Course - System Programming and Compiler Construction (SPCC)

UID	2021300108
Name	Hatim Sawai
Class and Batch	TE Computer Engineering - Batch C
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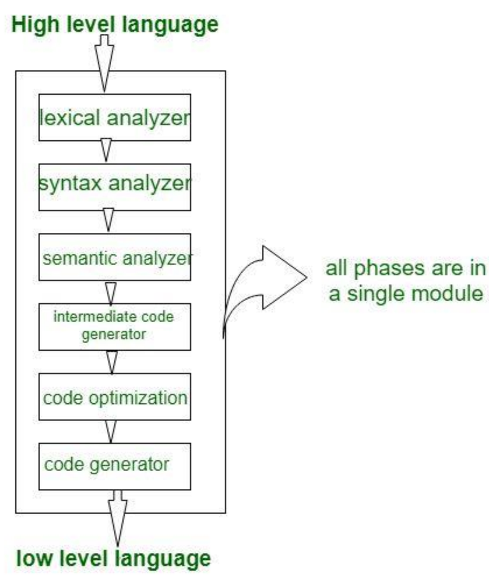
Lab #	8
Aim	Write a program to Implement a 2 pass Assembler.
Objective	Implement and evaluate the functionality of a two-pass assembler. Construct a symbol table, resolving forward references, and generating machine code.
Theory	**Compiler Pass[1]** A Compiler pass refers to the traversal of a compiler through the entire program. Compiler passes are of two types: Single Pass Compiler, and Two Pass Compiler or Multi-Pass Compiler. These are explained as follows. **Single Pass Compiler** If we combine or group all the phases of compiler design in a single module known as a single pass compiler. 

In the above diagram, there are all 6 phases are grouped in a single module, some points of the single pass compiler are as:

- A one-pass/single-pass compiler is a type of compiler that passes through the part of each compilation unit exactly once.
- Single pass compiler is faster and smaller than the multi-pass compiler.
- A disadvantage of a single-pass compiler is that it is less efficient in comparison with the multipass compiler.
- A single pass compiler is one that processes the input exactly once, so going directly from lexical analysis to code generator, and then going back for the next read.

Problems with Single Pass Compiler

- We can not optimize very well due to the limited context of expressions.
- As we can't back up and process it again so grammar should be limited or simplified.
- Command interpreters such as bash/sh/tcsh can be considered Single pass compilers, but they also execute entries as soon as they are processed.

Two Pass Compiler[2]

A two-pass assembler is a type of assembly language translator that processes the source code in two consecutive passes or phases. In the first pass, the assembler scans the entire source code, building a symbol table that contains information about labels, variables, and their memory locations. It also detects syntax errors and performs macro expansion if applicable. During the second pass, the assembler generates the actual machine code, using the information gathered in the first pass.

Pass 1: Symbol Table Construction

During the first pass, the assembler reads the source code line by line, analyzing each instruction and directive. It identifies and records the symbols (labels, variable names) along with their associated memory locations or addresses. Additionally, it resolves any forward references encountered, ensuring that all symbols are defined before they are used. The symbol table generated during this pass serves as a reference for the subsequent code generation phase.

Pass 2: Code Generation

In the second pass, the assembler utilizes the symbol table constructed in the first pass to generate the machine code instructions. It revisits each line of the source code, translating assembly instructions into their binary equivalents or relocatable machine code. This phase may also involve resolving any remaining unresolved symbols and generating appropriate relocation information if the target machine supports relocatable code.

Advantages of a Two-Pass Assembler

1. **Efficient Symbol Resolution**: By dividing the assembly process into two passes, a two-pass assembler can efficiently handle forward references, ensuring that all symbols are properly resolved.

2. **Error Detection:** The two-pass approach allows the assembler to detect syntax errors, undefined symbols, or other issues early in the assembly process, improving overall code quality and debugging.

3. **Macro Expansion:** Two-pass assemblers often support macro expansion, enabling the use of reusable code fragments and simplifying program development.

Difference between One Pass and Two Pass Compiler[1]

One pass Compiler	Two Pass Compiler
It performs Translation in one pass	It performs Translation in two pass
It scans the entire file only once.	It requires two passes to scan the source file.
It generates Intermediate code	It does not generate Intermediate code
It is faster than two pass assembler	It is slower than two pass assembler
A loader is not required	A loader is required.
No object program is written.	A loader is required as the object code is generated.
Perform some professing of assembler directives.	Perform processing of assembler directives not done in pass-1
The data structure used are: The symbol table, literal table, pool	The data structure used are: The symbol table, literal table, and

table, and table of incomplete.	pool table.
These assemblers perform the whole conversion of assembly code to machine code in one go.	These assemblers first process the assembly code and store values in the opcode table and symbol table and then in the second step they generate the machine code using these tables.
Example: C and Pascal uses One Pass Compiler.	Example: Modula-2 uses Multi Pass Compiler.

Implementation / Code

Python Code:

```python
import sys

def RemoveSpaces(x):
    if (x != " ") or (x != ", "):
        return x

def RemoveCommas(x):
    if x[-1] == ",":
        return x[ : len(x) - 1]
    else:
        return x

def CheckLiteral(element):
    if element[ : 2] == "='":
        return True
    else:
        return False

def CheckSymbol(Elements):
    global SymbolTable, Opcodes
```

```
    if (len(Elements) > 1) and ([Elements[-1], None, None, "Variable"]
not in SymbolTable) and (Elements[-1] != "CLA") and (Elements[-2] not
in ["BRP", "BRN", "BRZ"]) and (Elements[-1][ : 2] != "='") and
(Elements[-1][ : 3] != "REG") and (not Elements[-1].isnumeric()):
        return True
    else:
        return False

def CheckLabel(Elements):
    global SymbolTable, Opcodes

    if (len(Elements) >= 2) and (Elements[1] in Opcodes):
        if Elements[0] not in SymbolTable:
            return True
    else:
        return False

Opcodes = ["CLA", "LAC", "SAC", "ADD", "SUB", "BRZ", "BRN", "BRP",
"INP", "DSP", "MUL", "DIV", "STP", "DATA", "START"]
AssemblyOpcodes = {"CLA" : "0000", "LAC" : "0001", "SAC" : "0010",
"ADD" : "0011", "SUB" : "0100", "BRZ" : "0101","BRN" : "0110",
                   "BRP" : "0111", "INP" : "1000", "DSP" : "1001",
"MUL" : "1010", "DIV" : "1011", "STP" : "1100"}
SymbolTable = []
LiteralTable = []
Variables = []
Declarations = []
AssemblyCode = []
location_counter = 0
stop_found = False
end_found = False

file = open("Assembly Code Input.txt", "rt")

# ERROR 1 : Checking for missing START statement
for line in file:
```

```
    # Checking for comments
    if line[ : 2] != "//":
        if line.strip() != "START":
            print("STARTError : 'START' statement is missing. " + "( Line " + str(location_counter) + " )")
            sys.exit(0)
        else:
            file.seek(0, 0)
            break

# First Pass
for line in file:
    # Checking for comments
    if line[ : 2] != "//":
        Elements = line.strip().split(" ")
        Elements = list(filter(RemoveSpaces, Elements))
        Elements = list(map(RemoveCommas, Elements))

        # Removing comments
        for i in range(len(Elements)):
            if Elements[i][ : 2] == "//":
                Elements = Elements[ : i]
                break

        # ERROR 2 : Checking for too many operands
        # If the instruction doesn't contain a Label
        if (len(Elements) >= 3) and (Elements[0] in Opcodes):
            print("TooManyOperandsError : Too many operands used for the '" + Elements[0] + "' assembly opcode. " + "( Line " + str(location_counter) + " )")
            sys.exit(0)
        # If the instruction contains a Label
        elif (len(Elements) >= 4) and (Elements[1] in Opcodes):
            print("TooManyOperandsError : Too many operands used for the '" + Elements[1] + "' assembly opcode. " + "( Line " + str(location_counter) + " )")
```

```
            sys.exit(0)

        # ERROR 3 : Checking for less operands
        # If the instruction doesn't contain a Label
        if (len(Elements) == 1) and (Elements[0] in ["LAC", "SAC",
"ADD", "SUB", "BRZ", "BRN", "BRP", "INP", "DSP", "MUL", "DIV"]):
            print("LessOperandsError : Less operands used for the '" +
Elements[0] + "' assembly opcode. " + "( Line " +
str(location_counter) + " )")
            sys.exit(0)
        # If the instruction contains a Label
        elif (len(Elements) == 2) and (Elements[1] in ["LAC", "SAC",
"ADD", "SUB", "BRZ", "BRN", "BRP", "INP", "DSP", "MUL", "DIV"]):
            print("LessOperandsError : Less operands used for the '" +
Elements[1] + "' assembly opcode. " + "( Line " +
str(location_counter) + " )")
            sys.exit(0)

        # ERROR 4 : Checking for invalid opcodes
        if stop_found is False:
            if len(Elements) == 3:
                # If the instruction contains a Label
                if Elements[1] not in Opcodes:
                    print("InvalidOpcodeError : '" + Elements[1] + "'
is an invalid opcode. " + "( Line " + str(location_counter) + " )")
                    sys.exit(0)
            if (len(Elements) == 2) and (Elements[1] == "CLA"):
                pass
            elif len(Elements) == 2:
                # If the instruction doesn't contain a Label
                if Elements[0] not in Opcodes:
                    print("InvalidOpcodeError : '" + Elements[0] + "'
is an invalid opcode. " + "( Line " + str(location_counter) + " )")
                    sys.exit(0)

        # Check for STP
```

```
        if (len(Elements) == 3) and (Elements[1] == "DATA"):
            stop_found = True

        # Check for END
        if (len(Elements) == 1) and (Elements[0] == "END"):
            end_found = True

            for i in range(len(LiteralTable)):
                if LiteralTable[i][1] == -1:
                    LiteralTable[i][1] = location_counter
                    location_counter += 1

            break

        if not stop_found:
            # Check for Literal
            for x in Elements:
                if CheckLiteral(x):
                    LiteralTable.append([x, -1])

            # Check for Labels
            if CheckLabel(Elements):
                SymbolTable.append([Elements[0], location_counter,
None, "Label"])

            # Check for Symbols
            if CheckSymbol(Elements):
                SymbolTable.append([Elements[-1], None, None,
"Variable"])
        elif stop_found:
            if (Elements[0] != "STP") and (Elements[0] != "END"):
                # ERROR 5 : Checking for multiple definations
                if Elements[0] not in Variables:
                    Variables.append(Elements[0])
                    Declarations.append((Elements[0], Elements[2]))
                else:
```

```
                    print("DefinationError : Variable '" + Elements[0] + "' defined multiple times. " + "( Line " + str(location_counter) + " )")
                    sys.exit(0)

                # ERROR 6 : Checking for redundant declarations
                if [Elements[0], None, None, "Variable"] not in SymbolTable:
                    print("RedundantDeclarationError : " + Elements[0] + " declared but not used.")
                    sys.exit(0)
                location = SymbolTable.index([Elements[0], None, None, "Variable"])
                SymbolTable[location][1] = location_counter
                SymbolTable[location][2] = Elements[2]

        location_counter += 1

# ERROR 7 : Checking for missing END statement
if end_found is False:
    print("ENDError : 'END' statement is missing." + "( Line " + str(location_counter) + " )")
    sys.exit(0)

# ERROR 8 : Checking for undefined variables
for x in SymbolTable:
    if x[1] is None and x[3] == "Variable":
        print("UndefinedVariableError : Variable '" + x[0] + "' not defined.")
        sys.exit(0)

# Printing Tables after First Pass
print(">>> Opcode Table <<<\n")
print("ASSEMBLY OPCODE     OPCODE")
print("-------------------------")
```

```
for key in AssemblyOpcodes:
    print(key.ljust(20) + AssemblyOpcodes[key].ljust(6))

print("--------------------------")
print("\n>>> Literal Table <<<\n")
print("LITERAL     ADDRESS")
print("-------------------")

for i in LiteralTable:
    print(i[0].ljust(12) + str(i[1]).ljust(7))

print("-------------------")
print("\n>>> Symbol Table <<<\n")
print("SYMBOL          ADDRESS     VALUE     TYPE")
print("----------------------------------------------")

for i in SymbolTable:
    print(i[0].ljust(16) + str(i[1]).ljust(12) + str(i[2]).ljust(10) + 
i[3].ljust(10))

print("----------------------------------------------")
print("\n>>> Data Table <<<\n")
print("VARIABLES     VALUE")
print("-------------------")

for i in Declarations:
    print(i[0].ljust(14) + str(i[1]).ljust(10))

print("-------------------\n")

# Second Pass
file.seek(0, 0)

print(">>> MACHINE CODE <<<\n")

for line in file:
```

```
    # Checking for comments
    if line[ : 2] != "//":
        Elements = line.strip().split(" ")
        Elements = list(filter(RemoveSpaces, Elements))
        Elements = list(map(RemoveCommas, Elements))
        s = ""

        # Removing comments
        for i in range(len(Elements)):
            if Elements[i][ : 2] == "//":
                Elements = Elements[ : i]
                break

        # To terminate machine code conversion
        if (len(Elements) == 3) and (Elements[1] == "DATA"):
            break

        if Elements[0] == "STP":
            AssemblyCode.append("00 "+ AssemblyOpcodes["STP"] + " 00
00 00")
            print("00 " + AssemblyOpcodes["STP"] + " 00 00 00")
        # If the CLA opcode has a Label before it
        elif (len(Elements) == 2) and (Elements[1] == "CLA"):
            for i in range(len(SymbolTable)):
                if Elements[0] == SymbolTable[i][0]:

AssemblyCode.append(str(SymbolTable[i][1]).rjust(2, "0") + " " +
AssemblyOpcodes["CLA"] + " 00 00 00")
                    print(str(SymbolTable[i][1]).rjust(2, "0") + " "+
AssemblyOpcodes["CLA"] + " 00 00 00")
        elif Elements[0] != "START":
            if (len(Elements) == 1) and (Elements[0] == "CLA"):
                AssemblyCode.append("00 " + AssemblyOpcodes["CLA"] + "
00 00 00")
                print("00 " + AssemblyOpcodes["CLA"] + " 00 00 00")
            # If there is no Label
```

```
            elif (len(Elements) == 2) and (Elements[1] != "CLA"):
                print("00 " + AssemblyOpcodes[Elements[0]], end = " ")
                s = "00 " + AssemblyOpcodes[Elements[0]] + " "

                # Dealing with Literals
                if CheckLiteral(Elements[1]):
                    for i in range(len(LiteralTable)):
                        if LiteralTable[i][0] == Elements[1]:
                            AssemblyCode.append(s + "00 00 " +
str(LiteralTable[i][1]).rjust(2, "0"))
                            print("00 00 " +
str(LiteralTable[i][1]).rjust(2, "0"))
                # Dealing with Lables (BRP, BRZ, BRN)
                elif Elements[0] in ["BRP", "BRN", "BRZ"]:
                    for i in range(len(SymbolTable)):
                        if SymbolTable[i][0] == Elements[1]:
                            AssemblyCode.append(s +
str(SymbolTable[i][1]).rjust(2, "0") + " 00 00")
                            print(str(SymbolTable[i][1]).rjust(2, "0")
+ " 00 00")
                # Dealing with Registers
                elif Elements[1][ : 3] == "REG":
                    AssemblyCode.append(s + "00 " + Elements[1][-
1].rjust(2, "0") + " 00")
                    print("00 " + Elements[1][-1].rjust(2, "0") + "
00")
                # Dealing with Variables
                else:
                    for i in range(len(SymbolTable)):
                        if SymbolTable[i][0] == Elements[1]:
                            AssemblyCode.append(s + "00 00 " +
str(SymbolTable[i][1]).rjust(2, "0"))
                            print("00 00 " +
str(SymbolTable[i][1]).rjust(2, "0"))
            # If the instruction conatins a Label
            elif len(Elements) == 3:
```

```
                for i in range(len(SymbolTable)):
                    if SymbolTable[i][0] == Elements[0]:
                        print(str(SymbolTable[i][1]).rjust(2, "0")
+ " " + AssemblyOpcodes[Elements[1]], end = " ")
                        s = str(SymbolTable[i][1]).rjust(2, "0") +
" " + AssemblyOpcodes[Elements[1]] + " "

                # Dealing with Literals
                if CheckLiteral(Elements[2]):
                    for i in range(len(LiteralTable)):
                        if LiteralTable[i][0] == Elements[2]:
                            AssemblyCode.append(s + "00 00 " +
str(LiteralTable[i][1]).rjust(2, "0"))
                            print("00 00 " +
str(LiteralTable[i][1]).rjust(2, "0"))
                # Dealing with Lables (BRP, BRZ, BRN)
                elif Elements[1] in ["BRP", "BRN", "BRZ"]:
                    for i in range(len(SymbolTable)):
                        if SymbolTable[i][0] == Elements[2]:
                            AssemblyCode.append(s +
str(SymbolTable[i][1]).rjust(2, "0") + " 00 00")
                            print(str(SymbolTable[i][1]).rjust(2, "0")
+ " 00 00")
                # Dealing with Registers
                elif Elements[2][ : 3] == "REG":
                    AssemblyCode.append(s + "00 " + Elements[2][-
1].rjust(2, "0") + " 00")
                    print("00 " + Elements[2][-1].rjust(2, "0") + "
00")
                # Dealing with Variables
                else:
                    for i in range(len(SymbolTable)):
                        if SymbolTable[i][0] == Elements[2]:
                            AssemblyCode.append(s + "00 00 " +
str(SymbolTable[i][1]).rjust(2, "0"))
```

```
                            print("00 00 " +
str(SymbolTable[i][1]).rjust(2, "0"))

file.close()

file = open("MachineCode.txt", "x")

file.write("------------\nMACHINE CODE\n------------\n\n")

for x in AssemblyCode:
    file.write(x + "\n")

file.close()
```

```
Assesmbly Code Input.txt:
START
// Comment Number One
// Comment Number Two
LoopOne        CLA       X
               LAC       A
               ADD       ='1'
               SUB       ='35'
Loop           BRP       Subtraction          // Comment Number Three
Subtraction    SUB       ='5'
               ADD       B                    // Comment Number Four
               MUL        C
               SUB       D
               MUL       ='600'
               BRZ       Zero1              // Comment Number Five
Division       DIV       E
               CLA
               LAC       REG1
               BRP       Positive
Zero           SAC       X
               DSP       X
```

	<pre> STP
	Positive CLA
	         DSP REG1
	         DSP REG2
	       A DATA 250
	       B DATA 125
	       C DATA 90
	       D DATA 88
	       E DATA 5
	       X DATA 0
	         END</pre>

Output	<pre>PS C:\Users\shabb\OneDrive\Desktop\Hatim\SPCC-Practicals>
	Exp8\exp8.py"
	>>> Opcode Table <<<
	
	ASSEMBLY OPCODE OPCODE
	-------------------------- 	
	CLA 0000
	LAC 0001
	SAC 0010
	ADD 0011
	SUB 0100
	BRZ 0101
	BRN 0110
	BRP 0111
	INP 1000
	DSP 1001
	MUL 1010
	DIV 1011
	STP 1100
	--------------------------</pre> 	

```
>>> Literal Table <<<

LITERAL      ADDRESS
-------------------
='1'         28
='35'        29
='5'         30
='600'       31
-------------------

>>> Data Table <<<

VARIABLES     VALUE
-------------------
A             250
B             125
C             90
D             88
E             5
X             0
-------------------
>>> MACHINE CODE <<<

01 0000 00 00 27
00 0001 00 00 22
00 0011 00 00 28
00 0100 00 00 29
05 0111 06 00 00
06 0100 00 00 30
00 0011 00 00 23
00 1010 00 00 24
00 0100 00 00 25
00 1010 00 00 31
00 0101 12 1011 00 00 26
00 0000 00 00 00
00 0001 00 01 00
00 0111 19 00 00
16 0010 00 00 27
00 1001 00 00 27
00 1100 00 00 00
19 0000 00 00 00
00 1001 00 01 00
00 1001 00 02 00
PS C:\Users\shabb\OneDrive\Desktop\Hatim\SPCC-Practicals>
```

Conclusion	In conclusion, the experiment demonstrated the effectiveness of a two-pass assembler in efficiently constructing symbol tables, resolving forward references, and generating machine code. The approach facilitated early error detection, contributing to improved code reliability and debugging. While supporting macro expansion and enabling reusable code fragments, the two-pass method may have limitations in terms of increased memory usage and processing time, particularly for complex programs. Nonetheless, its benefits in symbol resolution and error detection make it a valuable tool for assembly language programming tasks, offering insights into optimizing software development processes.
References	[1] GeeksforGeeks: Single Pass and Two Pass Compilers https://www.geeksforgeeks.org/single-pass-two-pass-and-multi-pass-compilers/ [2] ChatGPT (April 22, 2024) Code Generation https://chat.openai.com/c/cc26cb94-bc49-4b94-9324-afcfb22f1742