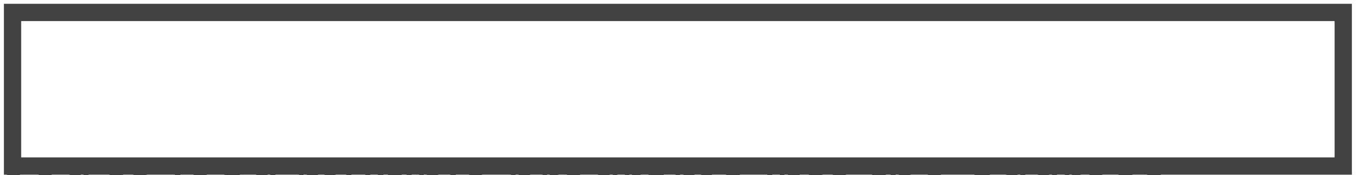
Module 3: Memory management

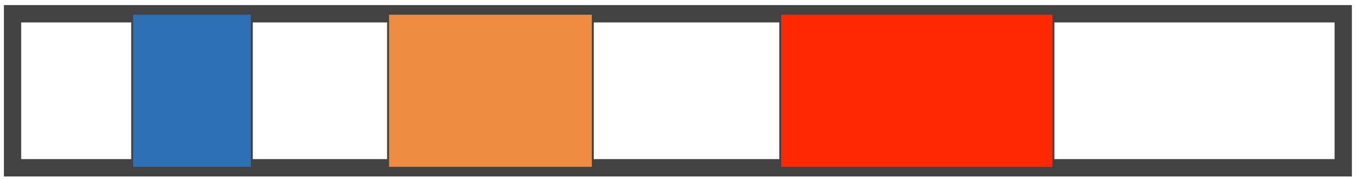
- Module 1 and 2 dealt with processes, scheduling and synchronization
- Next two modules will deal with memory and storage
- Processes require data to perform useful work
  - Stable storage (e.g. disk) is slow
  - Transient storage (e.g. RAM memory) is faster
    - multiple levels with different speeds
- Goal is to get as much performance out of the system by moving data between the levels

Memory management problem

- Physical memory large contiguous address



- Need to load multiple programs into the address

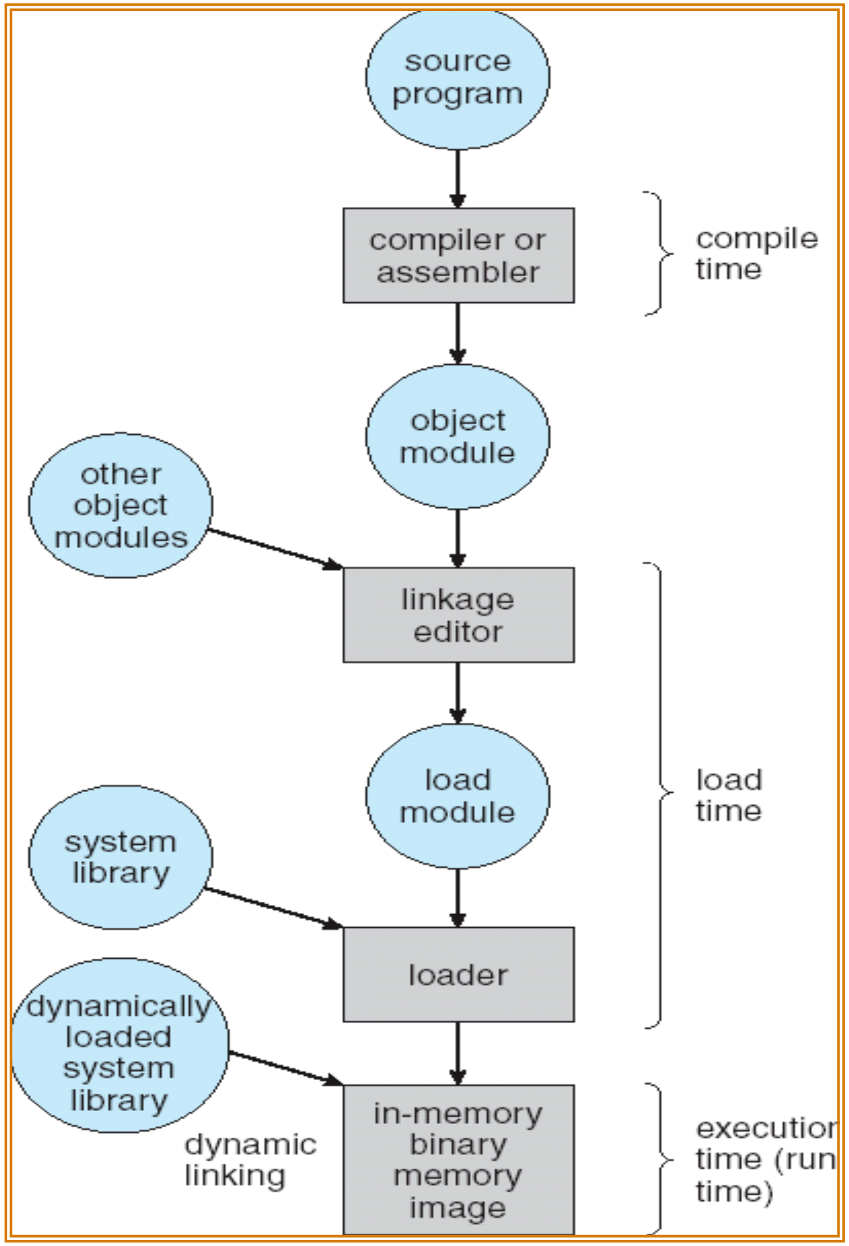


    - protect each process from others
        - Require hardware support - managed by OS
- Ideally the presence of multiple programs is transparent to the application
    - Relocation - use logical rather than physical addresses
    - Require hardware support - managed by OS
- Each program can access more than physical memory
    - Swap contents to lower levels in memory hierarchy
    - OS manages allocation of memory resources

Chapter 8: Memory management

- Program must be brought into memory and placed within a process for it to be run
- Memory hierarchy: Processor -> Registers, Cache (L1, L2, L3 ..), Main memory, hard disk
  - The closer to processor, the faster and expensive
- User programs go through several steps before being run

Multistep Processing of a User Program



Consider the helloworld.c

```
#include <stdio.h>
main() {
	printf(“Hello world\n”);
}
```

- gcc -v helloworld.c (shows what really happens)

1. cc1 -v helloworld.c -dumpbase helloworld.c -auxbase helloworld -version -o /tmp/cc9ORSny.s
2. as -V -Qy -o /tmp/ccoe1JH2.o /tmp/cc9ORSny.s
3. collect2 -m elf_i386 -dynamic-linker ld-linux.so.2 crt1.o crti.o crtbegin.o /tmp/ccoe1JH2.o -lgcc -lgcc_s -lc crtend.o crtn.o

- ldd a.out

  libc.so.6 => /lib/tls/libc.so.6 (0x009aa000)

  /lib/ld-linux.so.2 (0x00990000)

gcc -S helloworld.c to produce asm

```
 .file   "helloworld.c"
        .section        .rodata
.LC0:
        .string "Hello world\n"
        .text
.globl main
        .type   main, @function
main:
        pushl   %ebp
        [ ….. ]
        subl    $12, %esp
        pushl   $.LC0
        call    printf
        addl    $16, %esp
        leave
        ret
```

Binding of Instructions and Data to Memory

Address binding of instructions and data to memory addresses can happen at three different stages

- **Compile time**: If memory location known a priori, *absolute code* can be generated; must recompile code if starting location changes
- **Load time**: Must 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. Need hardware support for address maps (e.g., *base* and *limit registers*).

Looking into the a.out file

- nm a.out

0804958c A __bss_start

080482e4 t call_gmon_start

0804958c b completed.1

08049490 d __CTOR_END__

0804948c d __CTOR_LIST__

08049580 D __data_start

08049580 W data_start

08048430 t __do_global_ctors_aux

08048308 t __do_global_dtors_aux

08049584 D __dso_handle

…..

Loading programs

- Dynamic loading
  - Routine is not loaded until it is called
  - Better memory-space utilization; unused routine is never loaded
  - Useful when large amounts of code are needed to handle infrequently occurring cases
  - No special support from the operating system is required implemented through program design
- Dynamic Linking
  - Linking postponed until execution time
  - Small piece of code, *stub*, used to locate the appropriate memory-resident library routine
  - Stub replaces itself with the address of the routine, and executes the routine
  - Operating system needed to check if routine is in processes' memory address
  - Dynamic linking is particularly useful for libraries

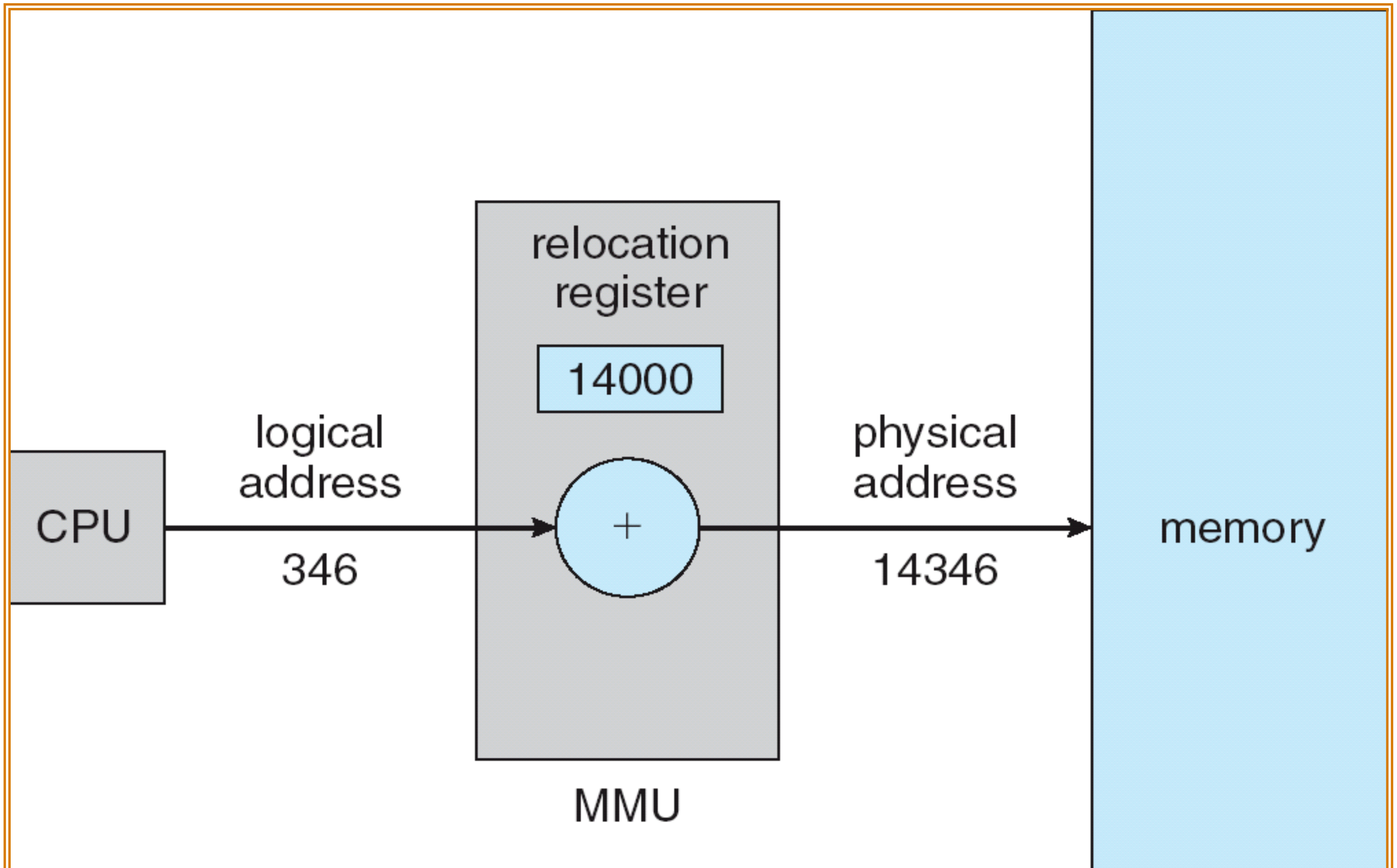
Logical vs. Physical Address Space

- The concept of a logical *address space* that is bound to a separate *physical address space* is central to proper memory management
  - **Logical address** – generated by the CPU; also referred to as *virtual address*
  - **Physical address** – address seen by the memory unit
- Logical and physical addresses are the same in compile-time and load-time address-binding schemes; logical (virtual) and physical addresses differ in execution-time address-binding scheme

Memory-Management Unit (MMU)

- Hardware device that maps virtual to physical address
- In MMU scheme, the value in the relocation register is added to every address generated by a user process at the time it is sent to memory
- The user program deals with *logical* addresses; it never sees the *real* physical addresses

Dynamic relocation using a relocation register



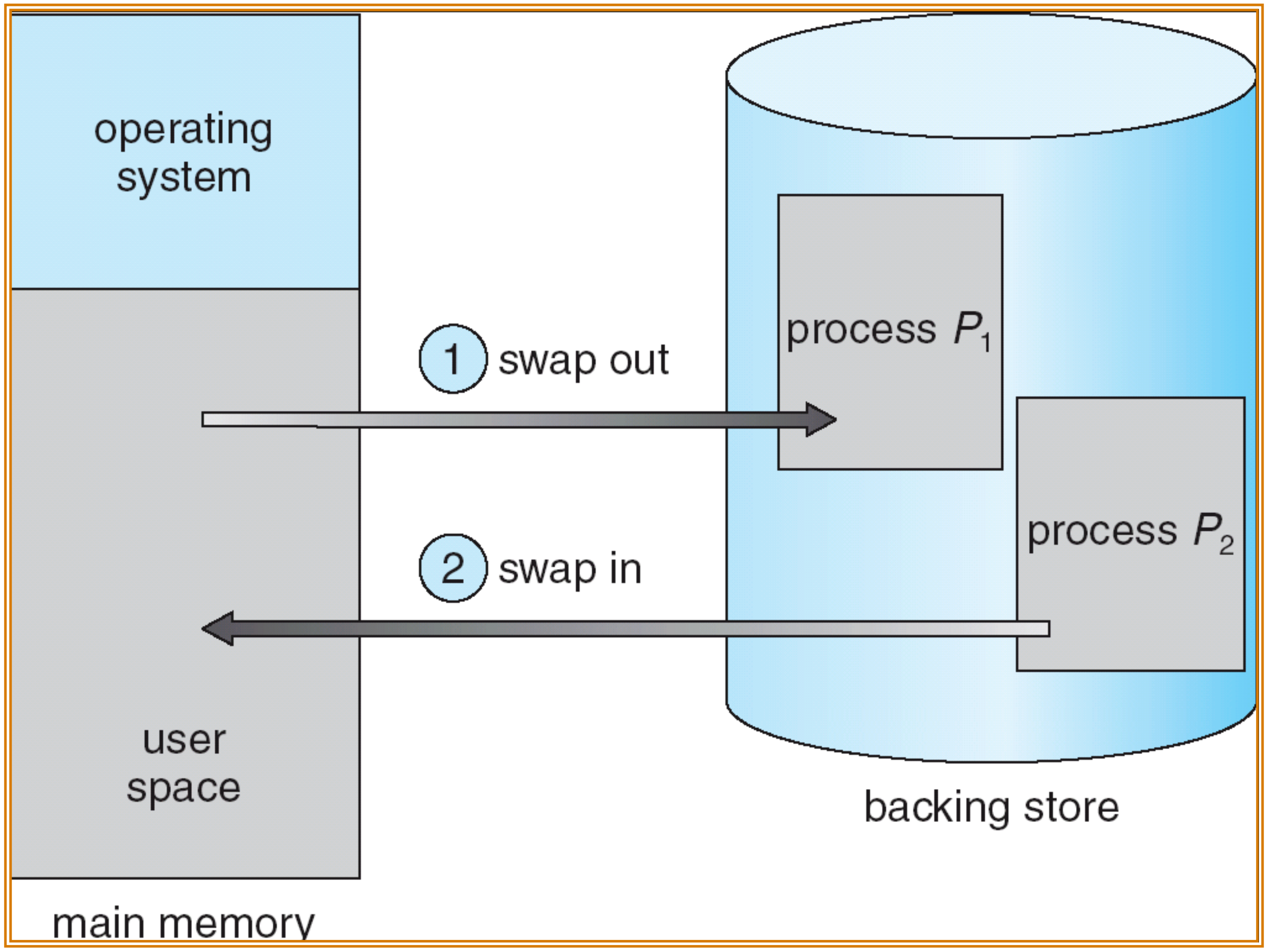
MMU is a hardware component

OS manages the relocation register
(e.g. modified while loading programs)

Swapping

- A process can be swapped temporarily out of memory to a backing store, and then brought back into memory for continued execution
- Backing store – fast disk large enough to accommodate copies of all memory images for all users; must provide direct access to these memory images
- Roll out, roll in – swapping variant used for priority-based scheduling algorithms; lower-priority process is swapped out so higher-priority process can be loaded and executed
- Major part of swap time is transfer time; total transfer time is directly proportional to the amount of memory swapped
- Modified versions of swapping are found on many systems (i.e., UNIX, Linux, and Windows)

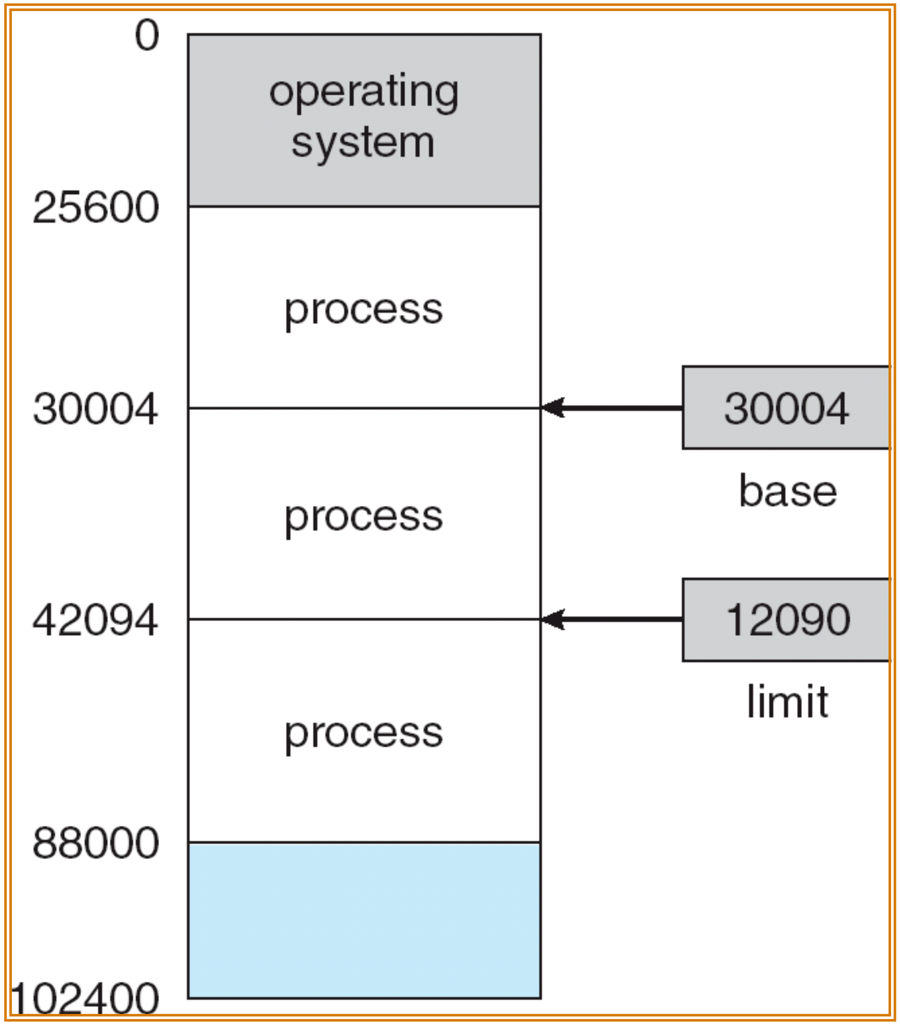
Schematic View of Swapping



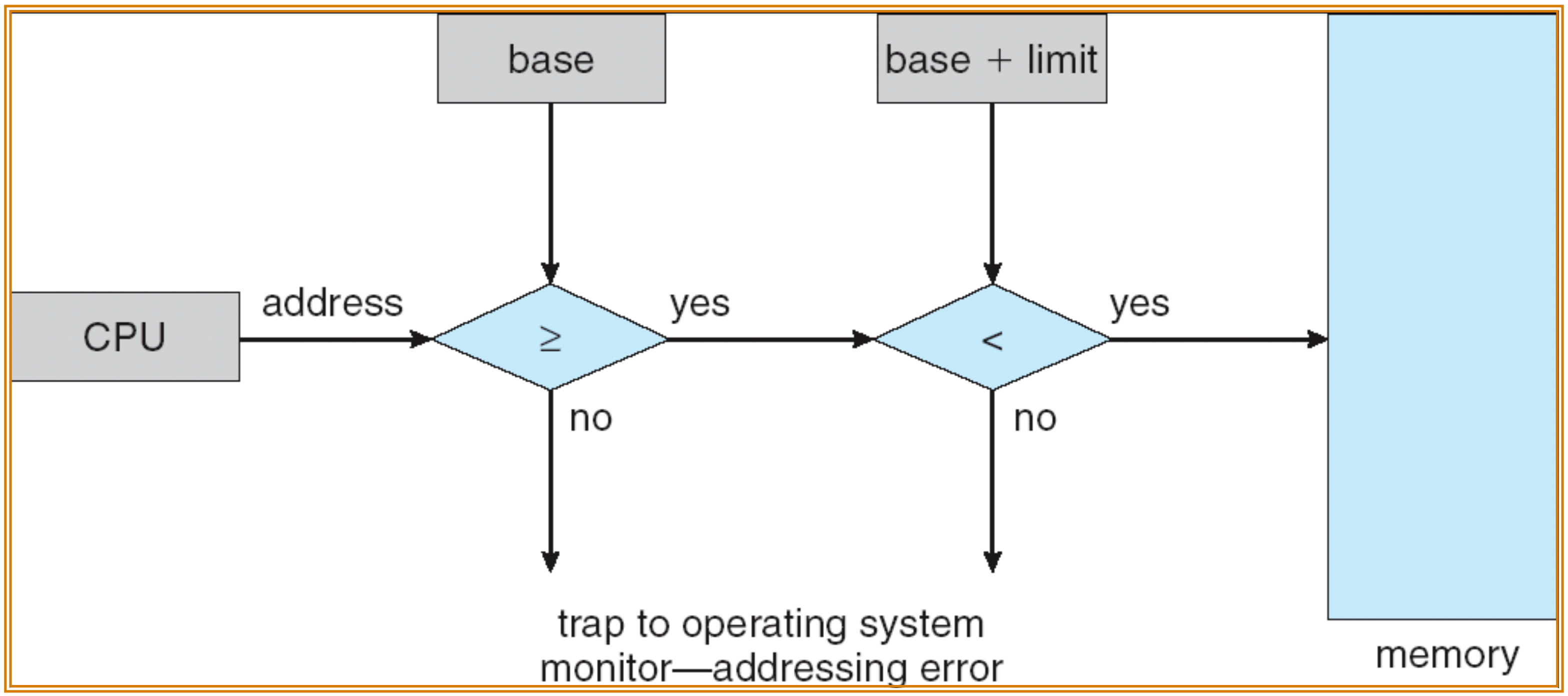
Contiguous Allocation

- Main memory usually into two partitions:
  - Resident operating system, usually held in low memory with interrupt vector
  - User processes then held in high memory
- Single-partition allocation
  - Relocation-register scheme used to protect user processes from each other, and from changing operating-system code and data
  - Relocation register contains value of smallest physical address; limit register contains range of logical addresses – each logical address must be less than the limit register

A base and a limit register define a logical address space

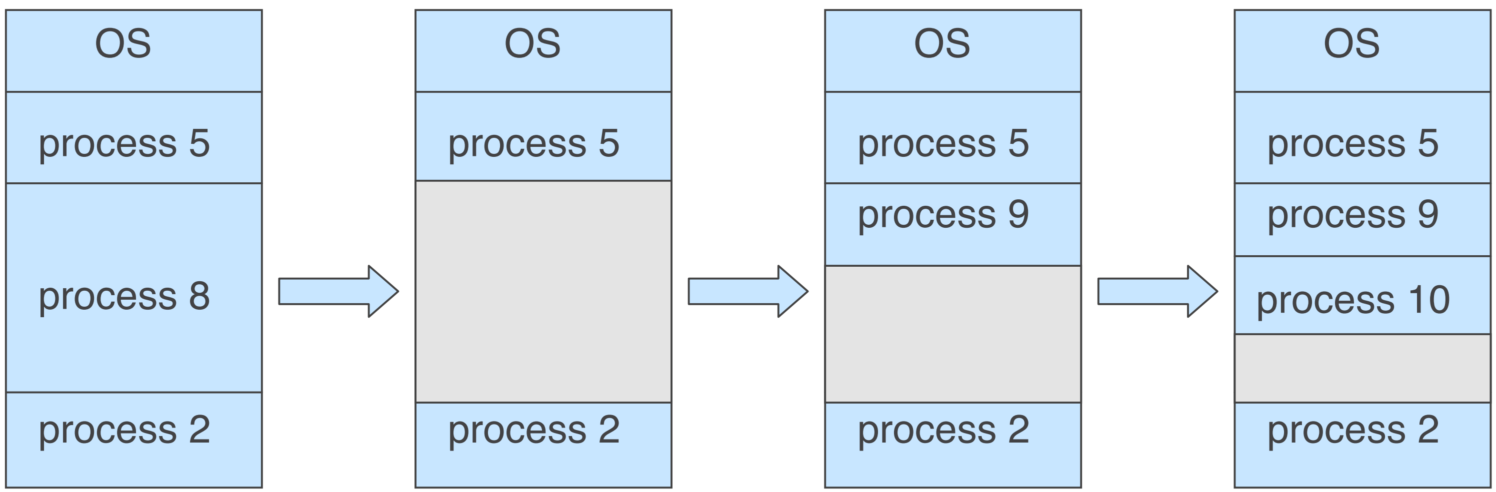


HW address protection with base and limit registers



Contiguous Allocation (Cont.)

- Multiple-partition allocation
  - *Hole* – block of available memory; holes of various size are scattered throughout memory
  - When a process arrives, it is allocated memory from a hole large enough to accommodate it
  - Operating system maintains information about:
    a) allocated partitions   b) free partitions (hole)



Dynamic Storage-Allocation Problem

How to satisfy a request of size *n* 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; must search entire list, unless ordered by size. Produces the smallest leftover hole.
- **Worst-fit**: Allocate the *largest* hole; must also search entire list. Produces the largest leftover hole.

First-fit and best-fit better than worst-fit in terms of speed and storage utilization

Fragmentation

- **External Fragmentation** – total memory space exists to satisfy a request, but it is not contiguous
- **Internal Fragmentation** – allocated memory may be slightly larger than requested memory; this size difference is memory internal to a partition, but not being used
- 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 is done at execution time
  - I/O problem - I/O may be performed by a DMA controller
    - Latch job in memory while it is involved in I/O
    - Do I/O only into OS buffers