# Chapter VII
# Memory Management

Jehan-François Pâris
jfparis@uh.edu

# Chapter Overview

- A review of classical approaches to memory management
  - Follows the evolution of operating systems from the fifties to the eighties

# Solution 0

- No memory management
- The very first computers had no operating system whatsoever
- Each programmer
  - Had access to whole main memory of the computer
  - Had to enter the bootstrapping routine loading his or her program into main memory.

# Solution 0

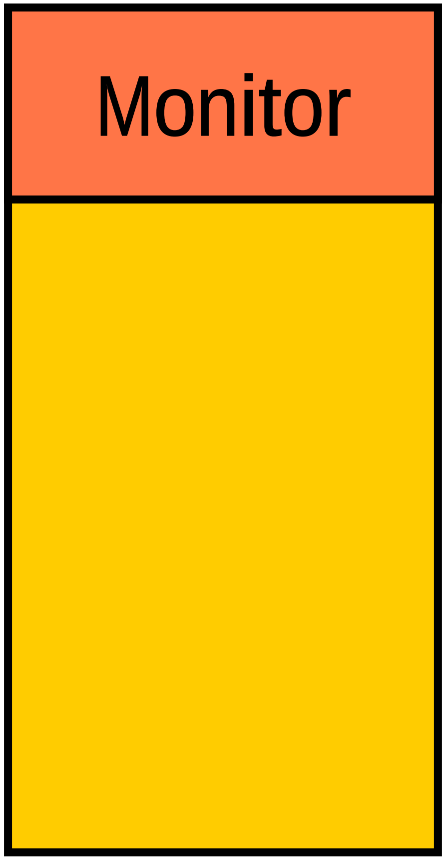
- ***Advantage:***
  - Programmer is in total control of the whole machine.
- ***Disadvantage:***
  - Much time is lost entering manually the bootstrapping routine.

# Solution 1

- ***Uniprogramming***
- Every system includes a ***memory-resident monitor***
    - Invoked every time a user program would terminate
    - Would immediately fetch the next program in the queue (***batch processing***)

# Solution 1

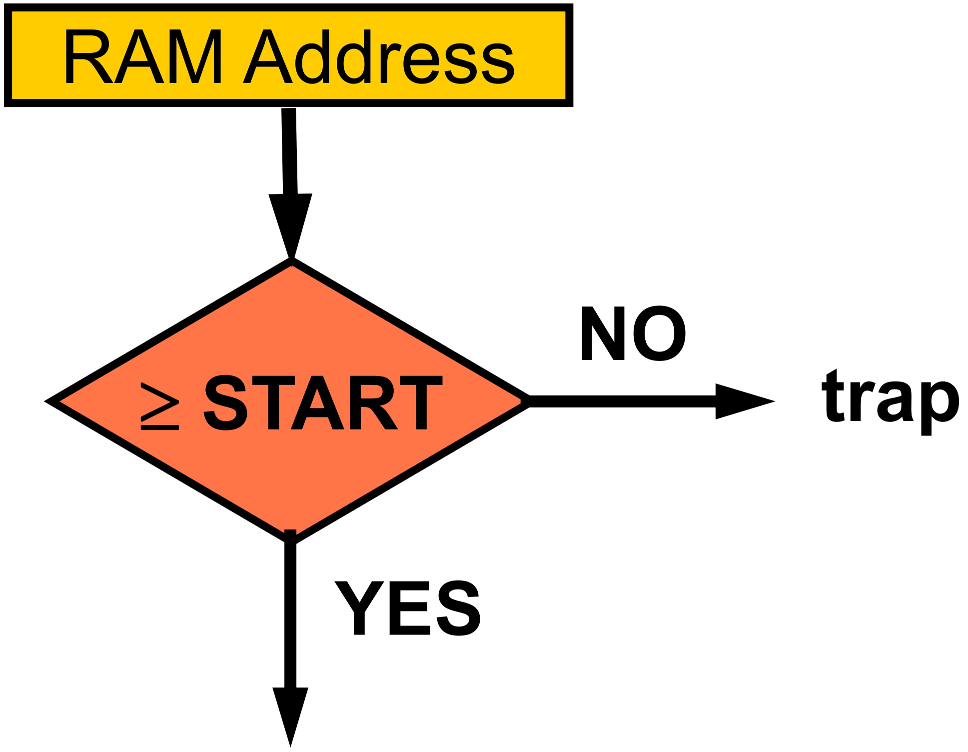
- Should prevent user program from corrupting the kernel
- Must add a Memory Management Unit (MMU)



# Solution 1

- Assuming that the monitor occupies memory locations 0 to START – 1
- MMU will prevent the program from accessing memory locations 0 to START – 1

# MMU for solution 1



# Solution 1

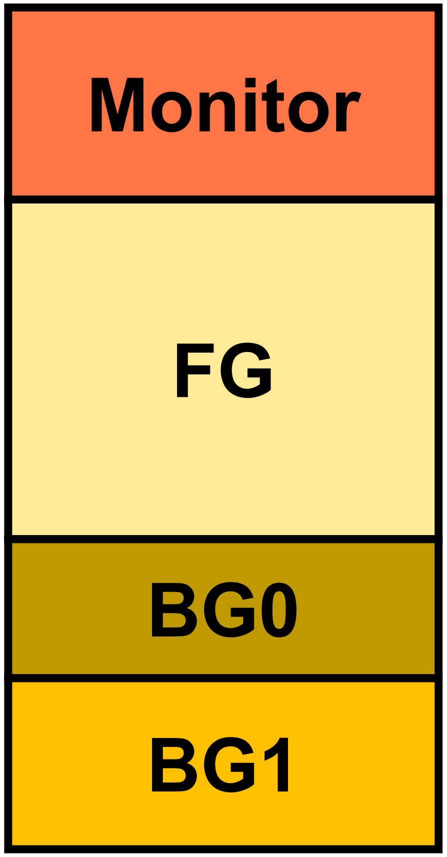
- ***Advantage:***
  - No time is lost re-entering manually the bootstrapping routine
- ***Disadvantage:***
  - CPU remains idle every time the user program does an I/O.

# Solution 2

- ***Multiprogramming with fixed partitions***
    - Requires ***I/O controllers*** and ***interrupts***
- OS dedicates multiple partitions for user processes
    - Partition boundaries are ***fixed***
- Each process must be ***confined*** between its ***first*** and ***last*** address

# Solution 2

- Computer often had
  - A foreground partition (FG)
  - Several background partitions (BG0, . . .)



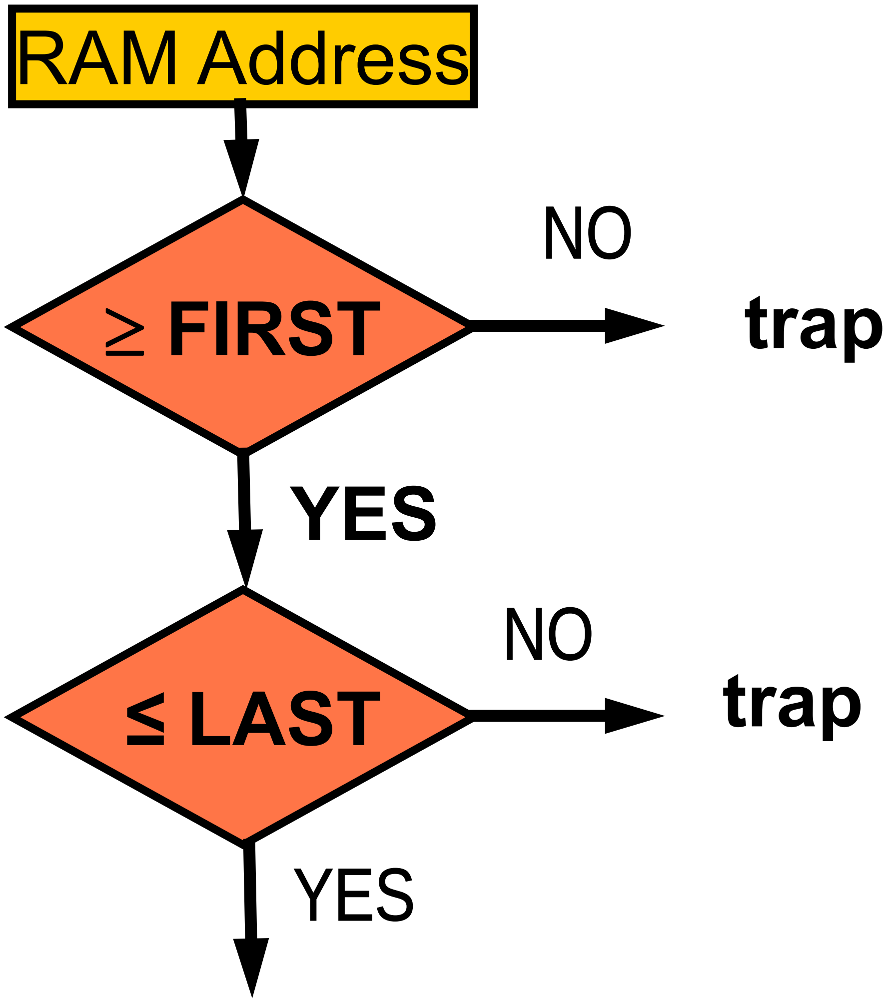
Monitor

FG

BG0

BG1

# MMU for solution 2



RAM Address

NO

**≥ FIRST**

**trap**

**YES**

NO

**≤ LAST**

**trap**

YES

# Solution 2

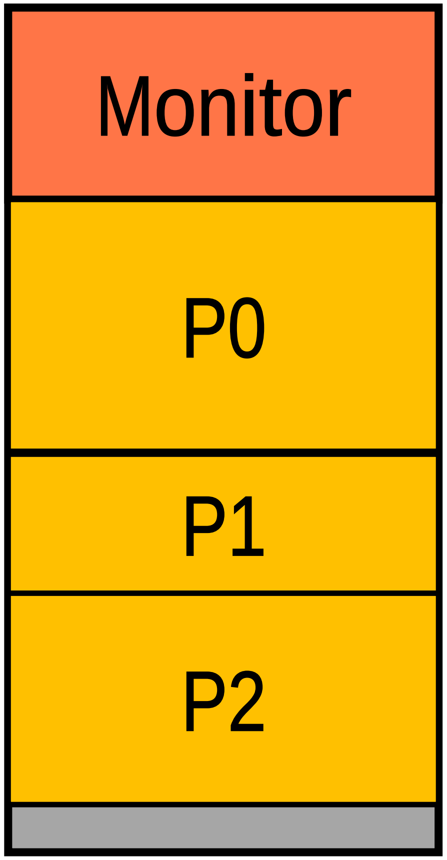
- ***Advantage:***
    - No CPU time is lost while system does I/O
- ***Disadvantages:***
    - Partitions are ***fixed*** while processes have different memory requirements
    - Many systems were requiring processes to occupy a ***specific partition***

# Solution 3

- ***Multiprogramming with variable partitions***
- OS allocates contiguous extents of memory to processes
  - ☐ Initially each process gets all the memory space it needs and nothing more
- Processes that are swapped out can return to ***any*** main memory location

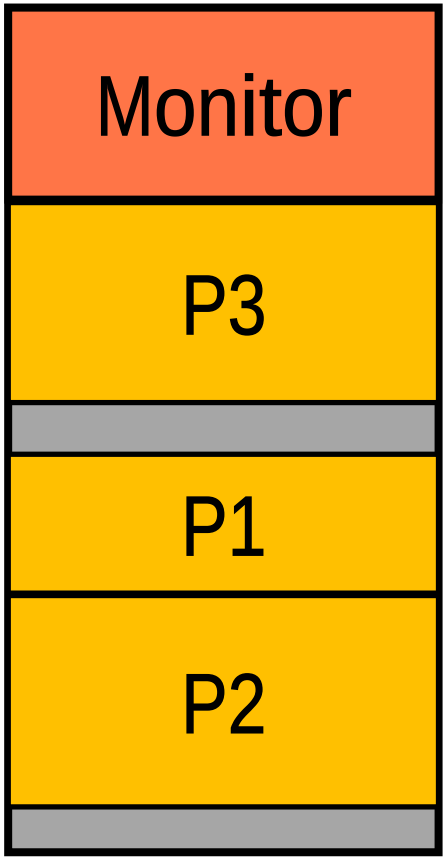
# Solution 3

- Initially everything works fine
  - Three processes occupy most of memory
  - Unused part of memory is very small



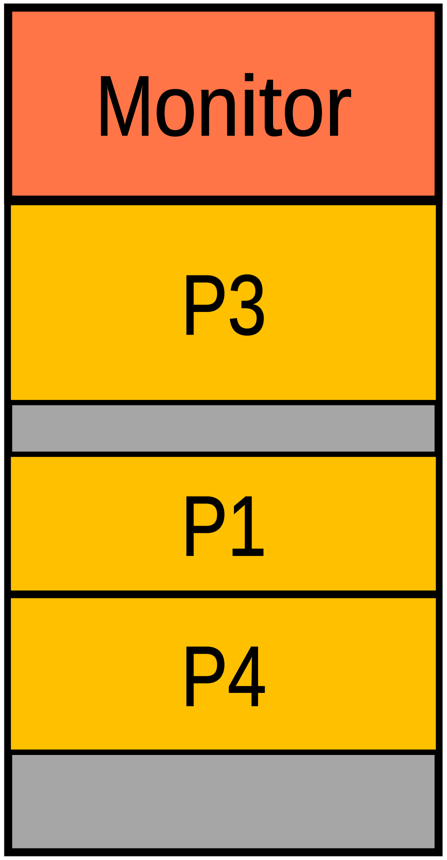
# Solution 3

- When P0 terminates
  - Replaced by P3
  - P3 must be smaller than P0
- Start wasting memory space



# Solution 3

- When P2 terminates
  - Replaced by P4
  - P4 must be smaller than P2 plus the free space
- wasting more memory space



# External fragmentation

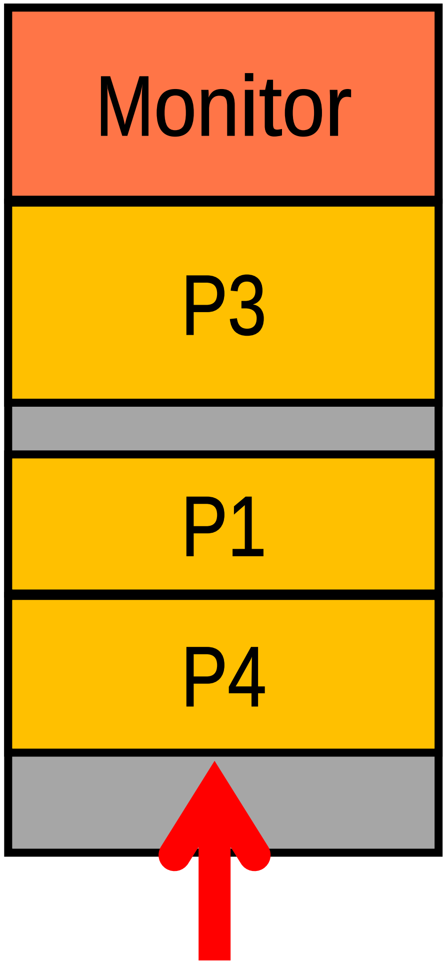
- Happens in all systems using multiprogramming with variable partitions
- Occurs because new process must fit in the hole left by terminating process
  - Very low probability that both process will have exactly the same size
  - Typically the new process will be a bit smaller than the terminating process

# An Analogy

- Replacing an old book by a new book on a bookshelf
- New book must fit in the hole left by old book
  - Very low probability that both books have exactly the same width
  - We will end with empty shelf space between books
- Solution it to push books left and right

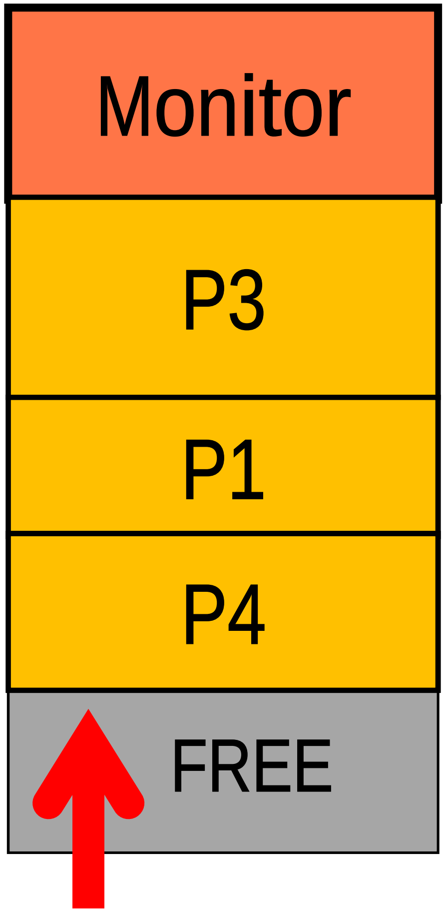
# Memory compaction

- When external fragmentation becomes a problem, we ***push*** processes around in order to consolidate free spaces



# Memory compaction

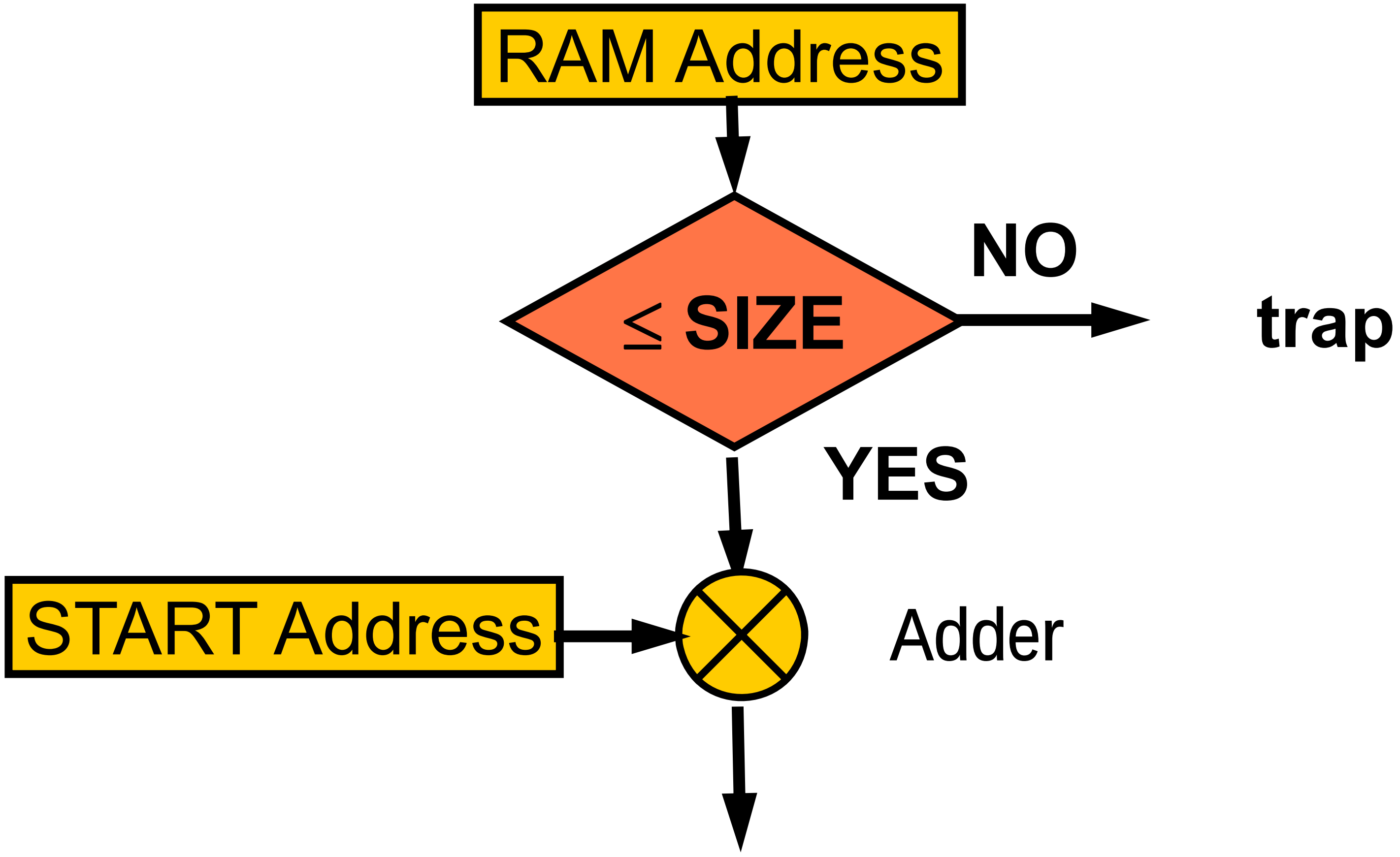
- Works very well when memory sizes were small



# Dynamic address translation

- Processes do not occupy fixed locations in main memory
    - Will let them run as if they were starting at location 0
    - MMU hardware will ***add the right offset***
    - Will test first that process does not try to access anything outside its boundaries

# MMU for solution 3



# Is it virtual or real?

- MMU translates
  - ***Virtual addresses*** used by the process

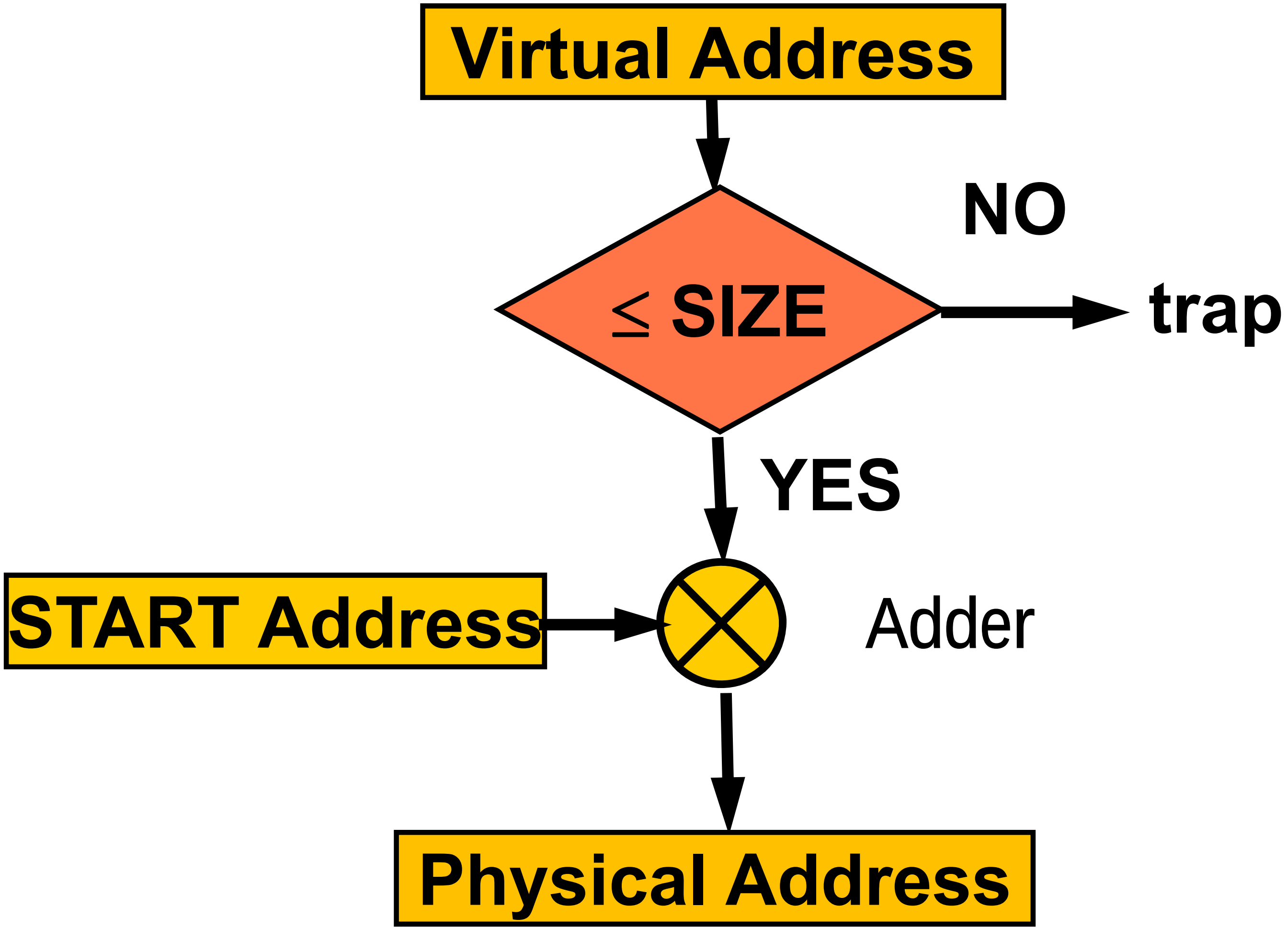
  into

  - ***Real addresses*** in main memory

# An analogy

- Living or visiting places that makes us believe we are in a different country
  - Little Italy in San Francisco, Bazaar del Mundo in San Diego, Chinatown everywhere
  - Subdivisions with “romantic” Spanish names in California
  - Streets with names of Ivy League schools or towns hosting them (Amherst, . . .)

# Another way to look at it



**Virtual Address**

**≤ SIZE**

**NO**

**trap**

**YES**

**START Address**

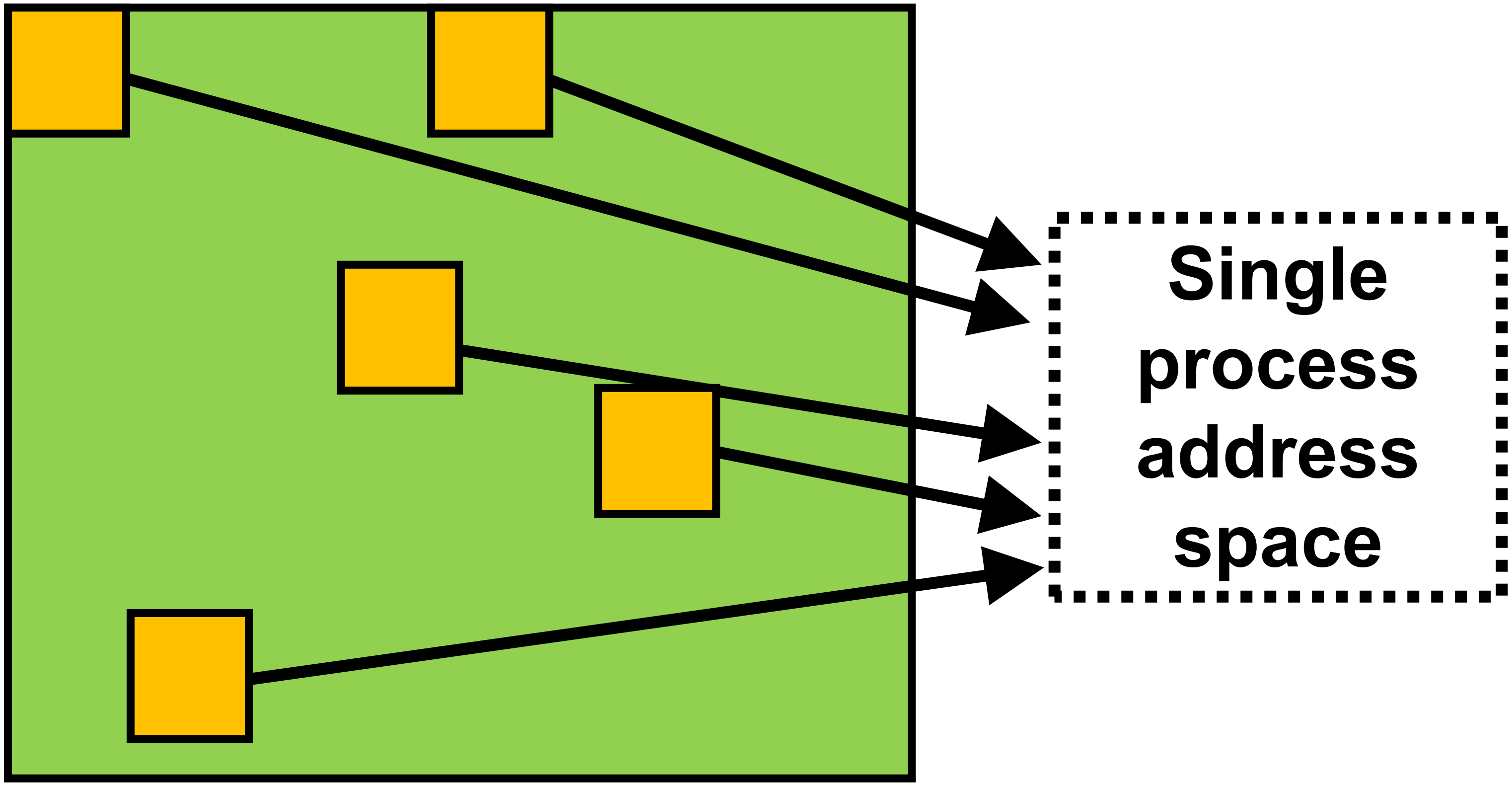
Adder

**Physical Address**

# Solution 4

- ***Non-contiguous allocation***
  - Partition main memory into fixed-size entities
    - ***Page frames***
  - *A*llocate non-contiguous page frames to processes
  - Let the MMU take care of the address translation

# Non-contiguous allocation



# Virtual v. real

- Processes are provided with the illusion of a vast linear address space
  - Virtual addresses starting at address zero

- In reality, this address space is made up of disjoint page frames
  - Non-contiguous real addresses