Operating Systems

Memory Management I

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Programmer's Dream

Memory

- Private
- Infinitely large
- Infinitely fast
- Non-volatile
- Inexpensive

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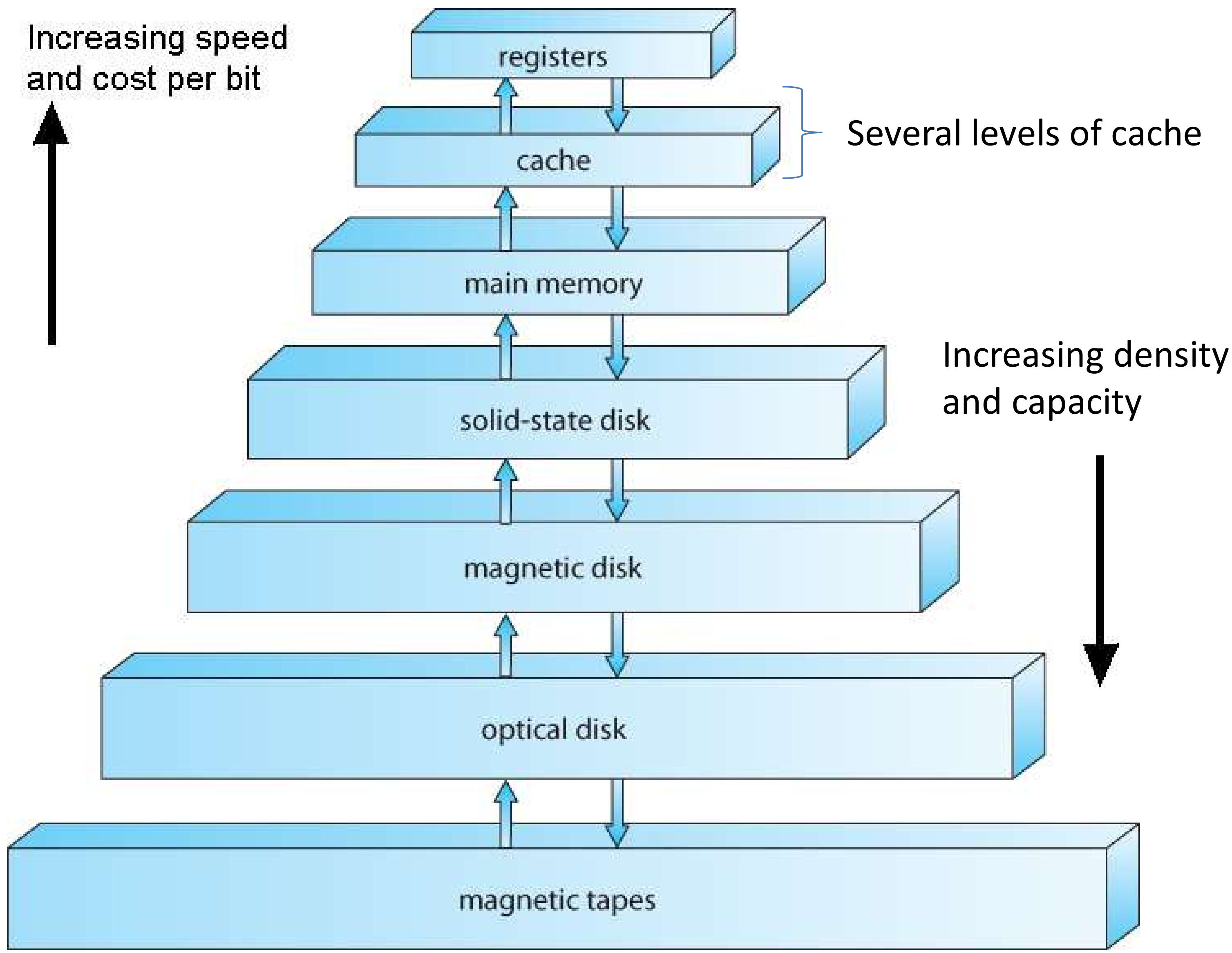
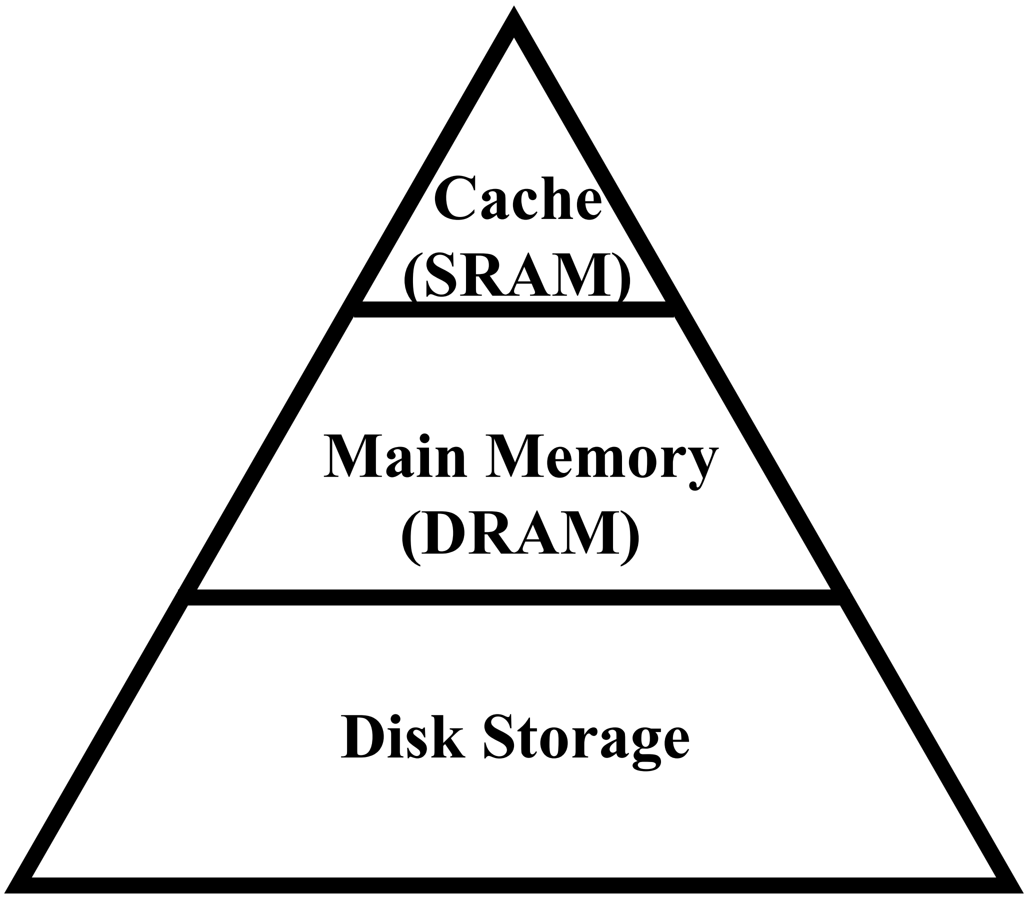
Programs are getting bigger faster than memories.

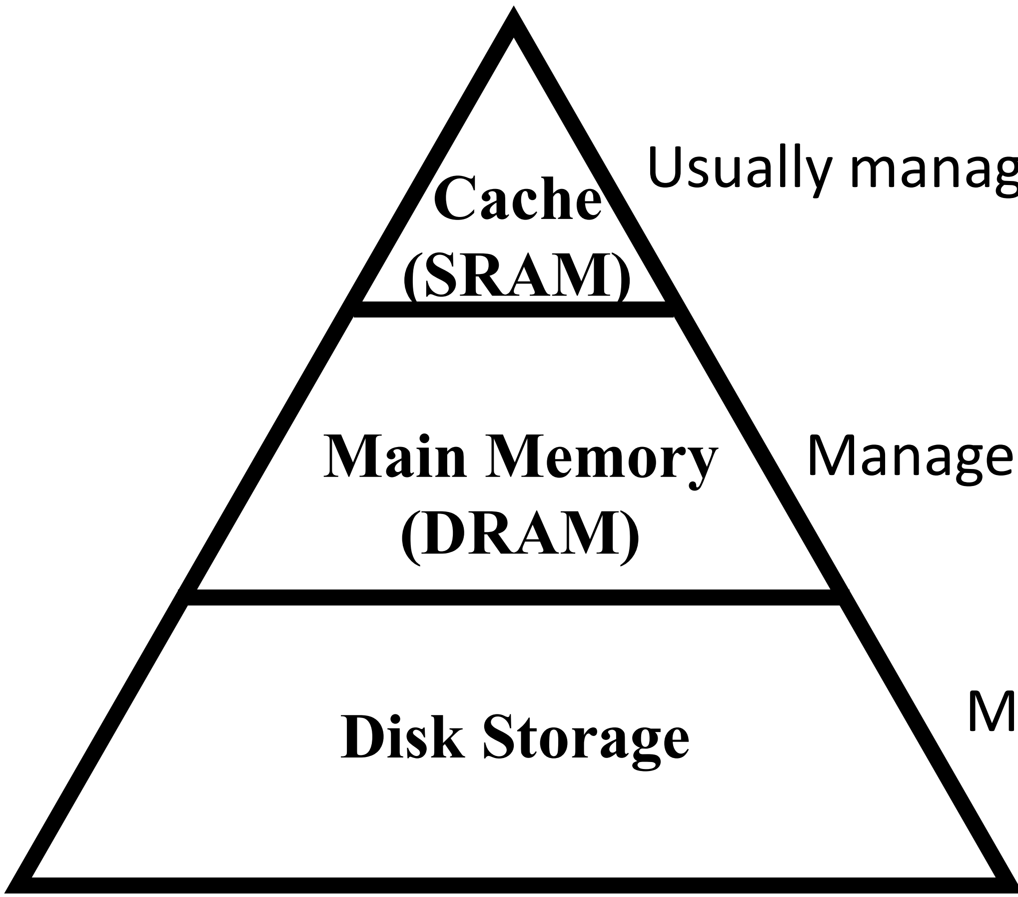
Storage/Memory Hierarchy



Memory Hierarchy



Memory Hierarchy

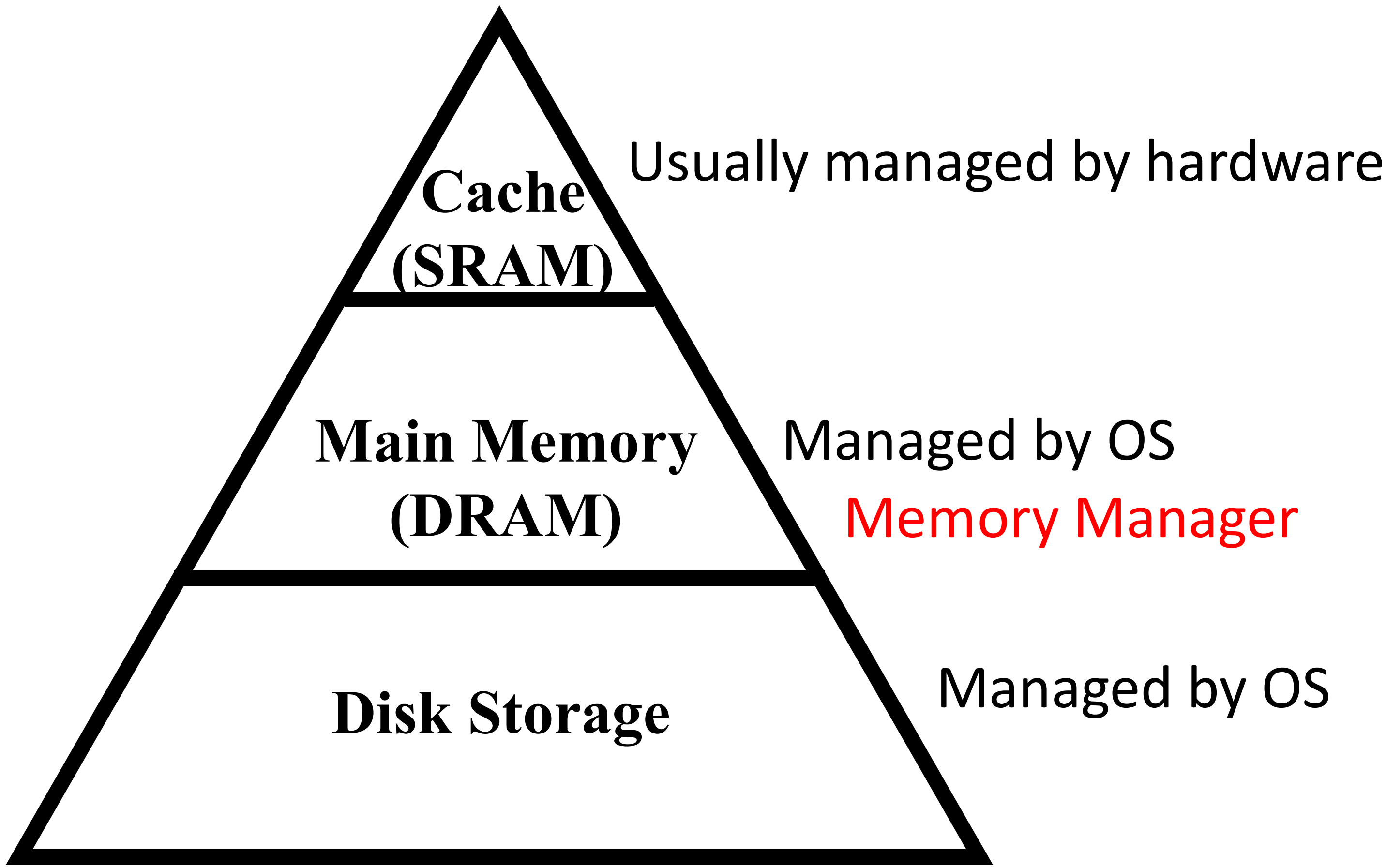


Usually managed by hardware

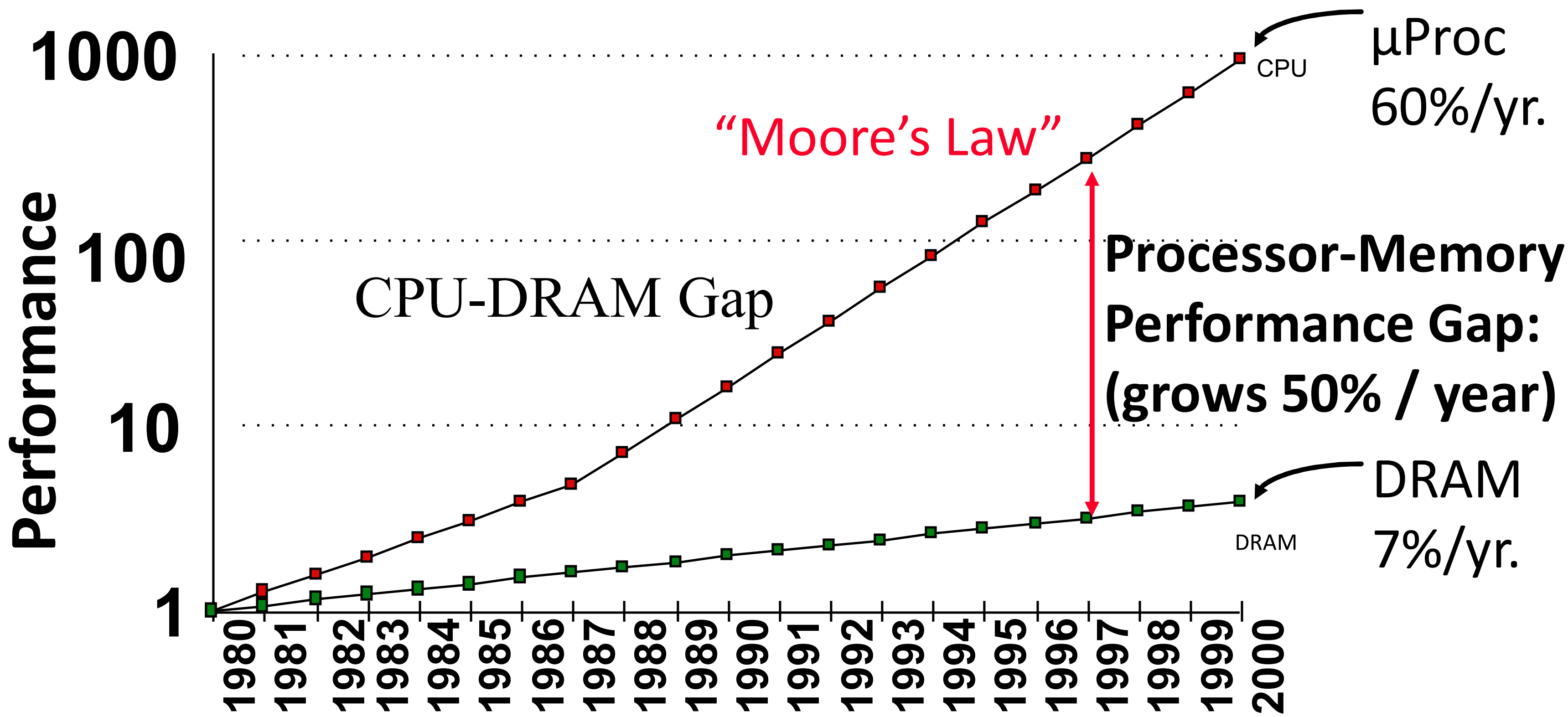
Managed by OS

Managed by OS

Memory Hierarchy



Question: Who Cares About the Memory Hierarchy?

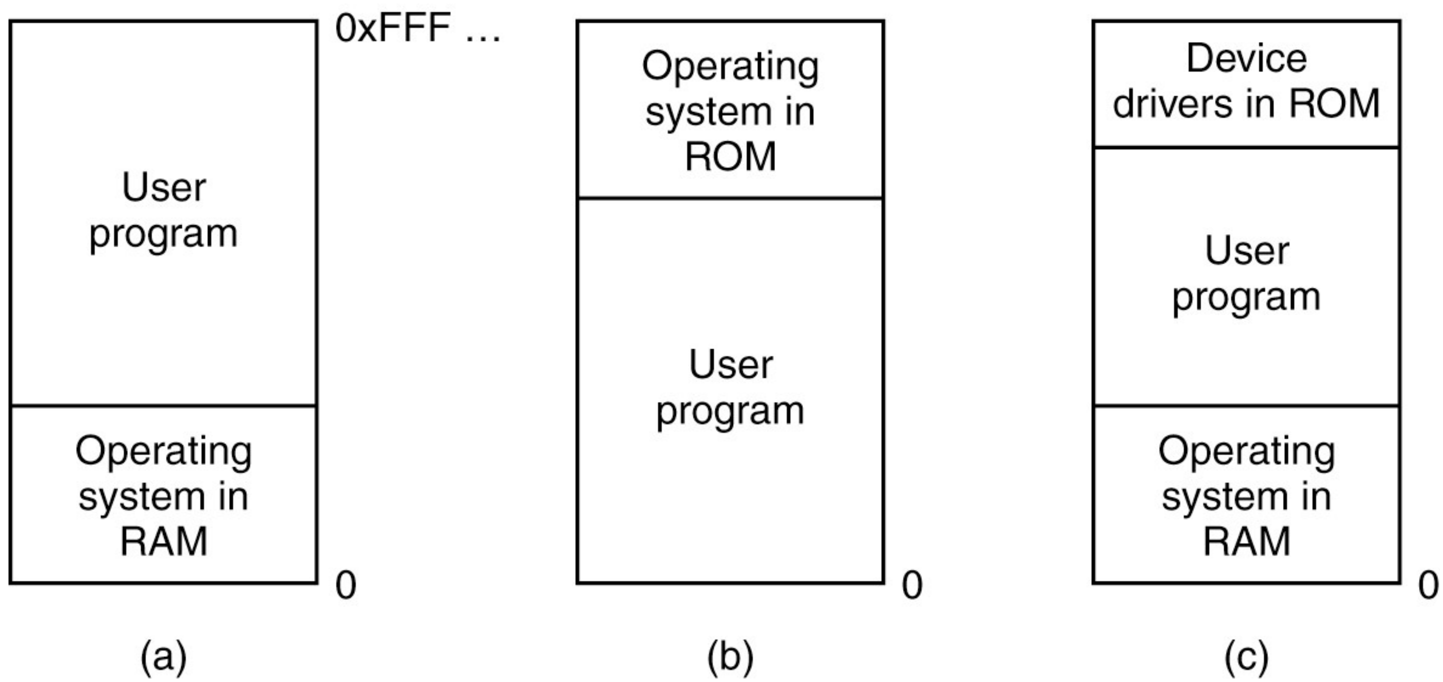


Memory Abstraction

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

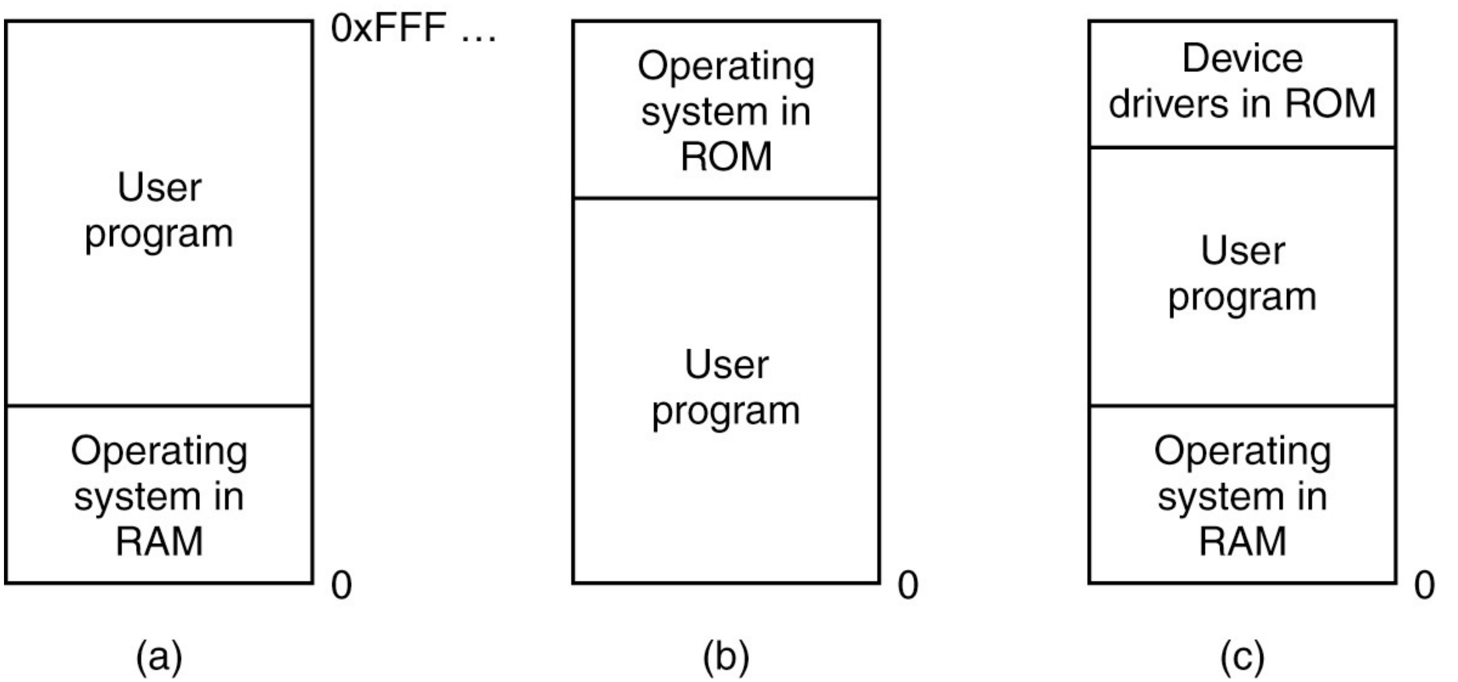
Is abstraction necessary?

No Memory Abstraction



Even with no abstraction, we can have several setups!

No Memory Abstraction



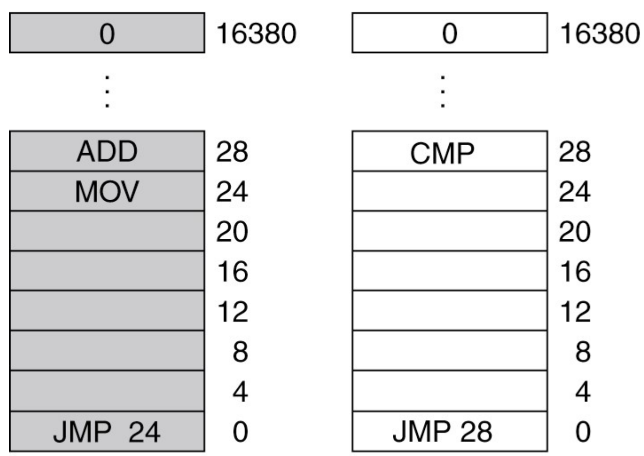
Only one process at a time can be running (threads??)

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

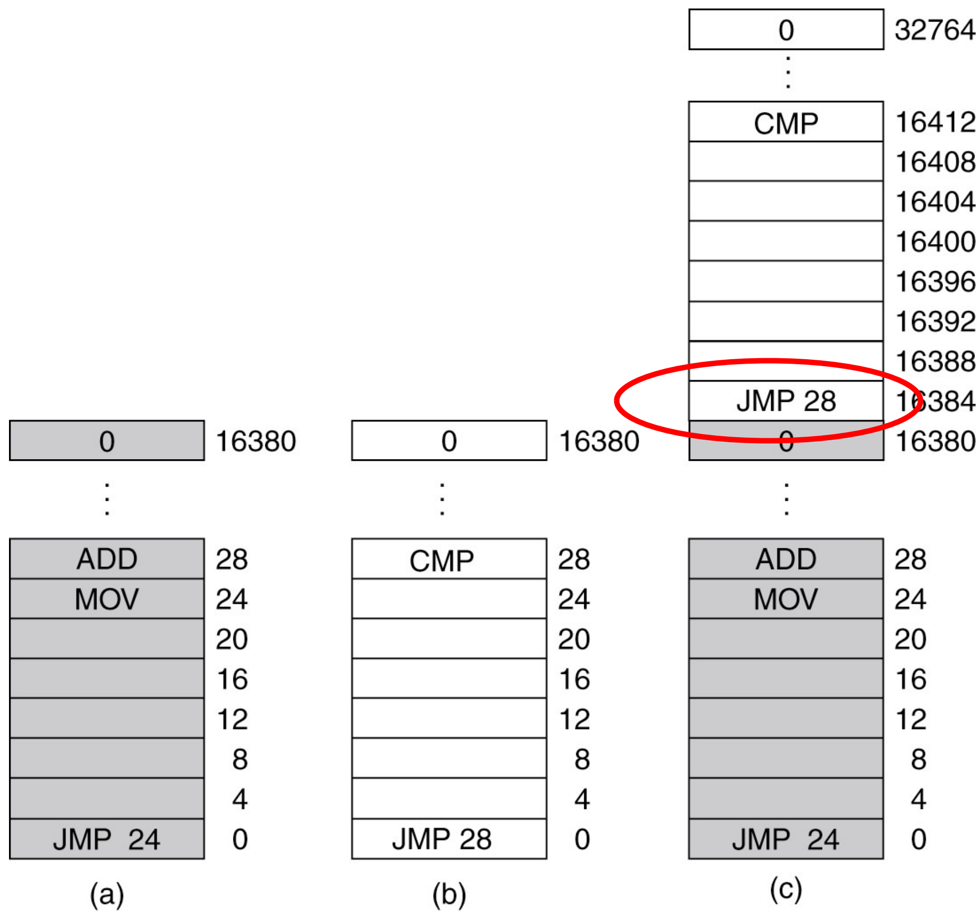
  Swapping
- We can use swapping to run multiple programs concurrently
  - Memory divided into blocks
  - Each block assigned protection bits
  - Program status word contains the same bits
  - Hardware needs to support this
  - Example: IBM 360

No Memory Abstraction



(a) (b)

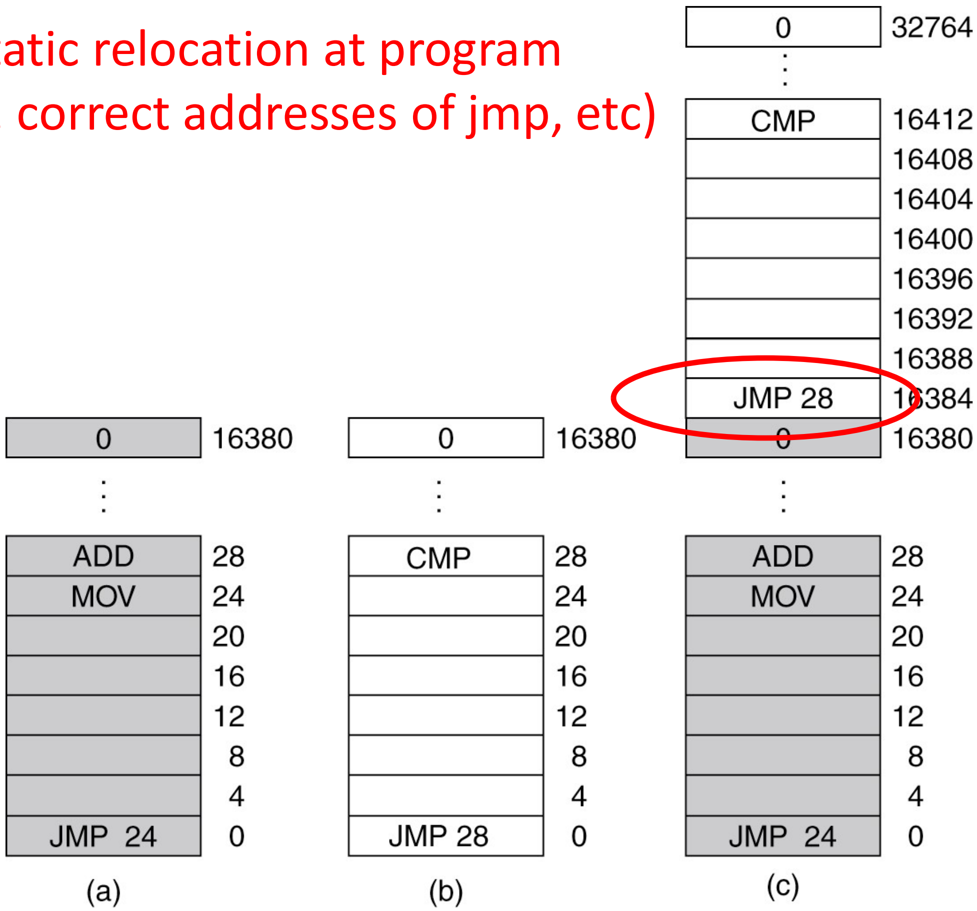
No Memory Abstraction



Using absolute address is wrong here

No Memory Abstraction

We can use static relocation at program load time (i.e. correct addresses of jmp, etc)



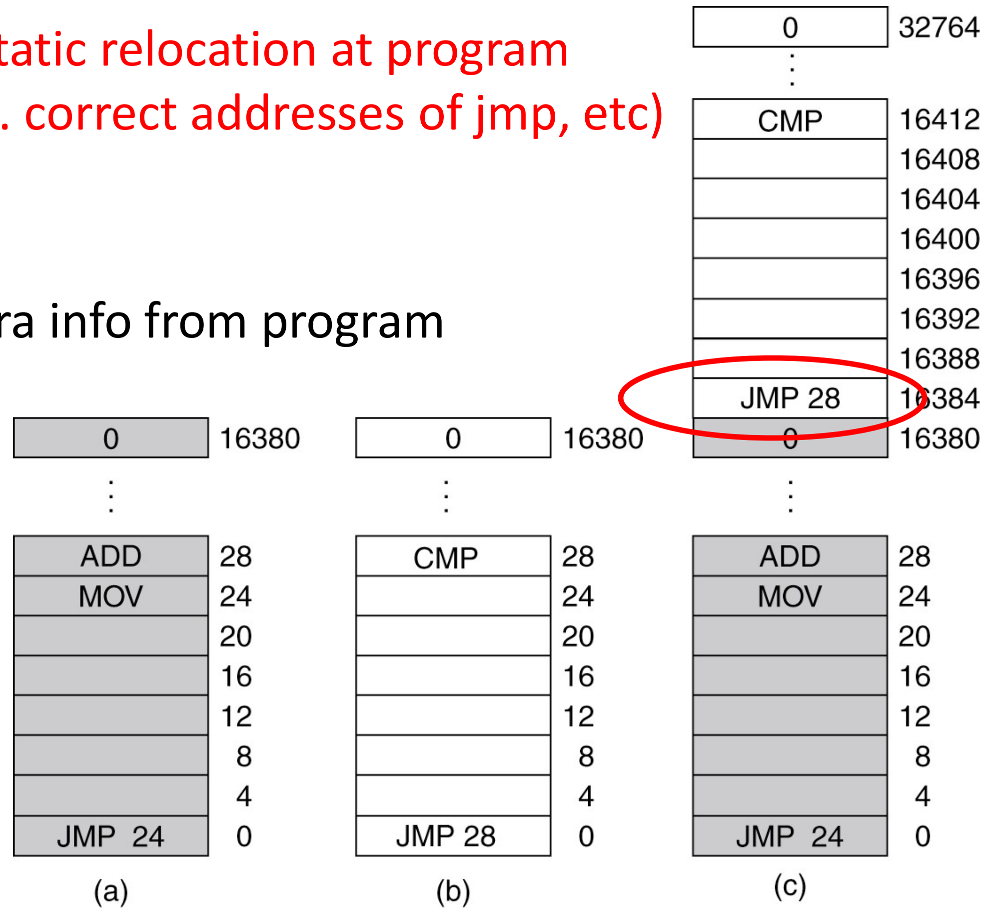
Using absolute address is wrong here

No Memory Abstraction

We can use static relocation at program load time (i.e. correct addresses of jmp, etc)

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/library/… 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

All of this must be done while ensuring:

- **Transparency**: the running programs must not know that all of this is happening.
- **Efficiency**: both in terms of time (speed) and space (not wasting a lot of memory)
- **Protection**: as we saw, protecting processes from each other

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 (**sometimes called **bound)**: length of the program
- For every memory access
  - Base is added to the address
  - Result compared to Limit
  - Who is doing this? A piece of hardware inside the processor called the memory management unit (MMU).
- Only OS can modify Base and Limit

Address Space: Base and Limit

Main drawbacks:

Need to add and compare for each memory address

What if memory space is not enough for all programs?

Address Space: Base and Limit

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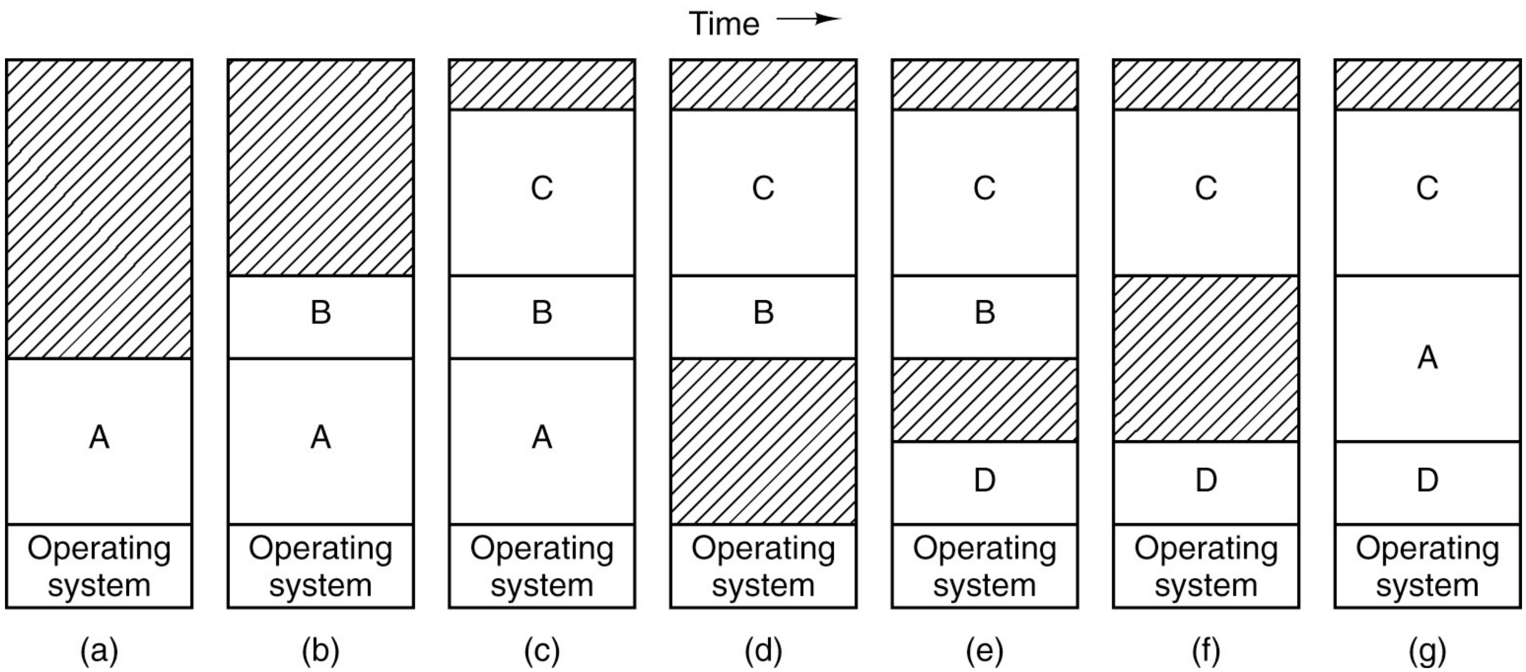
What if memory space is not enough for all programs?

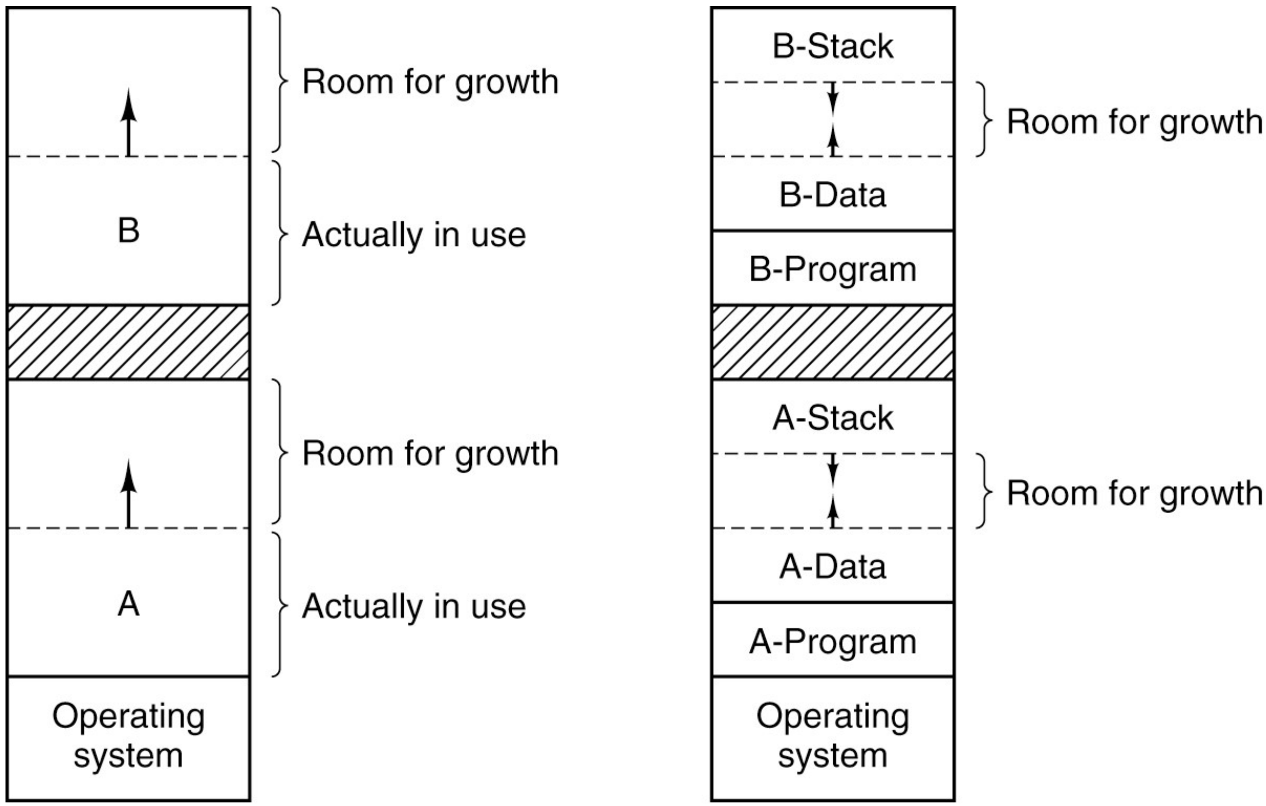
The we may need to swap some programs out of the memory.

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 must 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
B-Stack
Room for growth
B-Data
B-Program
A-Stack
Room for growth
A-Data
A-Program
Operating system

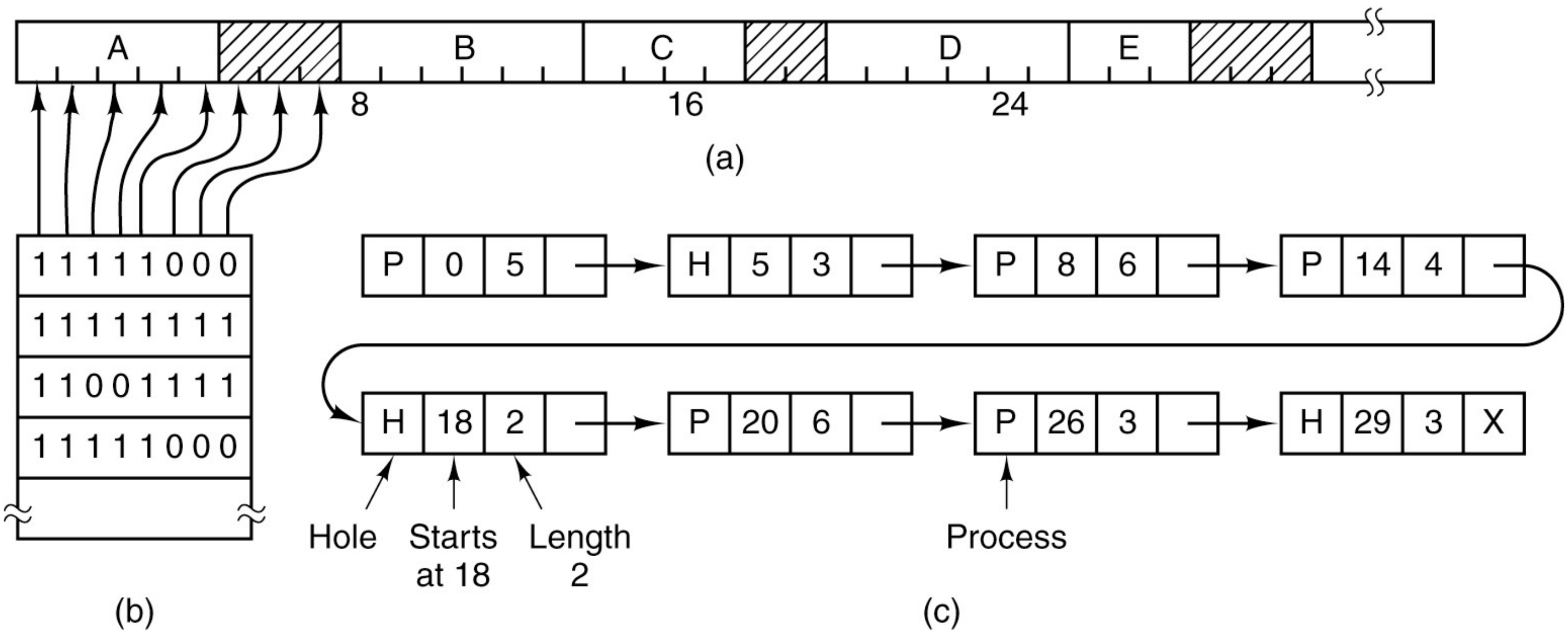
(a)

(b)

Managing Free Memory

- Bitmap:
  - Memory is divided into allocation units of equal size.
  - Each unit has a corresponding bit in the bitmap.
  - 0 = unit is free   1 = unit is occupied (or vice versa, doesn't matter).
- Linked List: of allocated and free memory segments.
  - Segments are of different sizes.

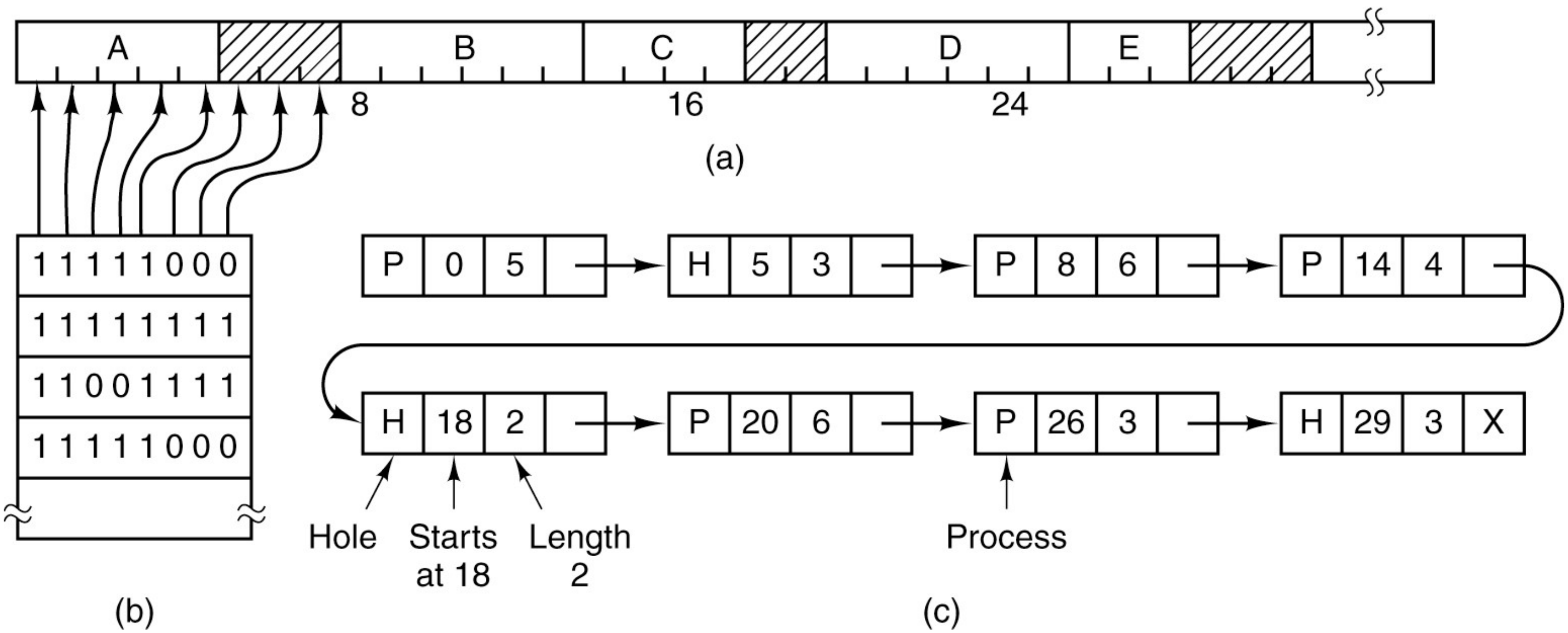
Managing Free Memory



Bitmap

Linked List

Managing Free Memory



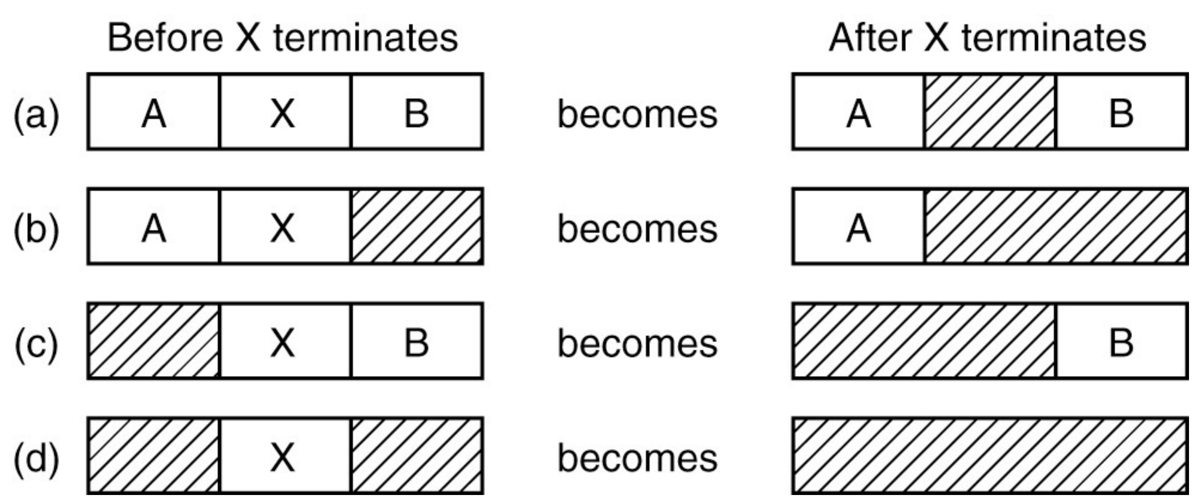
Bitmap

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 (variable size parts) or
    - paging (fixed size parts) ← next lecture

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