Memory Management

# Memory Abstraction

Lecture 7

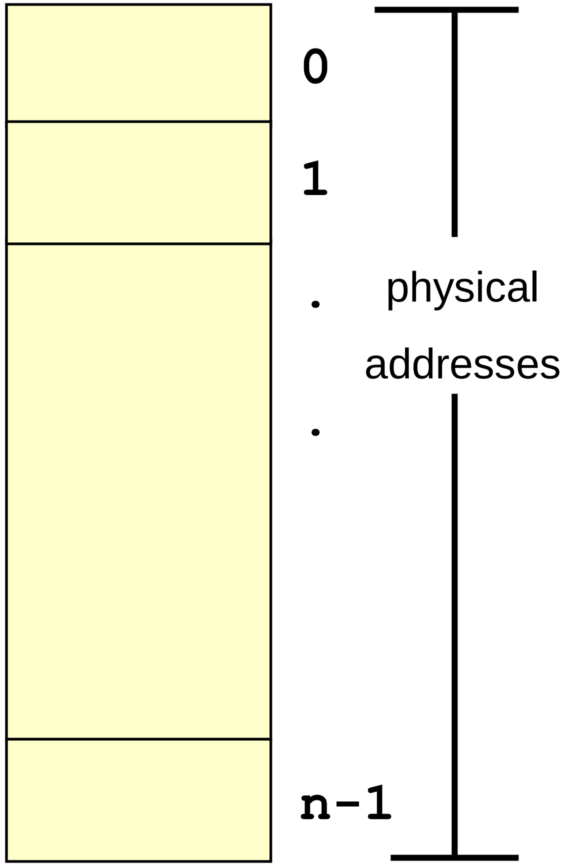
# Overview

- Basics of Memory:
  - Hardware
  - Memory usage of process
  - Role of OS
- Memory abstractions:
  - Physical address
  - Logical address
- Contiguous Memory Allocation:
  - Fixed Size Partition
  - Variable Size Partition

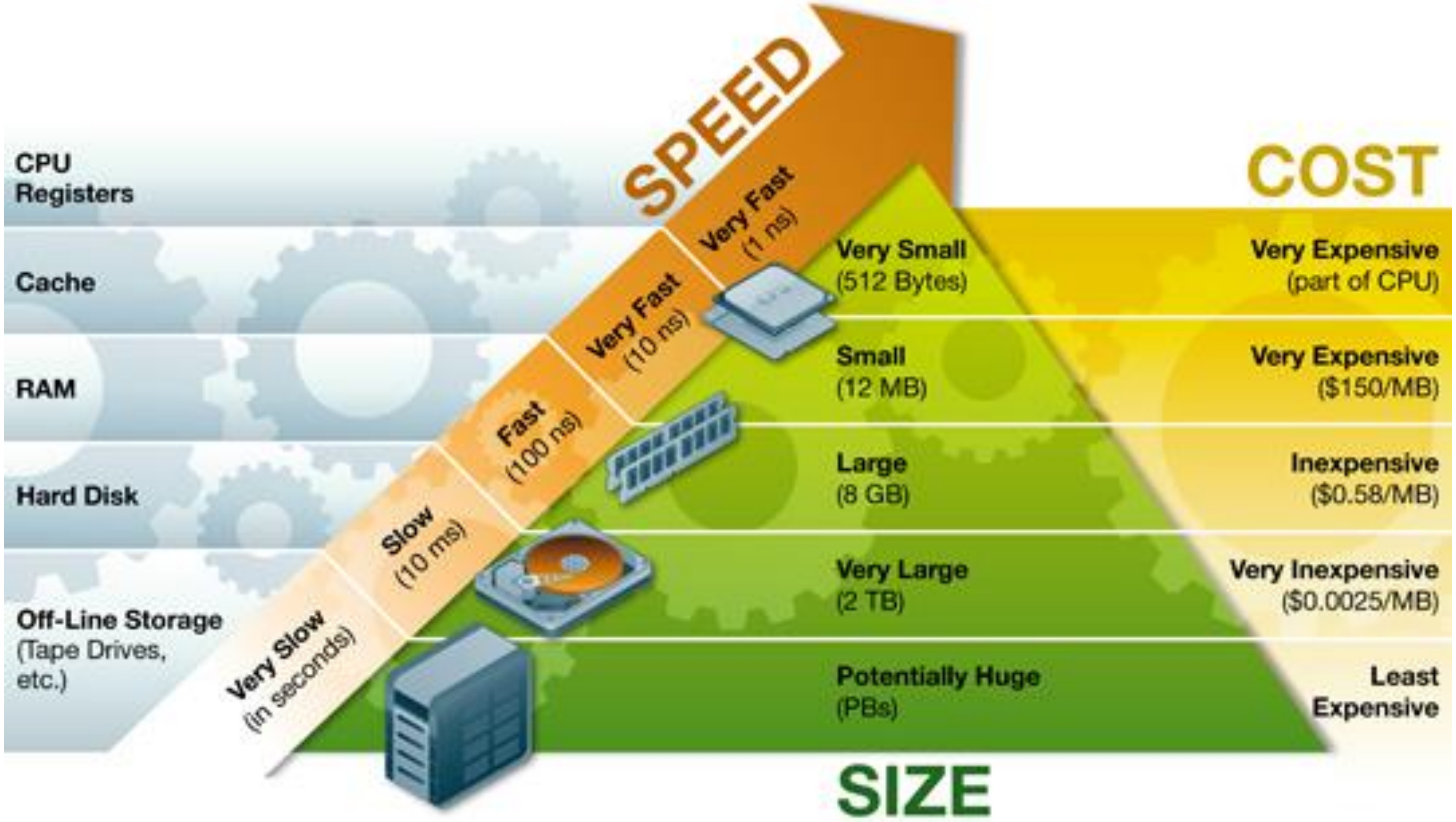
# Memory Hardware

- Physical memory storage:
  - Random Access Memory (RAM)
  - Can be treated as an array of bytes
  - Each byte has a unique index
    - Known as **physical address**

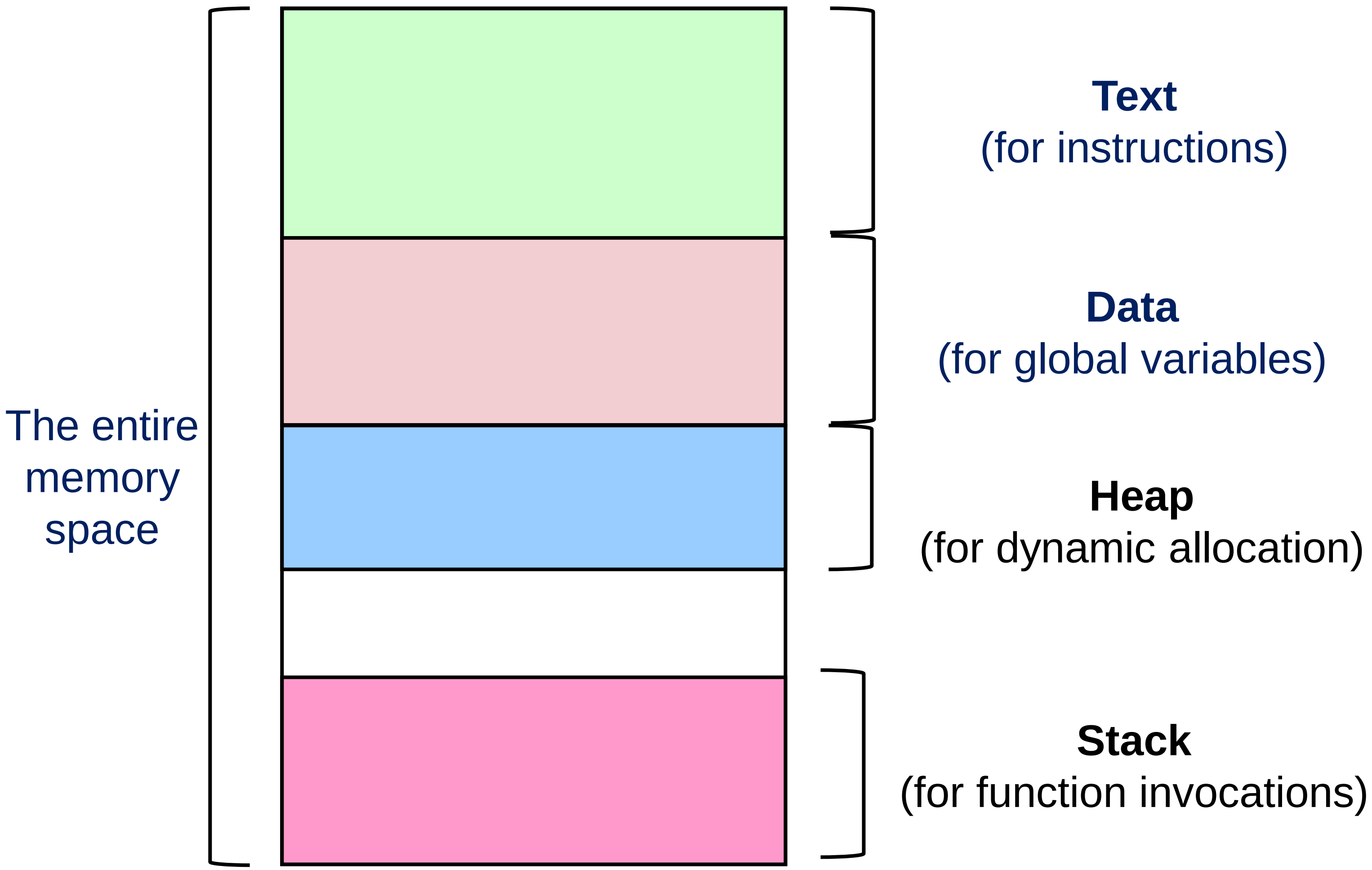
- A contiguous memory region:
  - An interval of consecutive addresses



# The Memory Hierarchy



# Recap: Memory Usage of Process



# Binding of Memory Address

```
int i = 0;

void inc()
{
     i = i + 20;
}

int main()
{
    inc();
    ...
    ...
}
```

Source Code

Compile

by

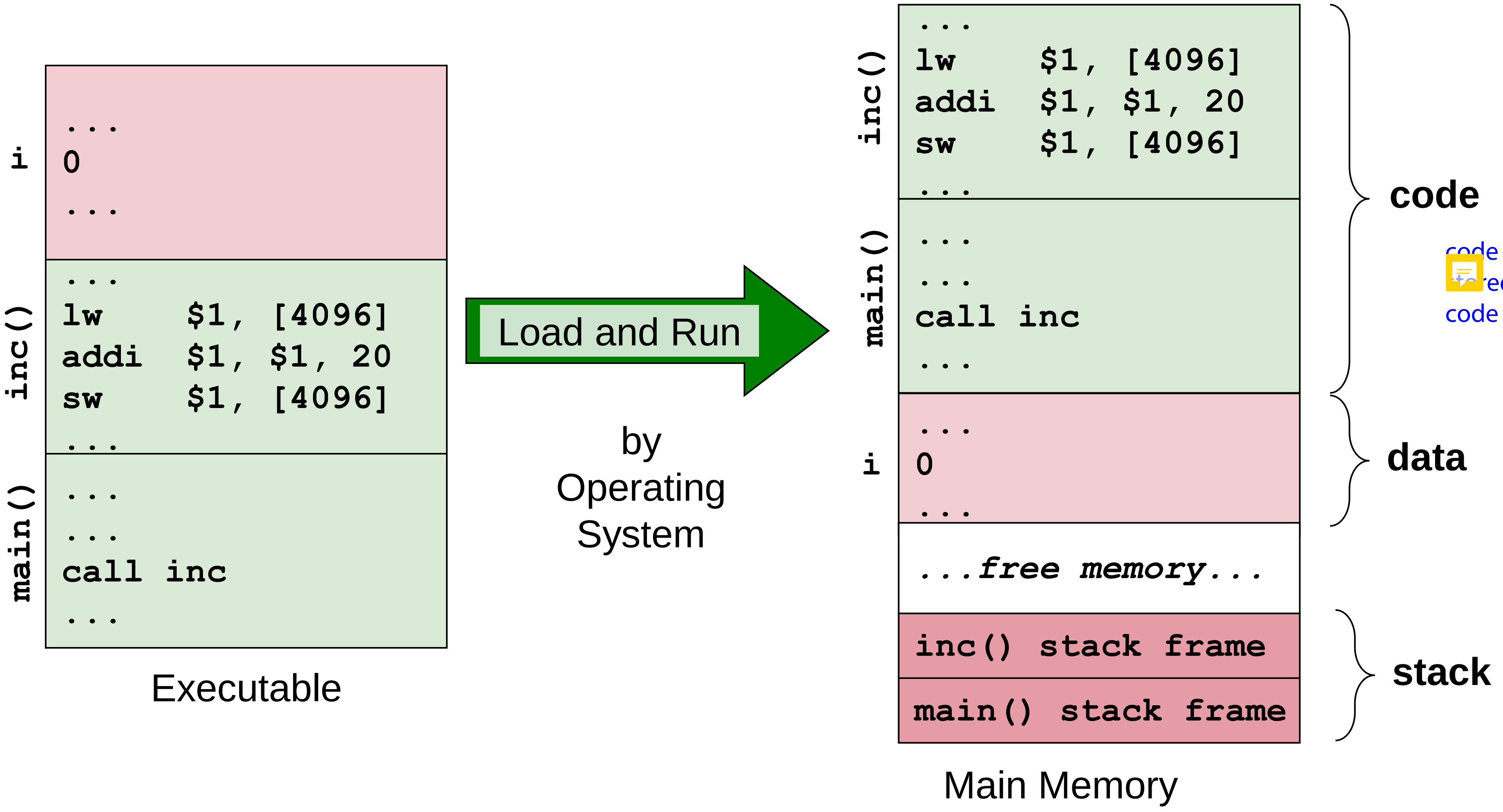
Compiler

```
         ...
i        0
         ...
inc()    ...
         lw     $1, [4096]
         addi   $1, $1, 20
         sw     $1, [4096]
         ...
main()   ...
         ...
         call inc
         ...
```

Executable

- Executable typically contains:
  - Code (for text region), Data layout (for data region)

# Actual Execution




code and data although are stored in similar areas - but code and data do not mix

# Memory Usage: **Summary**

- Generally, two types of data in a process:
  - **Transient** Data:
    - Valid only for a limited duration, e.g., during function call
    - e.g., parameters, local variables
  - **Persistent** Data:
    - Valid for the duration of the program unless explicitly removed (if applicable)
    - e.g., global variable, constant variable, dynamically allocated memory

      text, code, global, heap
- Both types of data sections can grow/shrink during execution

# Operating System: **Managing Memory**

- OS handles the following memory related tasks:
  - Allocate memory space to new processes
  - Manage memory space for processes
  - Protect memory space of processes from each other
  - Provides memory related system calls to processes
  - Manage memory space for internal use

# Key Topics

## Memory Abstraction

- Presenting a logical interface for memory accesses

## Contiguous Memory Allocation

- Allocating and managing continuous chunk of memory

## Disjoint Memory Allocation

- Allocating and managing memory in disjoint areas

## Virtual Memory Management

- Use of secondary storage as an extended memory region

You have to be logical!

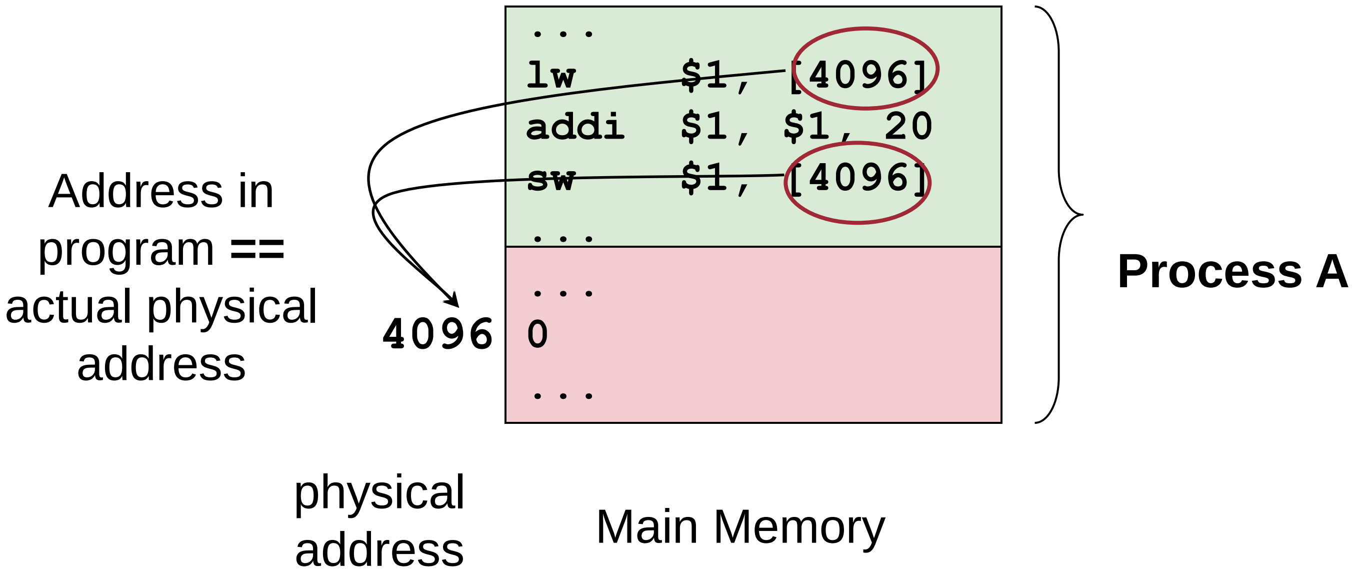
# MEMORY ABSTRACTION

# Without Memory Abstraction

- Suppose a process directly uses physical address:
  - i.e., no memory abstraction

- Using the example code, let us check:
  - How to access memory locations in a process?
  - Can multiple process share the physical memory correctly?
  - Can the address space of a process be protected easily?

# Without Memory Abstraction: **Pros**



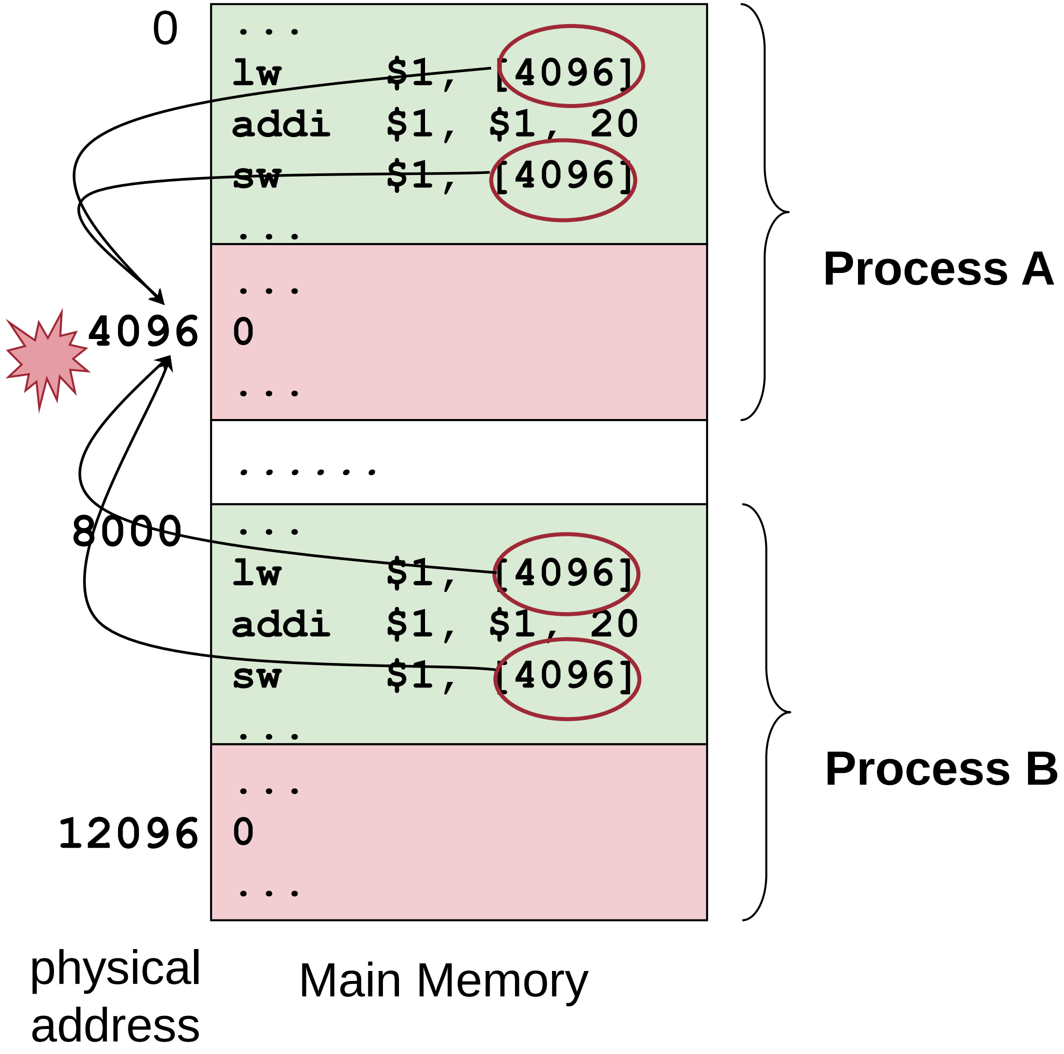

- Memory access is straightforward
  - Address in program == Physical Address
  - No conversion/mapping is required
  - Address fixed during compilation time

very efficient - especially if the system only will have this 1 process running

# Without Memory Abstraction: **Cons**

- If two processes are occupying the same physical memory:
  - Conflicts: both processes assume memory starts at 0!

➔ Hard to protect memory space!



# Fix Attempt: **Address Relocation**

- Recalculate the memory references when the process is loaded into memory:
  - e.g., add an offset of `8000` to ***all memory references*** in Process **`B`**
    - Since Process **`B`** is loaded at address **`8000`**

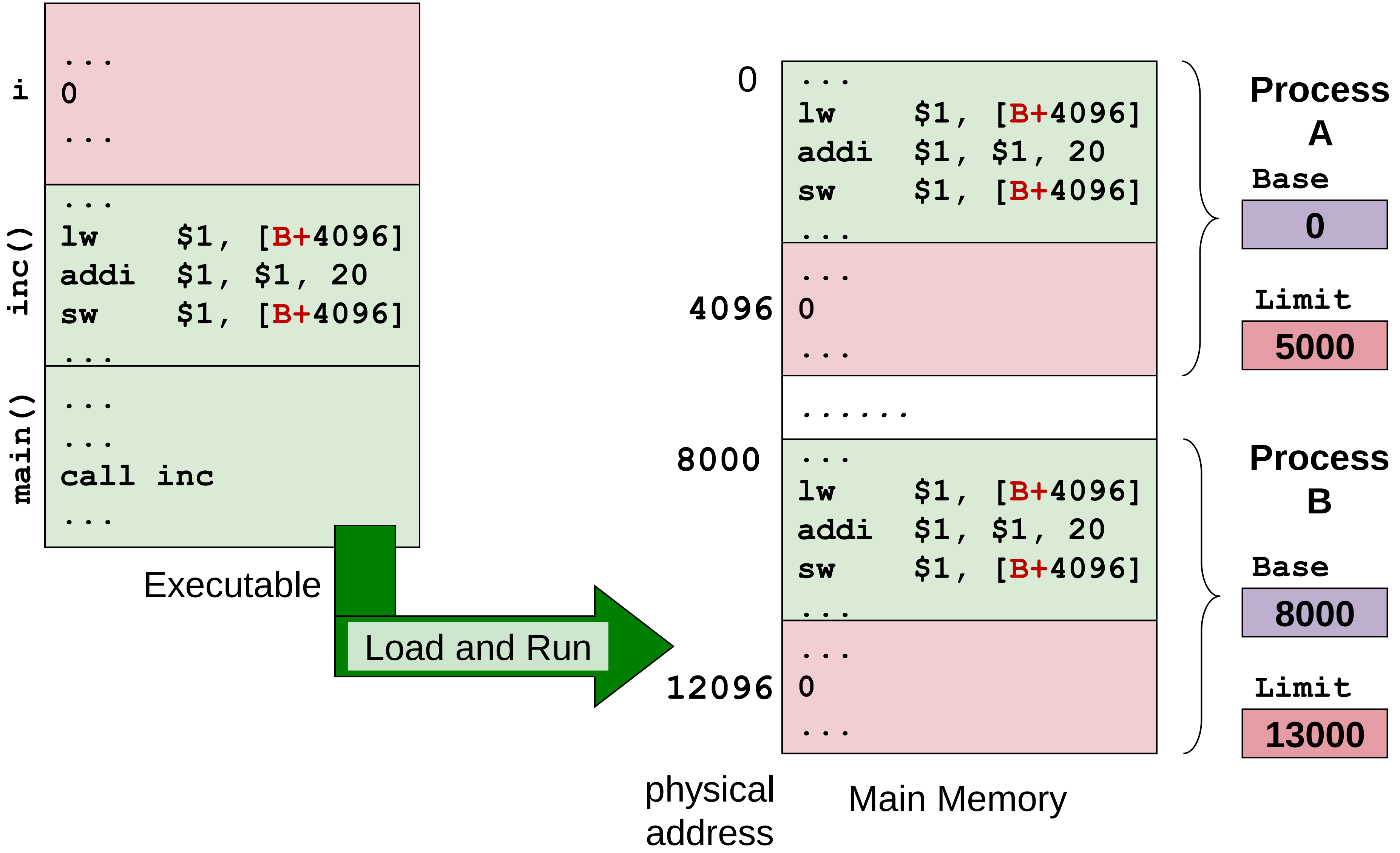
- **Problems:**
  - Slow loading time
  - Not easy to distinguish memory reference from normal integer constant

# Fix Attempt 2: Base + Limit Registers

1. Use a special register as the base of all memory references:
   - Known as **Base Register**
   - During compilation time, all memory references are compiled as an offset from this register
   - At loading time, the base register is initialized to the starting address of the process memory space

2. Add another special register to indicate the range of the memory space of current process:
   - Known as **Limit Register**
   - All memory access is checked against the limit to protect memory space integrity

# Base + Limit Register: Illustration



# Base + Limit: **Summary**

- Problems:

still not the most efficient

  - To access address Adr:
    - **`Actual = Base + Adr`**
    - Check **`Actual < Limit`** for validity
  - So, every memory access incurs an addition and a comparison

- The idea is very useful:
  - Later generalized to segmentation mechanism
  - Provides a crude memory abstraction:
    - Address **`4096`** in Process **`A`** and **`B`** are no longer the same physical location!

# Memory Abstraction: **Logical Address**

- Embedding physical memory address in program is a bad idea

➔Give birth to the idea of **logical address:**

- Logical address == how the process views its memory space
- Logical address != Physical address in general
  - Instead a mapping between logical address and physical address is needed
- Each process has a self-contained, independent logical memory space

Chunk of continuous addresses

# CONTIGUOUS MEMORY MANAGEMENT

# Contiguous Memory Management

- Process must be in memory during execution
  - Stored-program computer
  - Load-store memory execution model

- Let us assume:
  1. Each process occupies a **contiguous memory region**
  2. The **physical memory is large enough** to contain one or more processes with complete memory space
  - These assumptions will be removed in later topics

# Multitasking, Context Switching & Swapping

- To support multitasking:
  - Allow multiple processes in the physical memory at the same time
  - So that we can switch from one process to another

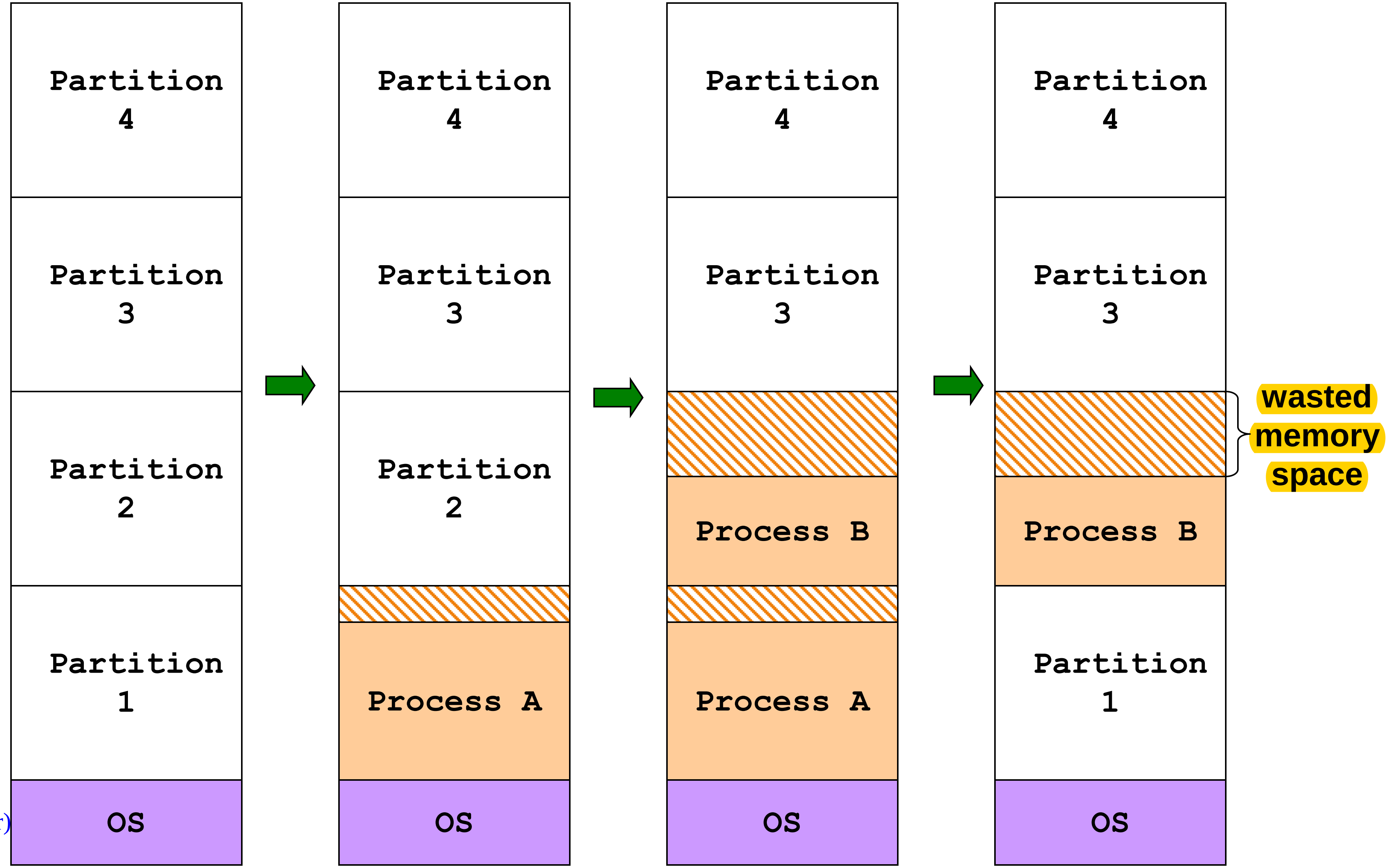
- When the physical memory is full:
  - Free up memory by:
    - Removing terminated process
    - Swapping blocked process to secondary storage

# Memory Partitioning

- **Memory Partition:**
  - The contiguous memory region allocated to a single process

- Two schemes of allocating partitions:
  1. **Fixed-Size Partition**
     - Physical memory is split into fixed number of partitions
     - A process will occupy one of the partitions
  2. **Variable-Size Partition**
     - Partition is created base on the actual size of process
     - OS keep track of the occupied and free memory regions
       - Perform splitting and merging when necessary

# Fixed Partitioning: Illustration

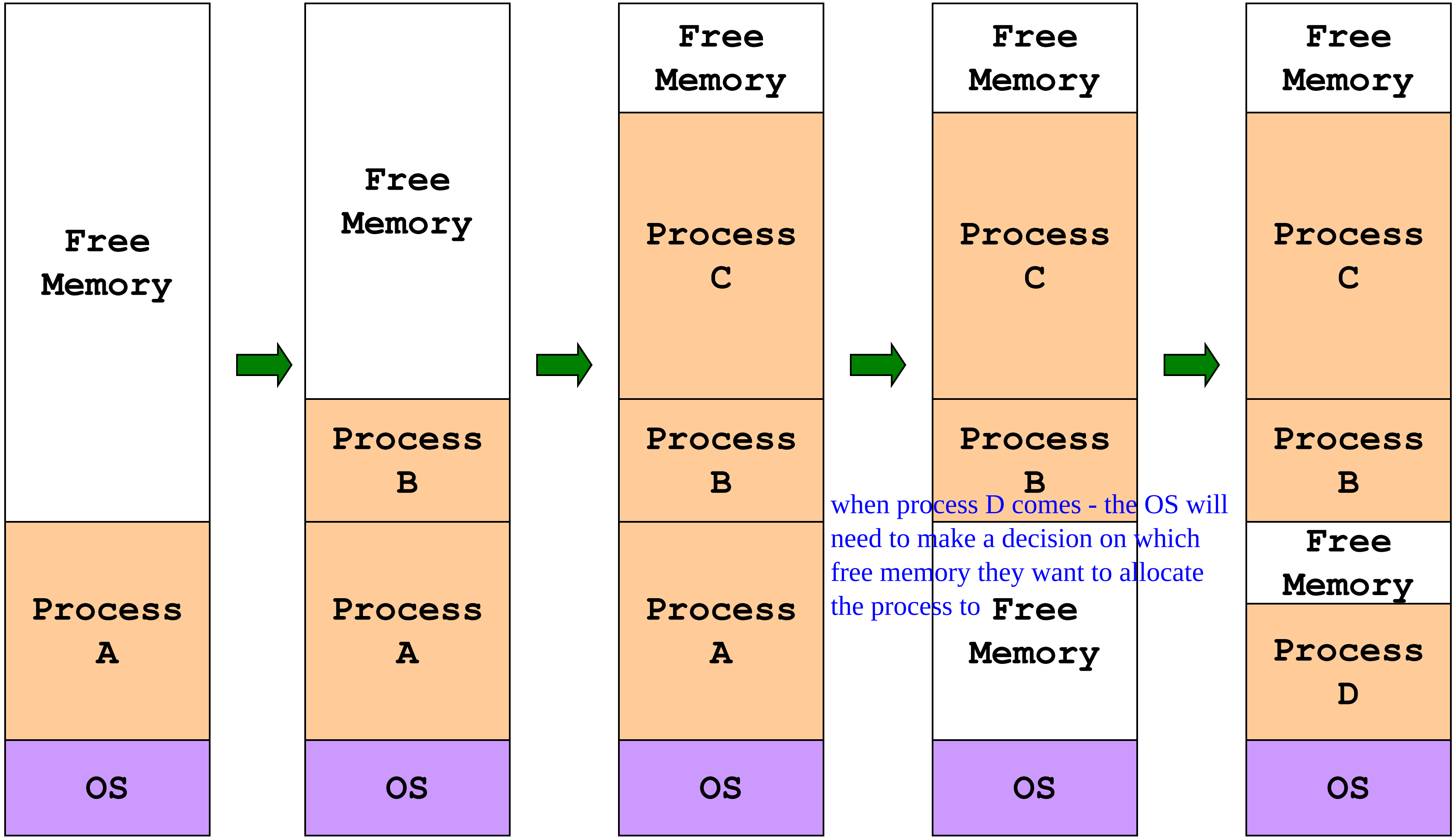



where the OS is does not matter (either high/low addr)

# Fixed Partitioning: **Summary**

- If a process does not occupy the whole partition:
  - Any left over space is wasted!
  - Known as **internal fragmentation**
- **Pros:**
  - Easy to manage
  - Fast to allocate
    - Every free partition is the same ➔ No need to choose
- **Cons:**
  - Partition size need be large enough to contain the largest of the processes
    - Smaller process will waste memory space ➔ internal fragmentation

# Dynamic Partitioning: Illustration




when process D comes - the OS will need to make a decision on which free memory they want to allocate the process to

However now when a new process - process E arrives

Even though process E will need a space smaller than the combined of the current Free memory - but larger than the individual free memory space

# Dynamic Partitioning: **Summary**

- Free memory space is known as **hole**
- With process creation/termination/swapping:

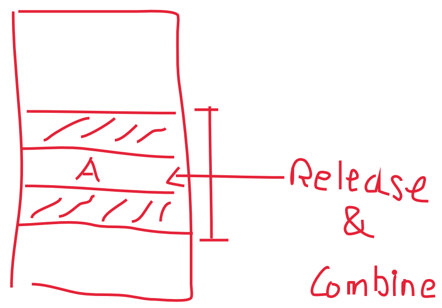
  ➔ tend to have a large number of holes
  - Known as **external fragmentation**
  - Merging the holes by moving occupied partitions can create larger hole (more likely to be useful)
- **Pros:**
  - Flexible and remove internal fragmentation
- **Cons:**
  - Need to maintain more information in OS
  - Takes more time to locate appropriate region

# Dynamic Partitioning: Allocation Algorithms

- Assuming the OS maintains a list of partitions and holes
- Algorithm to locate partition of size **N**:
  - Search for hole with size **M >= N**. Several variants:
    1. **First-Fit:**
       - Take the first hole that is large enough
    2. **Best-Fit:**  the rest need to use more time to go through all the partitions to find the best/worst
       - Find the smallest hole that is large enough
    3. **Worst-Fit:**
       - Find the largest hole
  - Split the hole into **N** and **M–N**
    - **N** will be the new partition
    - **M–N** will be the left over space → a new hole

# Dynamic Partitioning: Merging and Compaction

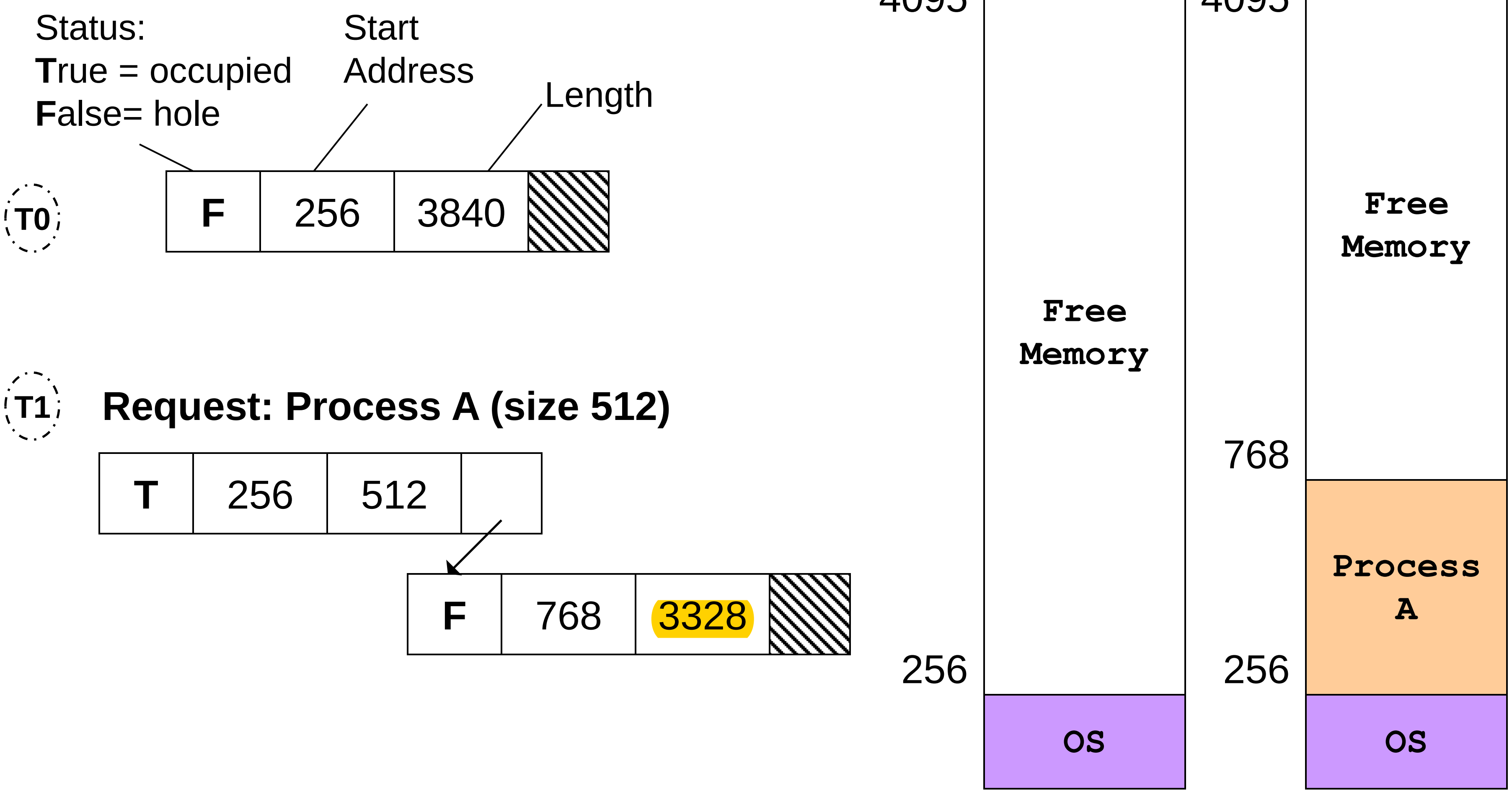
- When an occupied partition is freed:
  - Merge with adjacent hole if possible




- Compaction can also be used:
  - Move the occupied partition around to create consolidated holes
  - Cannot be invoked too frequently as it is very time consuming

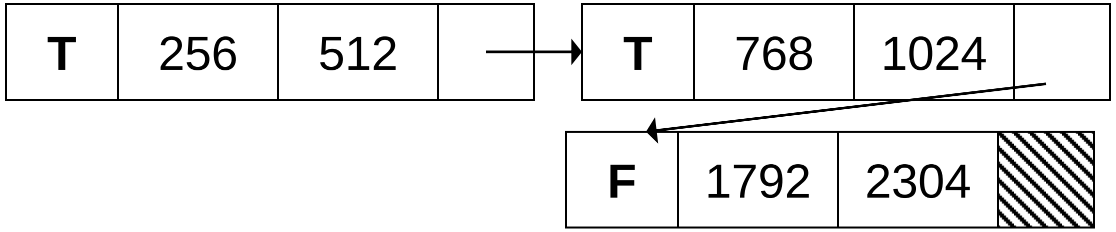
# Dynamic Partitioning in Action: Example

- OS maintains a linked list for partition info
  - First-Fit algorithm is used



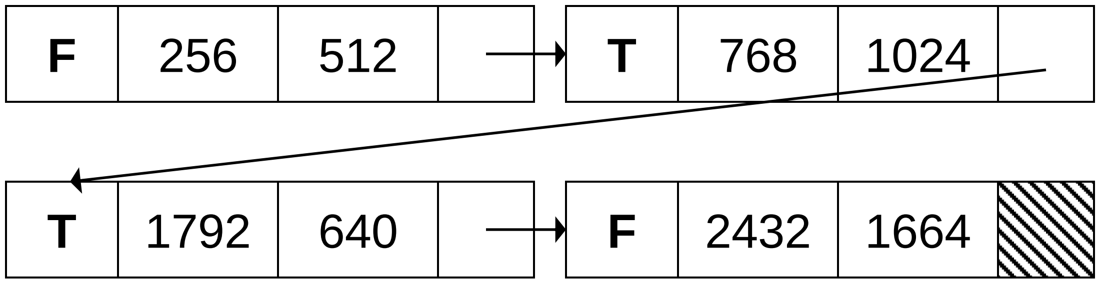
# Dynamic Partitioning in Action: Example

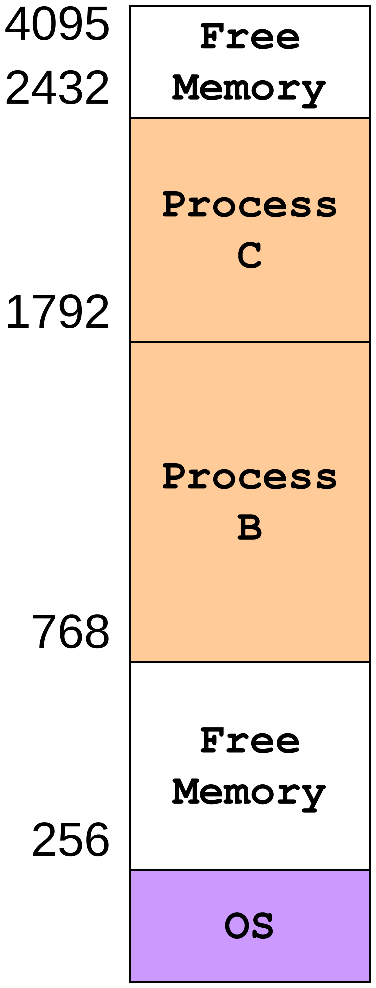
T2 **Request: Process B (size 1024)**




T3 **Free: Process A (not shown)**

T4 **Request: Process C (size 640)**



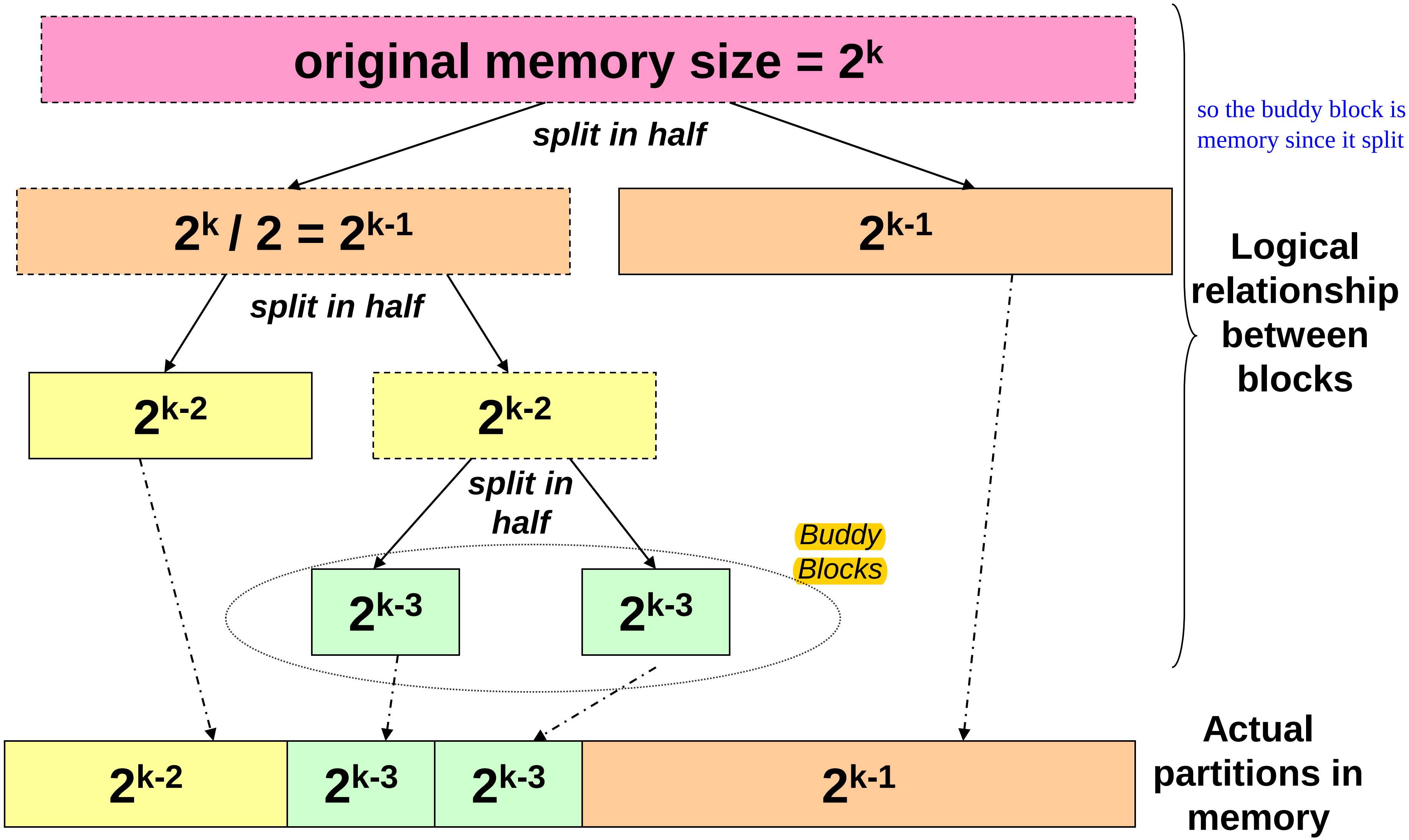

T4

# Dynamic Allocation Algorithm: **Buddy System**

- Buddy memory allocation provides efficient:
  1. Partition splitting
  2. Locating good match of free partition (hole)
  3. Partition de-allocation and coalescing

- Main idea: combining the idea of fixed blocks and dynamic blocks
  - Free block is split into half repeatedly to meet request
    - The two halfs forms a sibling blocks (buddy blocks)
  - When buddy blocks are both free
    - Can be merged to form larger block

# Buddy Blocks Illustration




so the buddy block is not actually in the memory since it split again

# Buddy System: **Implementation**

- Keep an array `A[0..K]`, where $2^K$ is the largest block size that can be allocated
  - Each array element `A[J]` is a linked list which keep tracks of free block(s) of the size $2^J$
  - Each free block is indicated just by the starting address

- In actual implementation, there may be a smallest block size that can be allocated as well
  - A block that is too small is not cost effective to manage
  - We will ignore this in the discussion

Both external and internal fragmentation will exist for buddy system

# Buddy System: **Allocation Algorithm**

allocation has O(1) complexity

- To allocate a block of size **N**:

1. Find the smallest **`S`**, such that $2^S$ **`>= N`**
2. Access **`A[S]`** for a free block
   a. If free block exists:
      - Remove the block from free block list
      - Allocate the block
   b. Else
      - Find the smallest **`R`** from **`S+1`** to **`K`**, such that **`A[R]`** has a free block **`B`**
      - For (**`R-1 to S`**)
        - Repeatedly split **B** → **`A[S...R-1]`** has a new free block
      - Goto Step 2

# Buddy System: **Deallocation Algorithm**

- To free a block **B**:

1. Check in **A[S]** , where $2^S$ **== size of B**
2. If the buddy **C** of **B** exists (also free)
   a. Remove **B** and C from list
   b. Merge **B** and **C** to get a larger block **B'**
   c. Goto step **1**, where **B** ← **B'**
3. Else (buddy of **B** is not free yet)
   - Insert **B** to the list in **A[S]**

deallocation will be O(N)

- since there is a need to find a buddy, this would mean that there is a need to go to each step and check if a free buddy exists.

# Buddy System: **Where is my Buddy?**

- Observe that:
  - Given block address **`A`** is **`xxxx`**`00..00`$_2$
  - Get 2 blocks of half the size after splitting:

    **`B`** `=` **`xxxx0`**`..00`$_2$ and **`C`** `=` **`xxxx1`**`..00`$_2$

- Example:
  - **`A = 0 (000000`$_2$`), size = 32`**
  - After splitting:
    - **`B`** `= 0  (`**`00`**`0000`$_2$`), size = 16`
    - **`C`** `= 16 (`**`01`**`0000`$_2$`), size = 16`

thus in this case they are buddy of size 32
since the 5th bit is complement

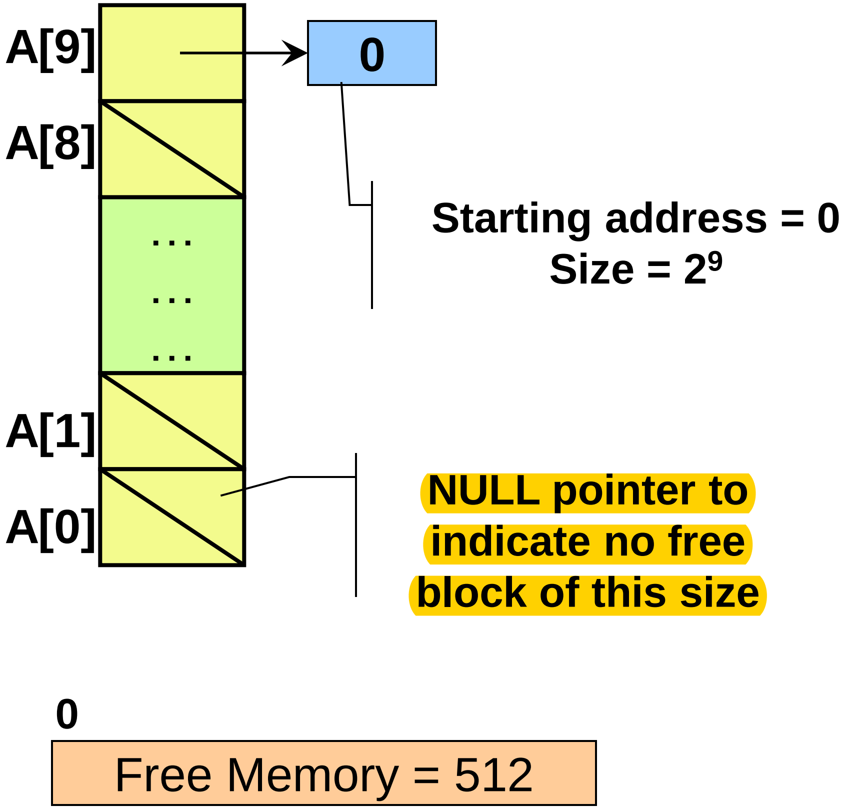
- So, two blocks **`B`** and **`C`** are buddy of size 2^**`S`**, if
  - The **`S`**th bit of **`B`** and **`C`** is a complement
  - The leading bits up to **`S`**th bit of **`B`** and **`C`** are the same

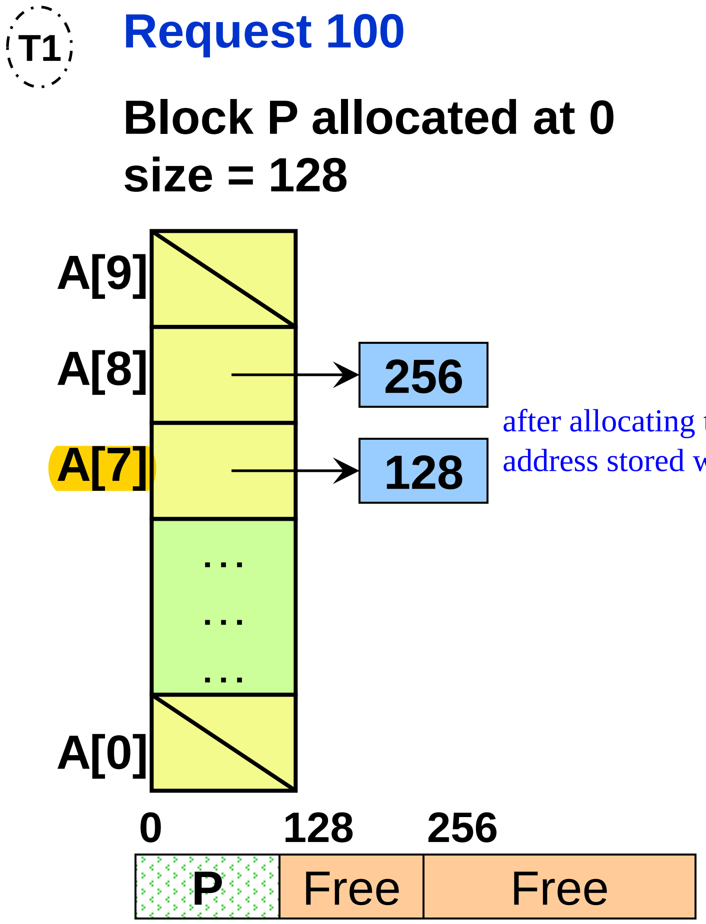
# Buddy System: Example

- Assume:
  - The largest block is 512 ($2^9$)
  - Only one free block of size 512 initially

using array as a data structure
- the array index will indicate the size of that block
- each array index will hold a linked list

A[9] will hold $2^9$ size
A[7] will hold $2^7$ size



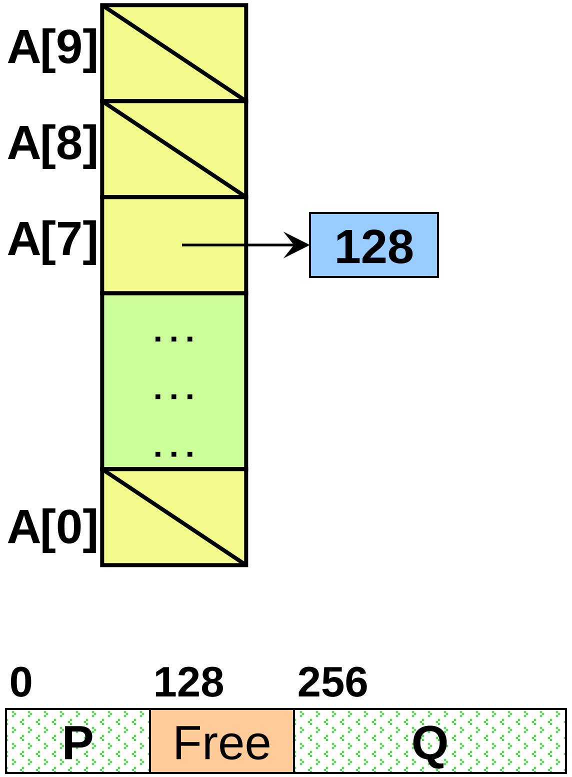




after allocating the required memory space, the starting address stored will only be for those free blocks

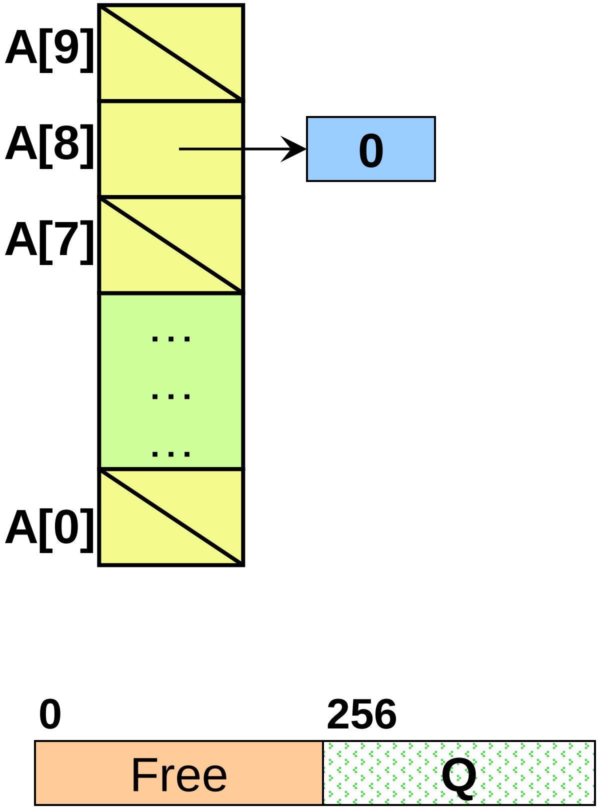
# Buddy System: Example (cont)

T2 **Request 250**

**Block Q allocated at 256**
**size = 256**




T3 **Free Block P**



# Summary

- Relationship between:
  - OS, Process and Memory

- Why memory abstraction is needed
  - The advantage of using logical address

- By assuming process uses contiguous memory:
  - Various partition schemes are discussed