PROGRAMMING LANGUAGES PROJECT

RPAL Interpreter

Group 126

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Contents

1 Project Overview

The project was to create an RPAL interpreter from scratch. Our project involves scanning, parsing, and the running of the CSE machine. In the upcoming pages, we will describe how each module of our interpreter works, including the important functions and inputs and outputs of each module.

1.1 Overall Architecture

The python package consists of 4 folders: lexical_analyser, parser, symbols and engine.

The lexical_analyser folder contains all the logic for the lexical analyser, parser for the parser and engine for the CSE Machine. The symbols folder consists of various classes created for each symbol that could be added to the Control Stack or Data Stack.

1.2 Lexical Analyser

The lexical analyzer takes as an input the name of the file containing the RPAL expression and it outputs a list of tokens.

1.2.1 TokenType.py

All this contains is an enum called TokenType. It specifies the various types of tokens that could be found when scanning an RPAL expression.

1.2.2 Token.py

This is simply a file implementing a Token class which has a simple constructor and a function to return the string representation of a token.

1.2.3 LexicalAnalyser.py

This file contains all the scanning logic. The logic is implemented in a class called LexicalAnaylser. It was a constructor and two important functions: scan() and tokenizeLine(line). The scan() function simply calls tokenizeLine(line) on each line of the input file, and the tokenizeLine function has all the tokenizing logic.

scan() function:

```python
def scan(self):
    try:
        p = Path(__file__).parent.parent.parent / self.inputFileName
        input_file = open(p, 'r')
        count = 0
        while True:
            count += 1
            line = input_file.readline()

            if not line:
                break

```

```
13              self.tokenizeLine(line)

14

15          input_file.close()

16

17      except IOError:

18          print("Could not read file {}".format(self.inputFileName))

19

20      filtered_tokens = [

21          token for token in self.tokens if token.type != TokenType.DELETE]

22

23      return filtered_tokens
```

tokenizeLine(line) function, which takes as input a a line and adds the tokens to a running list maintained by the LexicalAnaylser object:

```
1   def tokenizeLine(self, line):
2       digit = r"[0-9]"
3       letter = r"[a-zA-Z]"
4       operatorSymbol = r"[+\-*<>&.@/:=~|$!#%^_\[\]{}\"`?]"
5       punction = r"[();,]"
6
7       identifierPattern = re.compile(
8           letter+r"("+letter+r"|"+digit+r"|"+r"_)*")
9       integerPattern = re.compile(digit+r"+")
10      operatorPattern = re.compile(operatorSymbol+r"+")
11      stringPattern = re.compile(
12          r"'(\t|\n|\\|\"|"+punction+"| |"+letter+"|"+digit+"|"+operatorSymbol+")*'")
13      commentPattern = re.compile(r"//.*")
14      spacesPattern = re.compile(r"[ \t\n]+")
15      punctuationPattern = re.compile(punction)
16
17      currentIndex = 0
18
19      while (currentIndex < len(line)):
20          currentChar = line[currentIndex]
21
22          spaceMatch = re.match(spacesPattern, line[currentIndex:])
23          commentMatch = re.match(commentPattern, line[currentIndex:])
24
25          if commentMatch:
26              comment = commentMatch.group()
27              self.tokens.append(Token(TokenType.DELETE, comment))
28              currentIndex += len(comment)
29              continue
30
31          if spaceMatch:
32              space = spaceMatch.group()
33              self.tokens.append(Token(TokenType.DELETE, space))
34              currentIndex += len(space)
35              continue
36
37          match = re.match(identifierPattern, line[currentIndex:])
38          if match:
39              identifier = match.group()
40
```

```python
            keywords = ["let", "in", "fn", "where", "aug", "or", "not", "gr", "ge", "ls",
                        "le", "eq", "ne", "true", "false", "nil", "dummy", "within", "and", "rec"]

            if identifier in keywords:
                self.tokens.append(Token(TokenType.KEYWORD, identifier))
            else:
                self.tokens.append(Token(TokenType.IDENTIFIER, identifier))

            currentIndex += len(identifier)
            continue

        match = re.match(integerPattern, line[currentIndex:])
        if match:
            integer = match.group()
            self.tokens.append(Token(TokenType.INTEGER, integer))
            currentIndex += len(integer)
            continue

        match = re.match(stringPattern, line[currentIndex:])
        if match:
            string = match.group()
            self.tokens.append(Token(TokenType.STRING, string))
            currentIndex += len(string)
            continue

        match = re.match(operatorPattern, line[currentIndex:])
        if match:
            operator = match.group()
            self.tokens.append(Token(TokenType.OPERATOR, operator))
            currentIndex += len(operator)
            continue

        match = re.fullmatch(punctuationPattern, currentChar)
        if match:
            self.tokens.append(Token(TokenType.PUNCTUATION, currentChar))
            currentIndex += 1
            continue

        print("Unable to tokenize the character: {} at index: {}".format(
            currentChar, currentIndex))
        sys.exit()
```

1.3 Parser

This folder contains all the parsing logic. It takes as input the tokens outputted by the Lexical Analyser, and outputs the Abstract Syntax Tree (AST).

1.3.1 NodeType.py

This contains an enum, listing all the possible types of nodes the AST could have.

1.3.2 Node.py

Simply contains the implementation of the Node class with a constructor and a stringifier.

1.3.3 Parser.py

This contains all the parsing logic encapsulated by a class named Parser. It has several functions. The main ones are parse(), and all of the functions responsible for parsing each production. These functions were written based on the RPAL Phrase Structure Grammar. In addition it has certain helper functions.

parse() function:

```python
def parse(self):
    # To know when we have gotten the last token
    self.tokens.append(Token(TokenType.ENDOFTOKENS, ""))
    self.E()

    if (self.tokens[0].type == TokenType.ENDOFTOKENS):
        return self.AST

    else:
        print("Parsing unsuccessful...")
        print("Remaining unparsed tokens:")
        for token in self.tokens:
            print(token)
        return None
```

Functions for each production in the RPAL Phrase Grammar Structure

```
E      -> 'let' D 'in' E                          => 'let'
       -> 'fn'  Vb+ '.' E                         => 'lambda'
       ->  Ew;
Ew     -> T  'where' Dr                           => 'where'
       -> T;
```

Figure 1: Expression Productions

```python
def E(self):
    n = 0
    token = self.tokens[0]

    if token.type == TokenType.KEYWORD and token.value in ["let", "fn"]:
        if token.value == "let":
            self.tokens.pop(0)
            self.D()

            if (self.tokens[0].value != "in"):
                print("Parse error at E : 'in' expected")
                sys.exit()

            self.tokens.pop(0)
            self.E()
            self.AST.append(Node(NodeType.let, "let", 2))

        else:
            self.tokens.pop(0)

            while True:
                self.Vb()
                n += 1

                if ((self.tokens[0].type != TokenType.IDENTIFIER) and (self.tokens[0].value != "(")):
                    break

            if not self.tokens[0].value == ".":
                print("Parse error at E : '.' expected")
                sys.exit()

            self.tokens.pop(0)
            self.E()
            self.AST.append(Node(NodeType.lambda_, "lambda", n+1))

    else:
        self.Ew()

def Ew(self):
    self.T()
    if (self.tokens[0].value == "where"):
        self.tokens.pop(0)  # remove the "where"
        self.Dr()
        self.AST.append(Node(NodeType.where, "where", 2))
```

```
T      -> Ta ( ',' Ta )+                              => 'tau'
       -> Ta ;
Ta     -> Ta 'aug' Tc                                 => 'aug'
       -> Tc ;
Tc     -> B '->' Tc '|' Tc                            => '->'
       -> B ;
```

Figure 2: Tuple Expression Productions

```python
def T(self):
    self.Ta()
    n = 1

    while (self.tokens[0].value == ","):
        self.tokens.pop(0)  # remove commas
        self.Ta()
        n += 1

    if (n > 1):
        self.AST.append(Node(NodeType.tau, "tau", n))

def Ta(self):
    self.Tc()
    while (self.tokens[0].value == "aug"):
        self.tokens.pop(0)
        self.Tc()
        self.AST.append(Node(NodeType.aug, "aug", 2))

def Tc(self):
    self.B()
    if (self.tokens[0].value == "->"):
        self.tokens.pop(0)  # Remove the '->'
        self.Tc()

        if not self.tokens[0].value == "|":
            print("Parse error at Tc: conditional '|' expected")
            sys.exit()

        self.tokens.pop(0)
        self.Tc()
        self.AST.append(Node(NodeType.conditional, "->", 3))
```

```
B    -> B 'or' Bt                            => 'or'
     -> Bt ;
Bt   -> Bt '&' Bs                            => '&'
     -> Bs ;
Bs   -> 'not' Bp                             => 'not'
     -> Bp ;
Bp   -> A ('gr' | '>' ) A                    => 'gr'
     -> A ('ge' | '>=') A                    => 'ge'
     -> A ('ls' | '<' ) A                    => 'ls'
     -> A ('le' | '<=') A                    => 'le'
     -> A 'eq' A                             => 'eq'
     -> A 'ne' A                             => 'ne'
     -> A ;
```

Figure 3: Boolean Expression Productions

```python
1   def B(self):
2       self.Bt()
3
4       while (self.tokens[0].value == "or"):
5           self.tokens.pop(0)   # Remove the 'or'
6           self.Bt()
7           self.AST.append(Node(NodeType.op_or, "or", 2))
8
9   def Bt(self):
10      self.Bs()
11
12      while (self.tokens[0].value == "&"):
13          self.tokens.pop(0)   # Remove the '&'
14          self.Bs()
15          self.AST.append(Node(NodeType.op_and, "&", 2))
16
17  def Bs(self):
18      if (self.tokens[0].value == "not"):
19          self.tokens.pop(0)
20          self.Bp()
21          self.AST.append(Node(NodeType.op_not, "not", 1))
22
23      else:
24          self.Bp()
25
26  def Bp(self):
27      self.A()
28      token = self.tokens[0]
29
30      if token.value in [">", ">=", "<", "<=", "gr", "ge", "ls", "le", "eq", "ne"]:
31          self.tokens.pop(0)
32          self.A()
33
34          match token.value:
35              case ">":
36                  self.AST.append(Node(NodeType.op_compare, "gr", 2))
37              case ">=":
38                  self.AST.append(Node(NodeType.op_compare, "ge", 2))
39              case "<":
40                  self.AST.append(Node(NodeType.op_compare, "ls", 2))
41              case ">=":
42                  self.AST.append(Node(NodeType.op_compare, "le", 2))
43              case _:
44                  self.AST.append(Node(NodeType.op_compare, token.value, 2))
```

```
A    -> A '+' At                              => '+'
     -> A '-' At                              => '-'
     ->   '+' At
     ->   '-' At              .               => 'neg'
     -> At ;
At   -> At '*' Af                             => '*'
     -> At '/' Af                             => '/'
     -> Af ;
Af   -> Ap '**' Af                            => '**'
     -> Ap ;
Ap   -> Ap '@' '<IDENTIFIER>' R               => '@'
     -> R ;
```

Figure 4: Arithmetic Expression Productions

```python
def A(self):
    if self.tokens[0].value == "+":
        self.tokens.pop(0)
        self.At()

    elif self.tokens[0].value == "-":
        self.tokens.pop(0)
        self.At()
        self.AST.append(Node(NodeType.op_neg, "neg", 1))

    else:
        self.At()

    while self.tokens[0].value in ["+", "-"]:
        currTok = self.tokens[0]
        self.tokens.pop(0)  # Remove the + or - symbols
        self.At()
        if currTok.value == "+":
            self.AST.append(Node(NodeType.op_plus, "+", 2))
        else:
            self.AST.append(Node(NodeType.op_minus, "-", 2))

def At(self):
    self.Af()
    while (self.tokens[0].value in ["*", "/"]):
        currTok = self.tokens[0]
        self.tokens.pop(0)  # Remove the multiply or divide operator
        self.Af()

        if (currTok.value == "*"):
            self.AST.append(Node(NodeType.op_mul, "*", 2))

        else:
            self.AST.append(Node(NodeType.op_div, "/", 2))

def Af(self):
    self.Ap()

    if (self.tokens[0].value == "**"):
        self.tokens.pop(0)
        self.Af()
        self.AST.append(Node(NodeType.op_pow, "**", 2))


```

```python
45    def Ap(self):
46        self.R()
47
48        while self.tokens[0].value == "@":
49            self.tokens.pop(0)
50
51            if self.tokens[0].type != TokenType.IDENTIFIER:
52                print("Parsing error at Ap: IDENTIFIER expected")
53                sys.exit()
54
55            self.AST.append(Node(NodeType.identifier, self.tokens[0].value, 0))
56            self.tokens.pop(0)    # Remove IDENTIFIER
57
58            self.R()
59            self.AST.append(Node(NodeType.at, "@", 3))
```

```
R    -> R Rn                                => 'gamma'
     -> Rn ;
Rn   -> '<IDENTIFIER>'
     -> '<INTEGER>'
     -> '<STRING>'
     -> 'true'                              => 'true'
     -> 'false'                             => 'false'
     -> 'nil'                               => 'nil'
     -> '(' E ')'
     -> 'dummy'                             => 'dummy' ;
```

Figure 5: Rator and Rand Productions

```python
1    def R(self):
2        self.Rn()
3
4        while ((self.tokens[0].type in
5                [TokenType.IDENTIFIER, TokenType.INTEGER, TokenType.STRING])
6            or
7            (self.tokens[0].value in
8             ["true", "false", "dummy", "nil", "("])):
9            self.Rn()
10           self.AST.append(Node(NodeType.gamma, "gamma", 2))
11
12   def Rn(self):
13       match self.tokens[0].type:
14           case TokenType.IDENTIFIER:
15               self.AST.append(
16                   Node(NodeType.identifier, self.tokens[0].value, 0))
17               self.tokens.pop(0)
18           case TokenType.INTEGER:
19               self.AST.append(
20                   Node(NodeType.integer, self.tokens[0].value, 0))
21               self.tokens.pop(0)
22           case TokenType.STRING:
23               self.AST.append(Node(NodeType.string, self.tokens[0].value, 0))
24               self.tokens.pop(0)
25           case TokenType.KEYWORD:
26               match self.tokens[0].value:
27                   case "true":
```

11

```python
                    self.AST.append(Node(NodeType.true_value, "true", 0))
                    self.tokens.pop(0)
                case "false":
                    self.AST.append(Node(NodeType.false_value, "false", 0))
                    self.tokens.pop(0)
                case "nil":
                    self.AST.append(Node(NodeType.nil, "nil", 0))
                    self.tokens.pop(0)
                case "dummy":
                    self.AST.append(Node(NodeType.dummy, "dummy", 0))
                    self.tokens.pop(0)
                case _:
                    print("Parse error at Rn: Unexpected keyword")
                    sys.exit()

        case TokenType.PUNCTUATION:
            if self.tokens[0].value == "(":
                self.tokens.pop(0)  # Remove the opening bracket
                self.E()

                if (self.tokens[0].value != ")"):
                    print("Parsing error at Rn : Expected a matching ')'")
                    sys.exit()

                self.tokens.pop(0)  # Remove closing bracket
        case _:
            print("Parsing error at Rn: Expected an Rn, but got something else")
            sys.exit()
```

```
D    -> Da 'within' D                     => 'within'
     -> Da ;
Da   -> Dr ( 'and' Dr )+                  => 'and'
     -> Dr ;
Dr   -> 'rec' Db                          => 'rec'
     -> Db ;
Db   -> Vl '=' E                          => '='
     -> '<IDENTIFIER>' Vb+ '=' E          => 'fcn_form'
     -> '(' D ')' ;
```

Figure 6: Definition Productions

```python
def D(self):
    self.Da()
    if (self.tokens[0].value == "within"):
        self.tokens.pop(0)  # Remove 'within'
        self.D()
        self.AST.append(Node(NodeType.within, "within", 2))


def Da(self):
    self.Dr()
    n = 1

    while self.tokens[0].value == "and":
        self.tokens.pop(0)  # Remove 'and's
        self.Dr()
        n += 1
```

```python
16
17        if (n > 1):
18            self.AST.append(Node(NodeType.and_, "and", n))
19
20    def Dr(self):
21        isRec = False
22
23        if self.tokens[0].value == "rec":
24            self.tokens.pop(0)   # Remove 'rec' word
25            isRec = True
26
27        self.Db()
28
29        if isRec:
30            self.AST.append(Node(NodeType.rec, "rec", 1))
31
32    def Db(self):
33        if (self.tokens[0].type == TokenType.PUNCTUATION) and (self.tokens[0].value == "("):
34            self.tokens.pop(0)   # Remove the opening bracket
35            self.D()
36
37            if self.tokens[0].value != ")":
38                print("Parsing error at Db: Expected matching ')'")
39                sys.exit()
40
41            self.tokens.pop(0)
42
43        elif self.tokens[0].type == TokenType.IDENTIFIER:
44            # Hoping to get fcn_form
45            if (self.tokens[1].value == "(") or (self.tokens[1].type == TokenType.IDENTIFIER):
46                self.AST.append(
47                    Node(NodeType.identifier, self.tokens[0].value, 0))
48
49                self.tokens.pop(0)   # Remove the ID
50
51                n = 1
52
53                while True:
54                    self.Vb()
55                    n += 1
56
57                    if (self.tokens[0].type != TokenType.IDENTIFIER and self.tokens[0].value != "("):
58                        break
59
60                if (self.tokens[0].value != "="):
61                    print("Parsing error at Db : Expected an '='")
62                    sys.exit()
63
64                self.tokens.pop(0)
65                self.E()
66
67                self.AST.append(Node(NodeType.fcn_form, "fcn_form", n+1))
68
69            elif self.tokens[1].value == "=":
70                self.AST.append(
71                    Node(NodeType.identifier, self.tokens[0].value, 0))
```

```python
72              self.tokens.pop(0)   # Remove ID
73              self.tokens.pop(0)   # Remove '='
74              self.E()
75
76              self.AST.append(Node(NodeType.equal, "=", 2))
77
78          elif self.tokens[1].value == ",":
79              self.Vl()
80              if (self.tokems[0] != "="):
81                  print("Parsing error at Db : Expected an '='")
82                  sys.exit()
83
84              self.tokens.pop(0)
85              self.E()
86
87              self.AST.append(Node(NodeType.equal, "=", 2))
```

```
Vb    -> '<IDENTIFIER>'
      -> '(' Vl ')'
      -> '(' ')'                               => '()';
Vl    -> '<IDENTIFIER>' list ','               => ','?;
```

.

Figure 7: Variable Productions

```python
1   def Vb(self):
2       if self.tokens[0].type == TokenType.PUNCTUATION and self.tokens[0].value == "(":
3           self.tokens.pop(0)   # Remove the opening bracket
4           isVl = False
5
6           if self.tokens[0].type == TokenType.IDENTIFIER:
7               self.Vl()
8               isVl = True
9
10          if self.tokens[0].value != ")":
11              print("Parse error at Vb : Unmatched '('")
12              sys.exit()
13
14          self.tokens.pop(0)
15
16          if isVl:
17              self.AST.append(
18                  Node(NodeType.identifier, self.tokens[0].value, 0))
19              self.tokens.pop(0)
20
21          else:
22              self.AST.append(Node(NodeType.empty_params, "()", 0))
23
24      elif self.tokens[0].type == TokenType.IDENTIFIER:
25          self.AST.append(Node(NodeType.identifier, self.tokens[0].value, 0))
26          self.tokens.pop(0)
27
28  def Vl(self):
```

```
29        n = 0
30
31        while True:
32            if n > 0:
33                self.tokens.pop(0)
34
35            if (self.tokens[0].type != TokenType.IDENTIFIER):
36                print("Parse error at Vl : an ID was expected")
37                sys.exit()
38
39            self.AST.append(Node(NodeType.identifier, self.tokens[0].value, 0))
40            self.tokens.pop(0)
41            n += 1
42
43            if (self.tokens[0].value != ","):
44                break
45
46        if n > 1:
47            self.AST.append(Node(NodeType.comma, ",", n))
```

Helper functions: AstToString() and addStrings(dots, node): AstToString is a function to print the AST in a human readable format to the terminal. addStrings is a function used by AstToString to show the depth of a node in the AST.

```
1   # Function with the logic to convert AST to a list of strings to show their depth
2   # Depth is found here and the addString function uses the dots given from here to add to stringAST
3   def AstToString(self):
4       dots = ""
5       stack = []
6
7       while self.AST:
8           if not stack:
9               if self.AST[-1].children == 0:
10                  self.addStrings(dots, self.AST.pop())
11
12              else:
13                  node = self.AST.pop()
14                  stack.append(node)
15
16          else:
17              if self.AST[-1].children > 0:
18                  node = self.AST.pop()
19                  stack.append(node)
20                  dots += "."
21
22              else:
23                  stack.append(self.AST.pop())
24                  dots += "."
25
26                  while (stack[-1].children == 0):
27                      self.addStrings(dots, stack.pop())
28
29                      if not stack:
30                          break
31
```

```python
32                     dots = dots[:-1]
33                     node = stack.pop()
34                     node.children -= 1
35                     stack.append(node)
36
37         self.stringAST.reverse()
38         return self.stringAST
39
40     # Function to prepend the dots to a node, and add it to stringAST list
41     def addStrings(self, dots, node):
42         match node.type:
43             case NodeType.identifier:
44                 self.stringAST.append(dots+"<ID:"+node.value+">")
45             case NodeType.integer:
46                 self.stringAST.append(dots+"<INT:"+node.value+">")
47             case NodeType.string:
48                 self.stringAST.append(dots+"<STR:"+node.value+">")
49             case NodeType.true_value, NodeType.false_value, NodeType.nil, NodeType.dummy:
50                 self.stringAST.append(dots+"<"+node.value+">")
51             case NodeType.fcn_form:
52                 self.stringAST.append(dots+"function_form")
53             case _:
54                 self.stringAST.append(dots+node.value)
```

1.4 Symbols

This is just a folder containing all the files in which classes are implemented for each symbol. This was done while implementing the CSE Machine when we realised that using classes we can easily check what symbol is on the stack using isinstance().

1.5   Engine

This folder contains the logic of the CSE Machine. It takes as input to it, the AST generated from the parser, and outputs the result of the RPAL expression. In this section, for most of the classes we have created Factory classes. This was to abstract out the task of construction to a seperate class. That way, when a factory class returns an instance of a class we want, it has already been initialised to its required state.

1.5.1   NodeAndNodeFactory.py

This contains the logic of getting a node given certain arguments, and standardizing a node.

Logic for getting a node: This was implemented using the standardization rules in the lecture slides.

```python
def getNode(*args):
    node = Node()
    node.data = args[0]
    node.depth = args[1]

    if len(args) > 2:
        node.parent = args[2]
        node.children = args[3]
        node.isStandardized = args[4]

    return node
```

Function to standardize a node:

```python
def standardize(self):
    if not self.isStandardized:
        for child in self.children:
            child.standardize()

        # In accordance with CSE Rules 6 - 11, we don't standardize "tau", "UOp", "BOp", ",", and "->" nodes

        match self.data:
            # Standardizing "let" node
            case "let":
                E = self.children[0].children[1]
                E.parent = self
                E.depth = self.depth + 1
                P = self.children[1]
                P.parent = self.children[0]
                P.depth = self.depth + 2
                self.children[0].data = "lambda"
                self.children[1] = E
                self.children[0].children[1] = P
                self.data = "gamma"

            # Standardizing "where" node
            case "where":
```

```python
                    # Here, we can simply convert the "where" node into a "let" node and standardize it as above
                    P = self.children[0]
                    self.children[0] = self.children[1]
                    self.children[1] = P

                    self.data = "let"
                    self.standardize()

            case "function_form":
                E = self.children[len(self.children)-1]
                lambda_node = NodeFactory.getNode(
                    "lambda", self.depth + 1, self, [], True)

                # We can set isStandardized of this node to True, because since
                # we start standardization from the leaf nodes, E will already
                # be standardized.

                self.children.insert(1, lambda_node)

                while self.children[2] != E:
                    V = self.children.pop(2)
                    V.depth = lambda_node.depth + 1
                    V.parent = lambda_node
                    lambda_node.children.append(V)

                    if len(self.children) > 3:
                        lambda_node = NodeFactory.getNode(
                            "lambda", lambda_node.depth + 1, lambda_node, [], True)
                        lambda_node.parent.children.append(lambda_node)

                lambda_node.children.append(E)

                # Remove E from children of the fcn_form
                self.children.pop(2)
                self.data = "="

            case "lambda":
                degree = len(self.children)

                if degree > 2:
                    E = self.children[degree-1]

                    lambda_node = NodeFactory.getNode(
                        "lambda", self.depth + 1, self, [], True)
                    self.children.insert(1, lambda_node)

                    while self.children[2] != E:
                        V = self.children.pop(2)
                        V.depth = lambda_node.depth + 1
                        V.parent = lambda_node
                        lambda_node.children.append(V)

                        if len(self.children) > 3:
                            lambda_node = NodeFactory.getNode(
                                "lambda", lambda_node.depth + 1, lambda_node, [], True)
                            lambda_node.parent.children.append(lambda_node)
```

```python
                        lambda_node.children.append(E)

                        # Remove the E from the starting lambda node
                        self.children.pop(2)

            case "within":
                X1 = self.children[0].children[0]
                E1 = self.children[0].children[1]
                X2 = self.children[1].children[0]
                E2 = self.children[1].children[1]

                gamma = NodeFactory.getNode(
                    "gamma", self.depth + 1, self, [], True)
                lambda_node = NodeFactory.getNode(
                    "lambda", self.depth + 2, gamma, [], True)

                X1.depth += 1
                X1.parent = lambda_node

                X2.depth -= 1
                X2.parent = self

                E1.parent = gamma

                E2.depth += 1
                E2.parent = lambda_node

                lambda_node.children.append(X1)
                lambda_node.children.append(E2)

                gamma.children.append(lambda_node)
                gamma.children.append(E1)

                self.children.clear()
                self.children.append(X2)
                self.children.append(gamma)

                self.data = "="

            case "@":
                E1 = self.children[0]
                N = self.children[1]
                E2 = self.children[2]

                bottom_gamma = NodeFactory.getNode(
                    "gamma", self.depth+1, self, [], True)

                E1.depth += 1
                N.depth += 1

                N.parent = bottom_gamma
                E1.parent = bottom_gamma
                E2.parent = self

                bottom_gamma.children.append(N)
```

```python
136                 bottom_gamma.children.append(E1)
137
138                 self.children.pop(0)
139                 self.children.pop(0)
140                 self.children.insert(0, bottom_gamma)
141
142                 self.data = "gamma"
143
144             case "and":
145                 Xs = []
146                 Es = []
147
148                 comma = NodeFactory.getNode(
149                     ",", self.depth + 1, self, [], True)
150                 tau = NodeFactory.getNode(
151                     "tau", self.depth + 1, self, [], True)
152
153                 for equal in self.children:
154                     # No need to change depths of E's and X's, but we do need to change their parents
155                     equal.children[0].parent = comma
156                     equal.children[1].parent = tau
157
158                     Xs.append(equal.children[0])
159                     Es.append(equal.children[1])
160
161                 comma.children = Xs
162                 tau.children = Es
163
164                 self.children.clear()
165                 self.children.extend([comma, tau])
166
167                 self.data = "="
168
169             case "rec":
170                 X = self.children[0].children[0]
171                 E = self.children[0].children[1]
172
173                 gamma = NodeFactory.getNode(
174                     "gamma", self.depth + 1, self, [], True)
175                 Ystar = NodeFactory.getNode(
176                     "<Y*>", self.depth + 2, gamma, [], True)
177                 lambda_node = NodeFactory.getNode(
178                     "lambda", self.depth + 2, gamma, [], True)
179                 X2 = NodeFactory.getNode(
180                     X.data, self.depth + 3, lambda_node, X.children, True)
181
182                 X.depth -= 1
183                 X.parent = self
184
185                 E.depth += 1
186                 E.parent = lambda_node
187
188                 lambda_node.children.extend([X2, E])
189                 gamma.children.extend([Ystar, lambda_node])
190
191                 self.children.clear()
```

```
192                    self.children.extend([X, gamma])
193
194                    self.data = "="
195
196        self.isStandardized = True
```

1.5.2 ASTAndASTFactory.py

This file contains the details of the AST. The ASTFactory has a static method getAST(data). Here, data is the AST that was outputted from the Parser. The getAST function converts this string representation of the AST into an actual abstract data structure, and returns the root node.

getAST(data) function:

```
1    @staticmethod
2    # A function that takes in the string AST, and returns the root of the AST
3    # Each node in the AST will have a parent attribute as well as a list containing all its children
4    def getAST(data):
5        root = NodeFactory.getNode(data[0], 0)
6        prevNode = root
7        depth = 0
8
9        for string in data[1:]:
10           d = 0
11
12           while string[d] == '.':
13               d += 1
14
15           currNode = NodeFactory.getNode(string[d:], d)
16
17           if depth < d:
18               prevNode.children.append(currNode)
19               currNode.parent = prevNode
20
21           else:
22               while prevNode.depth != d:
23                   prevNode = prevNode.parent
24
25               prevNode.parent.children.append(currNode)
26               currNode.parent = prevNode.parent
27
28           prevNode = currNode
29           depth = d
30
31       return AST(root)
```

1.5.3 CSEMachineAndCSEMachineFactory.py

There are two classes implemented here: CSEMachineFactory and CSEMachine. All the background work is being done by the CSEMachineFactory class. And the CSEMachine does what it's supposed to do according to the lecture notes: Modify the Control, Stack, and Environment according to the CSE machine rules.

The functions of CSEMachineFactory are :

- **getSymbol(node)**

  This functions returns an instance of the appropriate symbol (based on the node inputted to the function) out of the symbol classes in the aforementioned Symbols folder.

```python
def getSymbol(self, node):
    match node.data:
        case "not" | "neg":
            return UOp(node.data)

        case "+" | "-" | "*" | "/" | "**" | "&" | "or" | "eq" | "ne" | "ls" | "le" | "gr" | "ge" | "aug":
            return BOp(node.data)

        case "gamma":
            return Gamma()

        case "tau":
            return Tau(len(node.children))

        case "<Y*>":
            return YStar()

        case _:
            if node.data.startswith("<ID:"):
                return Id(node.data[4:len(node.data)-1])
            elif node.data.startswith("<INT:"):
                return Int(node.data[5:len(node.data)-1])
            elif node.data.startswith("<STR:"):
                return Str(node.data[6:len(node.data)-2])
            elif node.data.startswith("nil"):
                return Tup()
            # Since we're using Python, we need to capitalize the boolean or else it will cause problems
            elif node.data.startswith("true"):
                return Bool("True")
            elif node.data.startswith("false"):
                return Bool("False")
            elif node.data.startswith("<dummy>"):
                return Dummy()
            else:
                return Err(f"No symbol found for given node: {node.data}")
```

- **getB(node)**

  A 'B' is the part of the conditional operator that evaluates to a truthvalue. This function is used to create the B symbol and initializing its list of symbols with the pre-order traversal of that node.

```python
1  def getB(self, node):
2      b = B()
3      b.symbols = self.getPreOrderTraversal(node)
4
5      return b
```

- **getDelta(node)**

  This function creates a Delta symbol and initializes its list of symbols to the pre-order traversal of the delta node.

```python
1  def getDelta(self, node):
2      delta = Delta(self.j)
3      self.j += 1
4      delta.symbols = self.getPreOrderTraversal(node)
5
6      return delta
```

- **getLambda(node)**

  This creates a Lambda symbol. The lambda symbol has an attribute called delta, which is the preorder traversal of the right child of the lambda. This connection is made within this function.

```python
1  def getLambda(self, node):
2      lambda_ = Lambda(self.i)
3      self.i += 1
4      lambda_.delta = self.getDelta(node.children[1])
5
6      if node.children[0].data == ",":
7          for identifier in node.children[0].children:
8              lambda_.identifiers.append(
9                  Id(identifier.data[4:len(identifier.data)-1]))
10     else:
11         bounded_var = node.children[0]
12         lambda_.identifiers.append(
13             Id(bounded_var.data[4:len(bounded_var.data)-1]))
14
15         return lambda_
```

- **getPreOrderTraversal(node)**

```python
1  def getPreOrderTraversal(self, node):
2      symbols = []
3      if node.data == "lambda":
4          symbols.append(self.getLambda(node))
5
6      elif node.data == "->":
7          symbols.append(self.getDelta(node.children[1]))  # delta then
8          symbols.append(self.getDelta(node.children[2]))  # delta else
9          symbols.append(Beta())
```

23

```
10              symbols.append(self.getB(node.children[0]))

11

12          else:
13              symbols.append(self.getSymbol(node))
14              for child in node.children:
15                  symbols.extend(self.getPreOrderTraversal(child))

16

17          return symbols
```

- **getControl(ast)**

  Sets control to its initial state (containing only e0 and delta1) and returns control.

```
1      def getControl(self, ast):
2          control = []
3          control.append(self.e0)
4          control.append(self.getDelta(ast.root))
5
6          return control
```

- **getStack()**

  Sets stack to its initial state (containing only e0) and returns it.

```
1      def getStack(self):
2          stack = []
3          stack.append(self.e0)
4
5          return stack
```

- **getEnv()**

  Returns a list, containing only e0, other envs to be added as the CSE machine executes.

```
1      def getEnv(self):
2          return [self.e0]
```

- **getCSEMachine(ast)**

  Initializes and returns a CSE machine with it's control, stack and env set to the proper initial state.

```
1      def getCSEMachine(self, ast):
2          return CSEMachine(self.getControl(ast), self.getStack(), self.getEnv())
```

The functions of CSEMachine are :

- **execute()**

  This is the main function, and it encapsulates all the logic of the CSE machine. If this functions successfully finishes execution, you will have the control empty and the stack containing the result of the RPAL expression.

```python
1   def execute(self):
2       currEnv = self.env[0]
3       j = 1
4
5       while self.control:
6           # print("\nControl stack: ")
7           # self.printControl()
8
9           # print("\nData stack: ")
10          # self.printStack()
11
12          # Pop the control
13          currentSymbol = self.control.pop()
14
15          # CSE Rule 1
16          if isinstance(currentSymbol, Id):
17              Ob = currEnv.lookup(currentSymbol)
18              self.stack.insert(0, Ob)
19
20          # CSE Rule 2
21          elif isinstance(currentSymbol, Lambda):
22              lambda_ = currentSymbol
23              lambda_.environment = currEnv.index
24              self.stack.insert(0, lambda_)
25
26          elif isinstance(currentSymbol, Gamma):
27              # Get stack-top
28              stackTop = self.stack.pop(0)
29              # CSE Rule 4
30              if isinstance(stackTop, Lambda):
31                  lambda_ = stackTop
32                  e = E(j)
33                  j += 1
34
35                  if (len(lambda_.identifiers) == 1):
36                      e.values[lambda_.identifiers[0]] = self.stack.pop(0)
37
38                  # CSE Rule 11
39                  else:
40                      tup = self.stack.pop(0)
41
42                      i = 0
43                      for id in lambda_.identifiers:
44                          e.values[id] = tup.symbols[i]
45                          i += 1
46
47                  for env in self.env:
48                      if env.index == lambda_.environment:
```

```python
49                          e.parent = env
50
51                  currEnv = e
52                  self.control.append(currEnv)
53                  self.control.append(lambda_.delta)
54                  self.stack.insert(0, currEnv)
55                  self.env.append(currEnv)
56
57              # CSE Rule 10
58              elif isinstance(stackTop, Tup):
59                  tup = stackTop
60                  index = int(self.stack.pop(0).data)
61
62                  # "index - 1" because Python lists are zero-indexed but RPAL lists are 1-indexed
63                  tupleValue = stackTop.symbols[index-1]
64                  self.stack.insert(0, tupleValue)
65
66              # CSE Rule 12
67              elif isinstance(stackTop, YStar):
68                  lambda_ = self.stack.pop(0)
69                  eta = Eta()
70                  eta.index = lambda_.index
71                  eta.environment = lambda_.environment
72                  eta.identifier = lambda_.identifiers[0]
73                  eta.lambda_ = lambda_
74
75                  self.stack.insert(0, eta)
76
77              # CSE Rule 13
78              elif isinstance(stackTop, Eta):
79                  eta = stackTop
80                  self.control.append(Gamma())
81                  self.control.append(Gamma())
82
83                  lambda_ = eta.lambda_
84
85                  self.stack.insert(0, eta)
86                  self.stack.insert(0, lambda_)
87
88              # Built-in functions
89              else:
90                  builtInFunction = stackTop.data
91
92                  match builtInFunction:
93                      case "Print":
94                          thingToBePrinted = self.stack.pop(0)
95                          if not isinstance(thingToBePrinted, Tup):
96                              print(thingToBePrinted.data)
97                          else:
98                              print(self.getStringTuple(thingToBePrinted))
99
100                         self.stack.insert(0, Dummy())
101
102                     case "Stem":
103                         stringToBeStemmed: Str = copy.deepcopy(
104                             self.stack.pop(0))
```

```python
                          stringToBeStemmed.data = stringToBeStemmed.data[0]
                      self.stack.insert(0, stringToBeStemmed)

                  case "Stern":
                      stringToBeSterned: Str = copy.deepcopy(
                          self.stack.pop(0))

                      stringToBeSterned.data = stringToBeSterned.data[1:]
                      self.stack.insert(0, stringToBeSterned)

                  case "Conc":
                      # The correct way for Conc A B to happen is
                      # Contol                        Stack              Env
                      # gamma gamma Conc A B
                      # gamma gamma                   Conc A B
                      # gamma                         ConcA B
                      #                               <result of A+B>

                      # Therefore, we need to pop the second gamma from the control too
                      self.control.pop()

                      str1 = self.stack.pop(0)
                      str2 = self.stack.pop(0)

                      resultantString = copy.deepcopy(str1)

                      resultantString.data += str2.data
                      self.stack.insert(0, resultantString)

                  case "Order":
                      tup: Tup = self.stack.pop(0)

                      size = len(tup.symbols)
                      self.stack.insert(0, Int(str(size)))

                  case "Null":
                      tup: Tup = self.stack.pop(0)
                      result = True

                      if tup.symbols:
                          result = False

                      self.stack.insert(0, Bool(str(result)))

                  case "Isinteger":
                      possibleInteger = self.stack.pop(0)

                      if isinstance(possibleInteger, Int):
                          self.stack.insert(0, Bool("True"))
                      else:
                          self.stack.insert(0, Bool("False"))

                  case "Isstring":
                      possibleString = self.stack.pop(0)
```

```python
161                        if isinstance(possibleString, Str):
162                            self.stack.insert(0, Bool("True"))
163                        else:
164                            self.stack.insert(0, Bool("False"))
165
166                    case "Istuple":
167                        possibleTuple = self.stack.pop(0)
168
169                        if isinstance(possibleTuple, Tup):
170                            self.stack.insert(0, Bool("True"))
171                        else:
172                            self.stack.insert(0, Bool("False"))
173
174                    case "Isdummy":
175                        possibleDummy = self.stack.pop(0)
176
177                        if isinstance(possibleDummy, Dummy):
178                            self.stack.insert(0, Bool("True"))
179                        else:
180                            self.stack.insert(0, Bool("False"))
181
182                    case "Istruthvalue":
183                        possibleTruthvalue = self.stack.pop(0)
184
185                        if isinstance(possibleTruthvalue, Bool):
186                            self.stack.insert(0, Bool("True"))
187                        else:
188                            self.stack.insert(0, Bool("False"))
189
190                    case "Isfunction":
191                        possibleLambda = self.stack.pop(0)
192
193                        if isinstance(possibleLambda, Lambda):
194                            self.stack.insert(0, Bool("True"))
195                        else:
196                            self.stack.insert(0, Bool("False"))
197
198            # CSE Rule 5
199            elif isinstance(currentSymbol, E):
200                value = self.stack.pop(0)
201                env = self.stack.pop(0)
202
203                self.stack.insert(0, value)
204
205                self.env[currentSymbol.index].isRemoved = True
206
207                y = len(self.env)
208
209                # Traverse list of envs in reverse order to find the new current env
210                while y > 0:
211                    if not self.env[y-1].isRemoved:
212                        currEnv = self.env[y-1]
213                        break
214                    y -= 1
215
216            elif isinstance(currentSymbol, Rator):
```

```python
217                 rator = currentSymbol
218                 # CSE Rule 6
219                 if isinstance(currentSymbol, BOp):
220                     rand1 = self.stack.pop(0)
221                     rand2 = self.stack.pop(0)
222
223                     result = self.applyBOp(rator, rand1, rand2)
224
225                 # CSE Rule 7
226                 elif isinstance(currentSymbol, UOp):
227                     rand = self.stack.pop(0)
228
229                     result = self.applyUOp(rator, rand)
230
231                 self.stack.insert(0, result)
232
233             # CSE Rule 8
234             elif isinstance(currentSymbol, Beta):
235                 boolOnStack = self.stack.pop(0)
236
237                 del_else = self.control.pop()
238                 del_then = self.control.pop()
239
240                 if (eval(boolOnStack.data)):
241                     self.control.append(del_then)
242
243                 else:
244                     self.control.append(del_else)
245
246             # CSE Rule 9
247             elif isinstance(currentSymbol, Tau):
248                 tup = Tup()
249                 for _ in range(currentSymbol.n):
250                     tup.symbols.append(self.stack.pop(0))
251
252                 self.stack.insert(0, tup)
253
254             # Encountering delta (delta-then or delta-else)
255             elif isinstance(currentSymbol, Delta):
256                 self.control.extend(currentSymbol.symbols)
257
258             elif isinstance(currentSymbol, B):
259                 self.control.extend(currentSymbol.symbols)
260
261             # Int
262             else:
263                 self.stack.insert(0, currentSymbol)
```

- **applyUOp and applyBOp**

  Functions to apply unary and binary operators on their respective operands. This functions is a helper function for execute()

```python
def applyUOp(self, rator, rand):
    if rator.data == "neg":
        return Int(str(-1 * int(rand.data)))

    elif rator.data == "not":
        return Bool(str(not eval(rand.data)))

    else:
        return Err("Unknown unary operator encountered!")

def applyBOp(self, rator, rand1, rand2):
    if rator.data == "+":
        return Int(str(int(rand1.data) + int(rand2.data)))

    elif rator.data == "-":
        return Int(str(int(rand1.data) - int(rand2.data)))

    elif rator.data == "*":
        return Int(str(int(rand1.data) * int(rand2.data)))

    elif rator.data == "/":
        return Int(str(int(rand1.data) / int(rand2.data)))

    elif rator.data == "**":
        return Int(str(int(rand1.data) ** int(rand2.data)))

    elif rator.data == "&":
        return Bool(str(eval(rand1.data) and eval(rand2.data)))

    elif rator.data == "or":
        return Bool(str(eval(rand1.data) or eval(rand2.data)))

    elif rator.data == "eq":
        return Bool(str(rand1.data == rand2.data))

    elif rator.data == "ne":
        return Bool(str(rand1.data != rand2.data))

    elif rator.data == "ls":
        return Bool(str(int(rand1.data) < int(rand2.data)))

    elif rator.data == "le":
        return Bool(str(int(rand1.data) <= int(rand2.data)))

    elif rator.data == "gr":
        return Bool(str(int(rand1.data) > int(rand2.data)))

    elif rator.data == "ge":
        return Bool(str(int(rand1.data) >= int(rand2.data)))

    elif rator.data == "aug":
```

```
52          if not isinstance(rand1, Tup):
53              return Err("'aug' operator expects either tuple or nil")
54
55          if isinstance(rand2, Tup):
56              rand1.symbols.extend(rand2.symbols)
57          else:
58              rand1.symbols.append(rand2)
59
60          return rand1
61
62      else:
63          return Err("Unknown binary operator encountered!")
```

- **getStringTuple(tup)**

  This functions returns the string representation of a tuple. This is done in case the RPAL program requires a tuple to be printed, or the value of the RPAL program is a tuple.

```
1   def getStringTuple(self, tup: Tup):
2       result = "("
3
4       for symbol in tup.symbols:
5           if isinstance(symbol, Tup):
6               result += self.getStringTuple(symbol) + ", "
7
8           else:
9               # We need to do the following because in RPAL, truthvalues are in lowercase, but in Python, the first
10              # letter is capitalized.
11              data = symbol.data.lower() if isinstance(symbol, Bool) else symbol.data
12              result += data + ", "
13
14      # Remove the ', ' from the last tuple element
15      result = result[0:len(result)-2] + ")"
16      return result
```

- **getResult()**

  This function runs the execute method and returns the answer (stack-top after execution).

```
1   def getResult(self):
2       self.execute()
3       answer = self.stack.pop(0)
4
5       if (isinstance(answer, Tup)):
6           return self.getStringTuple(answer)
7
8       # We need to do the following because in RPAL, truthvalues are in lowercase, but in Python, the first
9       # letter is capitalized.
10
11      return answer.data.lower() if isinstance(answer, Bool) else answer.data
```

2 How to run

2.1 Prerequisites

1. You need to have Python3 installed on your machine.

2.2 Steps

1. Extract the contents of the zipped folder onto your machine.

2. Either copy the input file containing the RPAL expression into the folder, or enter the program into the "input_file.txt" file. The file containing the RPAL program must be directly under the PROJECT-CS3513 folder.

3. Open a terminal at that directory, and run the following command :

```
python ./myrpal.py <name of file containing RPAL expression>
```

This will run the RPAL program. If a Print is called in the RPAL program, the printed value will be displayed on the console.

4. If you want to print the AST (Abstract Syntax Tree), you need to add a '-ast' flag to the above command. Keep in mind that this will only print the AST for the program, and the program will not actually execute. The new terminal command will look like :

```
python ./myrpal.py <name of file containing RPAL expression> -ast
```