Compliers

```
Module Code: U10793

Module Name: Fundamentals of Computer Systems

Credits: 15

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```

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THE #1 PROGRAMMER EXCUSE FOR LEGITIMATELY SLACKING OFF:
"MY CODE'S COMPILING."
HEY! GET BACK TO WORK!
COMPILING!
OH. CARRY ON.

What we will cover

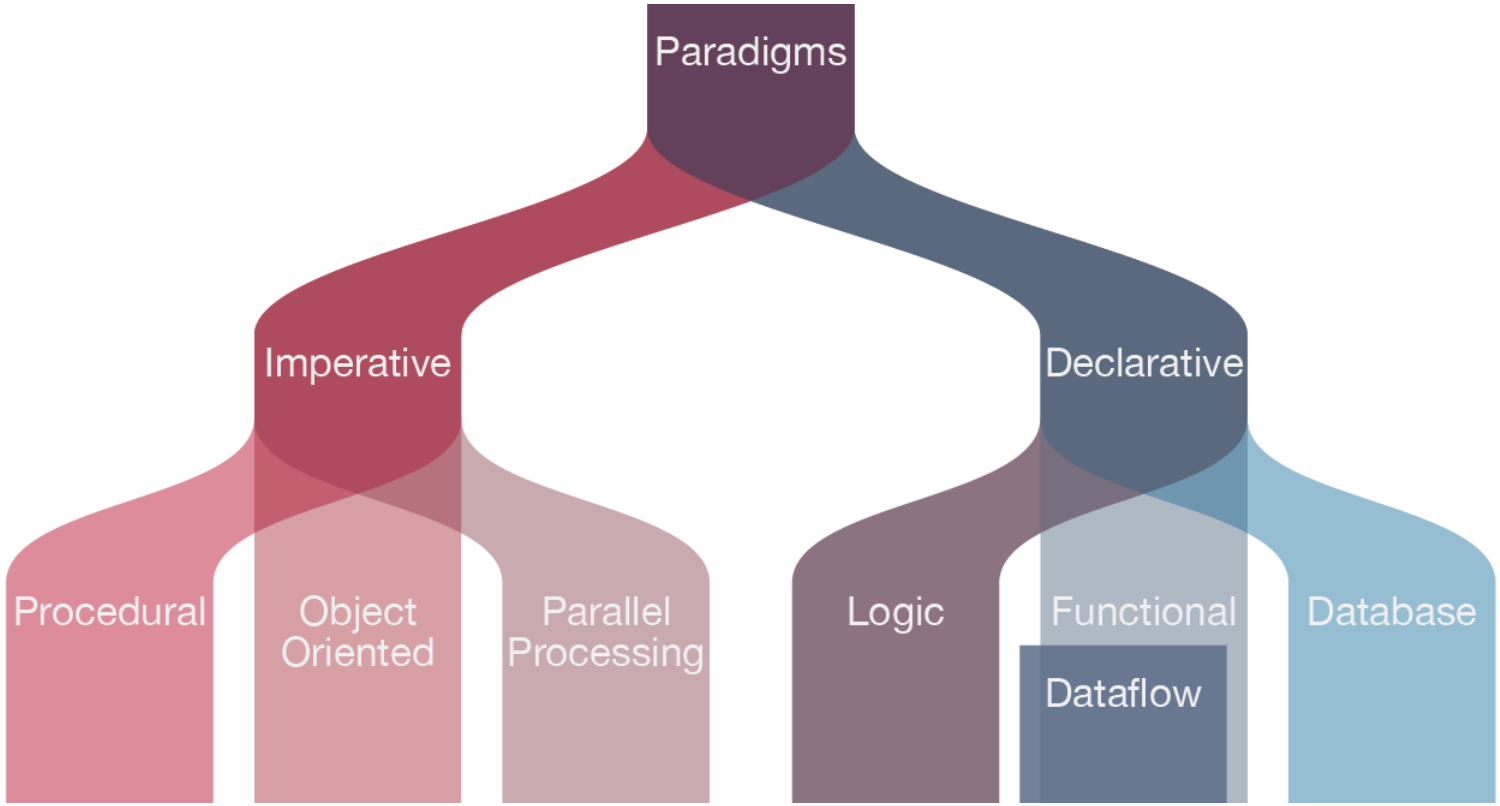
1. We will understand how ‘high’ and ‘low’ level programming languages are compiled to machine code so that it controls the hardware.
2. We will compare a number of programming languages and how they compile to machine code.

What is programming?

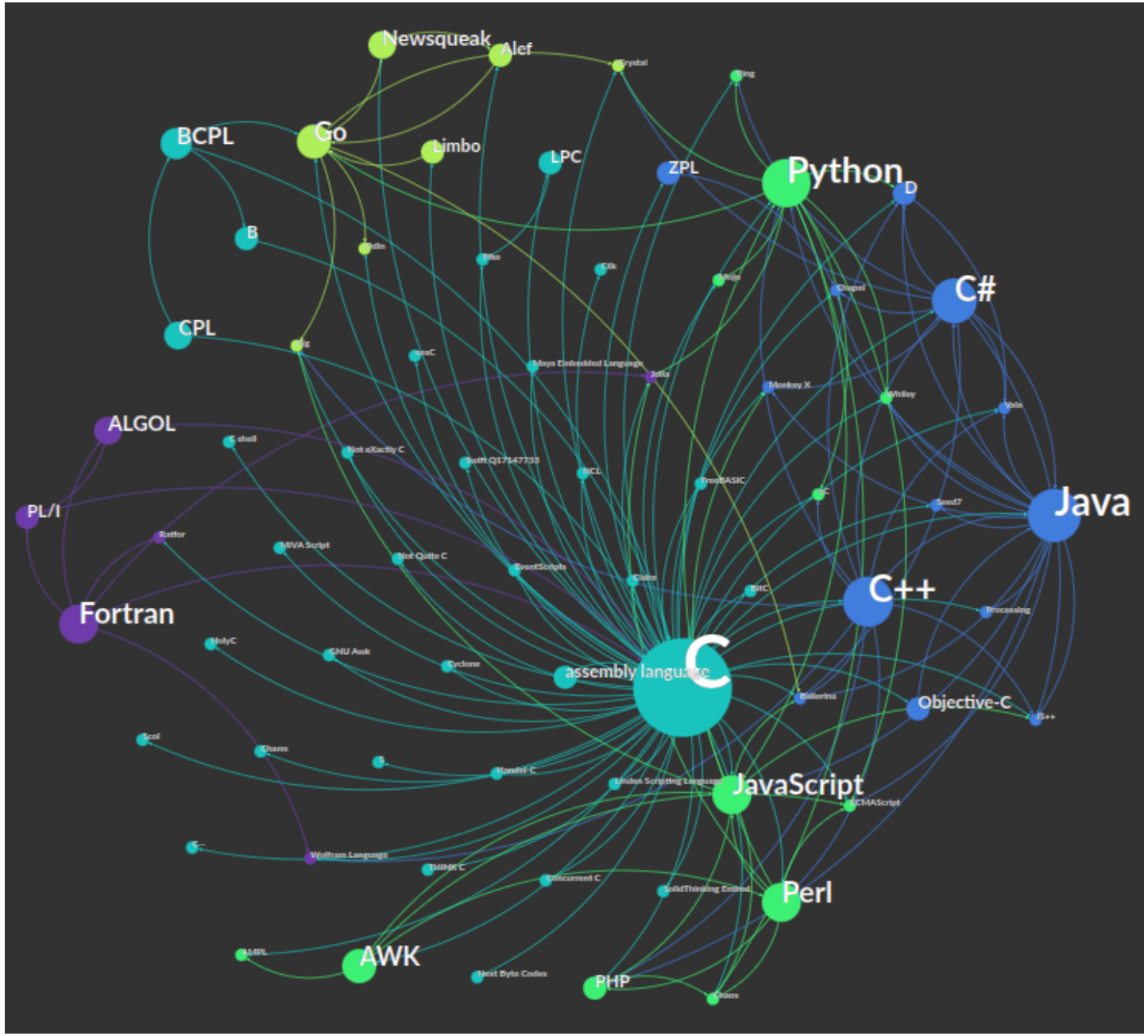
- ?
- Why program?

Programming Paradigms

- ~1605 programming lanaguages
- 94 Types
- 65 Paradigms



C Influences



Human Language and Programming Languages

- Are all programming languages in English?
- Does it matter when these are compiled down to machine code?

Some Examples of Non-English Programming Languages

Linotte

It has been a developer for using French keywords, and its “Hello world” program looks like this:

```
BonjourLeMonde:
  début
    affiche "Bonjour le monde!"

------------------------

HelloWorld:
  beginning
    poster "Hello world!
```

Has a web engine for HTML and PHP and JSP.

SAKO

System Automatycznego Kodowania Operacji (Automatic Operation Encoding System) programming language, which uses polish as for its keywords:

```
LINIA
  TEKST:
  HELLO WORLD
KONIEC

----------------------------------

LINE
  TEXT:
  HELLO WORLD
END
```

Really only used in the late 1950s and early 1960s for the XYZ computers.

Rapira

Rapira is another awesome example of non-english programming languages. It uses Russian keywords:

```
ПРОЦ СТАРТ()

    ВЫВОД: 'Привет, мир!'

КОН ПРОЦ

--------------------

proc start()
     output: 'Hello, world!!!';
end proc
```

EPL

易语言 (Easy Programming Language, as known as EPL):

```
公开 类 启动类
{
  公开 静态 启动()
  {
    控制台.输出("你好, 世界！");
  }
}
```

```
public class startup class
{
  public static start()
  {
    console.output("Hello, World!");
  }
}
```

Compiler

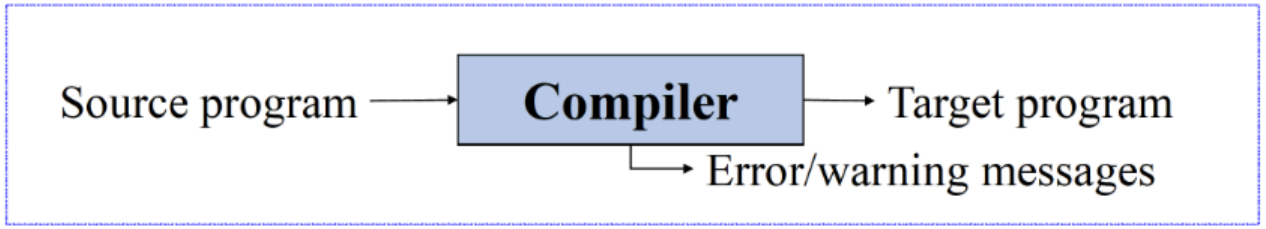
A compiler is a program that `processes` source code written in a programming language.

- **Program Processing:** A compiler serves as a crucial tool in handling programs written in various programming languages.
- **Program Generation:** It functions as a program generator, capable of producing executable programs in a specified language.
- **Language Translation:** The compiler translates programs written in one language into equivalent programs in another language.

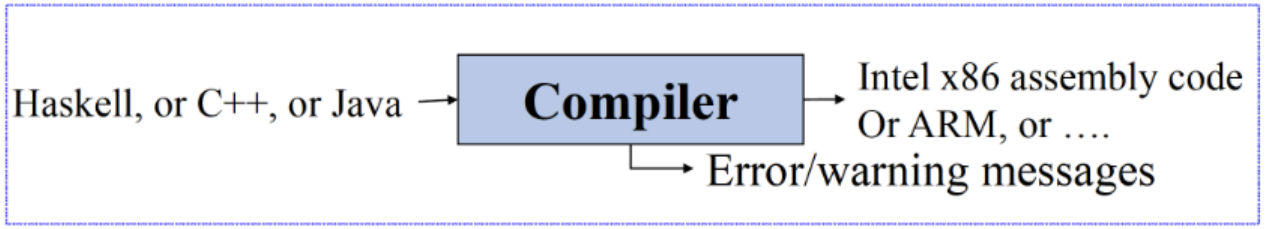
A tool to enable you to program at a higher level , by mapping high level concepts to low level implementation

- **Increased Productivity:** Allows for faster and more efficient development by focusing on the logic and design rather than intricate details.
- **Enhanced Readability:** Code becomes more readable and understandable, facilitating collaboration and maintenance.
- **Code Portability:** Encourages code portability by minimizing dependencies on specific hardware or architecture

- Translates from one language into another
- Output a low level program which behaves as specified by the input, higher level program.
- Mediate between higher level human concepts, and the word by word data manipulation which the machine performs.



For example:



Compliler and Interpreter

- Compiler?
- Interpreter?

GCC compiler example

- `$ gcc -S -O test.c`

Input file `test.c`

```
int A;
int B;
test_fun()
{
  A = b + 123;
}
```

Output file `test.out`

```
.comm _A,4
.comm _B,4
_test_fun:
pushl %ebp
movl %esp,%ebp
movl _B,%eax
addl $123,%_A
movl %ebp,%esp
popl %ebp
ret
```

The flag `S` tells the compiler to produce assembly code, `O` turns optimisation on

Assembly code

Assembly code is a `low-level` programming language that serves as an `interface` between `high-level` programming languages and the computer's `hardware`.

- **Human-Readable Machine Code**: Assembly code is a human-readable representation of machine code, making it more understandable than binary machine code.
- **Close to Hardware**: Unlike high-level languages, assembly code provides a direct correspondence to the architecture and operations of the underlying hardware.

Symbolic Representation

- Uses mnemonics and symbols to represent machine instructions, making it more comprehensible than raw machine code.

Binary	Opcode	Mnemonic	Description
1000 0111	87	`ADD A`	Add the contents of the register A to that of the accumulator
0011 1010	3A	`LDA`	Load data stored in the given memory address
0111 1001	79	`MOV A C`	Move data from register A to C
1100 0011	C3	`JMP`	Jump to instruction in specified memory address
1100 0001	C1	`POP` B	Pop from stack and copy to memory register B + C

Example:

- The .data section declares a null-terminated string "Hello, Assembly!".
- The .text section contains the program logic.
- The _start label marks the entry point of the program.

Source code in C

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

int main() {
    // Declare and initialize the
string
    char msg[] = "Hello, Assembly!";

    // Write the message to stdout
    write(1, msg, strlen(msg));

    // Exit the program with a return
code of 0
    exit(0);
}
```

Source code in Assembly

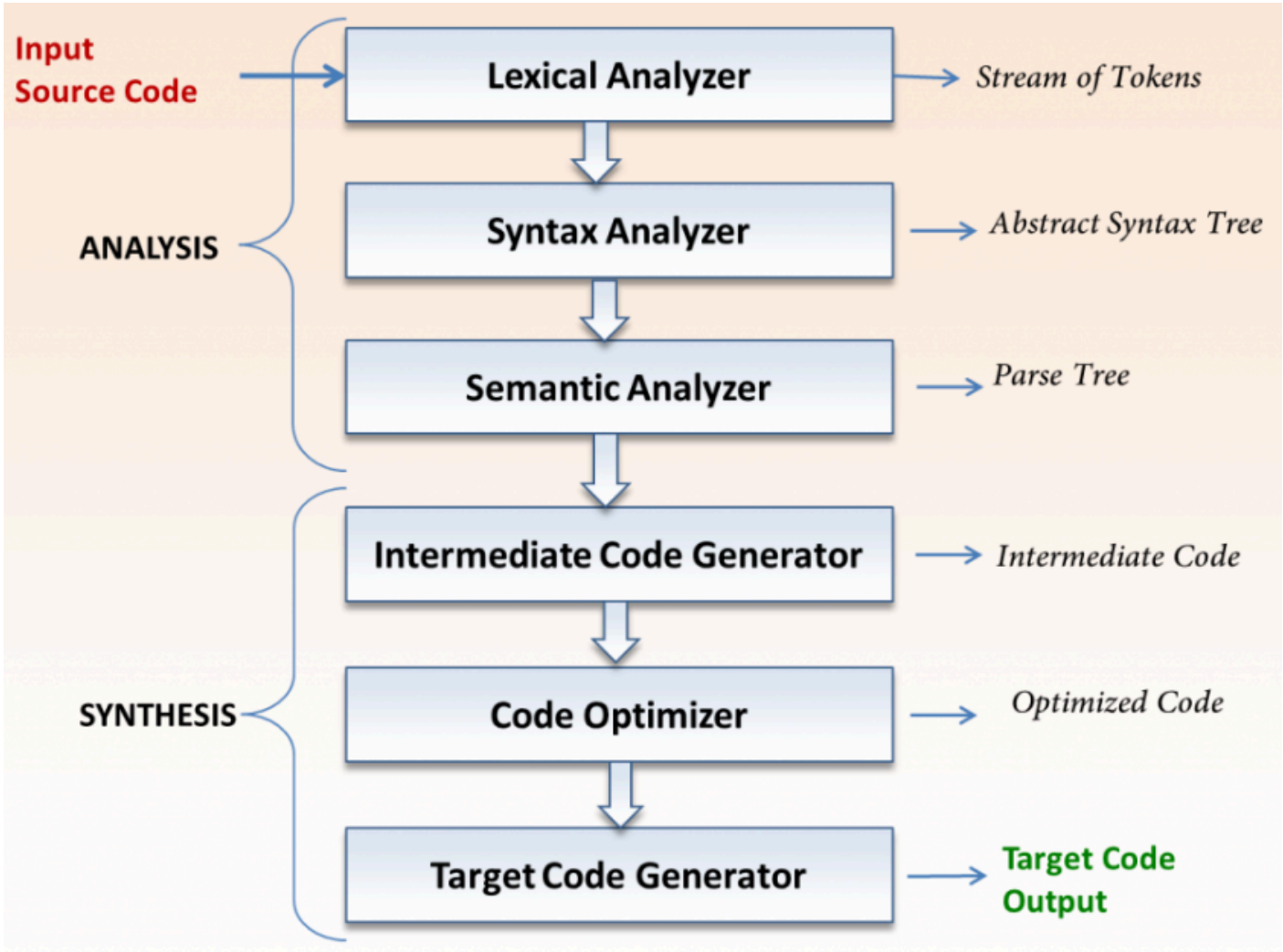
```
section .data
    msg db 'Hello, Assembly!',0

section .text
    global _start

_start:
    ; Write the message to stdout
    mov eax, 4            ; syscall: write
    mov ebx, 1            ; file descriptor: stdout
    mov ecx, msg          ; pointer to the message
    mov edx, 15           ; length of the message
    int 0x80              ; invoke the kernel

; Exit the program
    mov eax, 1            ; syscall: exit
    xor ebx, ebx          ; exit code 0
    int 0x80              ; invoke the kernel
```

Compiling Code



Lexical Analysis

The compiler begins converting the series of characters into tokens

High Level Code

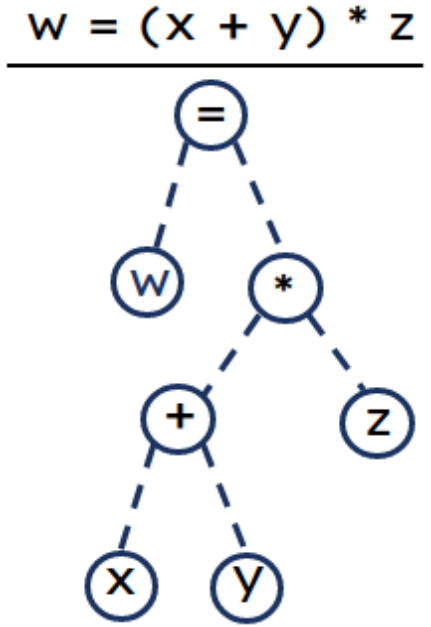
```
int n = 11;
float q = 1.618f;
if (n < 12)
{
  return q;
}
else
{
  return n;
}
```

Token name	Example token values
identifier	n, q
keyword	int, float, if, else, return, while
separator	{ }, ( ), [ ], ;
operator	+,- *, / , = ,< , >, : , ?
literal	True, false, 6.02e23, “string”
comment	// this is a comment */this is another comment/*

Syntax Analysis

Syntax analysis is based on the rules based on the specific programming language by constructing the parse tree with the help of tokens.

- Interior node: record with an operator filed and two files for children
  - Leaf: records with 2/more fields; one for token and other information about the token
  - Ensure that the components of the program fit together meaningfully
  - Gathers type information and checks for type compatibility
  - Checks operands are permitted by the source language



Semantic Analyser

Semantic Analyser will check for Type mismatches, incompatible operands, a function called with improper arguments, an undeclared variable, etc.

```
int n = 11;
float q = 1.618*n;
```

In the above code, the semantic analyser will typecast the `int n 11` to `float 11.0` before multiplication.

Intermediate Code Generation

Removes unnecessary code lines.

Arranges the sequence of statements to speed up the execution of the program without wasting resources.

Consider the following code, how can we remove unnecessary code?

```
a = int_to_float(10)
b = c * a
d = e + b
f = d
```

▶ Can become

Code Generation

The objective of this phase is to allocate **memory locations**, **storage** and **generate relocatable machine code** or **machine instructions**.

The code generated by this phase is executed to take inputs and generate expected outputs, therefore, checks for unreachable statements.
Consider the following code, what error would be generated at this stage?

```
while (p == 10)
{
  break;
  int q = (0.5*8)*p;
}
```

Code Generation

Now we are going to see how we go from C to Assembly to machine code…

```c
int square(int num) {
    return num * num;
}
```

```
square:
  pushq  %rbp
  movq   %rsp, %rbp
  movl   %edi, -4(%rbp)
  movl   -4(%rbp), %eax
  imull  %eax, %eax
  popq   %rbp
  ret
```

	Memory Addresses
rbp[3]	0x0007556ff0e0
rbp[2]	0x0007556ff0df
rbp[1]	0x0007556ff0de
rbp[0]	0x0007556ff0dd
	0x0007556ff0dc
	0x0007556ff0db
	0x0007556ff0da
num	0x0007556ff0d9

```c
int square(int num) {
    return num * num;
}
```

∴

```
square:
  pushq  %rbp
  movq   %rsp, %rbp
  movl   %edi, -4(%rbp)
  movl   -4(%rbp), %eax
  imull  %eax, %eax
  popq   %rbp
  ret
```

```
HEX
55              01010101
48 89 e5        01001000 10001001 11100101
89 7d fc        10001001 01111101 11111100
0f af c0        00001111 10011111 11000000
54              01010100
C3              11000011
```

Symbol Management Table

A symbol table contains a record for each identifier with fields for the attributes of the identifier.

Operation	Function
allocate	to allocate a new empty symbol table
free	to remove all entries and free storage of symbol table
lookup	to search for a name and return a pointer to its entry
insert	to insert a name in a symbol table and return a pointer to its entry
set_attribute	to associate an atrribute to a given entry
get_attribute	to get an attribute associated with a given entry

Error Handling Routine

During compilation process error(s) may occur in all the below-given phases:

- Lexical analyser: Wrongly spelled tokens
- Syntax analyser: Missing parenthesis
- Semantic analyser: Mismatched data types, missing arguments
- Intermediate code generator: Mismatched operands for an operator
- Code Optimizer: When the statement is not reachable
- Code Generator: Unreachable statements
- Symbol tables: Error of multiple declared identifiers

Labs

Begin the lab from blackboard, where you are going experience programming in several languages <C , Python and Ada> to do similar operations, and see how the code compiles and the subsequent outputs!,