Memory Management

Memory Abstraction

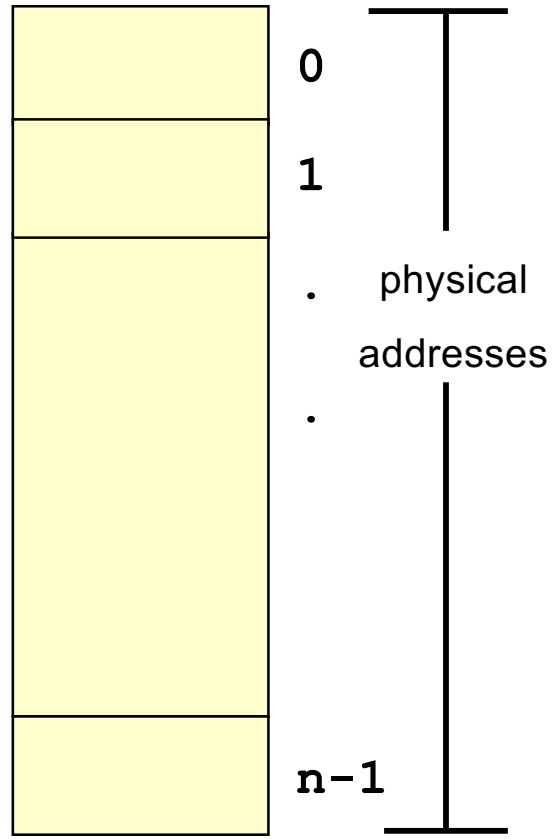
Lecture 7

Overview

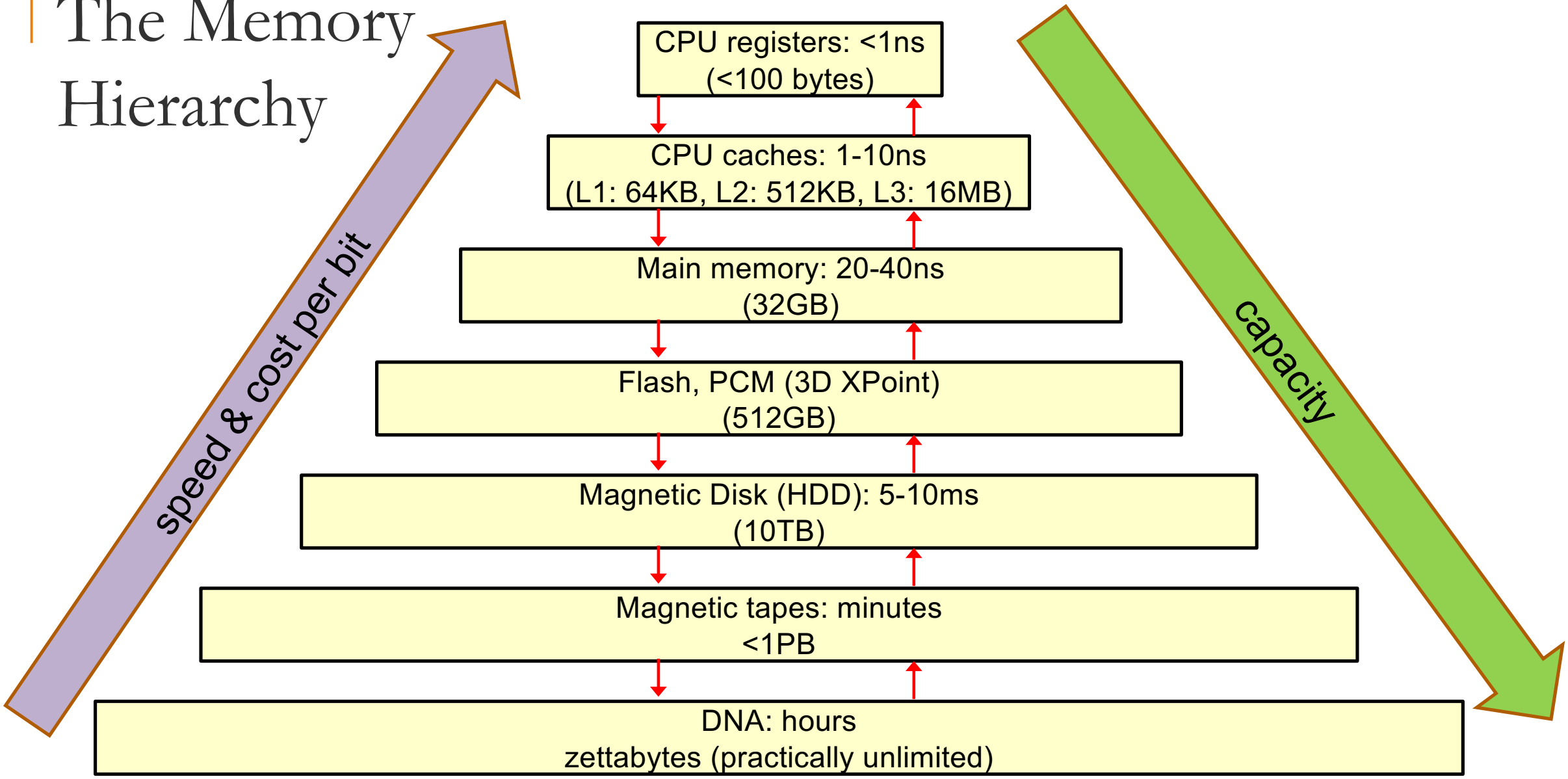
- Basic of Memory:
  - Hardware
  - Memory usage of process
  - Role of OS
- Memory abstractions:
  - Physical address
  - Logical address
- Contiguous Memory Allocation:
  - Fixed Size Partition
  - Variable Size Partition

Memory Hardware

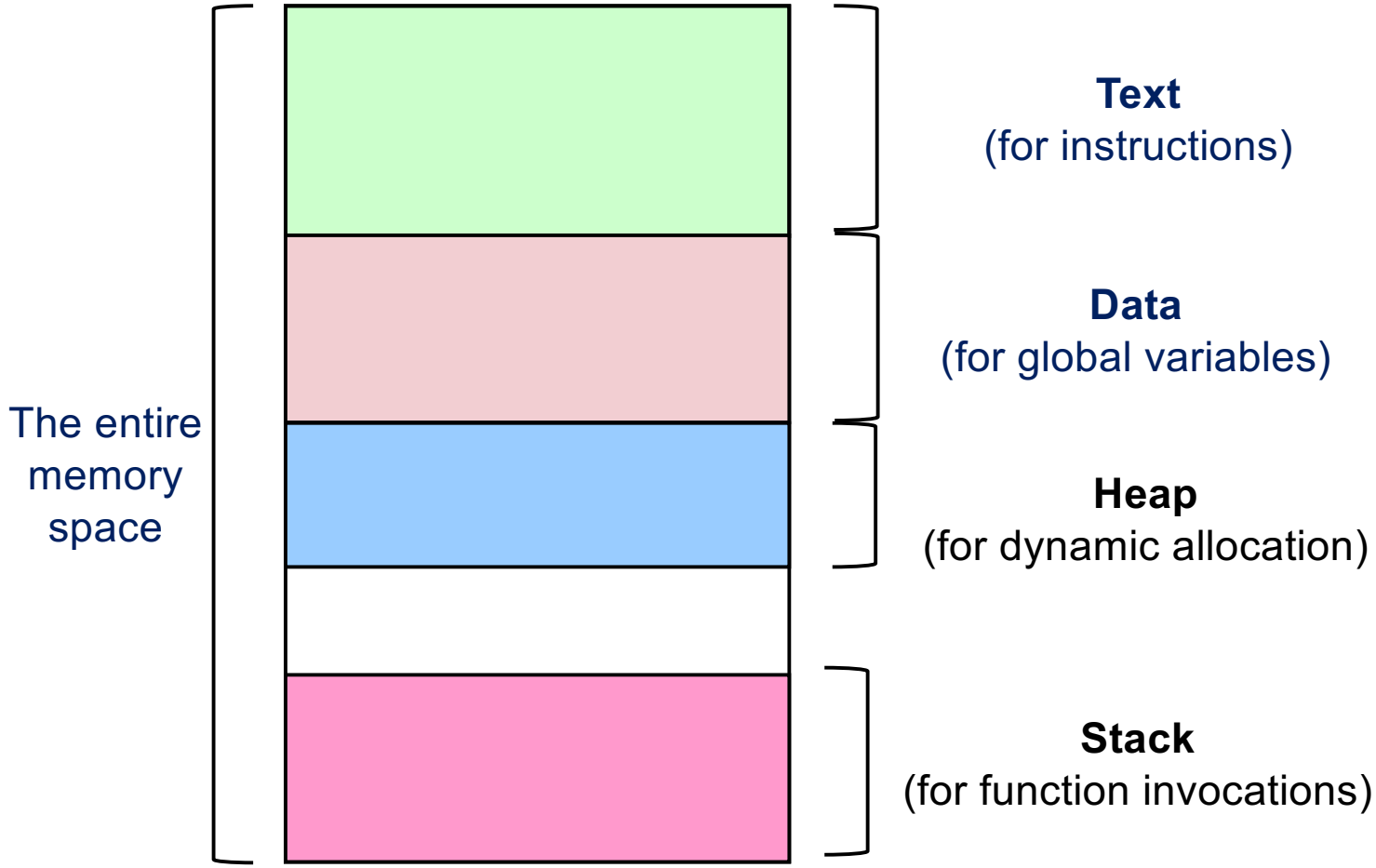
- Physical memory storage:
  - Random Access Memory (RAM)
  - Can be treated as an array of bytes
  - Each byte has a unique index
    - Known as **physical address**
- A contiguous memory region:
  - An interval of consecutive addresses



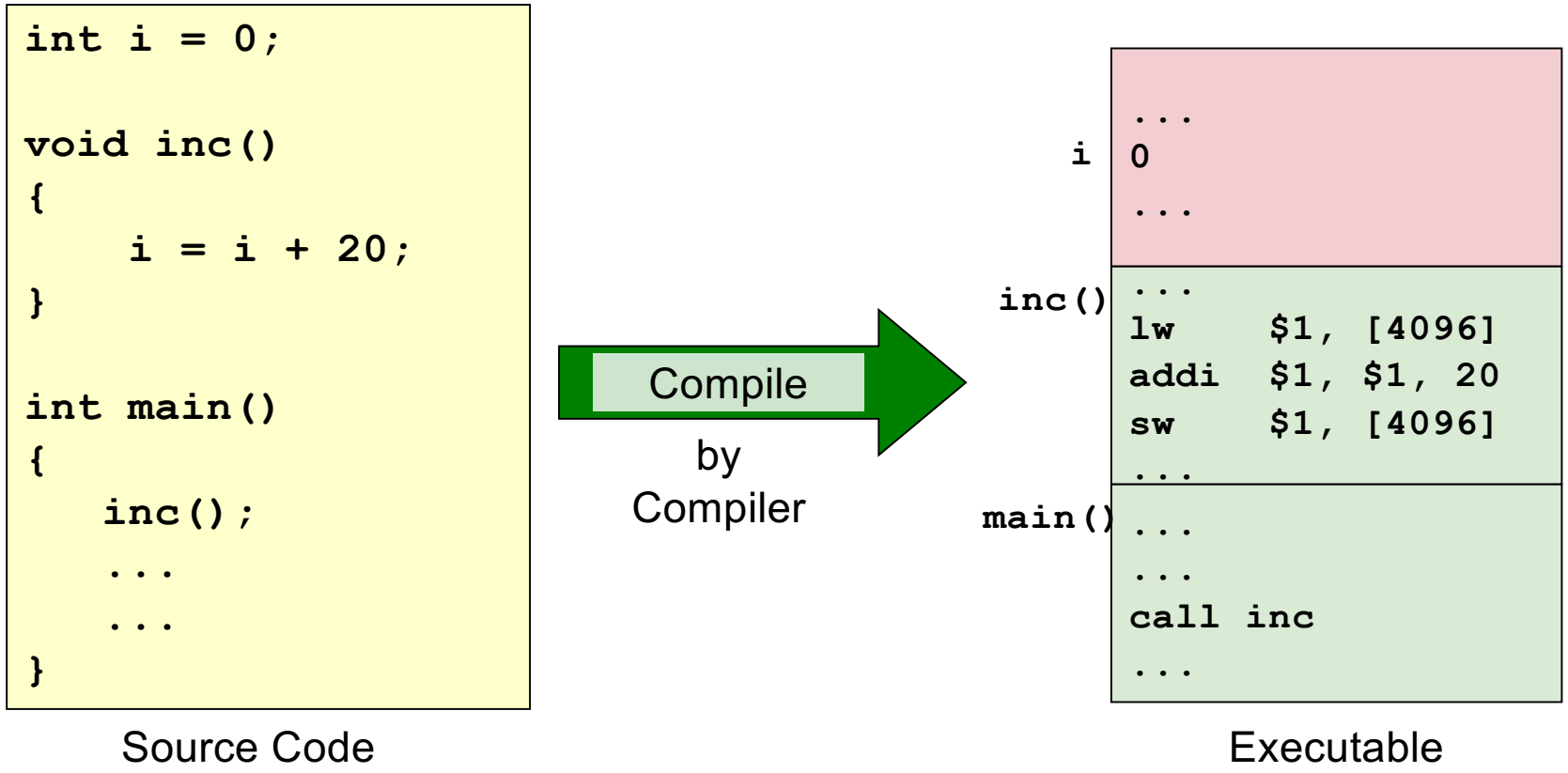
The Memory Hierarchy



Recap: Memory Usage of Process

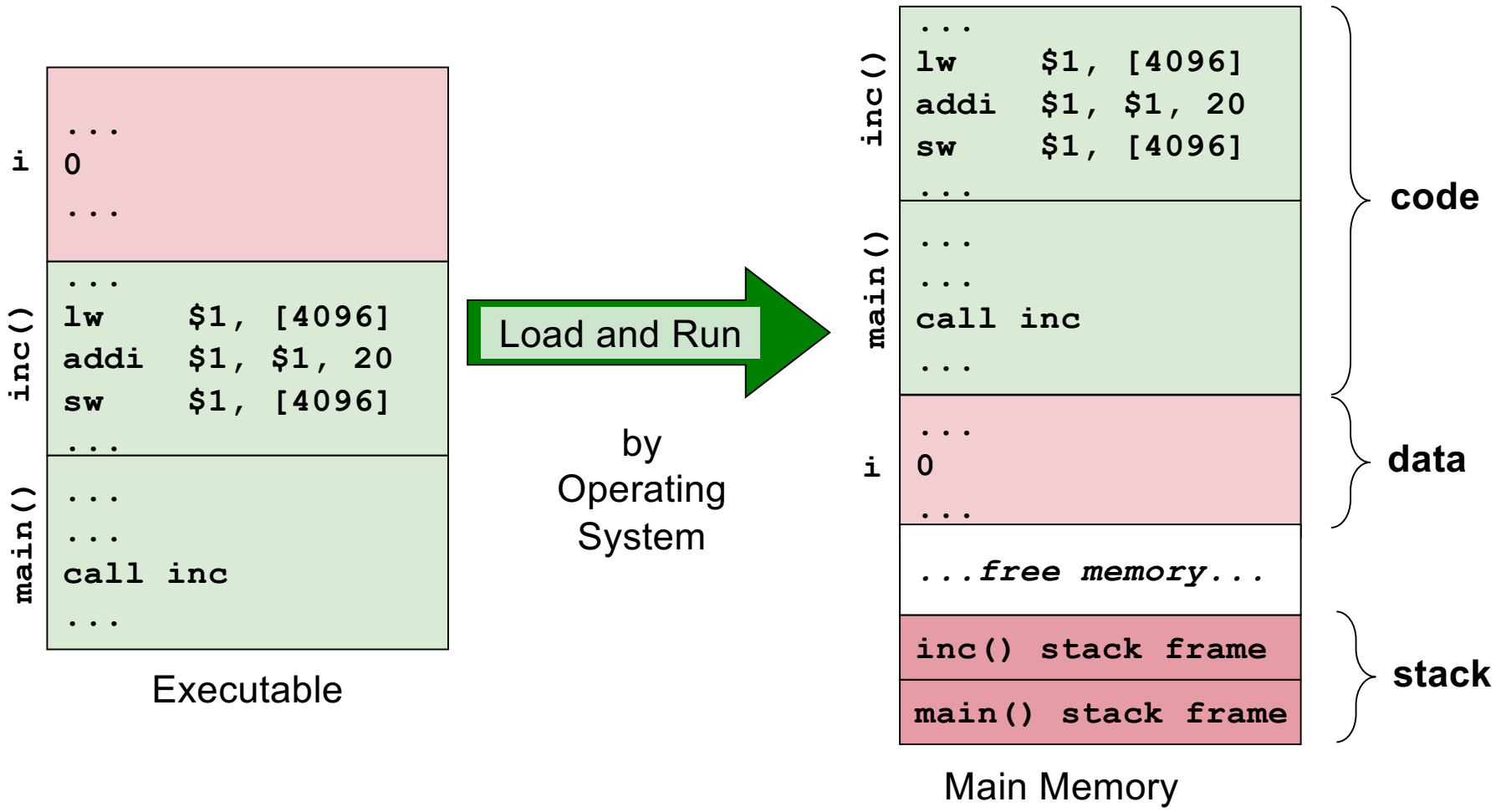


Binding of Memory Address



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

Actual Execution



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. parameter, local variable
  - **Persistent** Data:
    - Valid for the duration of the program unless explicitly removed (if applicable)
    - e.g. global variable, constant variable, dynamically allocated memory
- 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 process
  - Manage memory space for process
  - Protect memory space of process from each other
  - Provides memory related system calls to process
  - 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!

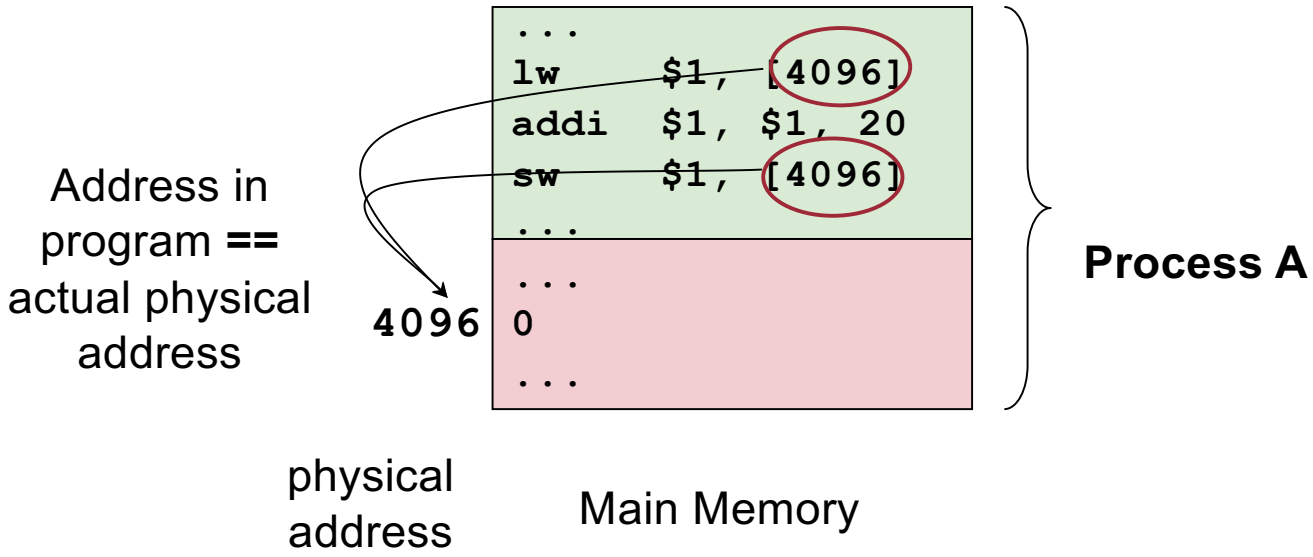
MEMORY ABSTRACTION

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**

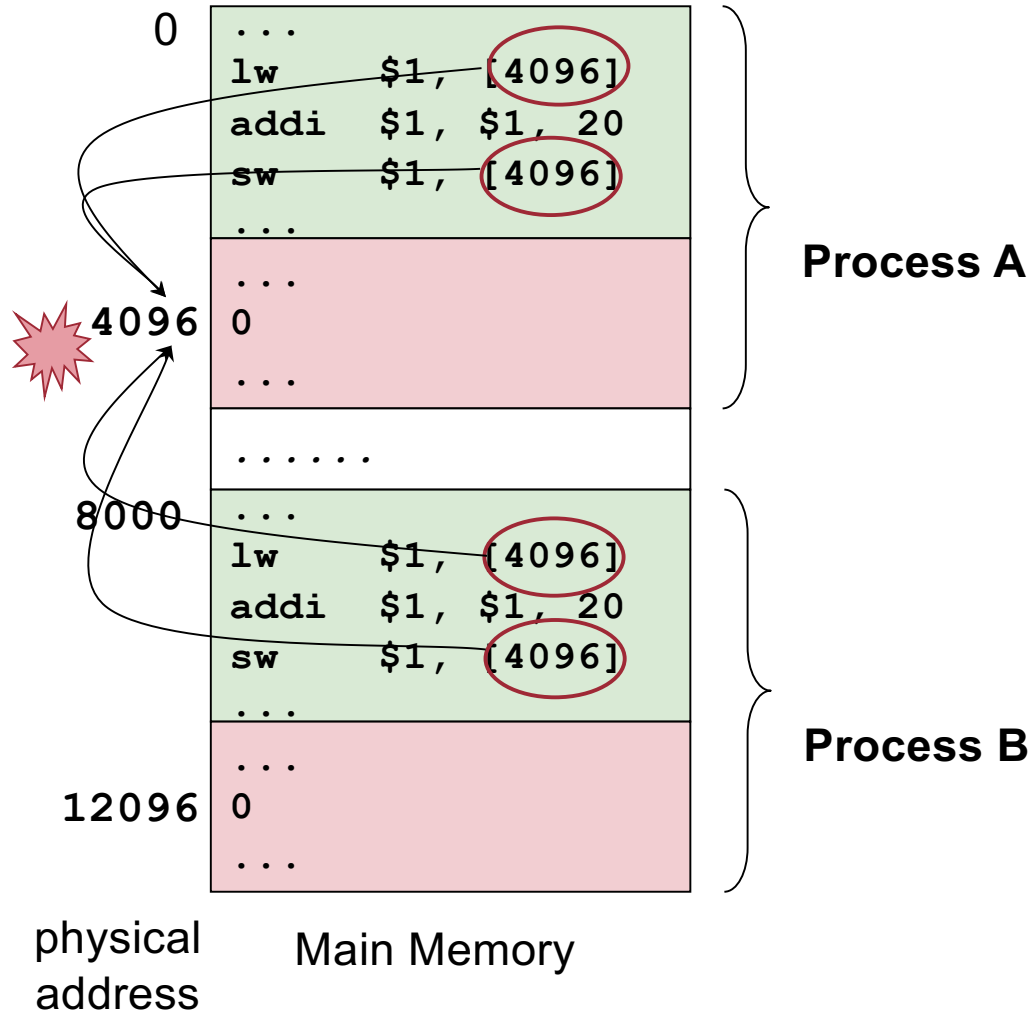


- Memory access is straightforward
  - Address in program == Physical Address
  - No conversion/mapping is required
  - Address fixed during compilation time

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`**

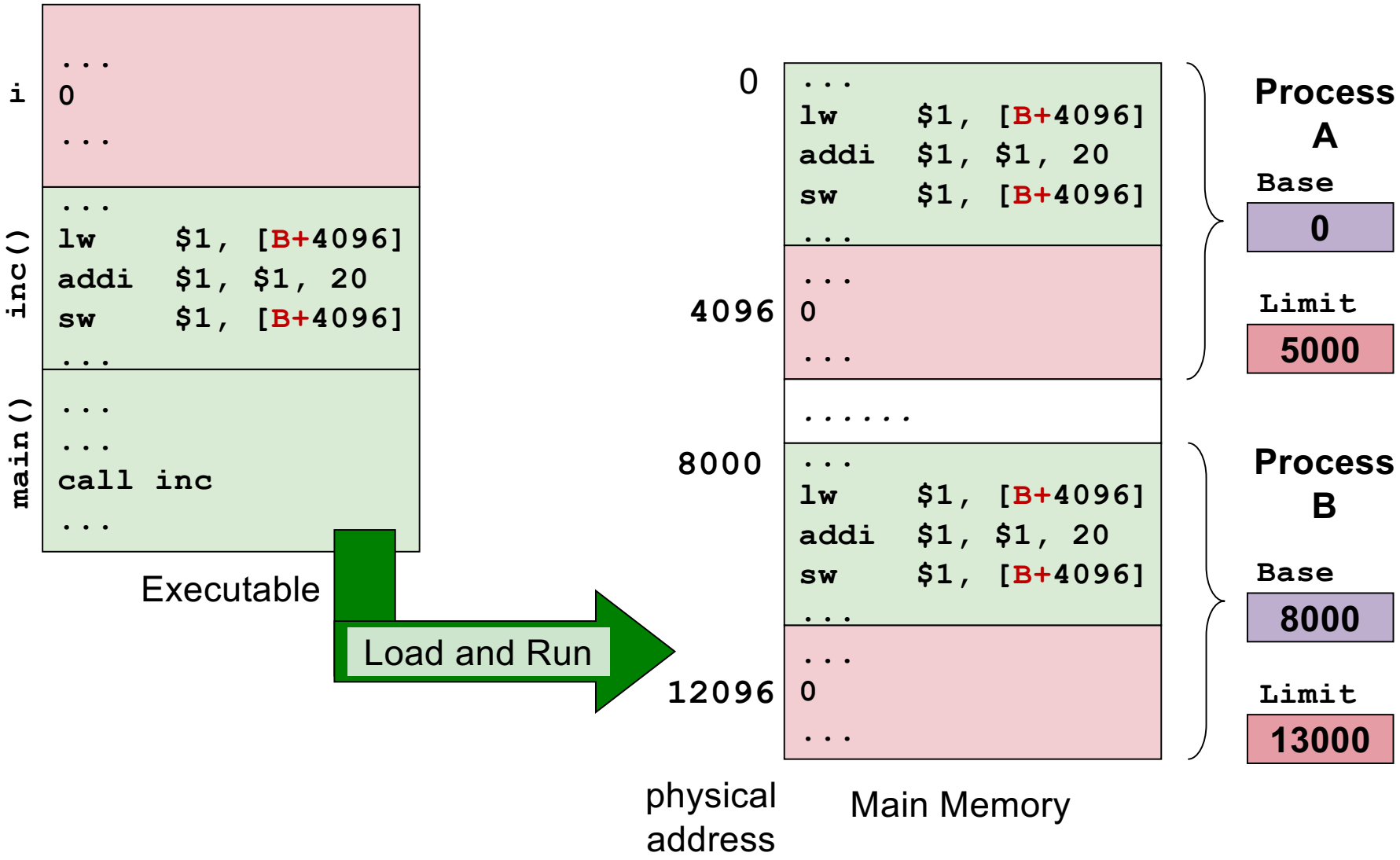
- **Problems:**
  - Slow loading time
  - Not easy to distinguish memory reference from normal integer constant

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:
  - 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 view 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
  - Store Memory concept
  - 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

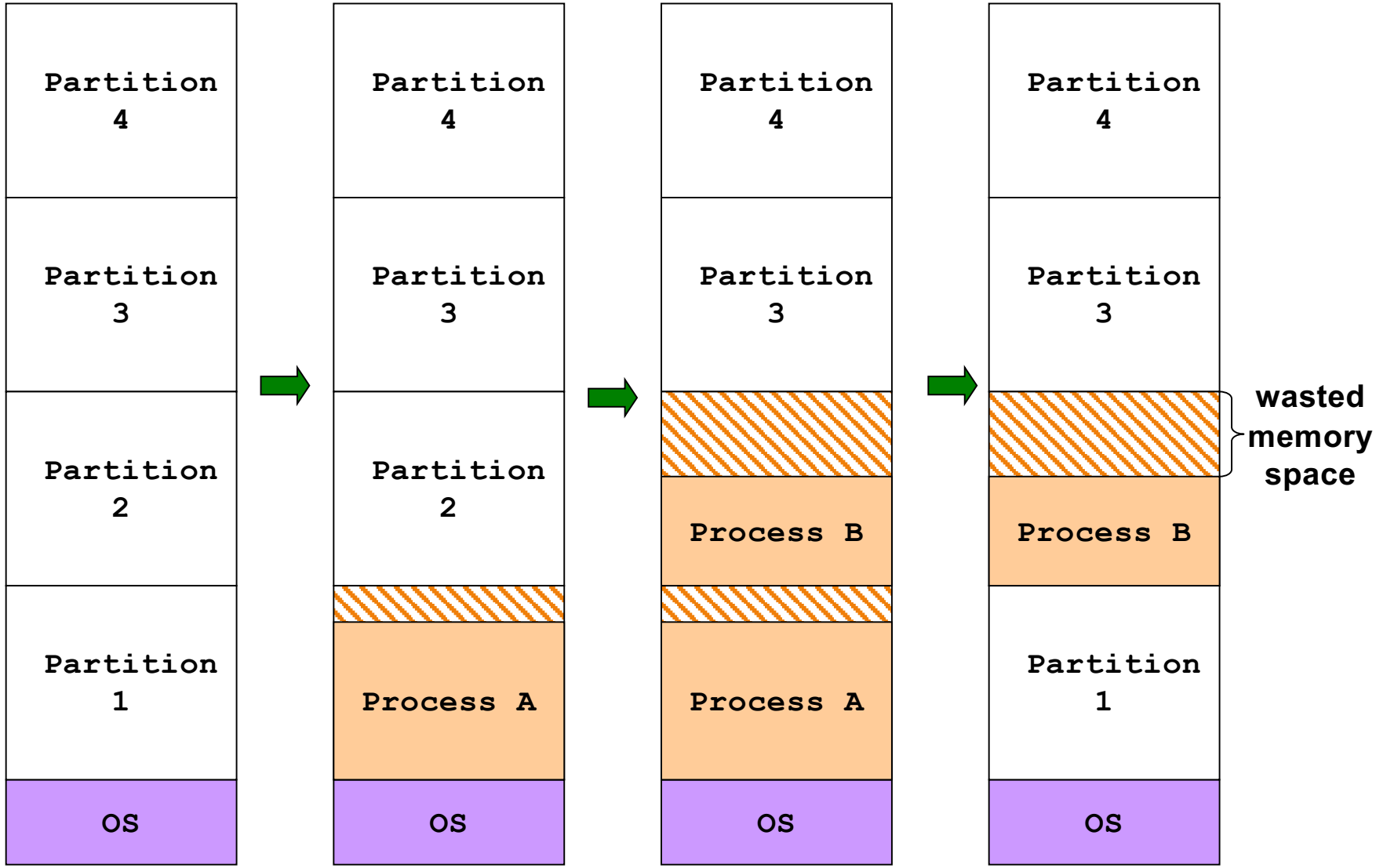
- When the physical memory is full:
  - Free up memory by:
    - Removing terminated process
    - Swapping blocked process to secondary storage

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

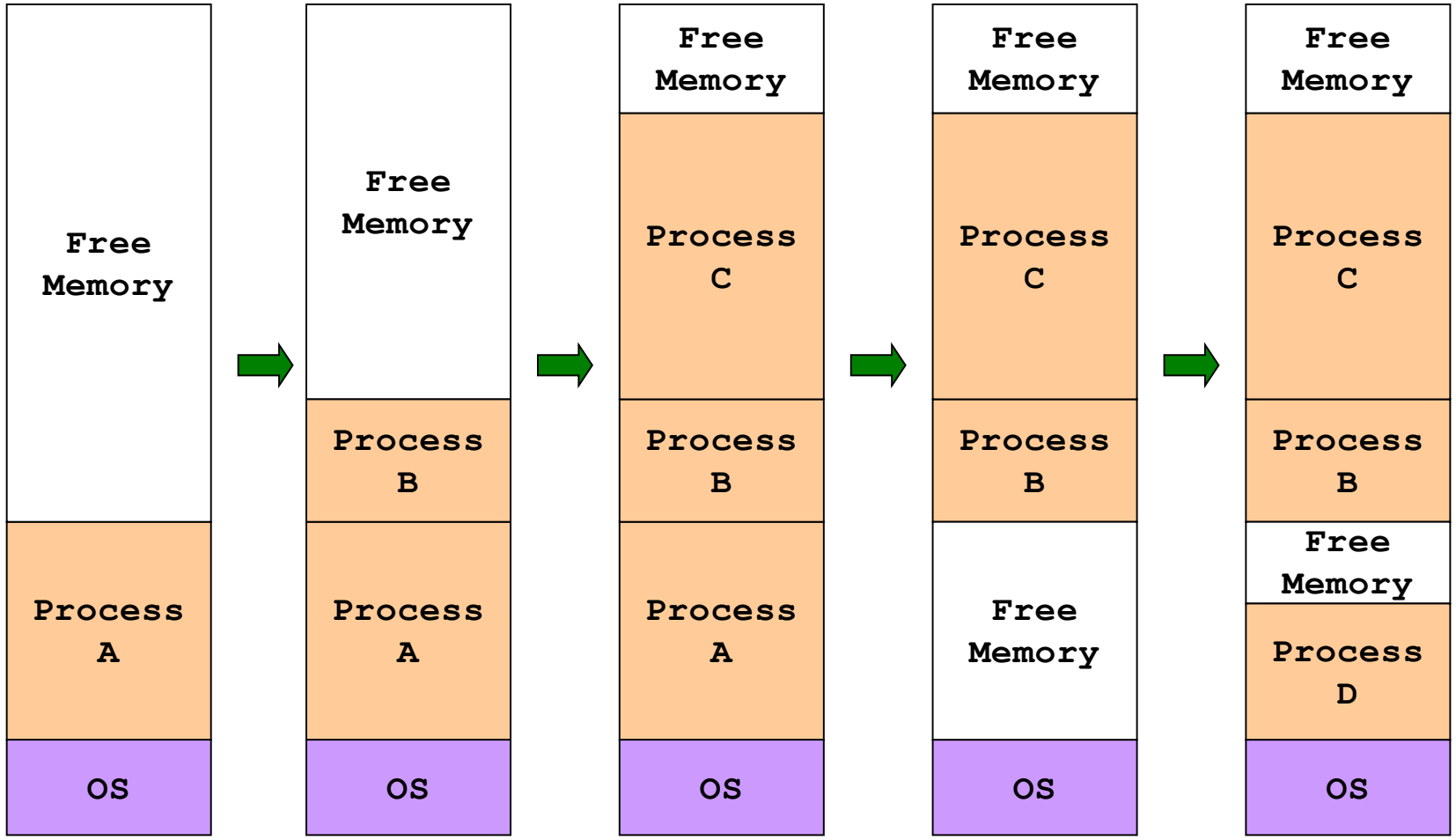
Fixed Partitioning: Illustration



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



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 maintain 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:**
       - 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

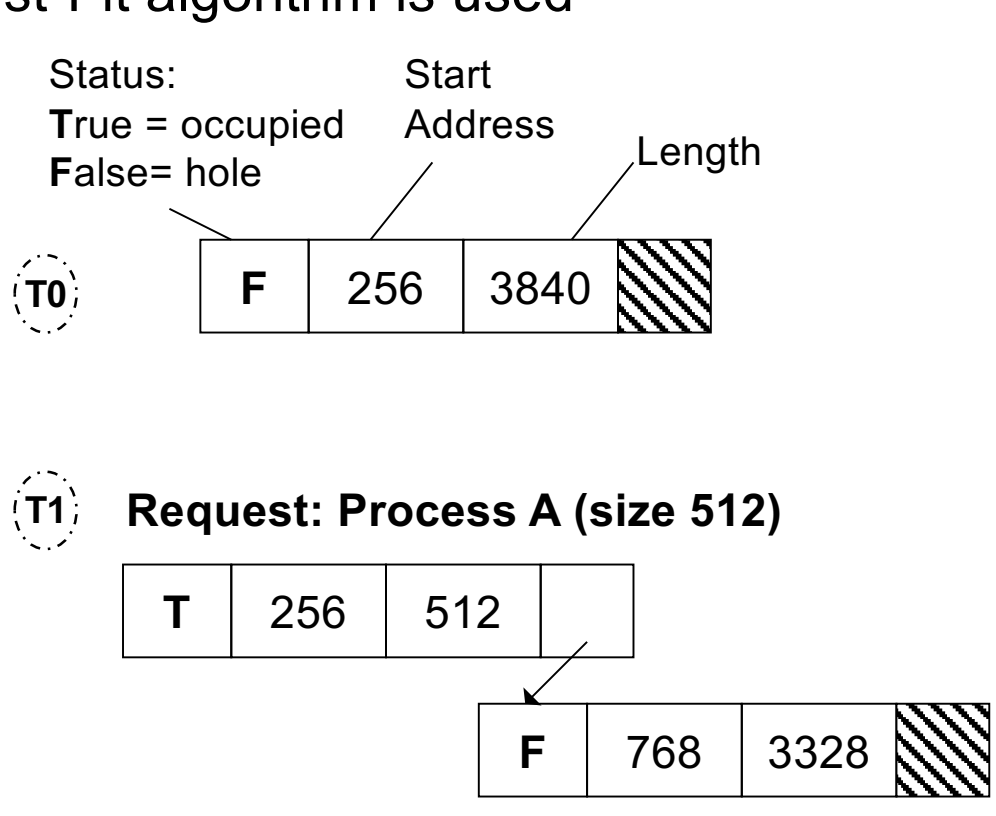
Dynamic Partitioning: Merging and Compaction

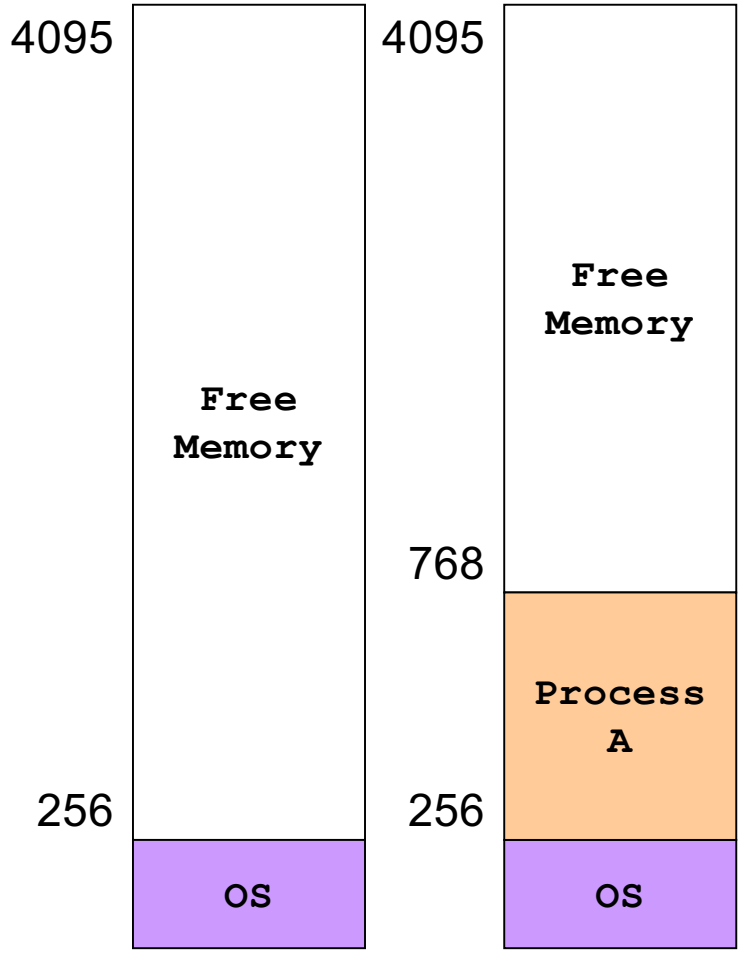
- When an occupied partition is freed:
  - Merge with adjacent hole if possible

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

Dynamic Partitioning in Action: Example

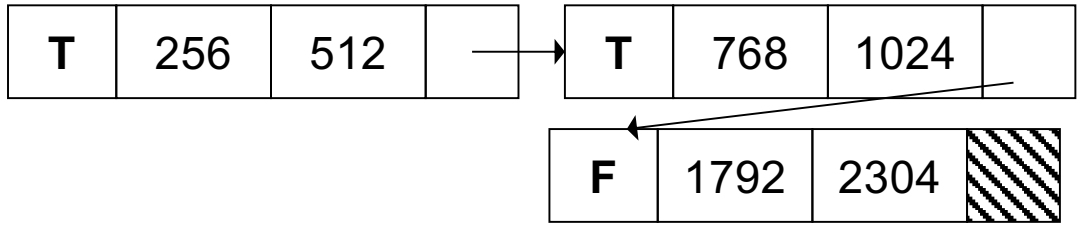
- OS maintains a linked list for partition info
  - First-Fit algorithm is used





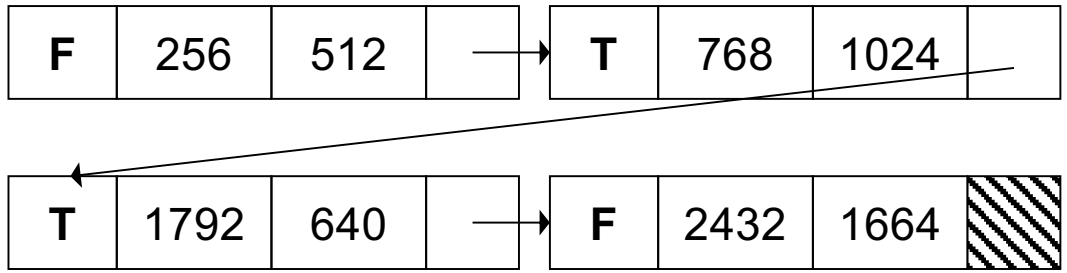
Dynamic Partitioning in Action: Example

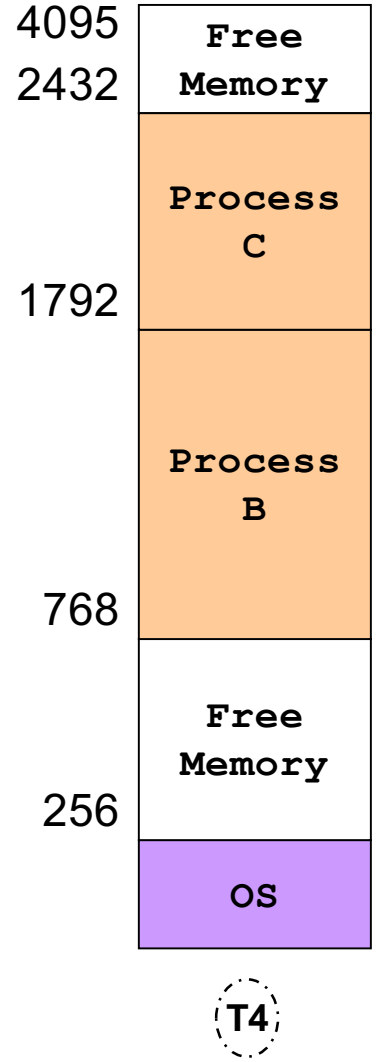
T2 **Request: Process B (size 1024)**



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

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



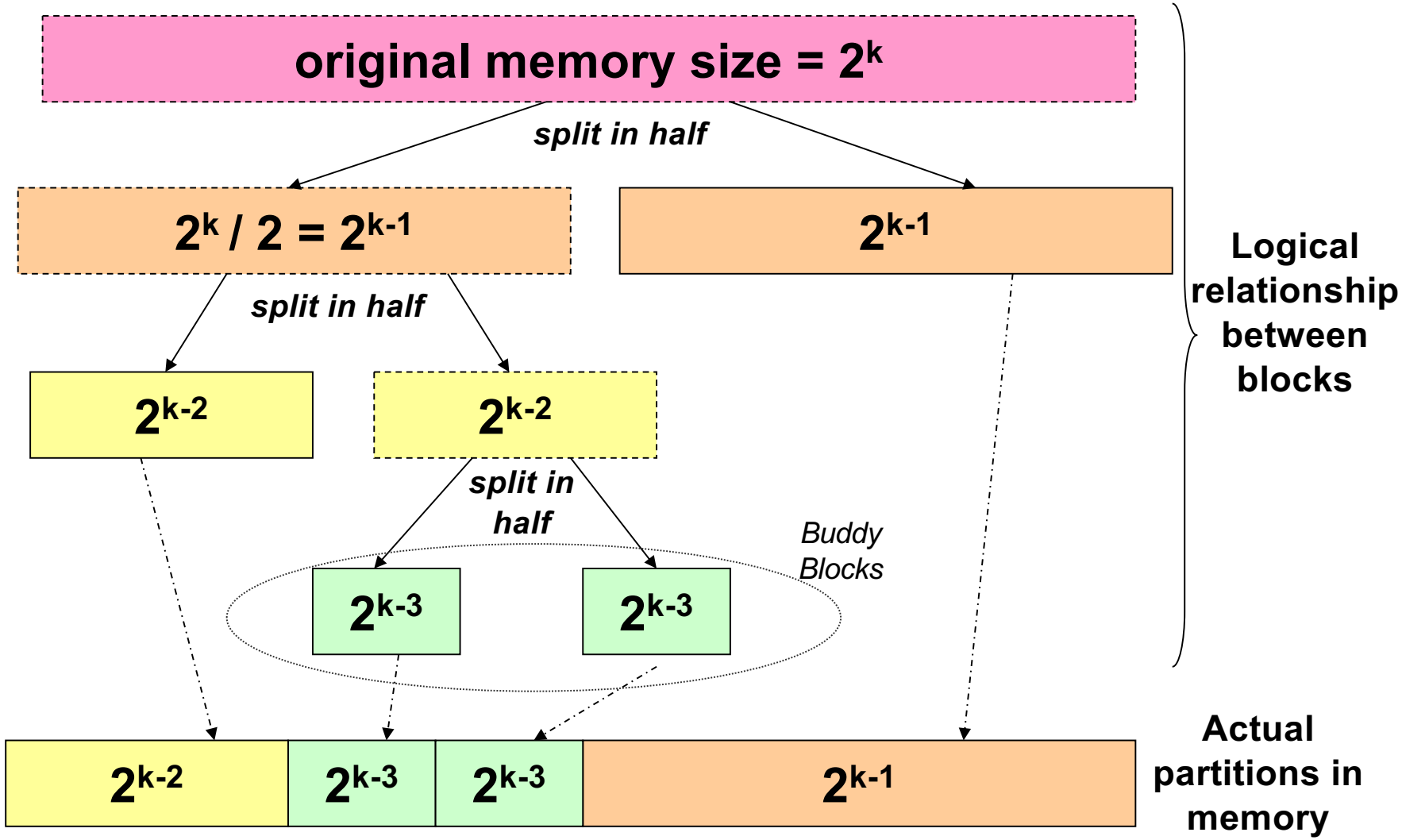


Dynamic Allocation Algorithm: **Buddy System**

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

- Main idea:
  - 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



Buddy System: **Implementation**

- Keep an array **`A[0…K]`**, where 2^K is the largest allocatable block size
  - 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 allocatable block size as well
  - A block that is too small is not cost effective to manage
  - We will ignore this in the discussion

Buddy System: **Allocation Algorithm**

- 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**:

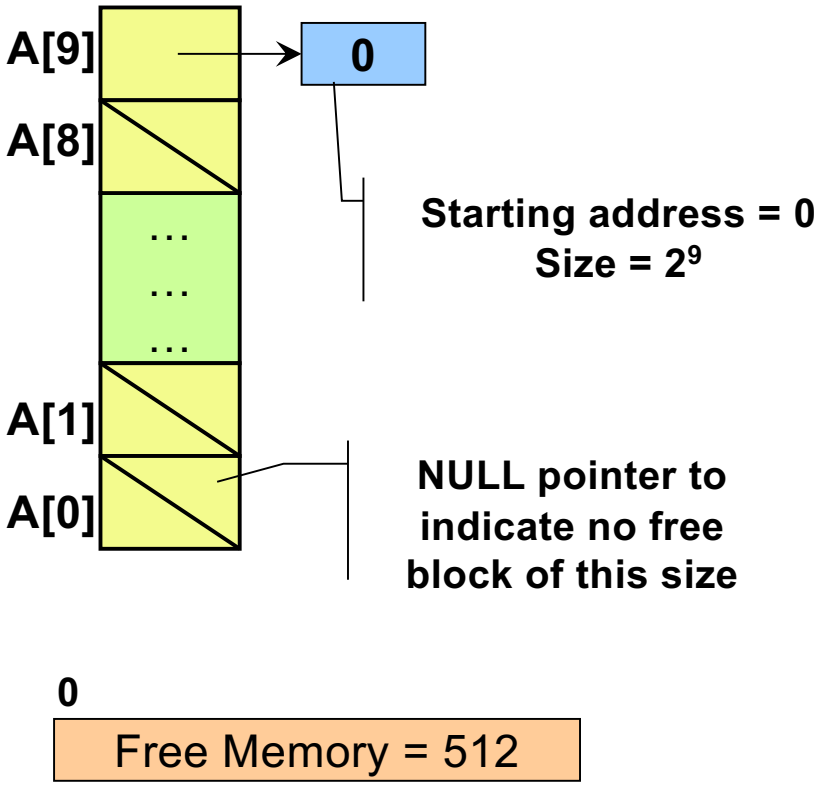
1. Check in **A[S]** , where **2^s == size of B**
2. If the buddy **C** of **B** exists (also free)
   a. Remove **B** and C from list
   b. Merge **B** and **C** to get a larger block **B'**
   c. Goto step **1**, where **B ← B'**
3. Else (buddy of **B** is not free yet)
   - Insert **B** to the list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

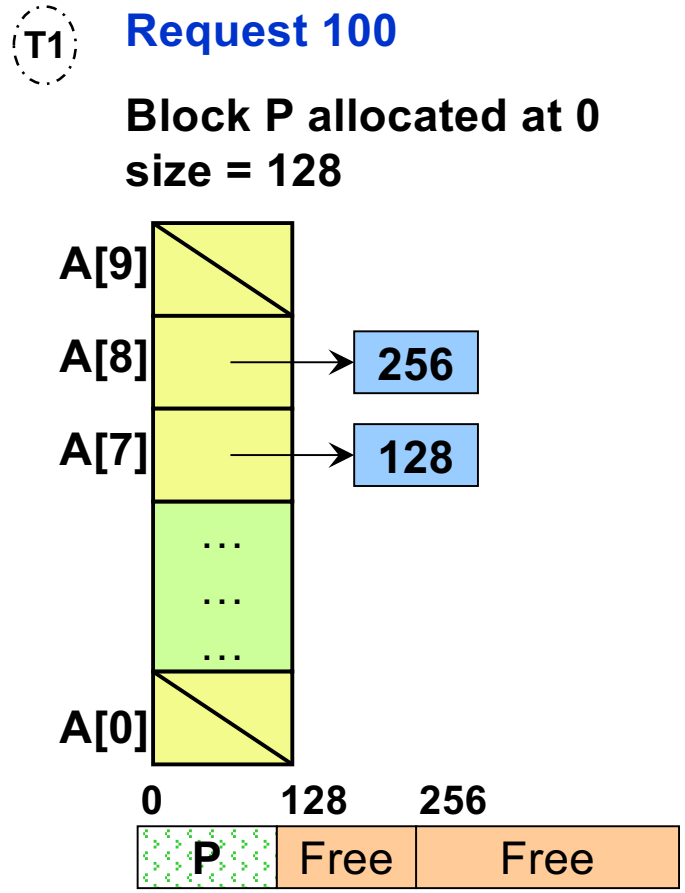
Buddy System: **Where is my Buddy?**

- Observe that:
  - Given block address **A** is **xxxx**00..00_2
  - Get 2 blocks of half the size after splitting:
    B = **xxxxx**0..00_2 and **C** = **xxxxx**1..00_2
- Example:
  - **A = 0 (000000_2), size = 32**
  - After splitting:
    - **B** = 0 (**0**00000_2), size = 16
    - **C** = 16 (**01**0000_2), size = 16
- 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

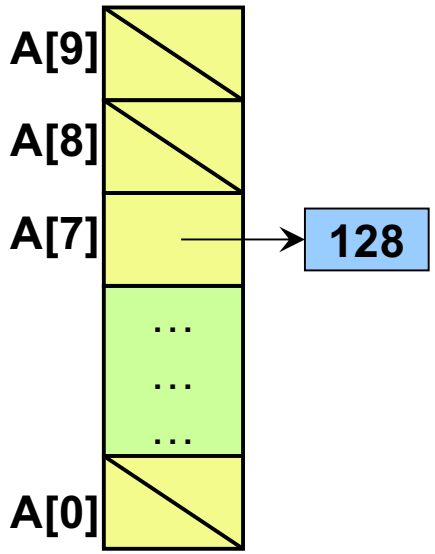


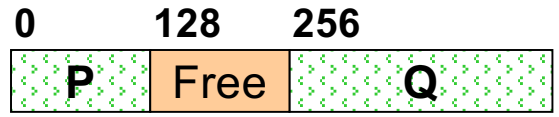


Buddy System: Example (cont)

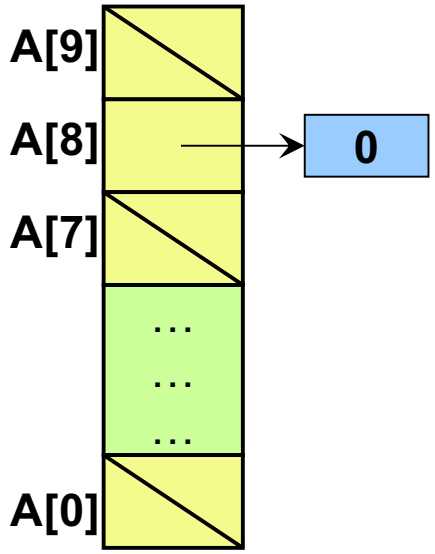
T2 **Request 250**

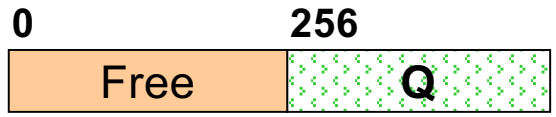
Block Q allocated at 0
size = 128





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