MEMORY SEGMENTATION | SEC204

Overview

- Exchanging data
- Optimising memory access
- Memory segmentation
- The stack

EXCHANGING DATA

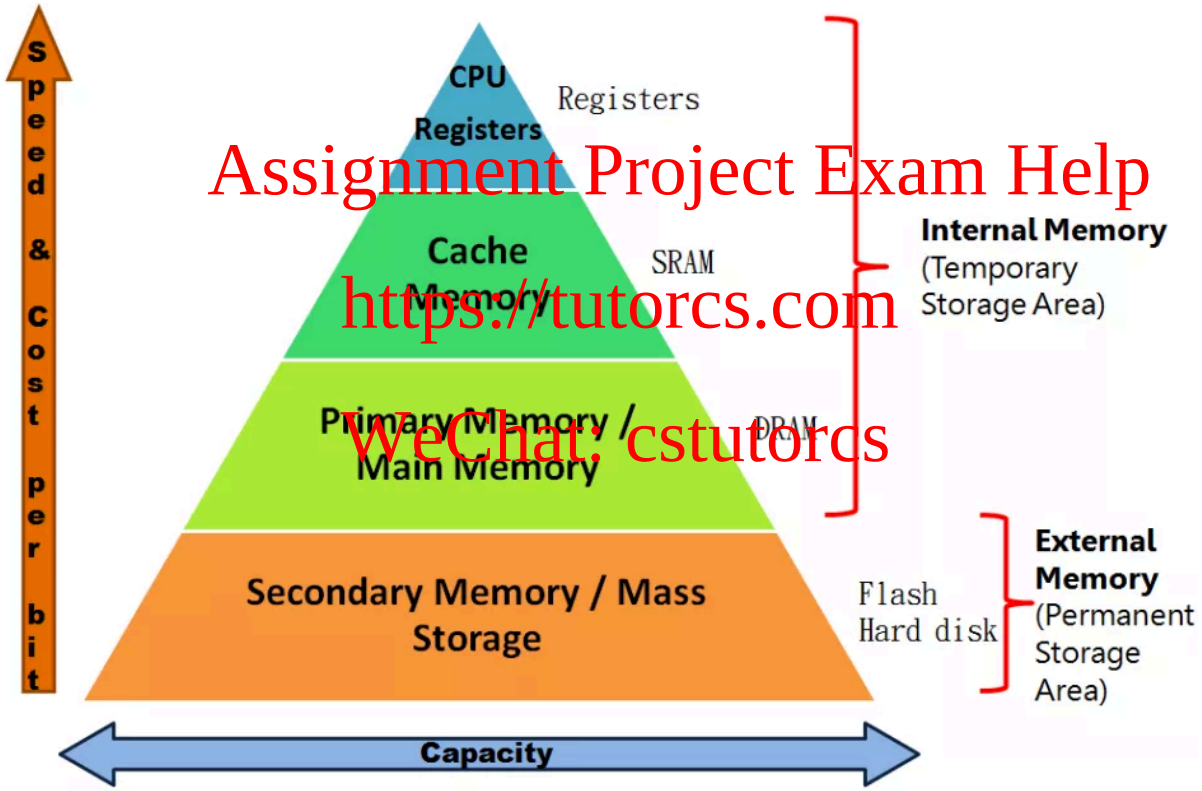
EXCHANGING DATA, NOP

- To swap the values of two registers with the MOV instruction, you need a temporary intermediate register
  - Data exchange functions do that without needing intermediate registers

- XCHG exchanges the values of 2 registers, or a register and a memory location
  - **`xchg %eax, %ebx`**
    exchanges values between %eax and %ebx
  - **`xchg %eax, %eax`**
    This is the NOP operation, which essentially does nothing, other than delay execution or pad bytes

OPTIMISING MEMORY ACCESS

MEMORY HIERARCHY



Source: https://www.vlsifacts.com/classification-of-semiconductor-memories-and-computer-memories/

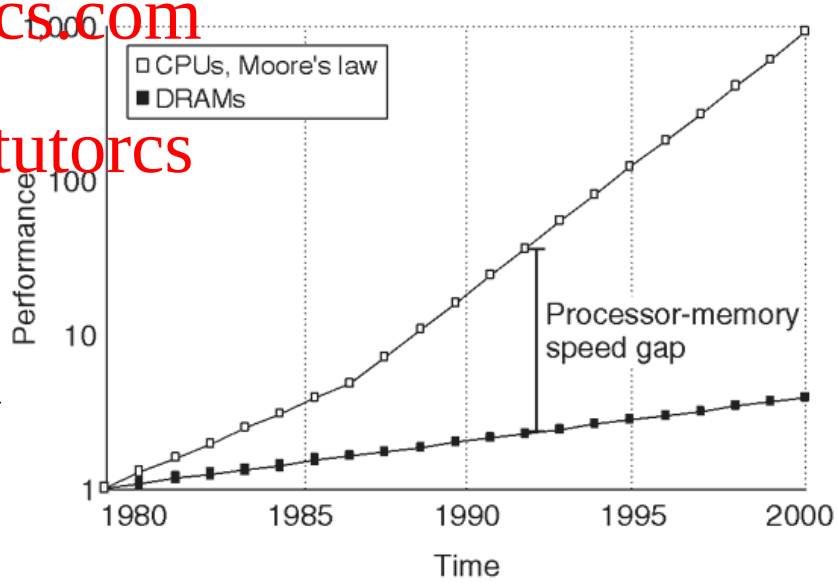
MEMORY COMPONENTS

- SRAM (Static Random Access Memory):
  - Value is stored on a pair of inverting gates.
    - Very fast, constant access time.
    - Needs more space than DRAM (4 to 6 transistors).
    - We use it for cache memory
- DRAM (Dynamic Random Access Memory):
  - Value is stored as a charge on capacitor.
    - Slower than SRAM, variable access time.
    - Very dense but slower than SRAM
    - We use it for RAM memory

DRAM memory slow, but cheap. SRAM memory faster but expensive

CPU is getting faster more quickly

Technology	Speed	$$/Gigabyte
SRAM	0.5-5 ns	$2000-$5000
DRAM	50-70 ns	$20 - $75
Disk	5-20 million ns	$0.20 - $2



Source: https://www.computer.org/csdl/mags/dt/2005/06/d6540.html

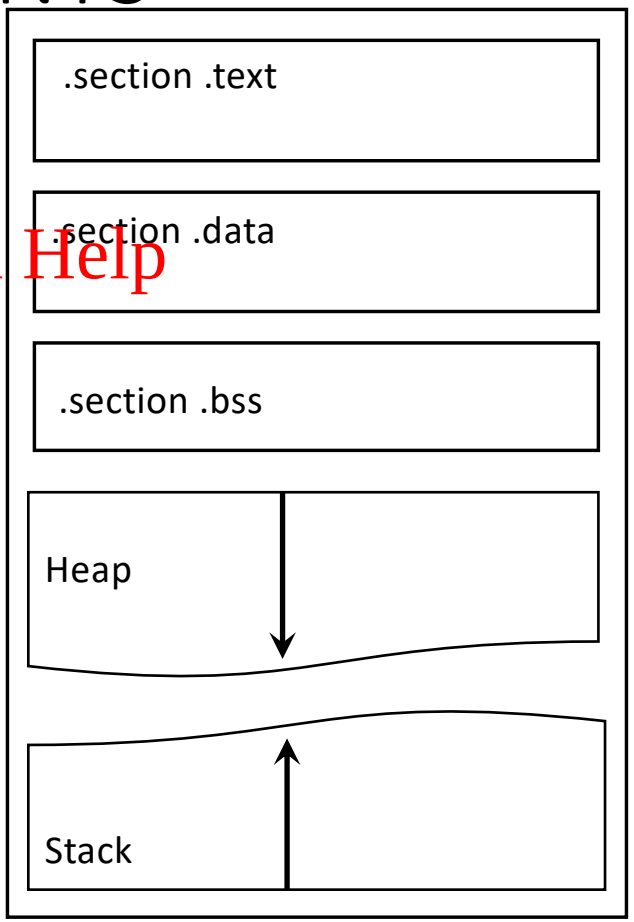
OPTIMISING MEMORY ACCESS

- Memory bottleneck
  - When access to memory slows down the computer
  - To avoid this, it is preferable to use registers as much as possible and avoid memory access.
  - Most processors with cache will access sequential blocks of memory and copy into cache at a time.
  - For more efficiency, IA32 suggests data alignment (data memory addresses are multiple of their data size)
    - Align 16-bit data on a 16-byte boundary
    - Align 32-bit data so that its base address is a multiple of four
    - Align 64-bit data so that its base address is a multiple of eight
    - Avoid small data transfers. Instead use a single large data transfer
    - Avoid using larger data sizes (ie 80 and 128-bit floating point values) in the stack
  - Good practice for programmers
    - define and place similarly-sized data elements together at beginning of data section
    - Define strings/buffers and other odd-sized data elements towards the end of the data section

MEMORY SEGMENTATION

PROGRAM'S MEMORY SEGMENTS

- A compiled program's memory is divided into 5 segments
  - Text (code)
  - Data (initialized static and global variables)
  - Bss (uninitialized variables)
  - Heap
    - Volatile, dynamically allocated memory for program needs (via malloc() and free() in C)
    - Grows towards higher memory addresses
  - Stack
    - Volatile, dynamic, FILO structure
    - Grows towards lower memory addresses



Memory segments example

Download memory_segments.c file from the DLE. Compile it and run it:

```
#include <stdio.h>
int global_var;
int global_initialized_var = 5;
void function() {  // This is just a demo function
   int stack_var; // notice this variable has the same name as the one in main()
   printf("the function's stack_var is at address 0x%08x\n", &stack_var);
}
int main() {
   int stack_var; // same name as the variable in function()
   static int static_initialized_var = 5;
   static int static_var;
   int *heap_var_ptr;
   heap_var_ptr = (int *) malloc(4);
   // These variables are in the data segment
   printf("global_initialized_var is at address 0x%08x\n", &global_initialized_var);
   printf("static_initialized_var is at address 0x%08x\n\n", &static_initialized_var);
   // These variables are in the bss segment
   printf("static_var is at address 0x%08x\n", &static_var);
   printf("global_var is at address 0x%08x\n\n", &global_var);
   // This variable is in the heap segment
   printf("heap_var is at address 0x%08x\n\n", heap_var_ptr);
   // These variables are in the stack segment
   printf("stack_var is at address 0x%08x\n", &stack_var);
   function();
}
```

THE STACK

THE STACK

- The stack is a special reserved area in memory for placing data.
- A stack is a Last-In-First-Out (LIFO/FILO) data structure
  - Data elements are “pushed” on to the top of the stack in sequential manner
  - Data are “popped” off the top of the stack in reverse order
  - You cannot remove data from the middle of the stack
- The stack grows toward lower memory addresses
  - Adding something to the stack means the top of the stack is now at a lower memory address
  - ESP points towards the top of the stack

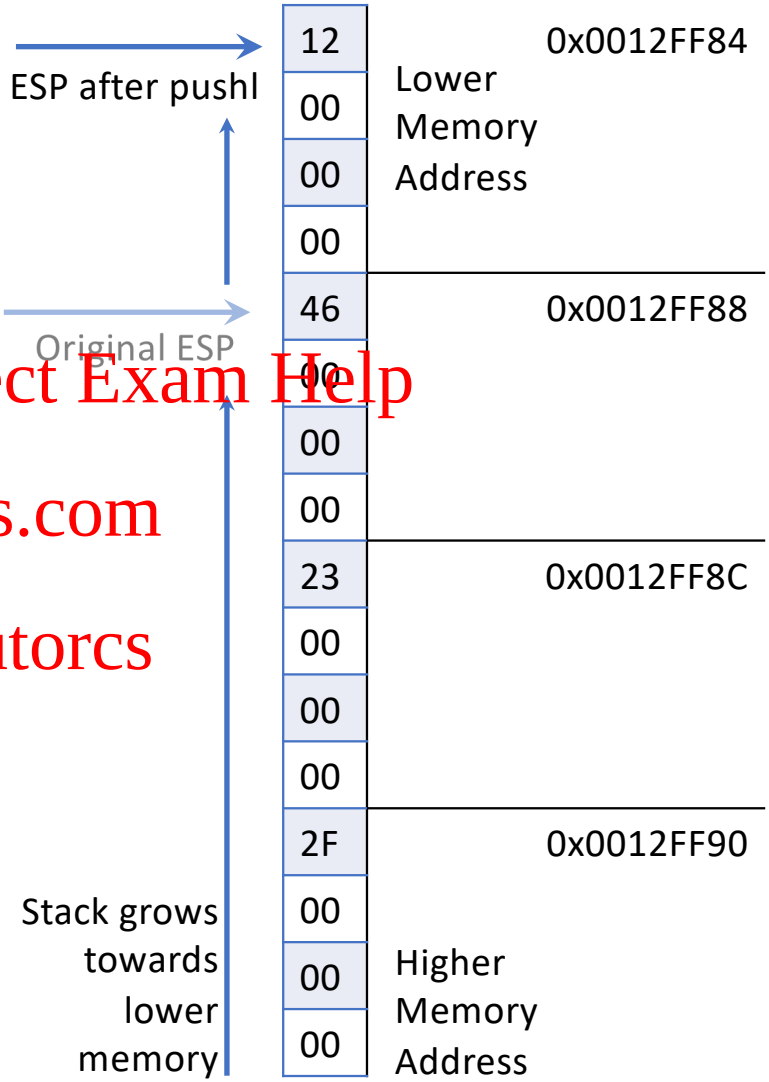
HOW THE STACK WORKS

- The stack is reserved at the end of the memory area
  - ESP points towards the top of the stack
  - EBP points towards the bottom of the working stack
- It grows towards lower memory addresses
  - To add elements to the stack (push), ESP will point to lower memory addresses

  For example:

```
pushl %ecx
```

- It shrinks towards higher memory addresses
  - To remove elements from the stack (pop), ESP will point to higher addresses



WHY WE USE IT

- To keep track of which functions were called before the current one
- To pass arguments between functions/subroutines
- When running a program:
  - The bottom of the stack contains data elements placed by the O/S when the program is run
  - Any command-line parameters when running the program are also entered onto the stack
  - Then we place our program data

PUSH AND POP

1. Adding data elements to the stack

```
push source
For example (l for long word
32-bits, w for word 16-bits):
pushl %ecx
pushw %cx
pushl $100
```

2. Removing data elements from the stack

```
pop destination
For example (l for long word 32-
bits, w for word 16-bits):
popl %ecx
popw %cx
popl value
```


3. To do these manually:
   - You can manually place data on the stack using ESP as a pointer, then update ESP to point towards the top of the stack.
   - You can manually remove data from the stack by updating the ESP to point towards the previous data element.
   - Will ESP increase value or decrease when removing data?

PUSH, POP EXAMPLE

Remember example movtest3.s from last week? Where is the pop?

```
.section .data
output:
   .asciz "The value is %d\n"
values:
   .int 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60
.section .text
.globl _start:
 _start:
   movl $0, %edi
loop:
   movl values(,%edi,4),%eax
   pushl %eax
   pushl $output
   call printf
   addl $8, %esp
   inc %edi
   cmpl $11, %edi
```

…cont…

```
   jne loop
   movl $0, %ebx
   movl $1, %eax
   int $0x80
```

Stack example

1. Create a stack_example.c file with the following contents:

```
void test_function(int a, int b, int c, int d) {
   int flag;
   char buffer[10];

   flag = 31337;
   buffer[0] = 'A';
}

int main() {
   test_function(1, 2, 3, 4);
}
```


3. In (gdb):

```
disass main
disass test_function
list main
break 10
break test_function
run
i r esp ebp eip
cont
i r esp ebp eip
cont
```

2. Compile it and run it in gdb to watch how esp, ebp, and eip change

```
$ gcc -g stack_example.c
$ gdb -q ./a.out
```

Heap example

1. Download heap_example.c file from DLE. Extract below:

```
int main(int argc, char *argv[]) {
   char *char_ptr;  // a char pointer
   int *int_ptr;    // an integer pointer
   int mem_size;

   if (argc < 2)      // if there aren't commandline arguments,
      mem_size = 50; // use 50 as the default value.
   else
      mem_size = atoi(argv[1]);

   printf("\t[+] allocating %d bytes of memory on the heap for char_ptr\n", mem_size);
   char_ptr = (char *) malloc(mem_size); // allocating heap memory
```


2. Compile it and run it to watch how heap memory is allocated and freed

```
$ gcc -o heap_example heap_example.c
$ ./heap_example
$ ./heap_example 100
```

FURTHER READING

- Professional Assembly Language, chapter 5, pg 106-124
- Hacking: The art of exploitation, section 0x270, pg 69-81