CS-3013 — Operating Systems

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CS-3013 — Operating Systems

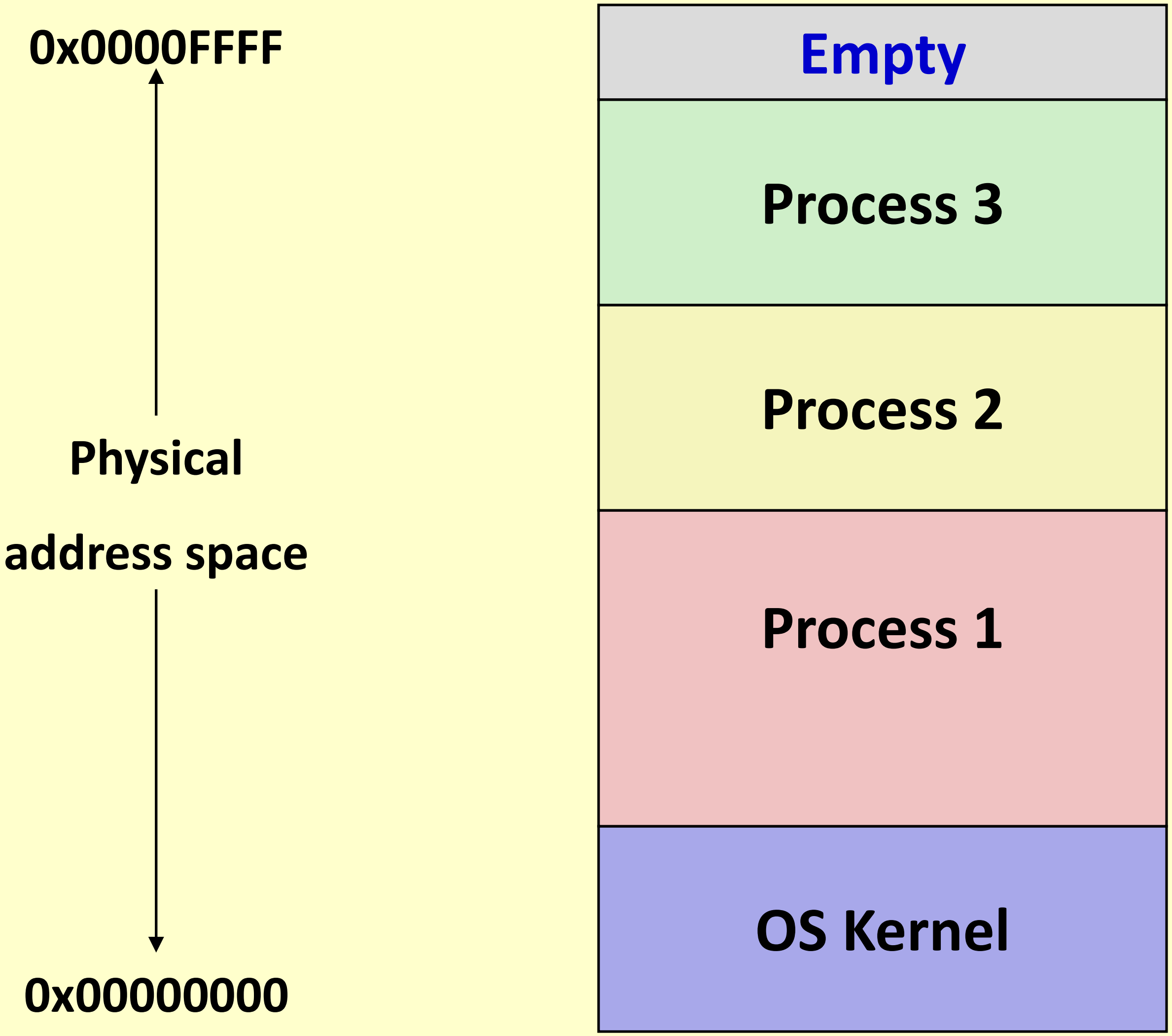
In the beginning (prehistory)…

- **Single usage (or batch processing) systems**
  - One program loaded in physical memory at a time
  - Runs to completion
- **If job larger than physical memory, use *overlays***
  - Identify sections of program that
    - Can run to a result
    - Can fit into the available memory
  - Add commands after result to load a new section
  - Example: passes of a compiler
  - Example: SAGE – *North American Air Defense System*

Still near the beginning (multi-tasking) …

- **Multiple processes in physical memory at the same time**
  - allows fast switching to a ready process
  - *Partition* physical memory into multiple pieces
    - One partition for each program
  - Some modern operating systems
    - *Real-time* systems
    - Small, dedicated systems (mobile phone, automotive processors, etc.)
- **Partition requirements**
  - *Protection* – keep processes from smashing each other
  - *Fast execution* – memory accesses can't be slowed by protection mechanisms
  - *Fast context switch* – can't take forever to setup mapping of addresses

Physical memory

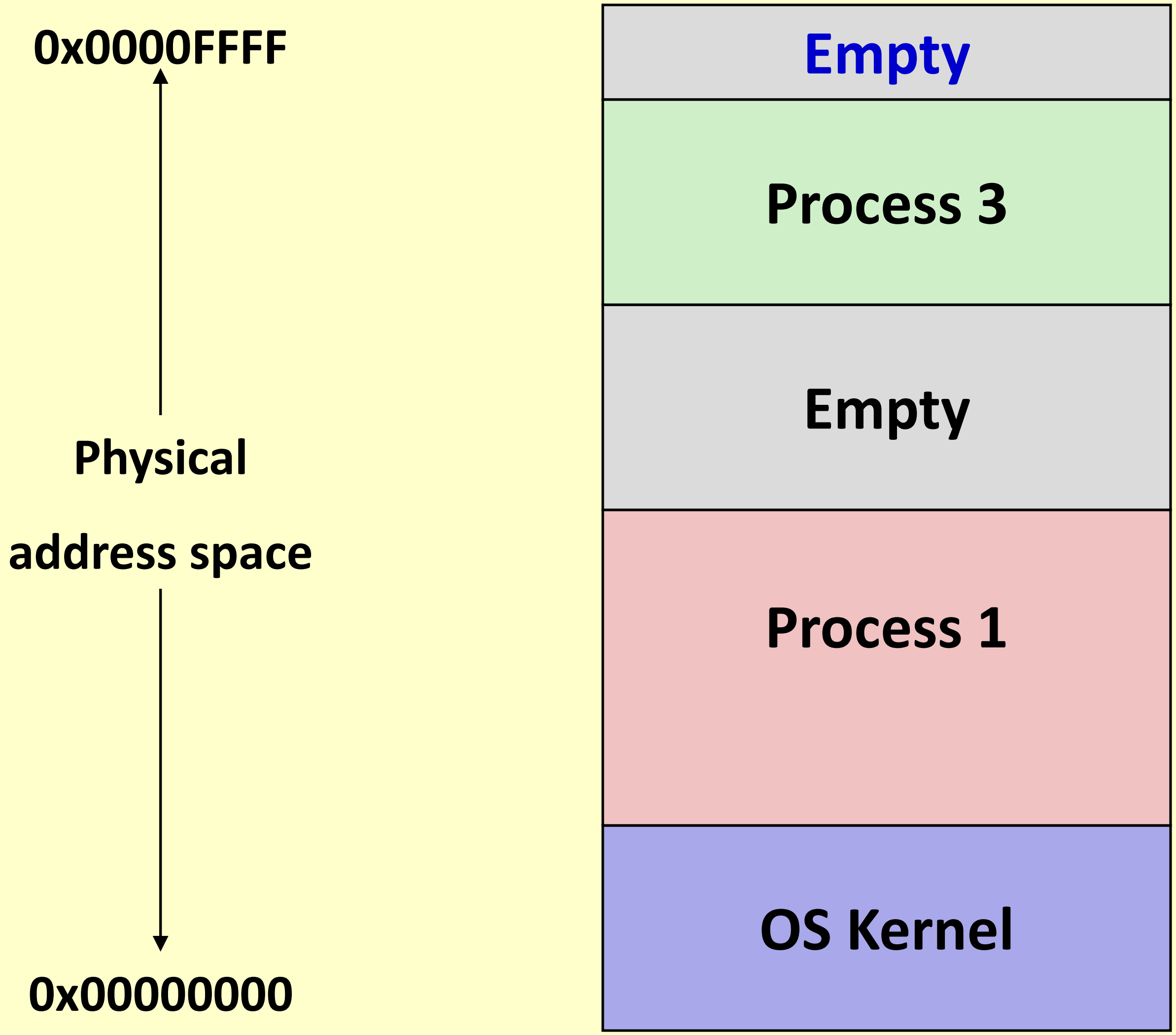


E.g, *OS360*

Loading a process

- **Relocate all addresses relative to start of partition**
  - See *Linking and Loading*
- **Memory protection assigned by OS**
  - Block-by-block to physical memory
  - Base and limit registers
- **Once process starts**
  - Partition cannot be moved in memory
  - *Why?*

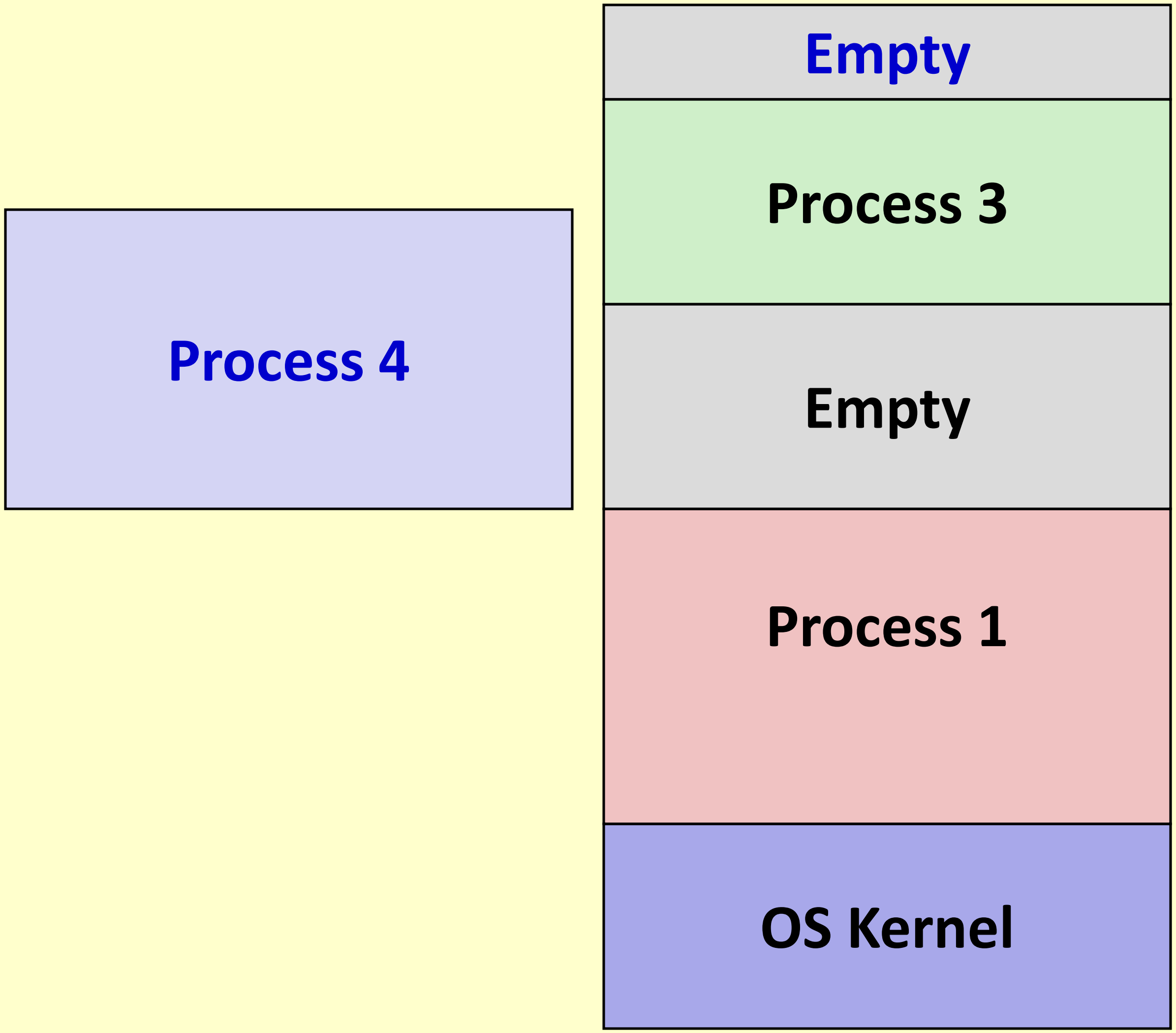
Physical memory – process 2 terminates



Problem

- **What happens when Process 4 comes along and requires space larger than the largest empty partition?**
  - Wait
  - Complex resource allocation problem for OS
  - Potential starvation

Physical memory



Solution

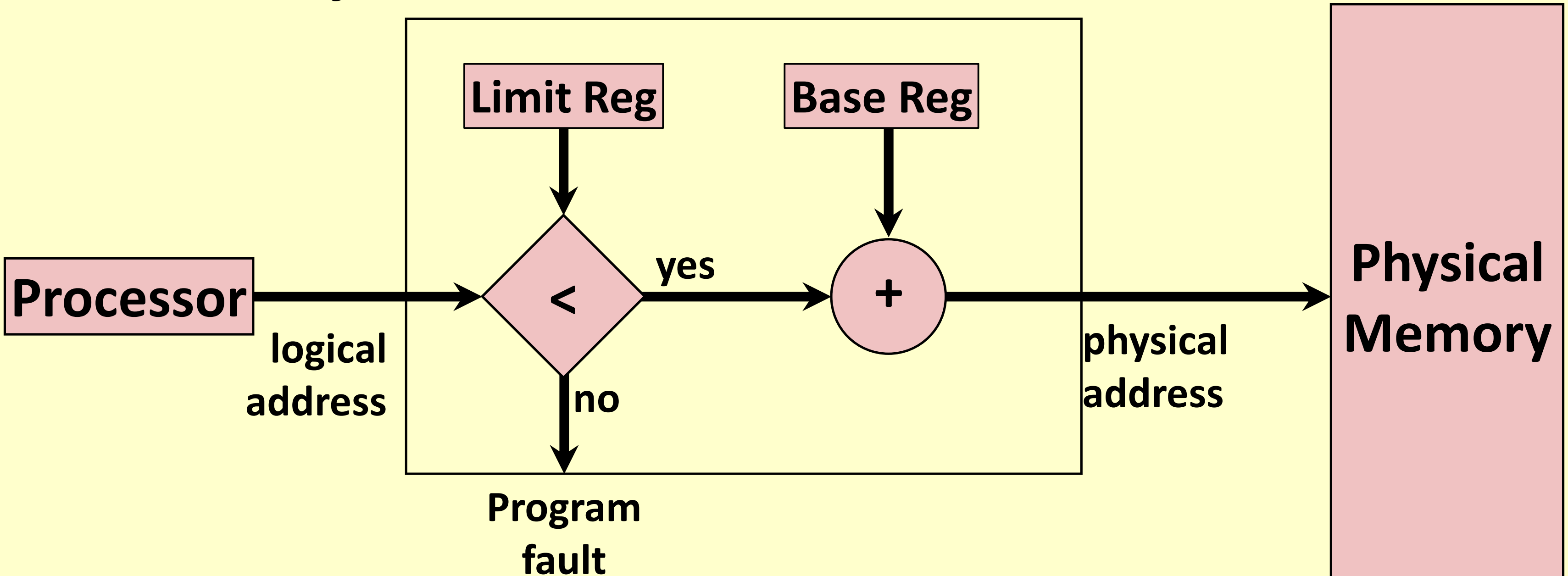
- ***Virtual Address:*** **an address used by the program that is translated by computer into a *physical address* each time it is used**
  - Also called *Logical Address*

- **When the program utters `0x00105C`, …**
- **… the machine accesses `0x01605C`**

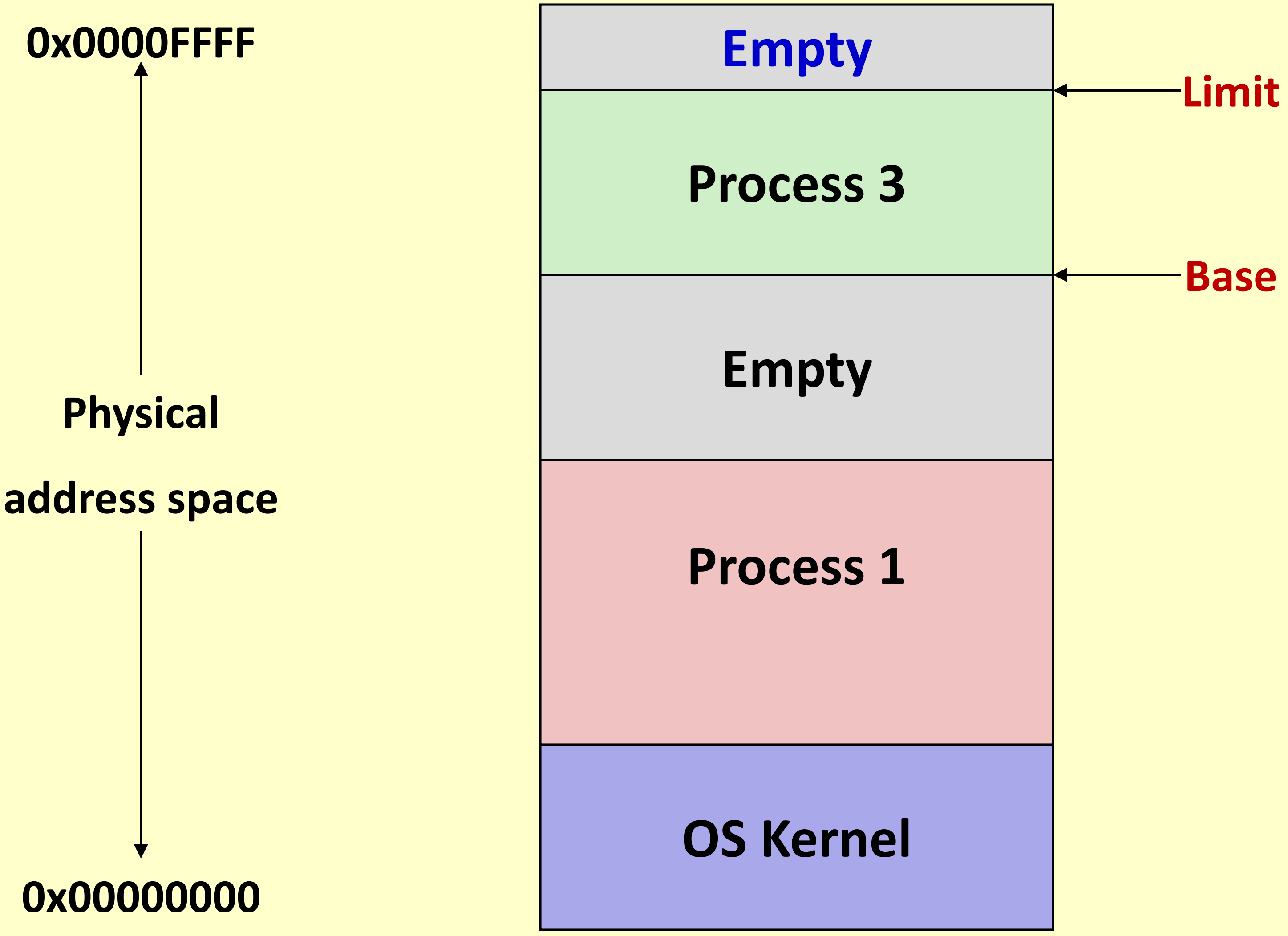
OSTEP §12-15

First implementation

- ***Base*** **and** ***Limit*** **registers**
  - *Limit* is checked on all memory references
  - *Base* is automatically added to all addresses
  - Introduced in minicomputers of early 1970s
- **Loaded by OS at each context switch**



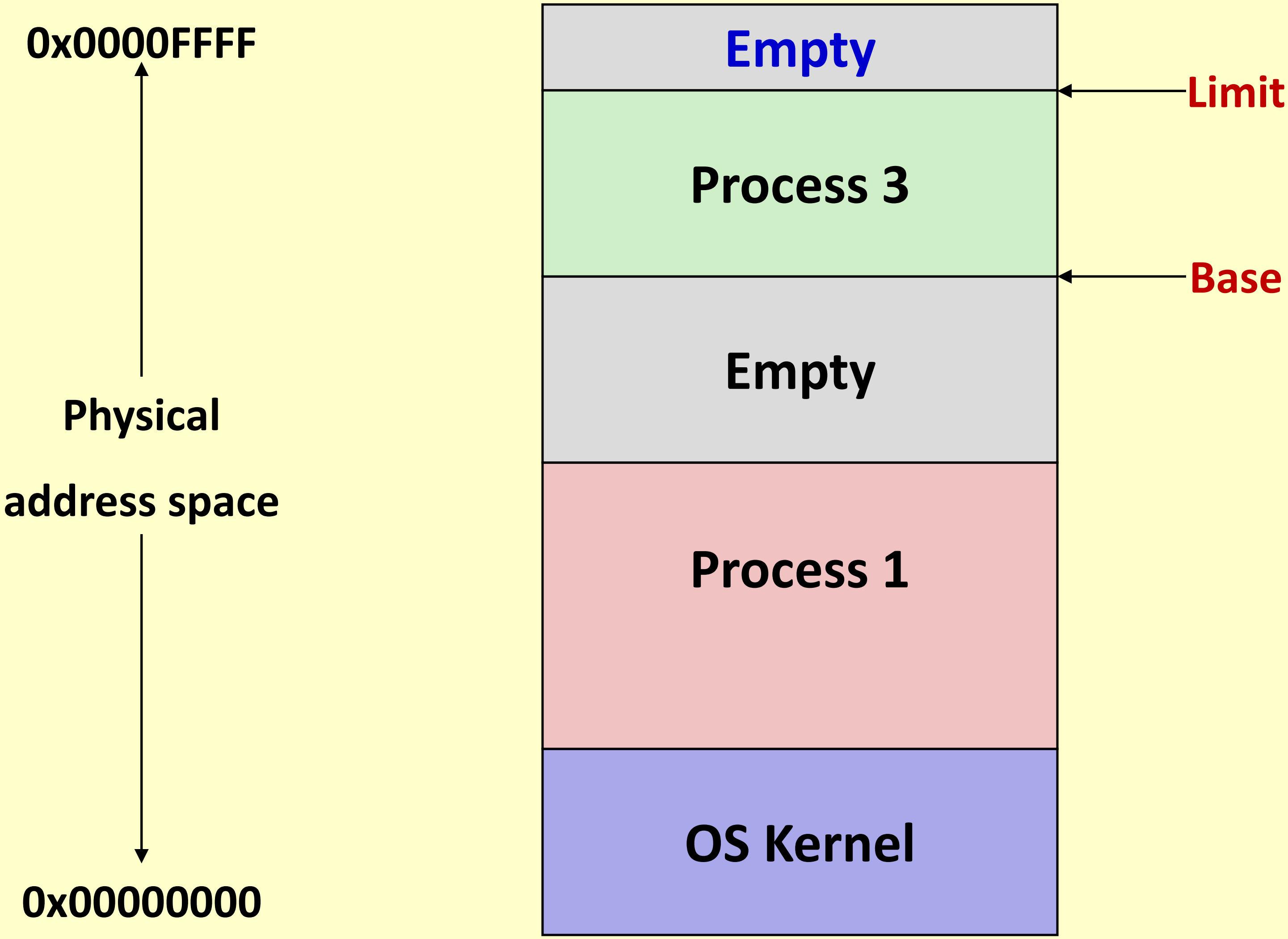
Physical memory



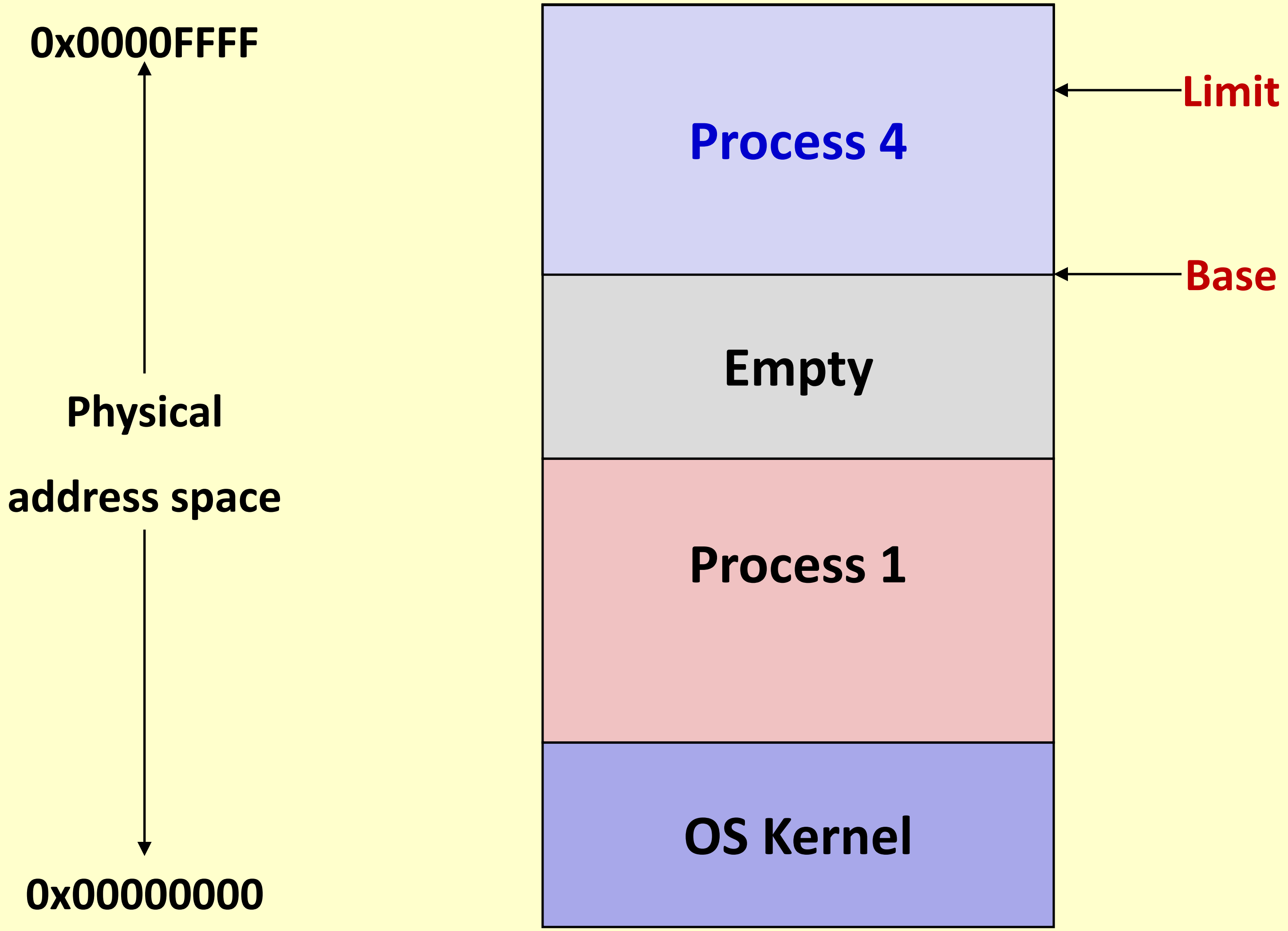
Advantages

- **No relocation of program addresses at load time**
  - All addresses relative to zero!
- **Built-in protection provided by *Limit***
  - No physical protection per page or block
- **Fast execution**
  - Addition and limit check at hardware speeds within each instruction
- **Fast context switch**
  - Need only change base and limit registers
- **Partition can be suspended and moved at any time**
  - Process is unaware of change
  - Potentially expensive for large processes due to copy costs!

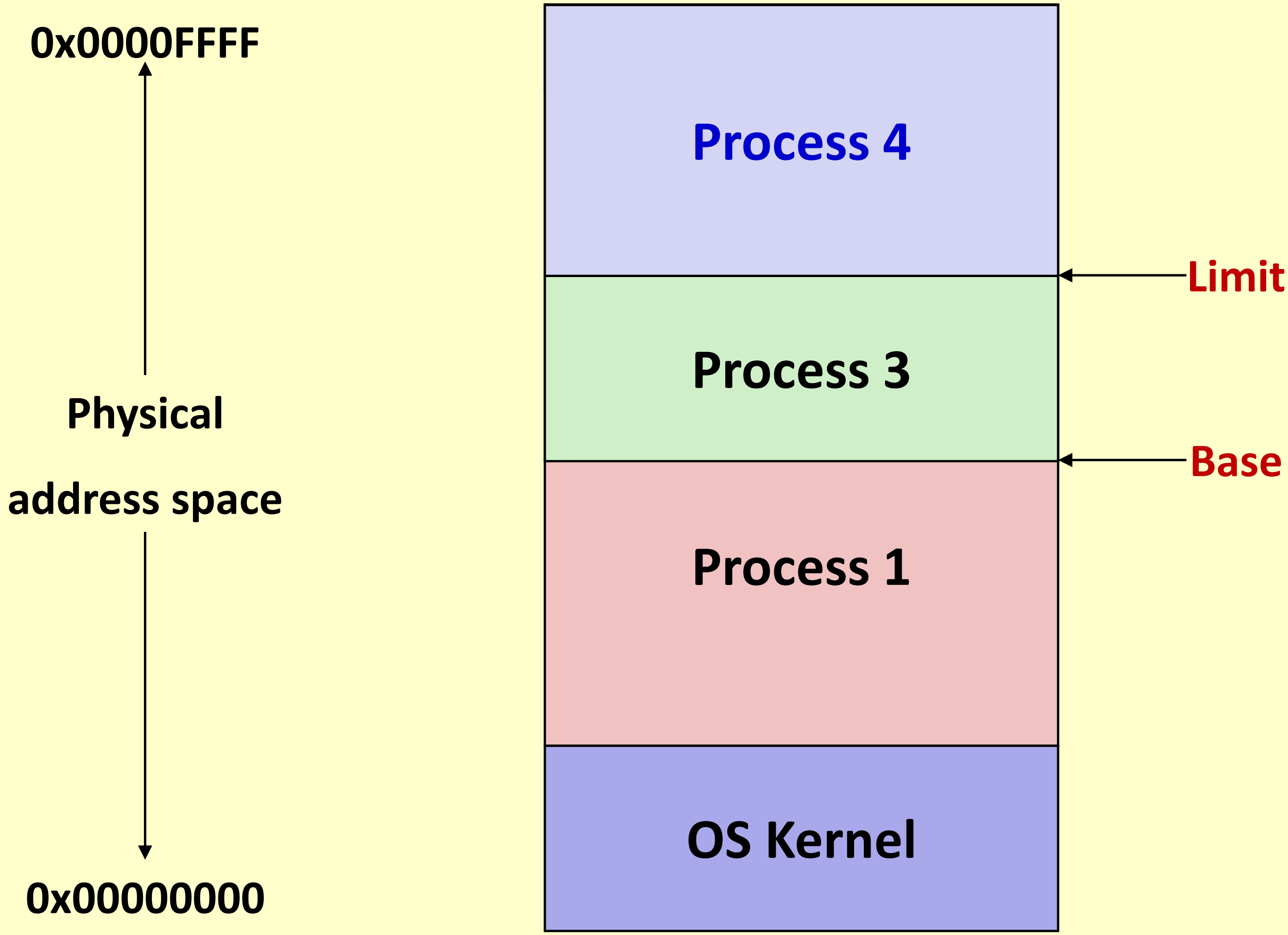
Physical memory



Physical memory



Physical memory

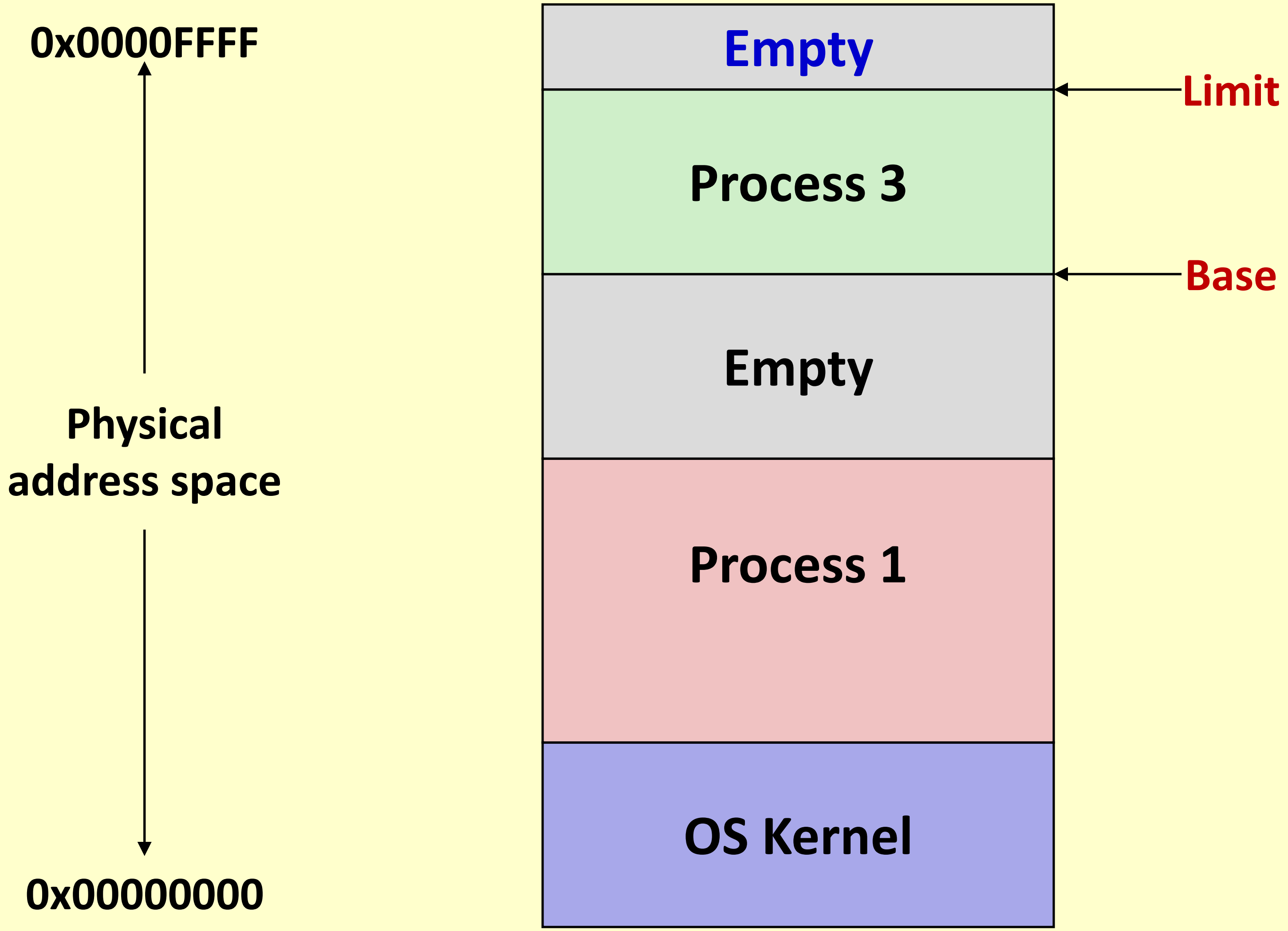


Definition

- ***Virtual Address Space:***
  - The address space in which a process or thread "thinks"
  - Address space with respect to which pointers, code & data addresses, etc., are interpreted
  - Separate and independent of *physical address space* where things are actually stored

A fundamental decoupling of addresses uttered by program from hardware addresses

Physical memory



New problem:– how to manage memory

- **Fixed partitions**
  - Easy
- **Variable partitions**
  - Seems to make better use of space

This is a general problem with broad applicability — e.g., to files systems, databases, etc.

Anything having to do with managing space — warehouse design, packaging, etc.

Partitioning strategies – fixed

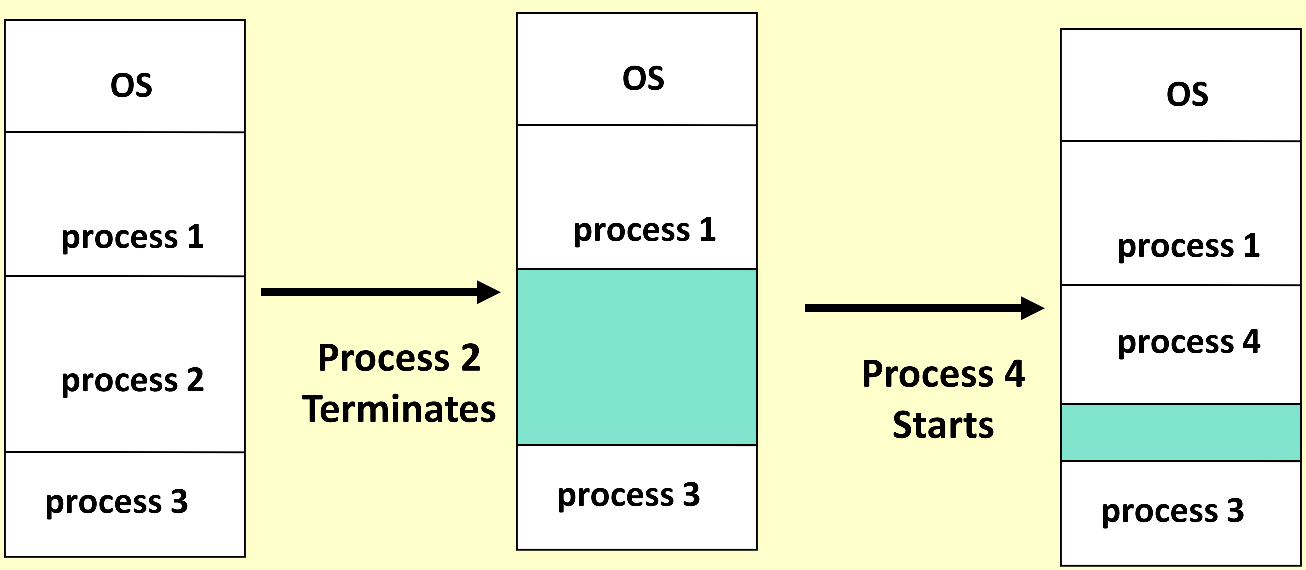
- **Fixed Partitions – divide memory into equal sized pieces (except for OS)**
  - Degree of multiprogramming = number of partitions
  - Simple policy to implement
    - All processes must fit into partition space
    - Find any free partition and load the process
- **Problem – what is the "right" partition size?**
  - Process size is limited
  - *Internal Fragmentation* – unused memory within a partition that is not available to other processes

Partitioning strategies – variable

- **Idea: remove "wasted" memory that is not needed in each partition**
    - Eliminating *internal fragmentation*
- **Memory is dynamically divided into partitions based on process needs**
- **Definition:**
    - *Hole:* a block of free or available memory
    - Holes are scattered throughout physical memory
- **Memory is allocated to new process from hole large enough to fit it**

Variable partitions

- **More complex management problem**
  - Must track free and used memory
  - Need data structures to do tracking
  - What holes are used for a process?
- ***External fragmentation***
  - memory that is <u>outside any partition</u> and is too small to be usable by any process



Definitions – *fragmentation*

- **Unused space that cannot be allocated to fill a need**

- ***Internal* fragmentation**
  - Unused or unneeded space *within* an allocated part of memory.
  - Cannot be allocated to another task/job/process
- ***External* fragmentation**
  - Unused space *between* allocations.
  - Too small to be used by other requests

- **Applies to all forms of *spatial* resource allocation**
  - RAM, Disk, Virtual memory within process
  - File systems
  - …

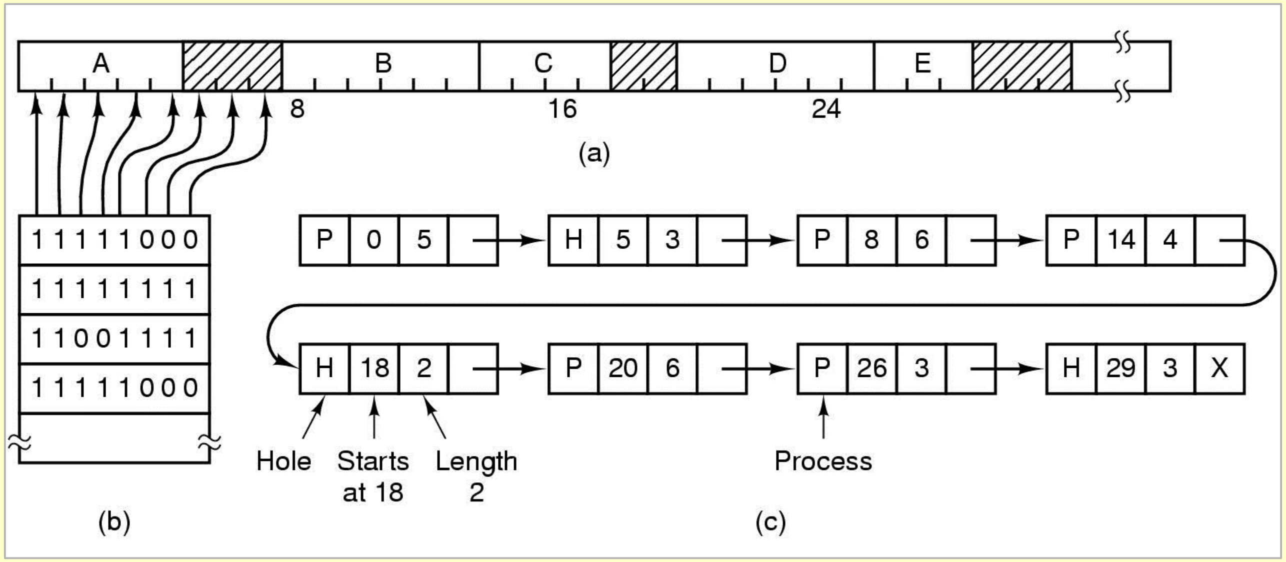
Memory allocation – mechanism

- **MM system maintains data about free and allocated memory alternatives**
  - *Bit maps* – 1 bit per "allocation unit"
  - *Linked Lists* – free list updated and coalesced when not allocated to a process
- **At swap-in or process create**
  - Find free memory that is large enough to hold the process
  - Allocate part (or all) of memory to process and mark remainder as free
- ***Compaction***
  - Moving things around so that *holes* can be consolidated
  - Expensive in OS time

See OSTEP, §17.1

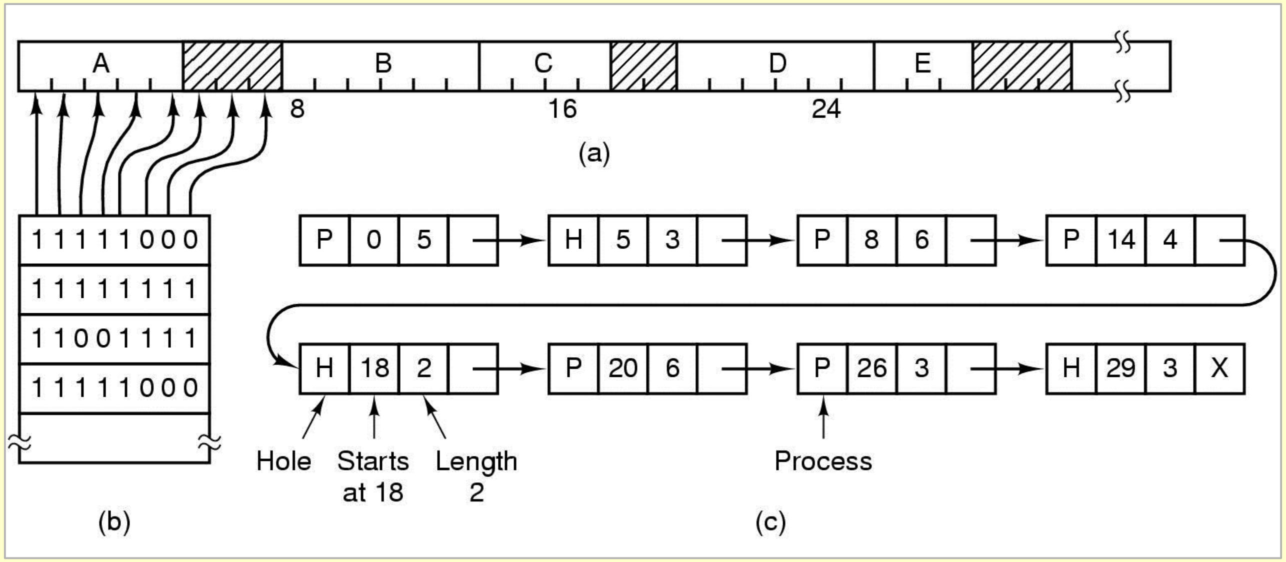
Memory management – list *vs.* map

- **Part of memory with 5 processes, 3 holes**
  - tick marks show allocation units
  - shaded regions are free
- **Corresponding bit map**
- **Same information as a list**



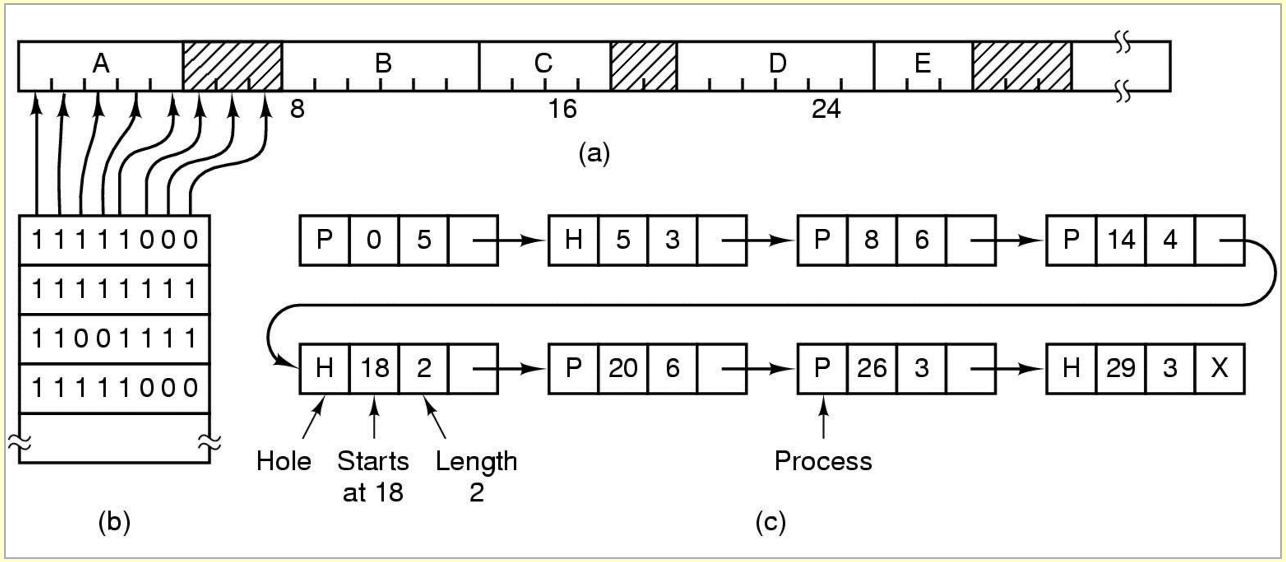
Memory management – bit map

- **Advantages:–**
  - Can see big picture
  - Easy to search using bit instructions in processor
  - Holes automatically coalesce
- **Disadvantage**
  - No association between blocks and processes that own them



Memory management – list

- **Advantages:–**
  - Direct association between block and process owning it
- **Disadvantages:–**
  - Cannot see big picture
  - Searching is expensive
  - Coalescing adjacent blocks requires extra effort (sorted order)



Memory allocation – policies

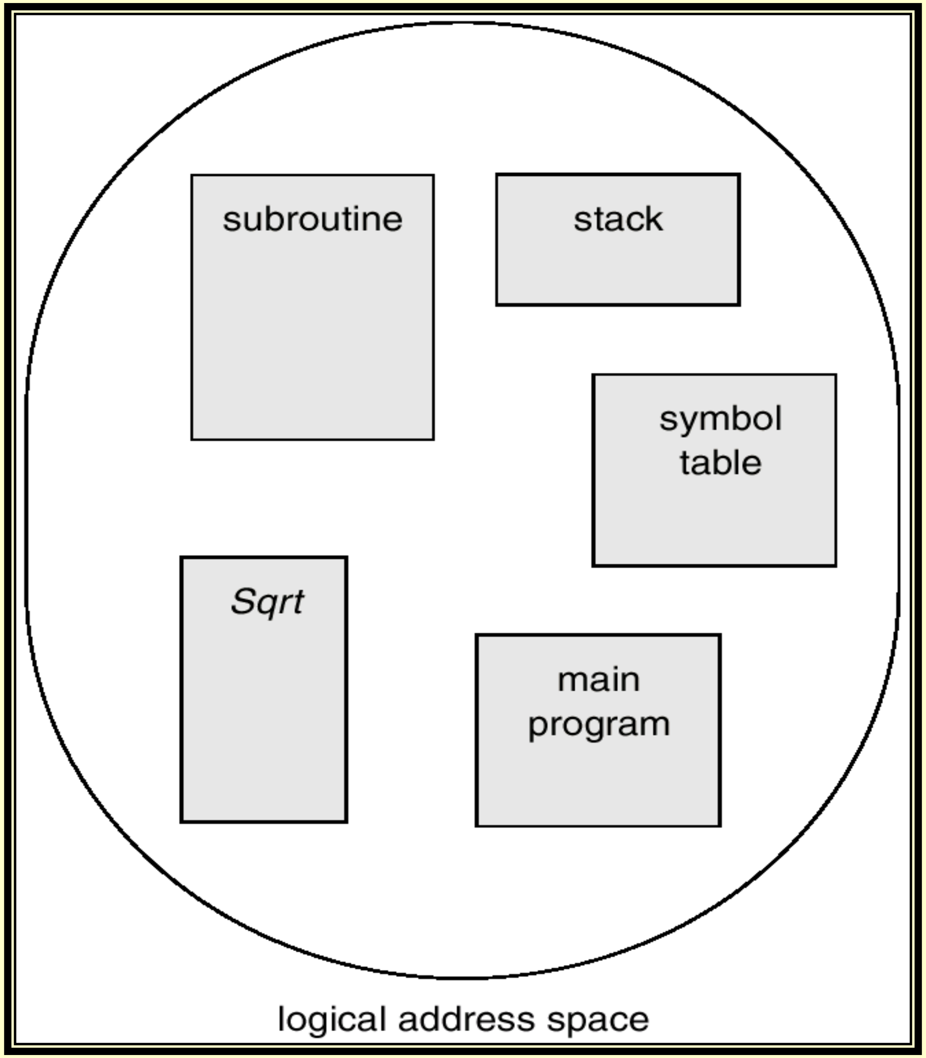
- **Policy examples**
  - *First Fit:* scan free list from beginning and allocate first hole that is large enough – fast
  - *Next Fit:* start search from end of last allocation
  - *Best Fit:* find smallest hole that is adequate – slower and lots of fragmentation
  - *Worst fit:* find largest hole
- **Simulation results show that *First Fit* usually works out to be the best**

Swapping and scheduling

- ***Swapping***
  - Move process from memory to disk (swap space)
    - Process is blocked or suspended
  - Move process from swap space to big enough partition
    - Process is ready
    - Set up Base and Limit registers
  - Memory Manager (MM) and Process scheduler work together
    - Scheduler keeps track of all processes
    - MM keeps track of memory
    - Scheduler marks processes as swap-able and notifies MM to swap in processes
    - Scheduler policy must account for swapping overhead
    - MM policy must account for need to have memory space for ready processes

Can we do better?

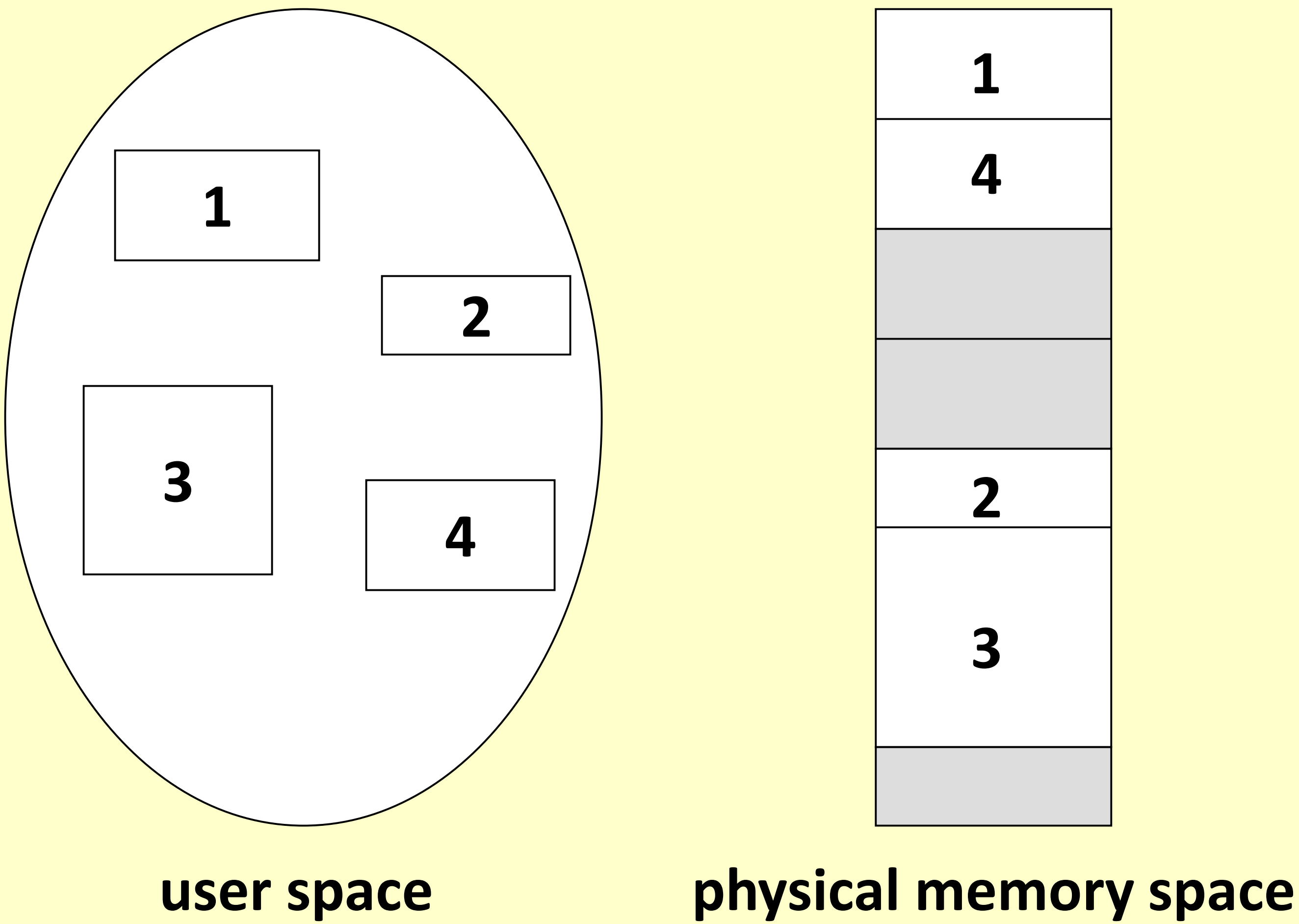
User's view of a program



Memory management — beyond partitions

- **Can we improve memory utilization & performance**
  - Processes have distinct parts
    - *Code* – program and maybe shared libraries
    - *Data* – pre-allocated and heap
    - *Stack*
  - Solution – slightly more Memory Management hardware
    - Multiple sets of “base and limit” registers
    - Divide process into logical pieces called *segments*
- **Advantages of *segments***
  - Code segments don’t need to be swapped out and may be shared
  - Stack and heap can be grown – may require segment swap
  - With separate I and D spaces can have larger virtual address spaces
    - “I” = *Instruction* (i.e., code, always read-only)
    - “D” = *Data* (usually read-write)

Logical view of segmentation



Segmentation

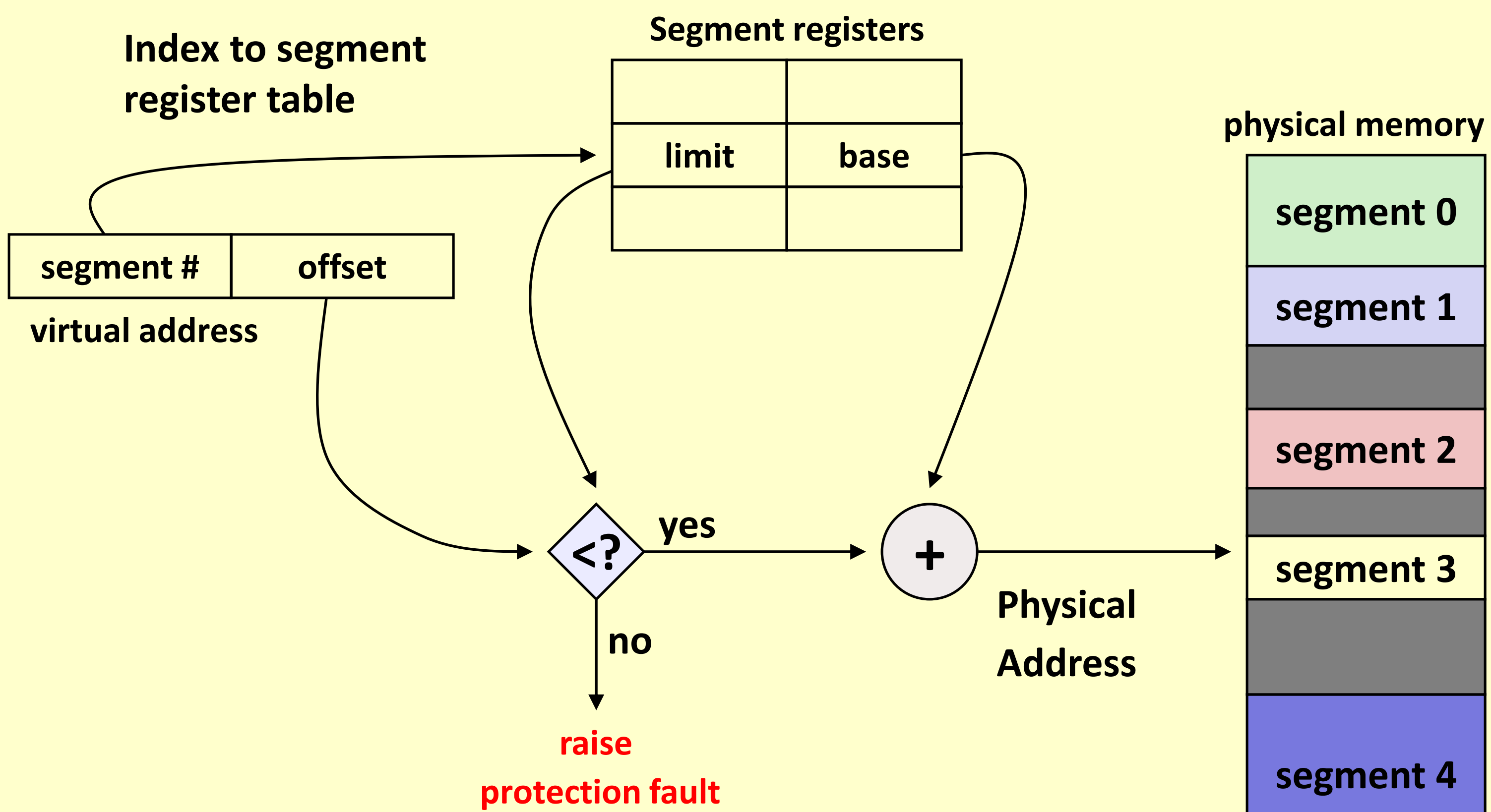
- **Logical address consists of a pair:–**

  `<segment-number, offset>`

- **Segment table – maps two-dimensional physical addresses; each table entry has:**
  - *Base:* contains the starting physical address where the segments reside in memory.
  - *Limit:* specifies the length of the segment.

OSTEP §16-17

Segment lookup



Segmentation

- ***Protection*. With each pair of segment registers, include:**
  - *validation bit* = 0 $\Rightarrow$ illegal segment
  - *read/write/execute* privileges
- ***Protection bits* associated with segments; code sharing occurs at segment level.**
- **Since segments vary in length, memory allocation is a dynamic storage-allocation problem**
  - With all the problems of fragmentation!

Segmentation

- **Common in early minicomputers**
  - Small amount of additional hardware – 4 or 8 segments
  - Used effectively in classical Unix
- **Good idea that has persisted and supported in current hardware and OSs**
  - Pentium, x86 supports segments
  - Linux supports segments (sort of)
- **Still have *external fragmentation* of memory**
- **What is the next level of Memory Management improvement?**
  - Next topic

Questions?