COMP 4735: Operating Systems Concepts

Lecture 10: Memory Management

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Administrative

- No quiz this week.
- No quiz next week.
- Next quiz (on Memory Management) is March 30th.

- Wednesday this week: no lecture. Go to career day, get a job, make money, do stuff like that.

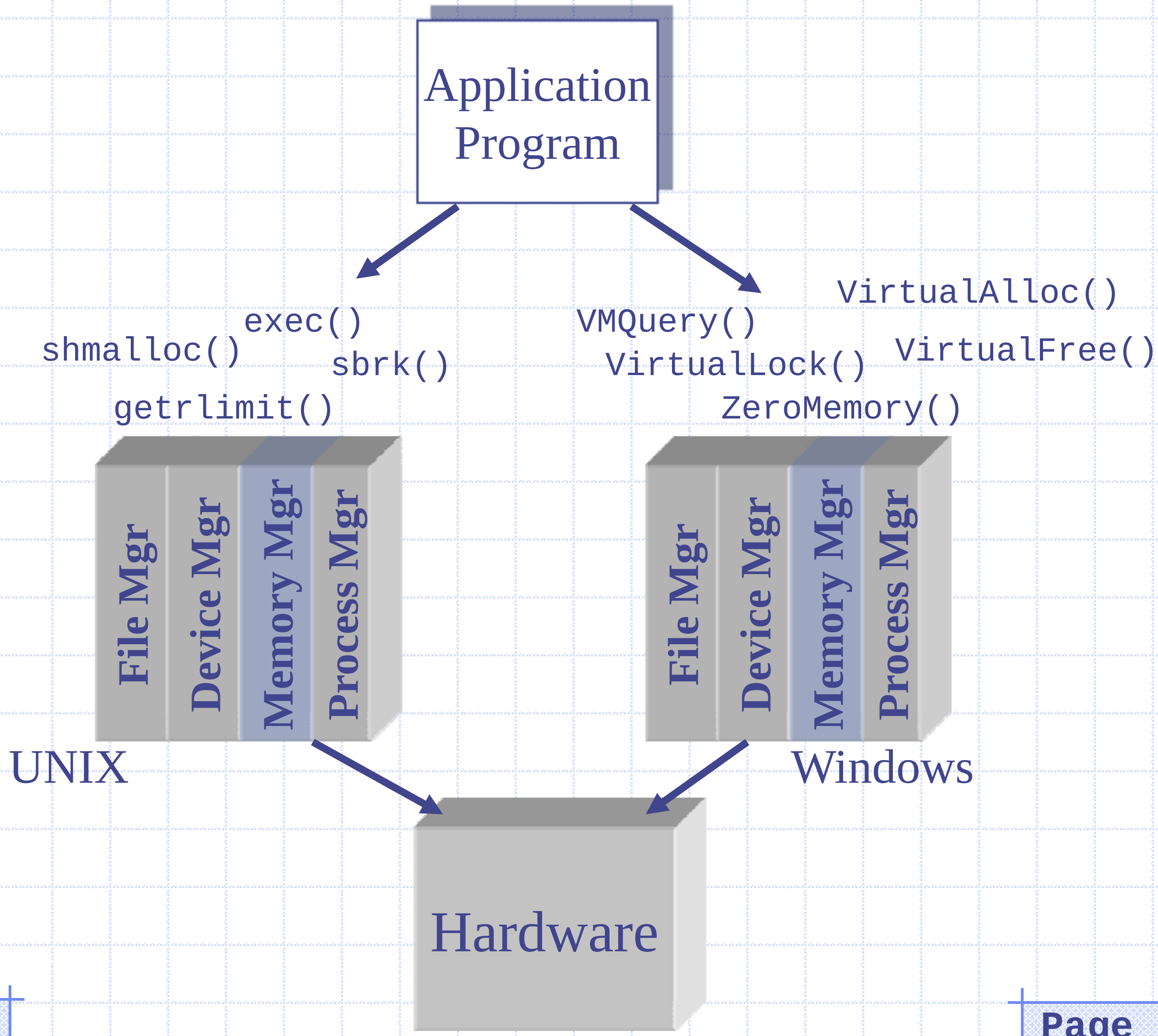
Acknowledgements ...

- *some of the slides in this lesson are courtesy of Jonathan Walpole, who teaches at Portland State University*

Today's Topics

- What is a Memory Manager?
- The Address Spaces Abstraction
- Static Address Binding
- Memory Allocation & Partitioning Strategies
- Dynamic Address Space Binding
- Swapping Systems

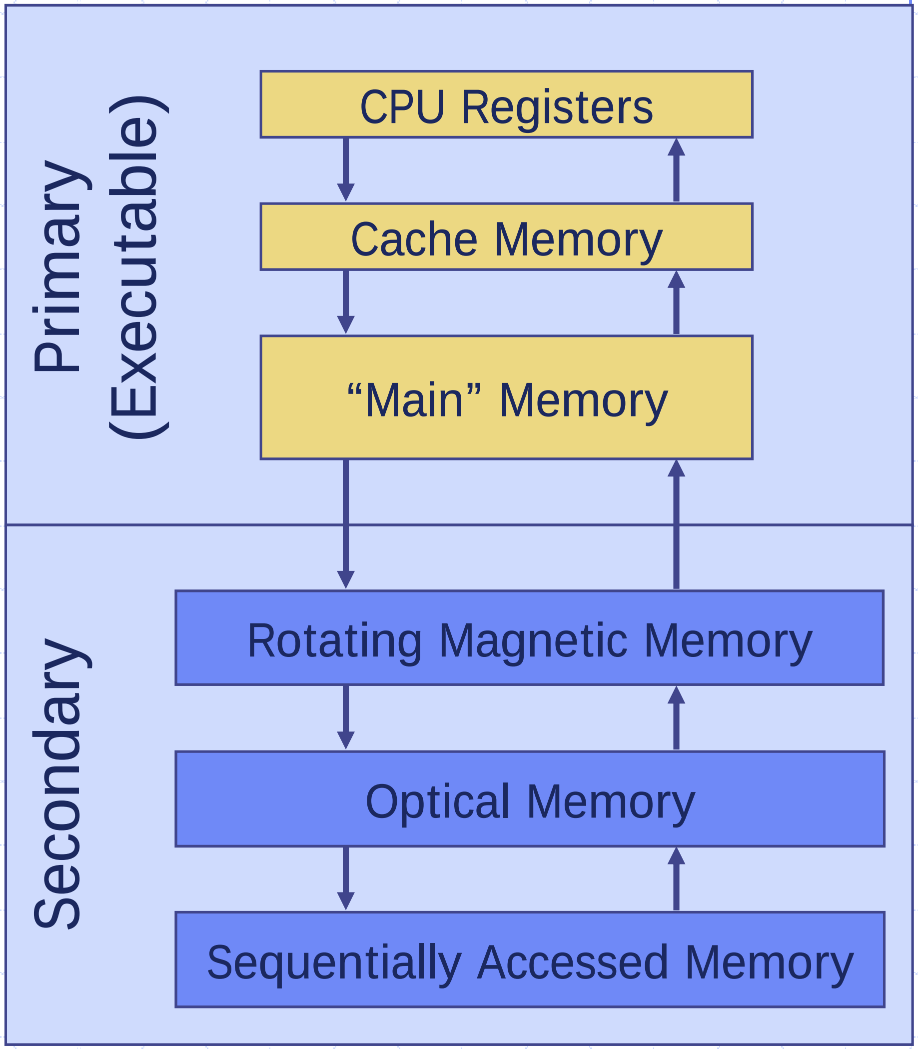
What is a Memory Manager?



Primary vs Secondary Memory

Memory Manager is responsible for

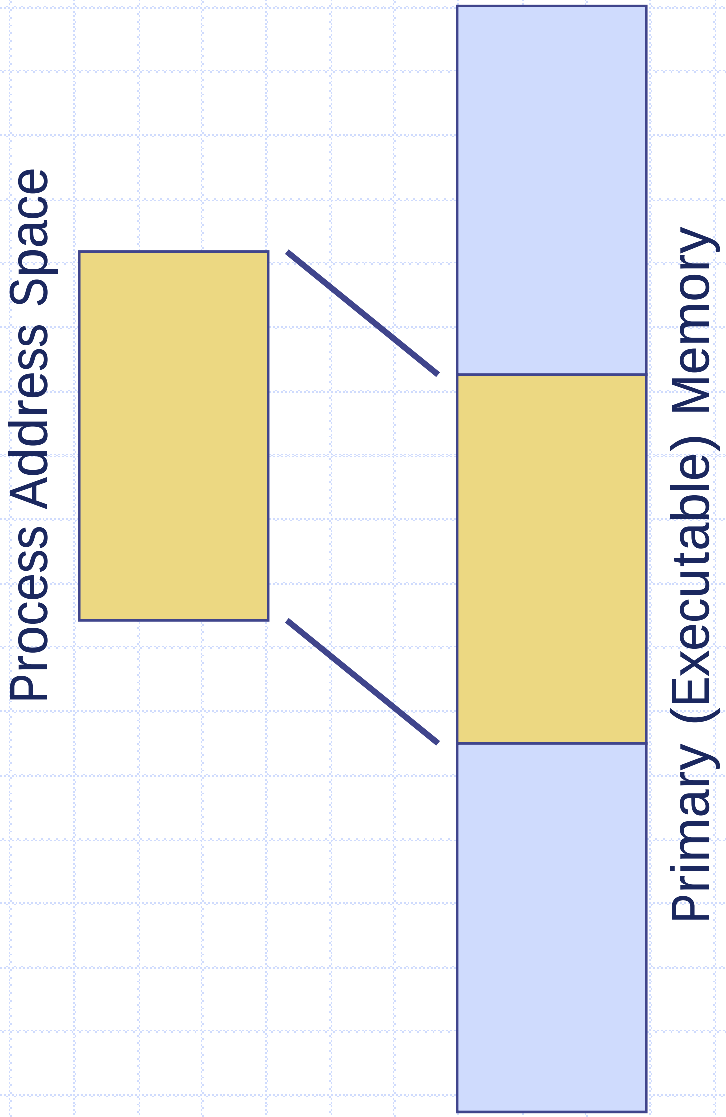
- automatically moving programs and data back and forth between *primary* and *secondary* memory



Address Space Abstraction

Memory Manager is responsible for

- automatically moving programs and data back and forth between *primary* and *secondary* memory
- managing the mapping of addresses between a processes address space and physical memory (binding)

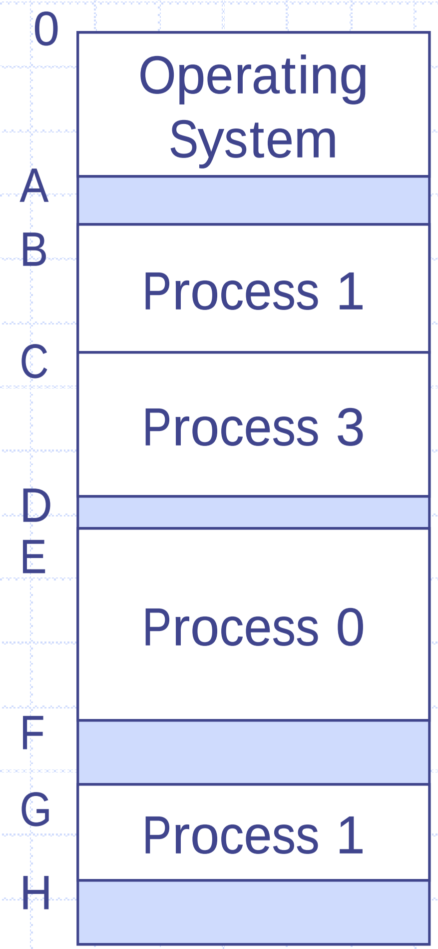


Memory Allocation

Memory Manager is responsible for

- automatically moving programs and data back and forth between *primary* and *secondary* memory
- managing the mapping of addresses between a processes address space and physical memory
- allocating/releasing blocks of memory as requested by processes

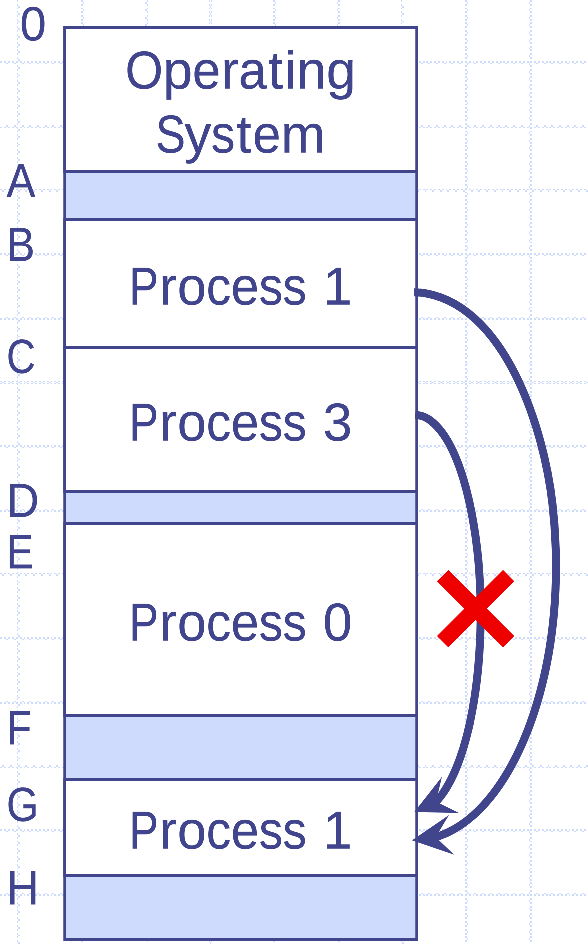
Physical Memory



Isolation

Memory Manager is responsible for

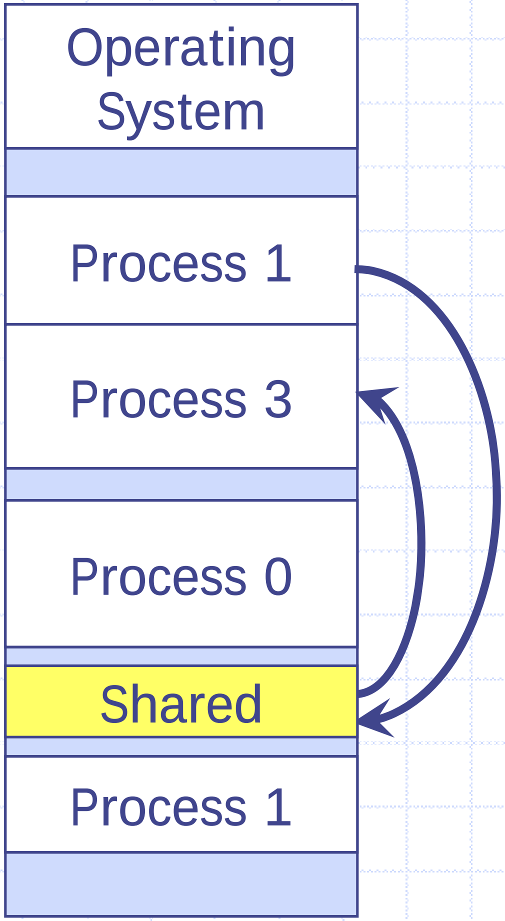
- automatically moving programs and data back and forth between *primary* and *secondary* memory
- managing the mapping of addresses between a processes address space and physical memory
- allocating/releasing blocks of memory as requested by processes
- ensuring that processes have exclusive use of the blocks of memory that are allocated to them



Sharing

Memory Manager is responsible for

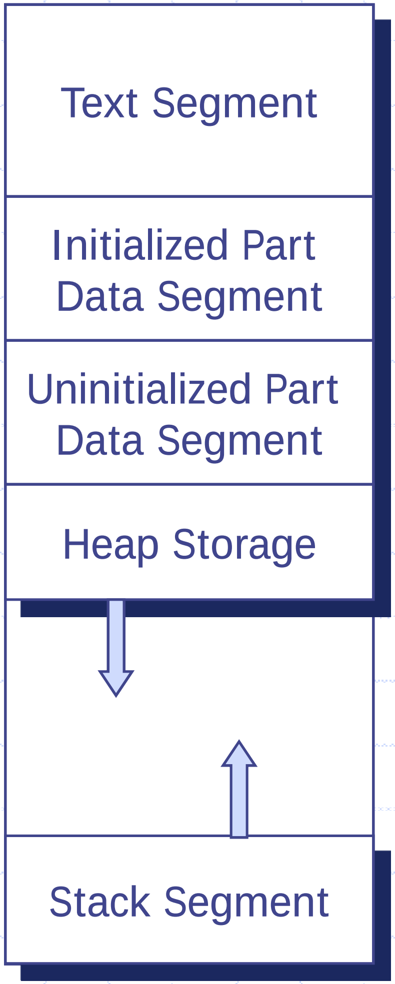
- automatically moving programs and data back and forth between *primary* and *secondary* memory
- managing the mapping of addresses between a processes address space and physical memory
- allocating/releasing blocks of memory as requested by processes
- ensuring that processes have exclusive use of the blocks of memory that are allocated to them
- facilitating shared access to blocks of memory by multiple processes (based on capabilities supported by the OS)



Address Space Abstraction

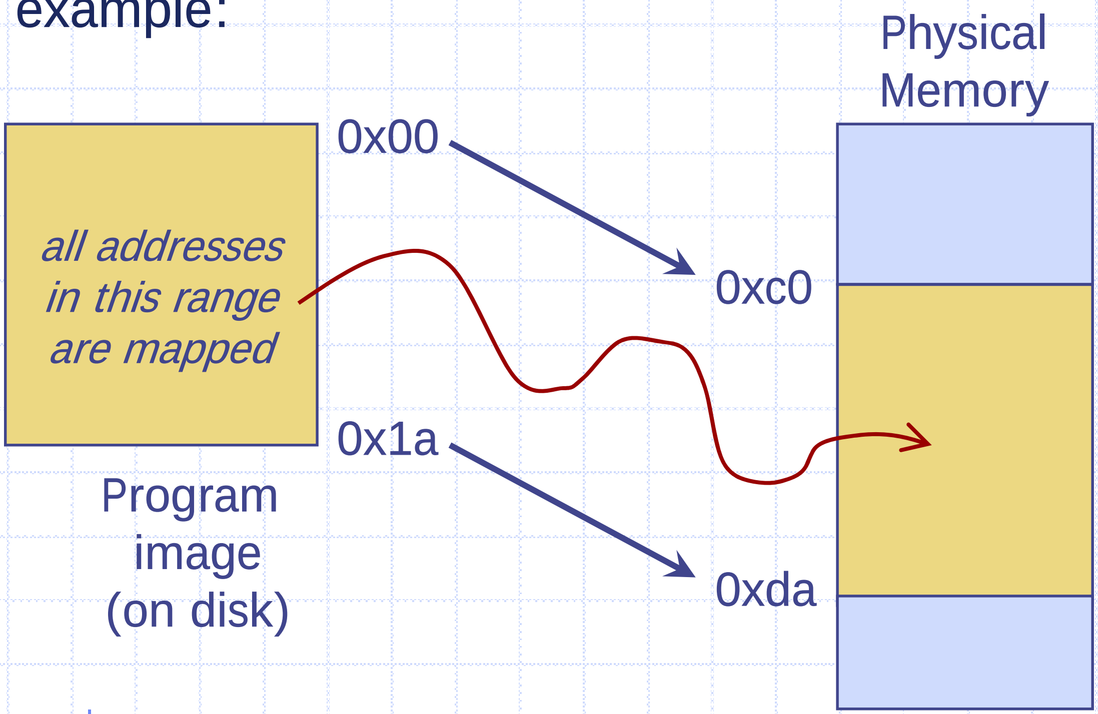
Memory Management

- Memory is presented as a linear array of bytes
  - Holds OS and programs (processes)
- Recall, processes are defined by an *address space,* consisting of text, data, and stack segments
- Process execution
  - CPU fetches instructions from the text region according to the value of the program counter (PC)
  - Each instruction may request additional operands from the data or stack region



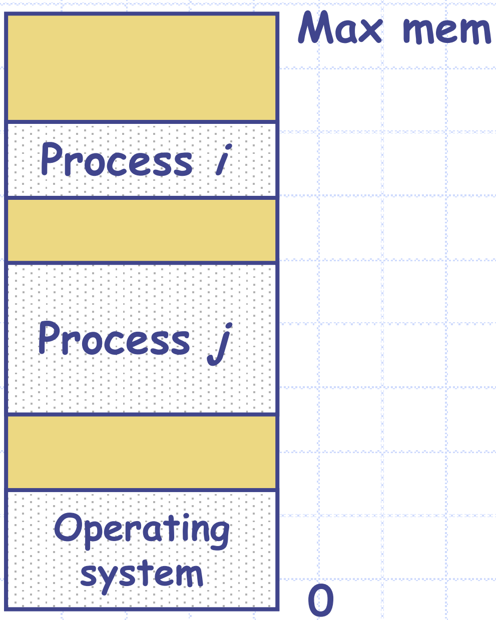
Addressing Memory

- We cannot know ahead of time where in memory a program will be loaded!
  - we don’t know what memory is available or allocated
- Memory Manager uses the notion of *address binding* to map programs (processes) into physical memory
- For example:



Multiple Processes

- in the simplest case, there are many processes mapped into different places in physical memory, and each process is mapped into one contiguous block of memory



Consider how a program gets organized / laid out within the process ...

Compiler

- Compiler produces code containing embedded addresses
  - these addresses can't be absolute (physical addresses)
  - compiler (and assembler) produces a *relocatable object module*

```
Prog P
   :
   :
  foo()
   :
   :
End P
```

```
P:
   :
  push ...
  jmp _foo
   :

foo: ...
```

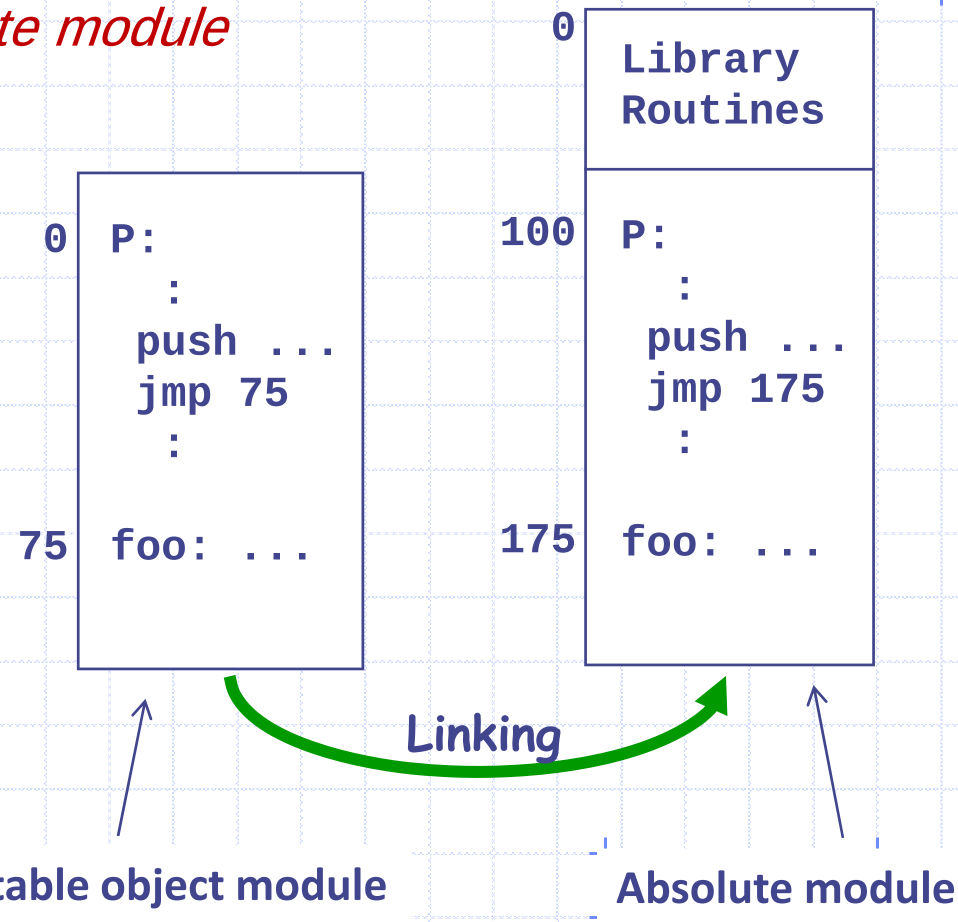
```
0   P:
       :
      push ...
      jmp 75
       :

75  foo: ...
```

Compilation

Assembly

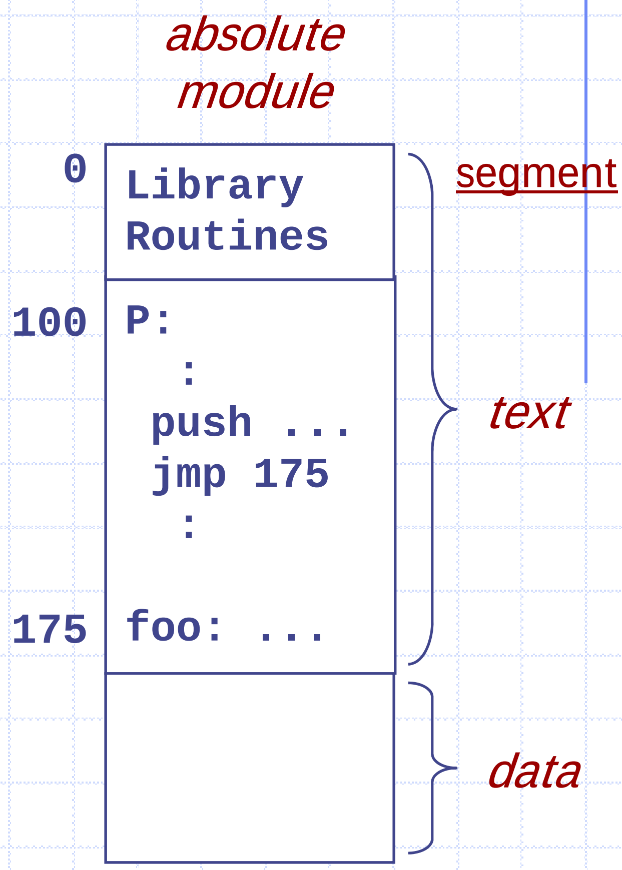
Linker

- Linker combines pieces of the program
  - combines the program with other object modules (eg: library calls)
  - linker produces an *absolute module*
  - linker assumes the program will be loaded at address 0
  - *the organization of the absolute module defines the address space*



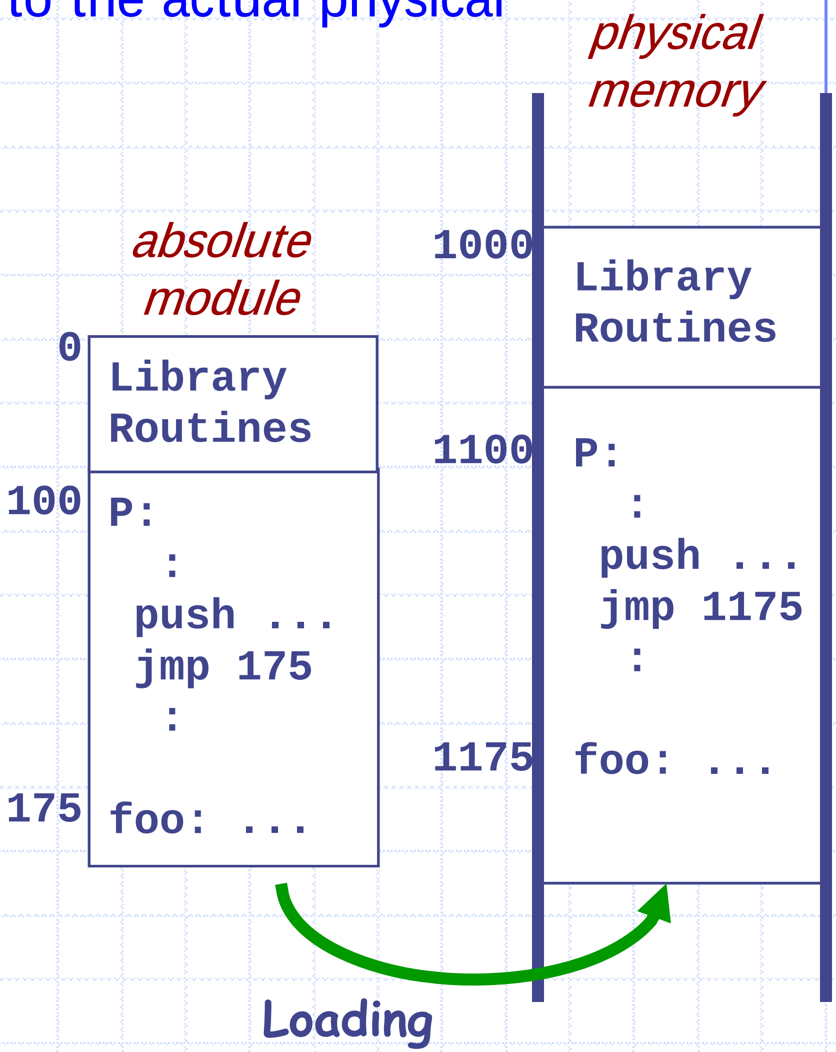
Linker (cont)

- In addition to resolving external references, linker also structures the program into segments, thereby defining the address space
- The absolute module is basically an image of the process, and includes all the non-empty segments
- The absolute module is of course much smaller than the entire address space



Loader

- Loader maps the absolute module to the actual physical memory
  - first it allocates a block of physical memory that can hold the process
  - next, all addresses in the absolute module are modified (mapped) to match the allocated physical memory addresses
  - finally, the image (code, data etc) is copied from secondary storage into the physical memory



Static Relocation

- we have been discussing a three step technique for mapping a program into memory:
  1. compile: produce a relocatable object
  2. link: produce an absolute module
  3. load: map the module into a range of allocated memory

- this technique is known as ***Static Relocation***
  - note: sometime referred to as *static address binding*

- in this technique, the address space is essentially defined by the structure of the absolute module

- the address binding occurs at when the module is loaded
  - ie: at load time

Another Example

- consider the following segment of a C program
  - it contains one static variable (with global scope)
  - it contains one function
  - it contains one function call to an external reference (put_record is extern)

```
...
static int gVar;
...
int proc_a(int arg){
        ...
        gVar = 7;
        put_record(gVar);
        ...
}
```

Another Example (after compilation)

Code Segment

Relative Address	***Generated Code***
0000	...
...	
0008	entry proc_a
...	
0220	load =7, R1
0224	store R1, 0036
0228	push 0036
0232	call 'put_record'
...	
0400	External reference table
...	
0404	'put_record' 0232
...	
0500	External definition table
...	
0540	'proc_a' 0008
...	
0600	(symbol table)
...	
0799	(end of code segment)

Data Segment

Relative Address	***Generated variable space***
...	
0036	[Space for gVar]
...	
0049	(end of data segment)

relocatable object module (includes two segments)

```
...
static int gVar;
...
int proc_a(int arg){
        ...
        gVar = 7;
        put_record(gVar);
        ...
}
```

Another Example (after linking)

Code Segment

```
Relative
Address   Generated Code

0000      (Other modules)
...
1008      entry   proc_a
...
1220      load    =7, R1
1224      store   R1, 0136
1228      push    0136
1232      call    2334
...
1399      (End of proc_a)
...
2334      entry   put_record
...
2670      (optional symbol table)
...
2999      (end of code segment)
```

Data Segment

```
Relative
Address   Generated variable space
...
0136      [Space for gVar]
...
1000      (end of data segment)
```

absolute program

- the program is relocated to 1000 to make room for other object modules being linked in
- the original data segment is relocated to 100 to make room for other data
- external entry points are resolved

Another Example (after loading)

- the memory manager allocates 4000-8000 to this process
- the absolute program is mapped into this address range

```
Physical
Address   Generated Code
0000      (Other process's programs)
...
4000      (Other modules)
...
5008      entry   proc_a
...
5220      load    =7, R1
5224      store   R1, 7136
5228      push    7136
5232      call    6334
...
5399      (End of proc_a)
...
6334      entry   put_record
...
6670      (optional symbol table)
...
6999      (end of code segment)
7000      (start of data segment)
...
7136      [Space for gVar variable]
...
8000      (Other process's programs)
```

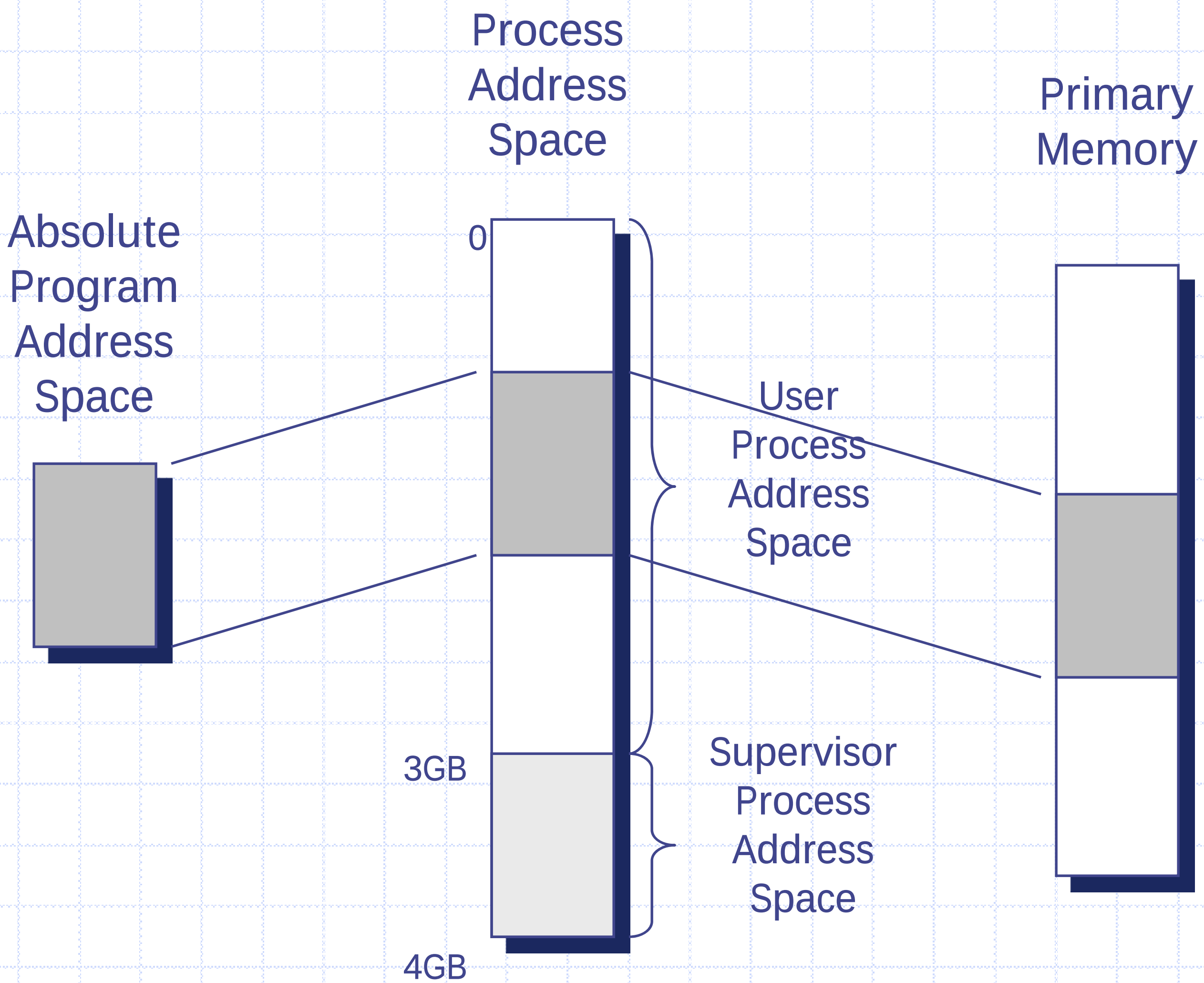
Modern Address Binding Mechanisms

- the modern process has a predefined address space
- for example linux reserves
  - 0 – 3GB for the user addressable locations
  - 3GB – 4GB for supervisor mode instructions

- with this process architecture predefined, the loader *binds the absolute module into the process address space* instead of into physical memory

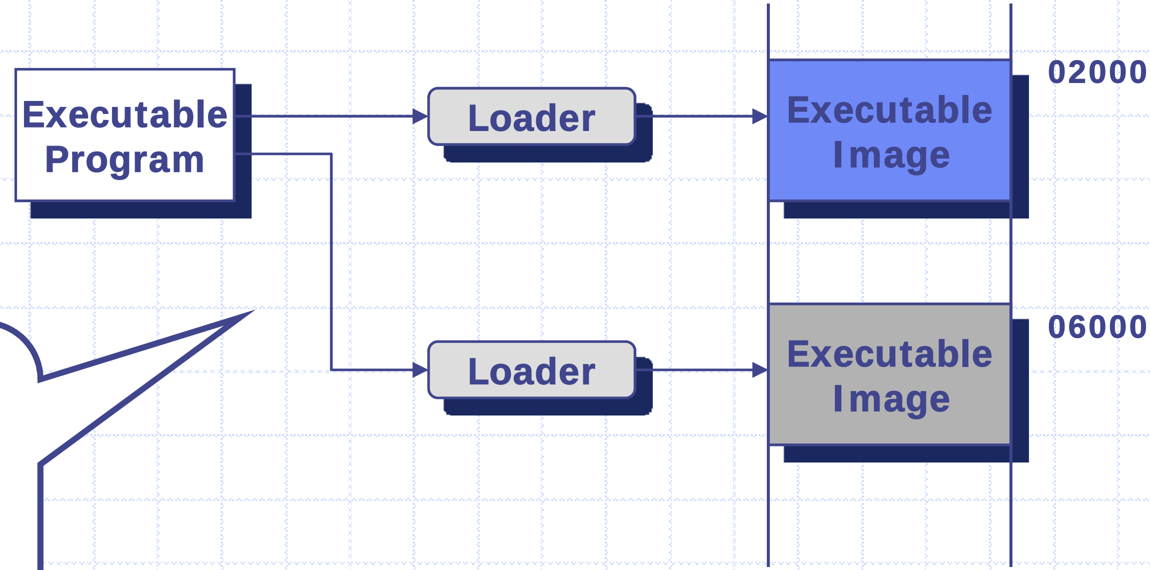
- the memory manager can then wait until *run-time* to *map the process address space into physical memory*
  - this allows the memory manager to make use of virtual memory and paging techniques (to be discussed in a subsequent lesson)
  - this also provides support for any “loadable module” mechanisms that the OS might provide

Program and Process Address Spaces



Relocating Programs in Memory

- in the previous discussion, a program always runs from the same memory location(s) after it has been loaded
- as we will see later, this can lead to memory fragmentation
- one method for dealing with fragmentation is to move programs around, to different locations
  - this requires us to re-run the loader on a program



we need a better mechanism than this to relocate programs in memory

Dynamic Relocation

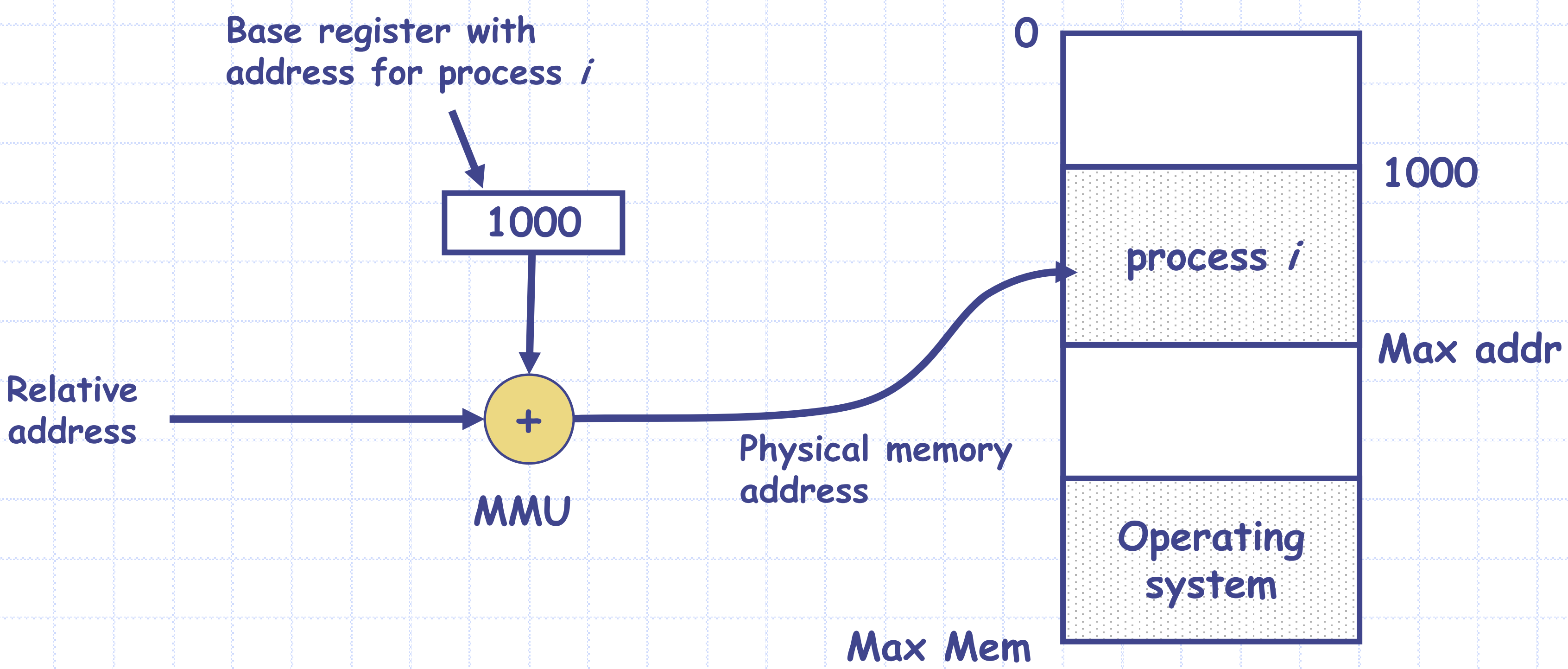
- Dynamic Relocation is:
  - mapping the physical memory to the program (or address space) at run-time
  - requires additional hardware support such as:
    - base & limit registers

- Simple runtime relocation scheme
  - use 2 registers to describe a program loaded into a partition in memory
    - base register defines the beginning of the program in memory
    - limit register is loaded with the length of the program in memory

- For every address generated, at runtime...
  - add address to the base register to give physical memory address
  - compare physical address to the limit register (& abort if larger)

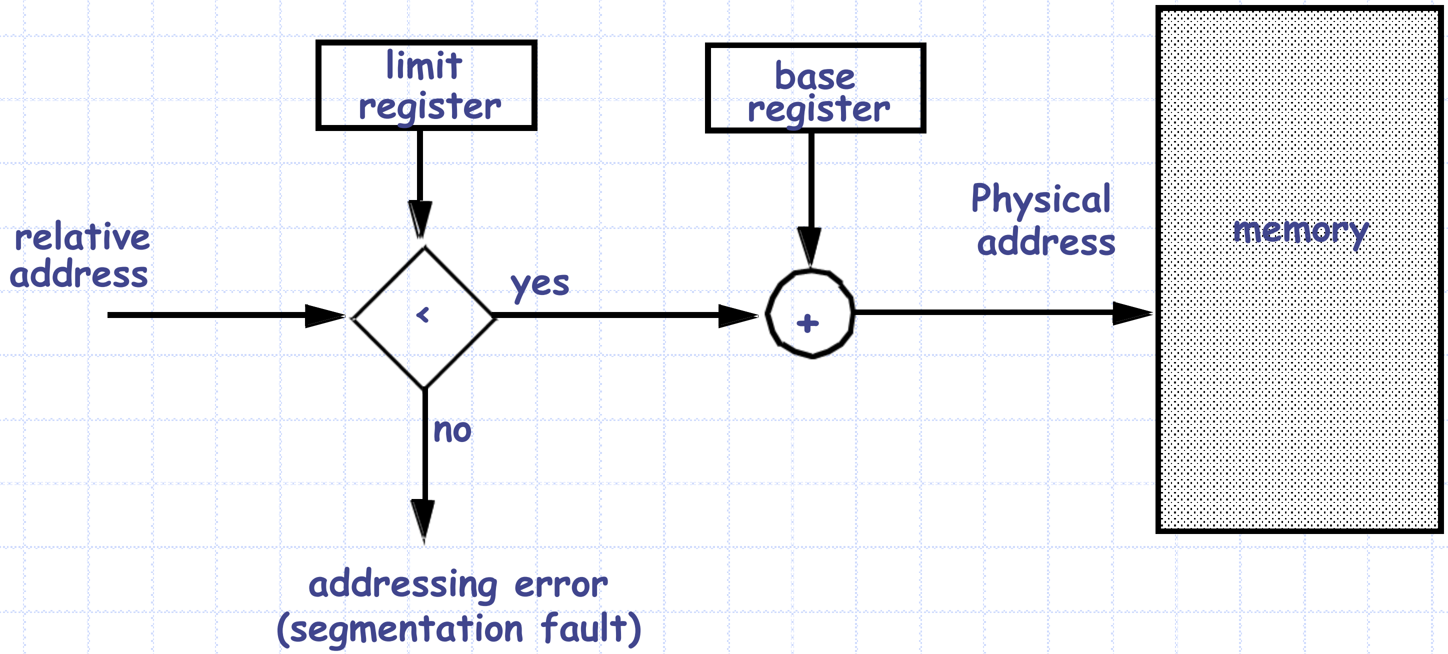
Dynamic relocation with a base register

- Memory Management Unit (MMU) - dynamically converts logical addresses into physical address
- MMU contains base address register for running process



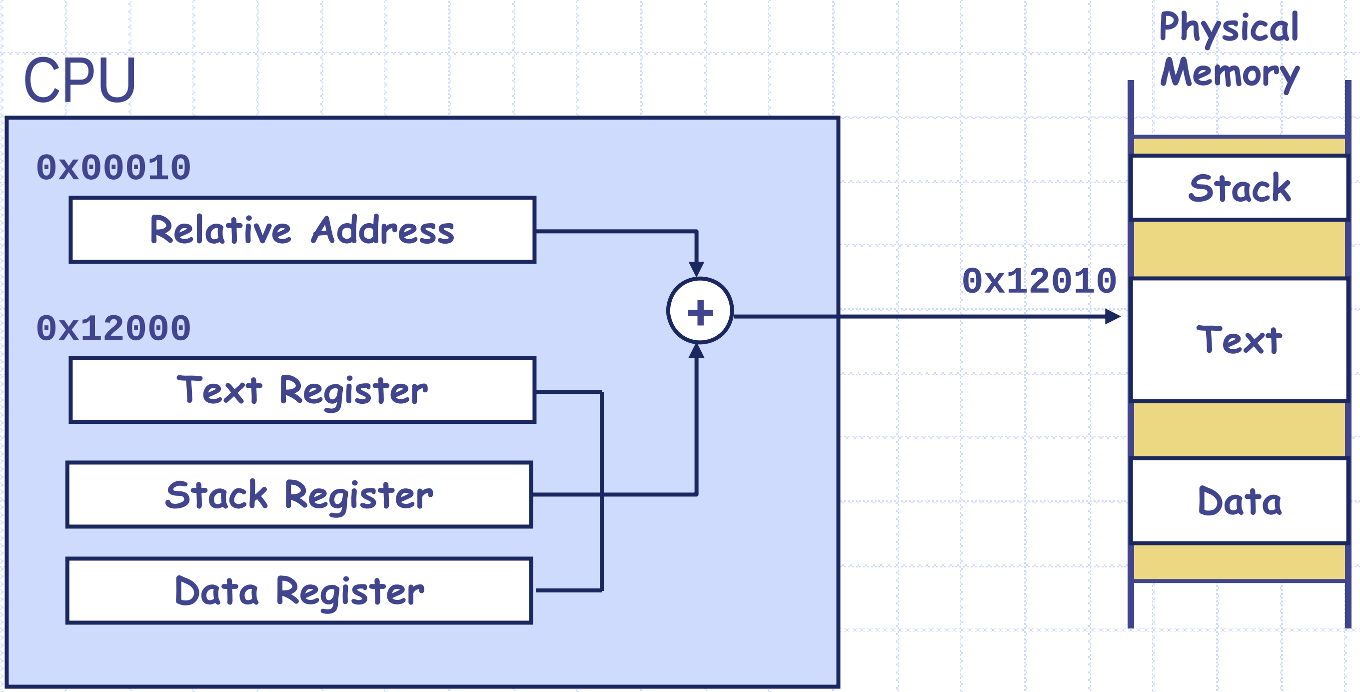
Protection using base & limit registers

- Memory protection
  - Base register gives starting address for process
  - Limit register limits the offset accessible from the relocation register



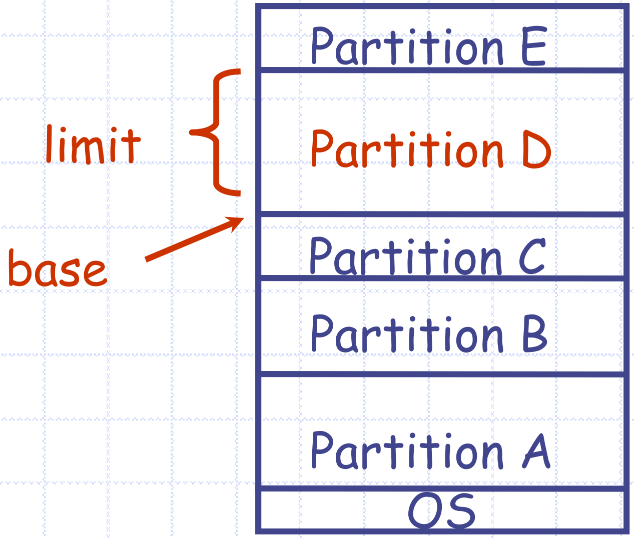
Multiple Base Registers

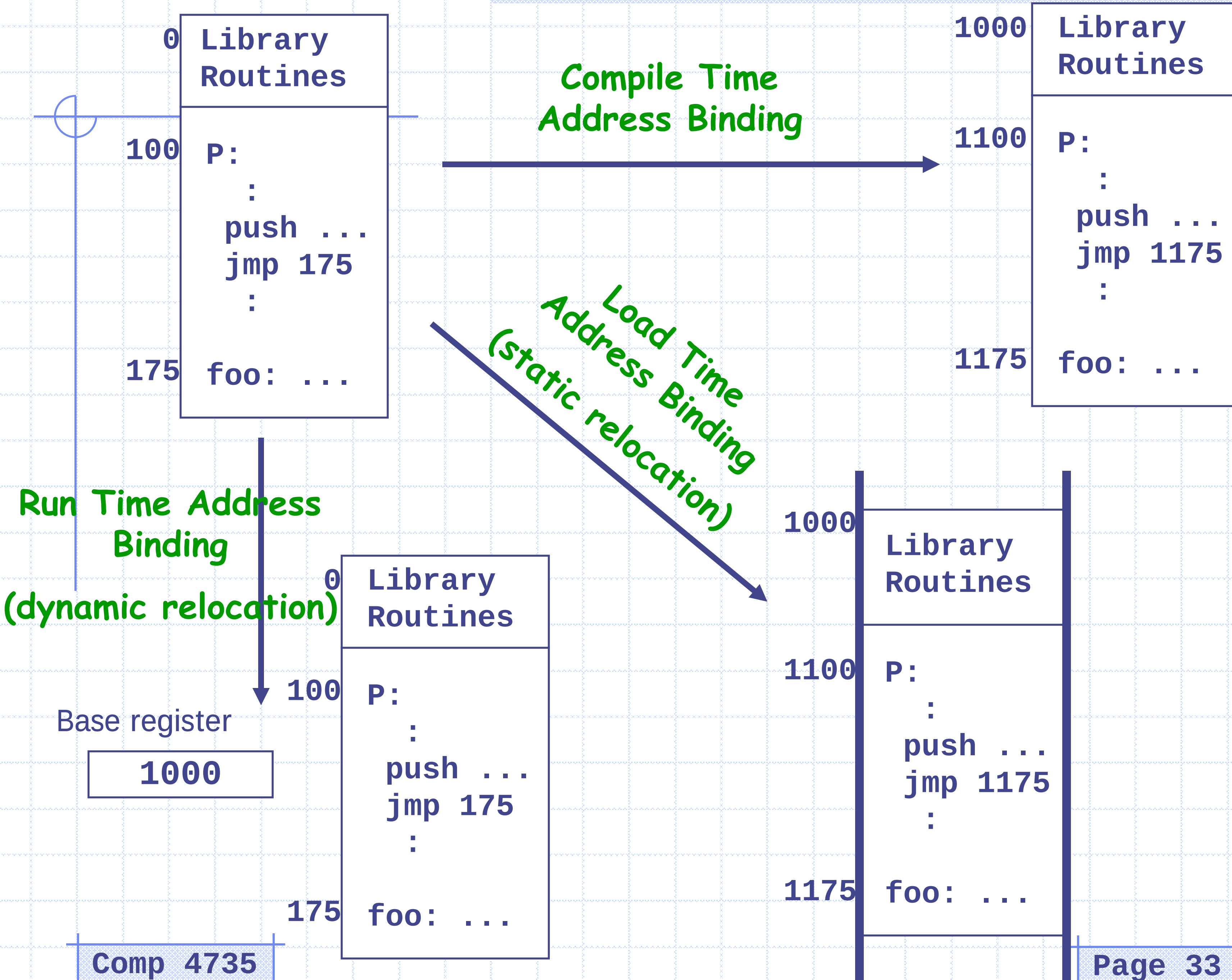
- we can use a different base register for each segment in the address space, for example:



Multiprogramming with base and limit registers

- Multiprogramming: a separate memory block (partition) for each process
- What happens on a context switch?
  - Store process A's base and limit register values
  - Load new values into base and limit registers for process B

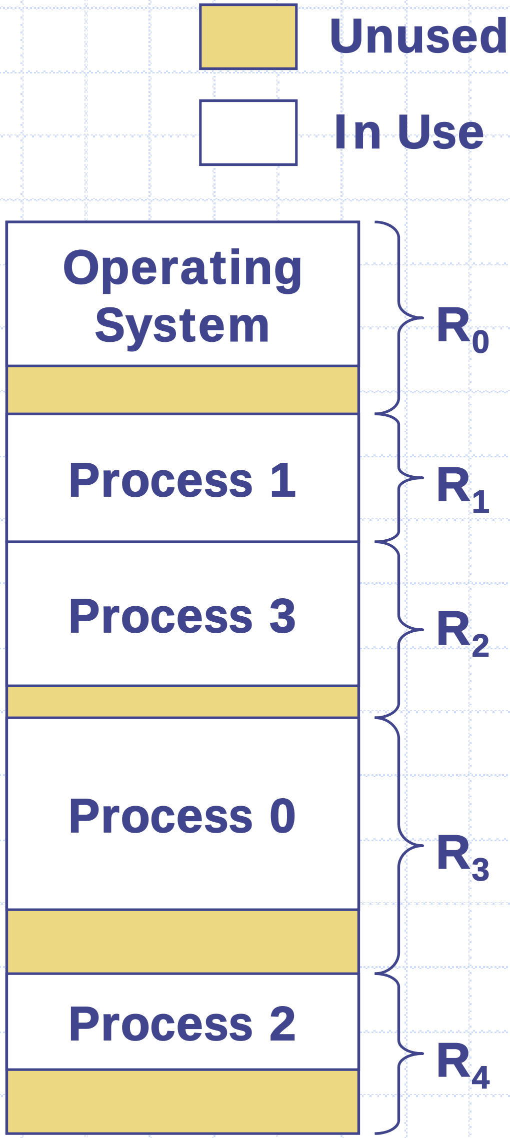



0
Library Routines
100
P:
:
push ...
jmp 175
:
175
foo: ...
Compile Time Address Binding
1000
Library Routines
1100
P:
:
push ...
jmp 1175
:
1175
foo: ...
Load Time Address Binding (static relocation)
1000
Library Routines
1100
P:
:
push ...
jmp 1175
:
1175
foo: ...
Run Time Address Binding
(dynamic relocation)
Base register
1000
0
Library Routines
100
P:
:
push ...
jmp 175
:
175
foo: ...

Memory Allocation

- to support multiprogramming, we need to allocate separate blocks (partitions) of memory to each process
- there are three basic strategies for doing this:

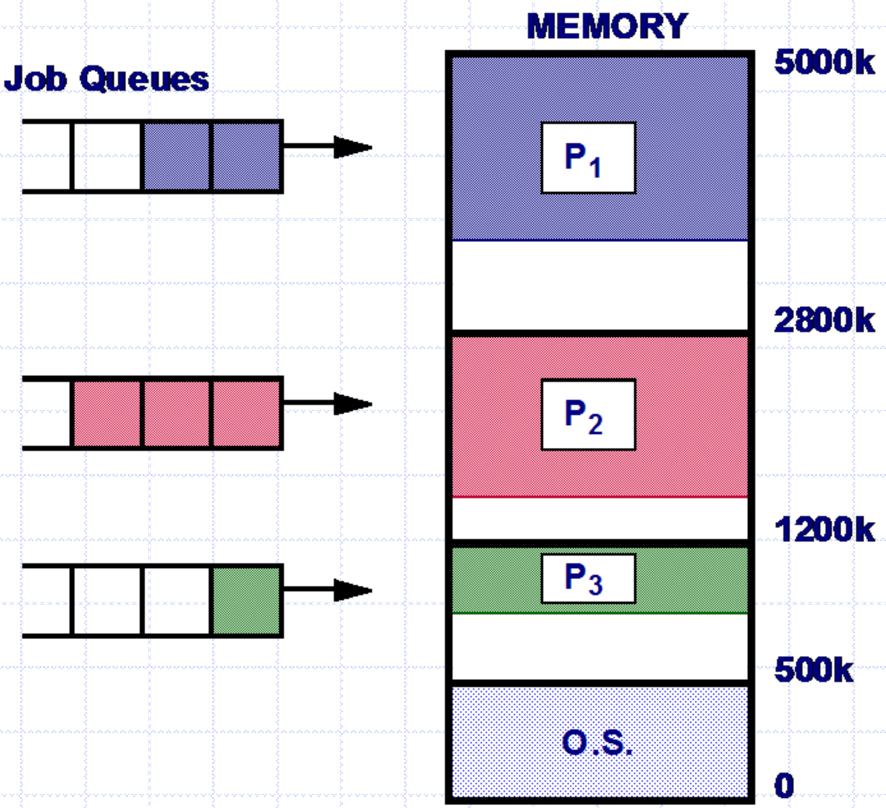
  1. use Fixed Size Partitions
  2. use Variable Size Partitions
  3. dynamically allocate memory as needed (pages … aka virtual memory)



Fixed Partition

- Memory is divided into fixed size partitions
- Processes loaded into partitions of equal or greater size

traditionally used in batch systems



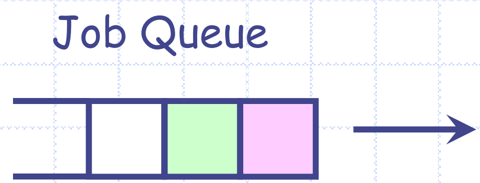
Internal Fragmentation

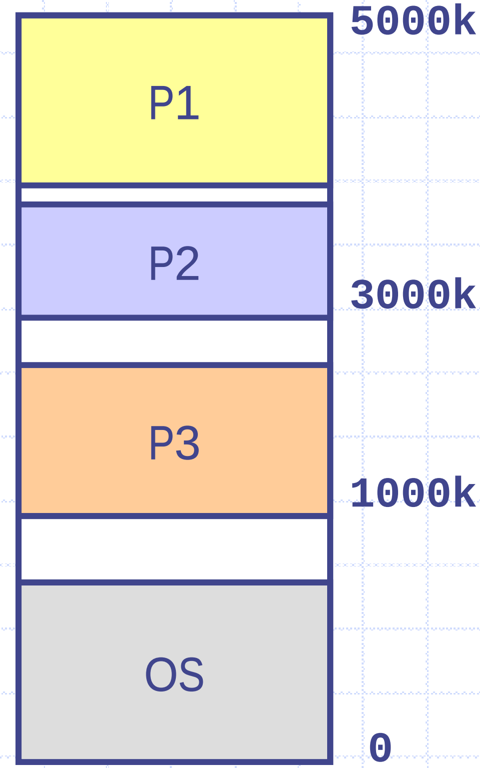
- can lead to wasted memory inside each allocated partition

Variable Partition

- Memory allocated to fit processes exactly
  - processes are loaded into regions of memory that are equal or greater size
  - there is really only one queue of jobs in this case

traditionally used in swapping systems



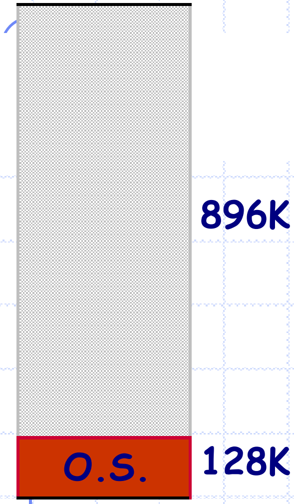


External Fragmentation

- can lead to wasted memory outside each allocated partition

Fragmentation in Variable Partition Strategies

- in most types of systems we are continually loading and unloading processes
- this leads to fragmentation, for example …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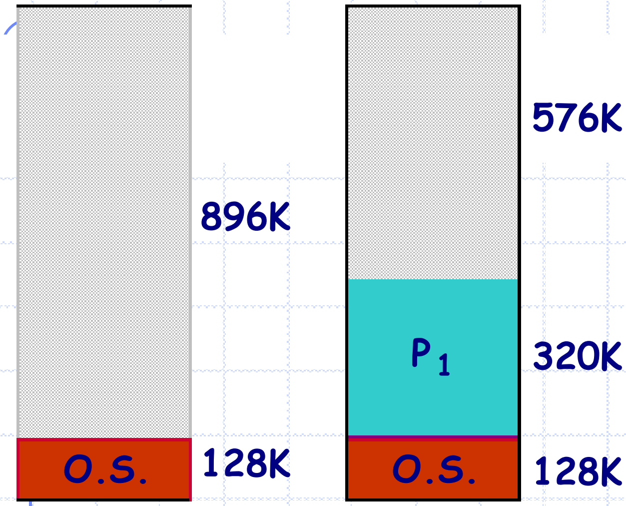
O.S.
128K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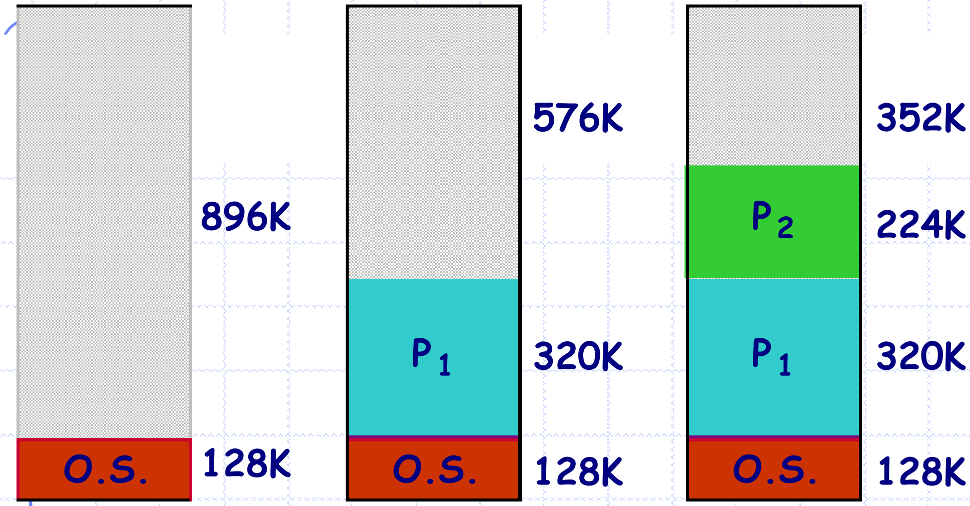
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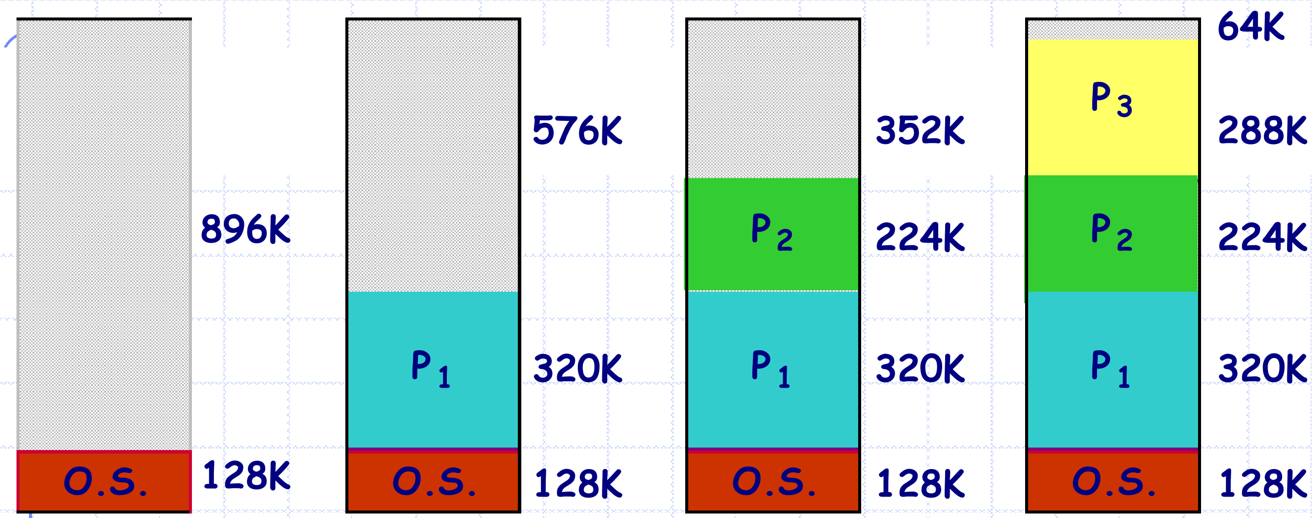
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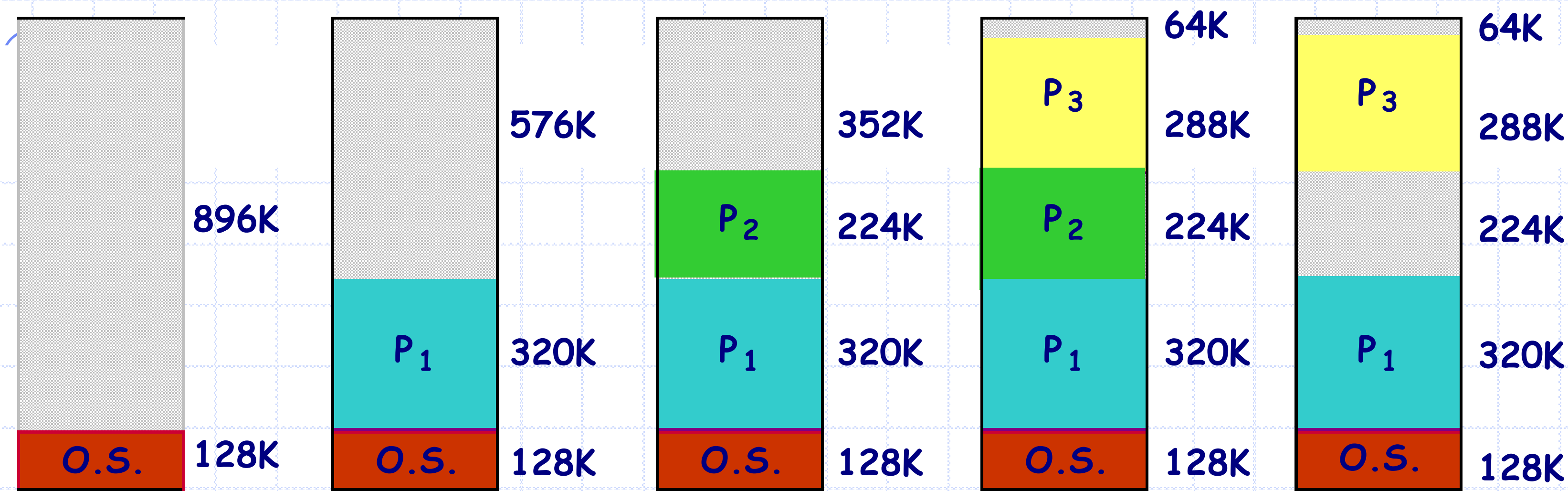
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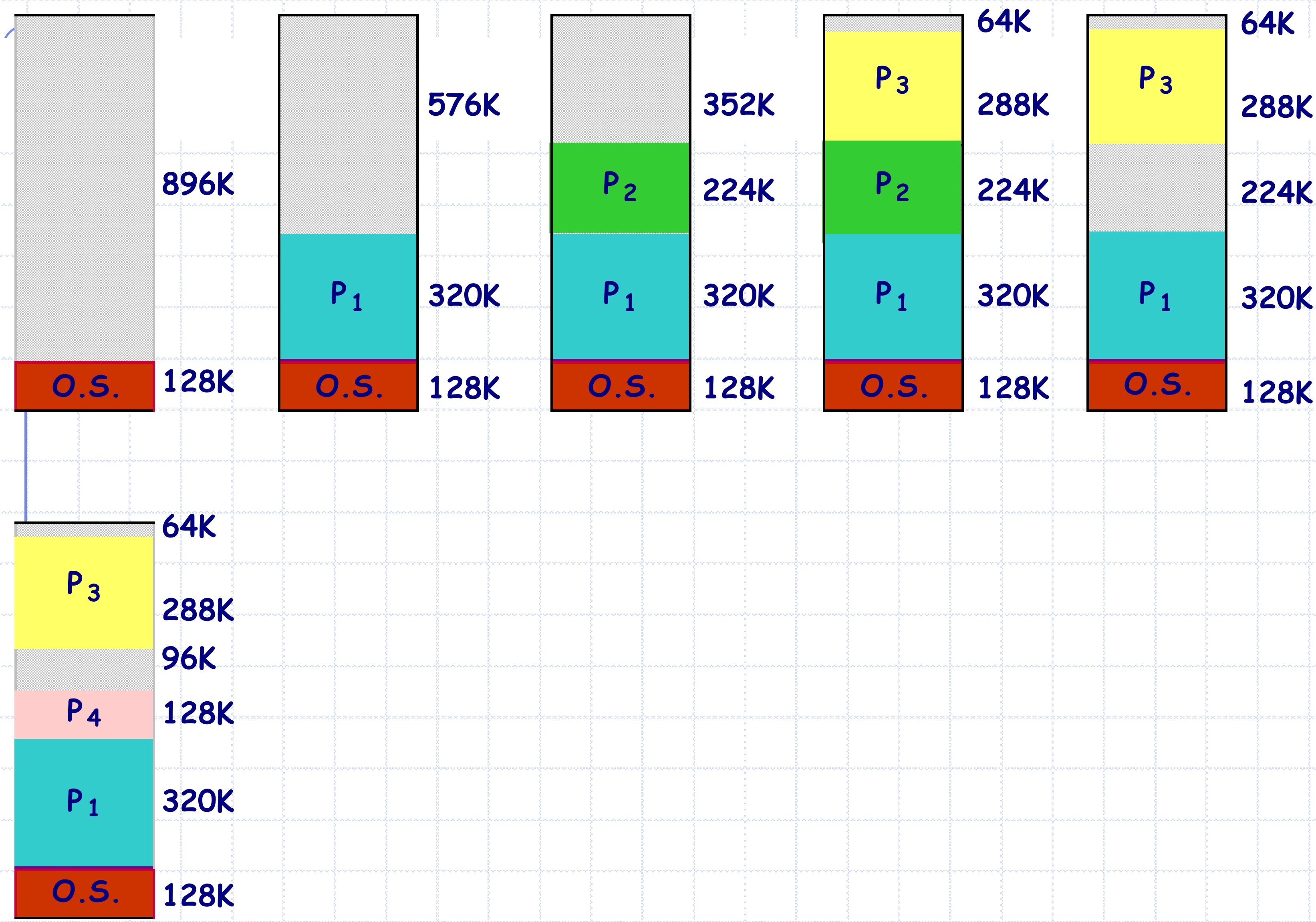
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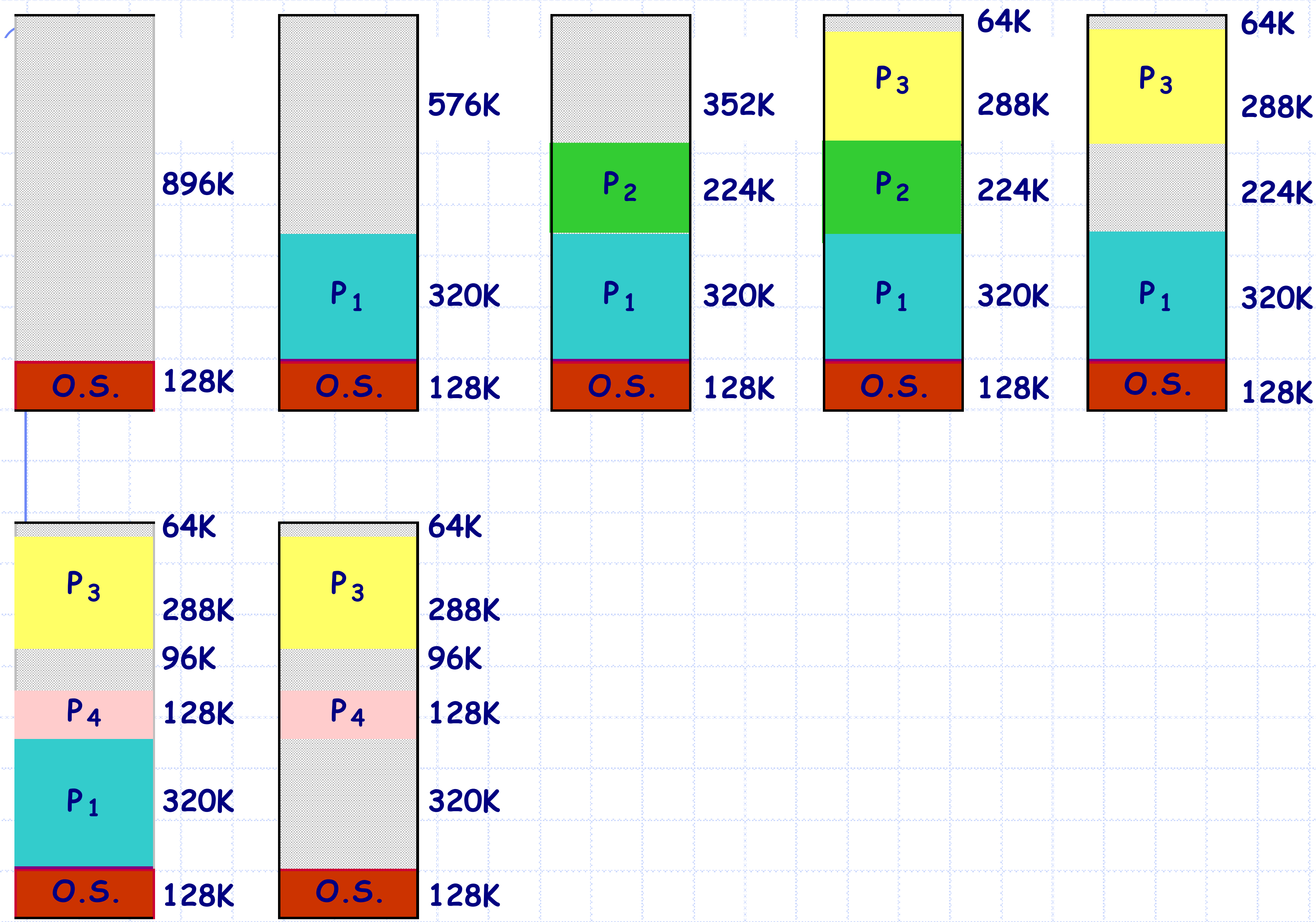
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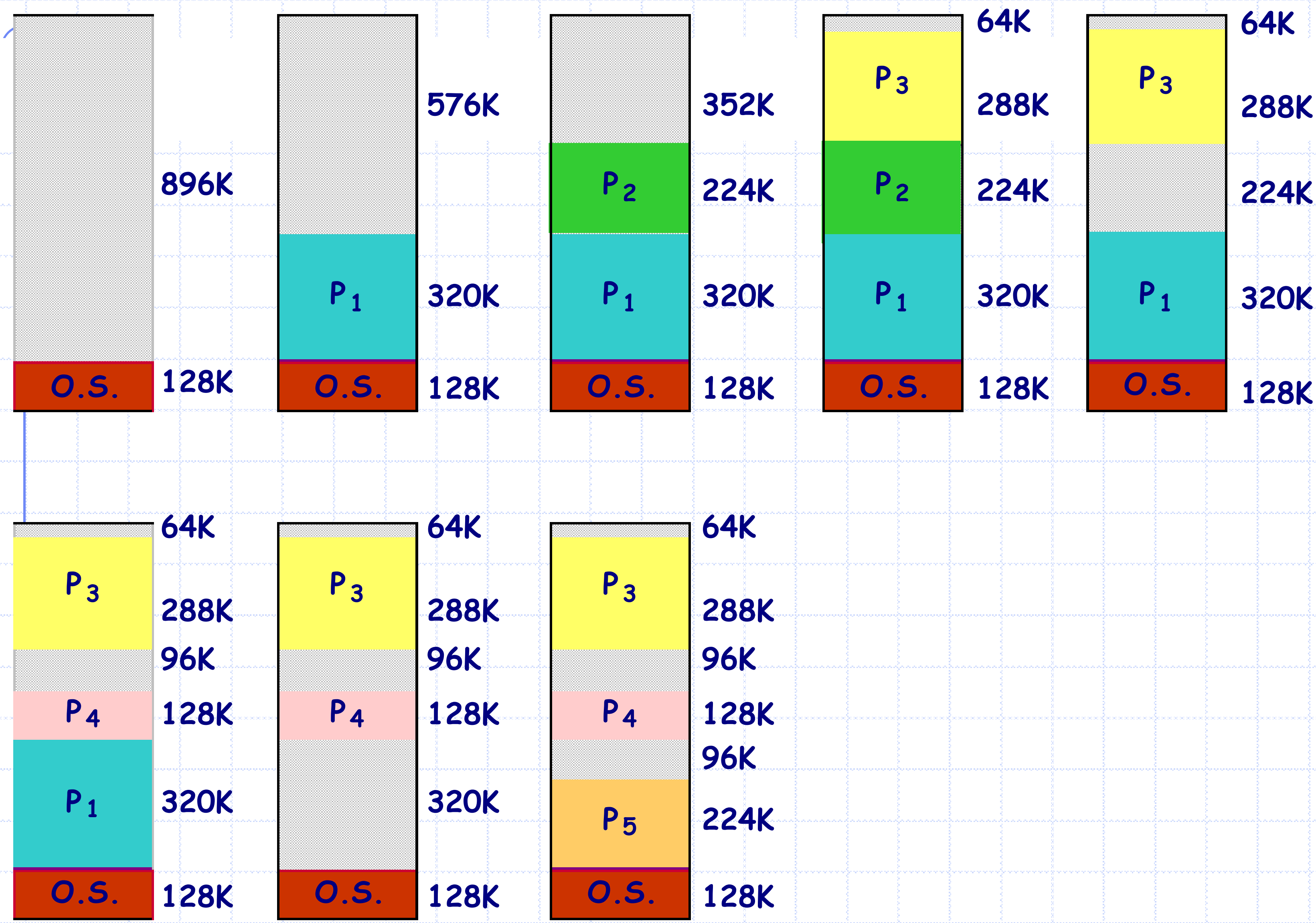
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128K

O.S.
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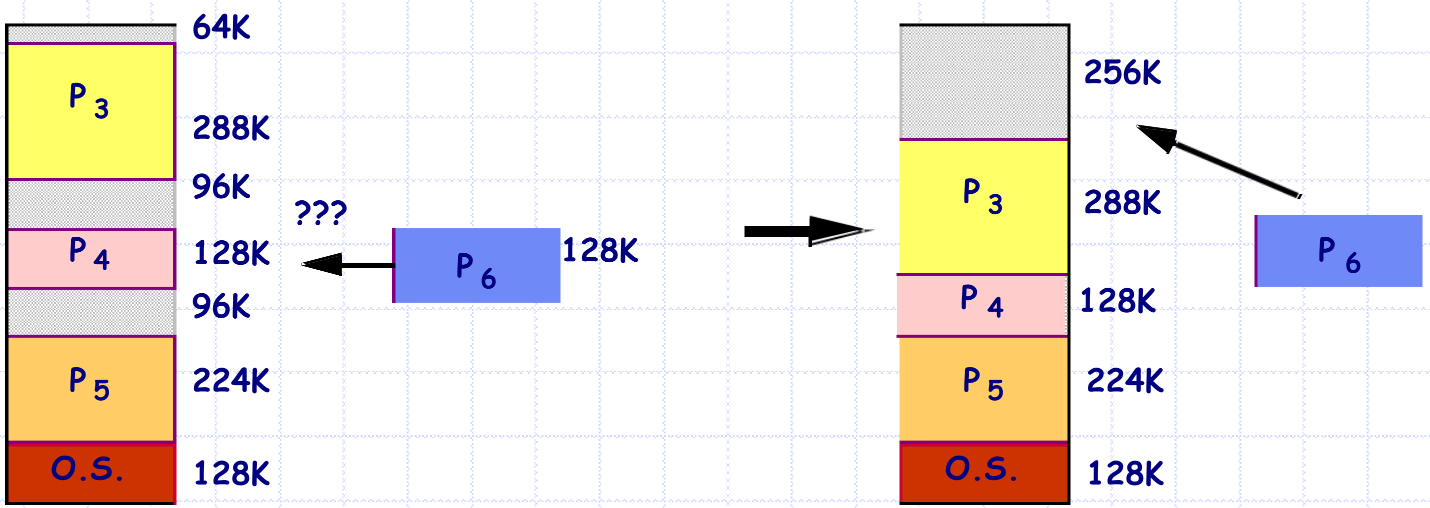
576K
P2
224K
352K
P3
288K
64K
P4
96K
P5
96K
???
P6
128K

Dealing with fragmentation

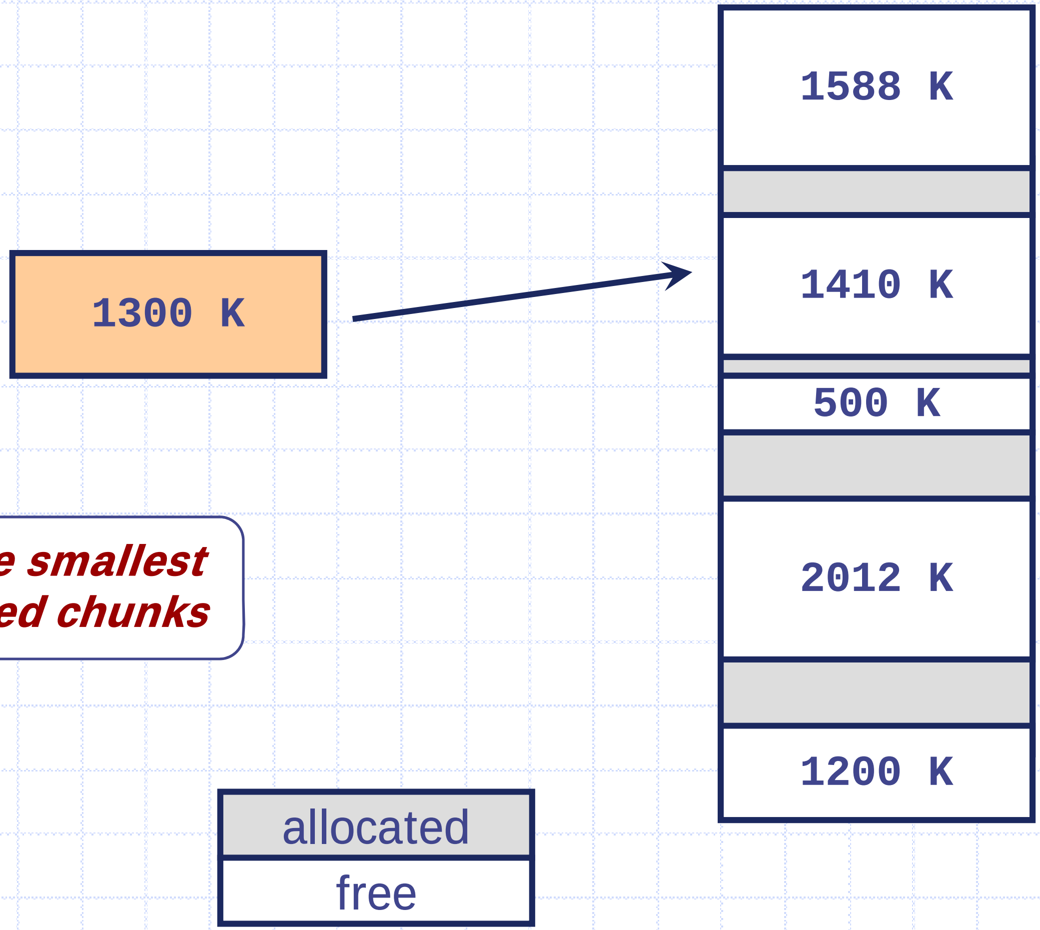
- *Compaction* – from time to time we move the processes around to collect all free space into one contiguous block



- Allocation Strategies: First-fit, best-fit, worst-fit
  - these affect the degree of fragmentation

Best Fit Memory Allocation

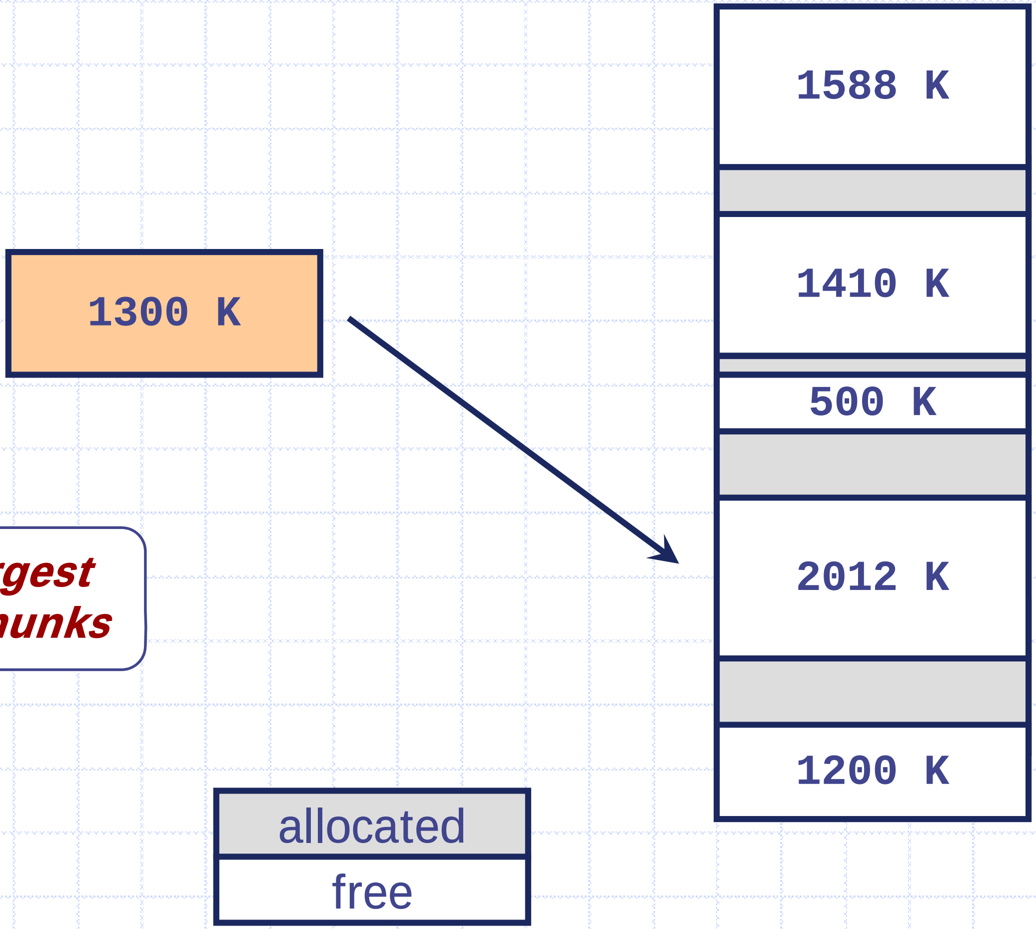
- allocate the smallest block of free memory in which the process will fit



leaves the smallest unallocated chunks

Worst Fit Memory Allocation

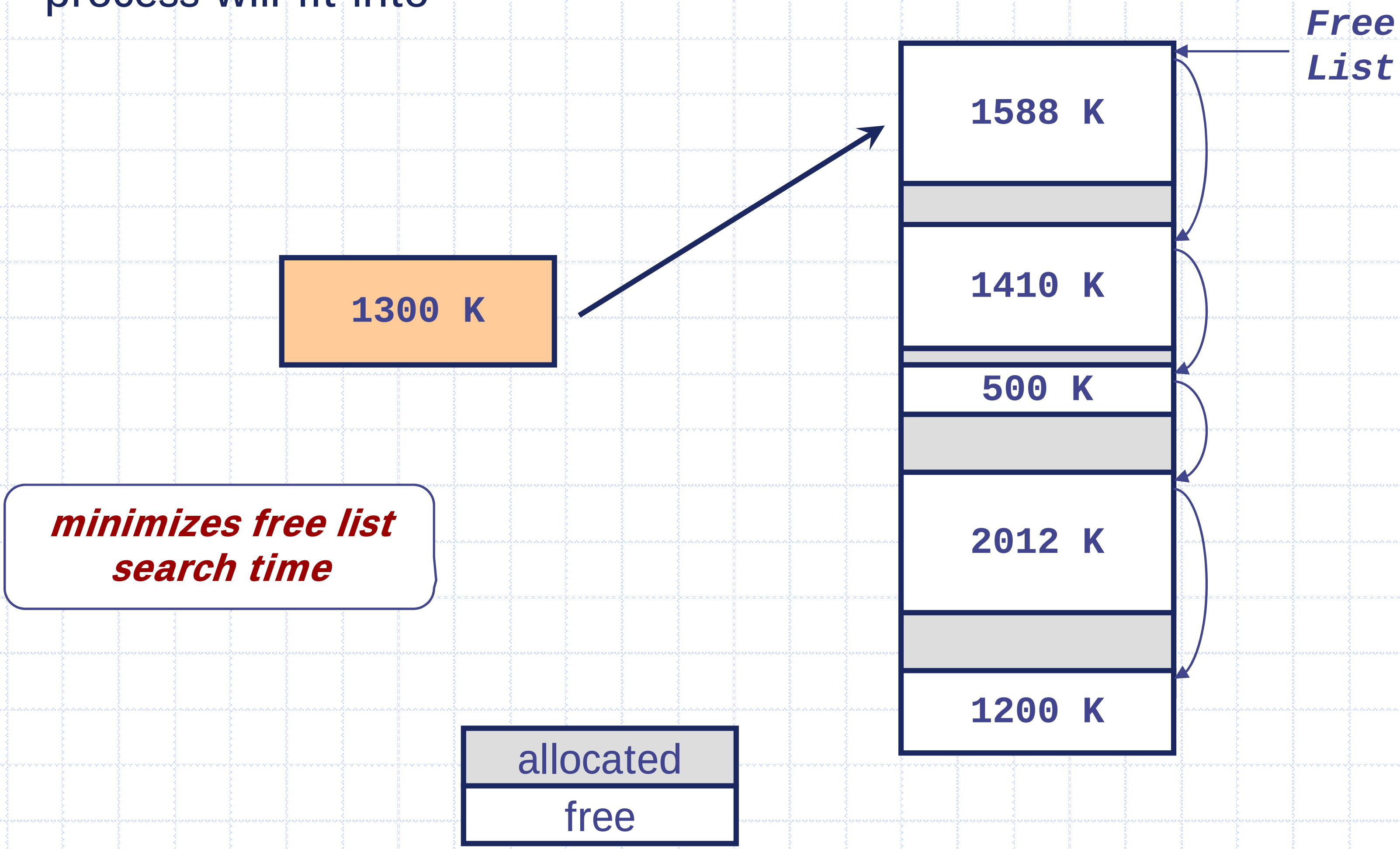
- allocate the largest block of free memory
  - as long as the process will fit



leaves the largest unallocated chunks

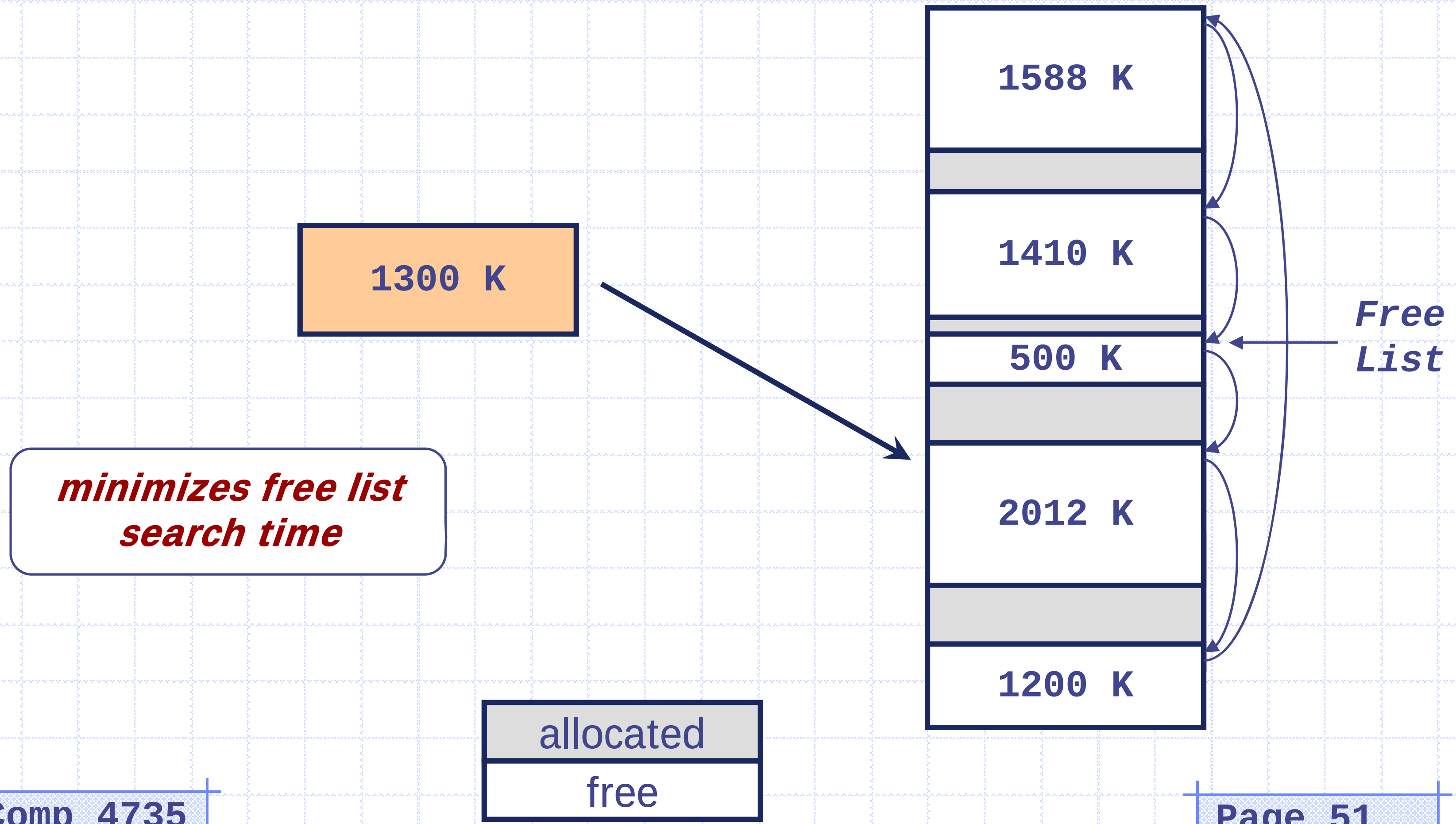
First Fit Memory Allocation

- allocate the first block of memory (from the free-list) that the process will fit into

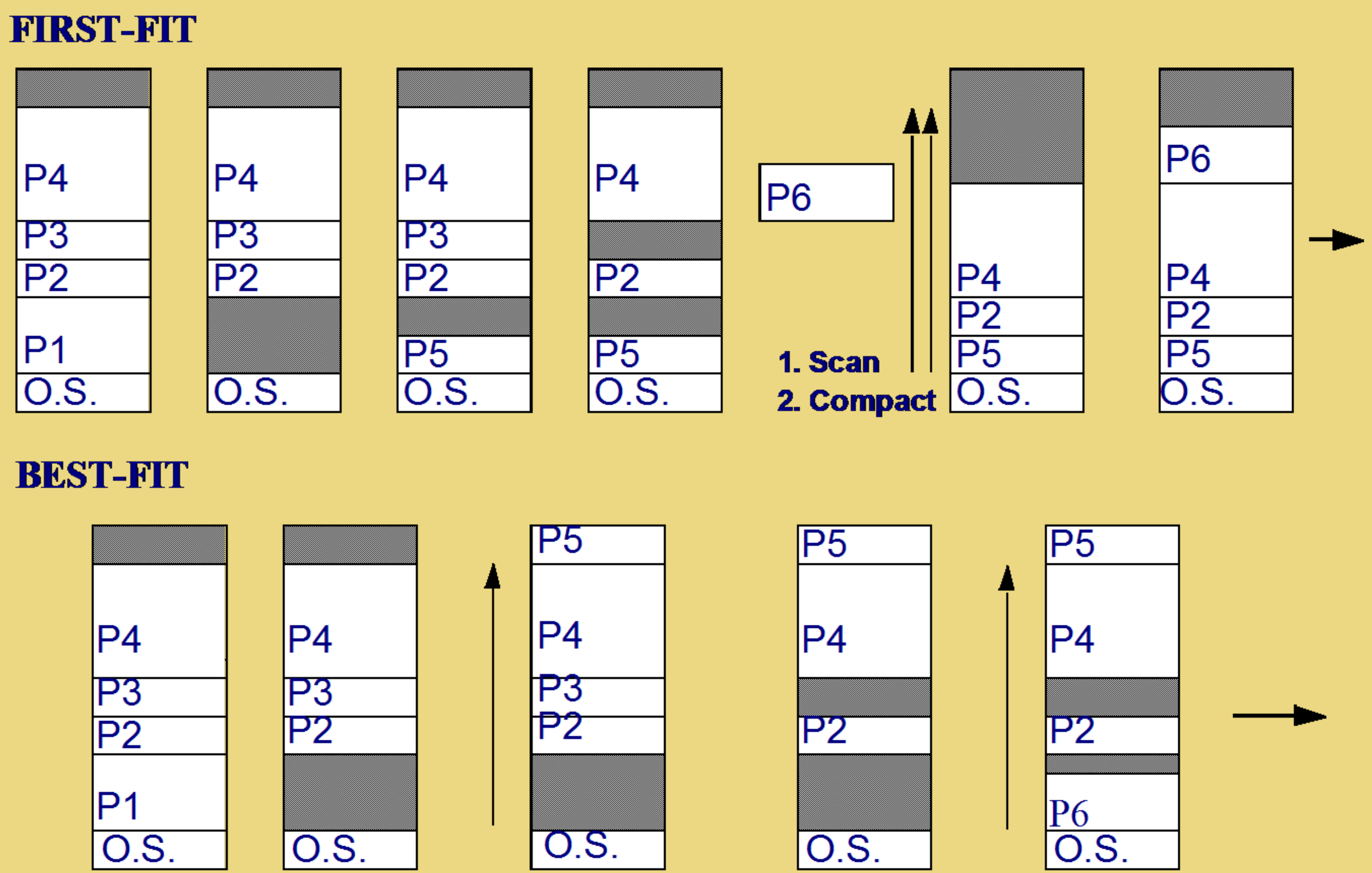


Next Fit Memory Allocation

- similar to first fit, but free-list is a circular list
  - start search at the first free block following the last one allocated



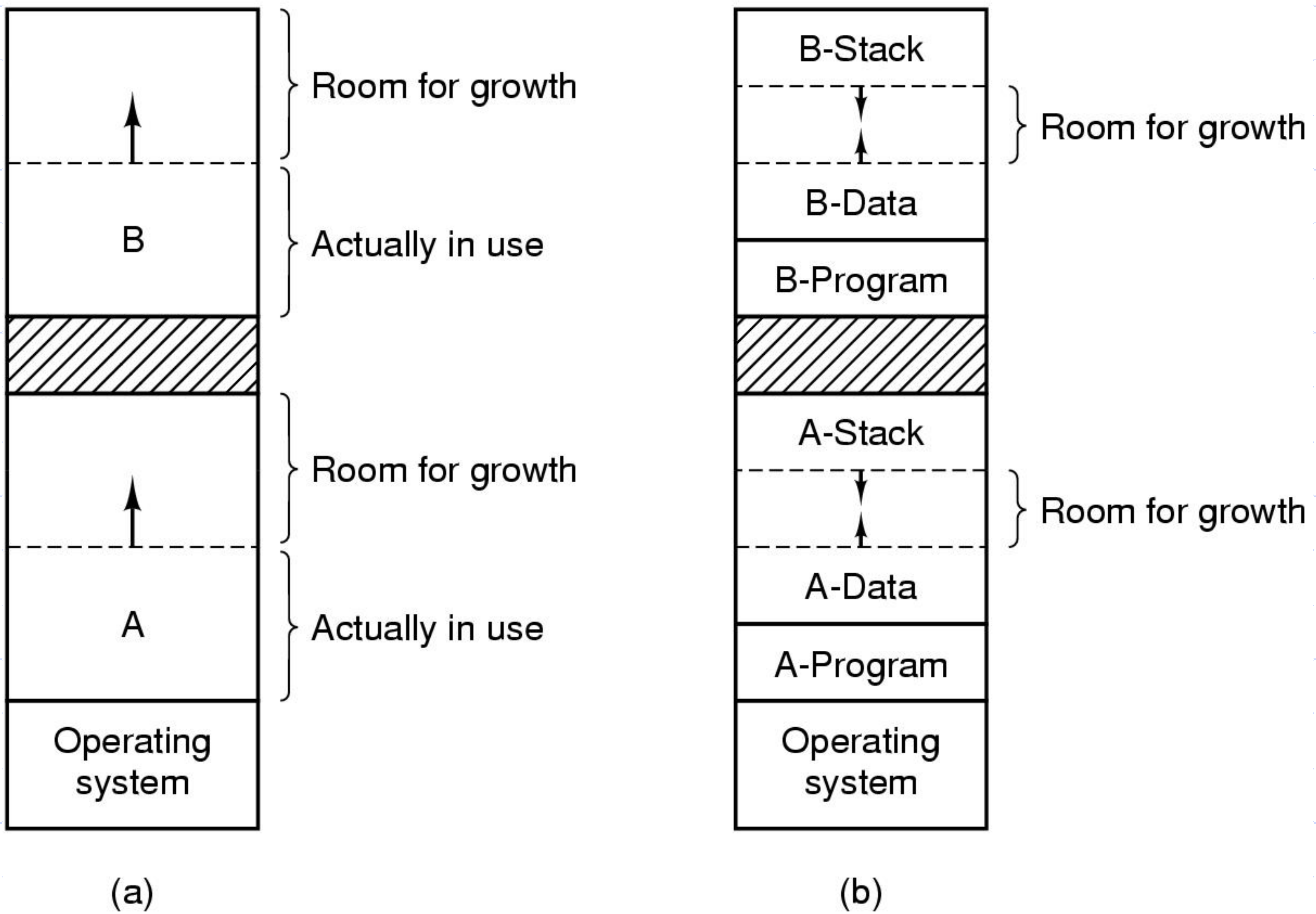
Influence of allocation policy



How big should partitions be?

- Programs may want to grow during execution
  - More room for stack, heap allocation, etc
- Problem:
  - If the partition is too small programs must be moved
  - Requires modification of base and limit regs
  - Why not make the partitions a little larger than necessary to accommodate “some” growth?
- Fragmentation:
  - External fragmentation = unused space between partitions
  - Internal fragmentation = unused space within partitions

Allocating extra space within partitions



Managing free memory

- Each chunk of memory is either
  - Used by some process or unused (“free”)

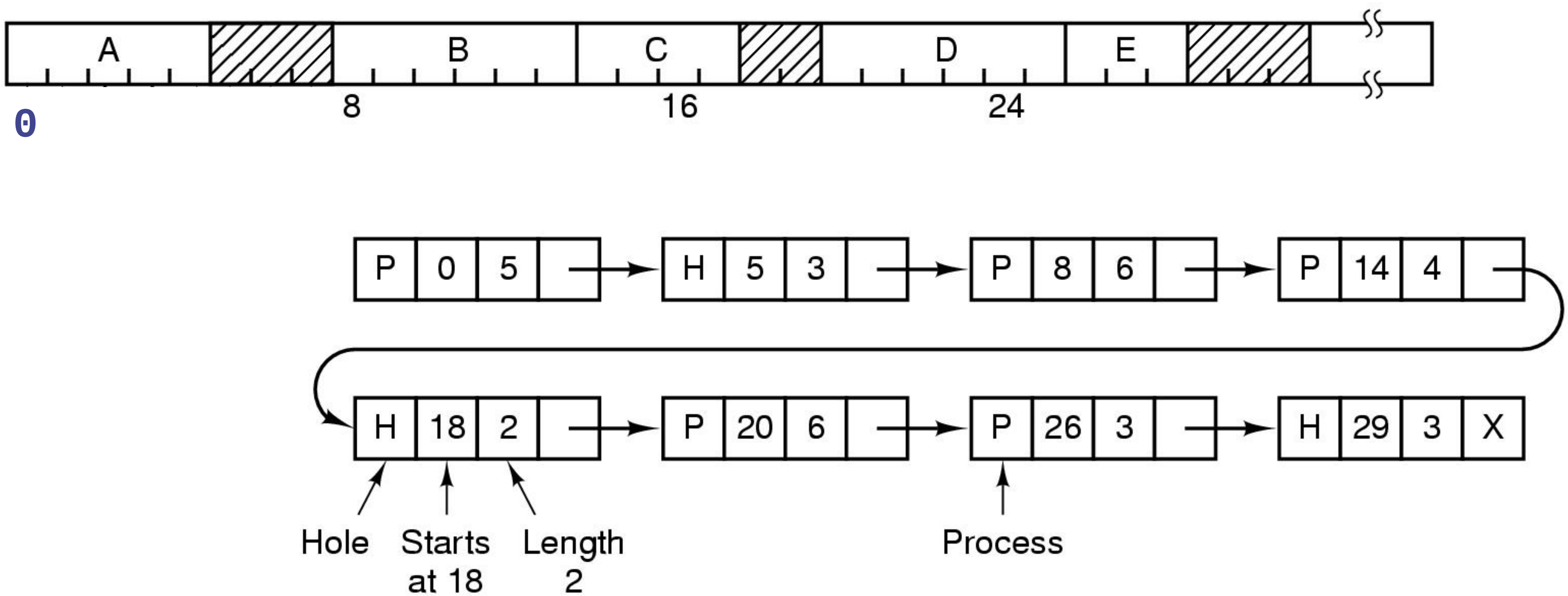
- Operations
  - Allocate a chunk of unused memory big enough to hold a new process
  - Free a chunk of memory by returning it to the free pool after a process terminates or is swapped out

Managing memory with linked lists

- Problem - we need to keep track of used and unused memory
- Technique: use a Linked List
- Keep a list of elements
- Each element describes one unit of memory
  - Free / in-use Bit ("P=process, H=hole")
  - Starting address
  - Length
  - Pointer to next element

Managing memory with linked lists

- the free-list structures indicate where processes and holes start
- each block of memory (free or otherwise) is on the list

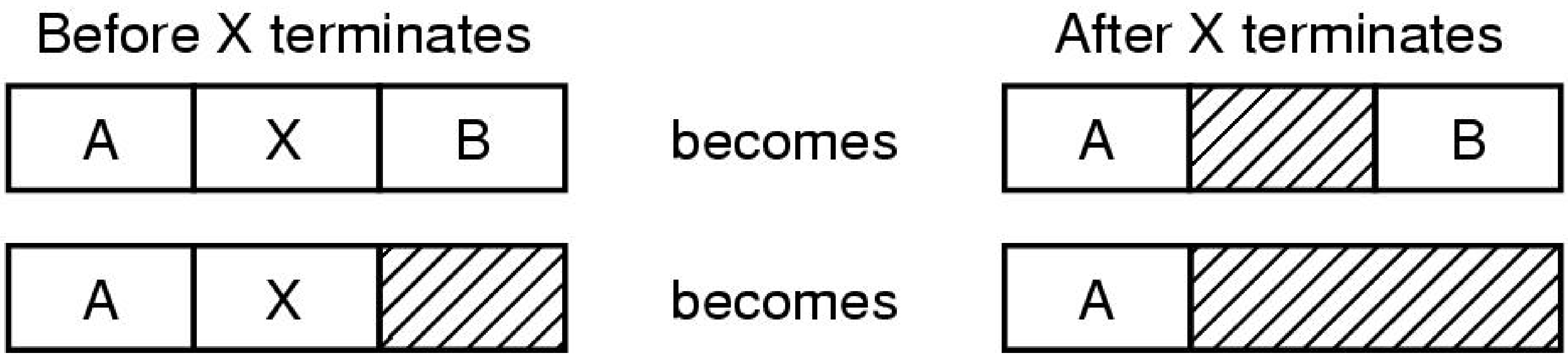


Merging holes

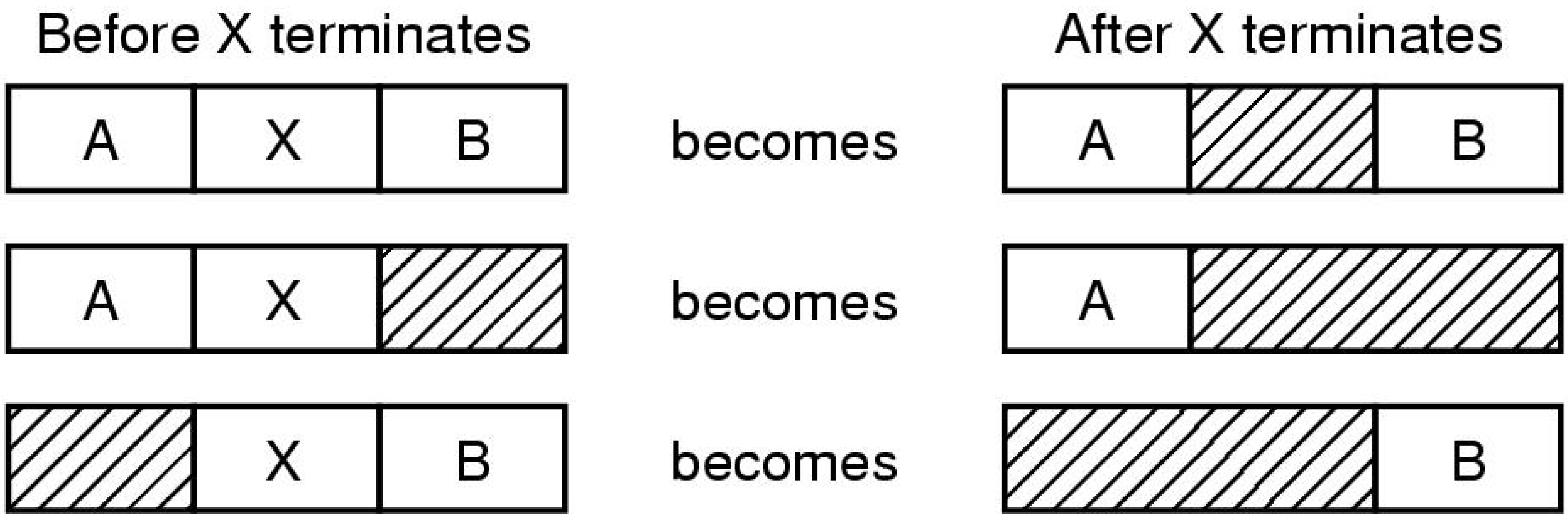
- Whenever a unit of memory is freed we want to merge adjacent holes …

Merging holes

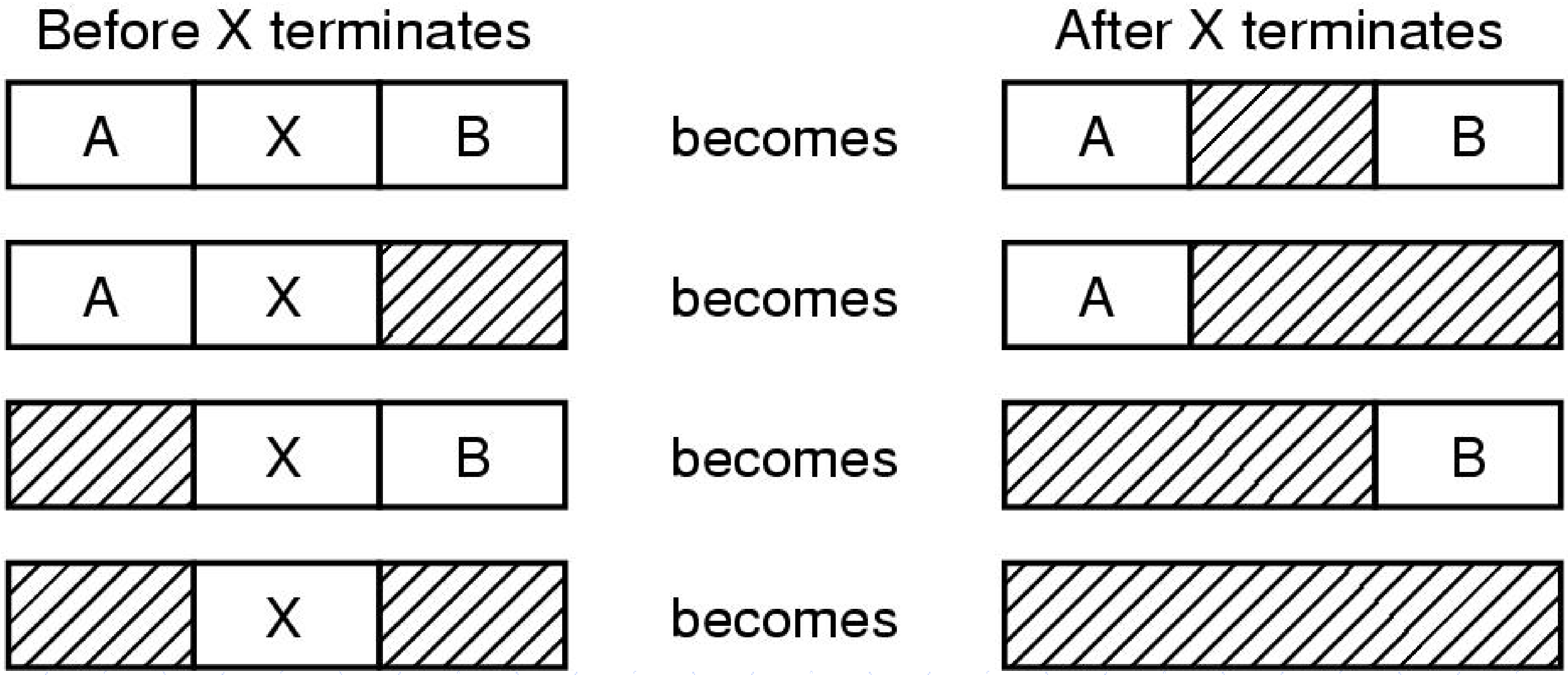
Merging holes



Merging holes



Merging holes

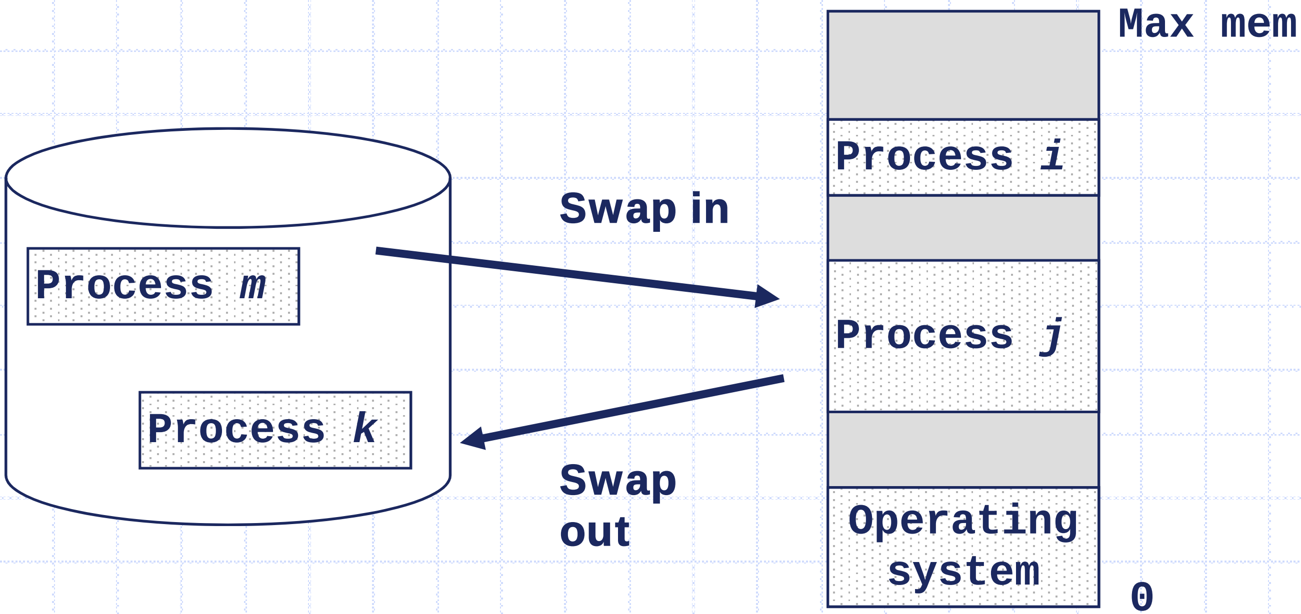


Swapping

- When a program is running…
  - The entire program must be in memory
  - Each program is put into a single partition
- When the program is not running…
  - May remain resident in memory
  - May get "*swapped*" out to disk
- If we consider the life of a program over time…
  - Programs come into memory when they get swapped in
  - Programs leave memory when they get swapped out
  - A program may execute out of many partitions as it is swapped into and out of memory

Basics - swapping

- Benefits of swapping:
  - Allows multiple programs to be run concurrently
  - ... more than will fit in memory at once



The End