CSCI 3753
Operating Systems

Memory Management

Chapters 8 and 9

Lecture Notes By
Shivakant Mishra
Computer Science, CU-Boulder
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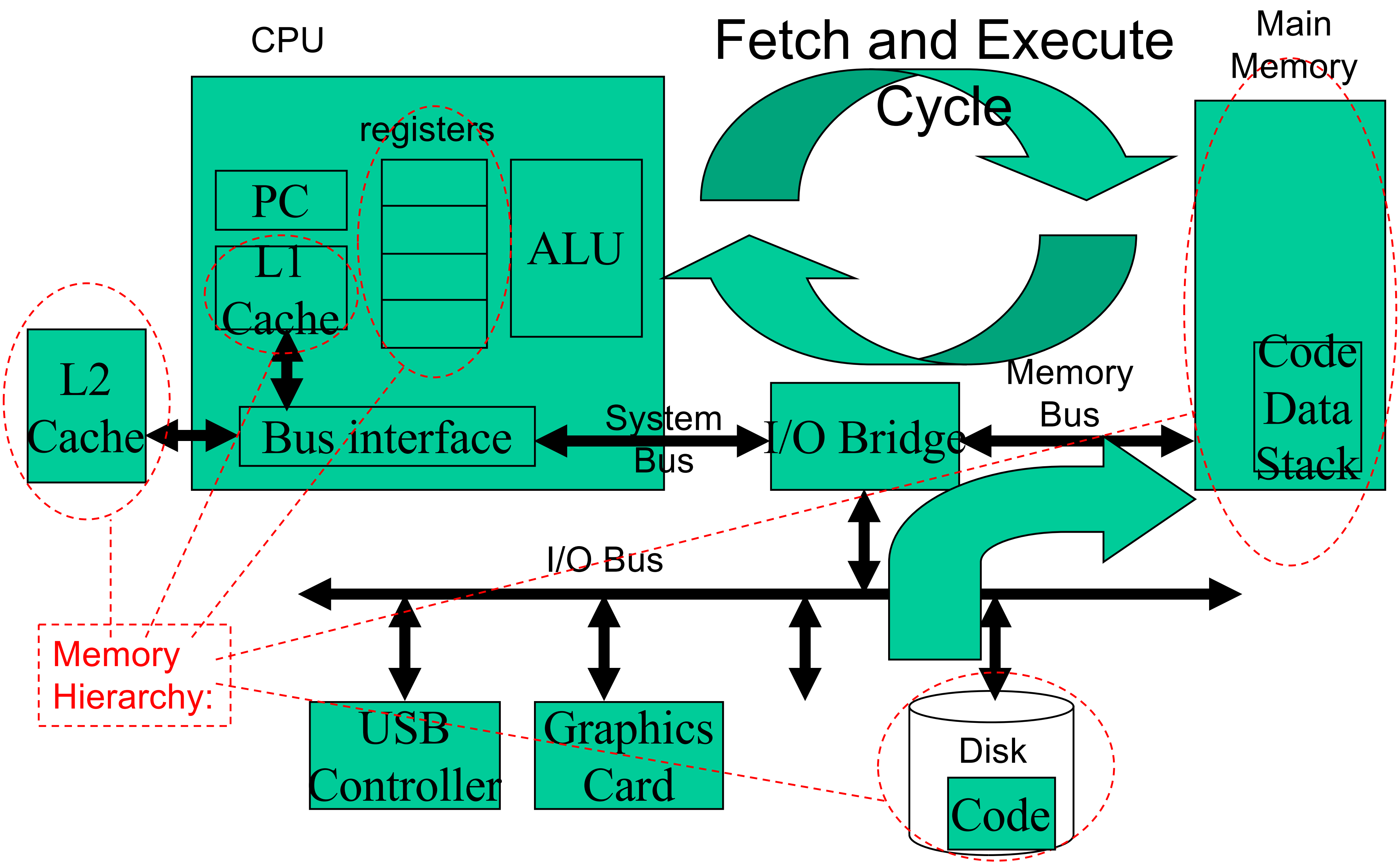
Memory Management



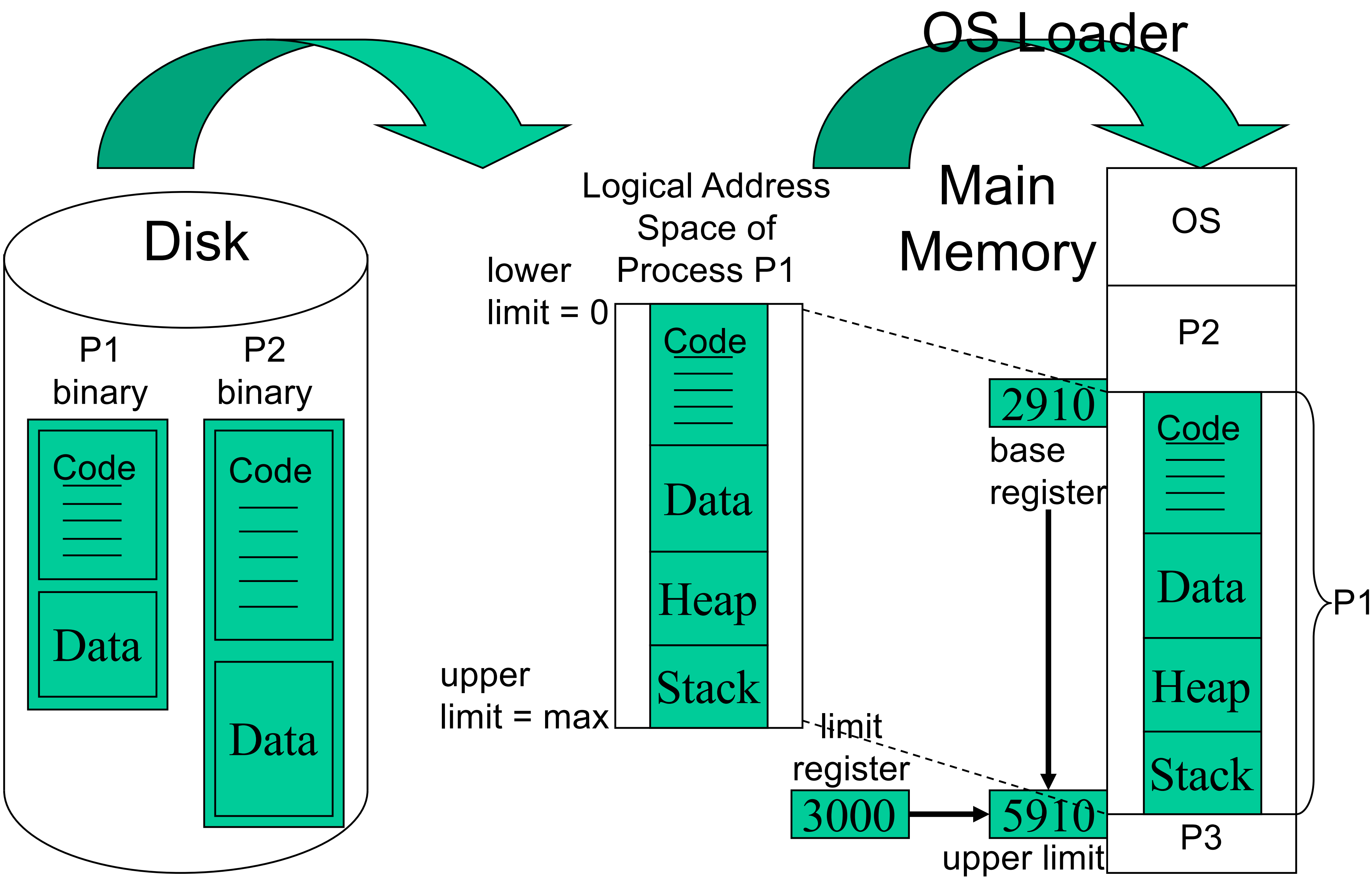
Memory Hierarchy

- CPU registers: fast and expensive
- L1, L2 and L3 cache between main memory and CPU
  - L1 = 1 clock cycle (~16 KB)
  - L2 = 4-5 clock cycles (~1 ns) (~1 MB)
  - L3 caches often shared between cores ~40 clock cycles (~10 ns) (~8-256 MB)
- Different types of cache
  - Instruction cache, data cache, TLB
  - e.g. AMD Athlon K8 has 64 KB L1 instruction cache, 64 KB L1 data cache, and 4 KB L1 TLB, and 1 MB L2 cache

Memory Hierarchy

- RAM = ~100 cycles/~10-50 ns
- Permanent storage
  - Flash = 10-100 μs (depends on read/write, flash type, etc.)
  - Disk = 10 ms

Memory Management



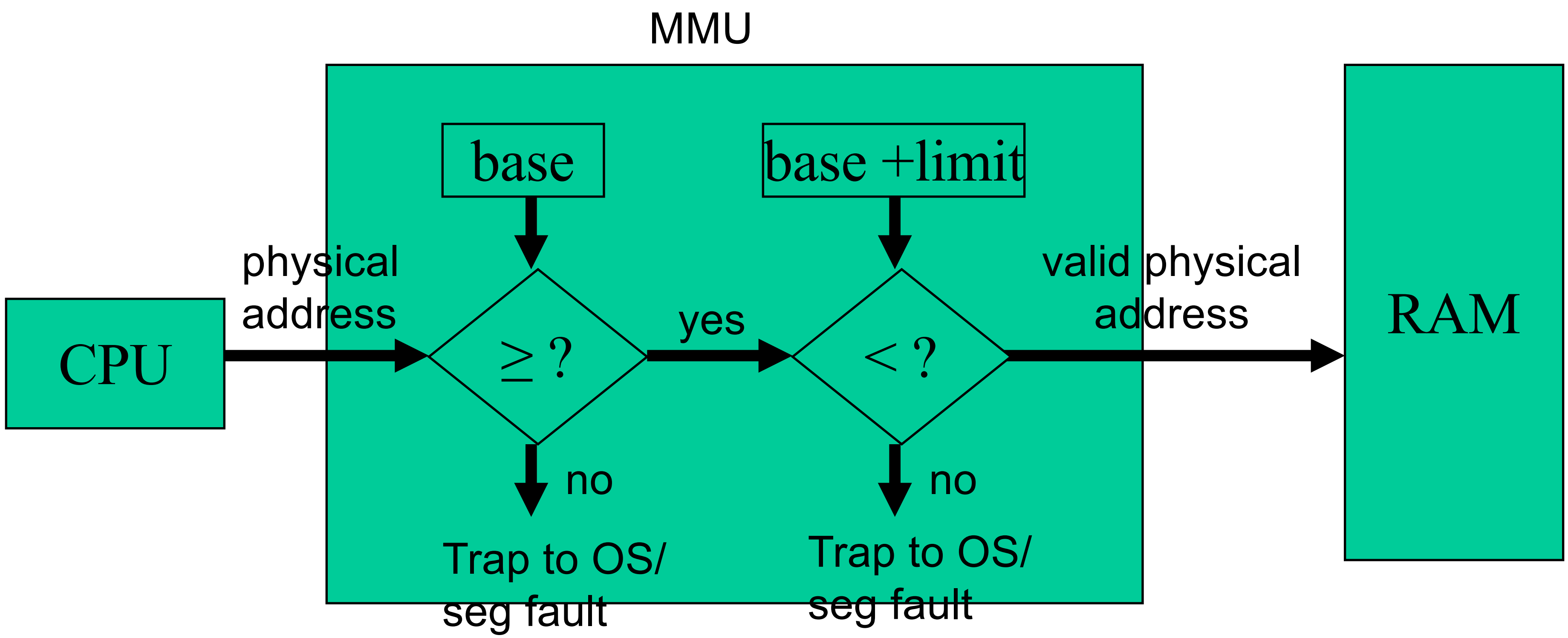
Memory Management

- When program P1 becomes an active process P1, then the process P1 can be viewed as conceptually executing in a *logical address space* ranging from *0* to *max*
  - In reality, the code and data are stored in physical memory
  - There needs to be a mapping from logical addresses to physical addresses - *memory management unit* (MMU) takes care of this.
- MMU
  - Address translation: translate logical addresses into physical addresses, i.e. map the logical address space into a *physical address space*
  - Bounds checking: check if the requested memory address is within the upper and lower limits of the address space
    - *base register* and *limit register*

Memory Management

- Base and limit registers provide hardware support for a simple MMU
  - Memory access should not go out of bounds. If out of bounds, then this is a segmentation fault so trap to the OS.
    - MMU will detect out-of-bounds memory access and notify OS by throwing an exception
- Only the OS can load the base and limit registers while in kernel/supervisor mode
  - These registers would be loaded as part of a context switch

Memory Management



Address Binding

- The process of mapping a program's logical addresses to corresponding physical addresses
- Compile Time:
  - If you know in advance where in physical memory a process will be placed, then compile your code with absolute physical addresses
- Load Time:
  - Code is first compiled in relocatable format with (logical) addresses 0 – MAX. Then replace logical addresses in code with physical addresses during loading → *load module*

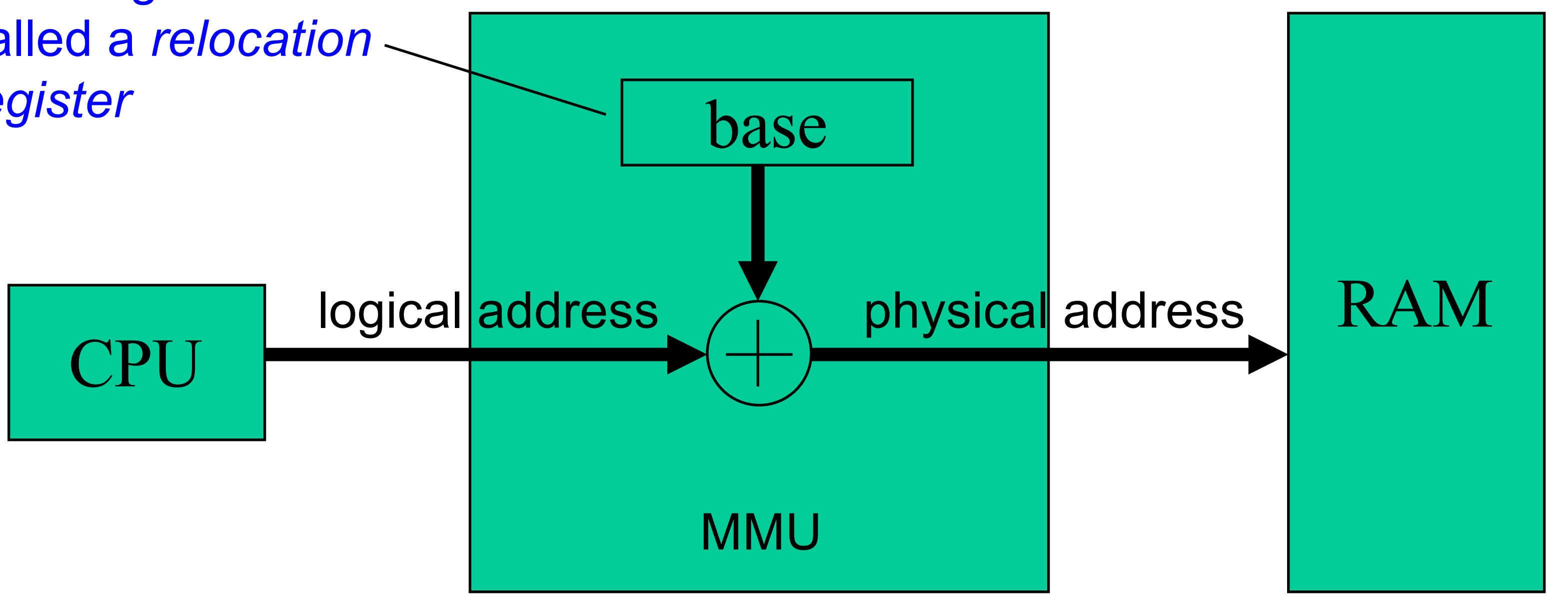
Address Binding

- Run Time/Execution Time: (most modern OS’s do this)
  - Code is first compiled ***and loaded*** in relocatable format as if executing in its own logical/virtual address space.
  - As each instruction is executed, i.e. at run time, the MMU relocates the logical address to a physical address using hardware support such as base/relocation registers.

Memory Management

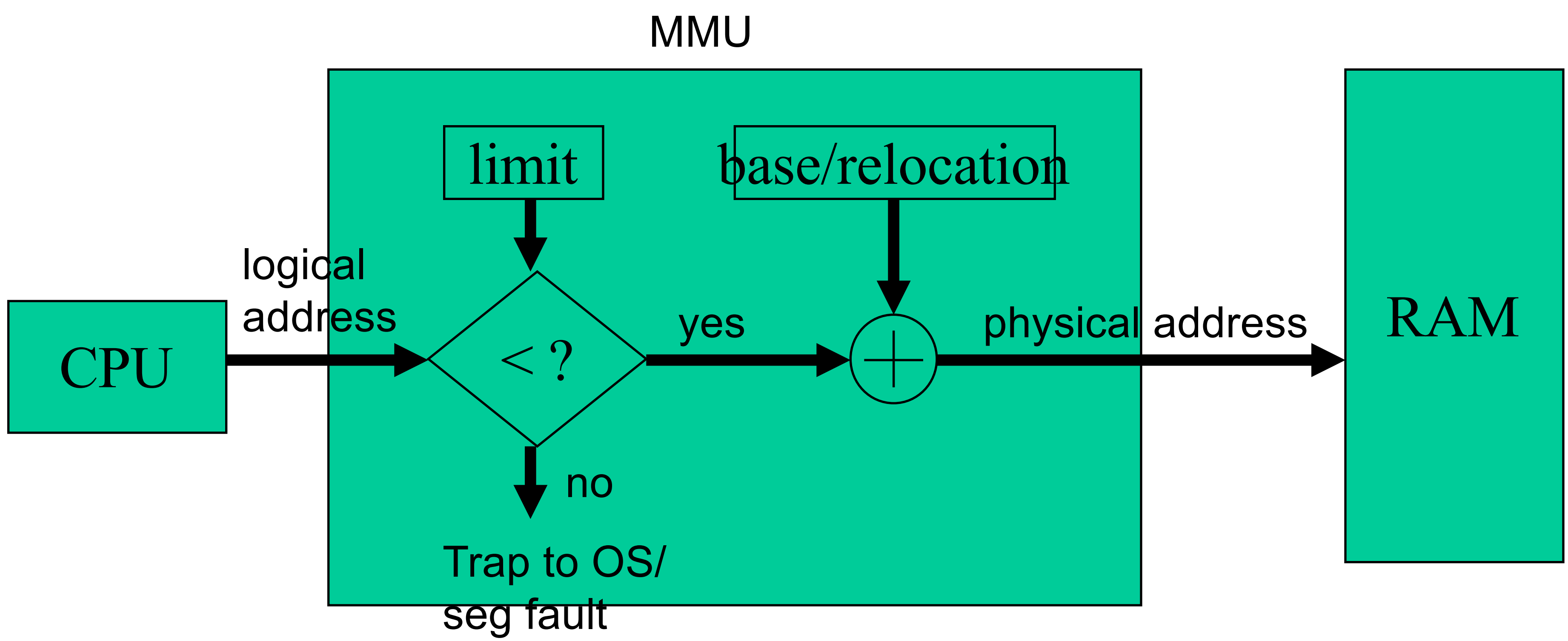
- For run-time address binding, MMU performs run-time *mapping* of logical addresses to physical addresses
  - each logical address is *relocated or translated* to a physical address that is used to access main memory
  - The application program never sees the actual physical memory - it just presents a logical address to MMU

base register is also called a *relocation register*



Memory Management

- Let's combine the MMU's two tasks (bounds checking, and memory mapping) into one figure
  - Since logical addresses can't be negative, then lower bound check is unnecessary - just check the upper bound by comparing to the limit register
  - Also, by checking the limit first, no need to do relocation if out of bounds



Execution/Run Time Binding With Static Linking

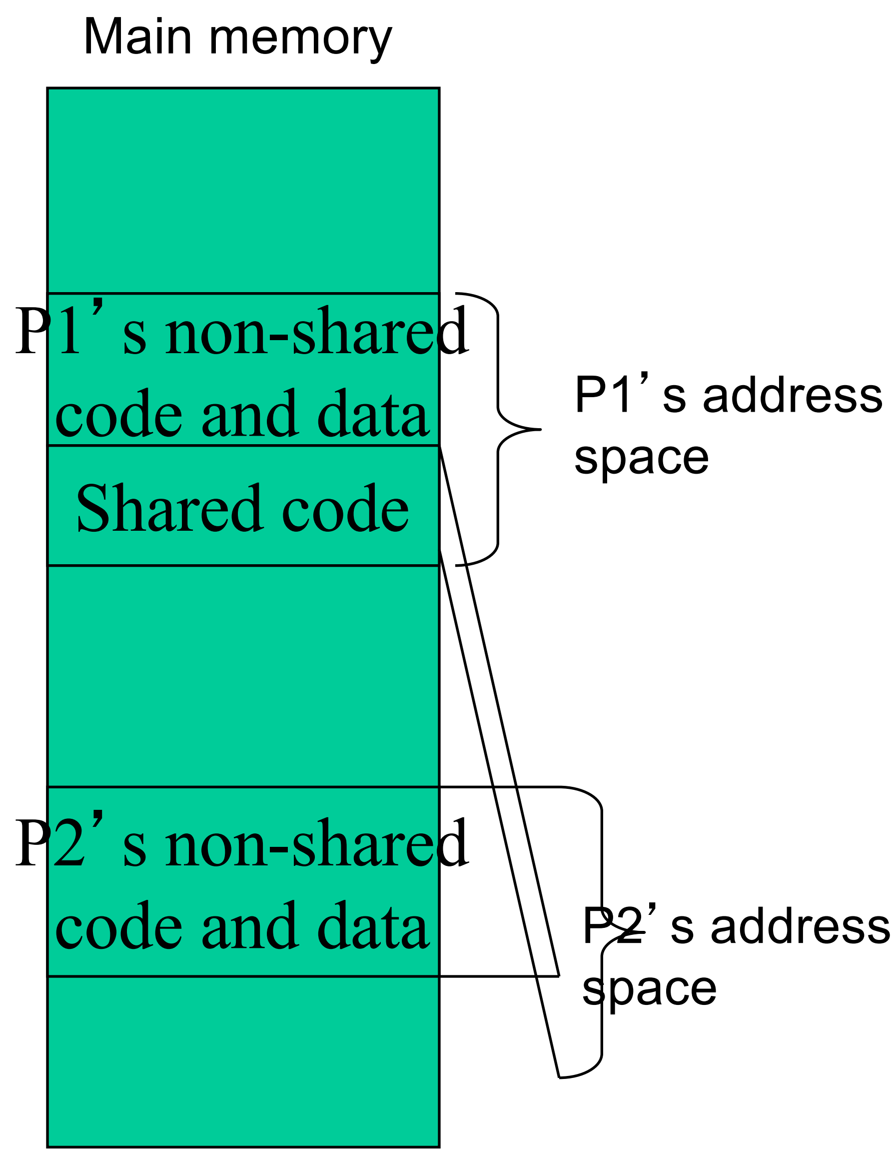
- What about external symbols, e.g. libraries?
- Logical addresses are translated instruction by instruction into physical addresses at run time, and the entire executable has all the code it needs at compile time through static linking
- Static linking can cause each application to have a copy of the same code
  - e.g. C library – not very efficient

Run Time Binding with Dynamic Linking

- Executable code does not have all the code it needs at compile time
  - At compile time, include only a *stub* that contains info on how to find the dynamically linked library function
  - At run time, translate logical to physical addresses instruction by instruction, but when hitting a stub, the OS looks for the dll function, loads it if it's not already loaded, and replaces itself with a reference to the actual function
    - Dll is written as position-independent and reentrant code, so it can be put anywhere in memory and executed by multiple processes
    - In UNIX, dynamically linked libraries are typically named with a *.so* suffix, i.e. *libfoo.so*

Run Time Binding with Dynamic Linking

- One copy of the code shared among all programs
  – We'll see later how code is shared between address spaces
- Programs have access to the most recently patched dll's
  – Compare to a statically compiled executable that may have a much older version of code when it was originally compiled years ago
- Smaller size – stubs stay stubs unless activated

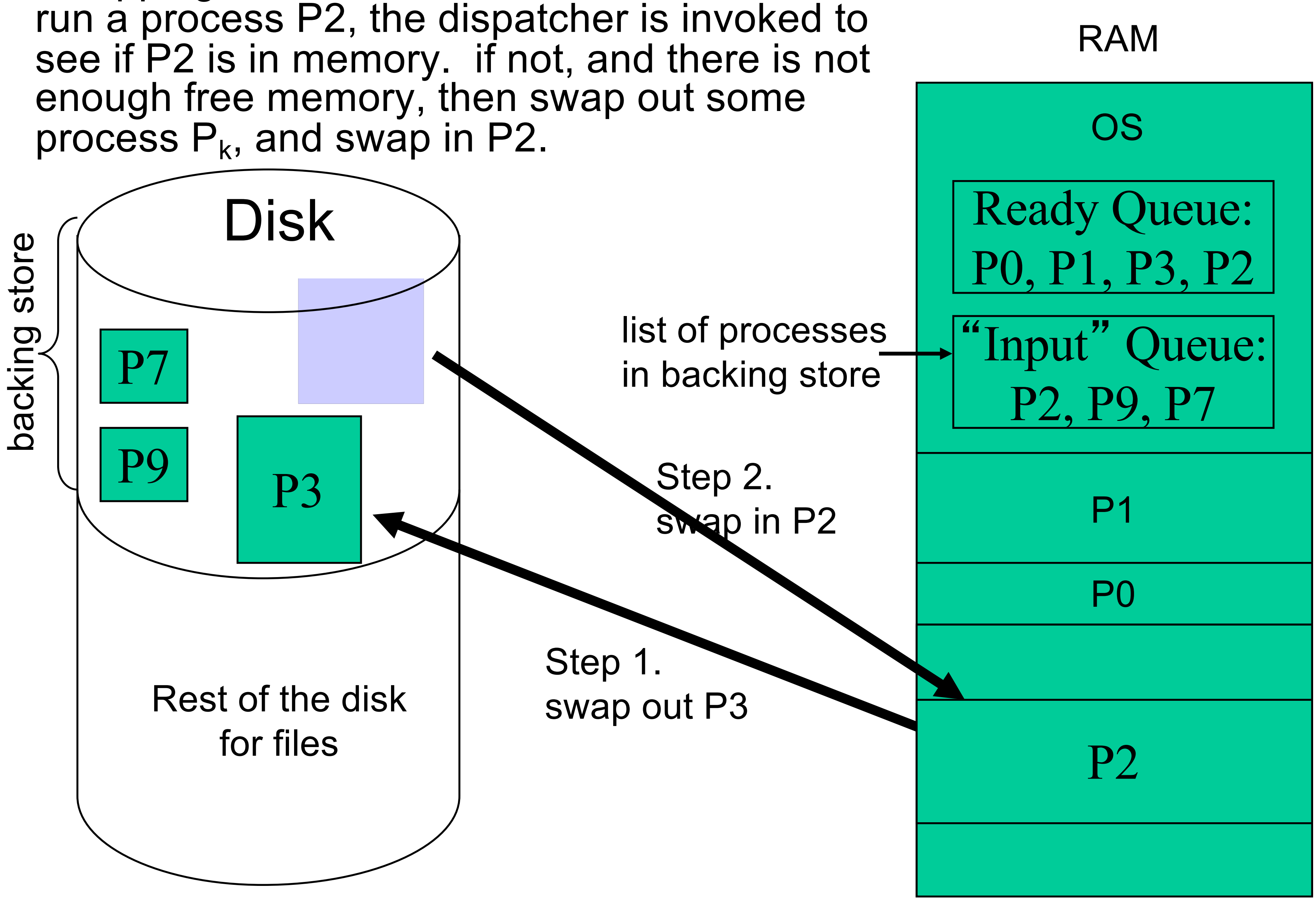


Swapping

- Memory may not be sufficient to store all processes that are ready to run, i.e. that are in the ready queue
- Use disk/secondary storage to store some processes that are temporarily swapped out of memory, so that other (swapped in) processes may execute in memory
  - Special area on disk allocated for this is called *backing store* or *swap space*. This is faster to access – don’t go through the normal file system.
- If run time binding is used, then a process can be easily swapped back into a different area of memory.
- If compile time or load time binding is used, then process swapping will become very complicated and slow - basically undesirable

Swapping

- Swapping: when the OS scheduler wants to run a process P2, the dispatcher is invoked to see if P2 is in memory. if not, and there is not enough free memory, then swap out some process P_k, and swap in P2.

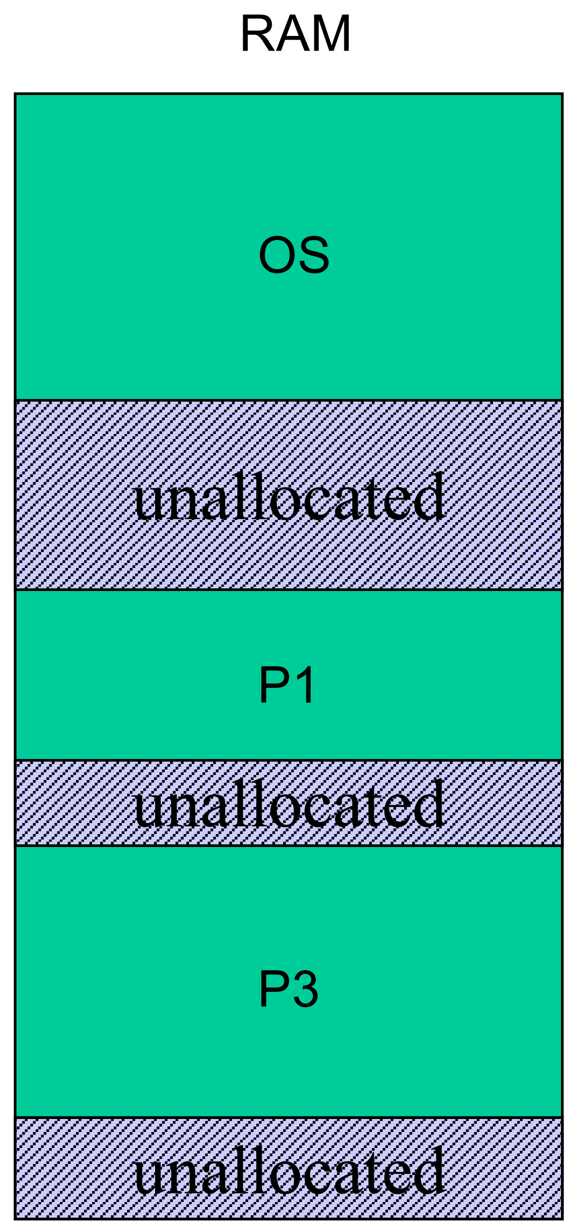


Problem with Swapping

- Context-switch time of swapping is very slow
  - On the order of tens to hundreds of milliseconds
  - Hide this latency by having other processes to run while swap is taking place, e.g. in RR, swap out the just-run process, and have enough processes in round robin to run before swap-in completes
  - Can't always hide this latency if in-memory processes are blocked on I/O
  - UNIX avoids swapping unless the memory usage exceeds a threshold
- Swapping of processes that are blocked or waiting on I/O becomes complicated
  - One rule is to simply avoid swapping processes with pending I/O
- *fragmentation* of main memory becomes a big issue
  - can also get fragmentation of backing store disk

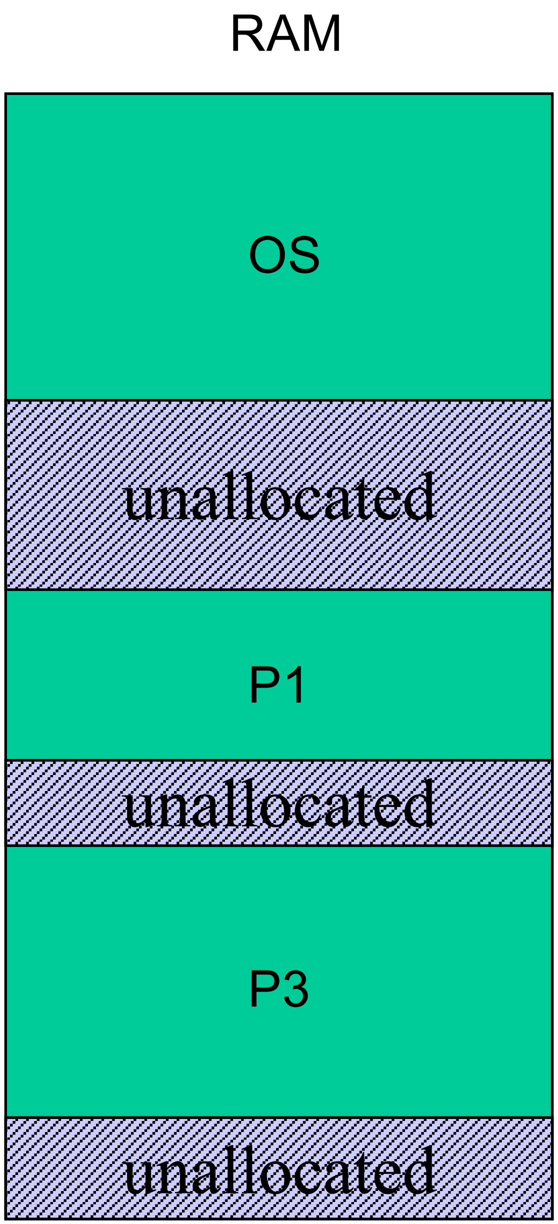
Memory Allocation

- As processes arrive, they're allocated a space in main memory
- Over time, processes leave, and memory is deallocated
- This results in *external fragmentation* of main memory, with many small chunks of non-contiguous unallocated memory between allocated processes in memory
- OS must find an unallocated chunk in fragmented memory that a process fits into.



Memory Allocation Strategies

- *best fit* - find the smallest chunk that is big enough
  - This results in more and more fragmentation
- *worst fit* - find the largest chunk that is big enough
  - This leaves the largest contiguous unallocated chunk for the next process
- *first fit* - find the 1st chunk that is big enough
  - This tends to fragment memory near the beginning of the list
- *next fit* – view fragments as forming a circular buffer, find the 1st chunk that is big enough after the most recently chosen fragment



Memory Allocation

- Fragmentation can mean that, even though there is enough overall free memory to allocate to a process, there is not one contiguous chunk of free memory that is available to fit a process's needs
  - the free memory is scattered in small pieces throughout RAM
- Both first-fit and best-fit aggravate external fragmentation, while worst-fit is somewhat better
- Solution: execute an algorithm that *compacts* memory periodically to remove fragmentation
  - only possible if addresses are bound at run-time
  - expensive operation - takes time to translate the address spaces of most if not all processes, and CPU is unable to do other meaningful work during this compaction