



Sistemas de Operação / Fundamentos de Sistemas Operativos

Memory management

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Outline

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- ② Address space of a process
- ③ Contiguous memory allocation
- ④ Memory partitioning
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Memory management

Introduction

- To be executed, a process must have its address space, at least partially, resident in main memory
- In a multiprogrammed environment, to maximize processor utilization and improve response time (or turnaround time), a computer system must maintain the address spaces of multiple processes resident in main memory
- But, there may not be room for all
 - because, although the main memory has been growing over the years, it is a fact that “data expands to fill the space available for storage”

(Corollary of the Parkinson's law)

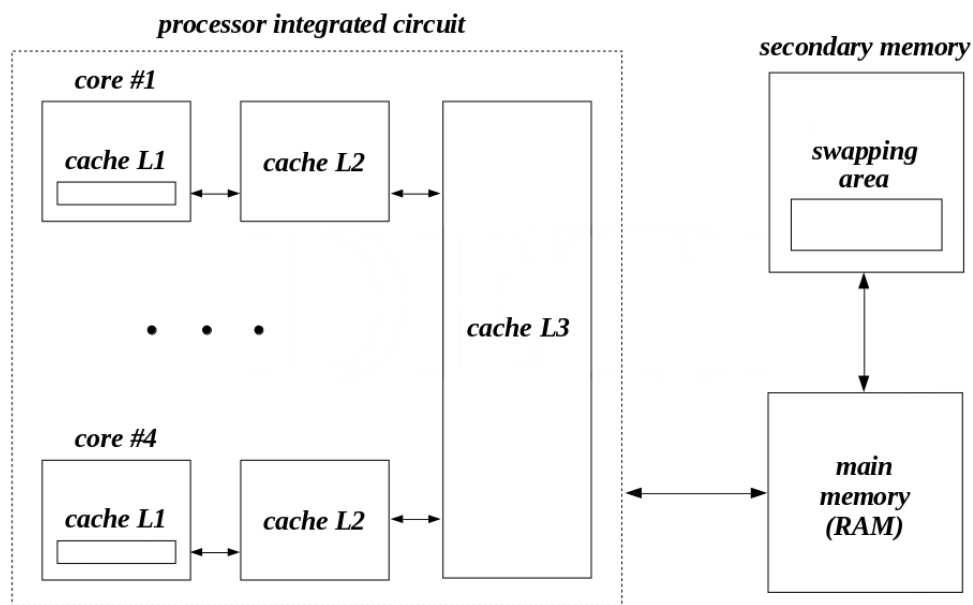
Memory management

Memory hierarchy

- Ideally, an application programmer would like to have infinitely large, infinitely fast, non-volatile and inexpensive available memory
 - In practice, this is not possible
- Thus, the memory of a computer system is typically organized at different levels, forming a hierarchy
 - **cache memory** – small (tens of KB to some MB), very fast, volatile and expensive
 - **main memory** – medium size (hundreds of MB to hundreds of GB), volatile and medium price and medium access speed
 - **secondary memory** – large (tens, hundreds or thousands of GB), slow, non-volatile and cheap

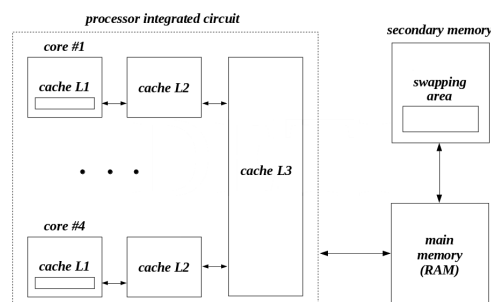
Memory management

Memory hierarchy (2)



Memory management

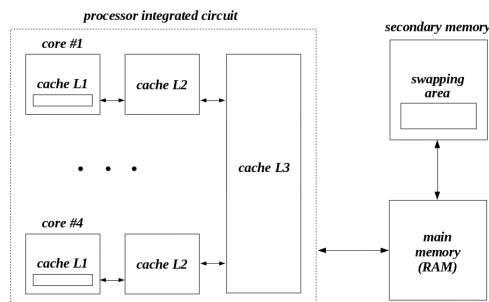
Memory hierarchy (3)



- The **cache memory** will contain a copy of the memory positions (instructions and operands) most frequently referenced by the processor in the near past
 - The cache memory is located on the processor's own integrated circuit (**level 1**)
 - And on an autonomous integrated circuit glued to the same substrate (**levels 2 and 3**)
- Data transfer to and from main memory is done almost completely transparent to the system programmer

Memory management

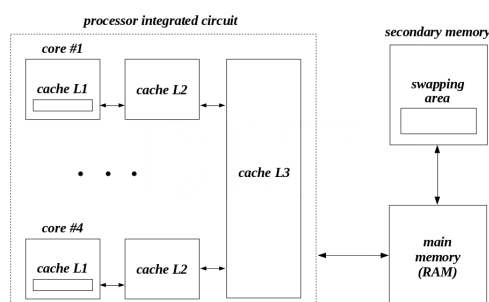
Memory hierarchy (3)



- **Secondary memory** has two main functions
 - **File system** – storage for more or less permanent information (programs and data)
 - **Swapping area** – Extension of the main memory so that its size does not constitute a limiting factor to the number of processes that may currently coexist
 - the swapping area can be on a disk partition used only for that purpose or be a file in a file system

Memory management

Memory hierarchy (4)



- This type of organization is based on the assumption that the further an instruction or operand is away from the processor, the less times it will be referenced
 - In these conditions, the mean time for a reference tends to be close to the lowest value
- Based on the **principle of locality of reference**
 - The tendency of a program to access the same set of memory locations repetitively over a short period of time

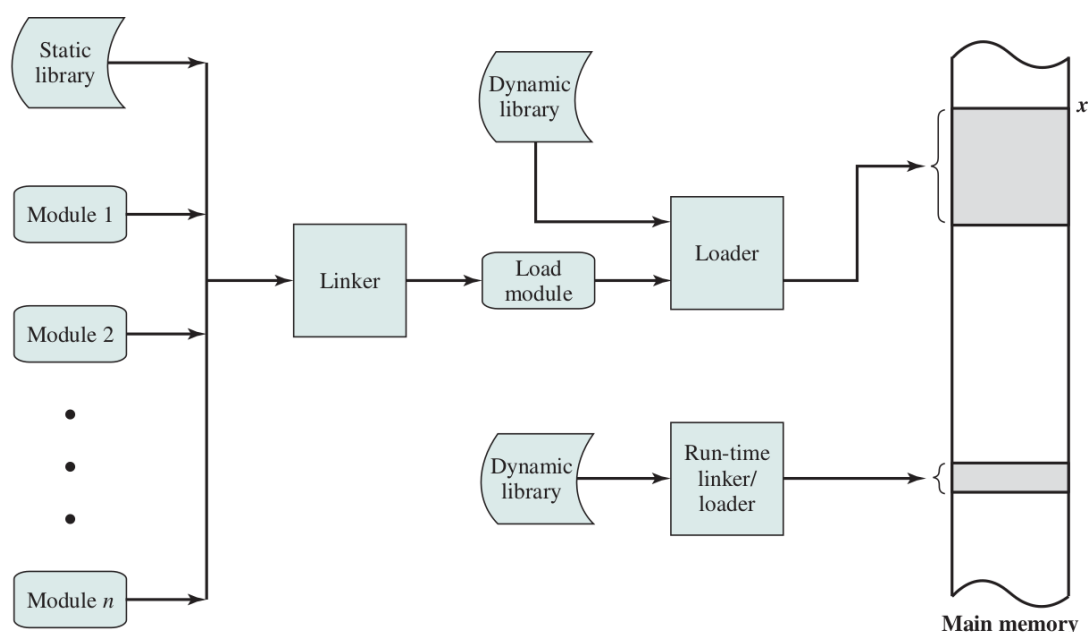
Memory management

Role

- The role of memory management in a multiprogramming environment focuses on allocating memory to processes and on controlling the transfer of data between main and secondary memory (**swapping area**), in order to
 - **Maintaining a register** of the parts of the main memory that are occupied and those that are free
 - **Reserving portions** of main memory for the processes that will need it, or **releasing** them when they are no longer needed
 - **Swapping out** all or part of the address space of a process when the main memory is too small to contain all the processes that coexist.
 - **Swapping in** all or part of the address space of a process when main memory becomes available

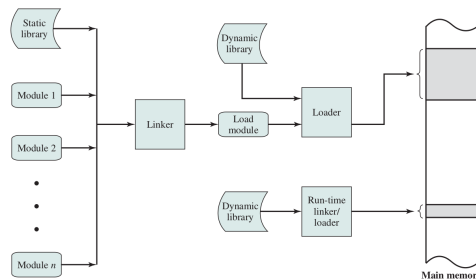
Address space

Linker and loader roles



Address space

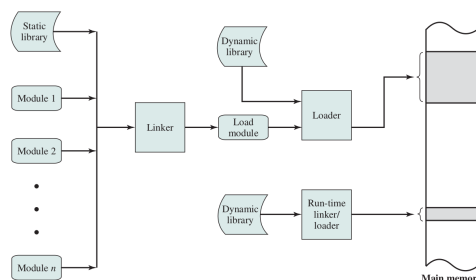
Linker and loader roles (2)



- The **object files**, resulting from the compilation process, are relocatable files
 - The addresses of the various instructions, constants and variables are calculated from the beginning of the module, by convention the address 0
- The role of the **linking process** is to bring the different object files together into a single file, the **executable file**, resolving among themselves the various external references
 - **Static libraries** are also included in the linking process
 - **Dynamic (shared) libraries** are not

Address space

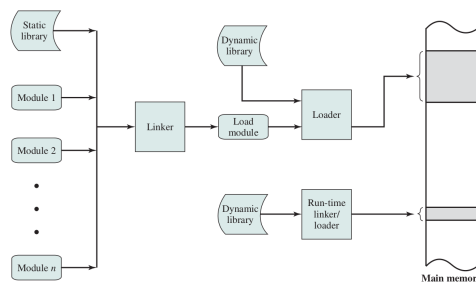
Linker and loader roles (3)



- The **loader** builds the binary image of the process **address space**, which will eventually be executed, combining the executable file and, if applicable, some **dynamic libraries**, resolving any remaining external references
- Dynamic libraries can also only be loaded at run time

Address space

Linker and loader roles (4)



- When the linkage is dynamic
 - Each reference in the code to a routine of a dynamic library is replaced by a **stub**
 - a small set of instructions that determines the location of a specific routine, if it is already resident in main memory, or promotes its load in memory, otherwise
 - When a stub is executed, the associated routine is identified and located in main memory, the stub then replaces the reference to its address in the process code with the address of the system routine and executes it
 - When that code zone is reached again, the system routine is now executed directly
- All processes that use the same dynamic library, execute the same copy of the code, thus minimizing the main memory occupation

Address space

Object and executable files

source file

```
#include <stdio.h>
#include <stdlib.h>

int main (void)
{
    printf ("hello, world!\n");
    exit (EXIT_SUCCESS);
}
```

object file

```
$ gcc -Wall -c hello.c

$ file hello.o
hello.o: ELF 64-bit LSB relocatable,
x86-64, version 1 (SYSV), not stripped
```

executable file

```
$ gcc -o hello hello.o

$ file hello
hello: ELF 64-bit LSB shared object, x86-64, version 1 (SYSV), dynamically
linked, interpreter /lib64/ld-linux-x86-64.so.2, for GNU/Linux 3.2.0,
BuildID[sha1]=48ac0a8ba08d8df6d5e8a27e00b50248a3061876, not stripped
```

Address space

Object and executable files (2)

```
$ objdump -fstr hello.o
hello.o:      file format elf64-x86-64
architecture: i386:x86-64, flags 0x00000011:
HAS_RELOC, HAS_SYMS
start address 0x0000000000000000
SYMBOL TABLE:
0000000000000000 1      df *ABS*          0000000000000000 z.c
0000000000000000 1      d  .text          0000000000000000 .text
0000000000000000 1      d  .data          0000000000000000 .data
0000000000000000 1      d  .bss 0000000000000000 .bss
0000000000000000 1      d  .rodata        0000000000000000 .rodata
0000000000000000 1      d  .note.GNU-stack 0000000000000000 .note.GNU-stack
0000000000000000 1      d  .eh_frame        0000000000000000 .eh_frame
0000000000000000 1      d  .comment        0000000000000000 .comment
0000000000000000 g      F  .text          0000000000000001a main
0000000000000000      *UND*          0000000000000000 _GLOBAL_OFFSET_TABLE_
0000000000000000      *UND*          0000000000000000 puts
0000000000000000      *UND*          0000000000000000 exit

...
```

Address space

Object and executable files (3)

```
RELOCATION RECORDS FOR [.text]:
OFFSET      TYPE      VALUE
0000000000000007 R_X86_64_PC32      .rodata-0x0000000000000004
000000000000000c R_X86_64_PLT32      puts-0x0000000000000004
0000000000000016 R_X86_64_PLT32      exit-0x0000000000000004

RELOCATION RECORDS FOR [.eh_frame]:
OFFSET      TYPE      VALUE
0000000000000020 R_X86_64_PC32      .text

Contents of section .text:
0000 554889e5 488d3d00 000000e8 00000000  UH..H.=.....
0010 bf000000 00e80000 0000      ....

Contents of section .rodata:
0000 68656c6c 6f2c2077 6f726c64 2100      hello, world!.

Contents of section .comment:
0000 00474343 3a202855 62756e74 7520372e  .GCC: (Ubuntu 7.
0010 332e302d 32377562 756e7475 317e3138  3.0-27ubuntu1~18
0020 2e303429 20372e33 2e3000      .04) 7.3.0.

Contents of section .eh_frame:
0000 14000000 00000000 017a5200 01781001  ....zR..x..
0010 1b0c0708 90010000 1c000000 1c000000  ....
0020 00000000 1a000000 00410e10 8602430d  ....A....C.
0030 06000000 00000000      .....
```


Address space

Object and executable files (4)

```
$ objdump -fTR hello
```

```
z:      file format elf64-x86-64
architecture: i386:x86-64, flags 0x00000150:
HAS_SYMS, DYNAMIC, D_PAGED
start address 0x00000000000000580
```

DYNAMIC SYMBOL TABLE:

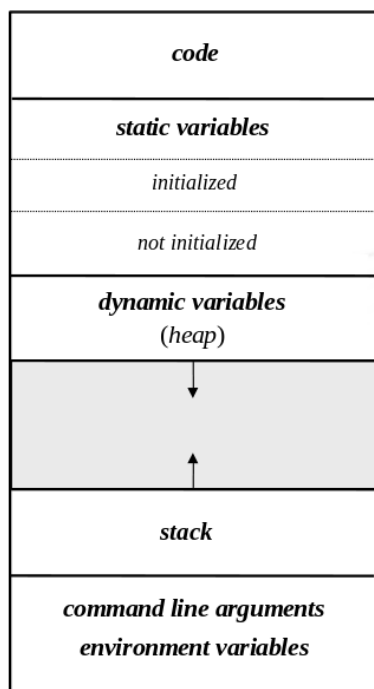
0000000000000000	w	D	*UND*	0000000000000000	
_ITM_deregisterTMCloneTable					
0000000000000000		DF	*UND*	0000000000000000	GLIBC_2.2.5 puts
0000000000000000		DF	*UND*	0000000000000000	GLIBC_2.2.5 __libc_start_main
0000000000000000	w	D	*UND*	0000000000000000	__gmon_start__
0000000000000000		DF	*UND*	0000000000000000	GLIBC_2.2.5 exit
0000000000000000	w	D	*UND*	0000000000000000	
_ITM_registerTMCloneTable					
0000000000000000	w	DF	*UND*	0000000000000000	GLIBC_2.2.5 __cxa_finalize

DYNAMIC RELOCATION RECORDS

OFFSET	TYPE	VALUE
0000000000200db0	R_X86_64_RELATIVE	*ABS*+0x00000000000000680
0000000000200db8	R_X86_64_RELATIVE	*ABS*+0x00000000000000640
0000000000201008	R_X86_64_RELATIVE	*ABS*+0x000000000000001008
0000000000200fd8	R_X86_64_GLOB_DAT	_ITM_deregisterTMCloneTable
0000000000200fe0	R_X86_64_GLOB_DAT	__libc_start_main@GLIBC_2.2.5
0000000000200fe8	R_X86_64_GLOB_DAT	__gmon_start__
0000000000200ff0	R_X86_64_GLOB_DAT	_ITM_registerTMCloneTable
0000000000200ff8	R_X86_64_GLOB_DAT	__cxa_finalize@GLIBC_2.2.5
0000000000200fc8	R_X86_64_JUMP_SLOT	puts@GLIBC_2.2.5
0000000000200fd0	R_X86_64_JUMP_SLOT	exit@GLIBC_2.2.5

Address space

Address space of a process



- **Code** and **static variables** regions have a fixed size, which is determined by the loader
- **Dynamic variables** and **stack** regions grow (in opposite directions) during the execution of the process
- It is a common practice to leave an unallocated memory area in the process address space between the dynamic definition region and the stack that can be used alternatively by any of them
- When this area is exhausted on the stack side, the execution of the process cannot continue, resulting in the occurrence of a fatal error: **stack overflow**

Address space

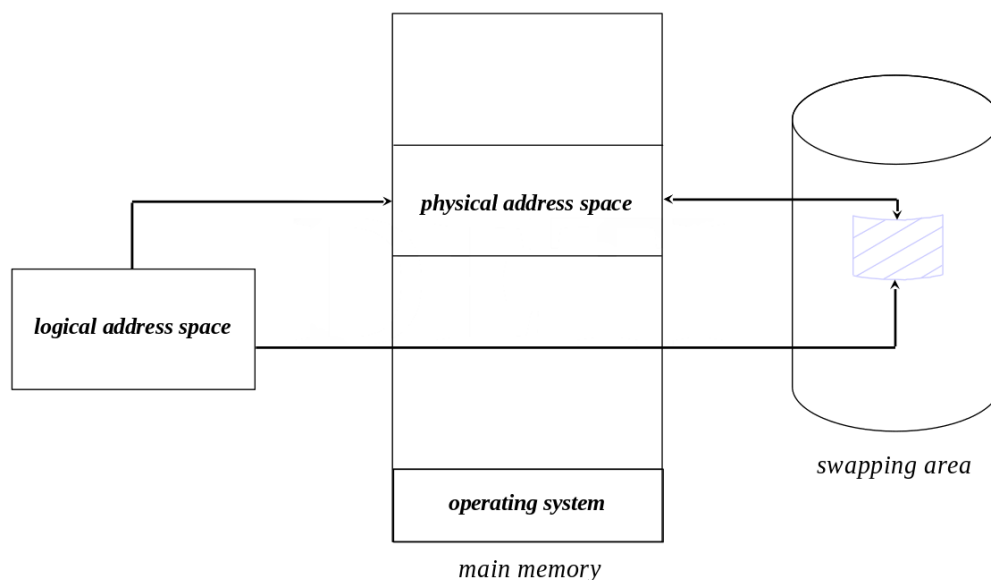
Address space of a process

- The binary image of the process address space represents a relocatable address space, the so-called **logical address space**
- The main memory region where it is loaded for execution, constitutes the **physical address space** of the process
- Separation between the logical and physical address spaces is a central concept to the memory management mechanisms in a multiprogrammed environment
- There are two issues that have to be solved
 - **dynamic mapping** – ability to convert a logical address to a physical address at runtime, so that the physical address space of a process can be placed in any region of main memory and be moved if necessary
 - **dynamic protection** – ability to prevent at runtime access to addresses located outside the process's own address space

Contiguous memory allocation

Logical and physical address spaces

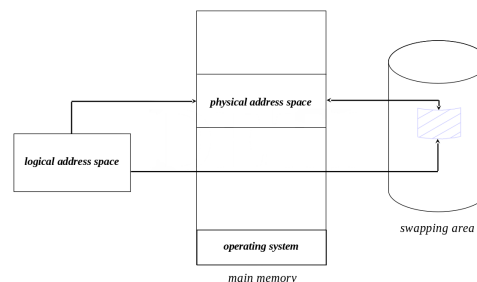
- In contiguous memory allocation, there is a **one-to-one correspondence** between the **logical address space** of a process and its **physical address space**



Contiguous memory allocation

Logical and physical address spaces

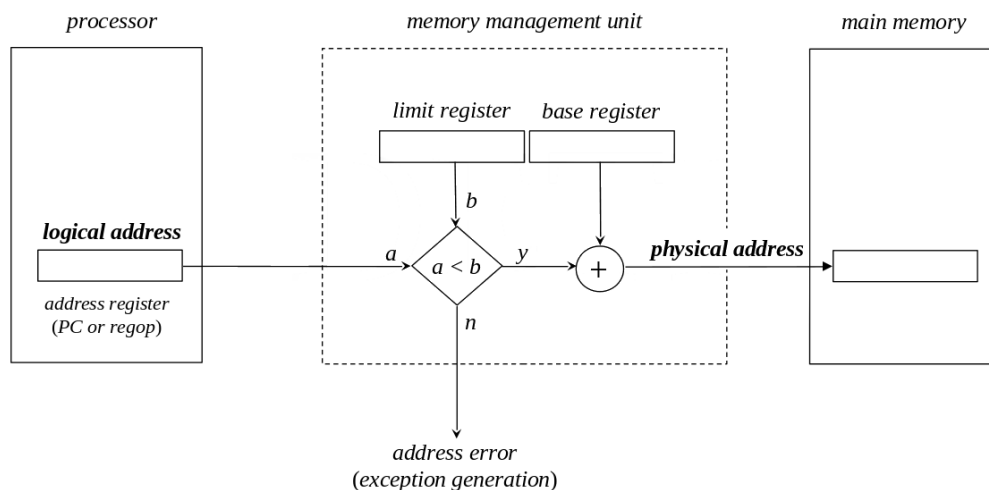
- Consequences:
 - **Limitation of the address space of a process** – in no case can memory management support automatic mechanisms that allow the address space of a process to be larger than the size of the main memory available
 - The use of overlays can allow to overcome that
 - **Contiguity of the physical address space** – although it is not a strictly necessary condition, it is naturally simpler and more efficient to assume that the process address space is contiguous
 - **Swapping area as an extension of the main memory** – it serves to storage the address space of processes that cannot be resident into main memory due to lack of space



Contiguous memory allocation

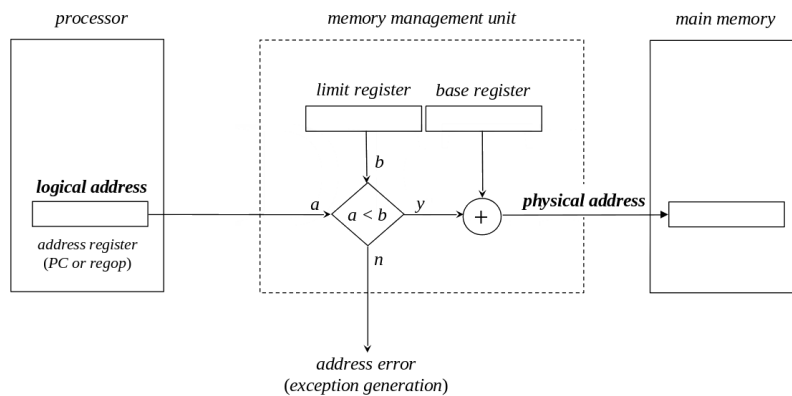
Logical address to physical address translation

- How are **dynamic mapping** and **dynamic protection** accomplished?
 - A piece of hardware (the MMU) is required



Contiguous memory allocation

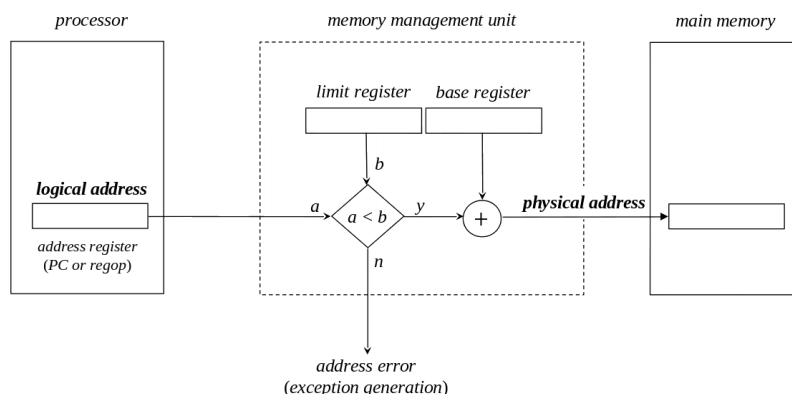
Logical address to physical address translation (2)



- The **limit register** must contain the size in bytes of the logical address space
- The **base register** must contain the address of the beginning of the main memory region where the physical address space of the process is placed
- On context switching, the **dispatch** operation loads the base and limit registers with the values present in the corresponding fields of the process control table entry associated with the process that is being scheduled for execution

Contiguous memory allocation

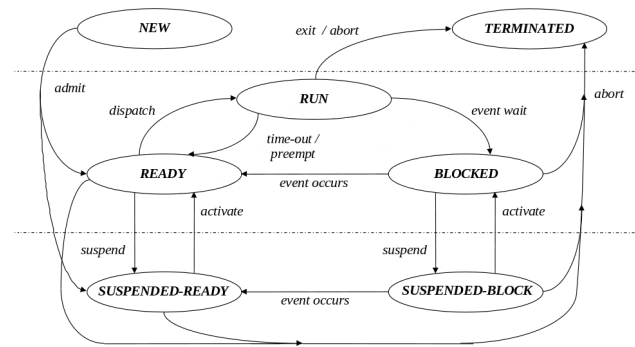
Logical address to physical address translation (2)



- Whenever there is a reference to memory
 - the logical address is first compared to the value of the limit register
 - if it is less, it is a valid reference (it occurs within the process address space) then the logical address is added to the value of the base register to produce the physical address
 - if it is greater than or equal, it is an invalid reference, then a null memory access (dummy cycle) is set in motion and an exception is generated due to address error

Contiguous memory allocation

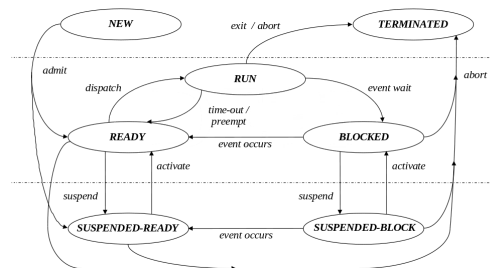
Long-term scheduling



- When a process is created, the data structures to manage it is initialized
 - Its logical address space is constructed, and the value of the limit register is computed and saved in the corresponding field of the process control table (PCT)
- If there is space in main memory, its address space is loaded there, the base register field is updated with the initial address of the assigned region and the process is placed in the READY queue
- Otherwise, its address space is temporarily stored in the swapping area and the process is placed in the SUSPENDED-READY queue

Contiguous memory allocation

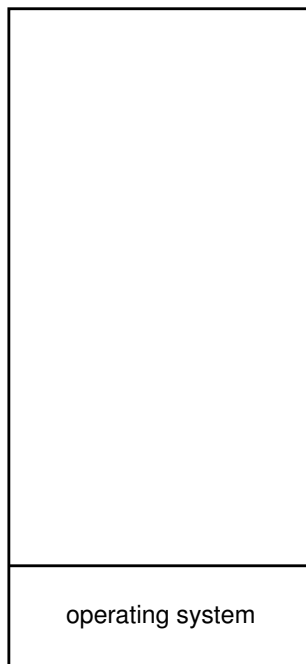
Medium-term scheduling



- If memory is required for another process, a BLOCKED (or even READY) process may be **swapped out**, freeing the physical memory it is using,
 - In such a case, its base register field in the PCT becomes undefined
- If memory becomes available, a SUSPENDED-READY (or even SUSPENDED-BLOCKED) process may be **swapped in**,
 - Its base register field in the PCT is updated with its new physical location
 - A SUSPENDED-BLOCK process is only selected if no SUSPENDED-READY one exists
- When a process terminates, it is **swapped out** (if not already there), waiting for the end of operations

Memory partitioning

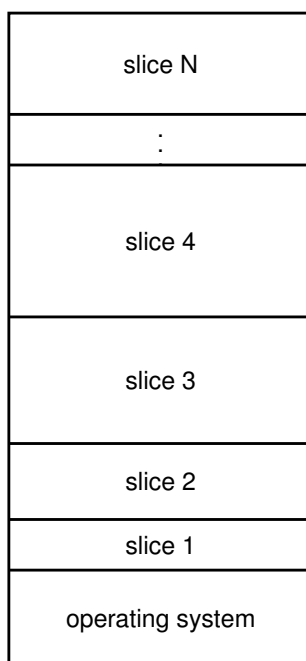
How to do it?



- After reserving some amount to the operating system, how to partition the real memory to accommodate the different processes?
- Fix partition
 - into slices of equal size
 - into slices of different size
- Dynamic partition
 - being done as being required?

Memory partitioning

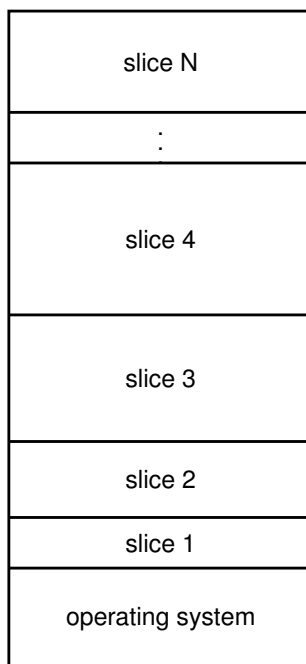
Fixed partitioning



- Main memory can be divided into a number of static slices at system generation time
 - not necessarily all the same size
- The logical address space of a process may be loaded into a slice of equal or greater size
 - thus, the largest slice determines the size of the largest allowable process
- Some features:
 - Simple to implement
 - Efficient – little operating system overhead
 - Fixed number of allowable processes
 - Inefficient use of memory due to internal fragmentation – the part of a slice not used by a process is wasted

Memory partitioning

Fixed partitioning (2)

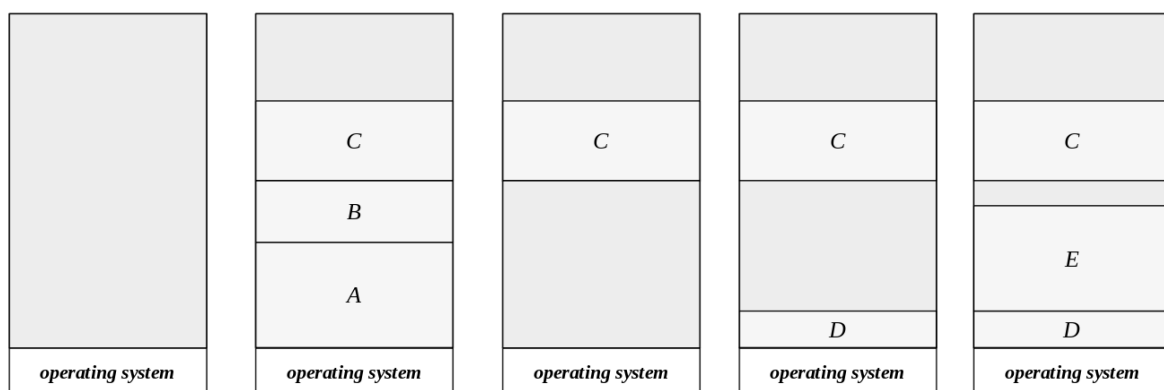


- If a slice becomes available, which of the SUSPENDED-READY processes should be placed there?
- Two different scheduling policies are here considered
 - **Valuing fairness** – the first process in the queue of SUSPENDED-READY processes whose address space fits in the slice is chosen
 - **Valuing the occupation of main memory** – the first process in the queue of SUSPENDED-READY processes with the largest address space that fits in the slice is chosen
 - to avoid starvation an aging mechanism can be used

Memory partitioning

Dynamic partitioning

- In dynamic partitioning, at start, all the available part of the memory constitutes a single block and then
 - reserve a region of sufficient size to load the address space of the processes that arises
 - release that region when it is no longer needed



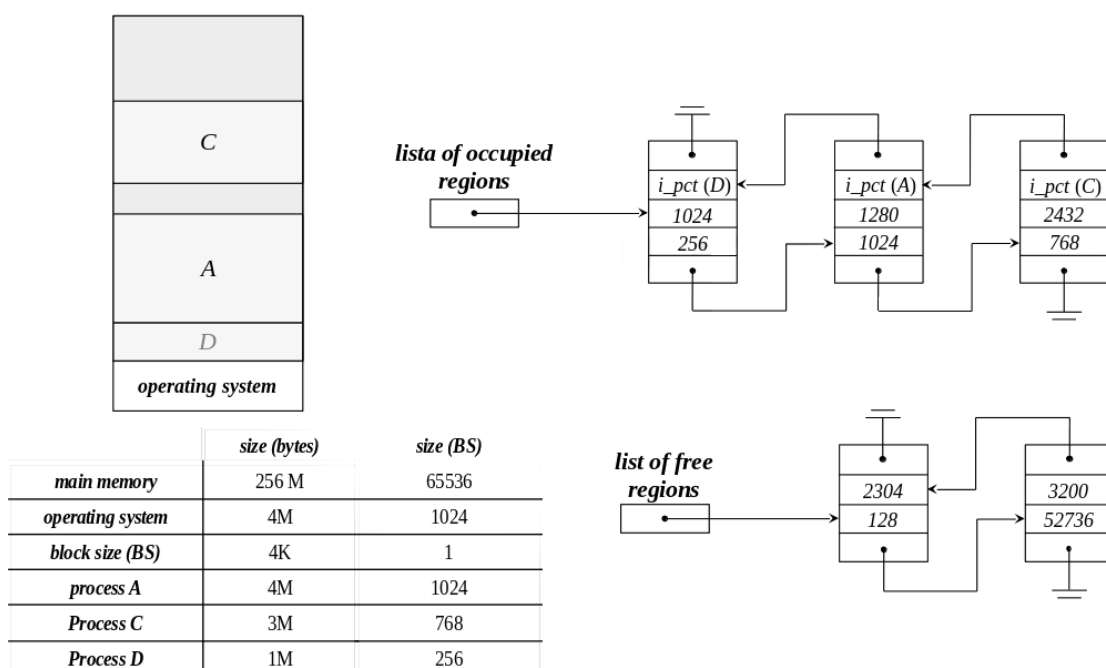
Memory partitioning

Dynamic partitioning (2)

- As the memory is dynamically reserved and released, the operating system has to keep an updated record of occupied and free regions
- One way to do this is by building two (bi)linked lists
 - **list of occupied regions** – locates the regions that have been reserved for storage of the address spaces of processes resident in main memory
 - **list of free regions** – locates the regions still available
- Memory is not allocated in byte boundaries, because
 - useless, very small free regions may appear
 - that will be included in the list of free regions
 - making subsequent searches more complex
- Thus, the main memory is typically divided into blocks of fixed size and allocation is made in units of these blocks

Memory partitioning

Dynamic partitioning (3)



Memory partitioning

Dynamic partitioning (4)

- **Valuing fairness** is the scheduling discipline generally adopted, being chosen the first process in the queue of SUSPENDED-READY processes whose address space can be placed in main memory
- Dynamic partitioning can produce **external fragmentation**
 - Free space is splitted in a large number of (possible) small free regions
 - Situations can be reached where, although there is enough free memory, it is not continuous and the storage of the address space of a new or suspended process is no longer possible
- The solution is **garbage collection** – compact the free space, grouping all the free regions into a single one
 - This operation requires stopping all processing and, if the memory is large, can have a very long execution time

Memory partitioning

Dynamic partitioning (5)

- In case there are several free regions available, which one to use to allocate the address space of a process?
- Possible policies:
 - **first fit** – the list of free regions is searched from the beginning until the first region with sufficient size is found
 - **next fit** – is a variant of the first fit which consists of starting the search from the stop point in the previous search
 - **best fit** – the list of free regions is fully searched, choosing the smallest region with sufficient size for the process
 - **worst fit** – the list of free regions is fully searched, choosing the largest existing region
- Which one is the best?
 - in terms of fragmentation
 - in terms of efficiency of allocation
 - in terms of efficiency of release

Memory partitioning

Dynamic partitioning (6)

- Advantages
 - **general** – the scope of application is independent of the type of processes that will be executed
 - **low complexity implementation** – no special hardware required and data structures are reduced to two (bi)linked lists
- Disadvantages
 - **external fragmentation** – the fraction of the main memory that ends up being wasted, given the small size of the regions in which it is divided, can reach in some cases about a third of the total (50% rule)
 - **inefficient** – it is not possible to build algorithms that are simultaneously very efficient in allocating and freeing space

Bibliography

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