CISC 7310X
C06: Memory Management

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Outline

- Recap & issues
  - Project 1 feedback
- Memory management: main memory
  - No memory abstraction
  - Memory abstraction: address space
  - Memory segmentation
- Assignment

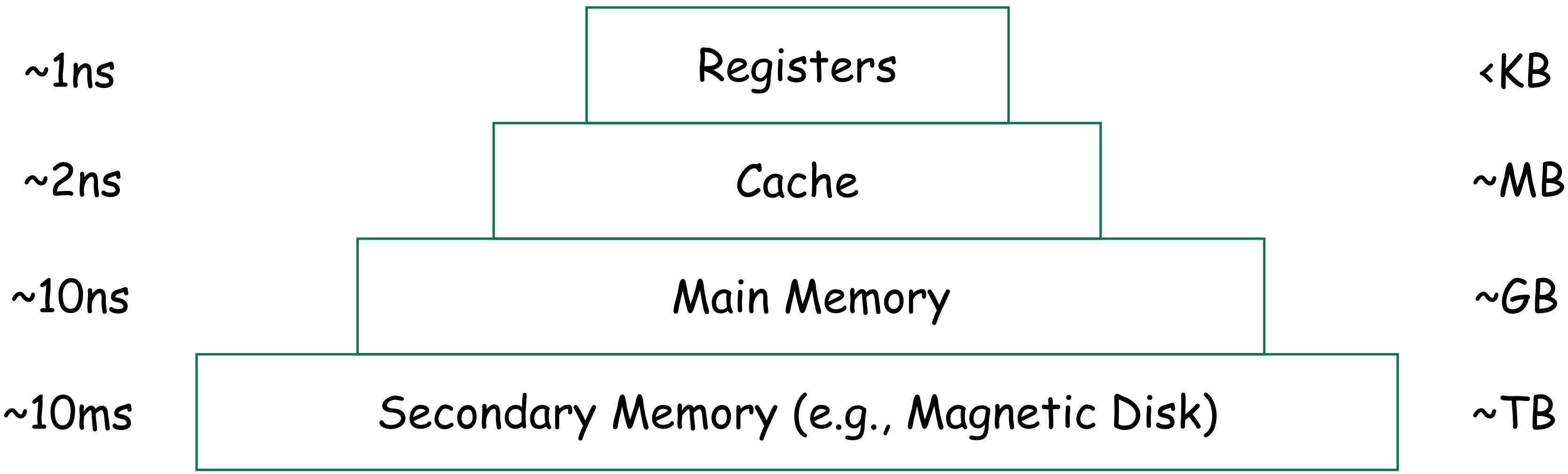
Project 1 Feedback

- Via commenting on git commits at Github

Questions?

- Project 1?
- Project 2?

Memory Hierarchy



Memory Management

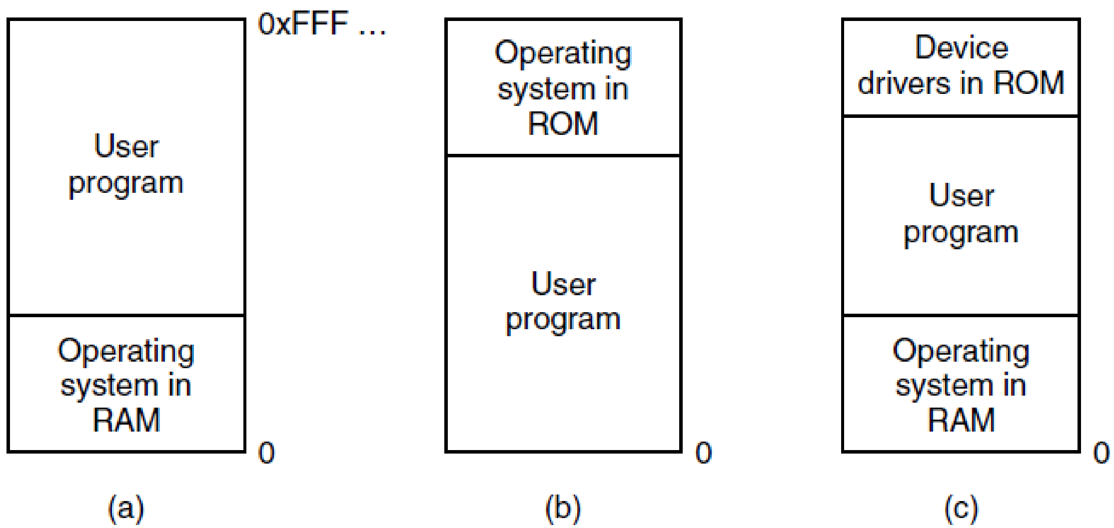
- How does an OS provide an abstraction of the memory hierarchy to make it "useful"?
  - Main memory
  - Virtual memory
  - Caching

Main Memory Management

- Without abstraction
- With abstraction
- Segmentation

No Abstraction

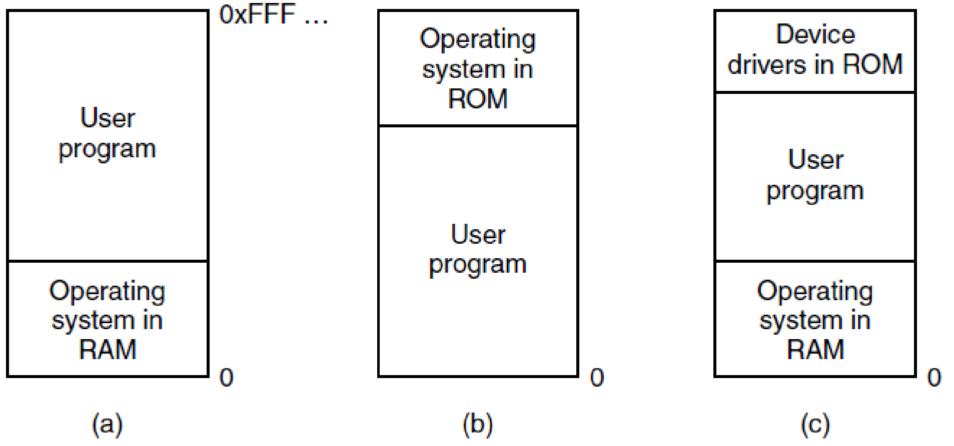
- Directly address physical memory
  - three variations



- Simple memory organization [Figure 3-1 in Tanenbaum & Bos, 2014]

What would happen if …

- Three variations




```
int *p = malloc(…)
while (1) {
    *p = value;
    p ++;
}
```

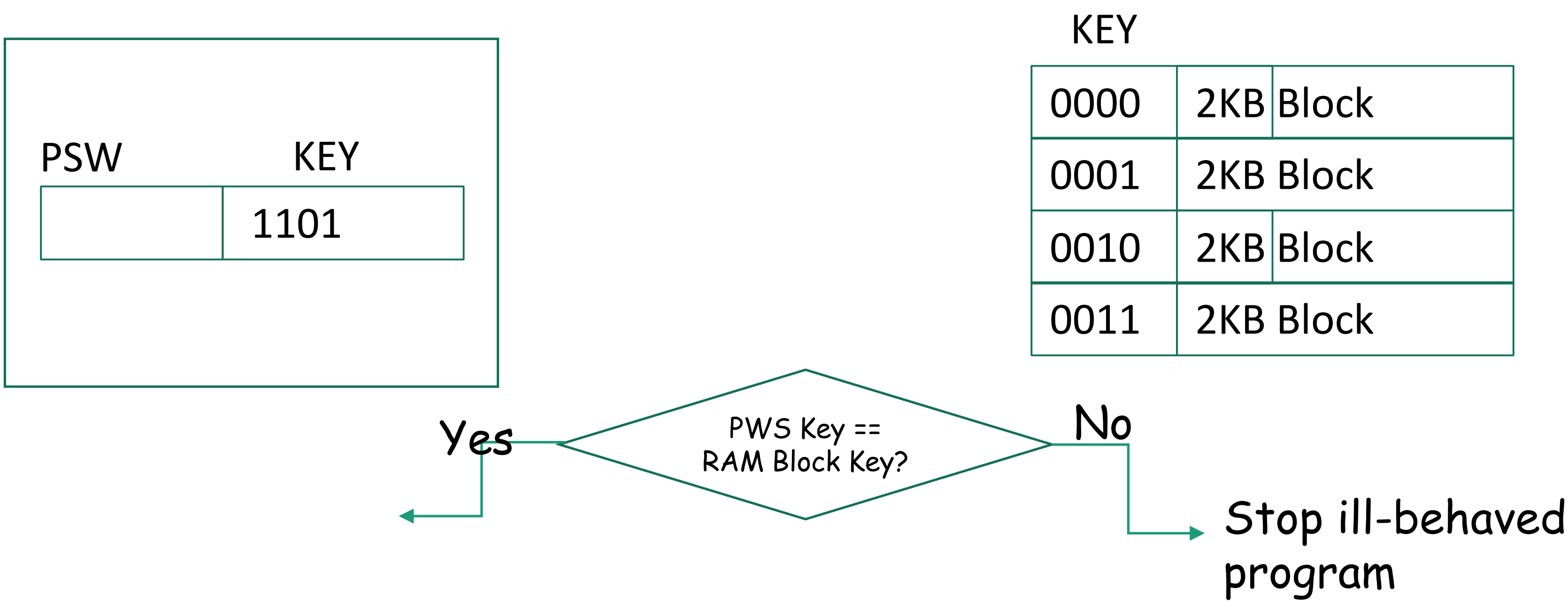
- Simple memory organization [Figure 3-1 in Tanenbaum & Bos, 2014]

Protection and Parallelism

- When without abstraction,
  - How to provide protection: prevent a program overwrite another program or the OS?
  - How to run multiple programs?
- Need additional hardware for protection

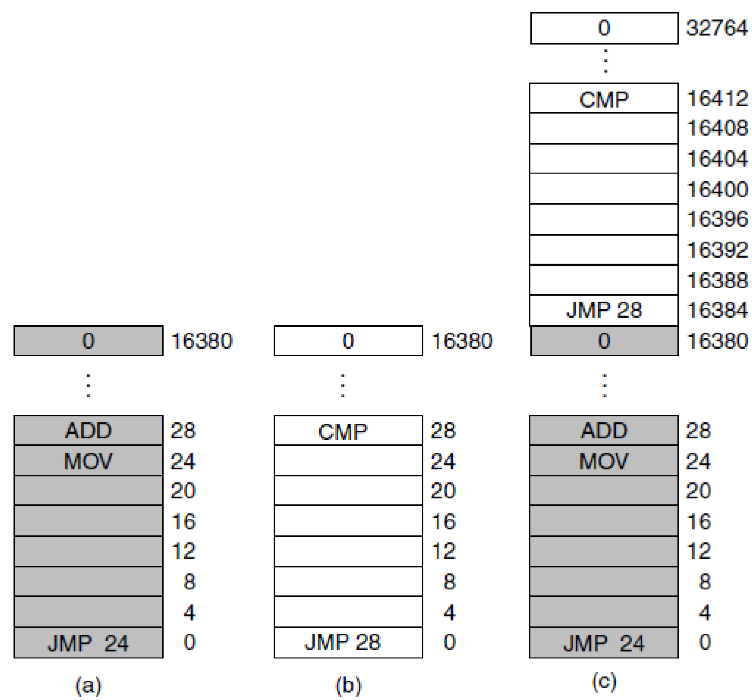
Example: IBM 360

- Allow access only when PSW key matches RAM block key



Example: Running Multiple Programs

- Naively loading two programs to run



- Loading two programs [Figure 3-2 in Tanenbaum & Bos, 2014]

Example: Static Relocation

- OS adds an offset to every address when loading
  - If the program is to load to 16384, then add 16380 to every address
    - JMP 28 → JMP 28 + 16384 → JMP 16412
  - Needs to know which is an address, which is not
    - MOV REGISTER1, 28
    - Is "28" an address or a constant?

Directly Addressing of Physical Memory

- Simple embedded devices
  - Examples: radios, washing machines, microwave ovens, coffee machines
  - A library on ROM loads a program to run and the program addresses physical memory without abstraction
  - Example: the eCos system (http://ecos.sourceware.org/)
    - "eCos is a single process, multiple thread operating environment. As such, memory management is not required. … There is no notion of separate address "spaces" in eCos like there would be in a system like Linux. All threads share the same address space and access capabilities. "
    - https://sourceware.org/viewvc/ecos/

Questions?

- No abstraction: directly addressing physical memory
  - How to run multiple programs?
  - How to provide protection?
  - How to provide relocation (static relocation)?
  - Where is it commonly used?

Memory Abstraction

- Notion of address space
- Base and limit registers
- Swapping
- Managing free memory

Address Space

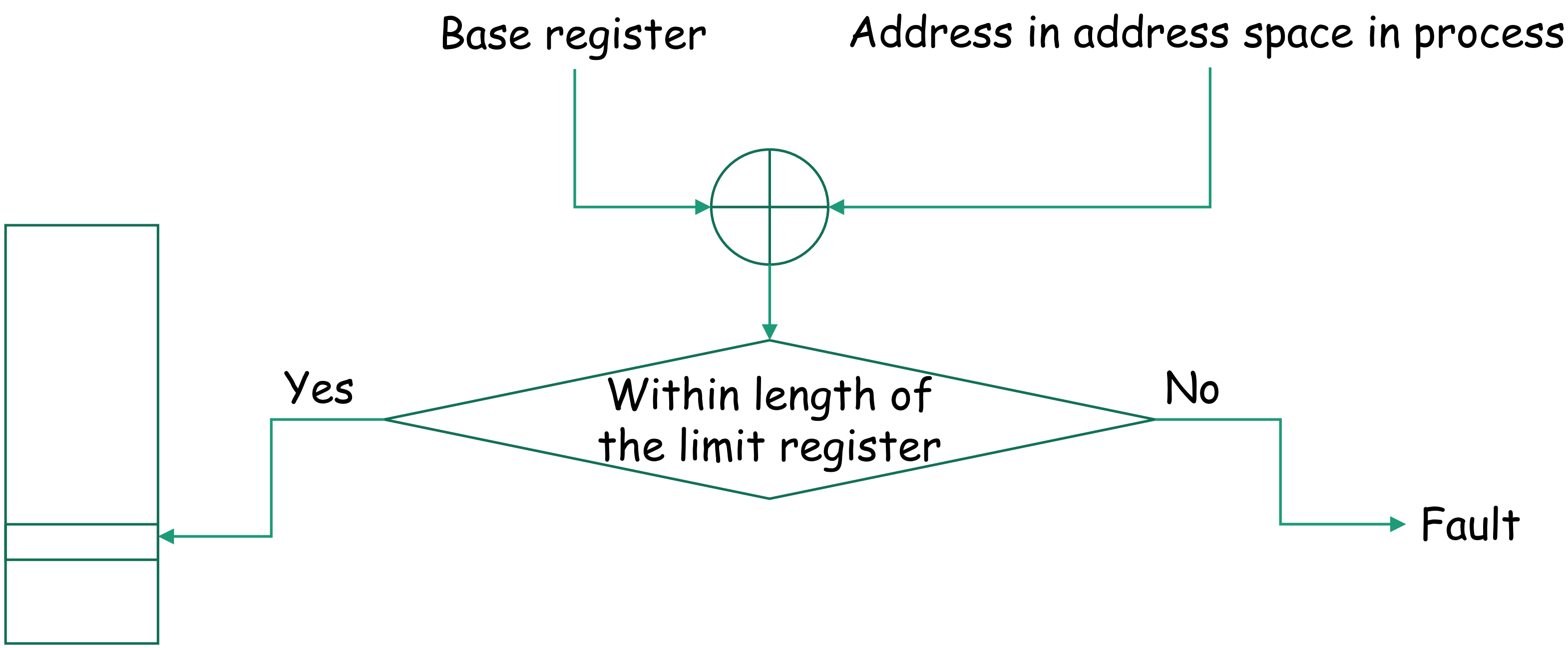
- Two problems
  - Protection and relocation
- A logical concept
  - A process has its own independent "address space", a set of addresses the process can use to address memory
    - How do we establish the correspondence between the "logical address" and the address of the physical memory?
      - Dynamic relocation

Dynamic Relocation

- Example: using base and limit registers
  - Map each process's address space onto a different part of physical memory
  - Processor has two registers
  - Base register loaded with beginning physical address
  - Limit register loaded with length of the program

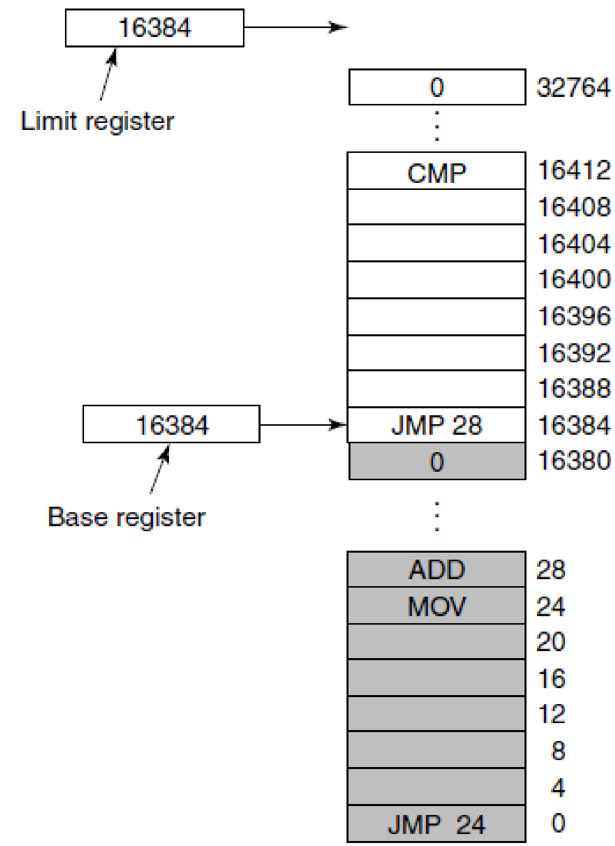
Base and Limit Registers

- Hardware support, when reference to a memory, CPU does the following,



Running Multiple Programs

- Base and limit registers realize a simple dynamic relocation and protection
  - Base register: dynamic relocation done by CPU
  - Limit register: protection done by CPU



- Dynamic relocation via base and limit registers [Figure 3-3 in Tanenbaum & Bos, 2014]

Base and Limit Registers: Examples

- Implementation vary
  - Whether base and limit registers are protected? Who can modify these registers?
    - CDC 6600 provides protection; Intel 8088 does not
  - Whether a processor has different base and limit registers to protect for programs (instructions) and data, respectively

Swapping

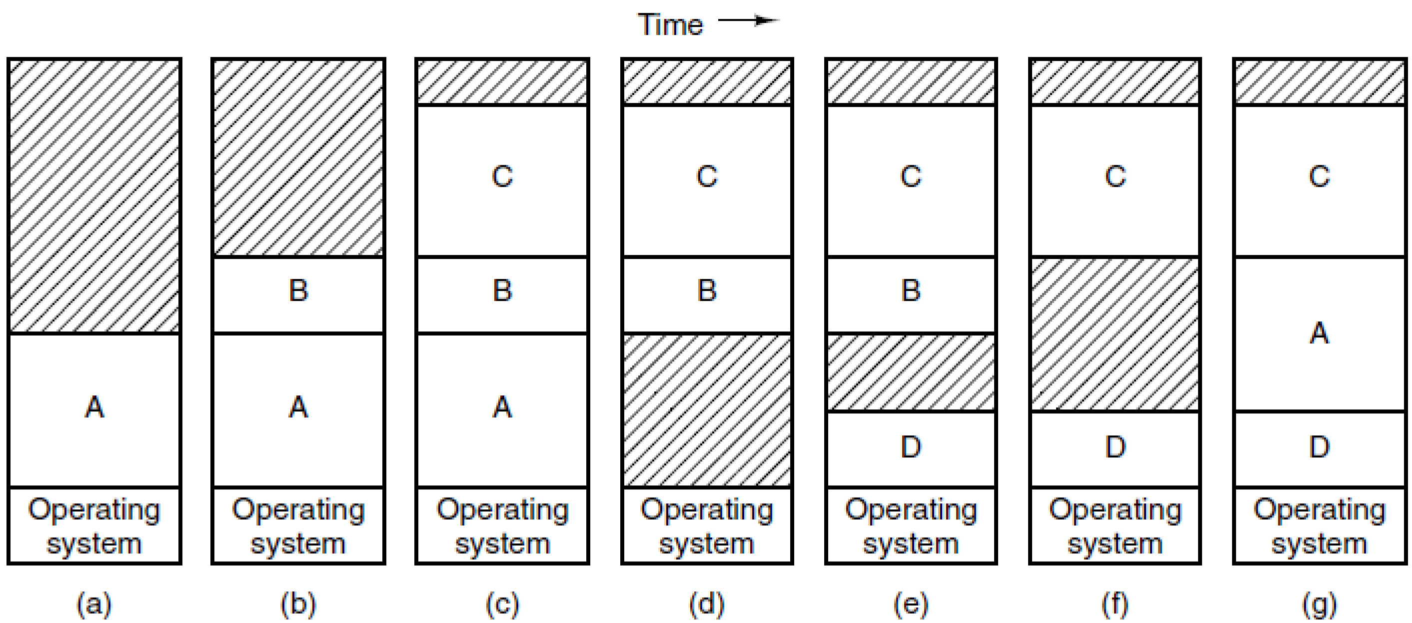
- A corollary to Parkinson's law: "Programs expands to fill the memory available to hold them"
- Running many programs may require more memory than is available
- Two solutions
  - Swapping
  - Virtual memory

Swapping & Virtual Memory

- Swapping
  - Brining in a process in entirety from the “disk”, run the process, and putting it back on the “disk”
  - Idle processes are mostly stored on disk
- Virtual memory
  - Allow a process to run even if it is only partially in main memory
  - To be discussed next

Swapping: Example

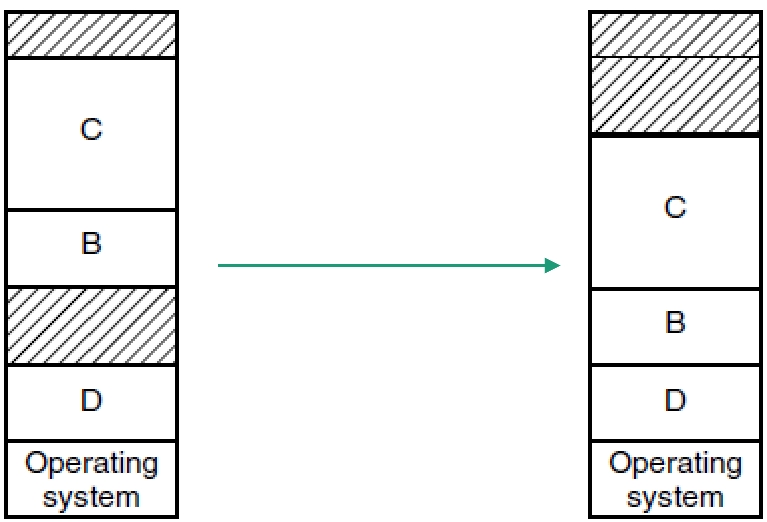
- Swapping of a few processes



- Swapping of multiple processes [Figure 3-4 in Tanenbaum & Bos, 2014]

Memory Compaction

- Swapping creates multiple holes in memory
- Sometimes it is necessary to combine multiple holes into big one



Growing Program Data Segment

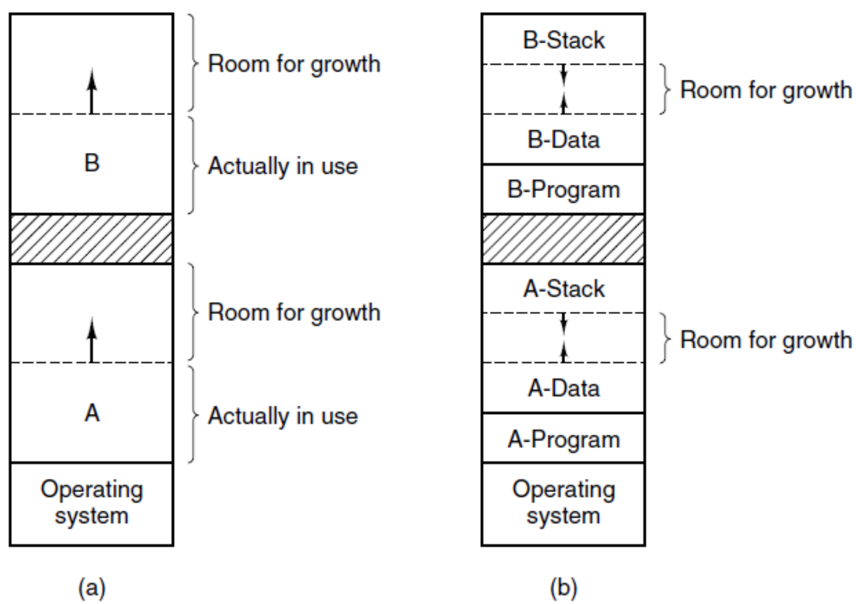
- In many programming languages, program data can grow in size
  - Example:
    - int *a = malloc(…)
    - Object o = new Object()
  - What if memory hole is not big enough to accommodate the growing program data?
    - Move process
    - Compact memory
    - Swap out one or more processes
    - Suspend the process until more memory is available
    - Killed

Proactive Approach

- Process growing in size expected, allocate extra memory when a process is swapped in or moved
- Growing data segment
- Growing stack segment

Proactive Approach: Examples

- For data segment; and for data & stack segments



  - Growing program data [Figure 3-5 in Tanenbaum & Bos, 2014]

Managing Free Memory

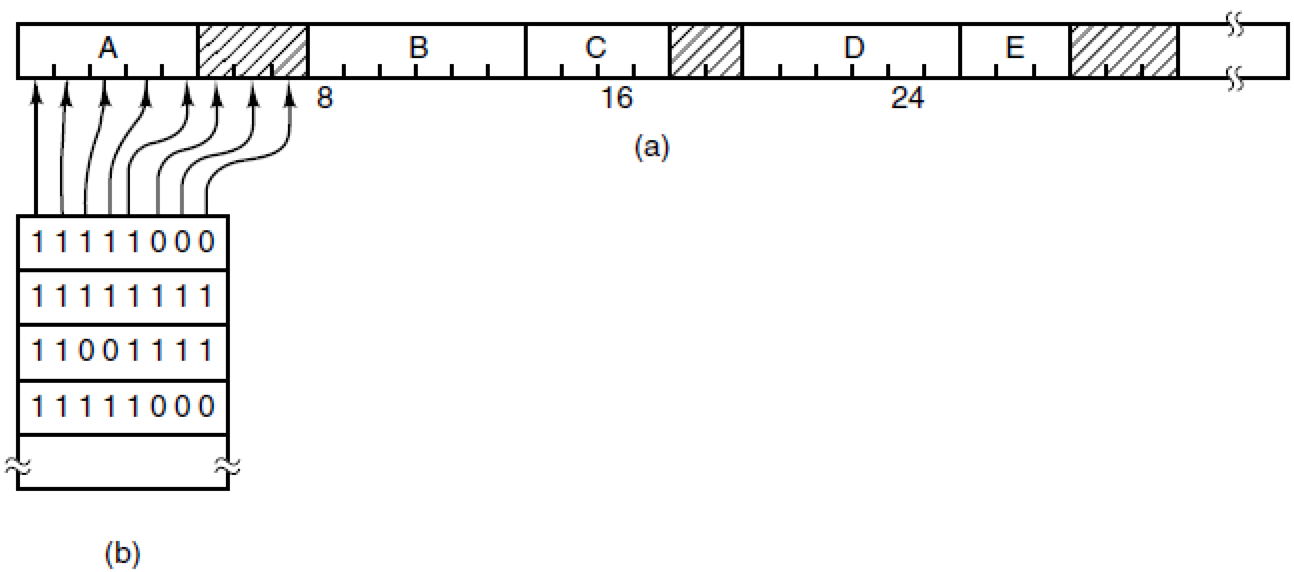
- Keep track of memory usage
- Data structures & algorithms
  - Bitmaps
  - Linked lists

Bitmaps

- A data structure keep tracks memory allocation
- Specify an allocation unit, have many allocation units
    - Example: 4 KB
- A bit in a bitmap indicate an allocation unit is free or allocated
    - Example
        - Free: 1
        - Allocated: 0

Bitmap: Example

- An example allocation and its bitmap



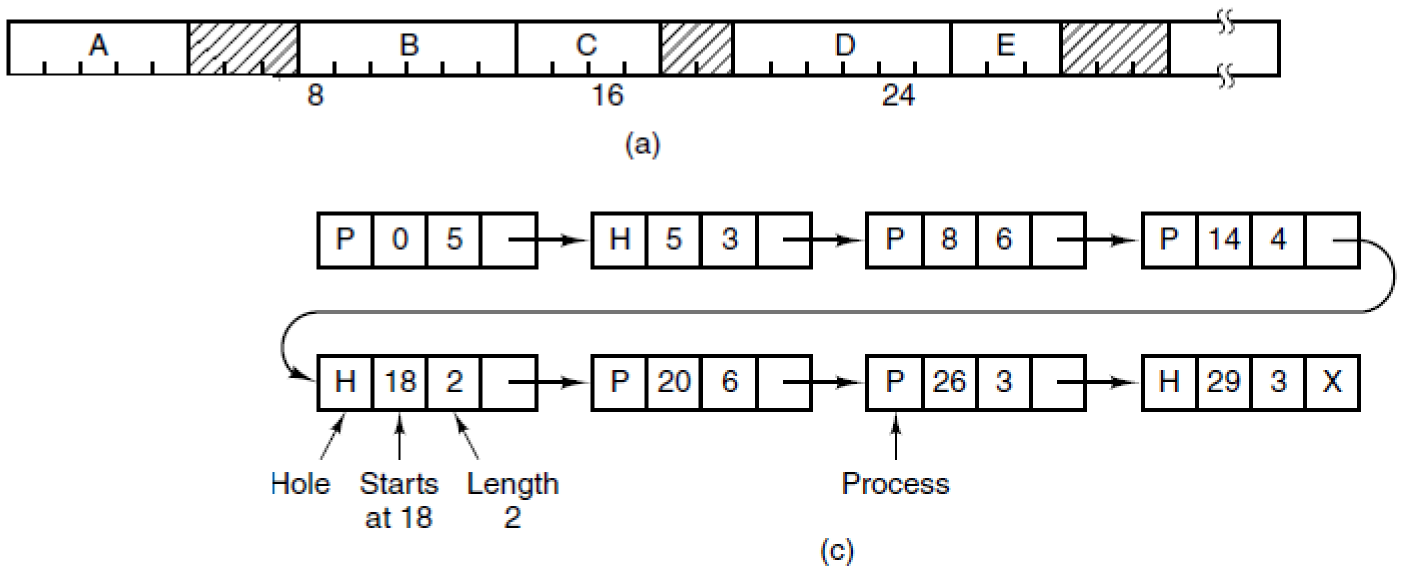
- Linked list of memory allocation [Figure 3-6 in Tanenbaum & Bos, 2014]

Design of Bitmap

- What should be the size of the allocation unit?
- Two competing factors
  - When allocation unit become smaller, bitmap larger
    - How big is a bitmap?
  - When allocation unit becomes larger, memory waste larger
    - How much waste is there?
  - How about search the bitmap to locate free memory?

Linked List

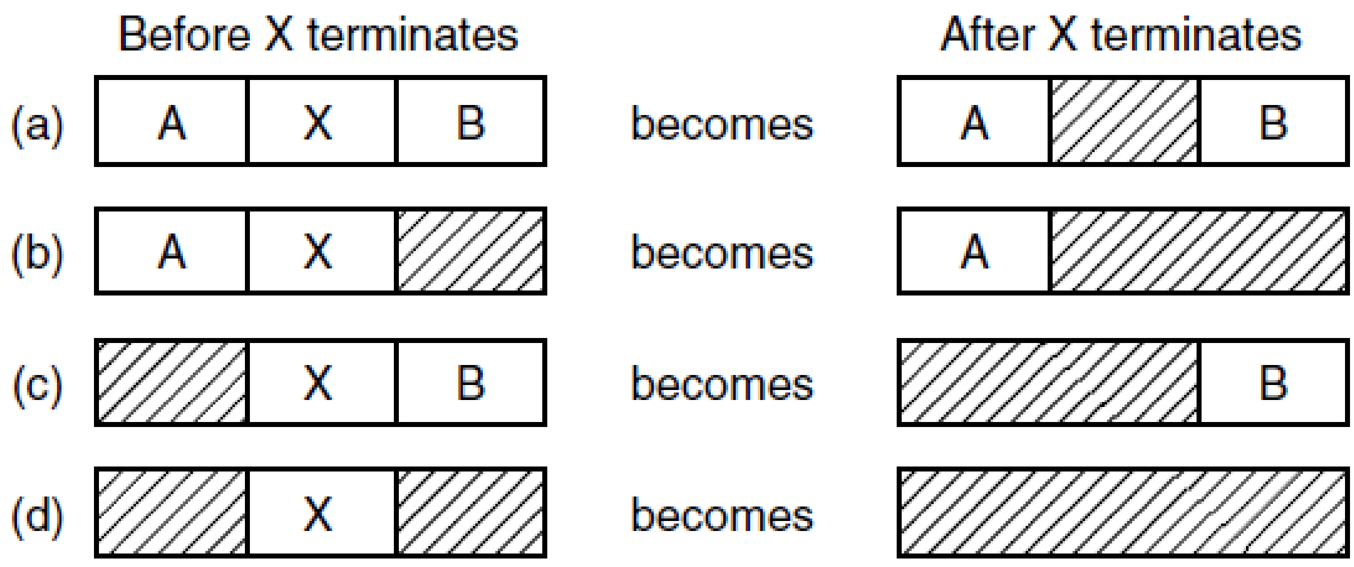
- Maintain a linked list of allocated memory and free memory segments



- Linked list of memory allocation [Figure 3-6 in Tanenbaum & Bos, 2014]

Linked List: Example

- Allocation and deallocation scenarios



- Linked list of memory allocation [Figure 3-7 in Tanenbaum & Bos, 2014]

Design of Linked List

- Single-linked list or double-linked list?
- Separate list of processes or holes?
- A few algorithms
  - First fit: starting from beginning
  - Next fit: starting from last time
  - Best fit: takes the smallest hole
  - Worst fit: takes the largest hole
  - Quick fit: based on allocation pattern
- Additional data structure?
  - Example: Holes can be sorted in size (any data structure for ordered list)

Questions?

- Address space
  - Concept?
  - Simple mechanism for dynamic allocation and protection
  - Swapping

Address Space and Process

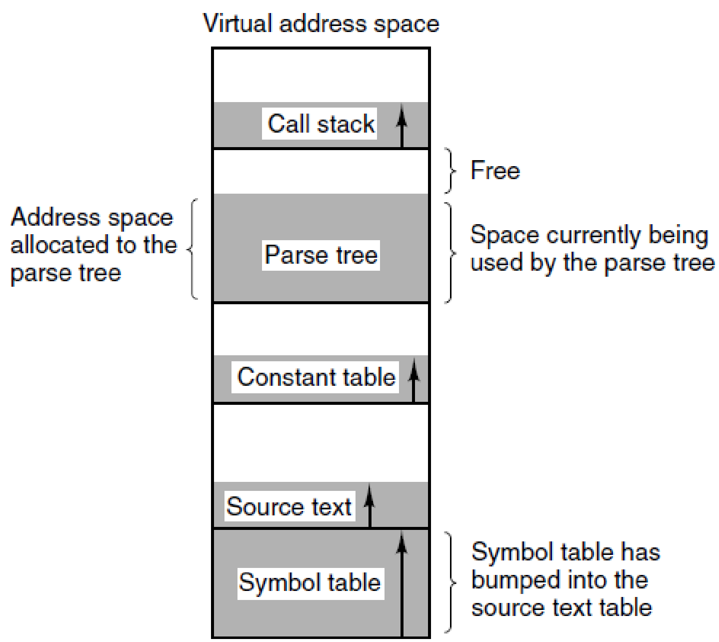
- One process one address space?

Compiled Tables

- A compiler typically builds many tables when processing a program
  1. The source text being saved for the printed listing
  2. The symbol table, names and attributes of variables.
  3. The table containing integer and floating-point constants used.
  4. The parse tree, syntactic analysis of the program.
  5. The stack used for procedure calls within compiler.
- Each of these grows continuously as compilation proceeds

Growing Tables: Example

- One address space for all?



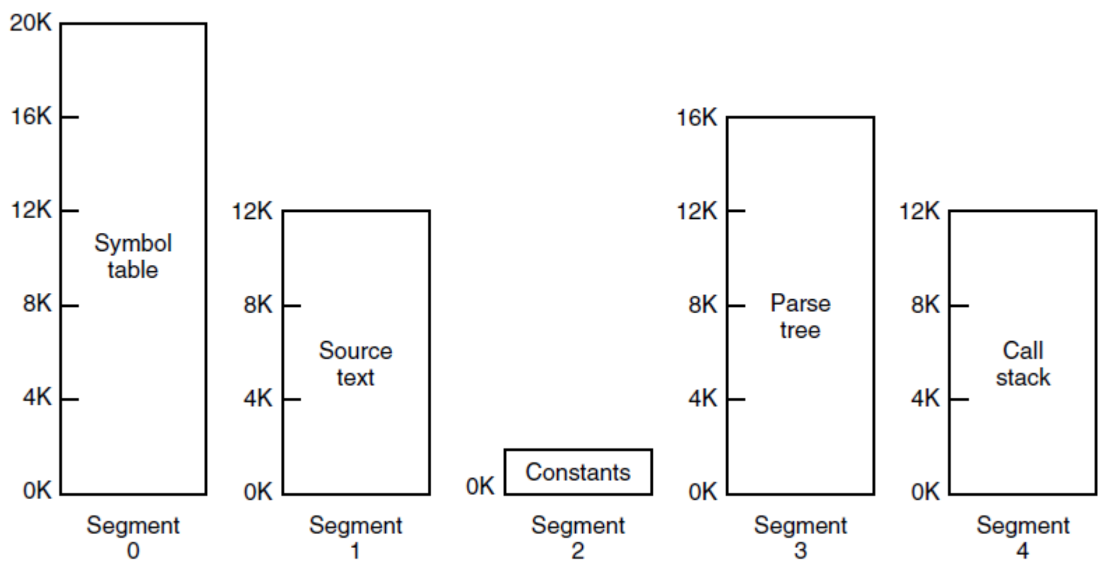
- One address space for all [Figure 3-30 in Tanenbaum & Bos, 2014]

Segmentation

- Provide many completely independent address spaces, called segments
  - Each segment consists of a linear sequence of address
  - Different segments can have different lengths
  - Segments can grow or shrink independently without affection others

Segmentation: Example

- Segments can grow or shrink independently without affection others



- Multiple segments [Figure 3-31 in Tanenbaum & Bos, 2014]

Questions

- Concept of segmentation

Assignment

- Practice assignment
- Review Guide #1 and Take-Home Test #1