5118020-03 Operating Systems

Address Space and Dynamic Relocation

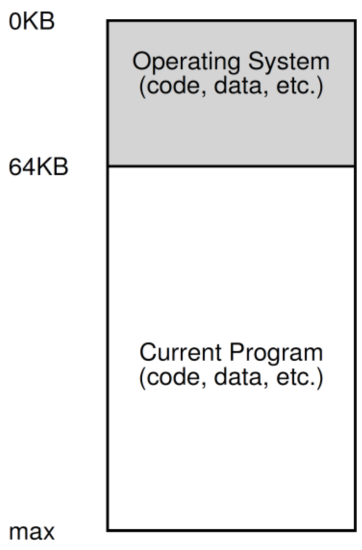
OSTEP Chapters 13 & 15

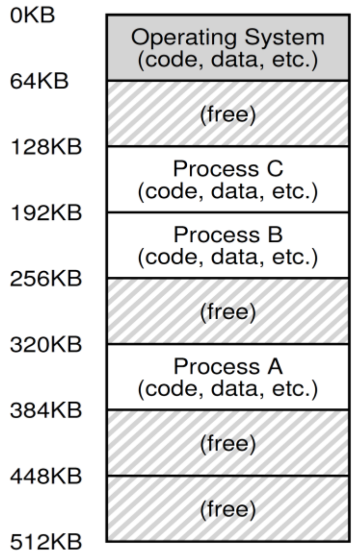
Shin Hong

Motivation

- Early computer systems did not need memory abstraction since there was no issue for a program to occupy whole memory

- Memory abstraction is required with time-sharing
  - approach 1. like CPU context switching, store the entire memory state to a storage device at a context switching
    - heavy context switching cost
  - approach 2. let a process use only a region of memory, and keep multiple processes in the memory at the same time
    - low utilization of memory
    - data protection issue

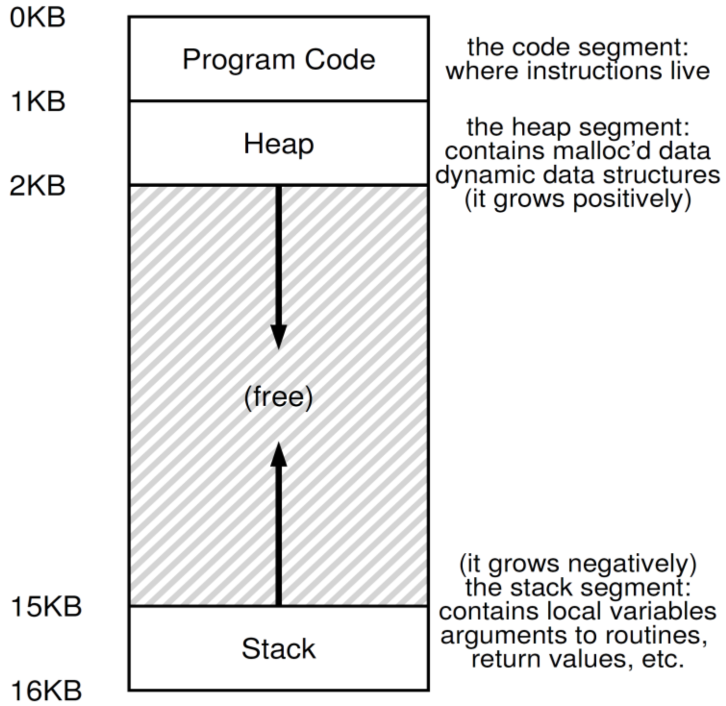




Abstraction: The Address Space

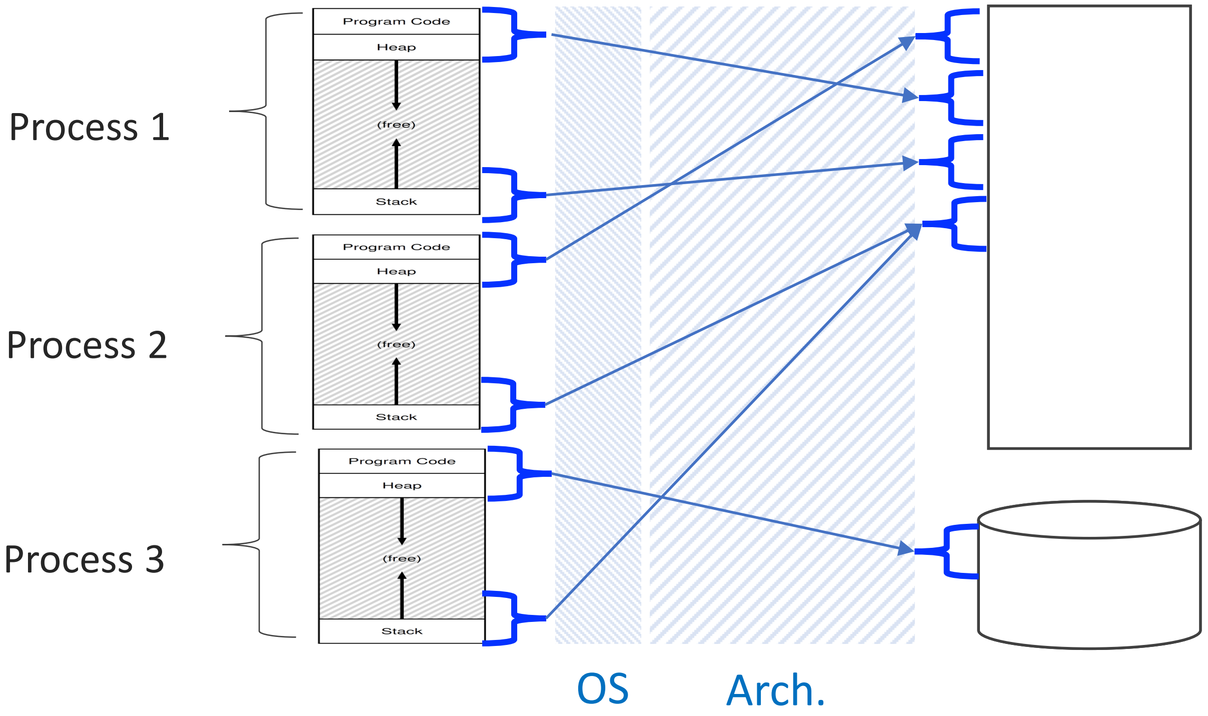
- Address space is the running program’s view of memory
  - interface between a process and memory devices

- The address space of a process has a continuous region of addresses which contains the code, the stack, the heap and all memory state



Virtual Memory

- The OS **virtualizes** memory in cooperation with computer architecture
  - the goals of memory virtualization
    - transparency (seamless-ness)
    - time-efficiency and space-efficiency
    - isolation



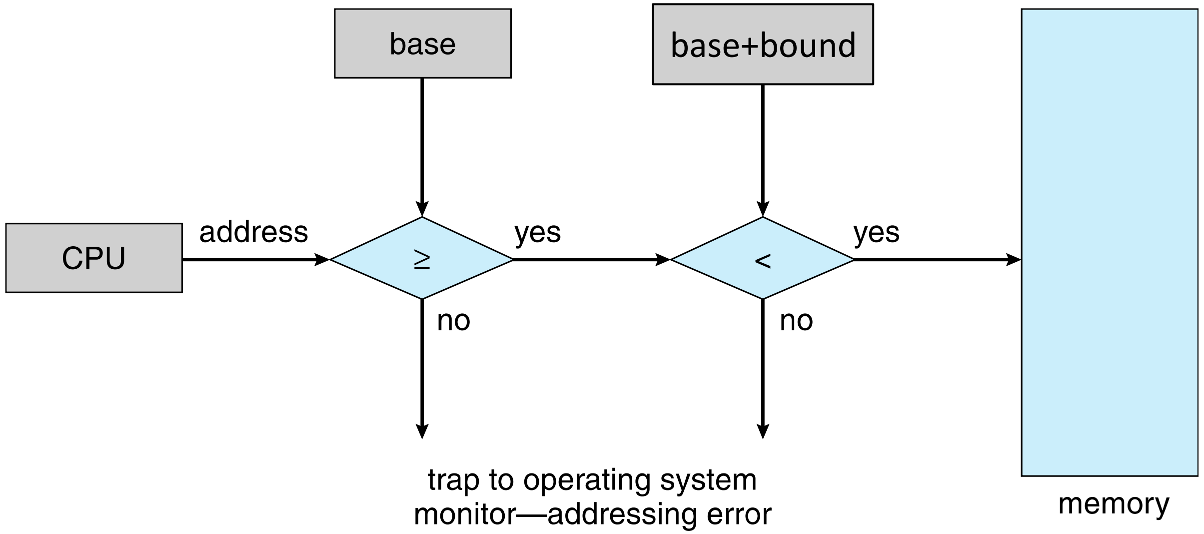
Hardware-based Address Translation

- Let a computer architecture transform each memory access by converting a virtual address to a physical address
  - like a computer architecture translates relative addresses to absolute addresses

- The OS manages a mapping from virtual addresses to physical addresses
  - the OS interposes between an application program and hardware operation at critical points to maintains control over the hardware
  - the critical points includes:
    - process creation/termination,
    - context switching,
    - when a process attends to access forbidden memory regions

Approach 1: Dynamic Relocation

- Assumption
  - The size of the address space for a process is much smaller than the total amount of available memory in the main memory device
  - Every process is given the same amount of address space
  - The MMU of the computer architecture supports the **base** register and the **bound** (limit) register
    - always translate a memory address if it's user mode
    - the base and the bound registers can be accessed only if it's in previlaged mode

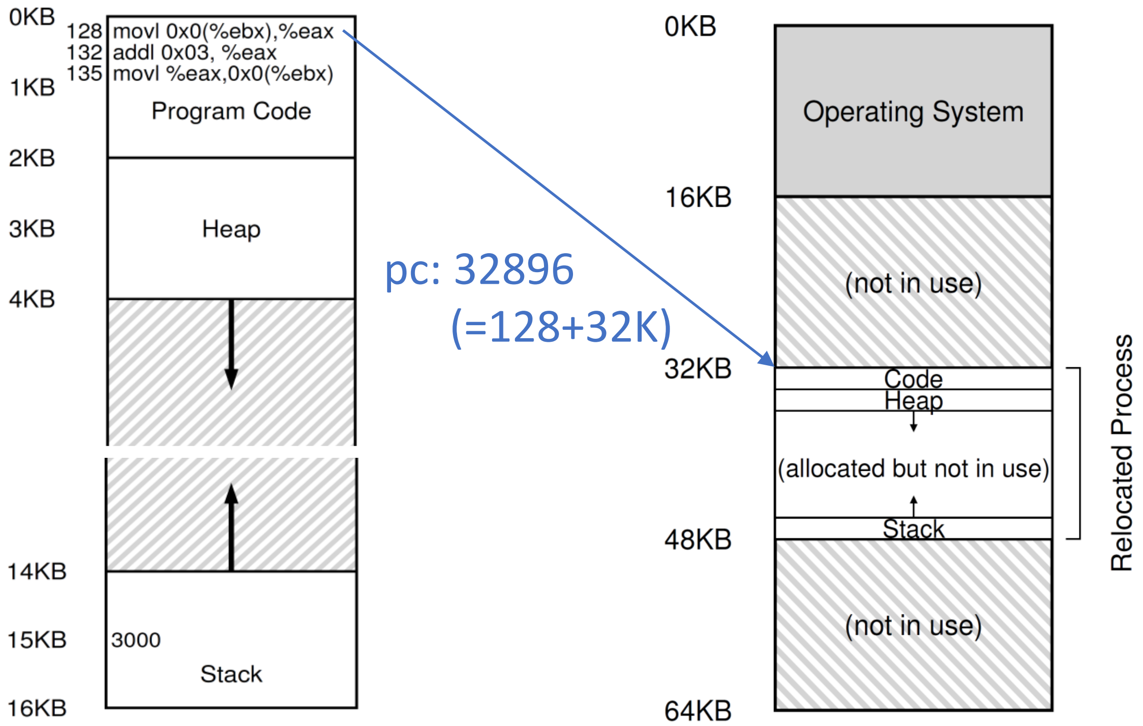


Approach 1: Dynamic Relocation

- Approach
  - Allocate a continuous region of physical memory to a process
  - Store the beginning of the allocated memory region to the base register *b*
  - Always translate a memory address of a program *m* into *m* + *b*
  - Set the bound register to raise a trap if the process tries to access an address beyond its given capacity

```
void func() {
    int x = 3000;
    x = x + 3;
    ...
```

```
128: movl 0x0(%ebx), %eax
132: addl $0x03, %eax
135: movl %eax, 0x0(%ebx)
```



Cooperation of CA and OS

- Computer Architecture
  - enforce address translation and bound check under user mode
  - raise a trap at a bound violation
  - disallow updating the base and the bound register under user mode

- OS
  - split available physical memory into multiple memory slots
    - maintain a process table and a list of free memory slots
  - allocate a free slot to a new process
  - reclaim the used slot at a process termination
  - update base at context switching
  - handle a trap (exception) raised by bound check

Example.
Limited Direct Execution
& Dynamic Relocation

OS @ run (kernel mode)	Hardware	Program (user mode)
To start process A: allocate entry in process table alloc memory for process set base/bound registers **return-from-trap** (into A)		
	restore registers of A move to **user mode** jump to A's (initial) PC	
		Process A runs Fetch instruction
	translate virtual address perform fetch	
		Execute instruction
	if explicit load/store: ensure address is legal translate virtual address perform load/store	
		(A runs...)
	Timer interrupt move to **kernel mode** jump to handler	
Handle timer decide: stop A, run B call `switch()` routine save regs(A) to proc-struct(A) (including base/bounds) restore regs(B) from proc-struct(B) (including base/bounds) **return-from-trap** (into B)		
	restore registers of B move to **user mode** jump to B's PC	
		Process B runs Execute bad load
	Load is out-of-bounds; move to **kernel mode** jump to trap handler	
Handle the trap decide to kill process B deallocate B's memory free B's entry in process table		

Limitations

- internal fragmentation
- the number of processes afforted in physical memory space
  - runtime cost of write-back at context-switching