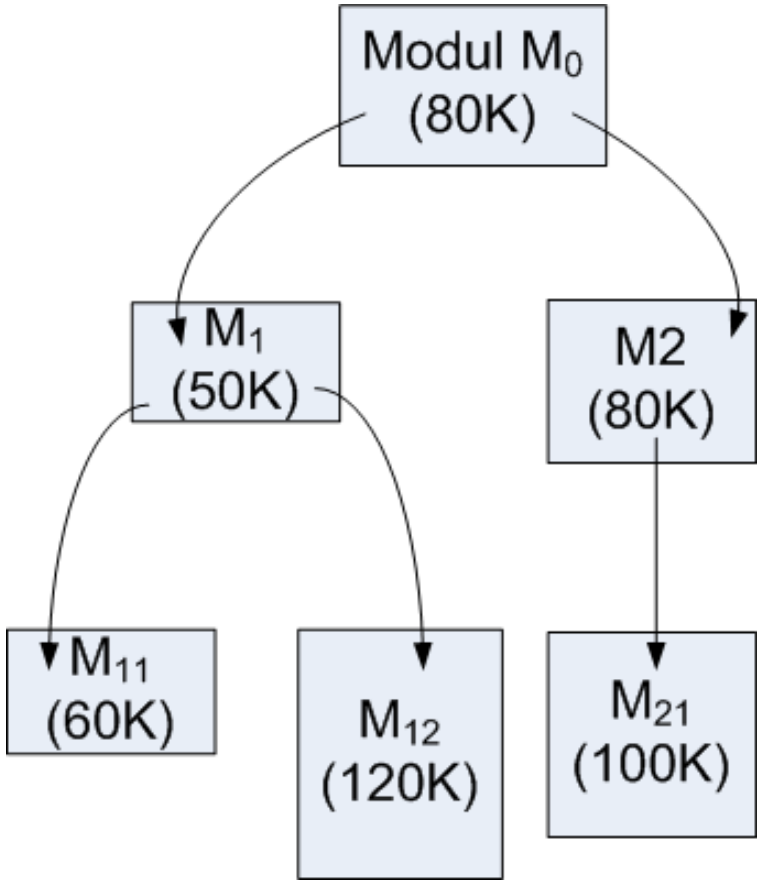


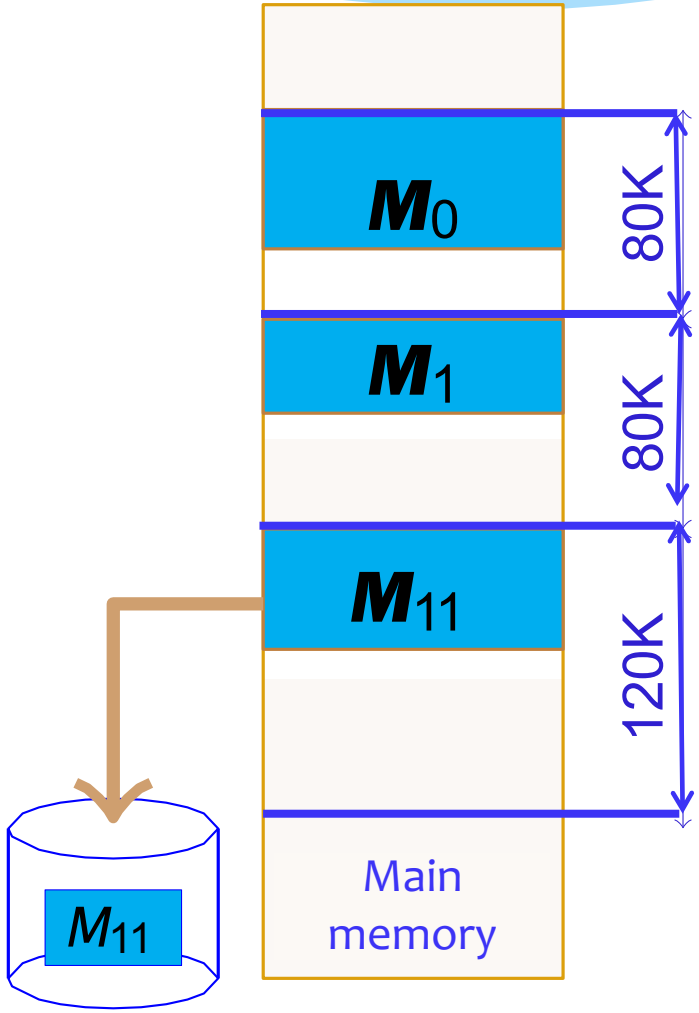

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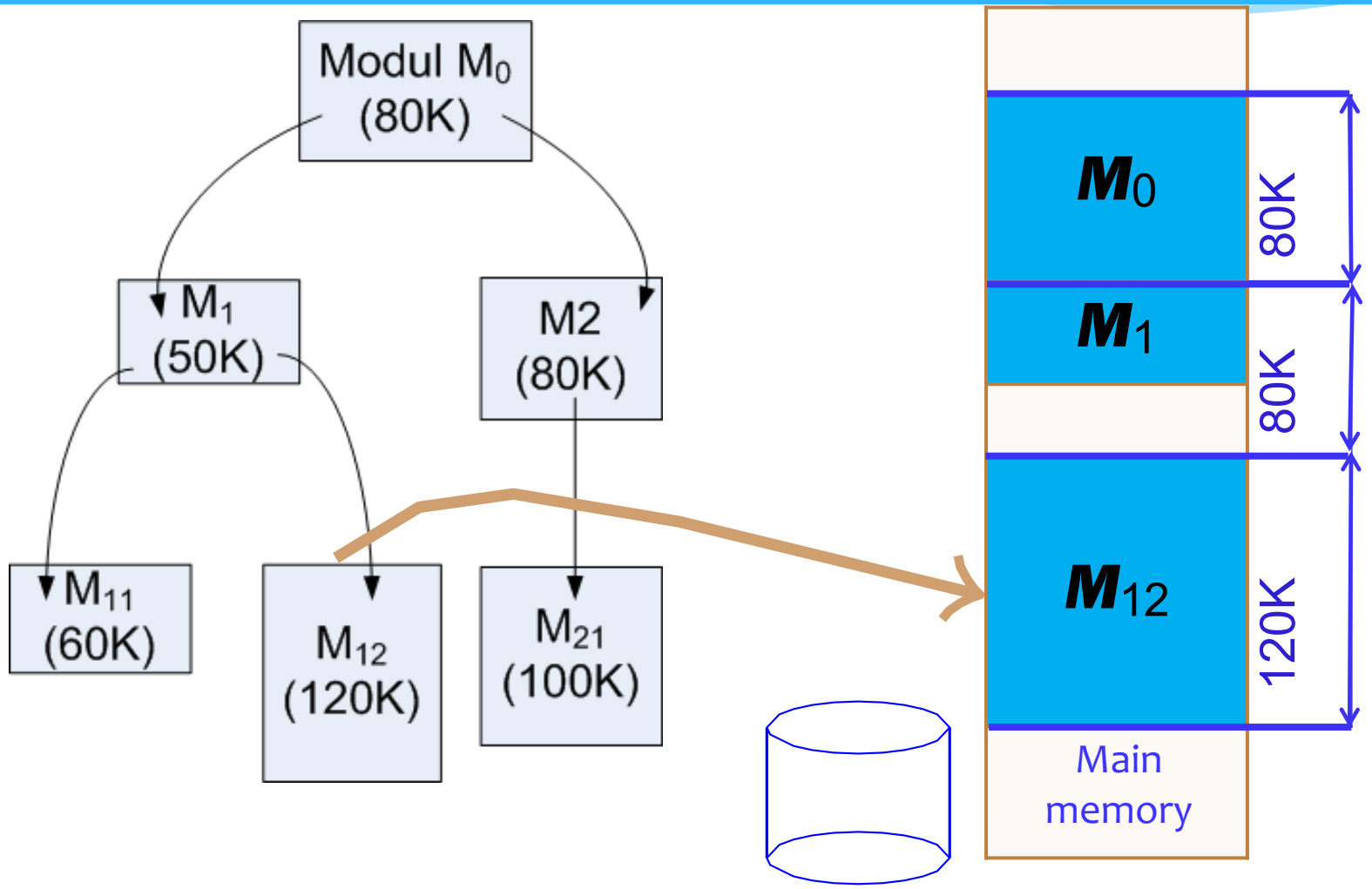

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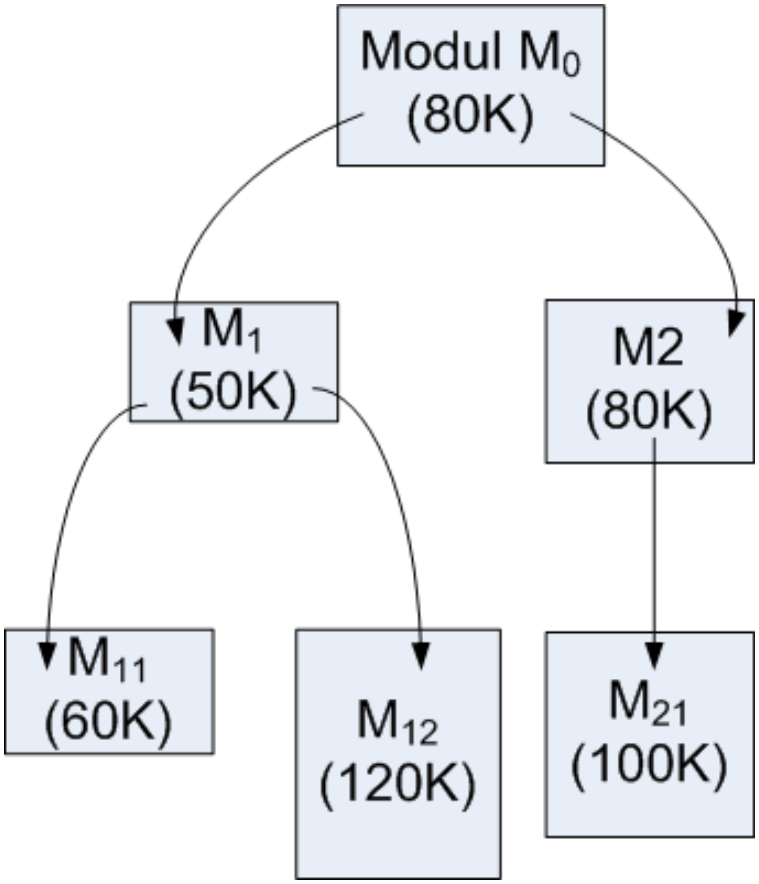


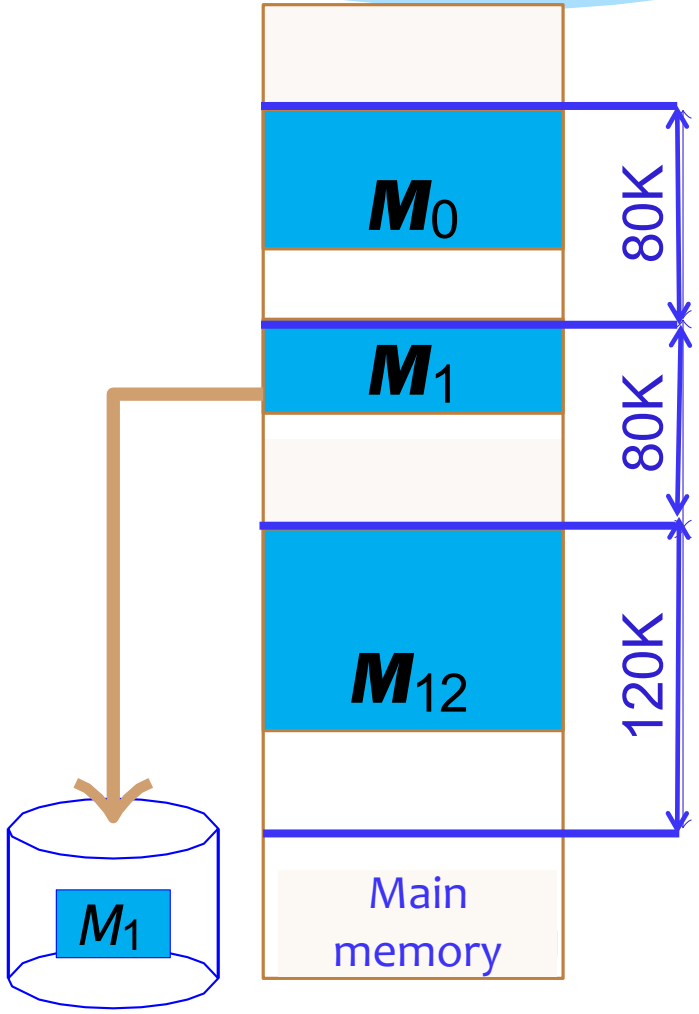

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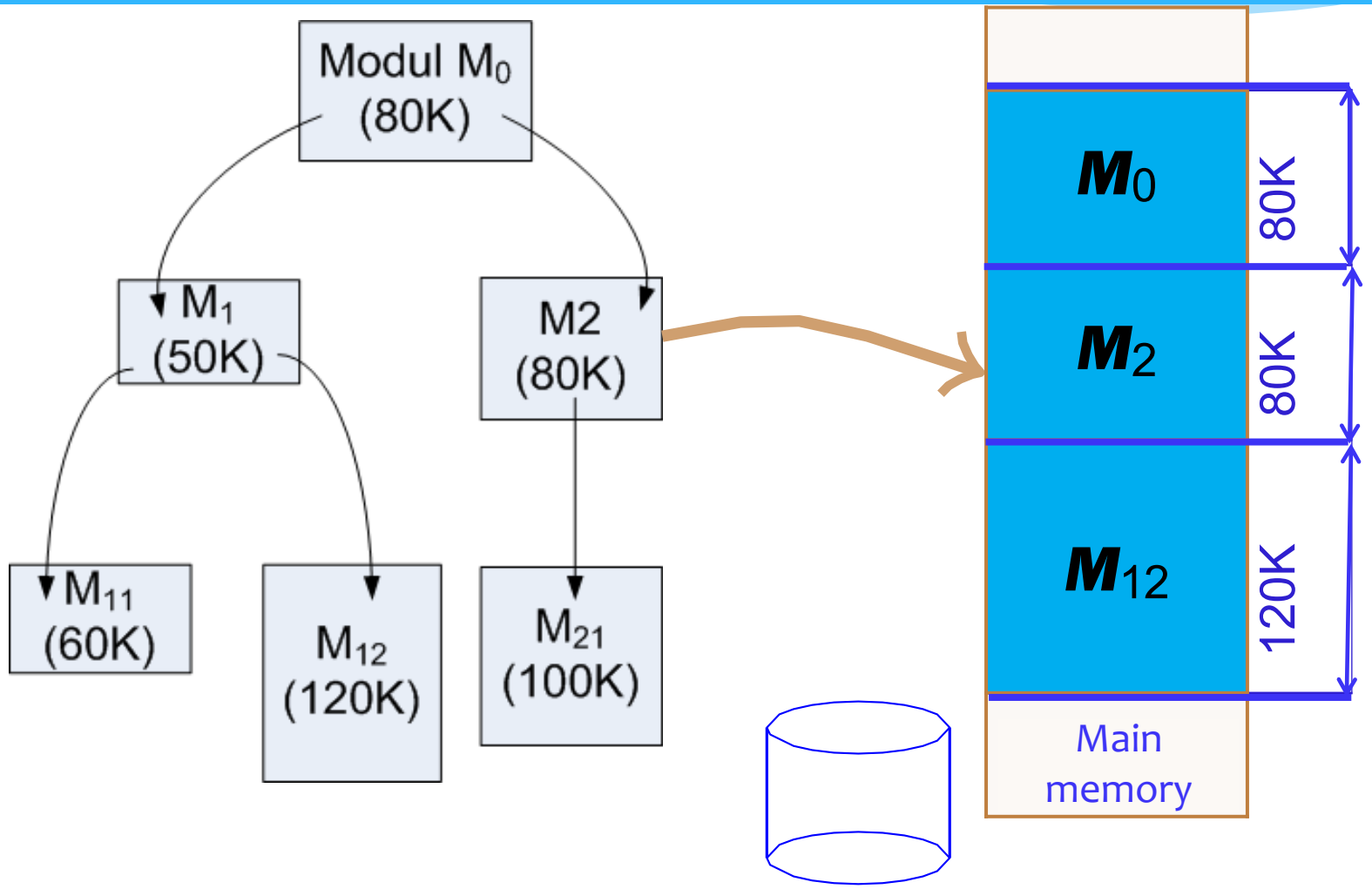


## Overlays structure - Conclusion

- Allow program with larger size than memory area size allocated by the operating system
- Require extra information from user
  - Effectiveness is depend on provided information
- Memory usage effectiveness is depend on how program's modules are organized (not effective when running smaller modules)
  - If there are exist modules that larger than other modules in the same level ⇒ the effective is reduced
- Module loading process is dynamic but program's structure is static ⇒ not change at each time running
  - Provide more memory, the effectiveness does not increase

* Requirement: Your module can NOT make the call to another module in the same level
  ↳ If this occurs (eg. $M_1$ calls $M_2$), the callee will OVERWRITE the caller!

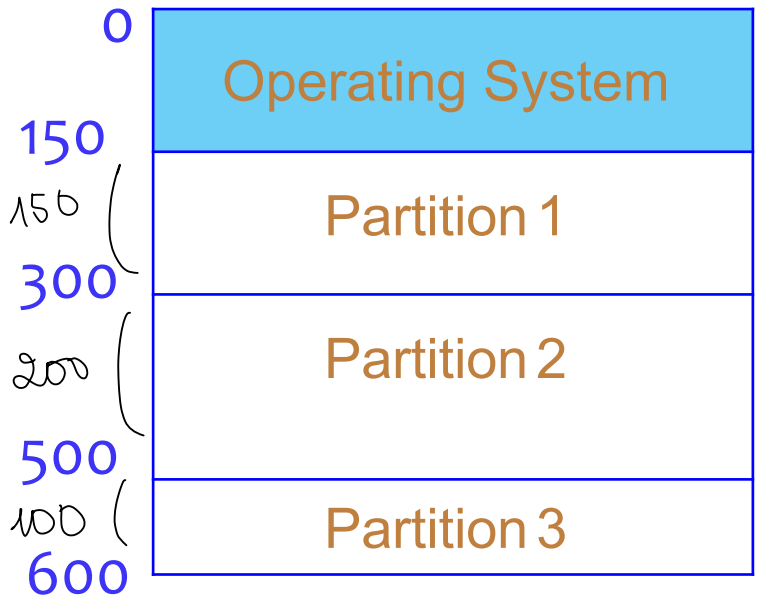
# Chap 3 Memory Management

① Introduction
② Memory management strategies
③ Virtual memory
④ Memory management in Intel's processors family

- Fixed partition strategy
- Dynamic partition strategy
- Segmentation strategy
- Paging strategy
- Segmentation and paging combination strategy

## Rule

- Memory is divided into ***n*** parts
- Each part is called a *partition*
  - size: can be unequal
  - Utilized as and independent memory area
    - At a single time, only one program is allowed to exist
    - Programs lie inside memory until finish
- Example: Consider the following system

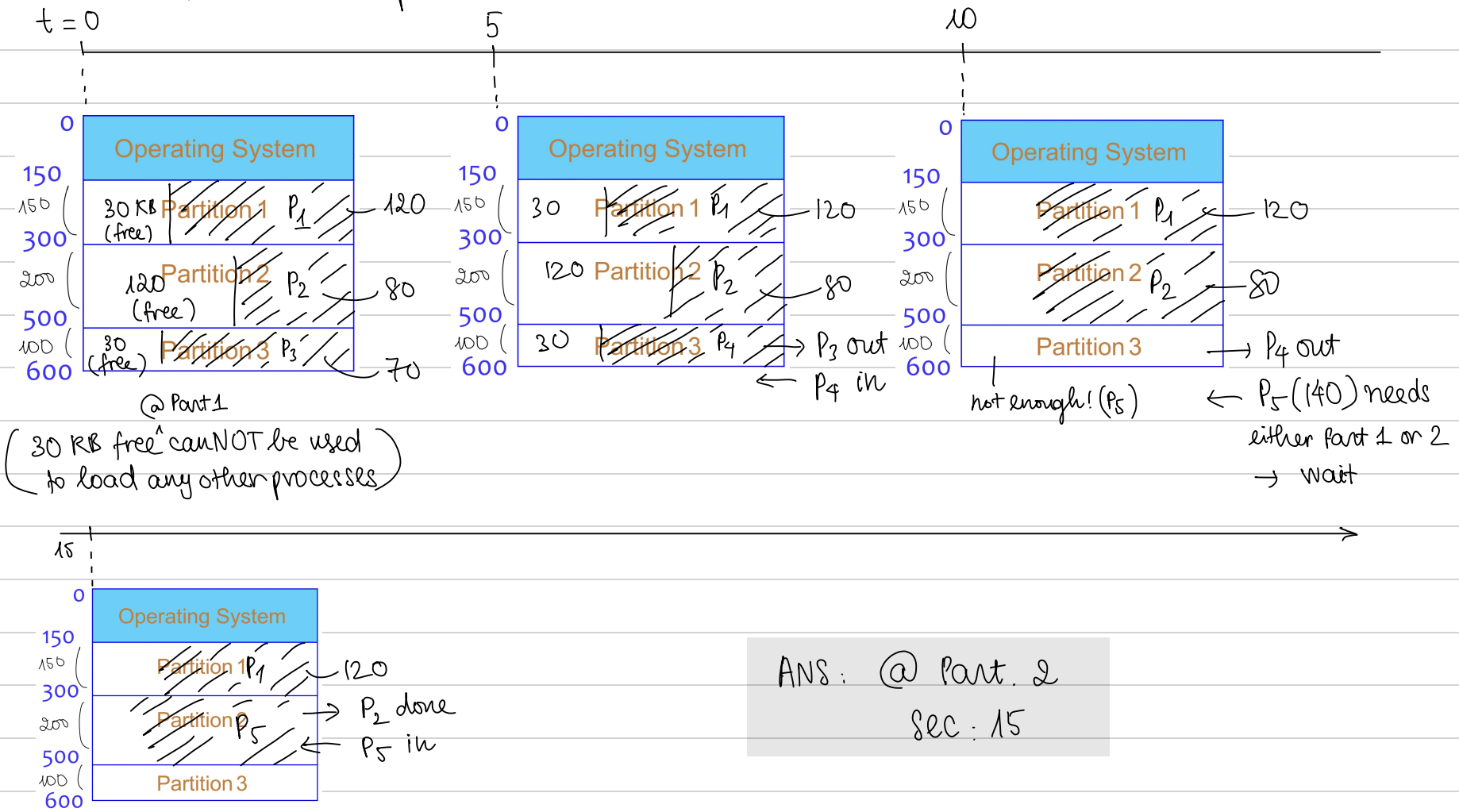



exetime

| Process | Size | time |
|---|---|---|
| $P_1$ | 120 | 20 |
| $P_2$ | 80 | 15 |
| $P_3$ | 70 | 5 |
| $P_4$ | 50 | 5 |
| $P_5$ | 140 | 12 |
| Queue | | |

What is the time and address that P5 is loaded into the memory?
(Hint: Draw a memory map.)

OS search for empty partition, find the large enough one
↳ Order: top → bottom




ANS: @ Part. 2
Sec: 15

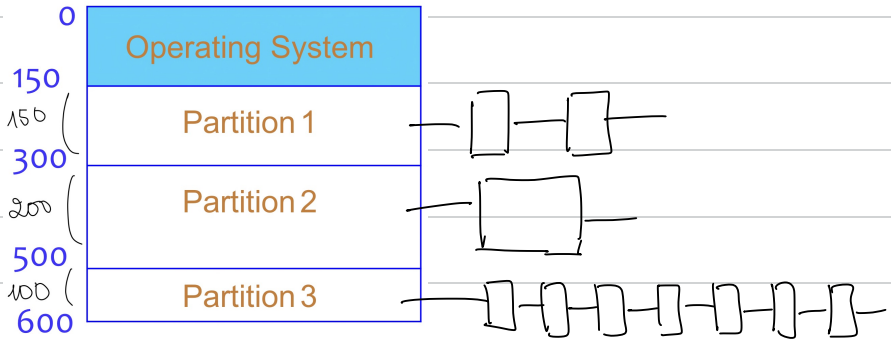
## Conclude

- Simple, easy for memory protection
  - Program and memory area have a protection lock
  - Compare 2 locks when program is loaded
- Reduce searching time
- Must copy controlling module into many versions and save at many places
- Parallel cannot be more than *n* (nb of partitions; the nb won't change until computer restart (when restart, the mem is partitioned again))
- Memory is segmented
  - Program's size is larger than the largest partition's size
  - Total free memory is large enough but can not load any program

  ⇒Fix partition structure, merge neighboring partition
- Application
  - Large size disk management
  - IBM OS/360 operating system

Problem. The fixed partion may make a small-sized process take the larger partition-which is needed to serve even larger process!

Maintaining queues that classify processes based on their size




↳ Prob: 1 process may need to wait for long

The unused part of a partition : Internal fragmentation

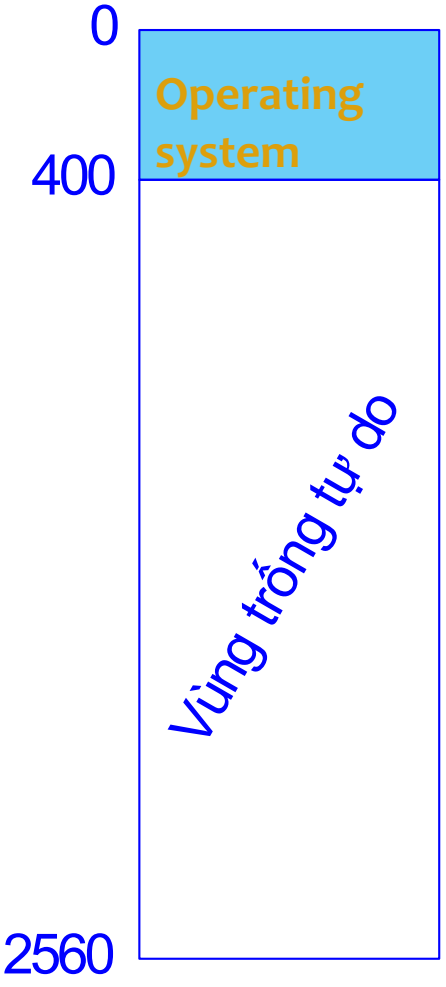
- Fixed partition strategy
- Dynamic partition strategy
- Segmentation strategy
- Paging strategy
- Segmentation and paging combination strategy

## Rule

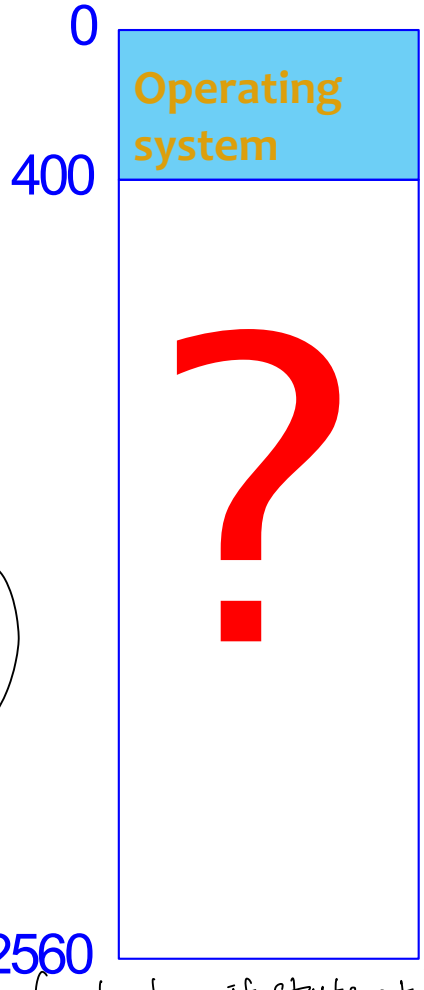
Only one management list for free memory

- At the start, the whole memory is free for processes ⇒ largest *hole*
- When a process requests for memory
  - Search in the list for a large enough hole for request
  - If found
    - Hole is divided into 2 parts
    - One part allocate to process as requested
    - One part return to the management list
  - If not found
    - Wait until there is a hole large enough
    - Allow another process in the queue to execution (if the priority is guaranteed)
- When the process finish
  - Allocated memory area is returned to the free memory management list
  - Combine with other neighboring holes if necessary

## Main memory

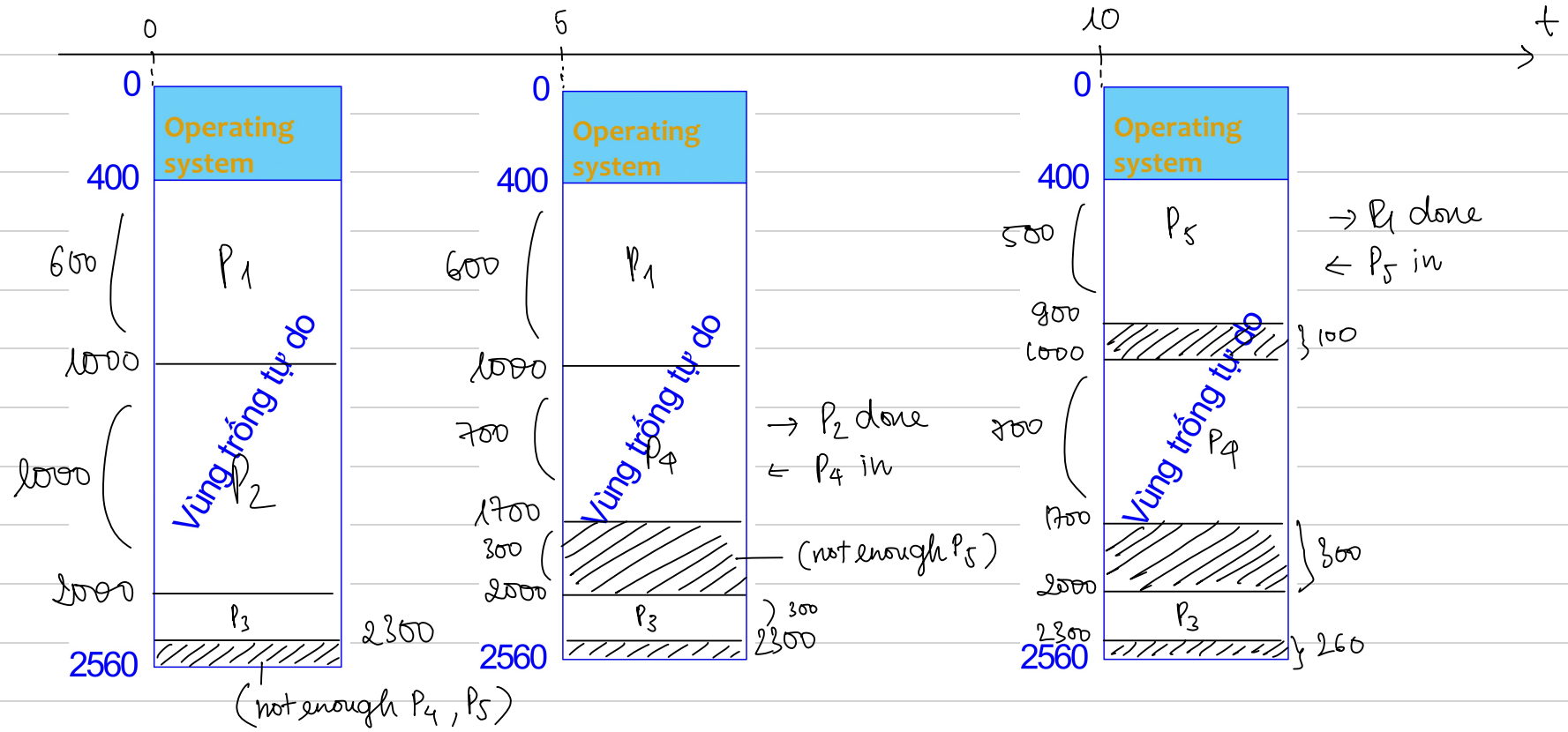



| Process | Size | time |
|---|---|---|
| $P_1$ | 600 | 10 |
| $P_2$ | 1000 | 5 |
| $P_3$ | 300 | 20 |
| $P_4$ | 700 | 8 |
| $P_5$ | 500 | 15 |
| Waiting file queue | | |




* My mistake :
Duration ≠ Time stamp finish
i.e. → Take 8 min ≠ Finish at the 8th minute! (only true if starts at t = 0)

Draw the memory map for this system





IMPORTANT

Exam question. Given the management list (above) → fill out certain blank slot w/ values

Problem

Everytime OS needs to traverse the list to find the hole

→ Process node is not helpful in finding hole(s)


Keep 2 lists:

1 list for occupied mem

1 list for free mem

↓

Method for selecting the hole that satisfy process's request?

# Free memory area selection strategy

Strategies to select free area for process's request

1) First Fit : First free area satisfy request

1.1 ↳ Next Fit : Start searching from the last alloc. partition → bottom
↳ avoid heavy use of the top part of the memory!

2) Best Fit : Most fitted area

3) Worst Fit : Largest area that satisfy request

↓
How can this be beneficial?

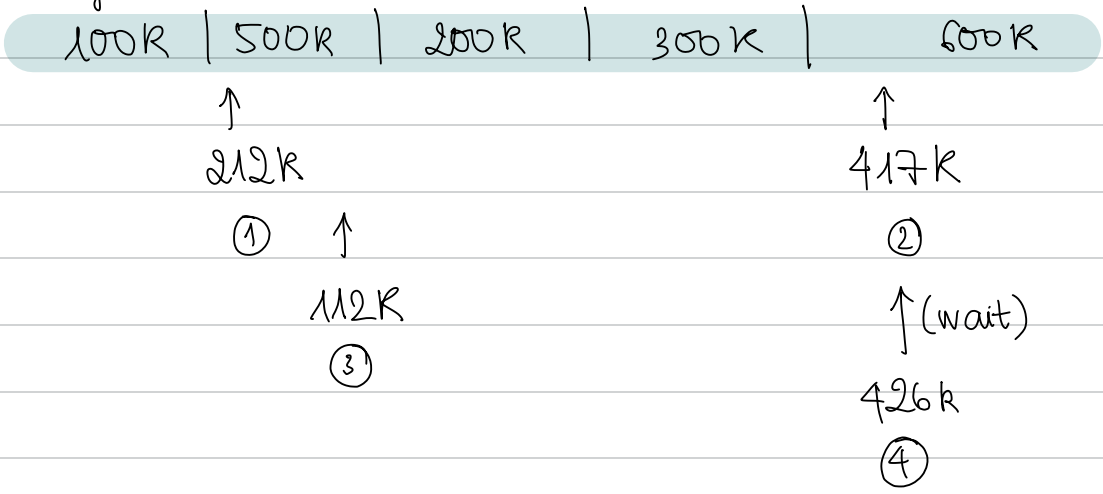
The worst fit may result in a remaining new section that is big enough to load other processes!

## Free memory area selection strategy

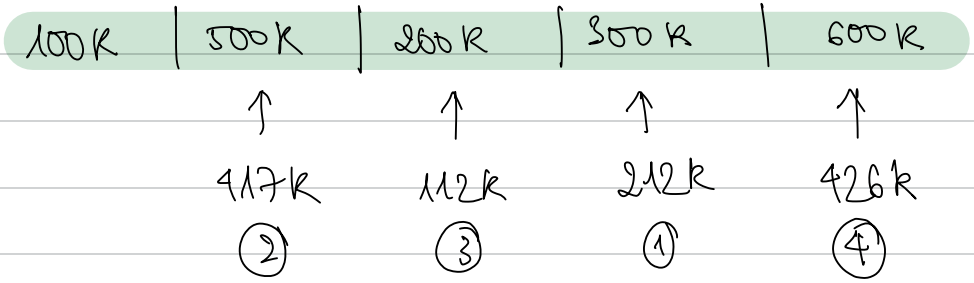
- Suppose free memory area have the size 100K, 500K, 200K, 300K, and 600K (consequently),
- First-fit, Best-fit, and Worst-fit

How will process with size 212K, 417K, 112K, and 426K loaded?

* First-fit




* Bestfit





Frequent Mistakes: Forgot / ignore to keep track of remaing hole of a partition after alloc. to a process : this may be large enough for future process.

## Memory reallocation problem

After a long working time, the free holes are distributed and caused memory lacking phenomenon ⇒ Need to rearrange memory

↳ External fragmentation

- Move process
  - Problem: internal objects when move to new place will has new address
    - Use relocation register to store process's relocation value
  - Select method for lowest cost
    - Move all process to one side ⇒ largest free holes (either top or bottom)
    - Move processes to create a sufficient free hole immediately
- Swapping process (one by one, til ∃ hole satisfies)
  - Select a right time to suspend process
  - Bring process and corresponding state to external memory
    - Free allocated memory area and combine with neighboring areas
  - Reallocation to former place and restore state
    - Use relocation register if process is moved to different places

## Concludes

- No need to copy the controlling modules to different places
- Increase/decrease parallel factor depend on the number and size of programs
- Cannot run program with size larger than the physical memory size
- Cause memory waste phenomenon
  - Memory area is not used and not in the memory management list
    - Cause by the operating system error
    - By malicious software
- Cause external memory defragment phenomenon
  - Free memory area is managed but distributed -> cannot used
- Cause internal memory defragment phenomenon
  - Memory allocated to process but not used by process

- Fixed partition strategy
- Dynamic partition strategy
- Segmentation strategy
- Paging strategy
- Segmentation and paging combination strategy

# Program

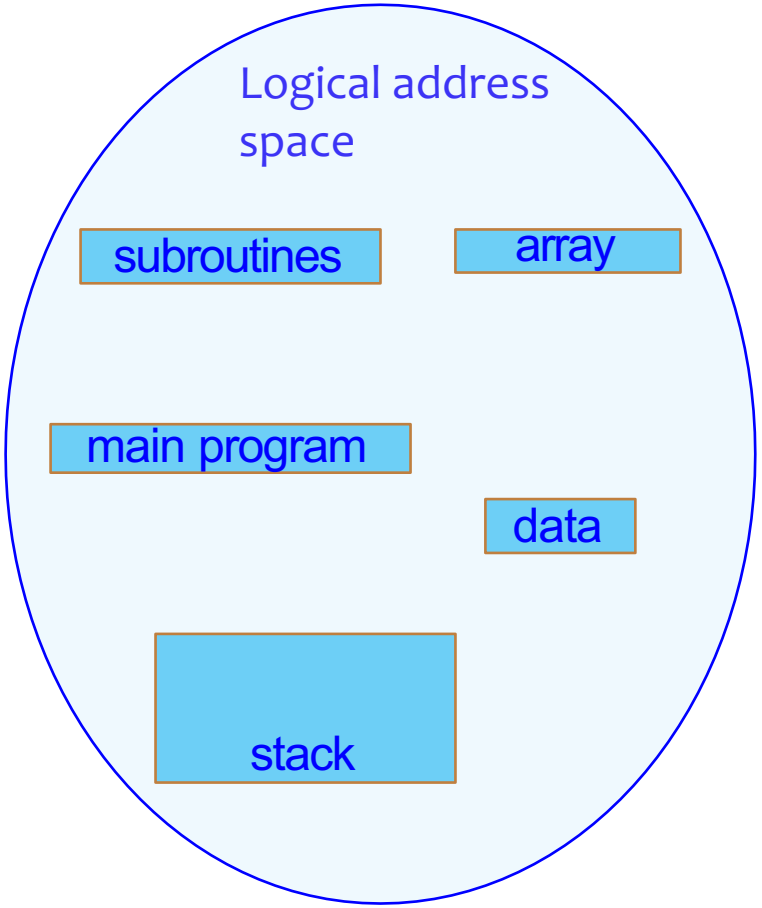
- In general, a program includes following modules
  - main program
  - Set of sub-routine
  - Variables, data structures,. . .
- Modules, objects in program are defined by name
  - function sqrt(), procedure printf() . . .
  - x, y, counter, Buffer. . .
- Member inside a module is determined based on the distance from the head of the module
  - Instruction 10th of function sqrt(). . .
  - Second element of array Buffer. . .

the 1st position

How program is placed inside memory?
- Stack stay at the higher area or Data stay at the higher area?
- Object's physical address . . .?

⇒ Users donot care

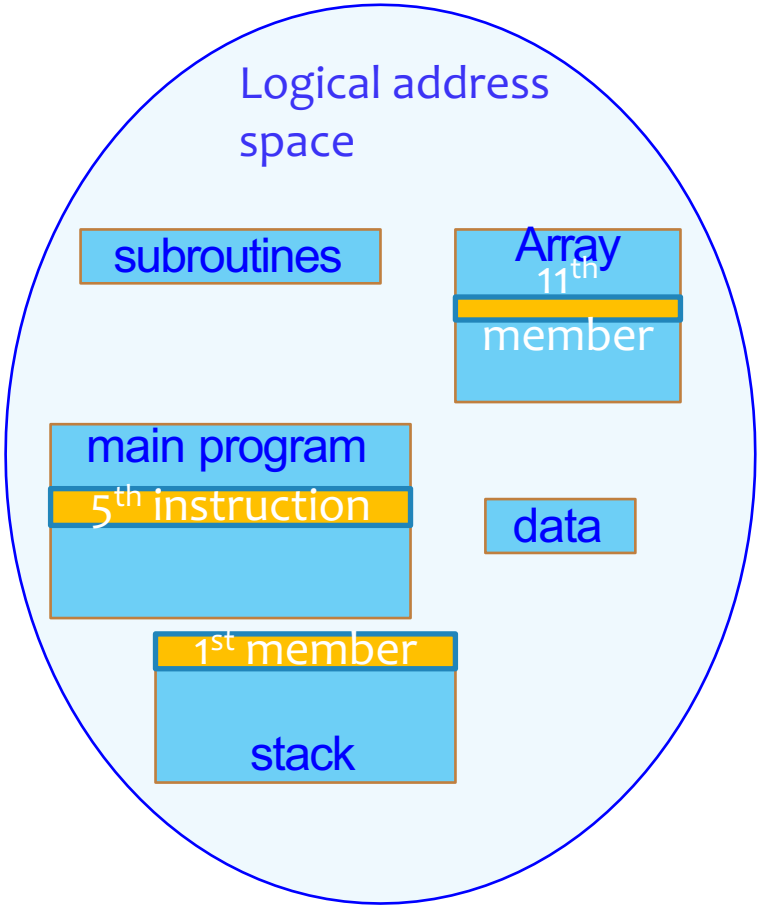
# User's perspective




When program is loaded into memory to execute. Program is combined of several segments

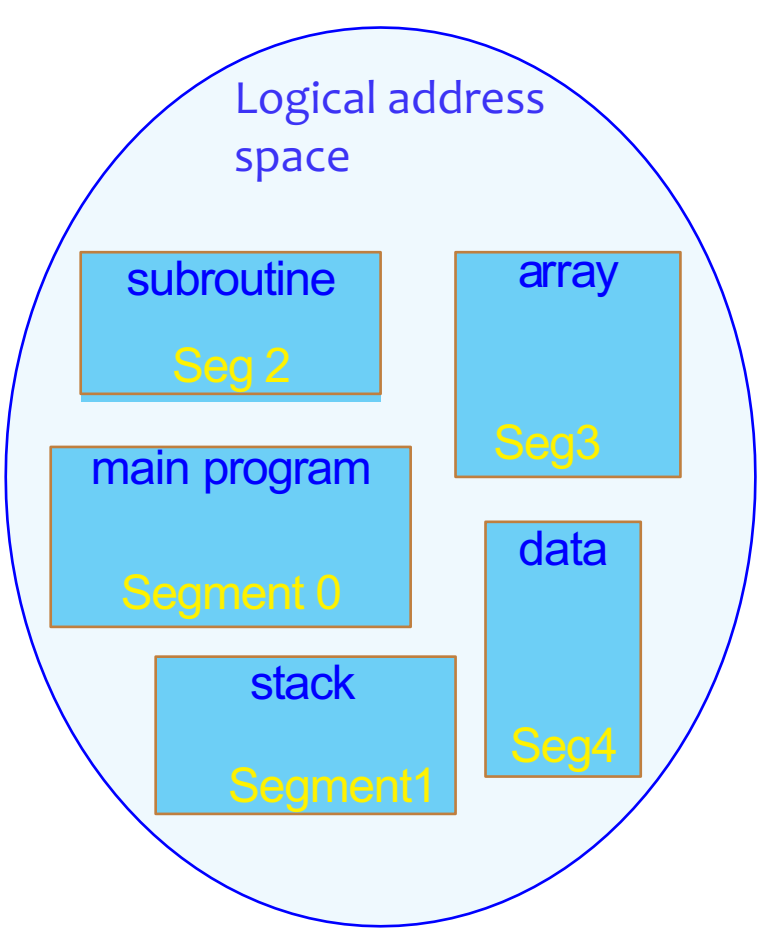
- Each segement is a logic block, corresponding to a module
  - Code: main(), procedure, function. . .
  - Data: Global objects
  - Other segments: stack, array. . .
- Each segment occupy an contiguous memory area ≈ continuous
  - Has a start position and size
  - Can be located at any place in the memory

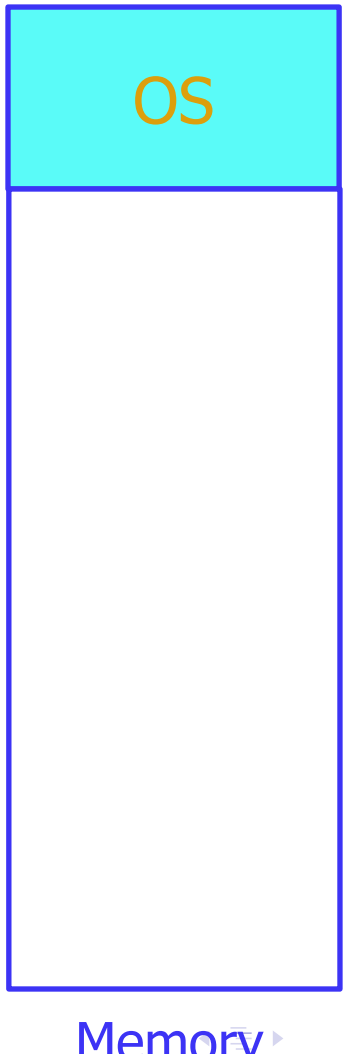
# User's perspective



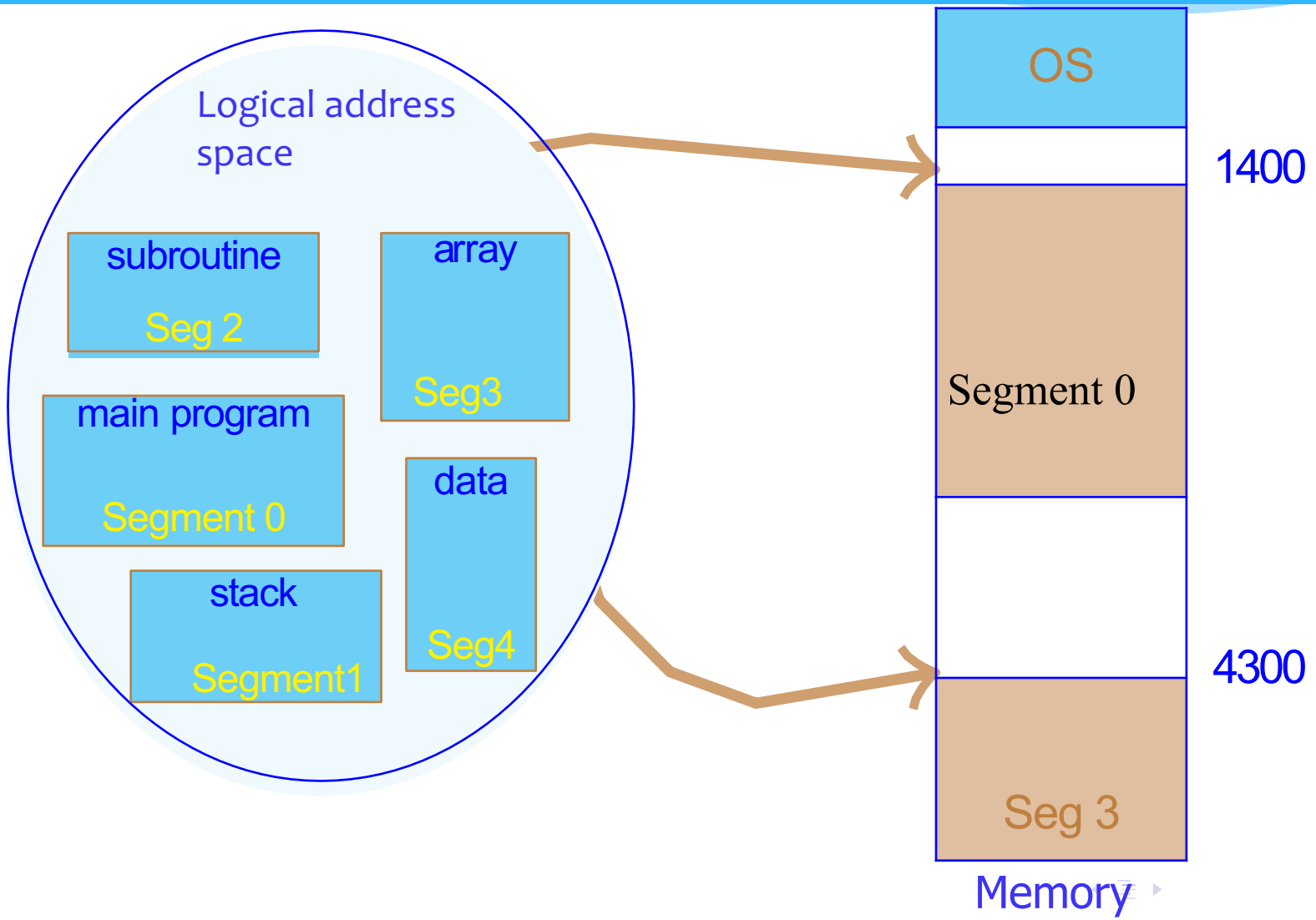

- Object in a segment is defined based on the relative distance from the start of the segment
  - 5th instruction of the main program
  - 1st member of the stack. . .
- Where is the location of these objects in the memory?

## Example

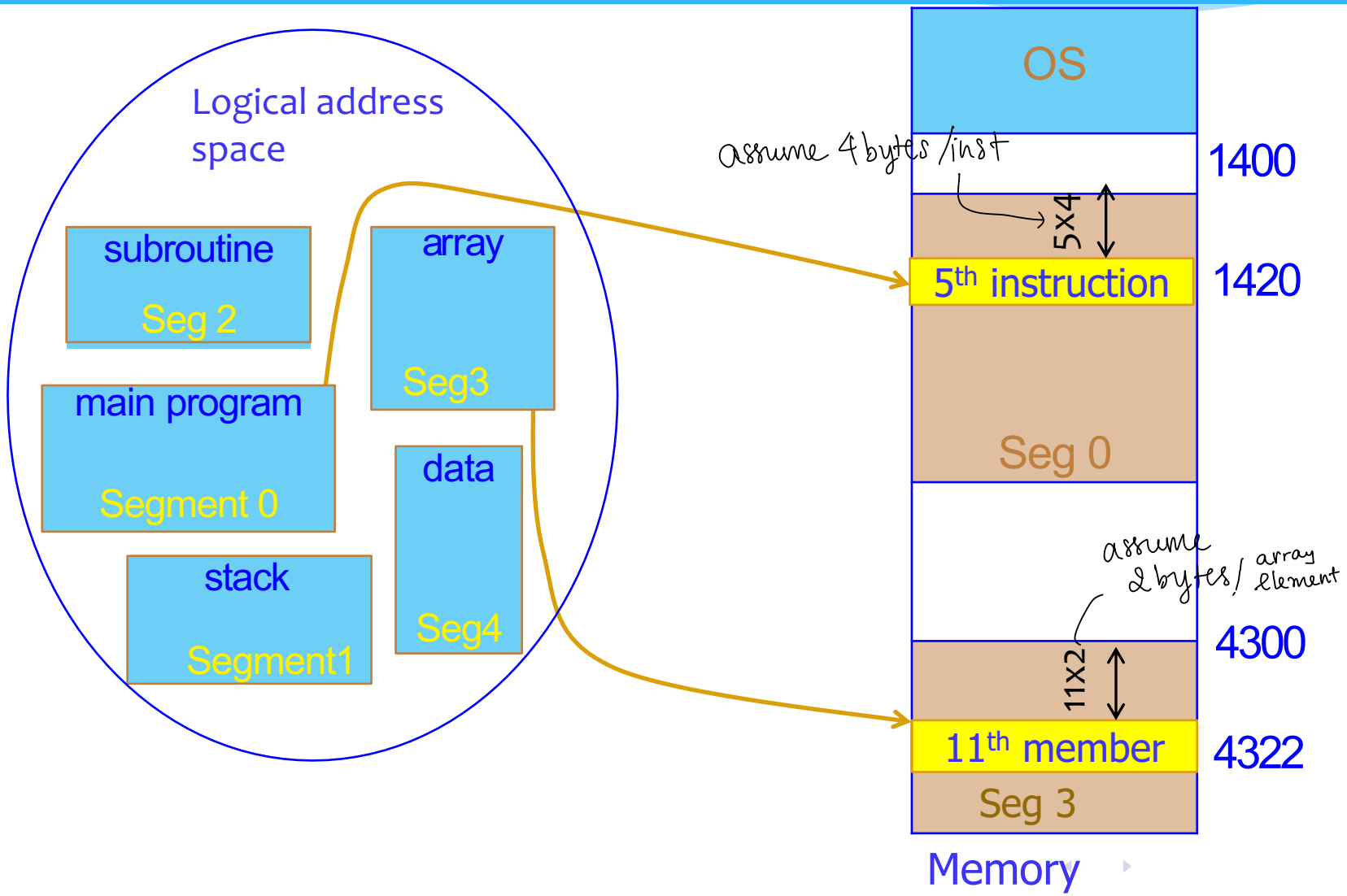

Logical address space
subroutine
Seg 2
array
Seg3
main program
Segment 0
data
Seg4
stack
Segment1


OS
Memory

## Example

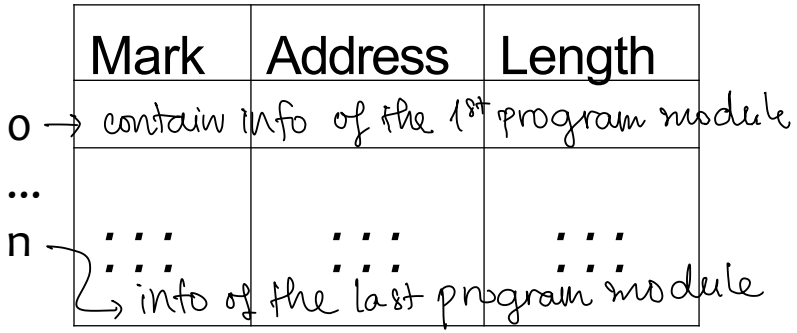

Logical address space
subroutine
Seg 2
array
Seg3
main program
Segment 0
data
Seg4
stack
Segment1
OS
1400
Segment 0
4300
Seg 3
Memory

## Example


Logical address space
subroutine
Seg 2
array
Seg3
main program
Segment 0
data
Seg4
stack
Segment1
OS
assume 4 bytes /inst
1400
5x4
5th instruction
1420
Seg 0
assume 2 bytes/ array element
4300
11X2
11th member
4322
Seg 3
Memory

# Segmentation structure

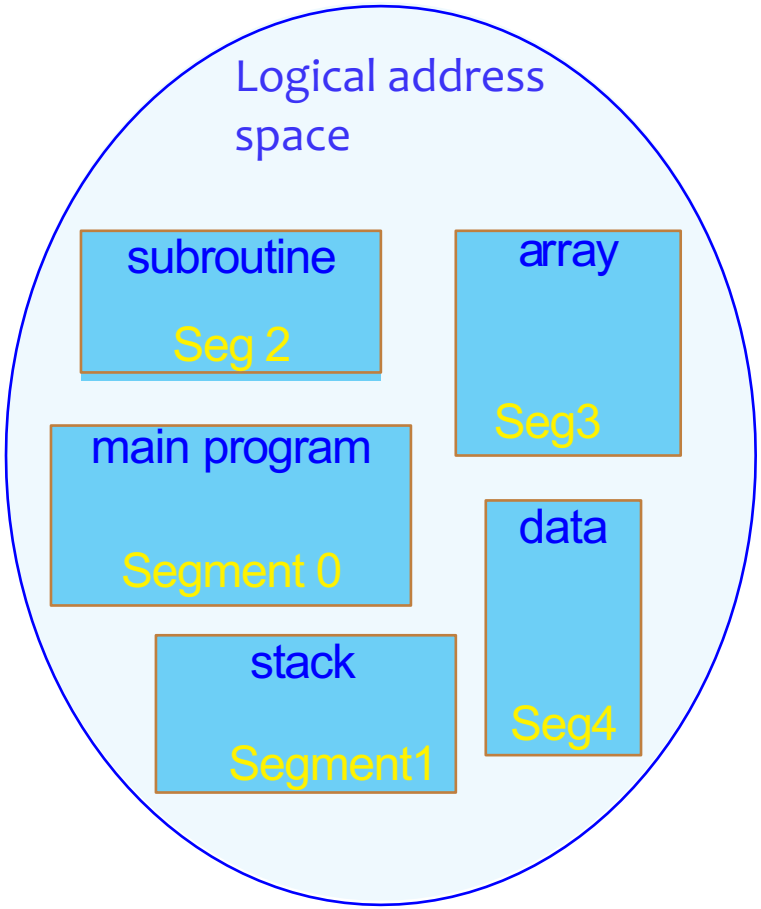
- Program is a combination of modul/segment
  - Segment number, segment's length
  - Each segment can be edited independently.
- Compile and edit program -> create SCB (Segement Control Block)
- Each member of SCB is corresponding to a program's segment



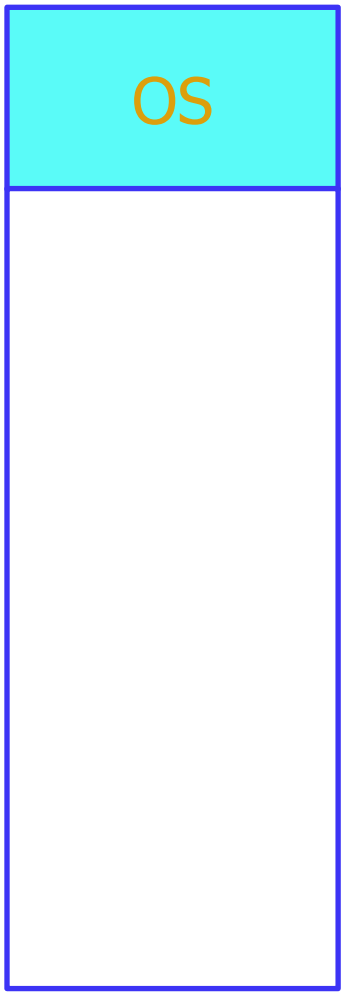

  - Mark(0/1) : Corresponding segment is already inside memory
  - Address: Segment's base location in memory
  - Length: Segment's length
- Accessing address: segment's name (number) and offset

Problem: Convert from 2 dimension address to 1 dimension address

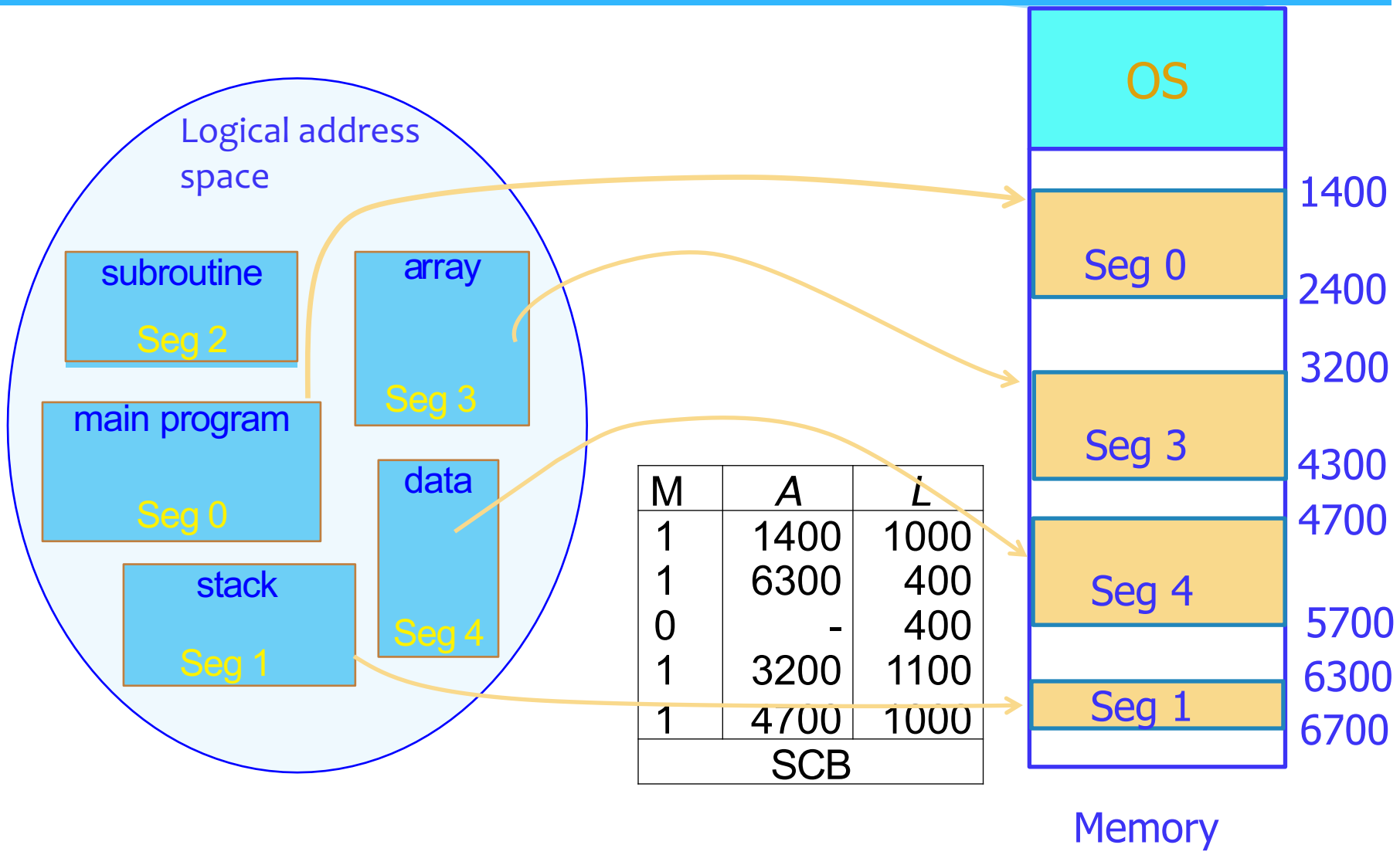
# Example




| M | *A* | *L* |
|---|---|---|
| 0 | - | 1000 |
| 0 | - | 400 |
| 0 | - | 400 |
| 0 | - | 1100 |
| 0 | - | 1000 |
| SCB | | |



# Example




| M | A | L |
|---|---|---|
| 1 | 1400 | 1000 |
| 1 | 6300 | 400 |
| 0 | - | 400 |
| 1 | 3200 | 1100 |
| 1 | 4700 | 1000 |
| SCB | | |

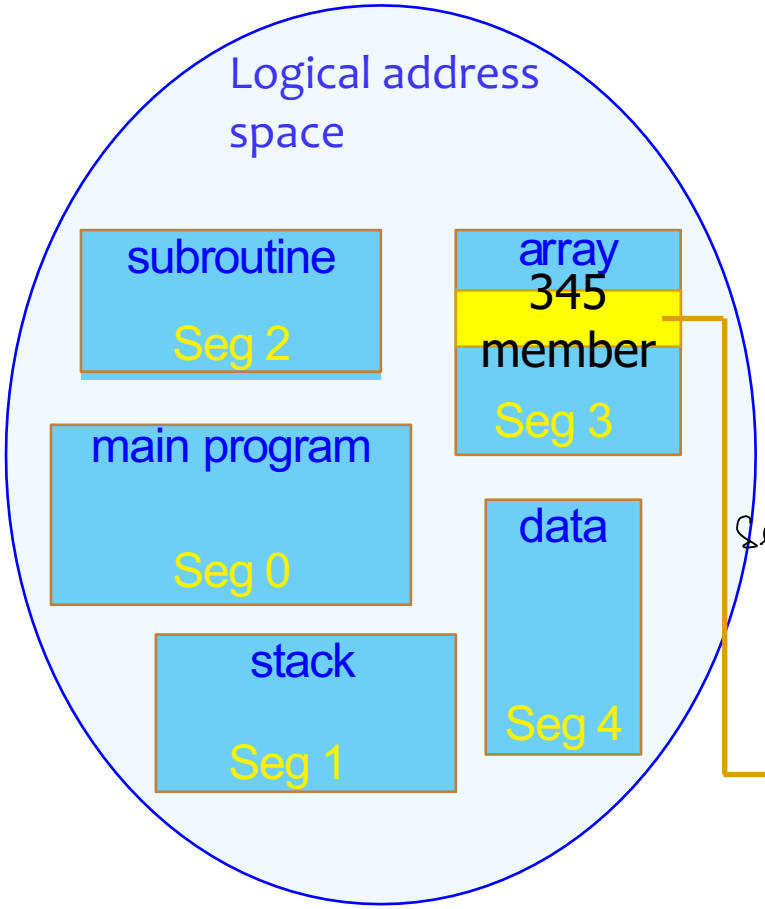
## Example

the offset

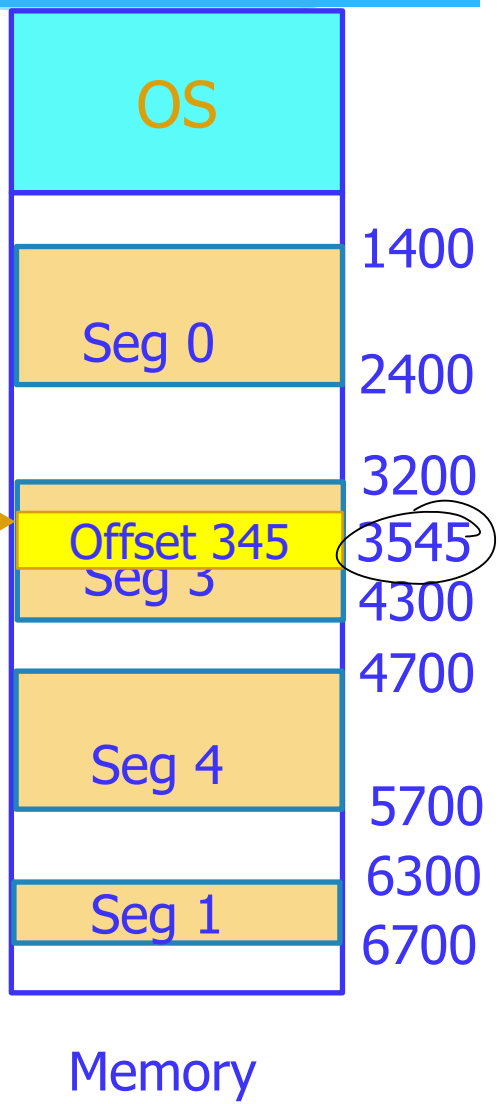
Address <3,345> = ?

the segment it's in

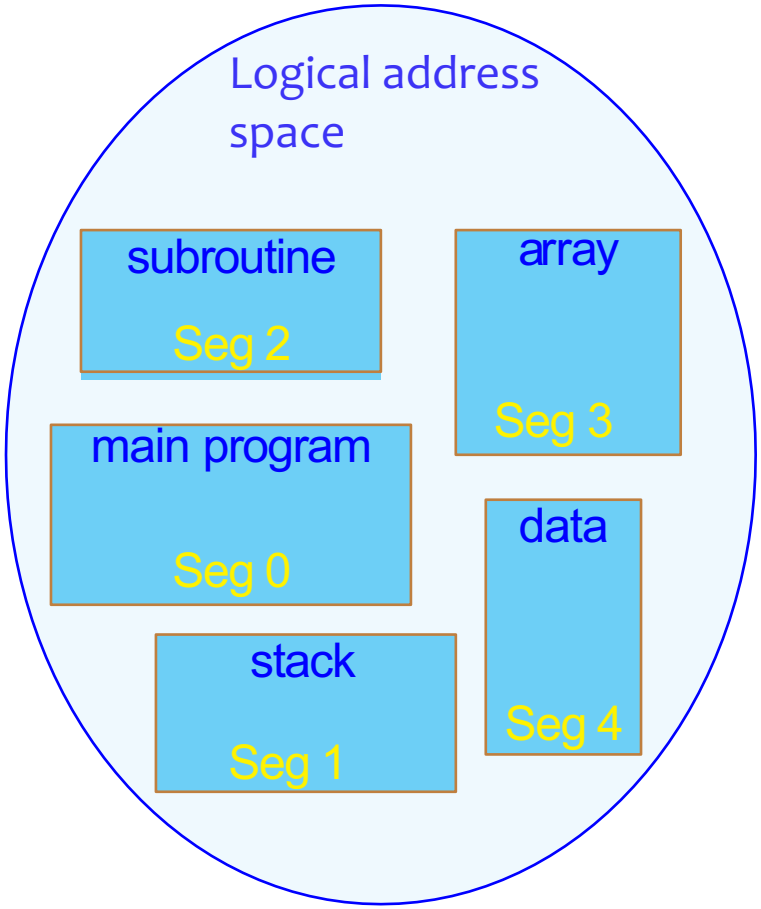
At seg 3, offset = 345
= 3200 + 345
= 3545




| Seg | M | A | L |
|---|---|---|---|
| 0 | 1 | 1400 | 1000 |
| 1 | 1 | 6300 | 400 |
| 2 | 0 | - | 400 |
| 3 | 1 | 3200 | 1100 |
| 4 | 1 | 4700 | 1000 |
| SCB | | | |



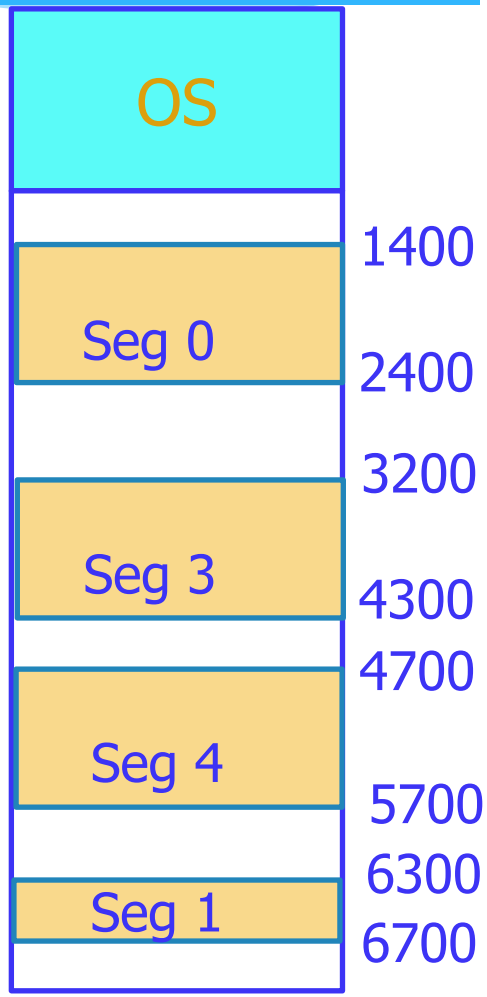
# Example




Address <4,185> = 4885

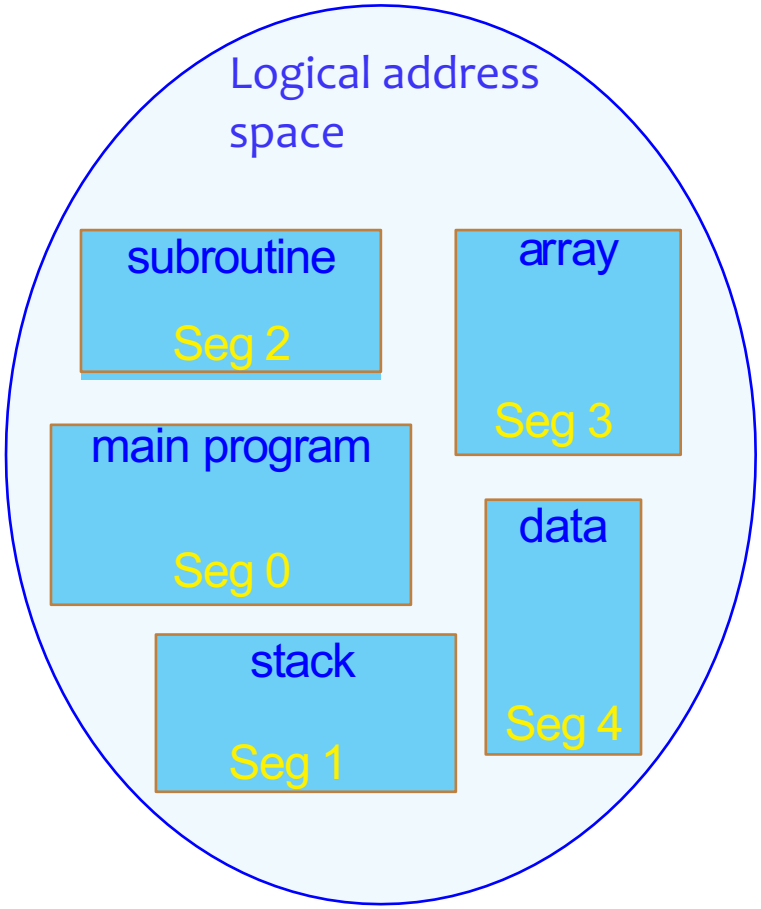
Seg 4, offset = 185
⇒ 4700 + 185

| M | *A* | *L* |
|---|---|---|
| 1 | 1400 | 1000 |
| 1 | 6300 | 400 |
| 0 | - | 400 |
| 1 | 3200 | 1100 |
| 1 | 4700 | 1000 |
| SCB | | |




Memory

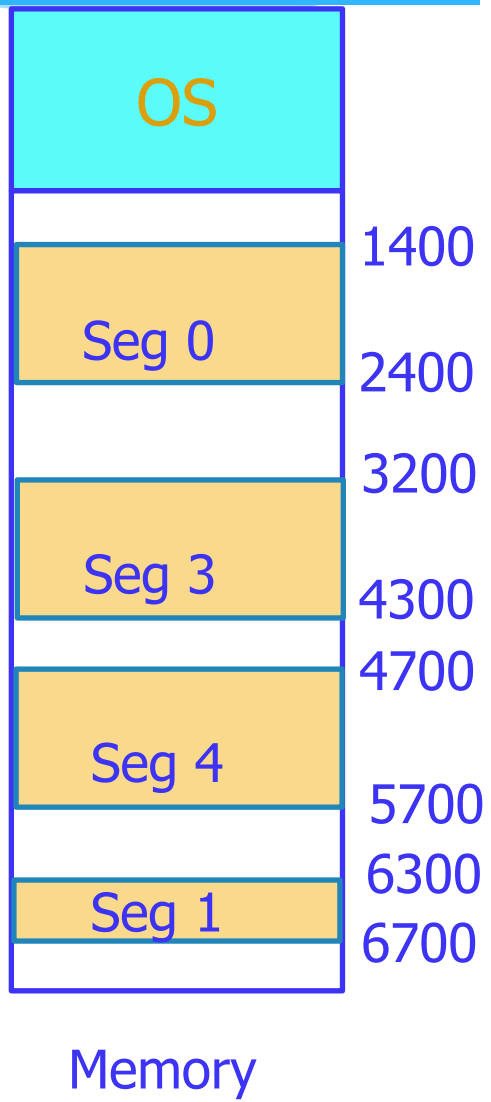
# Example




Address <2,120> = ?

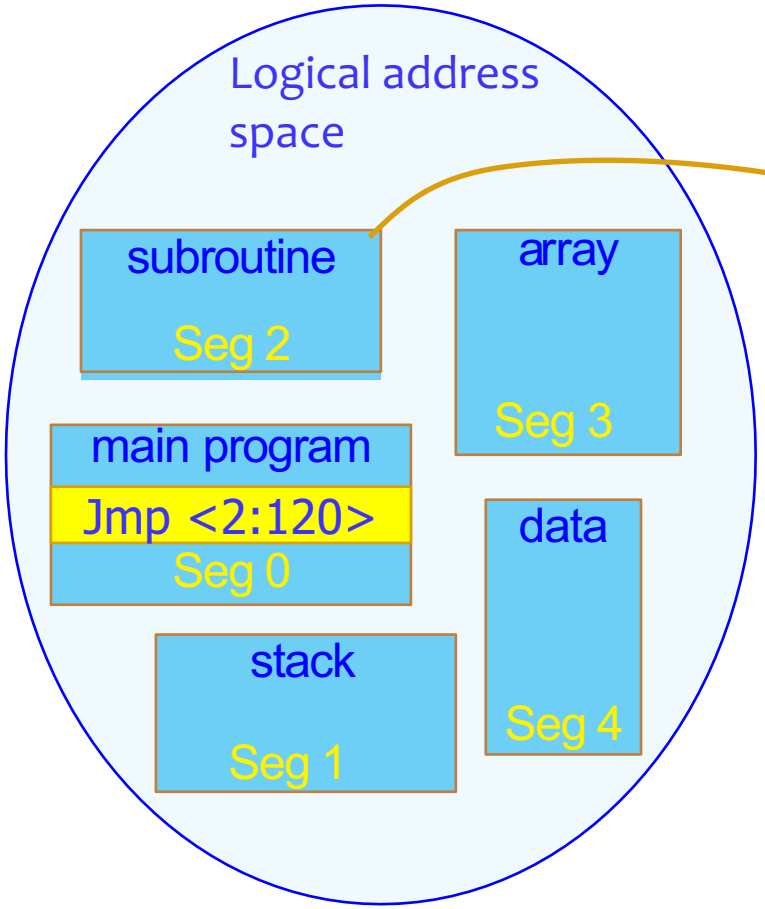
Seg 2, offset = 120

| M | *A* | *L* |
|---|---|---|
| 1 | 1400 | 1000 |
| 1 | 6300 | 400 |
| 0 | - | 400 |
| 1 | 3200 | 1100 |
| 1 | 4700 | 1000 |
| SCB | | |

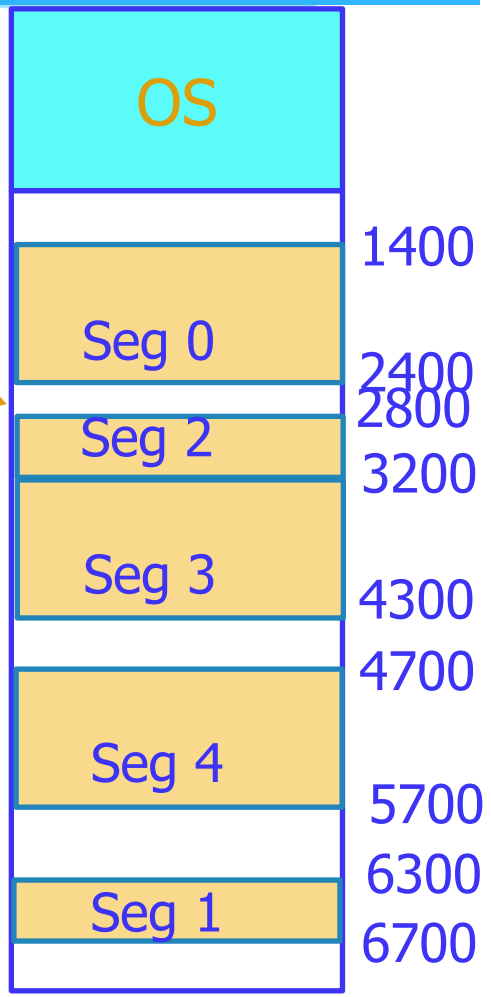


# Example

Address <2,120> = ?



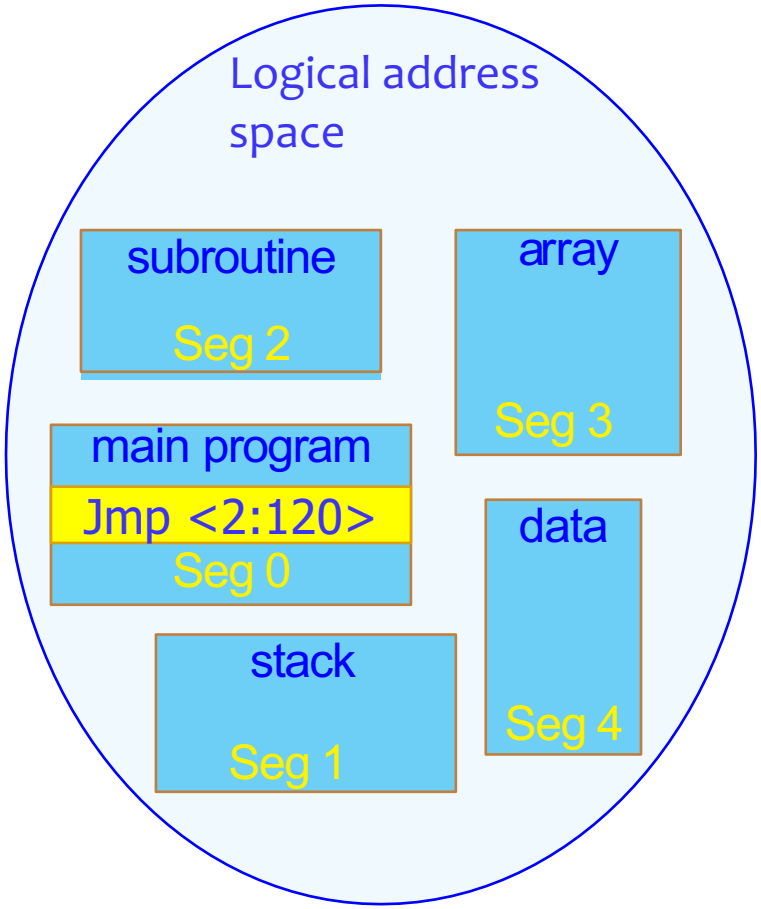

| M | *A* | *L* |
|---|---|---|
| 1 | 1400 | 1000 |
| 1 | 6300 | 400 |
| 0 | - | 400 |
| 1 | 3200 | 1100 |
| 1 | 4700 | 1000 |
| SCB | | |



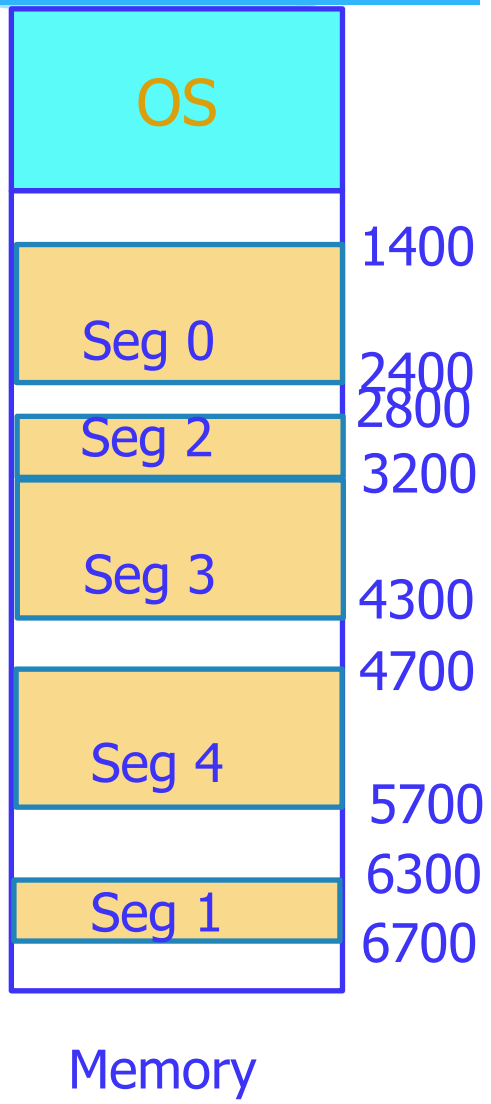

Memory

# Example

Address <2,120> = ?

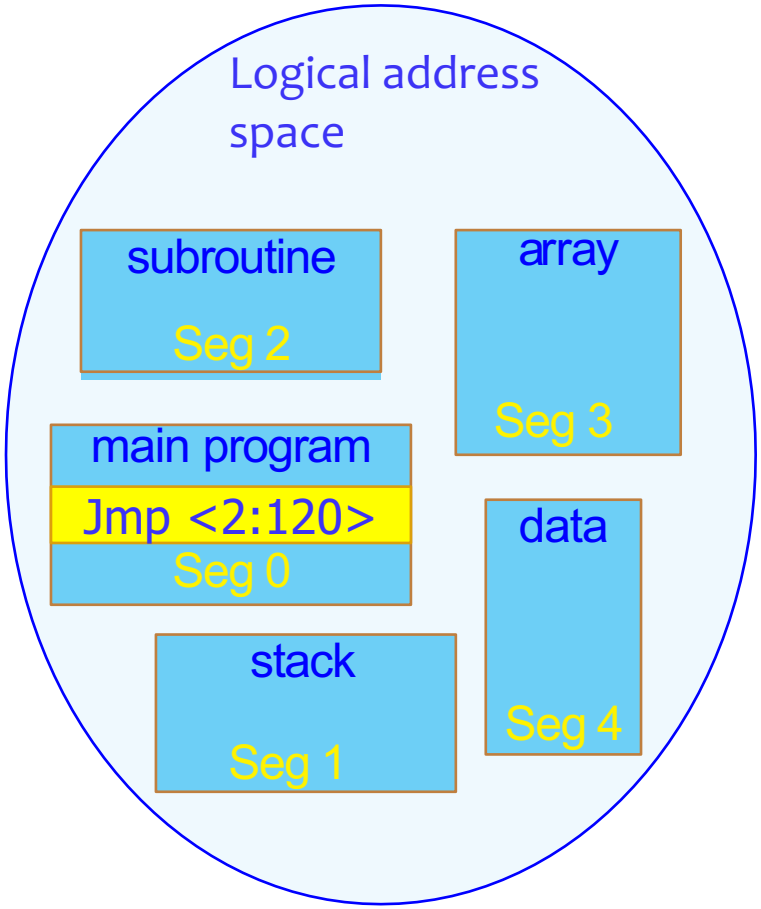



| M | *A* | *L* |
|---|---|---|
| 1 | 1400 | 1000 |
| 1 | 6300 | 400 |
| 1 | 2800 | 400 |
| 1 | 3200 | 1100 |
| 1 | 4700 | 1000 |
| SCB | | |

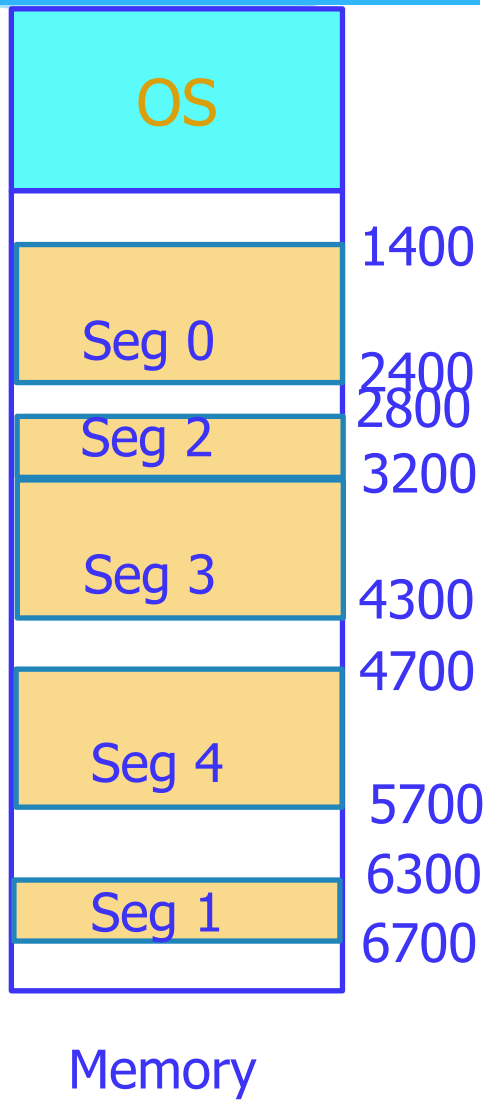


# Example

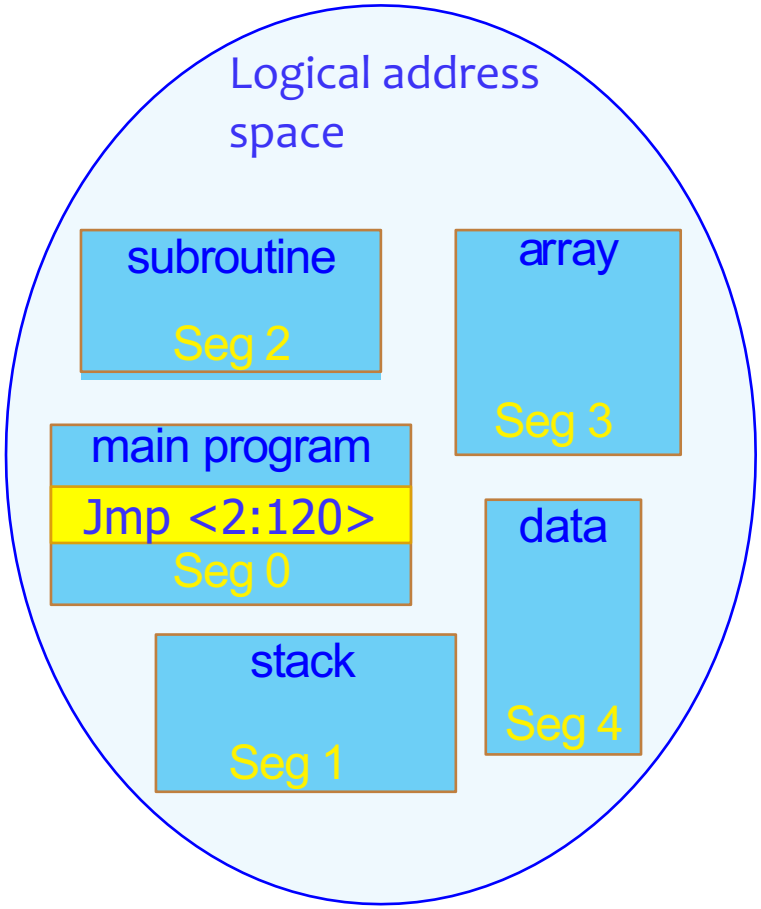
Address <2,120> = 2920




| M | *A* | *L* |
|---|---|---|
| 1 | 1400 | 1000 |
| 1 | 6300 | 400 |
| 1 | 2800 | 400 |
| 1 | 3200 | 1100 |
| 1 | 4700 | 1000 |
| SCB | | |



# Example



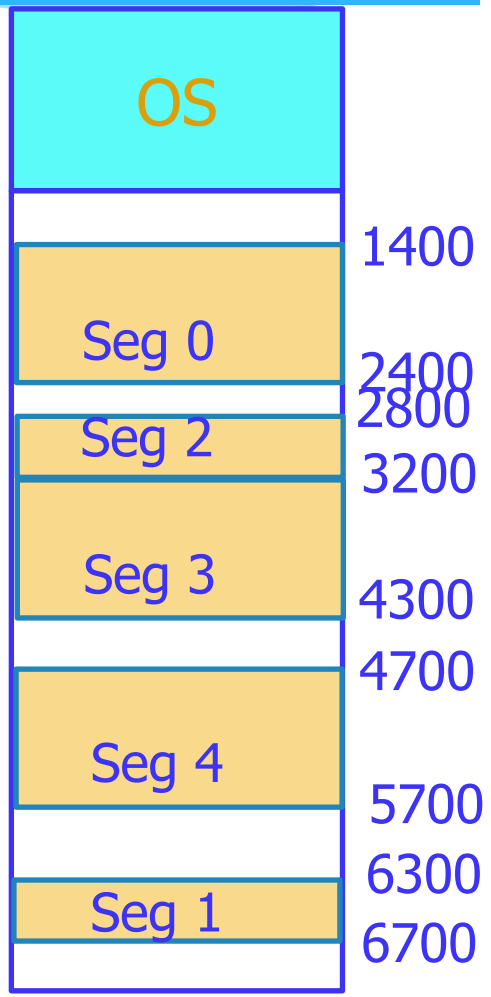

Address <2,450> = ?

Access error!

out of seg bound !

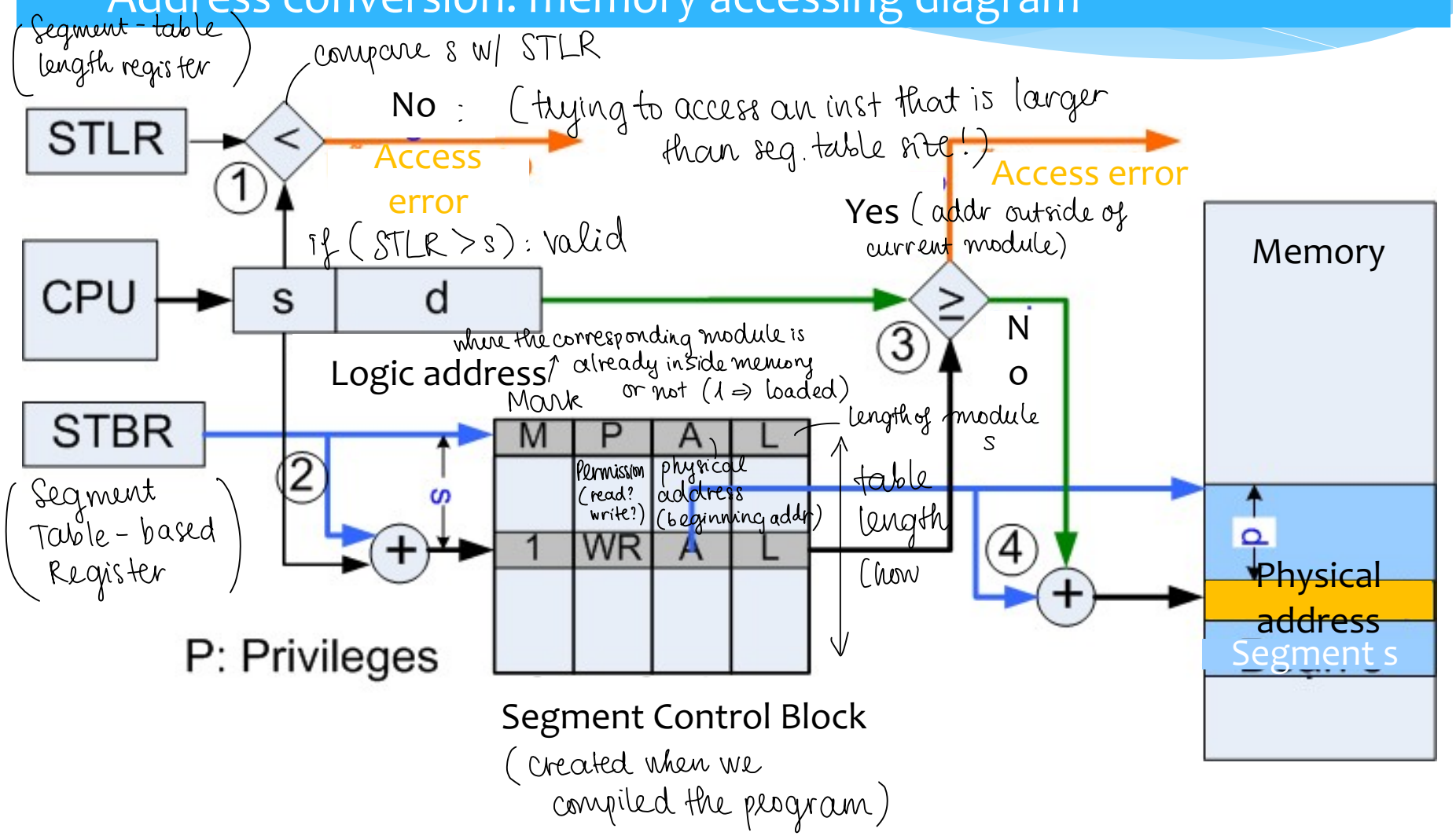
| M | *A* | *L* |
|---|---|---|
| 1 | 1400 | 1000 |
| 1 | 6300 | 400 |
| 1 | 2800 | 400 |
| 1 | 3200 | 1100 |
| 1 | 4700 | 1000 |

SCB



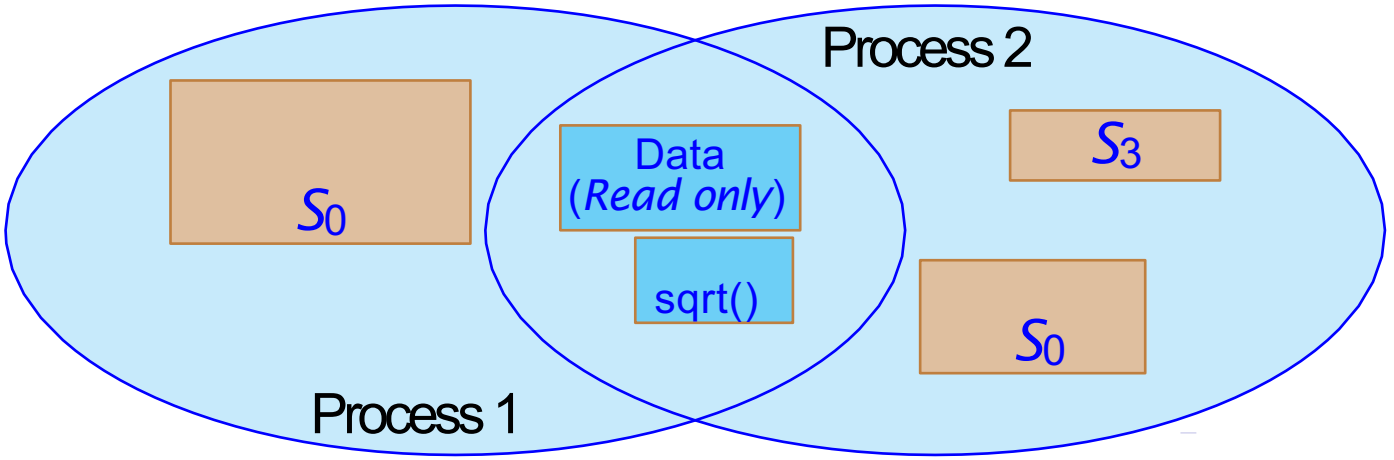

Memory

# Address conversion: memory accessing diagram

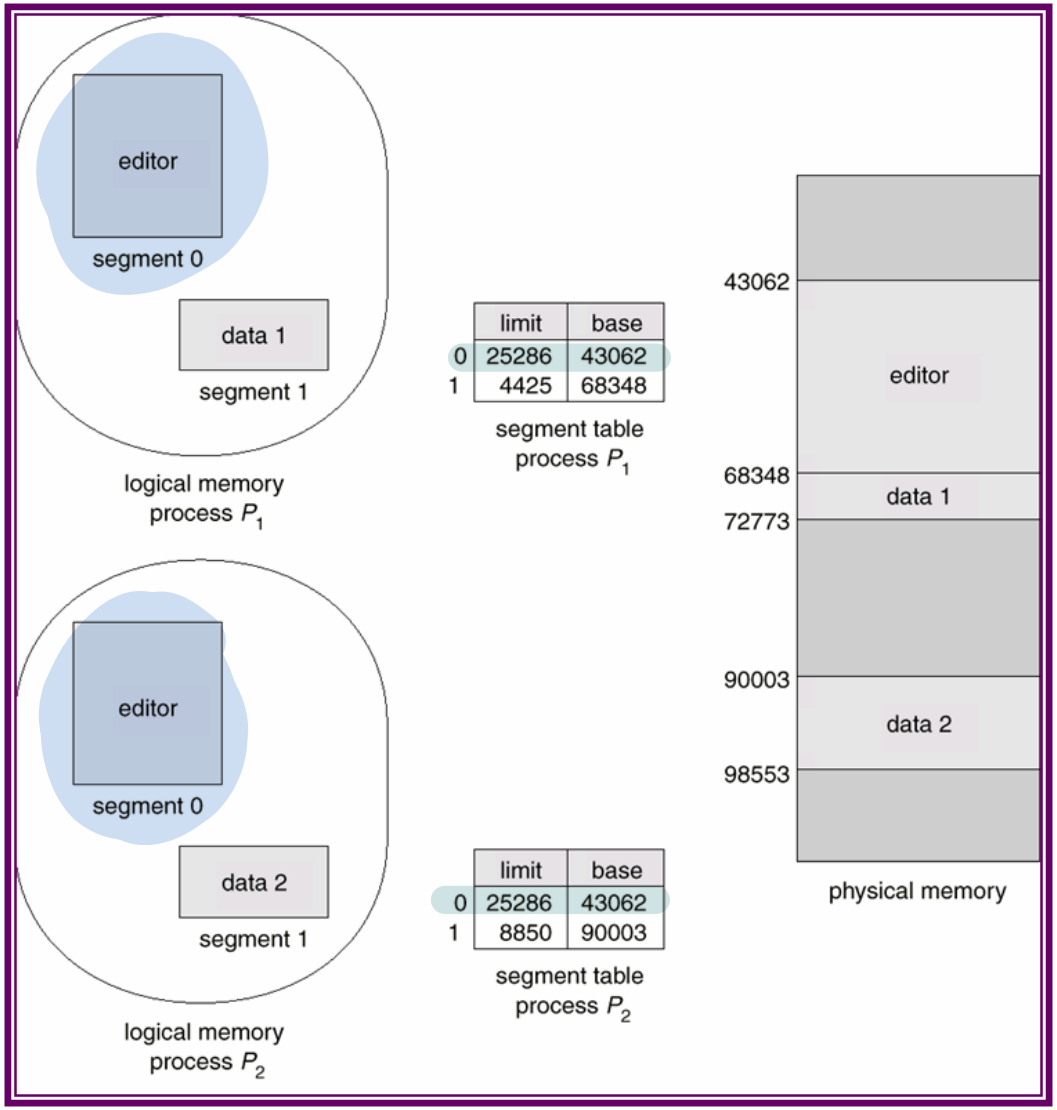


## Conclusion: pros

- Module loading diagram does not require user 's participation
- Easy to protect segments
  - Check memory accessing error
    - Invalid address : more than segment's length
  - Check accessing's property
    - Code segment: read only -> Write into code segment: accessing error
  - Check the right to access module
    - Add accessing right (user/system) into SCB
- Allow segment sharing (Example: Text editor)



# Segment sharing: Main problem




- Sharing segment
  - Call (0, 120) ?
  - Read (1, 245) ?

=>must has the same index number in the SCB

the shared segment (seg 0) are having the same idx in both table $P_1$, $P_2$

## Conclude: cons

- Effective is depended on the program's structure
- Memory is fragmented
  - Memory allocated by methods first fit /best fit...
  - Require memory rearrangement (relocation, swapping)
    - Easier with the help of SCB
      - M ← 0 : Segment is not in memory
      - Memory's area defined by A and L is returned to the free memory management list
    - Select which module to bring out [when mem is full]
      - Longest existed module
      - Last recently used module
      - Least frequently used module ⇒ Require media to record number and time that module is accessed
- Solution: allocate memory for equal size segment (page)?

- Fixed partition strategy
- Dynamic partition strategy
- Segmentation strategy
- Paging strategy
- Segmentation and paging combination strategy

## Rule

- Physical memory is divided into equal size blocks: page frames
  - Physical frame is addressed by number 0, 1, 2, . . . : frame's physical address
  - Frame is the unit for memory allocation
- Program is divided into blocks that have equal size with frame (pages)

program blocks

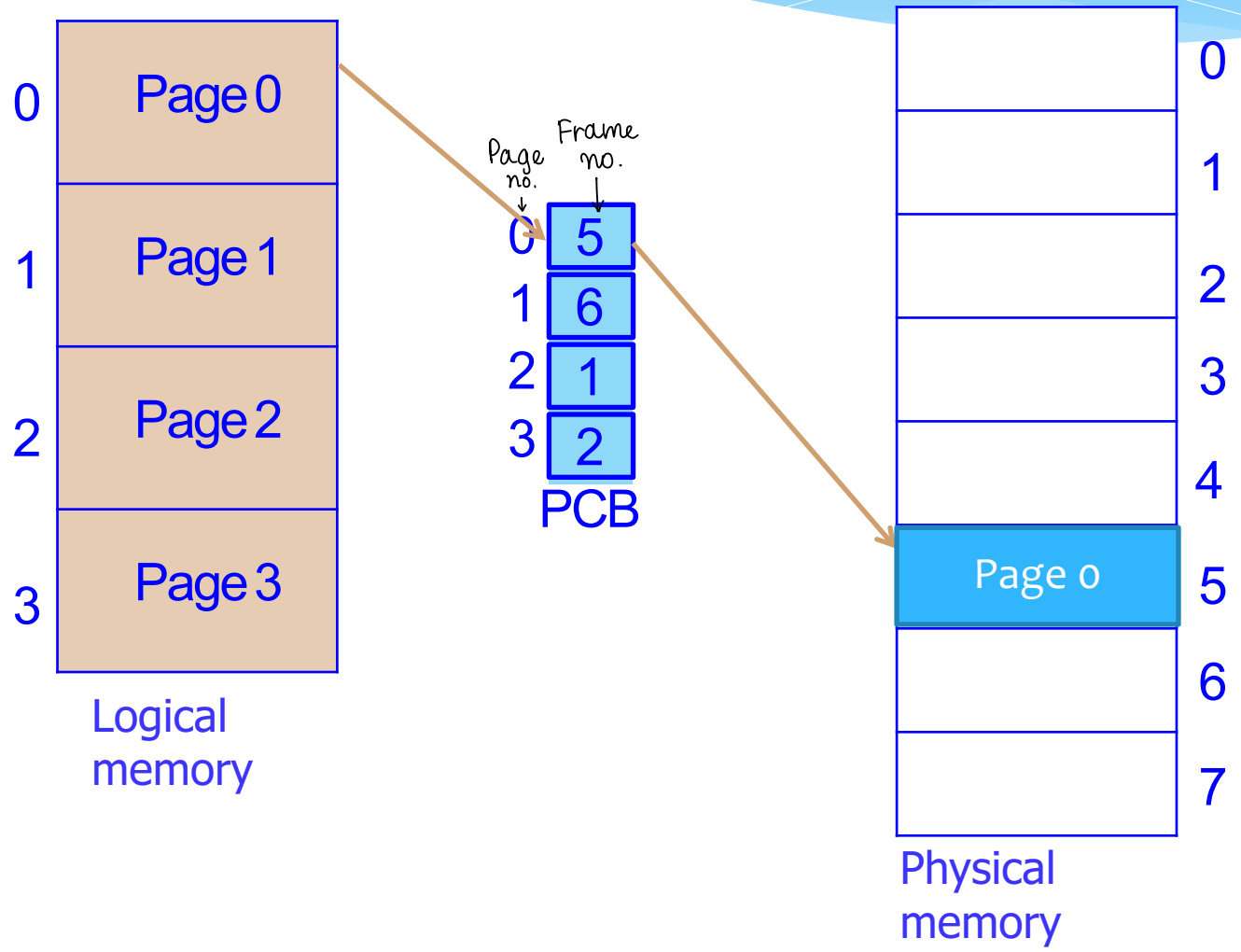
## Rule (cont)

- When program is executed
  - Load logical page (from external memory) into page's frame
    also called "Page Table" in some other docs
  - Construct a PCB( Page Control Block) to determine the relation between physical frame and logical page

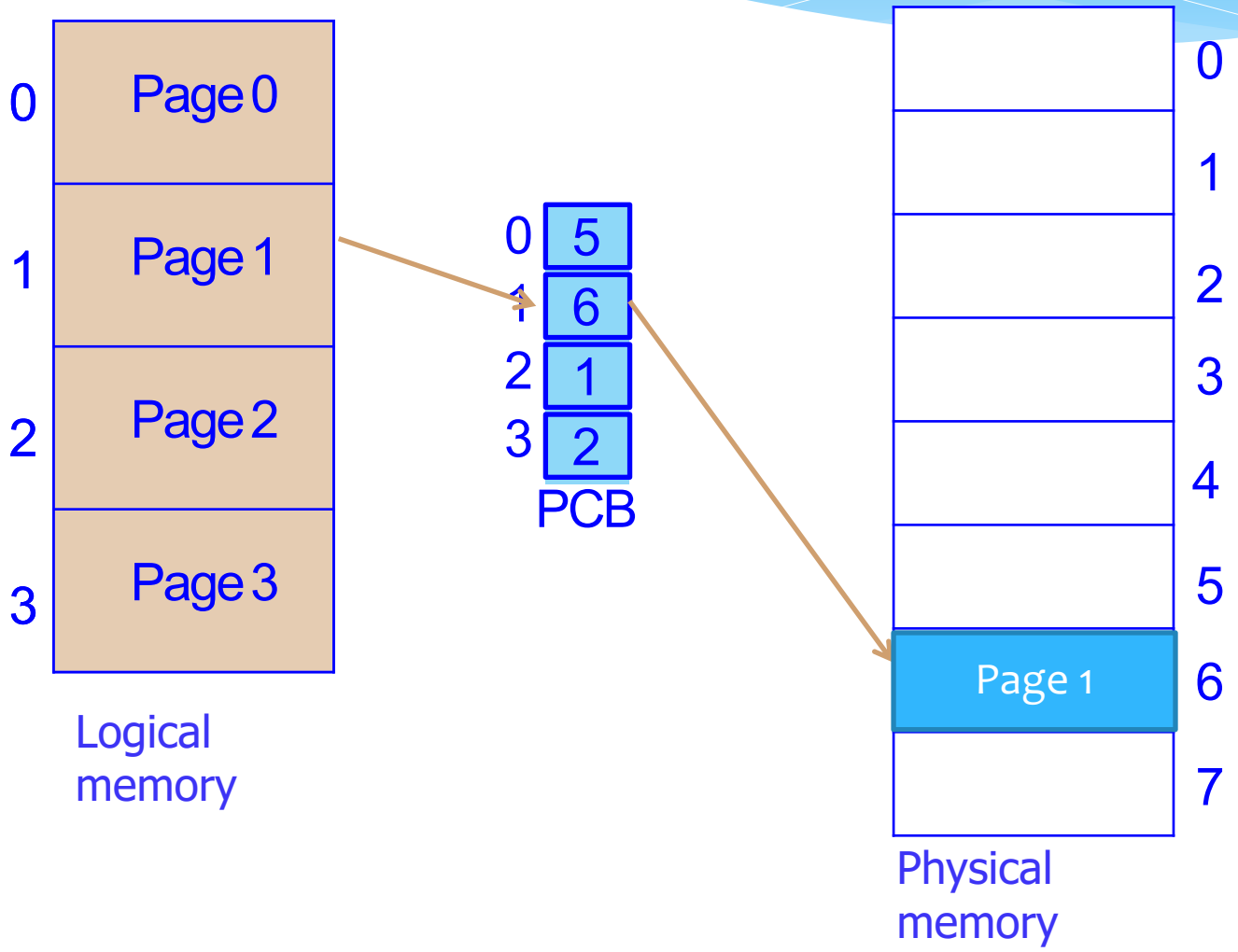
  - Each element of PCB is corresponding to a program's page
    - Show which frame is holding corresponding page
    - Example PCB[8] = 4 ⇒ ?

  - Accessing Address is combined of
    - Page's number (p) : Index in PCB to find page's base address
    - Displacement in page (d): Combined with base address to find the physical address NOTE: Do not use add operation here

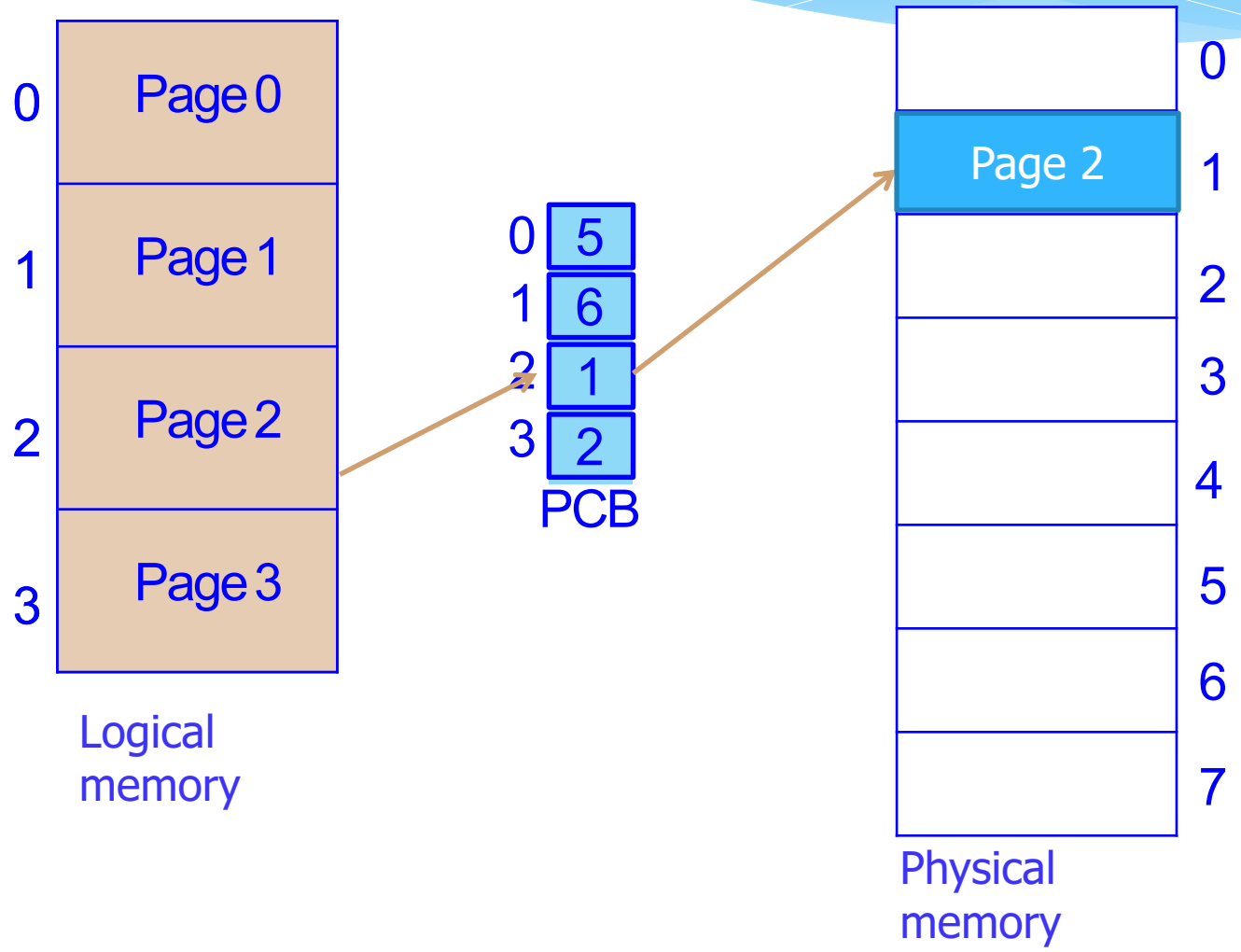
## Example


0
Page 0
1
Page 1
2
Page 2
3
Page 3
Logical memory
Page no.
Frame no.
0 5
1 6
2 1
3 2
PCB
0
1
2
3
4
Page 0
5
6
7
Physical memory

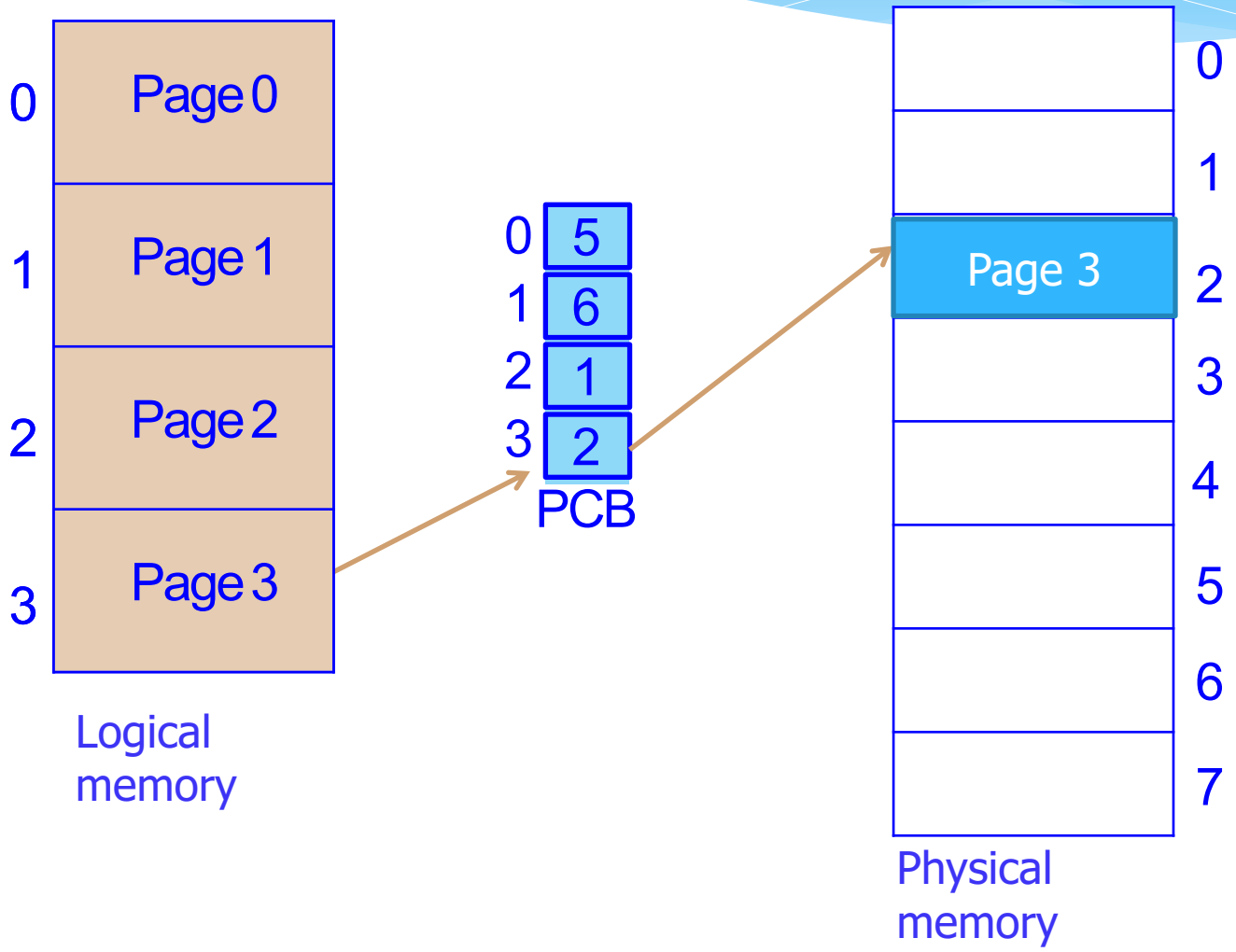
## Example


0
Page 0
1
Page 1
2
Page 2
3
Page 3
Logical memory
0 5
1 6
2 1
3 2
PCB
0
1
2
3
4
5
Page 1
6
7
Physical memory

## Example

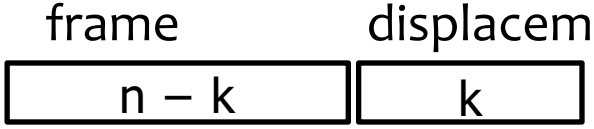

0
Page 0
1
Page 1
2
Page 2
3
Page 3
Logical memory
0 5
1 6
2 1
3 2
PCB
Page 2
0
1
2
3
4
5
6
7
Physical memory

## Example

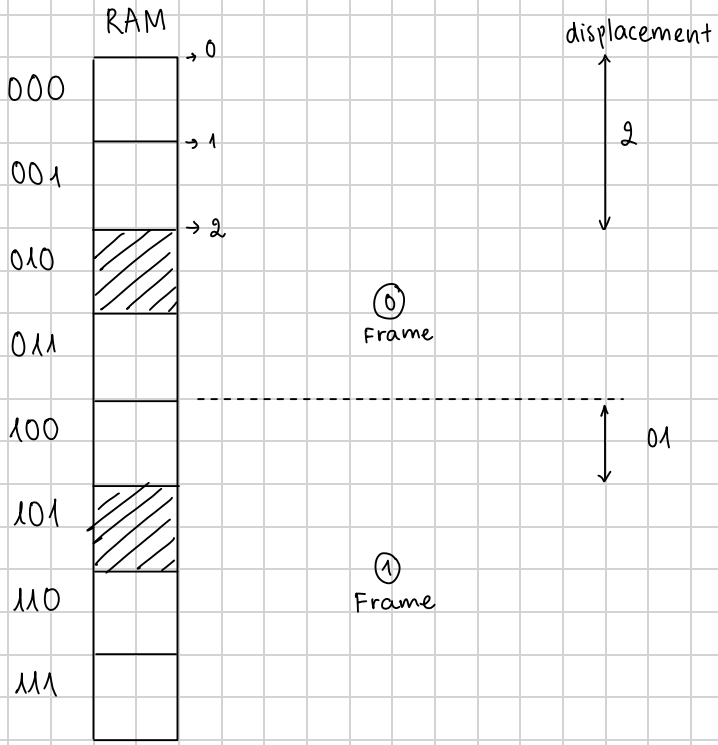

0
Page 0
1
Page 1
2
Page 2
3
Page 3
Logical memory
0 5
1 6
2 1
3 2
PCB
Page 3
0
1
2
3
4
5
6
7
Physical memory

## Note

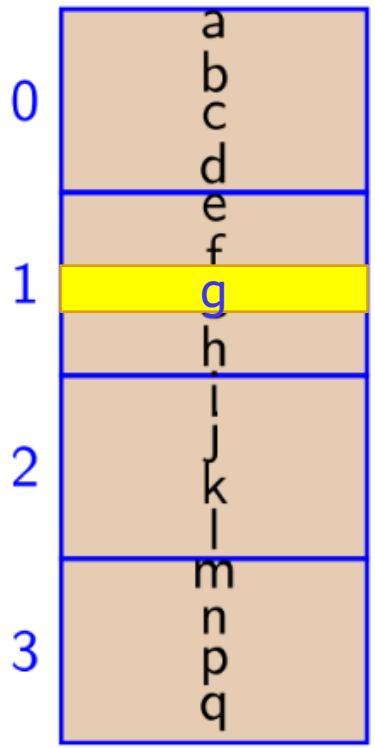
- Frame size is always power of 2
  - Allow connection between frame number and displacement
  - Example: memory is addressed by n bit, frame's size $2^k$




- Not necessary to load all page into memory
  - Number of frame is limited by memory's size, number of page can be unlimited
  - PCB need Mark filed to know if page is already loaded into memory
    - M = 0 Page is not loaded
    - M = 1 Page is loaded
- Distinguish between paging and segmentation
  - Segmentation
    - Module is depend on program's structure
  - Paging
    - Block's size is independent from program
    - Block size is depend on the hardware (e.g.: $2^9 \rightarrow 2^{13}$ bytes)

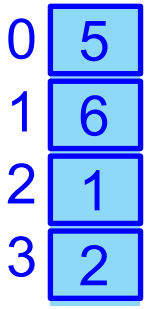

RAM
000
001
010
011
100
101
110
111
→ 0
→ 1
→ 2
displacement
2
0
Frame
01
1
Frame

# Example

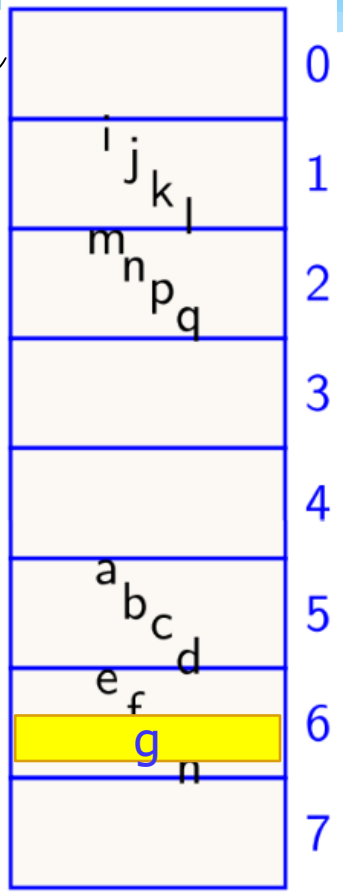



Logical memory

displacement from the beginning of the program




PCB




Physical memory

614

6%4

Access the logic address [ 6 ] ?

Address [ 6 ]: Page 1, displacement 2

Address <1,2> = 6*4 + 2 = 26 ($62_4$)

① which page? ② displacement by the beginning of that page?

| M | A |
|---|---|
| 0 | 6 |
| 1 | 4 |
| 0 | 5 |
| 0 | 3 |
| 1 | 7 |
| 1 | 8 |

Frame size : 1KB (1024 B)
Logical addr : 1234
Physical addr ?

(Same for Segmentation strategy : given SCB, calc physical address )

① Which logical page are our data in ?

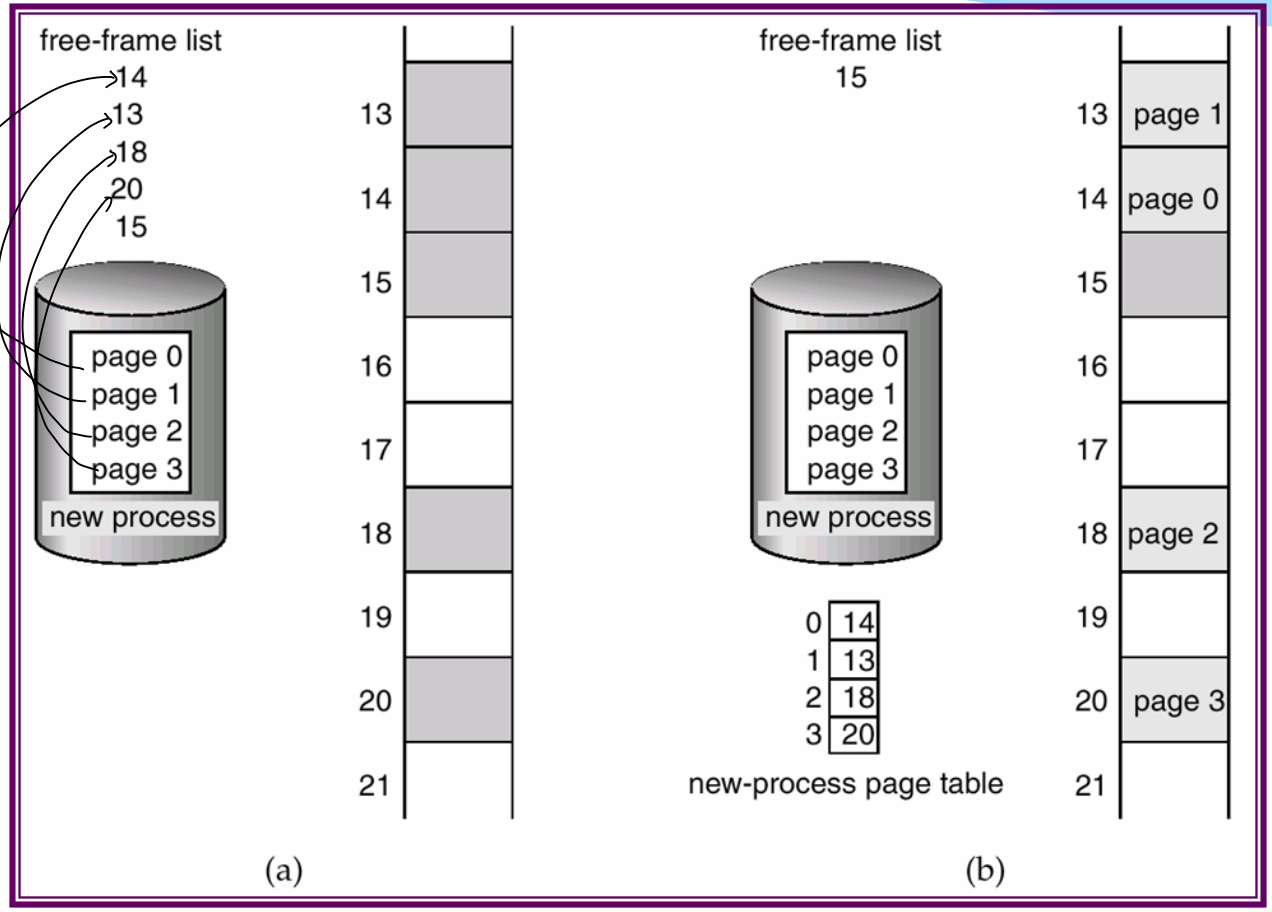
$$p = \frac{1234}{1024} = 1$$

$$d = 1234 \% 1024 = 210$$

② The physical address ?

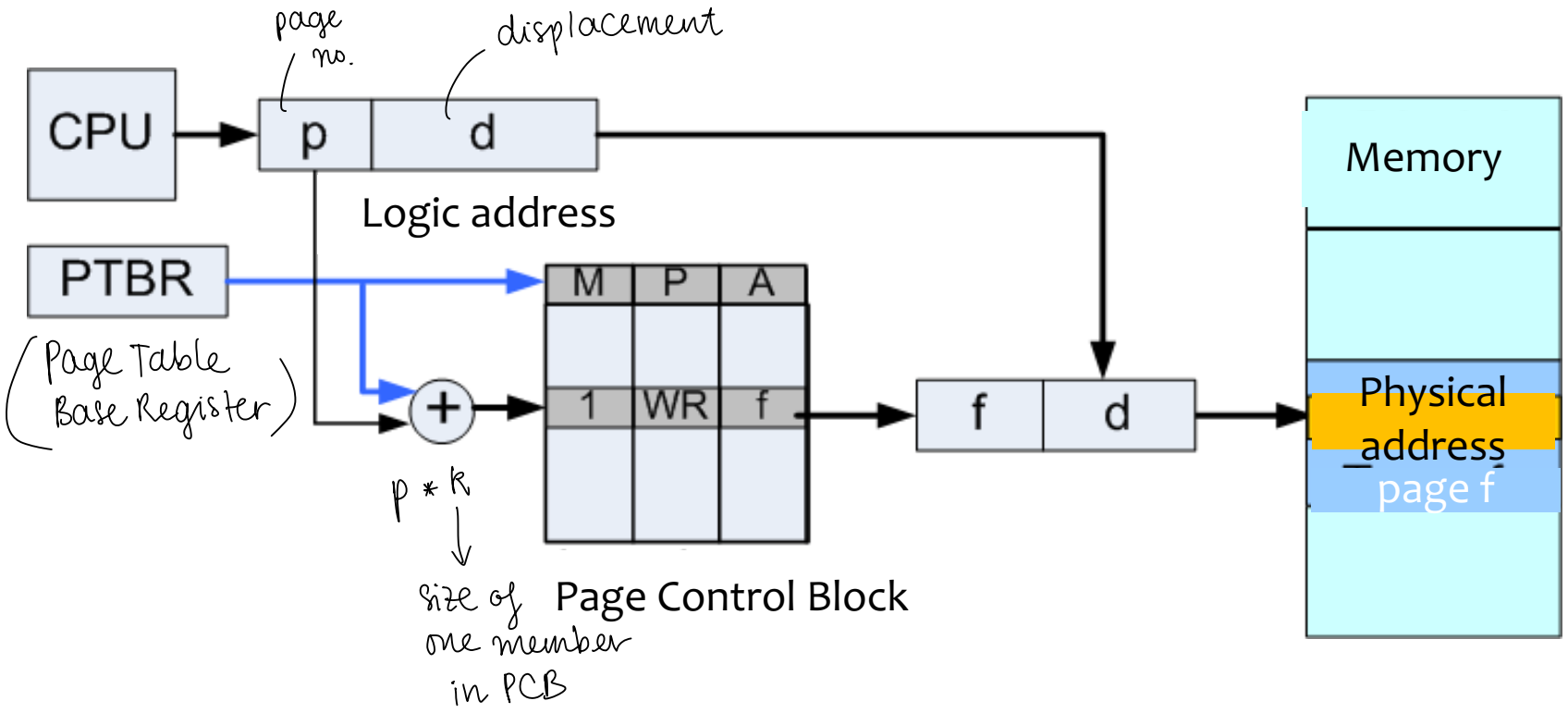
$$4 * 1024 + 210 = 4306$$

# Program is running → Load program into memory




- If number of unused frame is enough ⇒ load all page
- If not enough ⇒ load parts of pages

# Address conversion: Accessing diagram



## Load and replace page

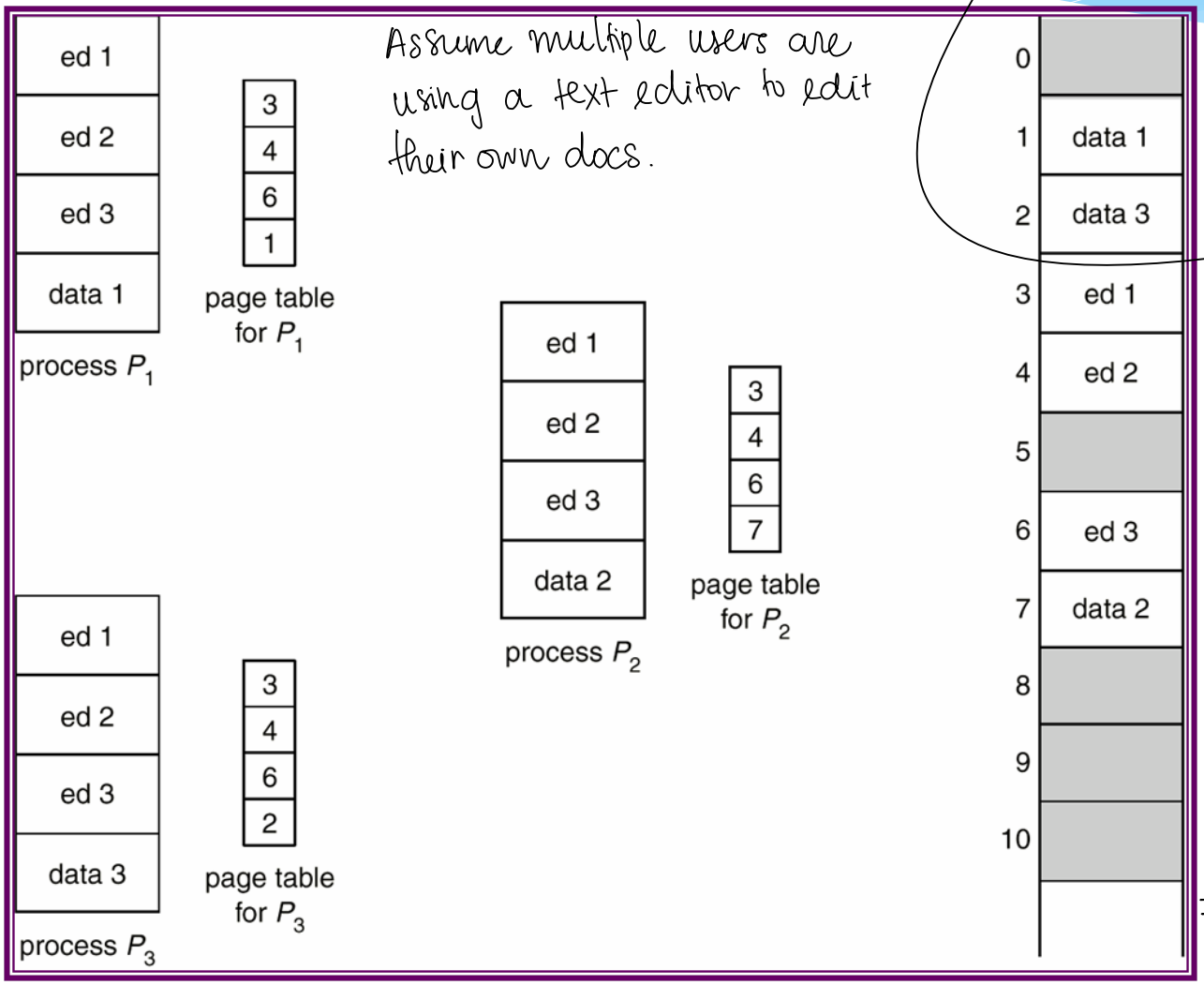
- Remark
  - Number of frame allocated to program
    - Large => Faster execution speed but parallel factor decrease
    - small => High parallel factor but execution speed slow because page is not inside memory

  ⇒ Effectiveness is depend on the page loading or page replacing strategy
- Page loading strategy
  - Load all page: Load all program
  - Prior loading: predict next page will be used
  - Load on demand: Only load page when it's necessary
- Page replacing strategy
  - FIFO First In First Out
  - LRU Least Recently Used
  - LFU Least Frequently Used
  - . . .

## Advantage

- Increase memory access speed
  - Access memory 2 times (PCB and required address)
  - Perform connecting instead of adding operation
- No external fragmentation phenomenon
- High parallel factor
  - Only need several program's page inside memory
  - Program can have any size
- Easy to perform memory protection
  - Legally access address (not more than page size)
  - Access property (read/write)
  - Access right (user/system)
- Allow sharing page between processes

# Page sharing: Text editor




No sharing

4 pages / program

- Each page size 50K
- 3 pages for code
- 1 page for data
- 40 user

= 50K * 4 pages * 40 users

- No sharing
  - Need 8000K
- Sharing (code shared / data sharing)
  - Require 2150K

= 50K * 1 data page * 40 users + 50K * 3 code pages

# Page sharing: rule

- Necessary while working in sharing environment
  - Reduce the size of memory area for all processes
- Sharing code
  - Only one copy of sharing page in the memory
    - Example: text editor, compiler....
  - Problem: Sharing code can not change
    - Sharing page must be in the same logic address of all address
      ⇒ Same page id in the PCB
- The code and data are separately
  - Separate for each process
  - Can be in any position in the logic memory of the process

## Disadvantage

- Have external memory fragmentation
  - Always appear at the last page
  - Reduce memory fragmentation by reduce page size ?
    - Page fault more frequent → program trying to access a page which is not loaded to memory yet
    - Large page control table
- Require support from hardware
  - Cost for paging is high
- When the program is large, page control block has many members
  - Program size $2^{30}$, page size $2^{12}$ -> PCB has $2^{20}$ members
  - Spend more memory for store PCB (~ 4 MB for PCB)
  - Solution: multi level page

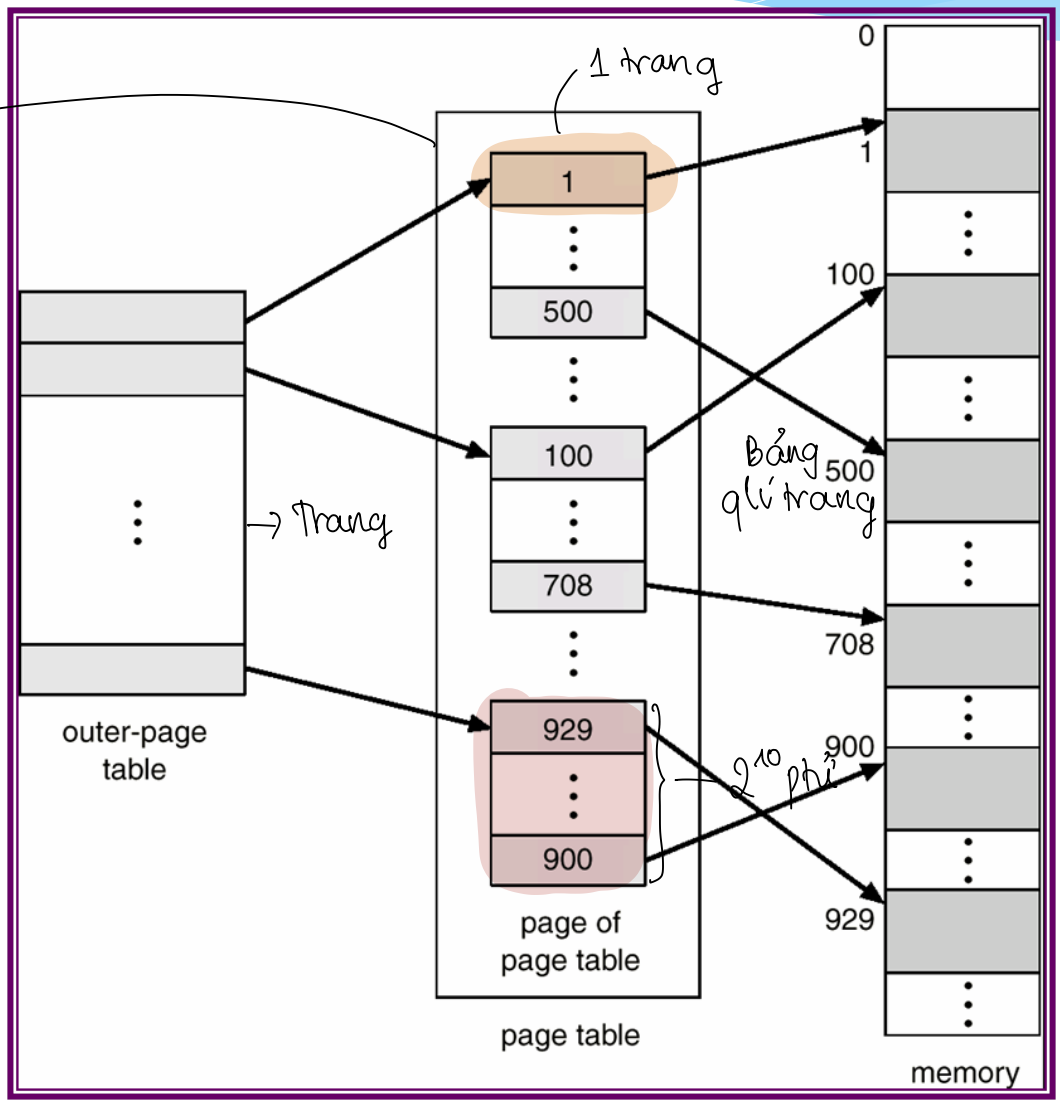
## Multi-level paging

Rule: Divide PCB into pages

Example: 2 level paging

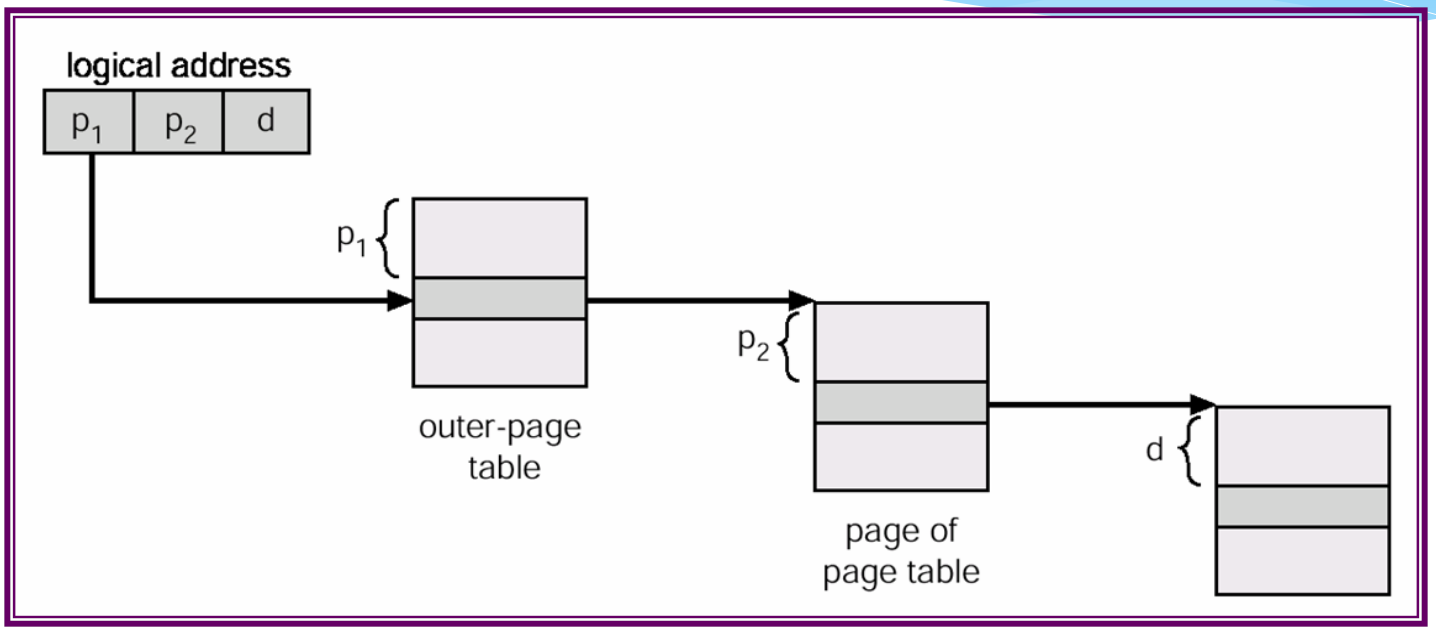
- Computer use 32 bit for addressing ($2^{32}$); Page size 4K ($2^{12}$)
  - Page number - 20 bit
  - Offset in page -12 bit
- PCB is paged. Page number is divided into
  - Outer page table (page directory) - 10 bit
  - Offset in a page directory – 10 bit
- Access address has the form $<p_1, p_2, d>$

# Multi-level page: Example 2 level paging




Do not load all pages
↳ Load page dir first
↳ See which page we need

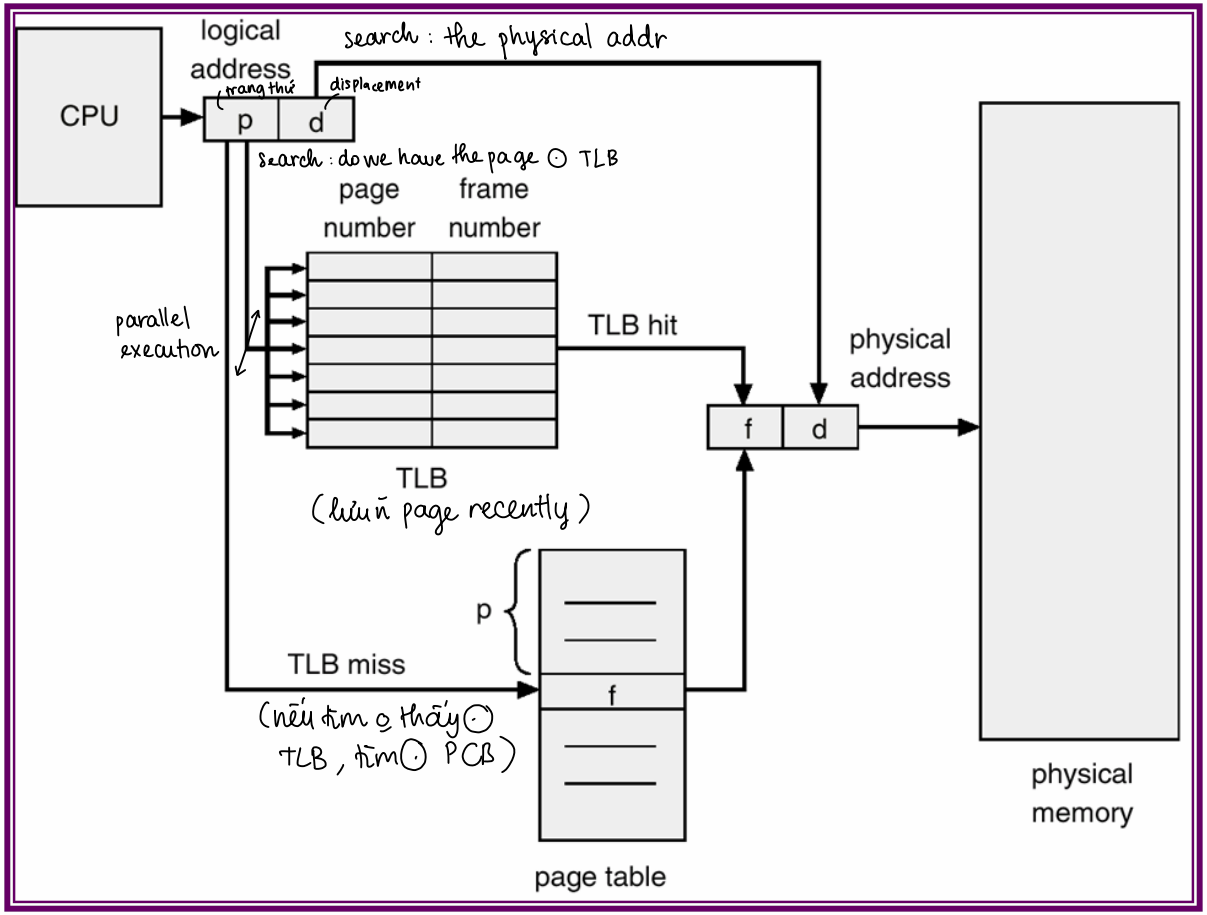
# Multi-level page: Memory access




- When access: System load page directory into memory
- Unused page table and unused page are not necessary loaded into memory
- Require 3 times access memory
- Problem: For 64 bit system
  - 3, 4,... Level paging
  - Require access memory 4, 5,... times ⇒ slow
  - Solution: address translation buffer

# Address translation buffer

TLB: translation look-aside buffers (bộ đệm chuyển hoá đ/chỉ) ← tập các thanh ghi




- Associative registers
- Parallel access
- Each member contains
  - Key: Page number
  - Value: Frame number
- TLB contain recently accessing page
- When requested <p,d>
  - Search p in TLB
  - Missing p, find p in PCB then add < p, f > into TLB

Tìm ⊙ TLB rất nhanh – hơn nhiều so với ⊙ PCB

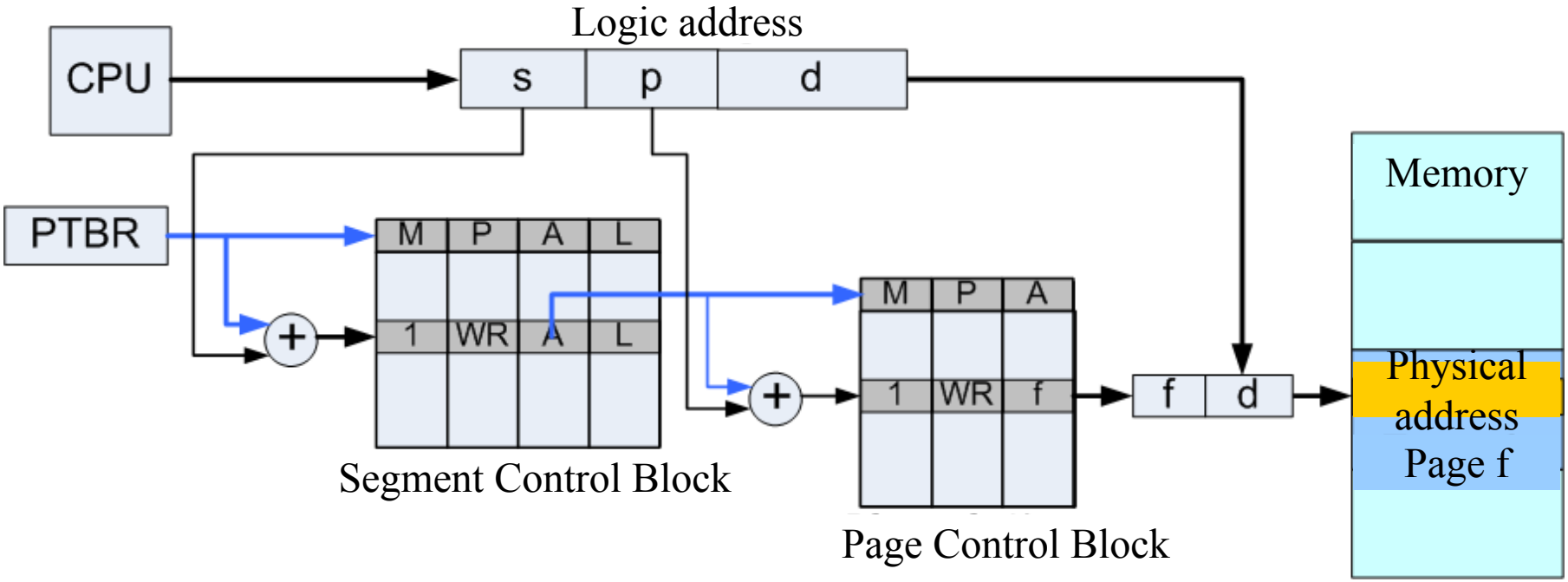
98% memory access is done via TLB

- Fixed partition strategy
- Dynamic partition strategy
- Segmentation strategy
- Paging strategy
- Segmentation and paging combination strategy

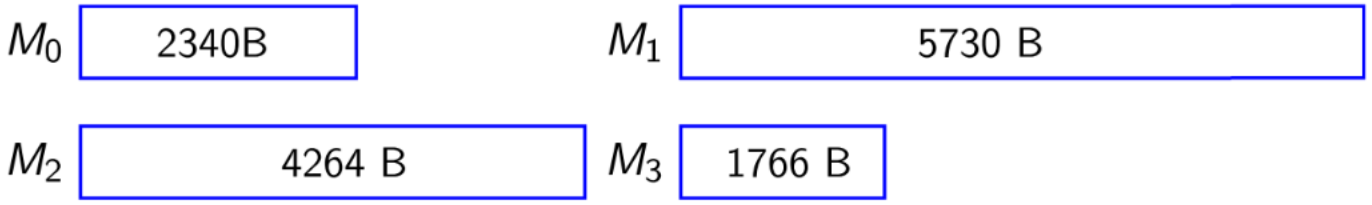
## Rule

- Program is edited as in segmentation strategy
  - Create SCB
  - Each member of SCB correspond to one segment, has 3 fields M, A, L
- Each segment is edited separately as in paging strategy
  - Create PCB for each segment
- Memory accessing address: combination of 3 < s, p, d >
- Perform accessing address
  - STBR + s ⇒: address of s member
  - Check value of Ms, load PCBs if it's necessary
  - As + p ⇒ Load the address of member p in PCBs
  - Check value of Mp, load page p if it's necessary
  - Connect Ap with d => physical address if it's necessary
- Utilized in processor Intel 80386, MULTICS . . .

# Memory access diagram



# Conclusion




## Segmentation

| M | A | L |
|---|---|---|
| 0 | – | 2340 |
| 1 | 2140 | 5730 |
| 0 | – | 4264 |
| 0 | – | 1766 |

SCB

## Segmentation and paging combination

| M | A | L |
|---|---|---|
| 0 | – | 3 |
| 0 | 5 | 6 |
| 0 | – | 5 |
| 0 | – | 2 |

SCB

| M | A |
|---|---|
| 0 | – |
| 1 | 8 |
| 0 | – |
| 0 | – |
| 0 | – |
| 0 | – |

$PCB_2$

# Chap 3 Memory Management

① Introduction
② Memory management strategies
③ Virtual memory
④ Memory management in Intel's processors family

① Introduction

② Page replacement strategy

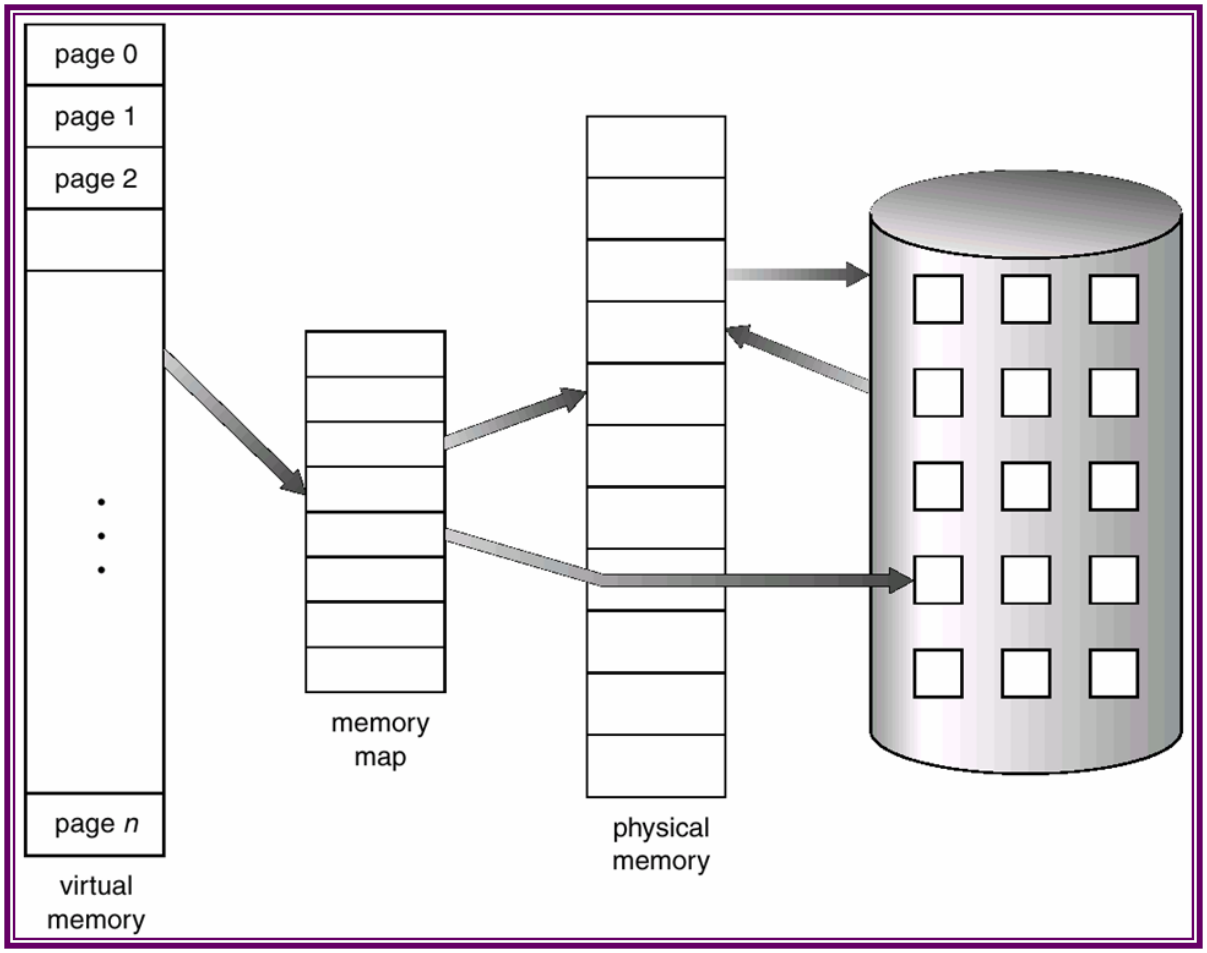
## Program and memory issue

- Instruction must be placed in memory when executed !
- Whole program must stay inside memory ?
  - Dynamic loading, Overlays structures... : Partly loaded
    - Require special notice from programmer

  ⇒ Not necessary
  - Program's segment for handling errors
    - Errors occur least frequently, least frequently executed
  - Unused declared data
    - Declare a matrix 100x100, use 10x 10
- Run program with one part inside memory will allow
  - Write program in virtual address space
    - Unlimited size
  - Many program concurrently existed

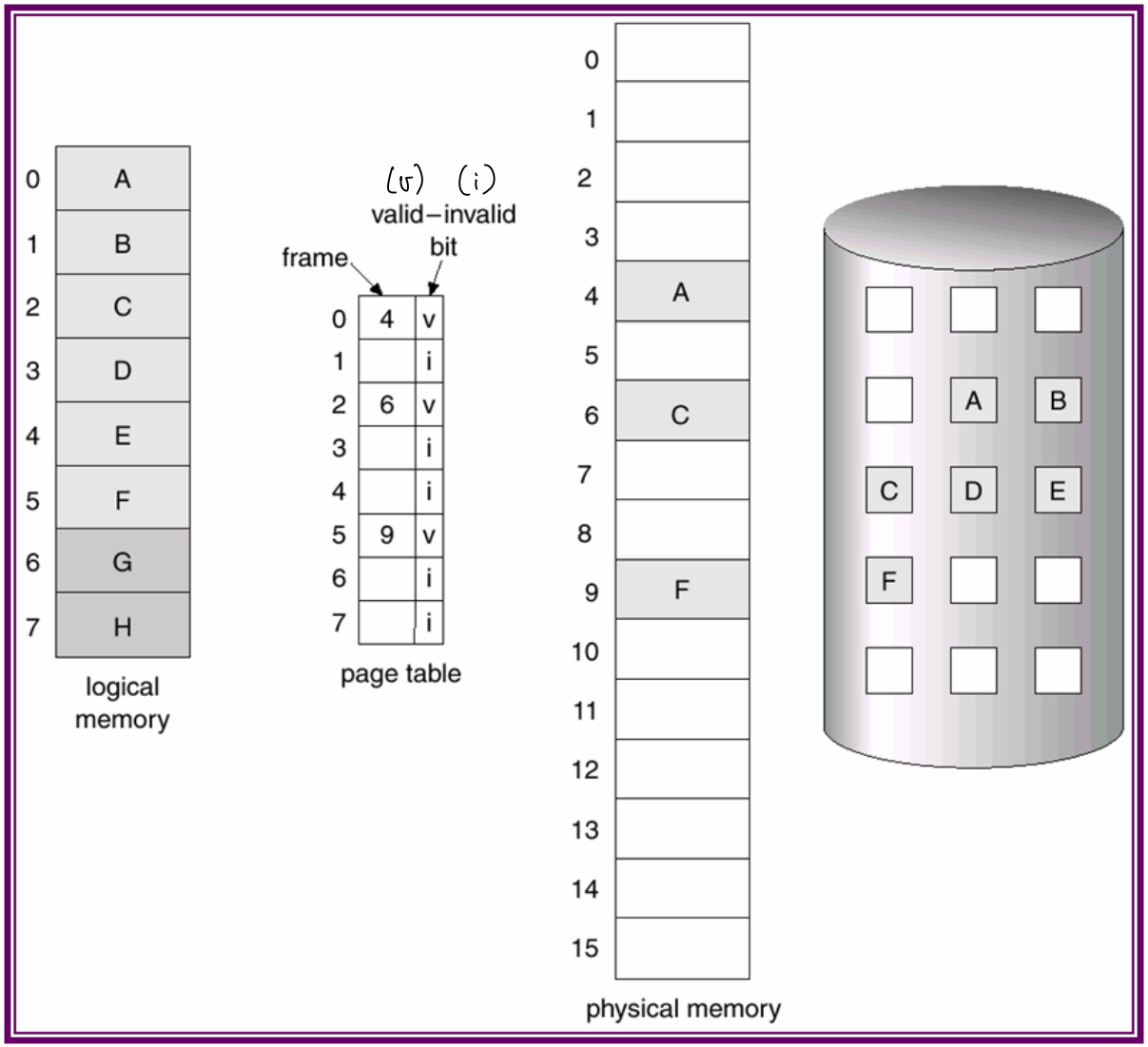
    ⇒ Increase CPU's productivity
  - Reduce I/O request for loading and swapping programs
    - The size of the swapped part is smaller

# Concept of virtual memory



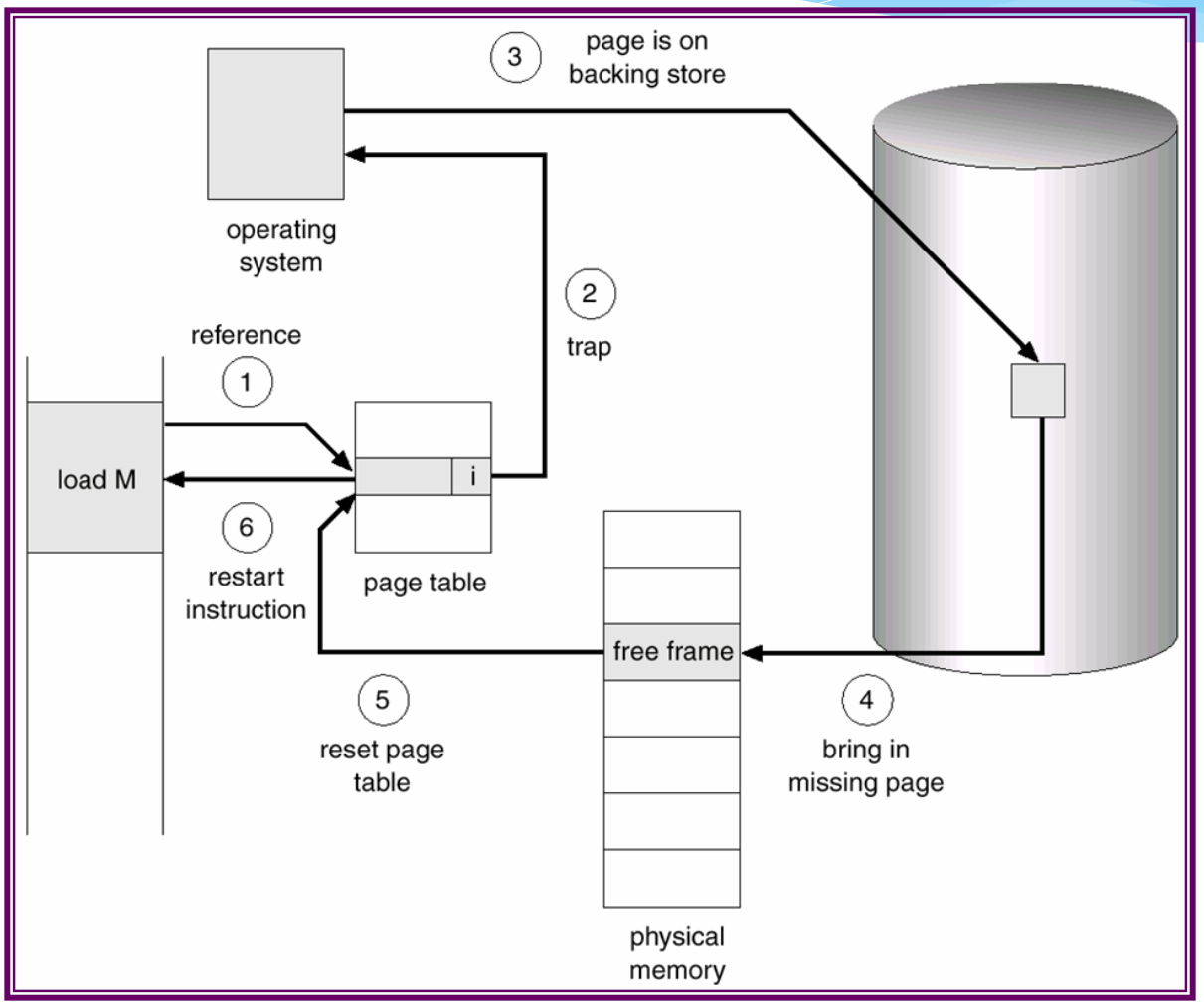

- Utilize the secondary storage (*HardDisk*) to store the unloaded program's part
- Separate logic memory (*user's space*) from physical memory
- Allow mapping large logical memory area to small physical memory area
- Implemented by
  - Segmentation
  - Paging

# Load parts of program into memory



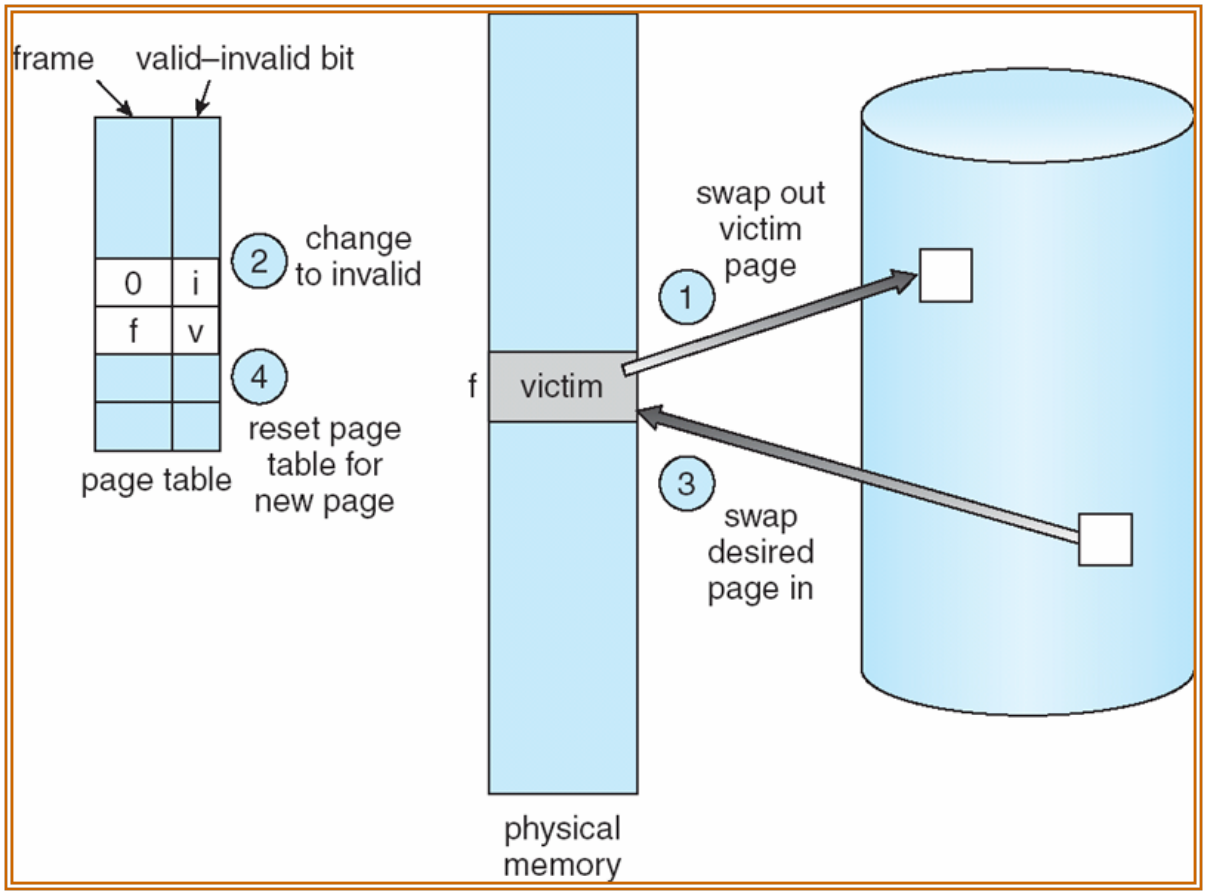

- Process's page:
  - Physical memory,
  - Some pages stay on disk (virtual memory)
- Represented by one bit in the PCB
- When a page is required, load page from secondary memory -> physical memory

# Page fault handling




If there are no free frames, need to replace pages

# Page replacement




① Determine location of logical page on disk

② Select physical frame
- Write to disk
- Modify bit valid-invalid

③ Load logic page into selected physical frame

④ Restart process

① Introduction

② Page replacement strategy

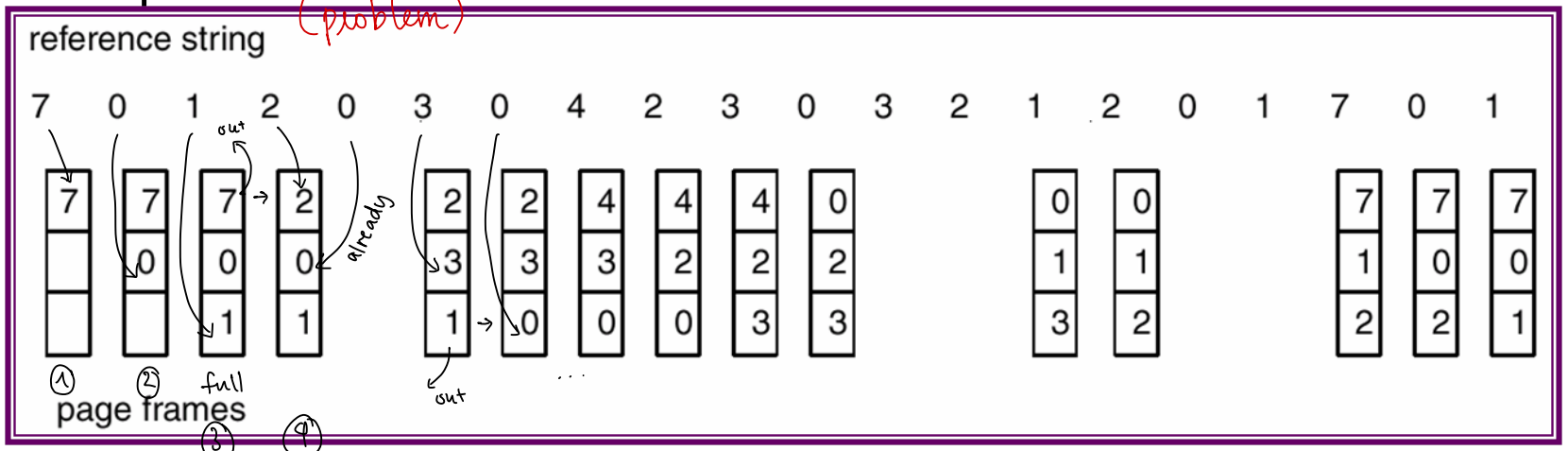
## Strategies

- FIFO: First In First Out
- OPT/MIN: Optimal page replacing algorithm
- LRU: page that is Least Recently Used
- LFU: page that is Least Frequently Used
- MFU: page that is Most Frequently Used
- . . .

# FIFO

Phenomenon
BÉLADY: When we↑ page frames for more slot, but the page fault does NOT ↓ (problem)

## Example




Remark → steps (progress)

- Effective when the program has the linear structure
- Least effective when the program has different modules call
- Easy to implement
  - Utilize a queue to store program's pages inside memory
  - Insert into last position in the queue, replace page at the first position
- Increase physical page, no guarantee of reducing page fault
  - Accessing sequence: 1 2 3 4 1 2 5 1 2 3 4 5
  - 3 frames: 9 page faults; 4 frames: 10 page faults

Count the number of page faults, given 3 frames
Assume page replacement follows FIFO (first page to enter = first page to be out)

| Page fault | ● 1 | ● 2 | ● 3 | ● 4 | ● 1 | ● 2 | ● 5 | 1 | 2 | ● 3 | ● 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frame 0 | 1 | 1 | 1 | 4 | 4 | 4 | 5 | | | 5 | 5 | |
| Frame 1 | | 2 | 2 | 2 | 1 | 1 | 1 | | | 3 | 3 | |
| Frame 2 | | | 3 | 3 | 3 | 2 | 2 | | | 2 | 4 | |

(9)

~ Given 4 frames

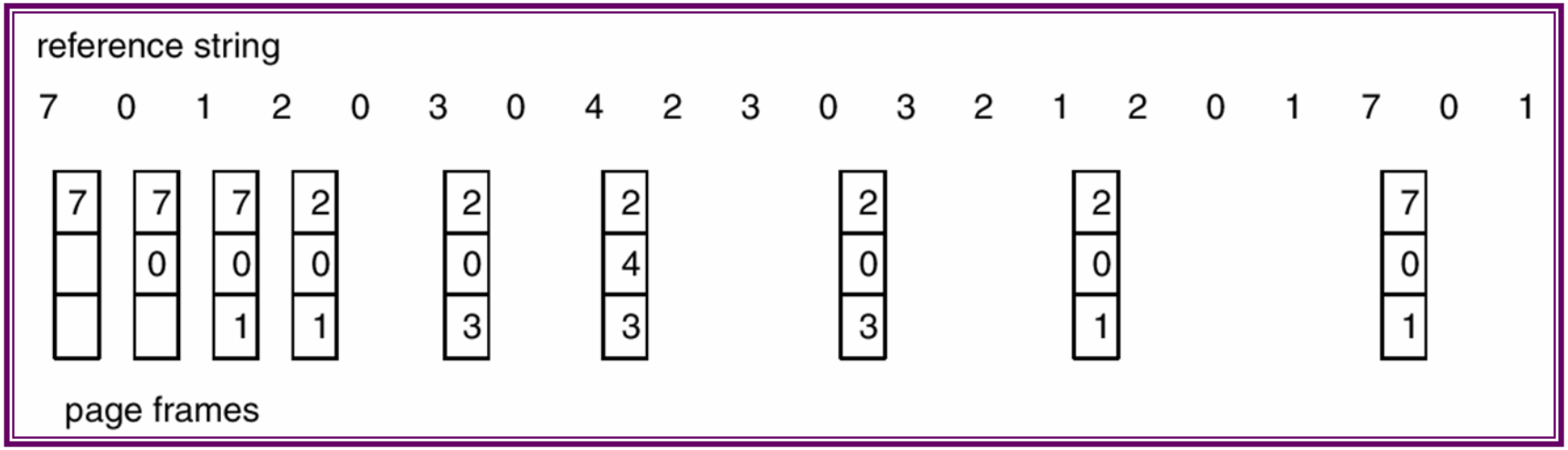
| Page fault | ● 1 | ● 2 | ● 3 | ● 4 | 1 | 2 | ● 5 | ● 1 | ● 2 | ● 3 | ● 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frame 0 | 1 | 1 | 1 | 1 | | | 5 | 5 | 5 | 5 | 6 | |
| Frame 1 | | 2 | 2 | 2 | | | 2 | 1 | 1 | 1 | 1 | |
| Frame 2 | | | 3 | 3 | | | 3 | 3 | 2 | 2 | 2 | |
| Frame 3 | | | | 4 | | | 4 | 4 | 4 | 3 | 4 | |

(9)

↳ BÉ LADY. The phenomenon in which we ↑ nb of frames but can NOT improve page fault rate!

## OPT (Optimal algo.)

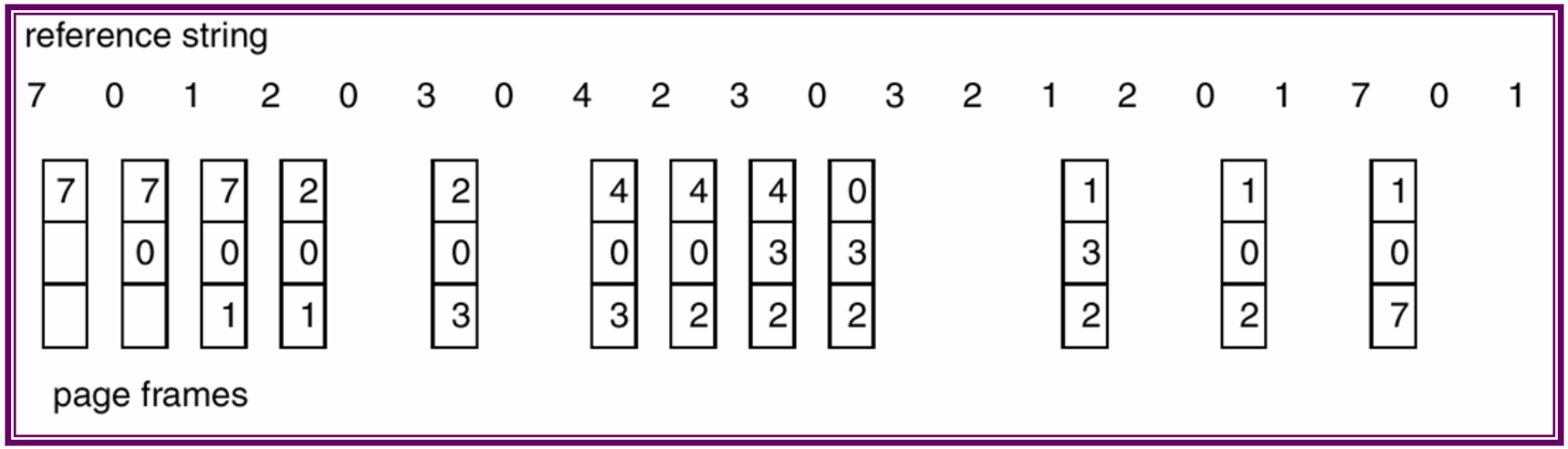
Rule: Replace page that has longest next used time




- Number of page fault is smallest
- Problem: it's hard to predict program sequence
  ↳ cannot implement IRL

# LRU

Rule: Replace page that is least recently used




- Effective for page replacing strategy
- Guarantee that page fault is reduced when increase physical frame
  - Set of pages in memory with n frames is always a subset of pages in memory that have n + 1 frames
- Require support to know the last recently accessed time
- How to implement?

# LRU: Implementation

- Counter
  - Add one more field to record the accessed time into each member of PCB
  - Add a clock/counter to the Control Unit
  - Where there is a page access request
    - Increase counter
    - Copy the counter content into the newly added field in PCB
  - Need a procedure to update PCB (write to the added field) and procedure to search for a smallest accessed time value
  - Number Overflow phenomenon !?
- List or Stack
  - Use a list or stack to record page number
    - Access to a page, put corresponding member to the top position
  - Replace: member in the last position
  - Usually implemented as a 2 dimension linked list
    - 4 pointer assigning operation $\Rightarrow$ time consuming

# Algorithm based on counter

Use counter (one field of PCB) to record the last time page is accessed

- LFU: Page that has smallest counter will be replaced
  - Page that is frequently used
    - Important page ⇒ reasonable
    - Initialization page, only used at start ⇒ unreasonable ⇒ Shift right the counter by 1 bit (time div 2)
- MFU: Replace page with largest counter
  - Page with smallest value, just recently loaded and not used much

(maybe the page most used should be done w/ by NOW - a newly loaded page may be of use more)

```
int A[100][100];
void main() {
    int i, j;
    for (i = 0; i < 100; i++)
        for (j = 0; j < 100; j++)
            A[i][j] = 0;
}
```

3 frames
FIFO

50 elements of a[i][j] ⊙ 1 frame

frame size: 200 B
sizeof(int): 4 B

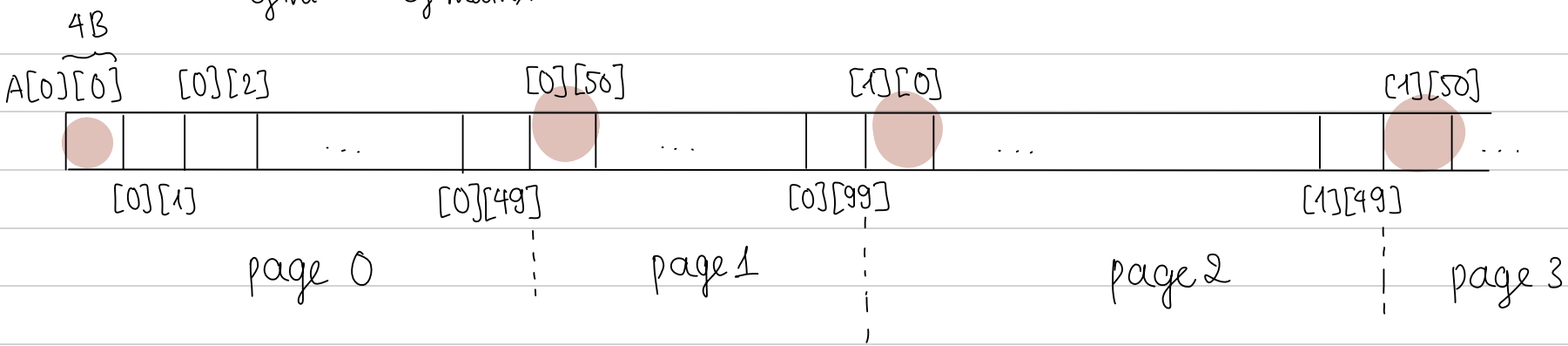
$\frac{200 \times 3}{4} = 150$ (int)

10.000

The program is divided into pages (including data + code)

DATA $4 * \underbrace{100 * 100}_{\text{size of matrix}} / 200\,B = 200$ pages

(4 = size of int)

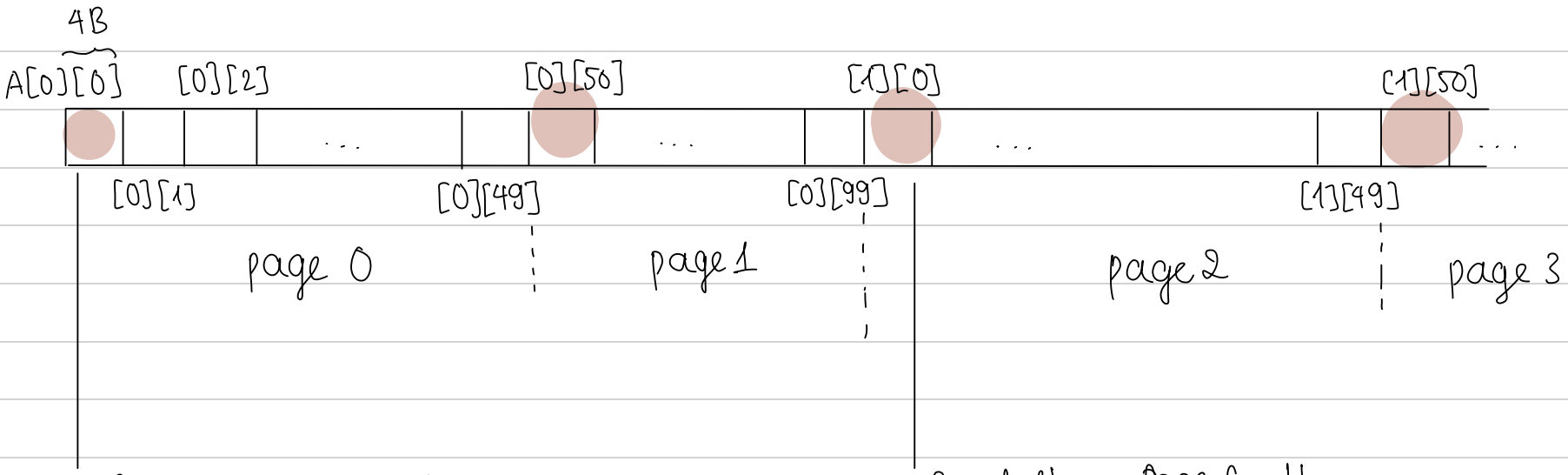



↳ 200 page faults (10000 / 50)

● = 1 page fault
After this: load 50 elements → frame

```
int A[100][100];
void main() {
    int i, j;
    for (i = 0; i < 100; i++)
        for (j = 0; j < 100; j++)
            A[j][i] = 0;
```

For each iter of j,
you have 1 page fault
⇓
10,000 page faults




(1) load this : page fault
load a[0][0] → a[0][49] ⇒ frame

(2) load this : page fault
(~)

Similarly, since each j iteration jumps to a segment of a[][] that is NOT in frame*

* frame = page in memory

# Chap 3 Memory Management

① Introduction
② Memory management strategies
③ Virtual memory
④ Memory management in Intel’s processors family

## Memory management modes

- Intel 8086, 8088
  - Only one management mode: Real Mode
  - Managed memory area up to 1MB ( 20bit )
  - Xác định địa chỉ ô nhớ bằng 2 giá trị 16 bit: Segment, Offset
    - Segment register: CS, SS, DS, ES,
    - Offset register: IP, SP, BP...
    - Physical address: Seg SHL 4 + Ofs
- Intel 80286
  - Real mode, compatible with 8086
  - Protected mode
    - Utilize segmentation method
    - Exploit physical memory up to 16M (24bit )
- Intel 80386, Intel 80486, Pentium,..
  - Real mode, compatible with 8086
  - Protected mode : Combination of segmentation and paging
  - Virtual mode
    - Allow to run 8086 code in protected mode

# Protected mode in Intel 386, 486, Pentium,..