INTRODUCTION TO ASSEMBLY LANGUAGE

CS 348

Implementation of Programming Languages Lab

Computer Science and Engineering Department

Indian Institute of Technology

Guwahati

Basics

Computer Architecture

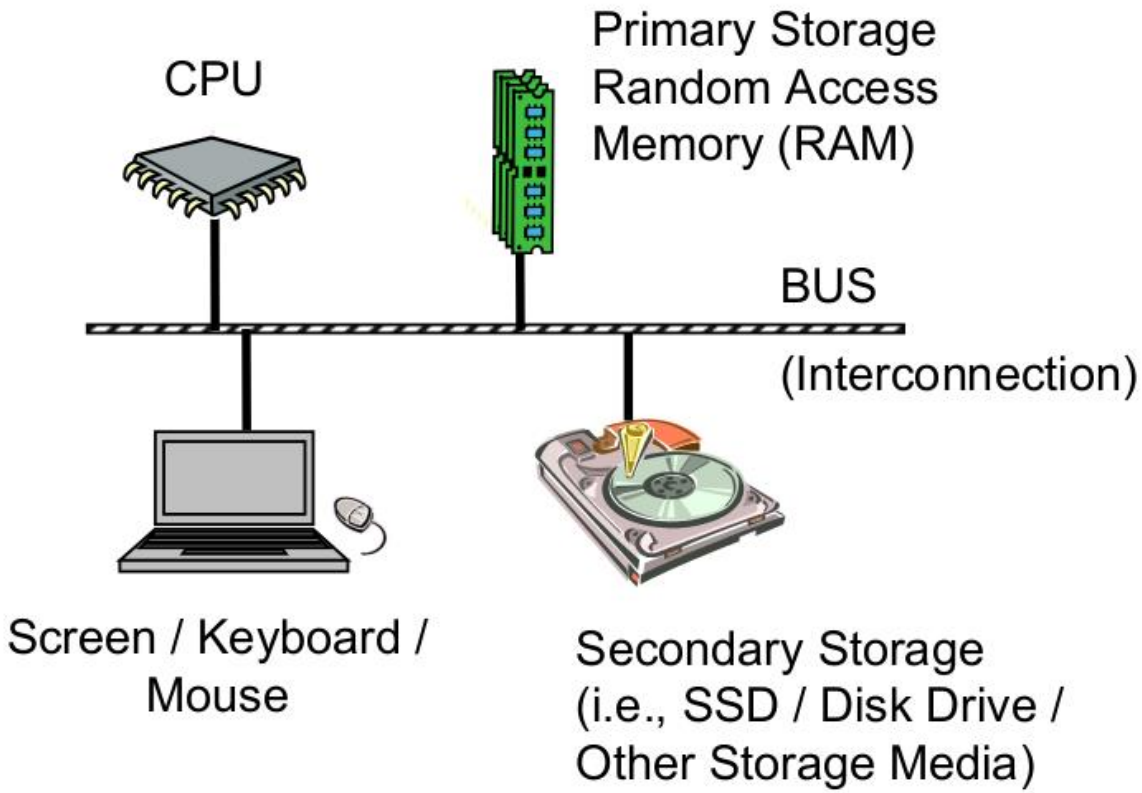
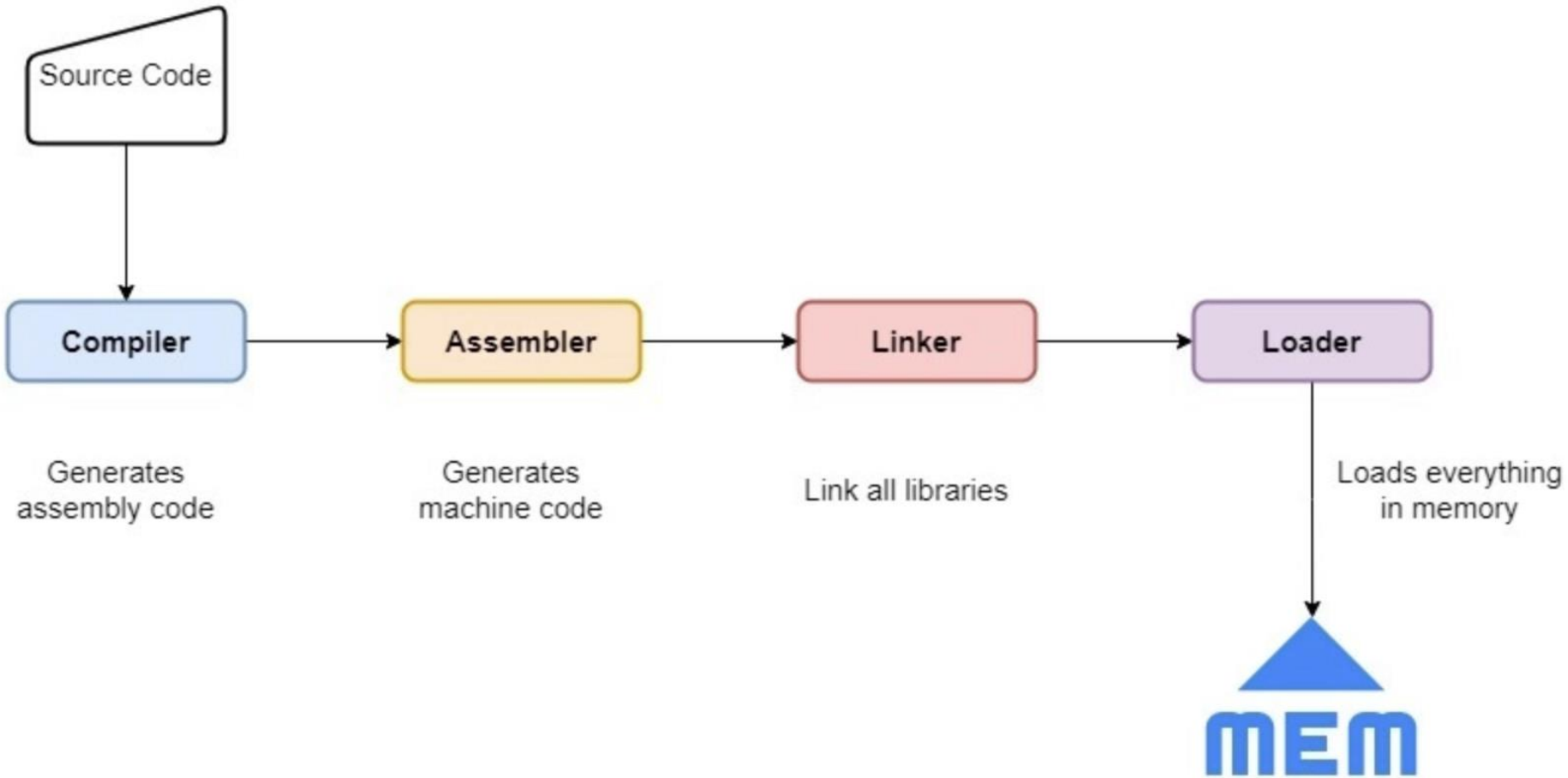


Illustration 1: Computer Architecture

Executable Generation



Assemble code steps

$nasm –f elf32 ex1.asm -o ex1.o

- Elf32: 32 bit executable linking format.
- -f: flag to create elf

$ld –m elf_i386 ex1.o -o ex1

- -m: flag to create linker executable from the object file

$./ex1

- Execute the final code.

$echo $?

- Inspects exit status

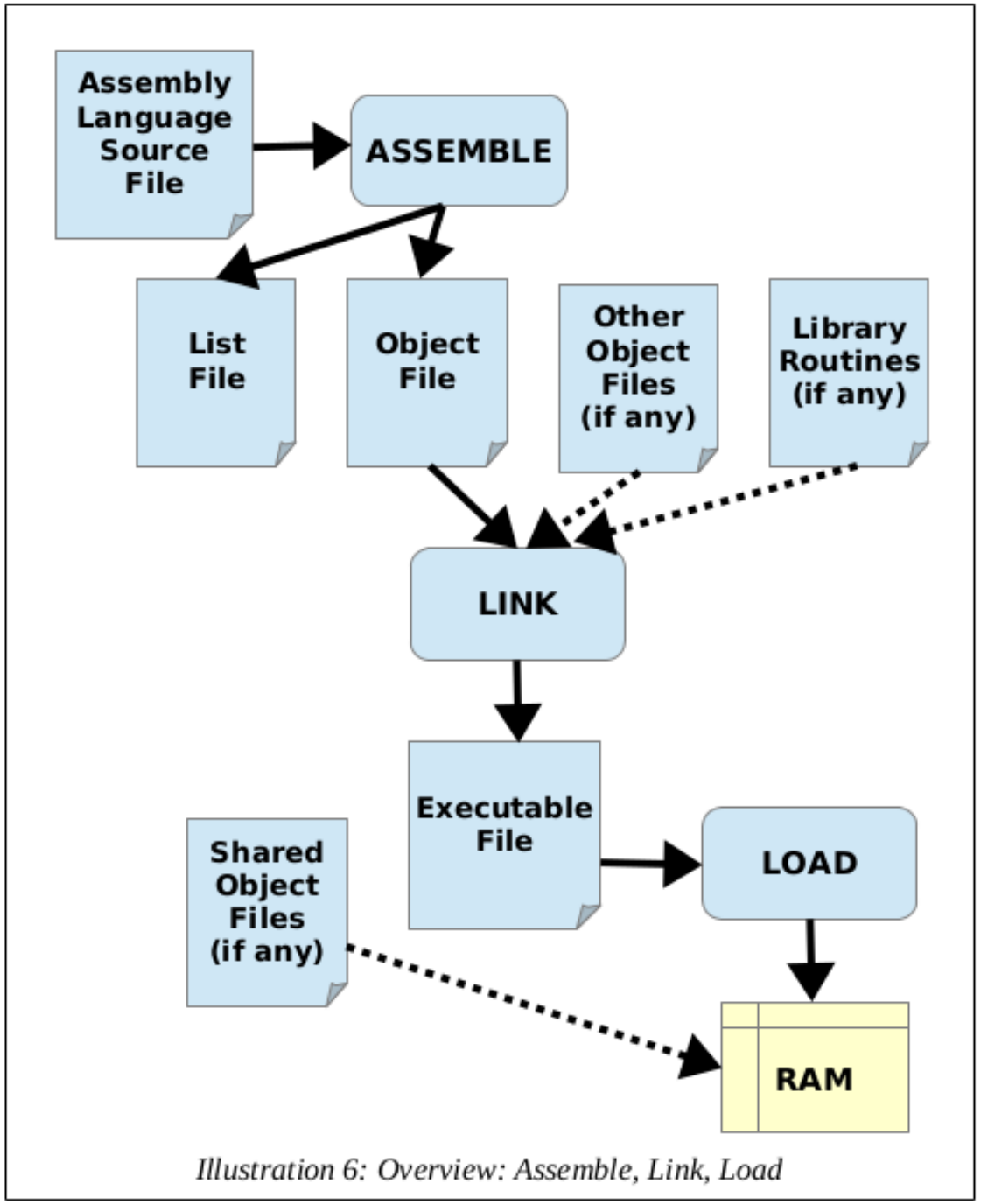


Illustration 6: Overview: Assemble, Link, Load

High Level language

- Characteristics:
  - Portable: Code from one CPU can be used in other CPUs.
  - Complex: One statement can perform multiple tasks.
  - Human Readable: Structured and can be easily understood.

Program to find if a number is even or odd:

Let, n is the number to be checked.

```
If (n%2 == 0)
{
    Print("Number is even");
}
Else
{
    Print("Number is odd");
}
```

Assembly Language

- Characteristics:
  - Not Portable: Each assembly language instruction maps to one machine language instruction.
  - Simple: Each instruction does a simple task.
  - Human Readable: Structured but not as easily understood as HLL.

```
        mov     w1, 0
loop:
        cmp     w0, 1
        ble     endloop
        add     w0, w0, #1
        ands    wzr, w0, #1
        beq     else
        add     w2, w0, w0
        add     w0, w0, w2
        add     w0, w0, 1
        b       endif
else:
        asr     w0, w0, 1
endif:
        b       loop
endloop:
```

Machine Language

- Characteristics:
  - Not Portable: Processor specific code.
  - Simple: Each instruction does a simple task.
  - Not Human Readable: Not Structured and requires lot of effort.

```
0000 0000 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000
9222 9120 1121 A120 1121 A121 7211 0000
0000 0001 0002 0003 0004 0005 0006 0007
0008 0009 000A 000B 000C 000D 000E 000F
0000 0000 0000 FE10 FACE CAFE ACED CEDE

1234 5678 9ABC DEF0 0000 0000 F00D 0000
0000 0000 EEEE 1111 EEEE 1111 0000 0000
B1B2 F1F5 0000 0000 0000 0000 0000 0000
```

Why learn assembly language?

- It is used for direct hardware manipulation.
- It helps us access specialized processor instructions.
- It helps us address critical performance issues.
- Many real time systems, low level embedded systems and device drivers use Assembly Language.
- We learn how the OS interacts with input/output, system calls such as interrupt.
- It helps us improves algorithm development skills.
- It helps us improve the understanding of functions/procedures.
- It helps us gain an understanding of I/O buffering.
- It helps us adapt to changes in the computing world.

x86 Architecture

Contents

- Instruction Set Architecture (ISA)
- RISC vs CISC
- x86 Architecture
- x86 Assembly Program Format
- NASM toolchain

Instruction Set Architecture (ISA)

- Interface between software and hardware
- Defines instructions, registers, data types and addressing modes
- There are two primary types of instruction set architectures:

  Reduced Instruction Set Computer (RISC)

  Complex Instruction Set Computer (CISC)
- **Assembly instructions are ISA-specific**
- Same high-level code can yield different assembly for different ISAs

RISC vs CISC

- **RISC (Reduced Instruction Set Computer)**
  - Small set of simple instructions
  - Emphasis on compiler optimization
- **CISC (Complex Instruction Set Computer)**
  - Large set of complex instructions
  - Designed to reduce number of instructions per program
- x86 belongs to the **CISC** family

Data Storage Sizes (x86)

- The x86 architecture supports a specific set of data storage size elements.
- The sizes are based on powers of 2.
- These storage sizes have a direct corelation to variable declarations in HLL (e.g., C, C++, Java, etc).

Storage	Size (bits)	Size (bytes)
Byte	8-bits	1 byte
Word	16-bits	2 bytes
Double-word	32-bits	4 bytes
Quadword	64-bits	8 bytes
Double quadword	128-bits	16 bytes

CPU Registers

- A CPU register is a temporary storage built into the CPU itself.
- Computations are typically performed on them.
- The types of such registers are:
  - General Purpose Registers (GPRs)
  - Stack Pointer Register (RSP)
  - Base Pointer Register (RBP)
  - Instruction Pointer Register (RIP)
  - Flag Registers (rFlags)
  - XMM Registers (SIMD and Floating Point)

64-bit register	Lowest 32-bits	Lowest 16-bits	Lowest 8-bits
rax	eax	ax	al
rbx	ebx	bx	bl
rcx	ecx	cx	cl
rdx	edx	dx	dl
rsi	esi	si	sil
rdi	edi	di	dil
rbp	ebp	bp	bpl
rsp	esp	sp	spl
r8	r8d	r8w	r8b
r9	r9d	r9w	r9b
r10	r10d	r10w	r10b
r11	r11d	r11w	r11b
r12	r12d	r12w	r12b
r13	r13d	r13w	r13b
r14	r14d	r14w	r14b
r15	r15d	r15w	r15b

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rcx	ecx	cx	cl
rdx	edx	dx	dl
rsi	esi	si	sil
rdi	edi	di	dil
rbp	ebp	bp	bpl
rsp	esp	sp	spl
r8	r8d	r8w	r8b
r9	r9d	r9w	r9b
r10	r10d	r10w	r10b
r11	r11d	r11w	r11b
r12	r12d	r12w	r12b
r13	r13d	r13w	r13b
r14	r14d	r14w	r14b
r15	r15d	r15w	r15b

Name	Symbol	Bit	Use
Carry	CF	0	Used to indicate if the previous operation resulted in a carry.
Parity	PF	2	Used to indicate if the last byte has an even number of 1's (i.e., even parity).
Adjust	AF	4	Used to support Binary Coded Decimal operations.
Zero	ZF	6	Used to indicate if the previous operation resulted in a zero result.
Sign	SF	7	Used to indicate if the result of the previous operation resulted in a 1 in the most significant bit (indicating negative in the context of signed data).
Direction	DF	10	Used to specify the direction (increment or decrement) for some string operations.
Overflow	OF	11	Used to indicate if the previous operation resulted in an overflow.

Flags

Process Stack

- The **rsp** is used to point to the current top of stack in memory.
- The stack is implemented growing down in the memory.
- The heap grows upwards, while the stack grows downward, to ensure most effective use of memory.
- If the stack and heap meet, the program will crash.

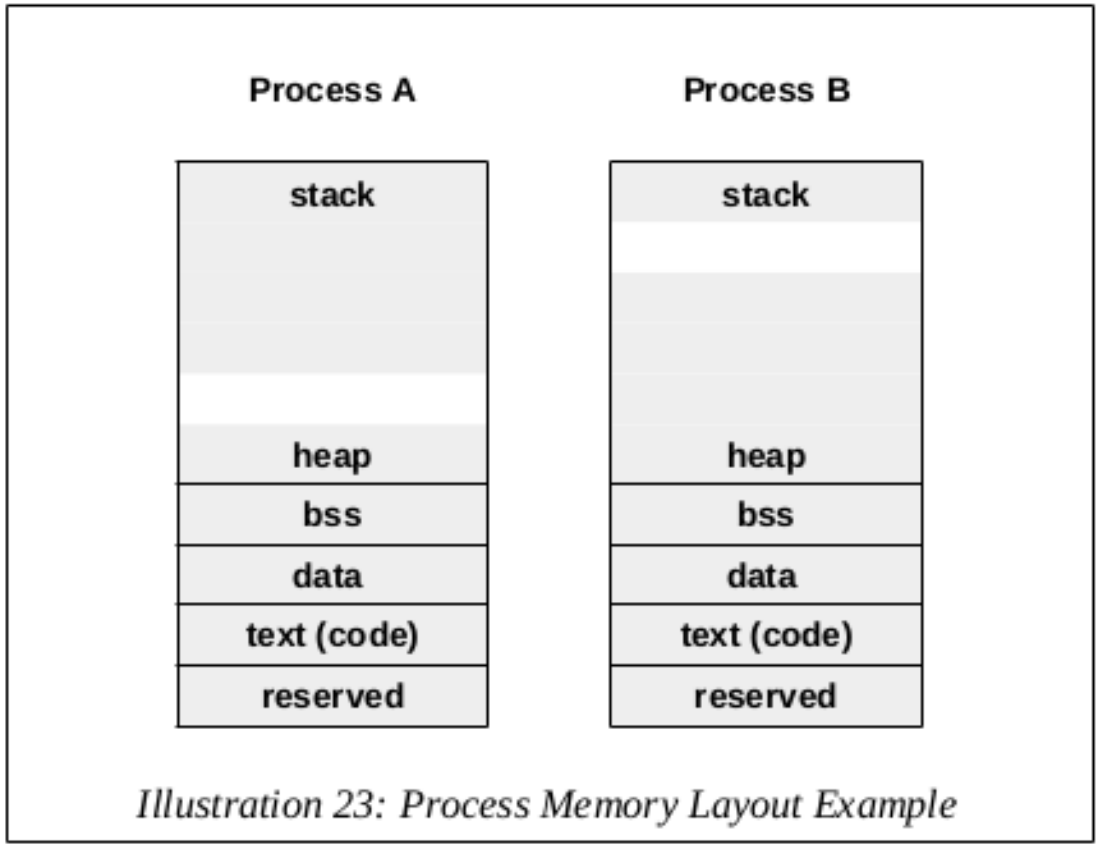
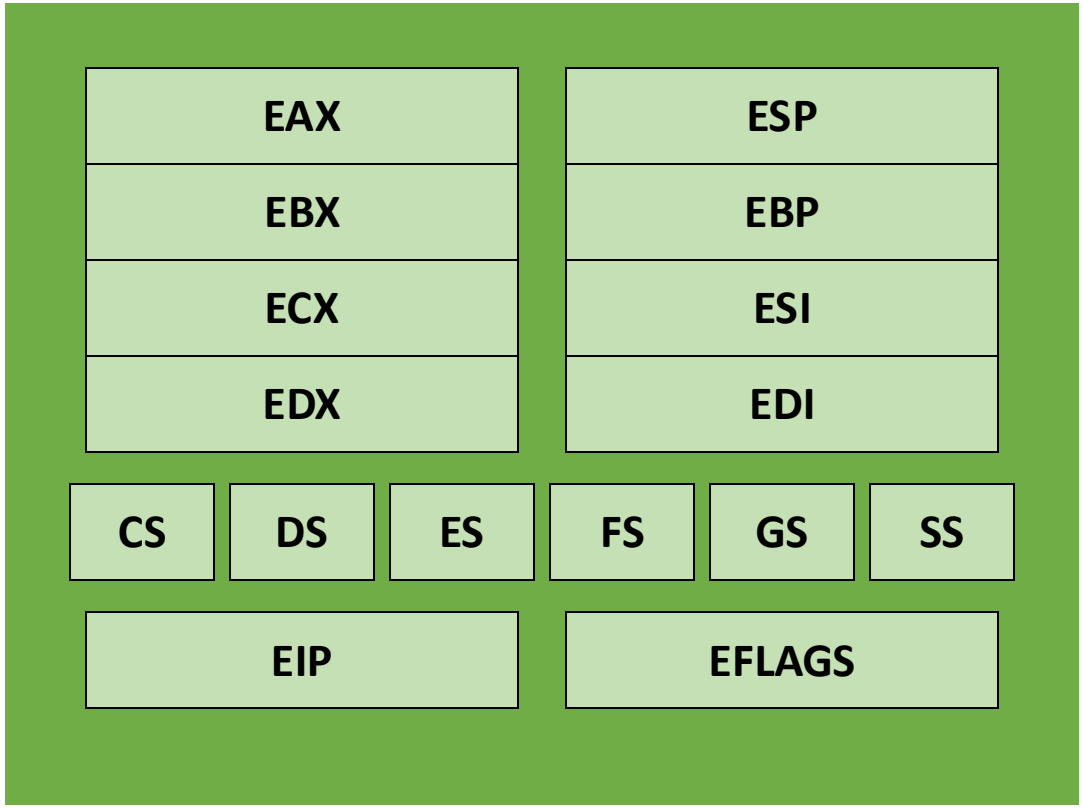


Illustration 23: Process Memory Layout Example

The sixteen x86 registers



Intel Pentium processor (32 bit)

Program Format

Program Example

```
section .data
num1    dd  5              ; Initialized integer variable
num2    dd  3              ; Initialized integer variable
```

DATA SECTION (.data)
Stores Initialized Variables

```
section .bss
result  resd 1             ; Reserve space for one integer
```

BSS SECTION (.bss)
Reserves Space for Uninitialized Data

```
section .text
global _start               ; Entry point for the linker

_start:                     ; Program execution begins here

    mov eax, [num1]         ; Load value of num1 into EAX
    mov ebx, [num2]         ; Load value of num2 into EBX
    add eax, ebx            ; EAX = num1 + num2

    mov [result], eax       ; Store result in memory

    mov ebx, eax            ; Set exit status
    mov eax, 1              ; System call number for exit
    int 0x80                ; Invoke Linux kernel
```

Text SECTION (.text)
Contains Executable Instructions

Program Format

- A properly formatted assembly source file consists of :
  - Data section: Initialized data is declared and defined.
  - BSS section: Uninitialized data is declared here.
  - Text section: Contains executable instructions.

- Comments can be placed after semicolon (;). Any instruction after ; are ignored by the compiler for that line.

- Numerical values may be specified in decimal, hex or octal.
  - '0x' preceeds hex values
  - 'q' preceeds octal values
  - Decimal doesnt require any notation.

Data Section

- The initialized data must be declared in the "section .data" section.
- Variable name must start with a letter, followed by letters or numbers, and some special characters.
- The general format is:
  <variable name> <dataType> <initialValue>

Supported Data Types

Declaration	
db	8-bit variable(s)
dw	16-bit variable(s)
dd	32-bit variable(s)
dq	64-bit variable(s)
ddq	128-bit variable(s) → integer
dt	128-bit variable(s) → float

Some simple examples include:

```
bVar        db      10                  ; byte variable
cVar        db      "H"                 ; single character
strng       db      "Hello World"       ; string
wVar        dw      5000                ; 16-bit variable
dVar        dd      50000               ; 32-bit variable
arr         dd      100, 200, 300       ; 3 element array
flt1        dd      3.14159             ; 32-bit float
qVar        dq      1000000000          ; 64-bit variable
```

BSS Section

- The uninitialized data is declared in the "section .bss" section.
- Variable name must start with a letter, followed by letters or numbers, and some special characters.
- The general format is:

<variable name> <resType> <count>

Supported Data Types

Declaration	
`resb`	8-bit variable(s)
`resw`	16-bit variable(s)
`resd`	32-bit variable(s)
`resq`	64-bit variable(s)
`resdq`	128-bit variable(s)

Some simple examples include:

```
bArr    resb    10          ; 10 element byte array
wArr    resw    50          ; 50 element word array
dArr    resd    100         ; 100 element double array
qArr    resq    200         ; 200 element quad array
```

The allocated array is not initialized to any specific value.

Text Section

- The code is placed in the "section .text" section.
- The instructions are specified one per line.
- Each instruction must be valid with appropriate operands.
- It includes some headers or labels that define initial program entry.
- Assuming a basic program using the standard system linked, the following declarations must be included.

```
global _start
_start:
```

- No special label is required to terminate the program.
- The OS should be informed so that resources can be recovered and re-utilized.

Text Section key terms

- **global**
  keyword used to make identifier accessible to linker.
- **_start**
  processor starts compiling from here . Equivalent to main() in C.
- **Label**:
  any word with a colon in the text section is a label. It can be accessed via jumps.
- **Int 0x__**
  interrupt specified by the hex code following it.
- **0x80**
  hex code used to call system calls based on the value in the 'eax' register.

Program Example

- A program to calculate 2^x

```
section .text
_start:
    mov ebx, 1          ; starts ebx to 1
    mov ecx, 4          ; no of iterations

label:
    add ebx, ebx        ; ebx = ebx + ebx
    dec ecx             ; ecx = ecx - 1
    cmp ecx, 0          ; compare ecx with 0
    jg label            ; jump to label if ecx is greater than 0

    mov eax, 1          ; sys_exit system call
    int 0x80            ; interrupt system call
```

The output of the program is 16.

NASM Toolchain

Tool Installation and Execution

```
$ sudo apt install nasm

$ gedit filename.asm
$ nasm -f elf32 filename.asm -o filename.o
$ ld -m elf_i386 filename.o -o filename

$ ./filename
```