CSCI-GA.2250-001

Operating Systems

Lecture 5: Memory Management I

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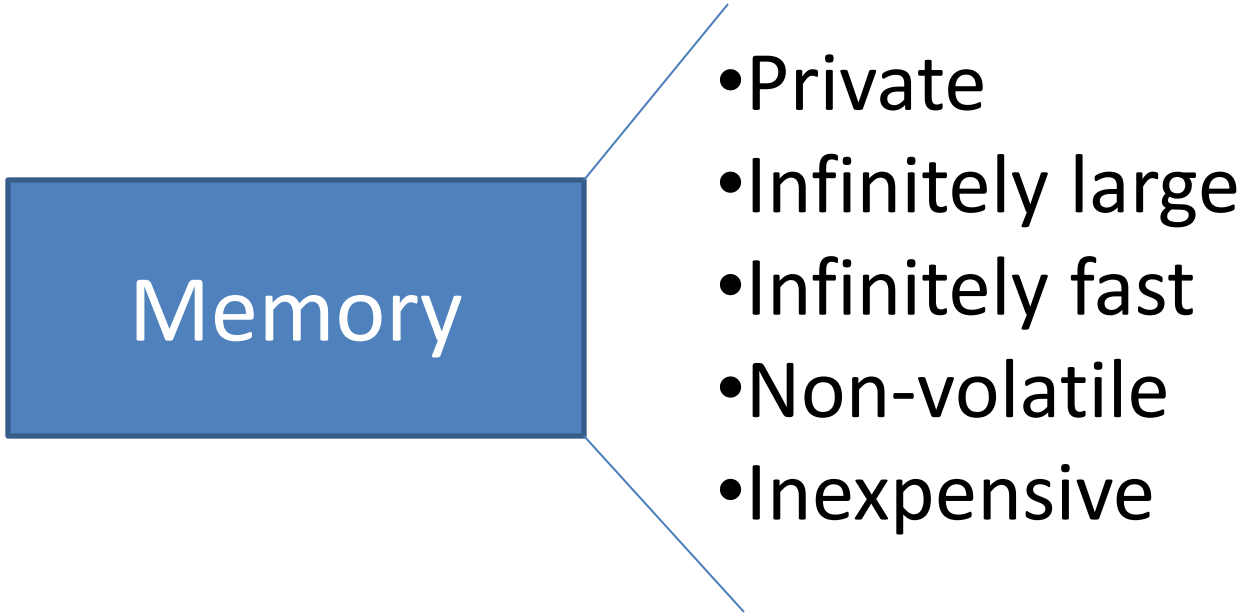
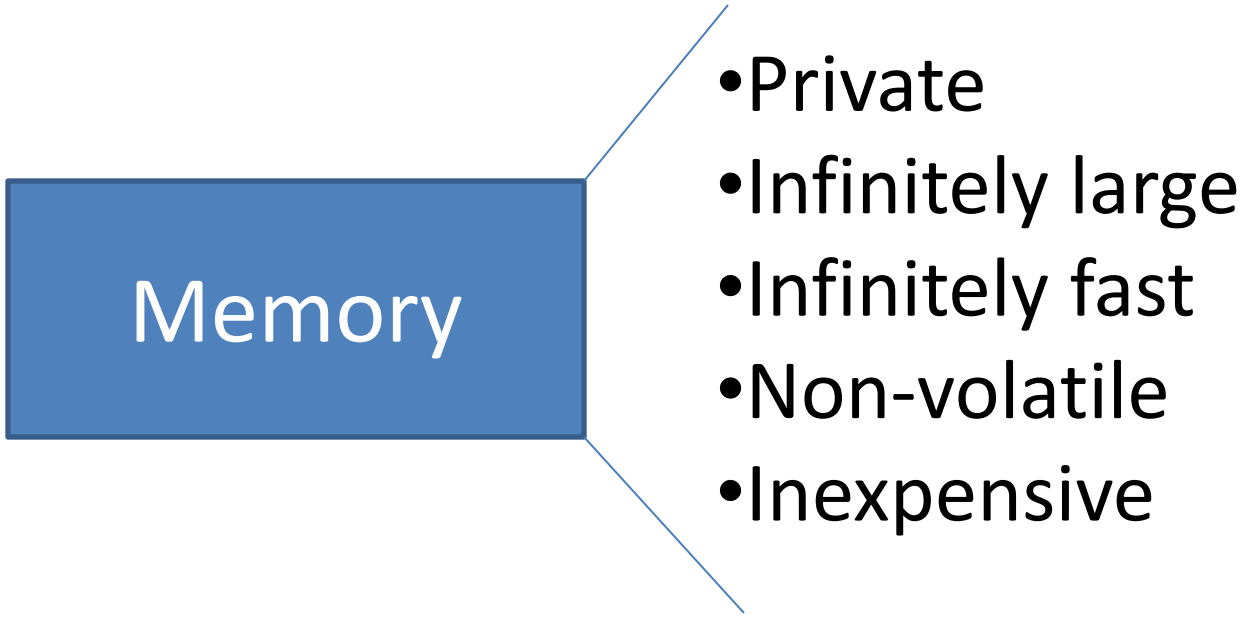
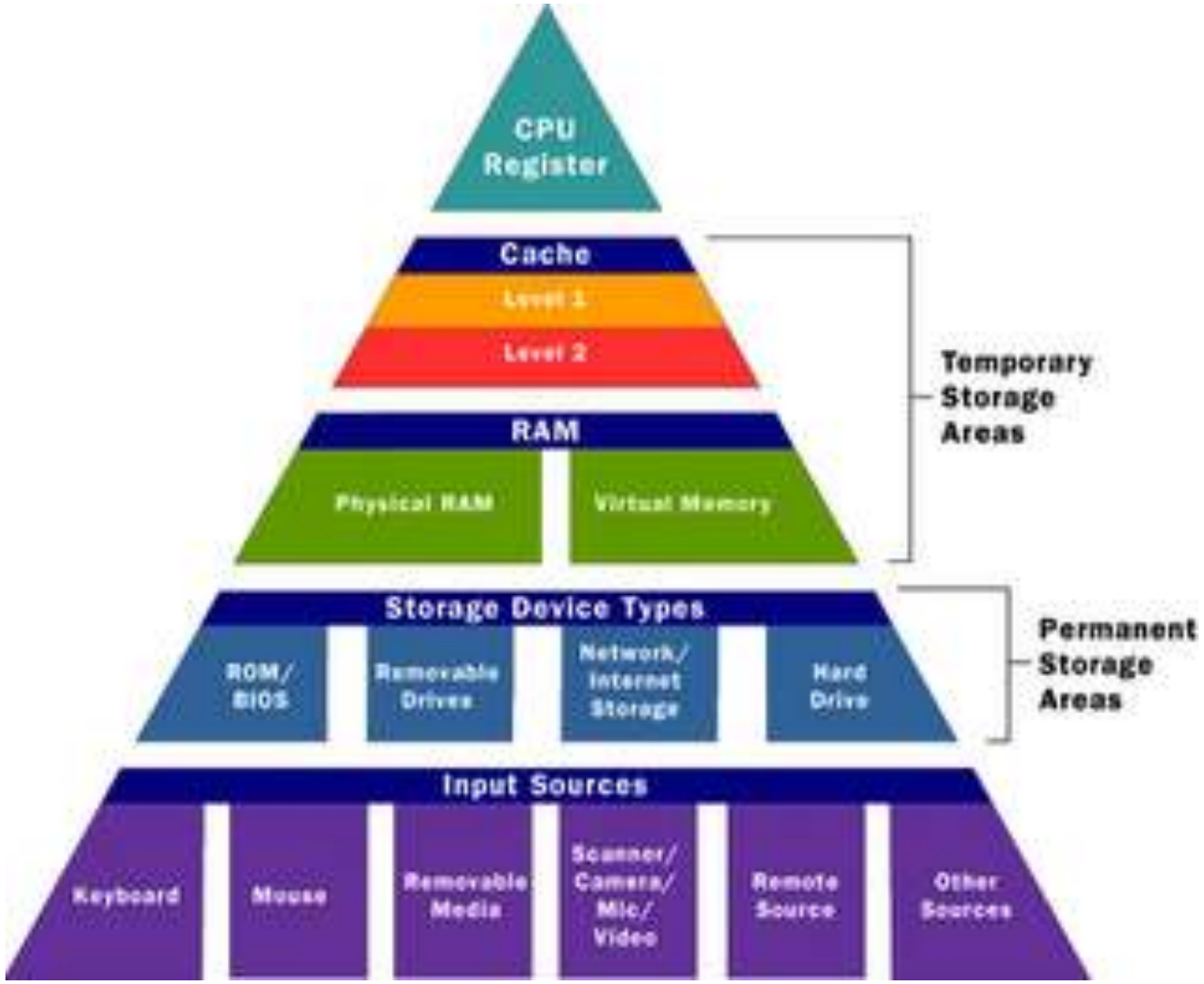
Programmer's dream



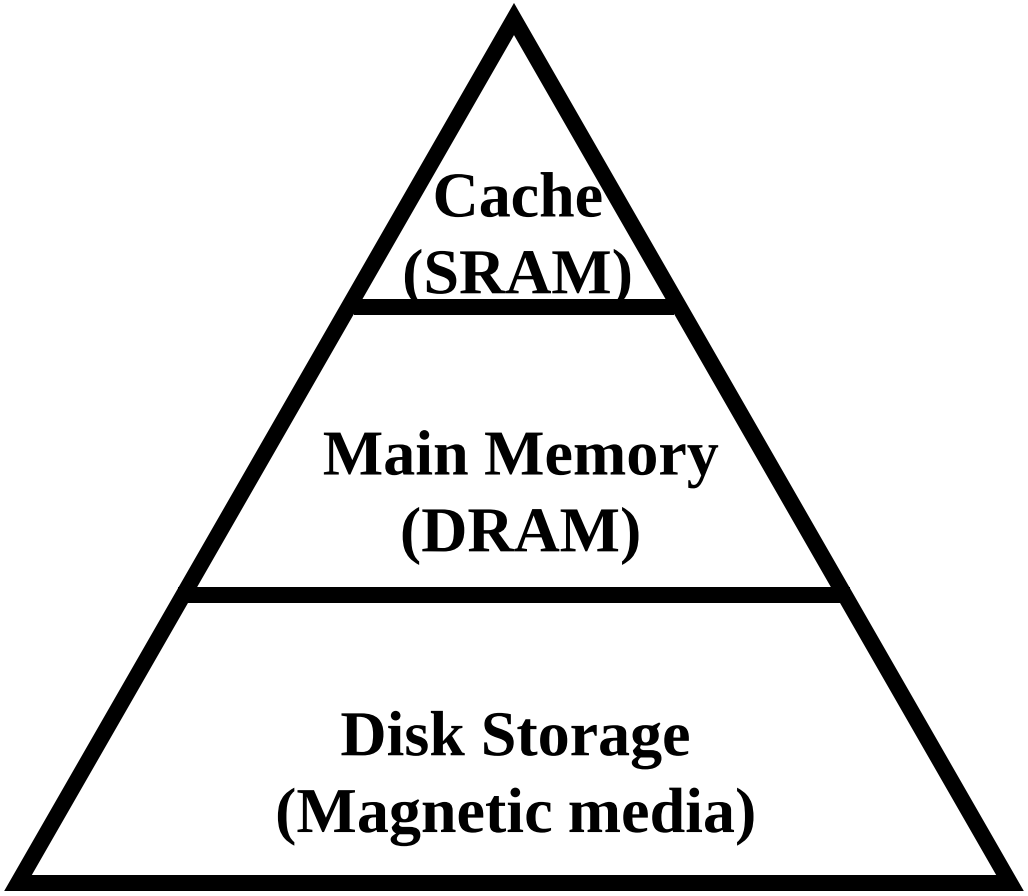
Programmer's Wish List



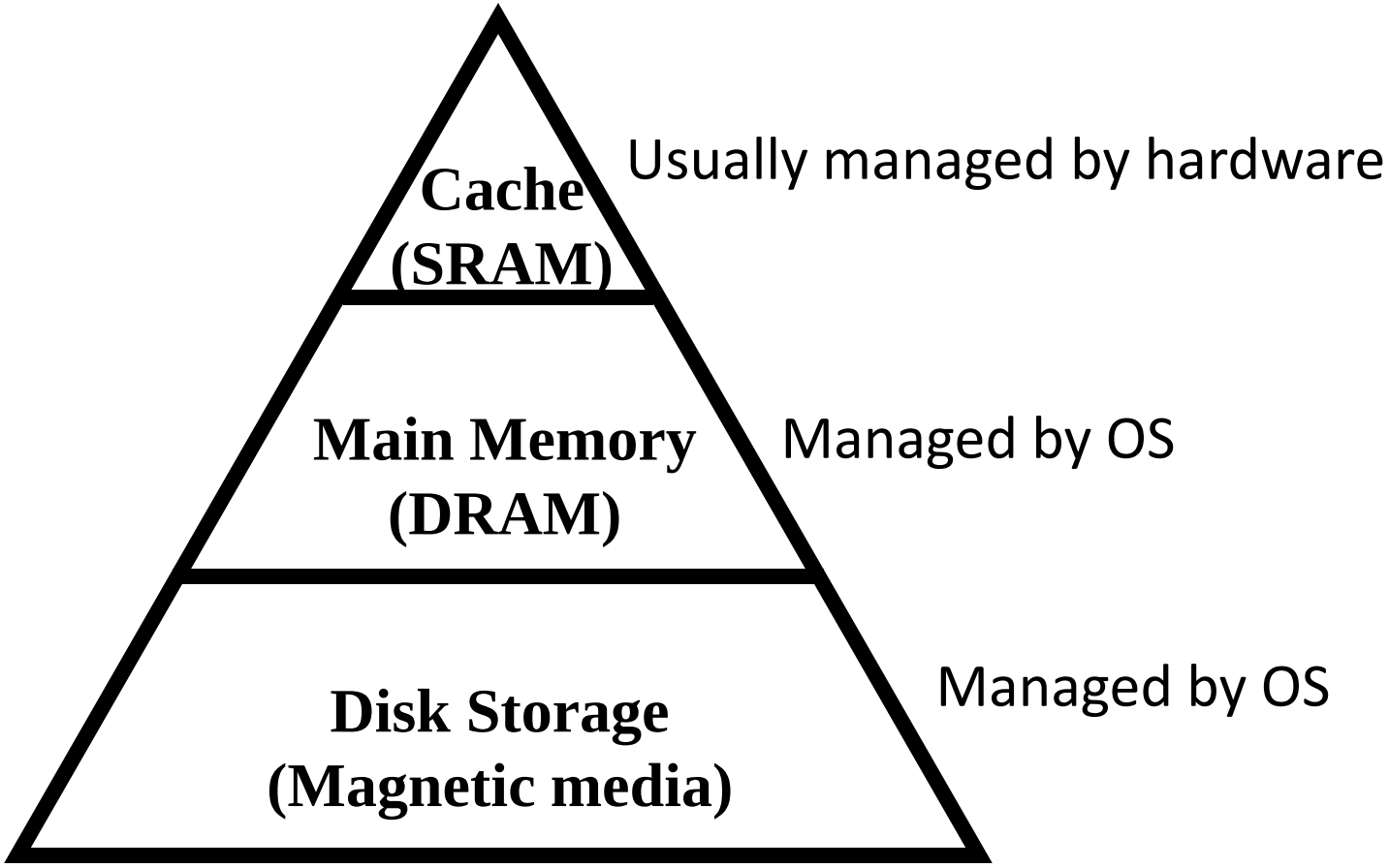
Programs are getting bigger faster than memories.


CPU
Register
Cache
Level 1
Level 2
RAM
Physical RAM
Virtual Memory
Temporary
Storage
Areas
Storage Device Types
ROM/
BIOS
Removable
Drives
Network/
Internet
Storage
Hard
Drive
Permanent
Storage
Areas
Input Sources
Keyboard
Mouse
Removable
Media
Scanner/
Camera/
Mic/
Video
Remote
Source
Other
Sources

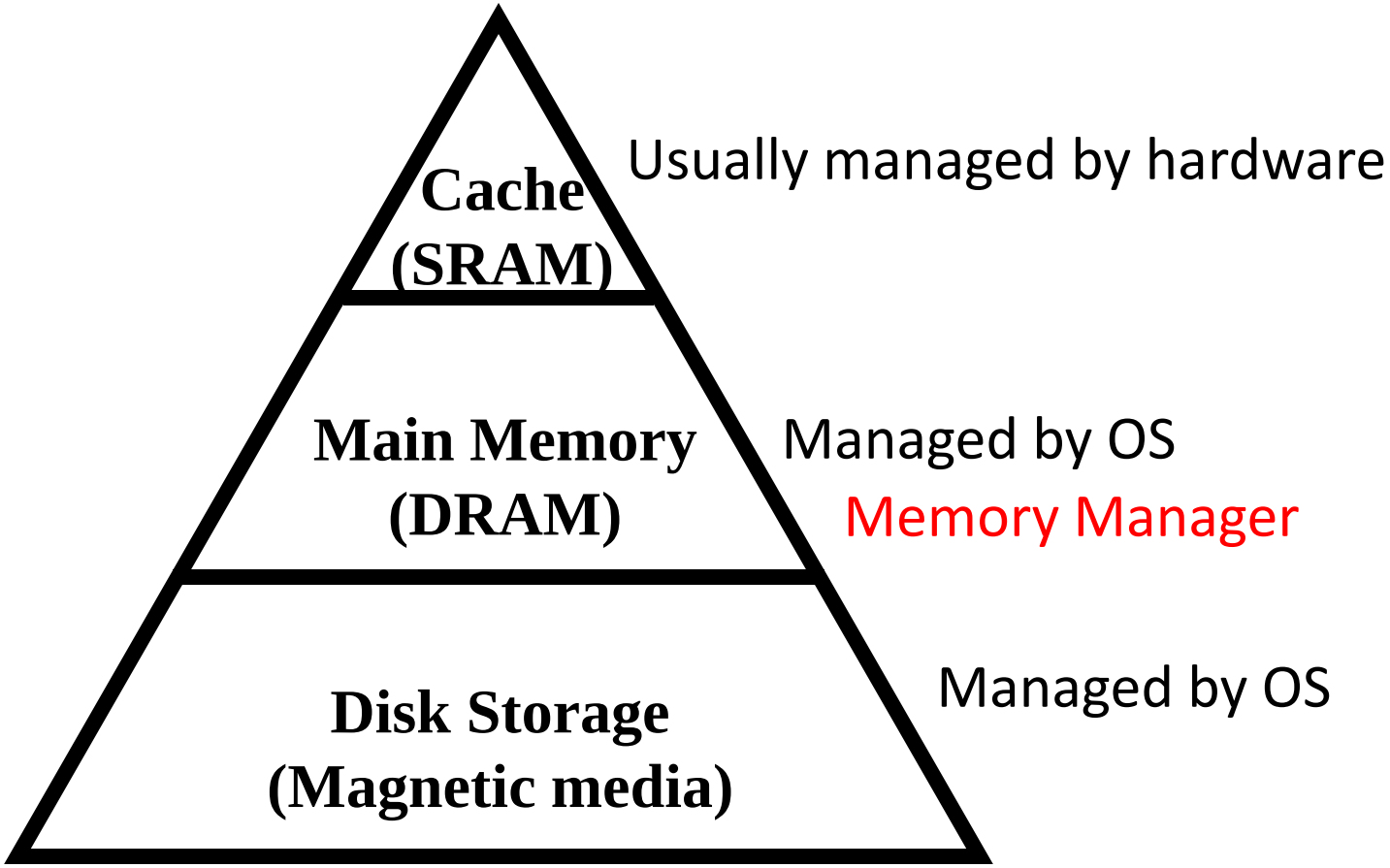
Memory Hierarchy



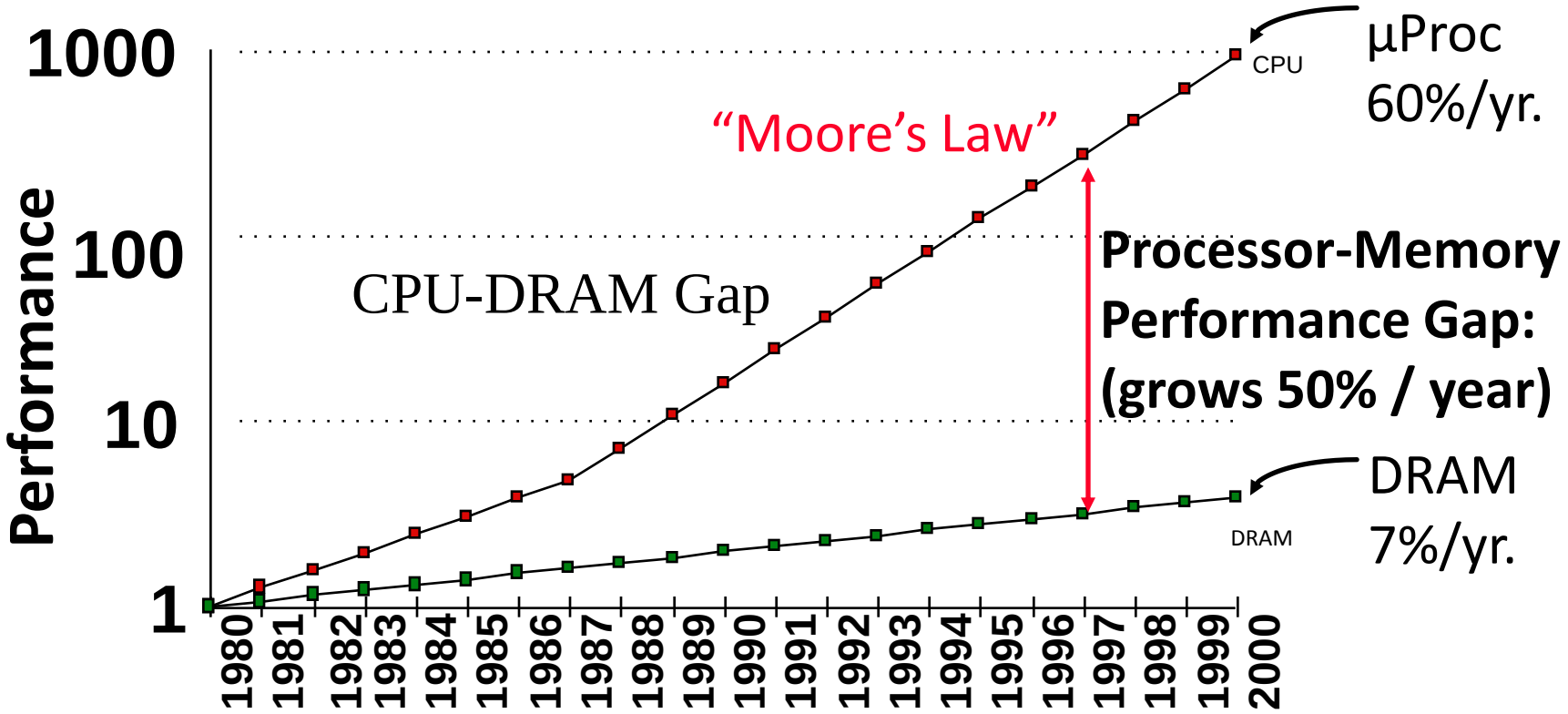
Memory Hierarchy



Memory Hierarchy



Question: Who Cares About the Memory Hierarchy?

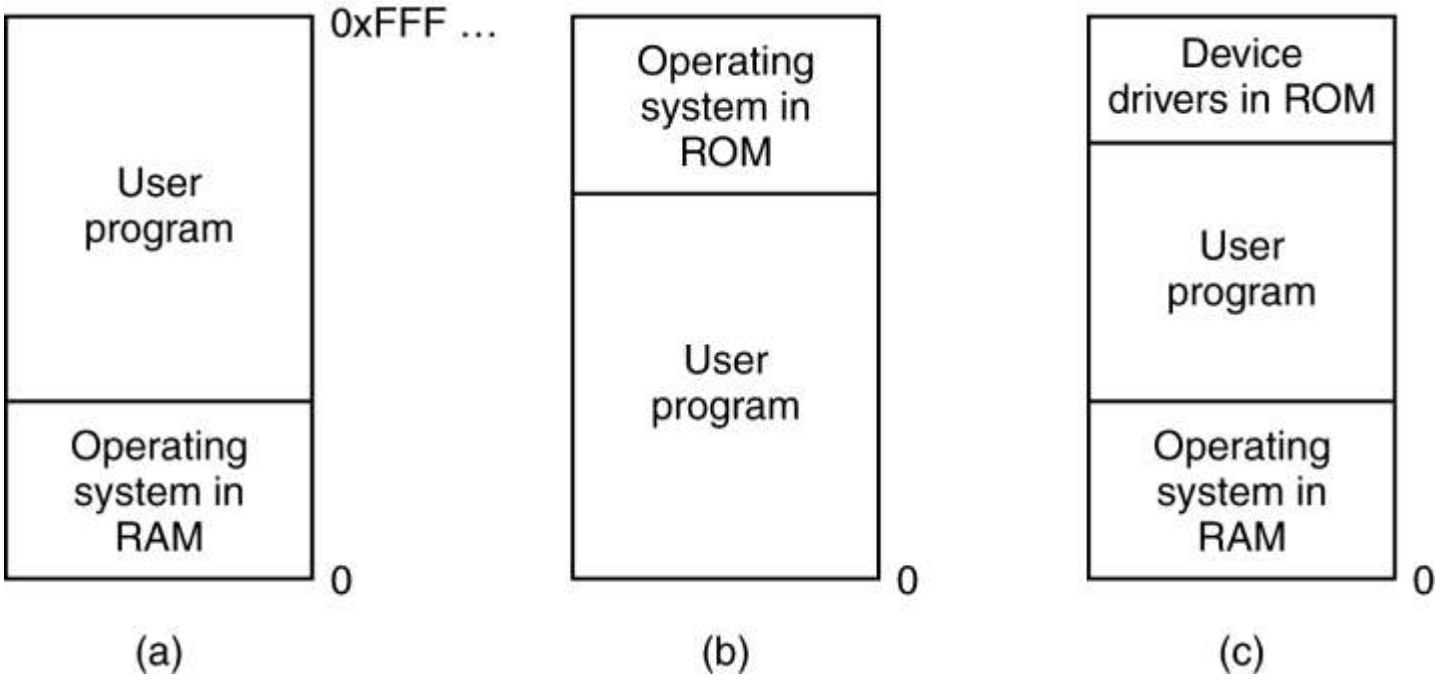


Memory Abstraction

- The hardware and OS memory manager makes you see the memory as a single contiguous entity
- How do they do that?
  - Abstraction

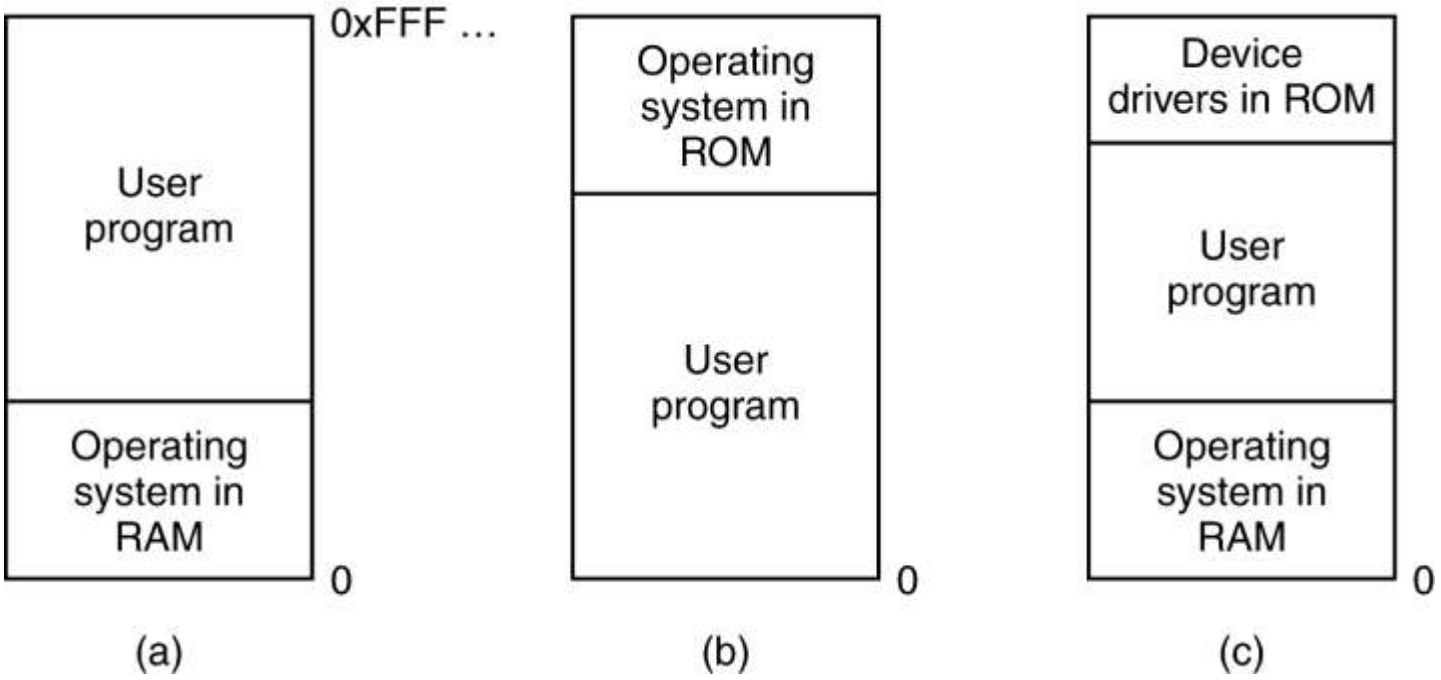
Is abstraction necessary?

No Memory Abstraction



Even with no abstraction, we can have several setups!

No Memory Abstraction



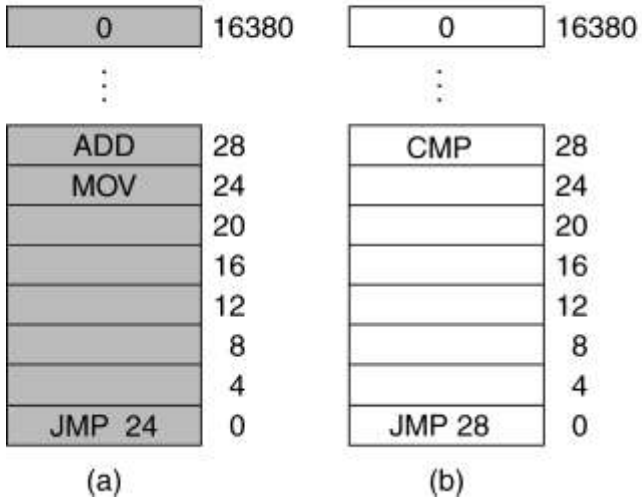
Only one process at a time can be running (threads??)

No Memory Abstraction

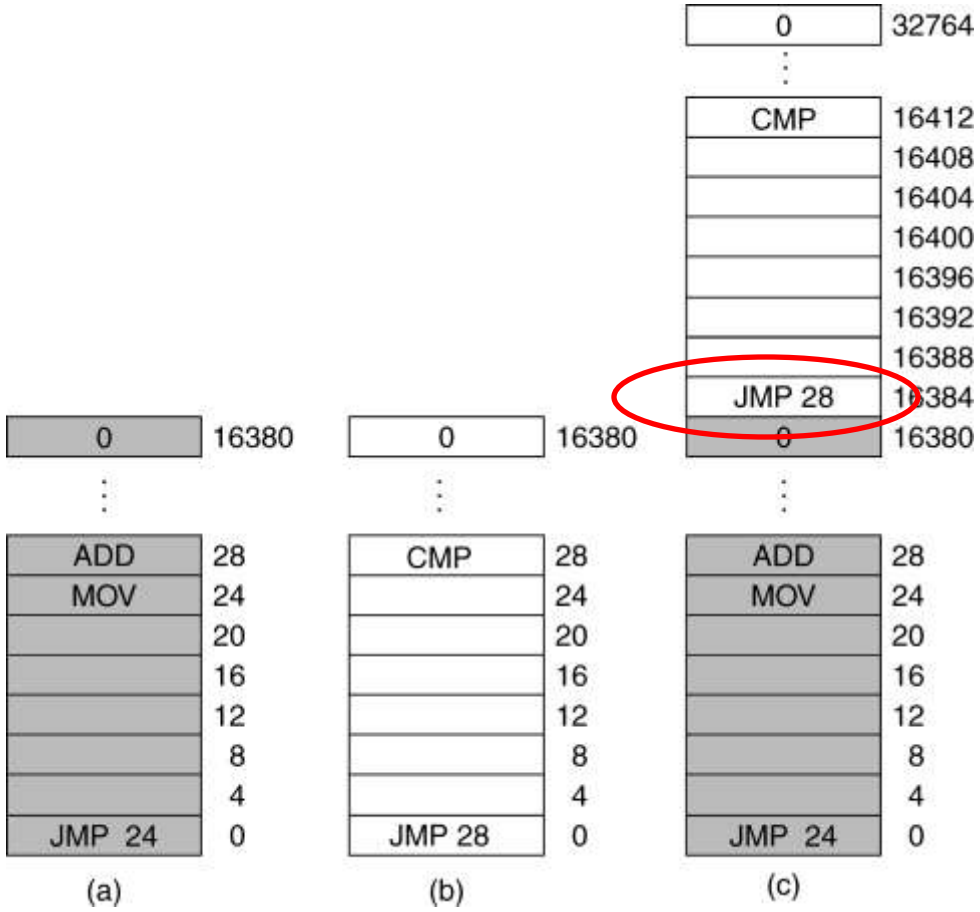
- What if we want to run multiple programs?
  - OS saves entire memory on disk
  - OS brings next program
  - OS runs next program

  } Swapping
- We can use swapping to run multiple programs concurrently
  - Memory divided into blocks
  - Each block assigned protection bits
  - Program status word contains the same bits
  - Hardware needs to support this
  - Example: IBM 360

No Memory Abstraction



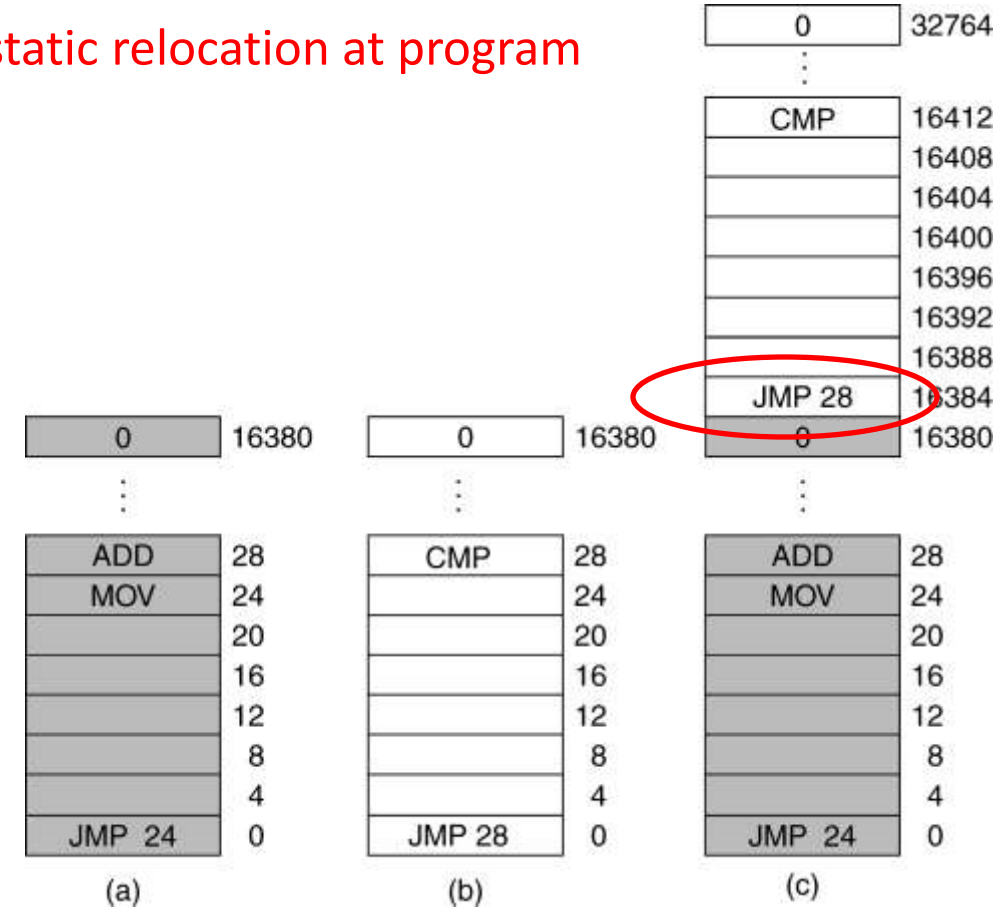
No Memory Abstraction



Using absolute address is wrong here

No Memory Abstraction

We can use static relocation at program load time



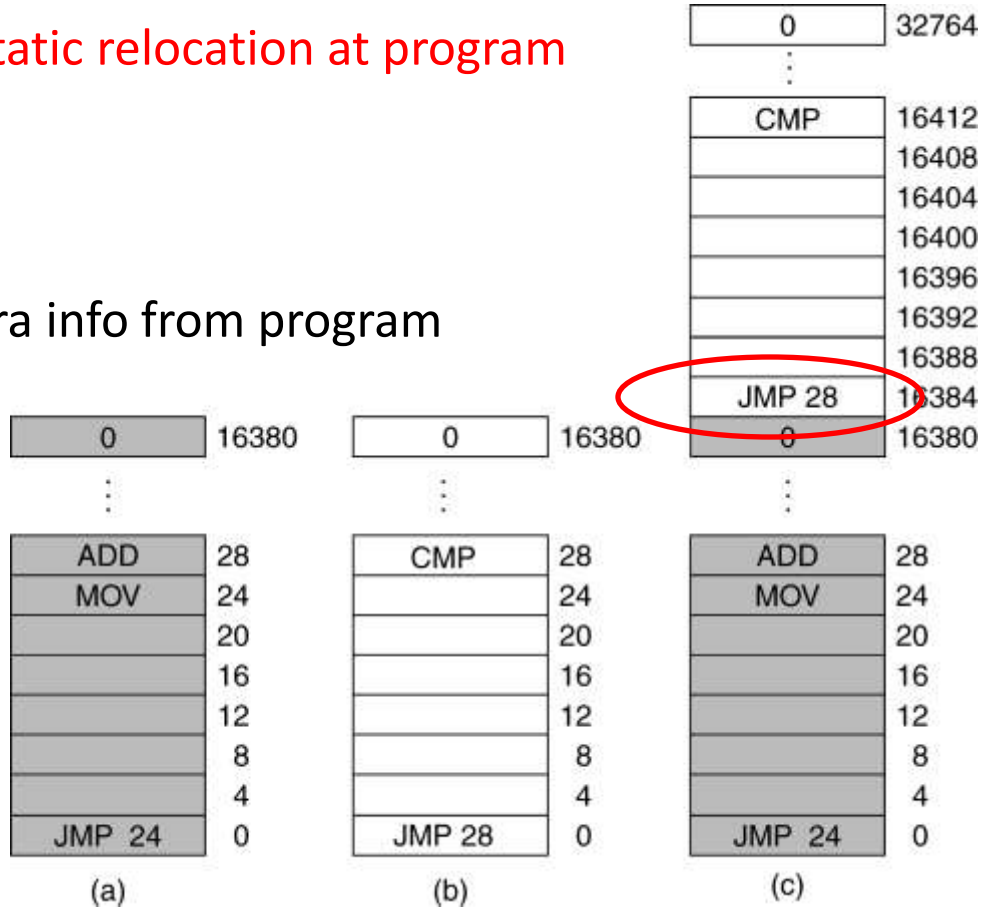
Using absolute address is wrong here

No Memory Abstraction

We can use static relocation at program load time

Bad Idea!

- Slow
- Require extra info from program



Using absolute address is wrong here

Bottom line: Memory abstraction is needed!

Memory Abstraction

- To allow several programs to co-exist in memory we need
  - Protection
  - Relocation
  - Sharing
  - Logical organization
  - Physical organization
- A new abstraction for memory: Address Space
- Address space = set of addresses that a process can use to address memory

Protection

- Processes need to acquire permission to reference memory locations for reading or writing purposes
- Location of a program in main memory is unpredictable
- Memory references generated by a process must be checked at run time

Relocation

- Programmers typically do not know in advance which other programs will be resident in main memory at the time of execution of their program
- Active processes need to be able to be swapped in and out of main memory in order to maximize processor utilization
- Specifying that a process must be placed in the same memory region when it is swapped back in would be limiting
  - may need to *relocate* the process to a different area of memory

Sharing

- It is advantageous to allow each process access to the same copy of the program rather than have their own separate copy
- Memory management must allow controlled access to shared areas of memory without compromising protection

Logical Organization

- We see memory as linear one-dimensional address space.
- A program = code + data + … = modules
- Those modules must be organized in that logical address space

Physical Organization

- Memory is really a hierarchy
  - Several levels of caches
  - Main memory
  - Disk
- Managing the different modules of different programs in such a way as:
  - To give illusion of the logical organization
  - To make the best use of the above hierarchy

Address Space: Base and Limit

- Map each process address space onto a different part of physical memory
- Two registers: Base and Limit
  - **Base**: start address of a program in physical memory
  - **Limit**: length of the program
- For every memory access
  - Base is added to the address
  - Result compared to Limit
- Only OS can modify Base and Limit

Address Space: Base and Limit

Main drawback:

Need to add and compare for each memory address

What if memory space is not enough for all programs?

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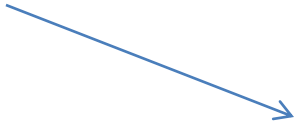
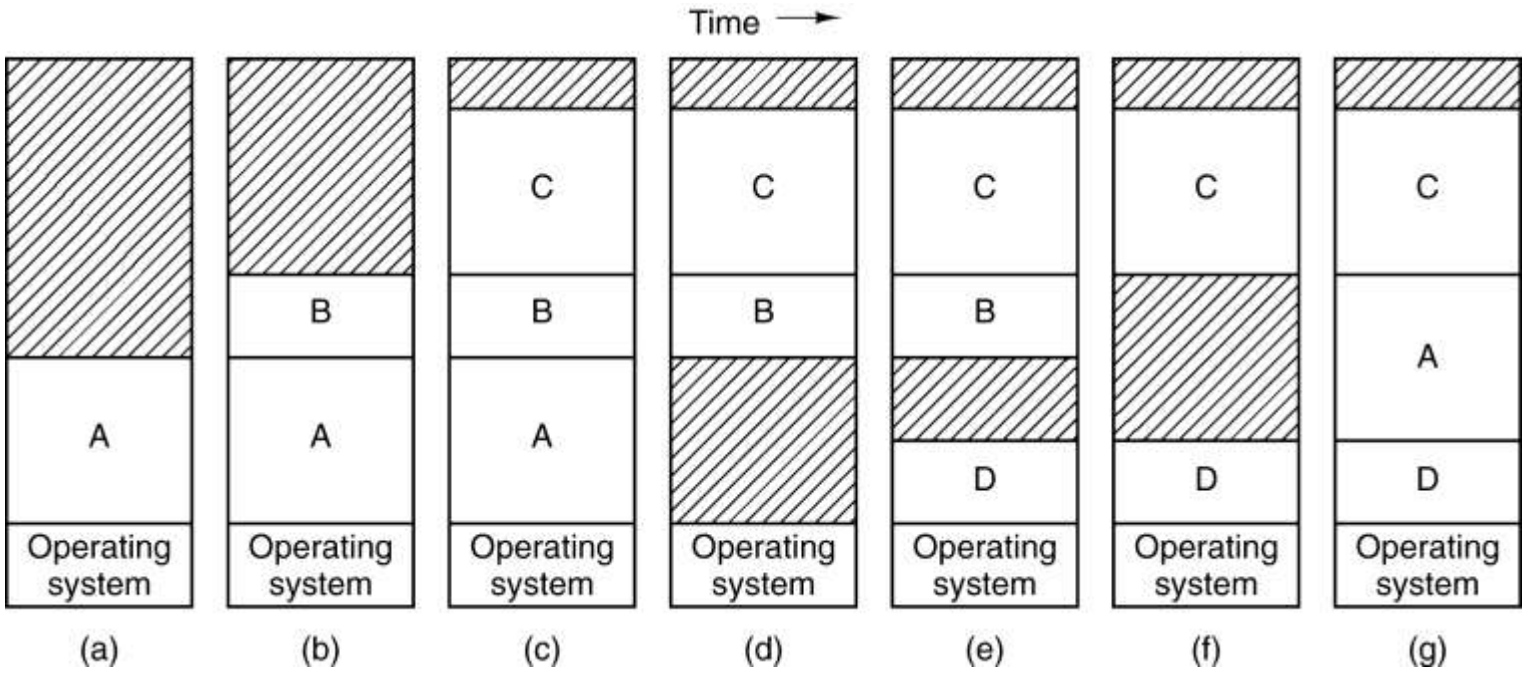
What if memory space is not enough for all programs?



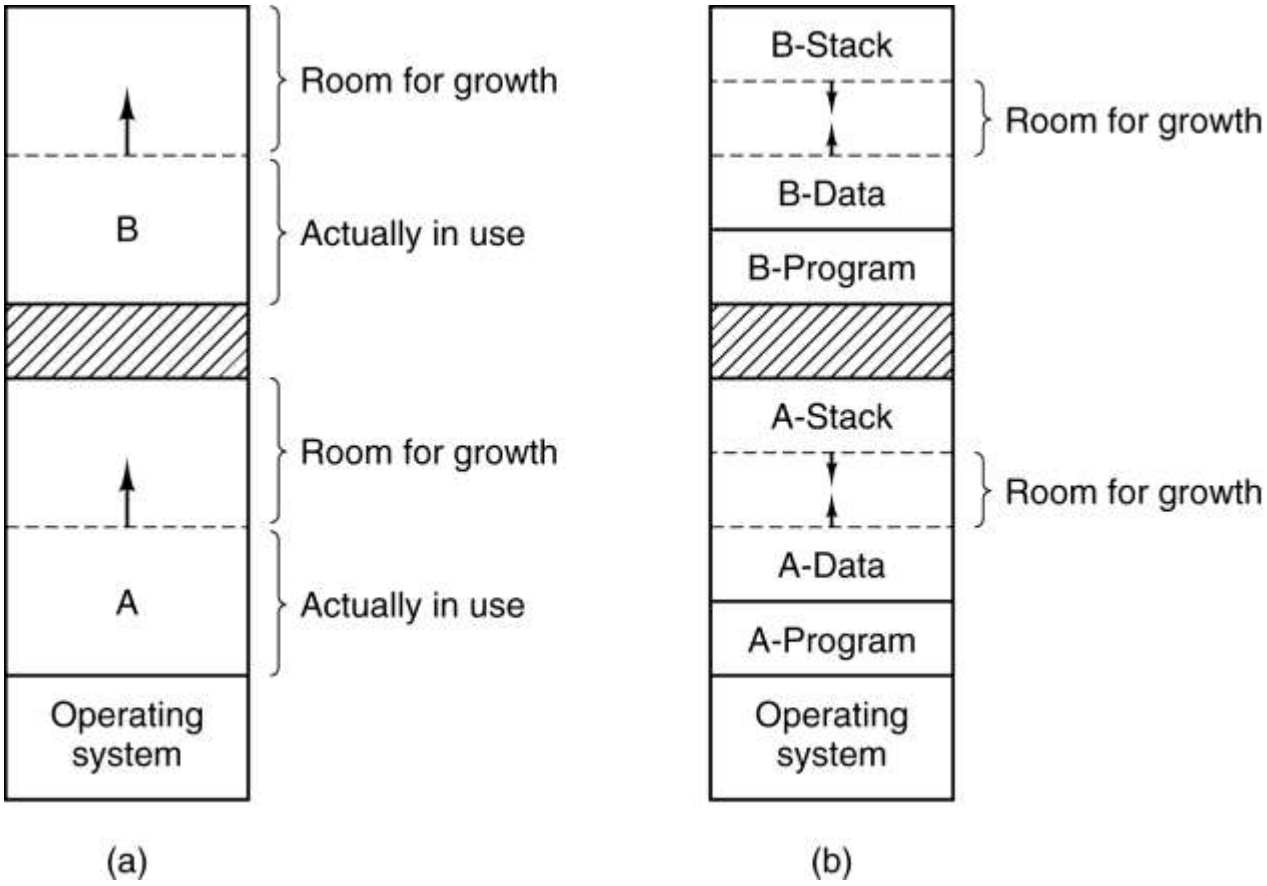
The we may need to swap some programs out of the memory.

Swapping

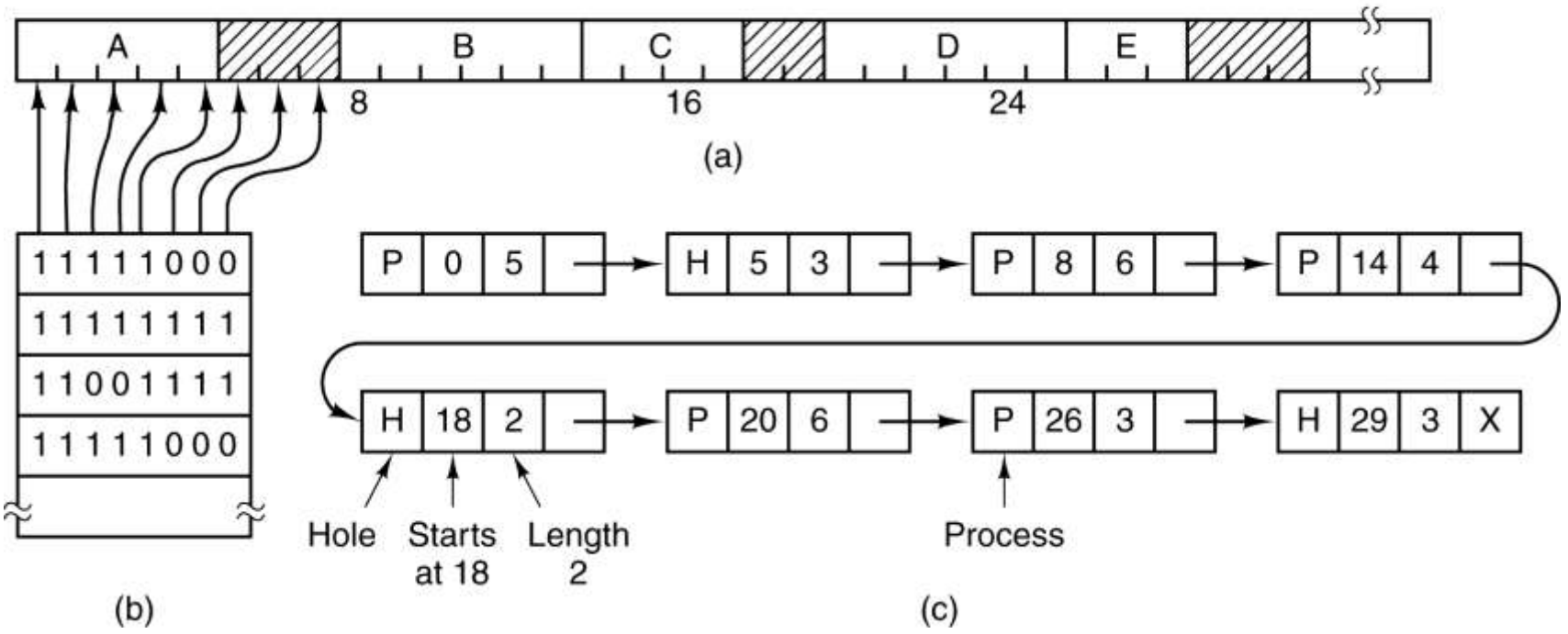


Swapping

- Programs move in and out of memory
- Holes are created
- Holes can be combined -> memory compaction
- What if a process needs more memory?
  - If a hole is adjacent to the process, it is allocated to it
  - Process has to be moved to a bigger hole
  - Process suspended till enough memory is there


Room for growth
B
Actually in use
Room for growth
A
Actually in use
Operating system
(a)
B-Stack
Room for growth
B-Data
B-Program
A-Stack
Room for growth
A-Data
A-Program
Operating system
(b)

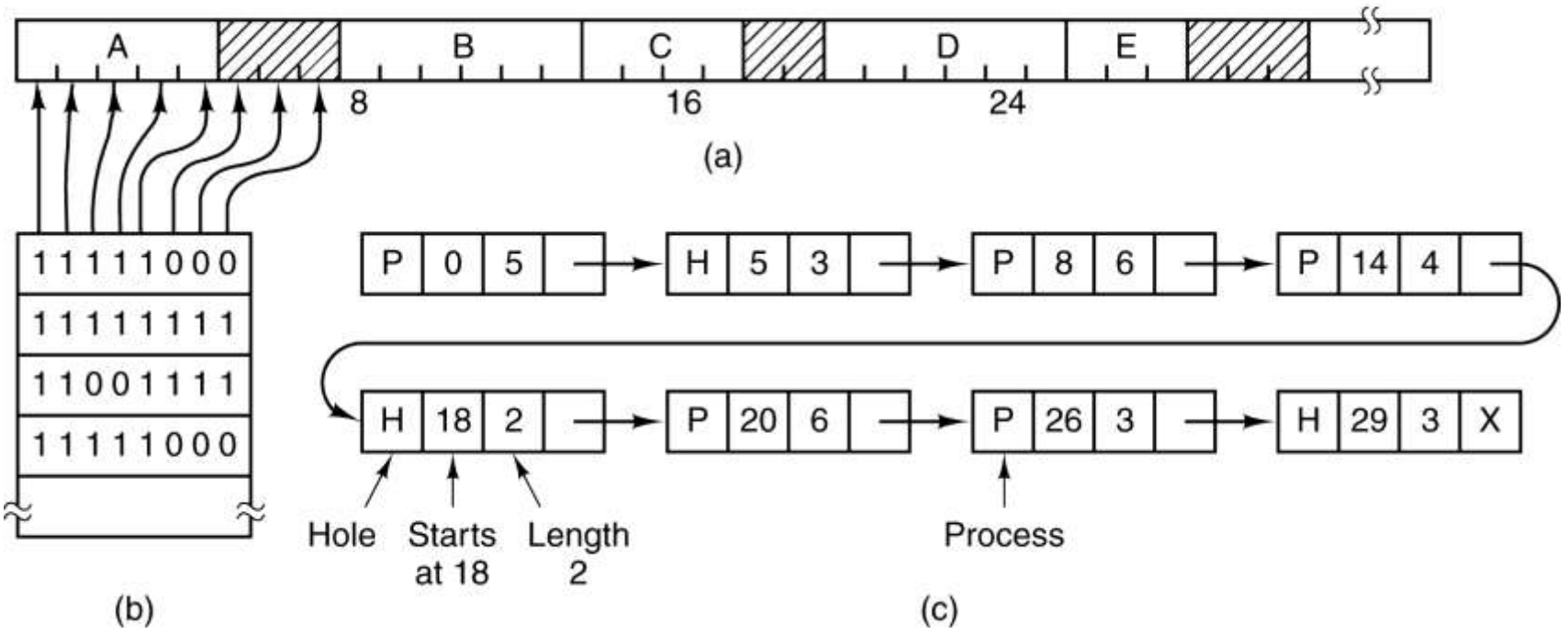
Managing Free Memory



Bitmap

Linked List

Managing Free Memory



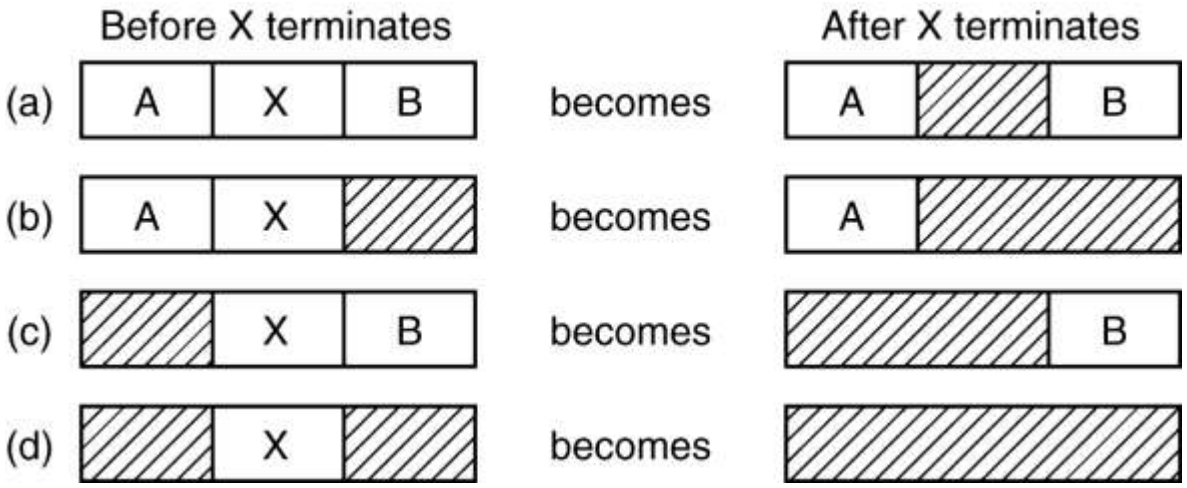
Bitmap

Linked List

Slow: To find k-consecutive 0s for a new process

Managing Free Memory: Linked List

- Linked list of allocated and free memory segments
- More convenient be double-linked list



Managing Free Memory: Linked List

- How to allocate?
  - First fit
  - Best fit
  - Next fit
  - Worst fit
  - …

Memory Management Techniques

- Memory management brings processes into main memory for execution by the processor
  - involves virtual memory
  - based on segmentation and paging

Technique	Description	Strengths	Weaknesses
Fixed Partitioning	Main memory is divided into a number of static partitions at system generation time. A process may be loaded into a partition of equal or greater size.	Simple to implement; little operating system overhead.	Inefficient use of memory due to internal fragmentation; maximum number of active processes is fixed.
Dynamic Partitioning	Partitions are created dynamically, so that each process is loaded into a partition of exactly the same size as that process.	No internal fragmentation; more efficient use of main memory.	Inefficient use of processor due to the need for compaction to counter external fragmentation.
Simple Paging	Main memory is divided into a number of equal-size frames. Each process is divided into a number of equal-size pages of the same length as frames. A process is loaded by loading all of its pages into available, not necessarily contiguous, frames.	No external fragmentation.	A small amount of internal fragmentation.
Simple Segmentation	Each process is divided into a number of segments. A process is loaded by loading all of its segments into dynamic partitions that need not be contiguous.	No internal fragmentation; improved memory utilization and reduced overhead compared to dynamic partitioning.	External fragmentation.
Virtual Memory Paging	As with simple paging, except that it is not necessary to load all of the pages of a process. Nonresident pages that are needed are brought in later automatically.	No external fragmentation; higher degree of multiprogramming; large virtual address space.	Overhead of complex memory management.
Virtual Memory Segmentation	As with simple segmentation, except that it is not necessary to load all of the segments of a process. Nonresident segments that are needed are brought in later automatically.	No internal fragmentation, higher degree of multiprogramming; large virtual address space; protection and sharing support.	Overhead of complex memory management.

Conclusions

- Process is CPU abstraction
- Address space is memory abstraction
  - OS memory manager and the hardware helps providing this abstraction
- Two main tasks needed from OS regarding memory management:
  - managing free space
  - making best use of the memory hierarchy