06. Memory Management

9th ed: Ch. 8, 9

10th ed: Ch. 9, 10

Objectives

- To describe the hardware required for memory protection
- To introduce the concepts of logical and physical addresses
- To discuss the problem of address binding
- To introduce the concept of segmentation
- To understand the problem of fragmentation

Outline

- Memory protection
- Memory allocation

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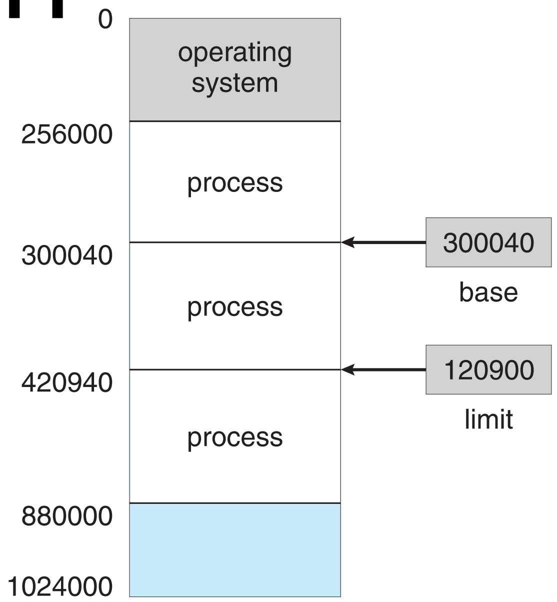
- Memory protection
  - Address binding
  - Logical and physical addresses
  - Memory Management Unit (MMU)
  - Linking and loading
- Memory allocation

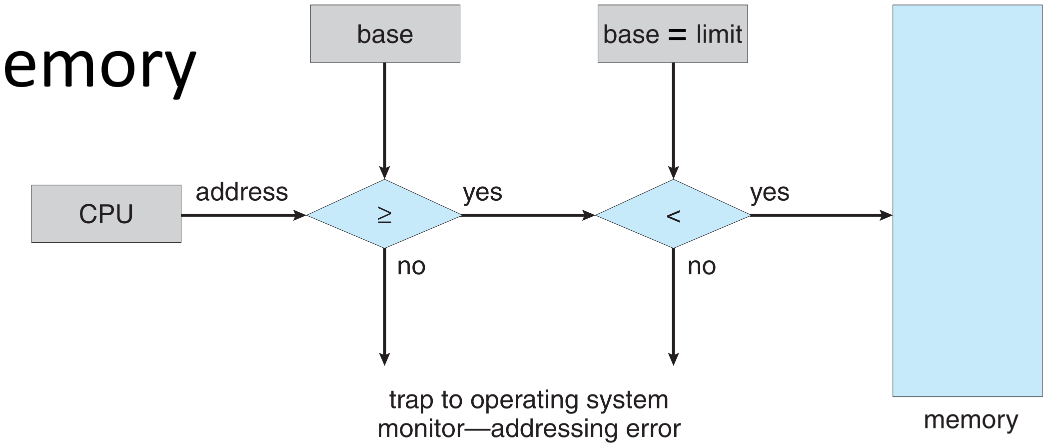
Memory management

- Will have many programs in memory simultaneously
  - Program code loaded from storage
- The CPU can only access registers and main memory directly
  - Register access in a single cycle, but memory access takes many cycles
  - Multiple levels of cache attempt to hide main memory latency (L1, L2, L3)
- Memory unit sees only a stream of
  - Address plus read request
  - Address plus data plus write request
- Need to protect memory accesses to prevent malicious or just buggy user programs corrupting other programs, including the kernel

Hardware address protection

- **Base** and **limit** registers define the logical address space
  - Base is the smallest legal address, e.g., 300040
  - Limit is the size of the range, e.g., 120900
  - Thus program can access addresses in the range [300040, 420940)
- CPU must check every user-mode memory access to ensure it is in that range
  - Exception raised to OS if not





Address binding

- Programs on disk are brought into memory to create running processes – but where in memory to put them given program code will refer to memory locations?
  - Consider a simple program and the assembly code it might generate
  - [Rx] means
    the contents of memory at address Rx

```
int x, y;
x = 5;
y = x + 3;
```

```
str #5, [Rx]     ; store 5 into x
ldr R1, [Rx]     ; load value of x from memory
add R2, R1, #3   ; and add 3 to it
str R2, [Ry]     ; and store result in y
```

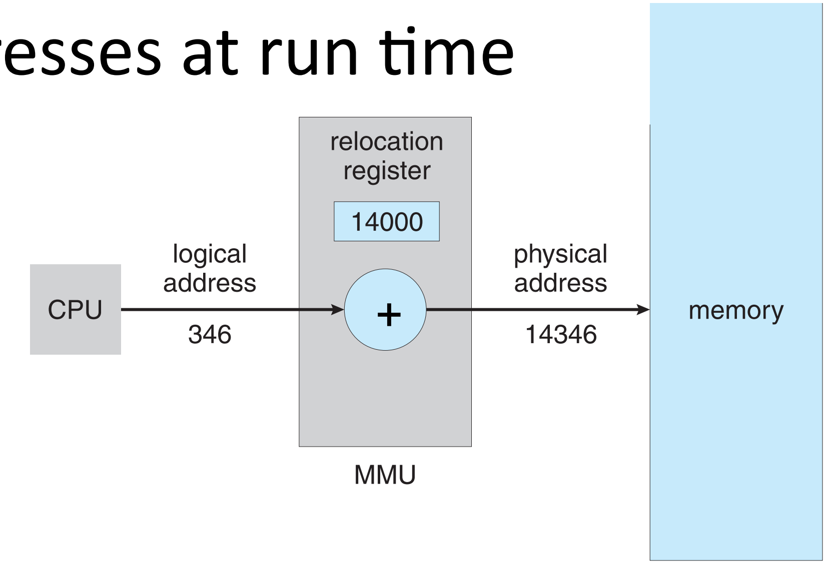
- Address binding happens at three different points
  - **Compile time**: If memory location known *a priori*, absolute code can be generated; requires recompilation if base location changes
  - **Load time**: Need to generate relocatable code if memory location is not known at compile time
  - **Execution time**: Binding delayed until run time if the process can be moved during its execution from one memory segment to another
- Bindings map one address space to another – requires hardware support

Logical vs physical addresses

- The concept of a logical address space that is bound to a separate physical address space is central to proper memory management
  - **Logical** (**virtual**) **address** – as generated by the CPU
  - **Physical address** – address seen by the memory unit
  - Identical in compile-time and load-time address-binding schemes
  - Differ in execution-time address-binding schemes
- The logical/physical address space is the set of all logical/physical addresses generated by a program
- Need hardware support to perform the mapping from logical to physical addresses at run time

Memory Management Unit (MMU)

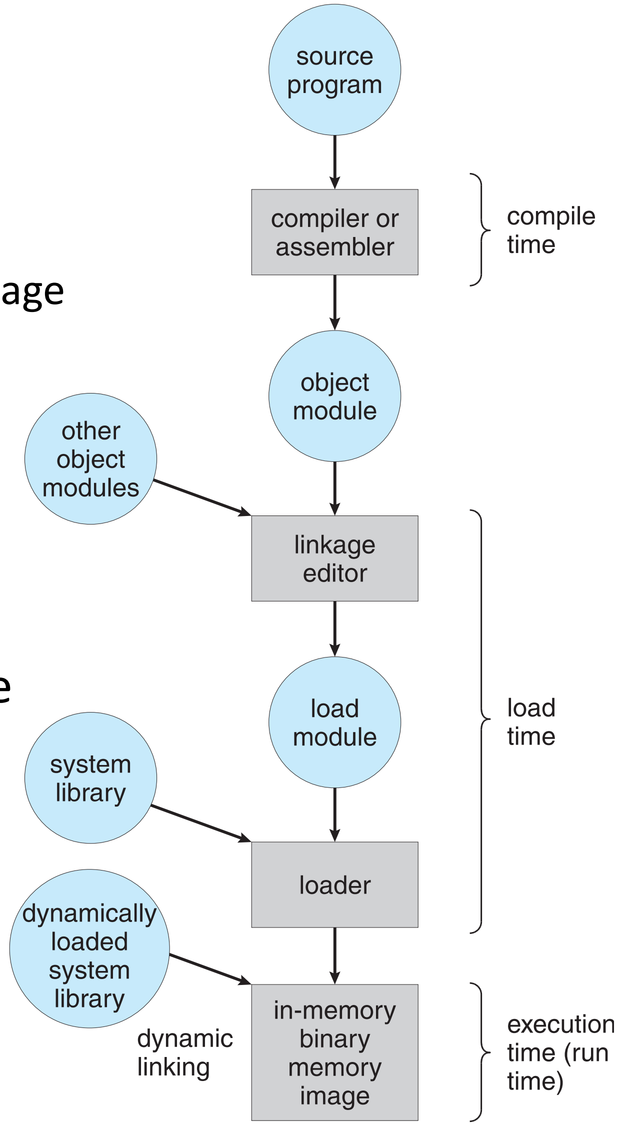
- Hardware that maps logical to physical addresses at run time
- Conceptually simple scheme: replace base register with **relocation register**



- Add the value in the relocation register to every address generated by a user process at the time it is sent to memory
  - User programs deal with logical addresses, never seeing physical addresses
- Execution-time binding occurs when reference is made to location in memory
  - Logical address is bound to physical address by the MMU

Dynamic linking and loading

- Linking combines different object code modules to create a program
  - **Static linking** – all libraries and program code combined into the binary program image
  - **Dynamic linking** – postpone linking to execution time
- Dynamic linking is particularly useful for **system** or **shared** libraries
  - May need to track versions
- Calls replaced with a **stub**
  - A small piece of code to locate the appropriate in-memory routine
- Stub replaces itself with the address of the routine, and executes the routine
  - Operating system checks if routine is in processes' memory address, adding it if not
- Dynamic loading avoids loading routines until they're called
  - Better memory usage as unused routines are never loaded
  - Requires they be compiled with relocatable addresses
  - Useful when large amounts of code are needed infrequently
- OS can help by providing libraries to implement dynamic loading

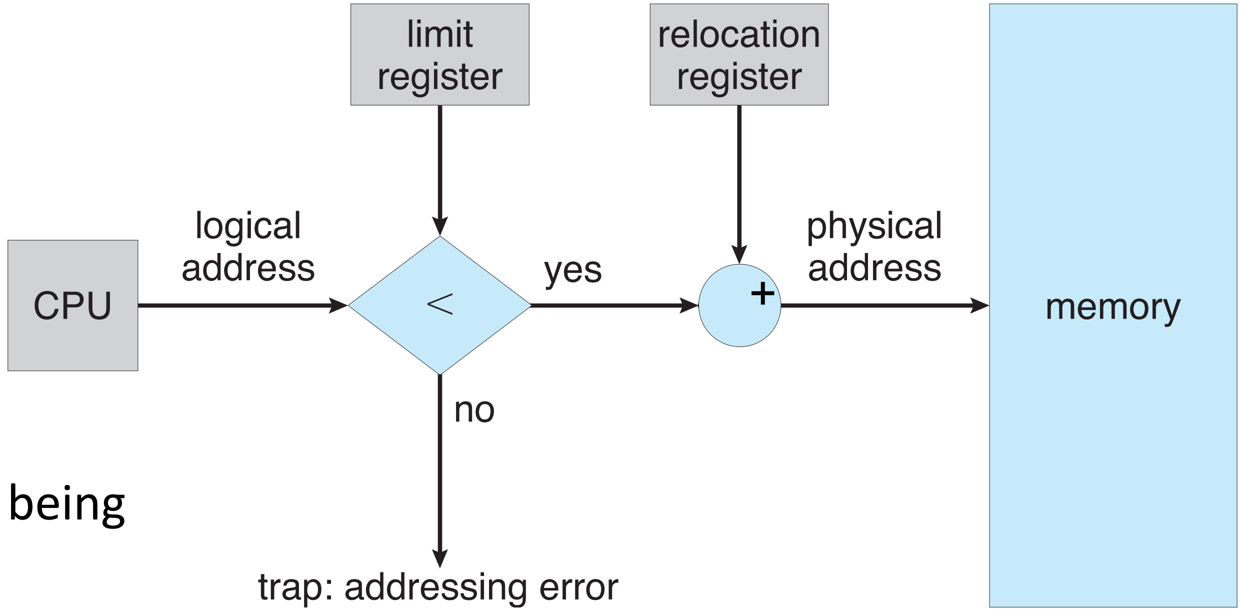


Outline

- Memory protection
- Memory allocation
  - Swapping
  - Dynamic allocation
  - Fragmentation
  - Compaction
  - Segmentation

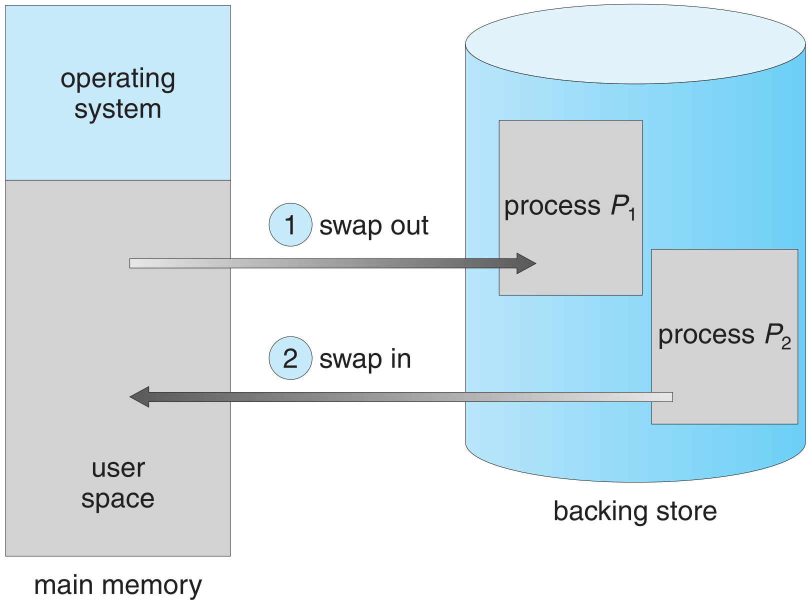
Memory allocation

- Main memory must support both kernel and user processes
  - Limited resource, must allocate efficiently
  - **Contiguous allocation** is early method putting each process in one chunk of memory
- How to determine chunks?
  - Multiple fixed-sized partitions limits the degree of multiprogramming; prefer **variable partitioning**
- Main memory usually partitioned into two
  - Resident kernel, usually held in low memory alongside interrupt vectors
  - User processes then held in high memory, each in a single contiguous section
- Relocation registers used to protect
  - User processes from each other, and
  - OS code and data from being modified
- Can then allow actions such as kernel code being transient and kernel changing size



Swapping

- When physical memory requested exceeds physical memory in machine, temporarily swap processes out
  - Move processes from main memory to storage
- Significant performance impact
  - Time to transfer process to/from storage directly proportional to the amount of memory swapped
  - Context switches can thus become very expensive
  - E.g., 100MB process with storage transfer rate of 50MB/s
- Swapping default disabled
  - Enabled only while allocated memory exceeds threshold
  - Plus consider pending I/O to or from process memory space
  - System maintains a ready queue of ready-to-run processes with memory images on disk
- Must swapped out processes be swapped into the same physical addresses?
  - Depends on address binding method



Multiple variable-partition allocation

- **Holes**, blocks of available memory of various size are scattered throughout memory
  - When a process arrives, it is allocated memory from a hole large enough to accommodate it
  - Process exiting frees its partition, adjacent free partitions combined
- OS maintains information about:
  - allocated partitions and
  - free partitions (holes)

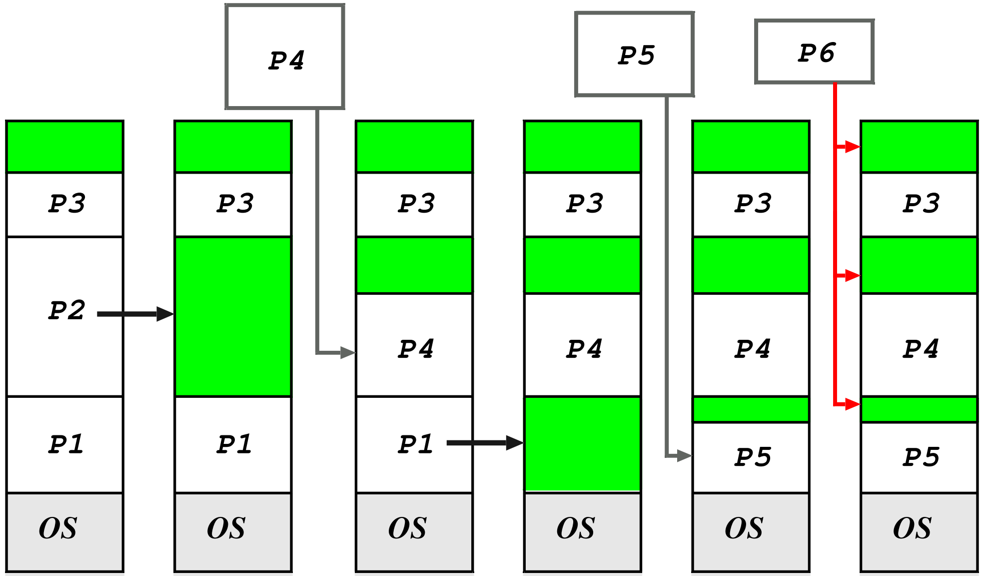
Dynamic allocation problem

- How to satisfy a request of size from a list of free holes?

- **First-fit**, allocate the first hole that is big enough
- **Best-fit**, allocate the smallest hole that is big enough
  - Requires searching entire list, unless maintained ordered by size
  - Produces the smallest leftover hole
- **Worst-fit**, allocate the largest hole
  - Also requires searching entire list, producing the largest leftover hole
- First-fit and best-fit better than worst-fit in terms of speed and storage utilization

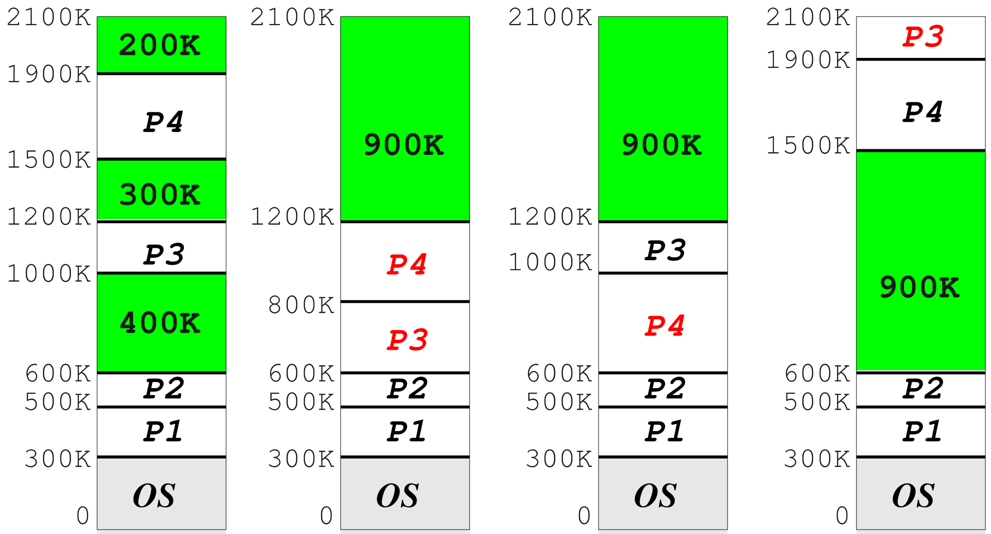
Fragmentation

- Fragmentation results in memory being unused and unusable
- **External Fragmentation**
  - Occurs when free memory exists to satisfy a request but it is not contiguous
  - Can eventually result in blocking as insufficient contiguous memory to swap any process in
- **Internal Fragmentation**
  - Occurs when allocated memory is slightly larger than requested memory
  - Memory internal to a partition, but unused
- Analysis of first-fit indicates that for *N* blocks allocated, 0.5 *N* blocks lost to fragmentation



Compaction

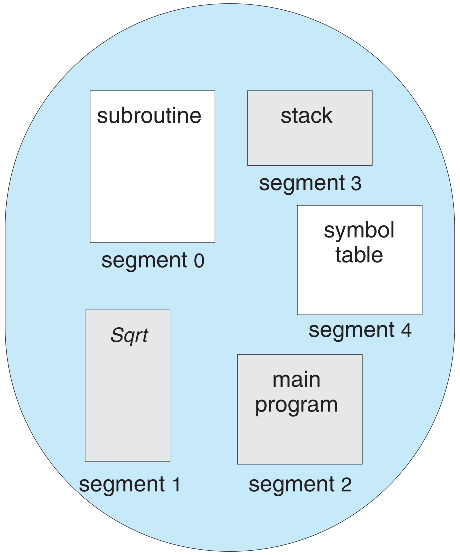
- Reduce external fragmentation by **compaction**
  - Shuffle memory contents to place all free memory together in one large block
- Compaction is possible only if
  - relocation is dynamic, and
  - done at execution time
- I/O problem
  - Pin job in memory while involved in I/O
  - Do I/O only into OS buffers



- Now consider that backing store has same fragmentation problems

Segmentation

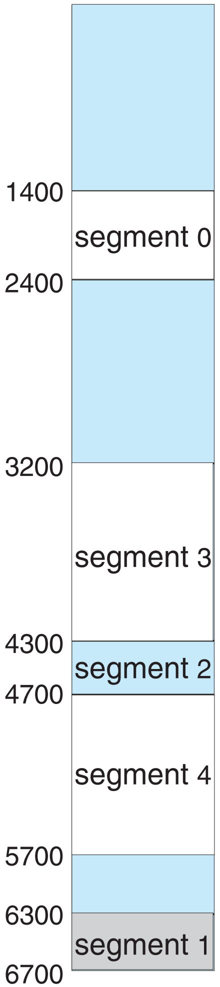
- Memory-management scheme supporting user view of memory
  - View a program as a collection of **segments**, logical program units such as the program, a procedure, an object, an array, etc
- Accessing memory requires user program to specify
  - **Segment name** (**number**) and
  - **Offset** within segment



logical address space

	limit	base
0	1000	1400
1	400	6300
2	400	4300
3	1100	3200
4	1000	4700

segment table

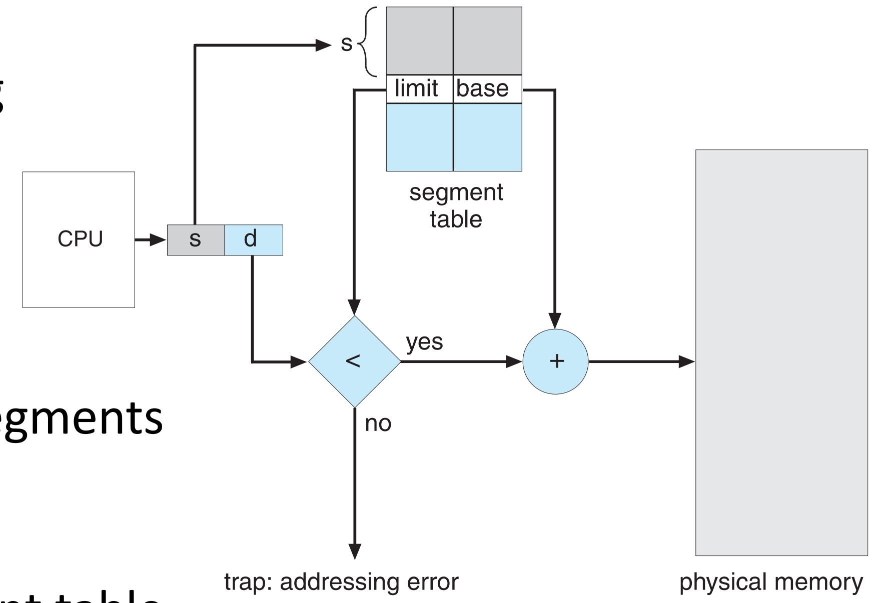


physical memory

Segmentation hardware

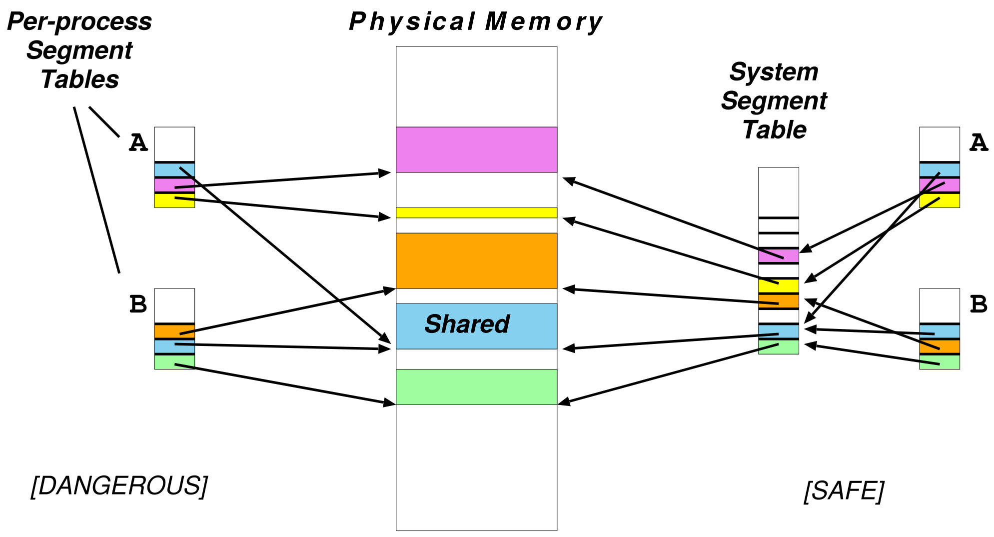
- Logical address is now a pair < *segment-number*, *offset* >
- **Segment table** maps to physical addresses via entries having
  - **Base**, the starting physical address where the segment resides
  - **Limit**, specifying the length of the segment
- **Segment-table base register** (**STBR**) points to the segment table's location in memory
- **Segment-table length register** (**STLR**) indicates number of segments used by a program;

  Segment number *s* is legal if *s* < STLR
- Protection provided by associating with each entry in segment table
  - Validation bit indicating legal / illegal segment
  - Read/Write/Execute privileges
  - Associated with segments so code sharing occurs at segment level
- Segments vary in length so memory allocation is a dynamic storage-allocation problem



Sharing segments is subtle

- Consider jumps within shared code
  - Specified as a condition and a transfer address < *segment-number*, *offset* >
  - *segment-number* is (of course) this one
- So all programs sharing this segment must use the same number to refer to it
  - The difficulty of finding a common shared segment number grows as the number of users sharing a segment
  - Thus, specify branches as PC-relative or relative to a register containing the current segment number
  - Read only segments containing no pointers may be shared with different segment numbers



- Wasteful to store common information on shared segment in each process segment table
  - Also dangerous as can get out of sync between processes
- Assign each segment a unique **System Segment Number (SSN)**
  - **Process Segment Table** then maps from a **Process Segment Number** (**PSN**) to SSN

Summary

- Memory protection
  - Address binding
  - Logical and physical addresses
  - Memory Management Unit (MMU)
  - Linking and loading
- Memory allocation
  - Swapping
  - Dynamic allocation
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