CPS2000 - Compiler Theory and Practice
Course Assignment 2017/2018

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Instructions

- This is **an individual** assignment. This assignment carries **50**% of the final **CPS2000** grade.
- It is strongly recommended that you start working on the tasks as soon as the related material is covered in class.
- The submission deadline is the **21**st **May 2018**. A soft-copy of the report and all related files (including code) must be uploaded to the VLE by 5pm of the indicated deadline. Hard copies **are not** required to be handed in. Source and executable files must be archived into a single .zip file before uploading to the VLE. It is the student's responsibility to ensure that the uploaded .zip file is valid. The PDF report must be submitted separately through the Turnitin submission system on the VLE.
- A report describing how you designed and implemented the different tasks of the assignment **is required**. Tasks (1-6) for which no such information is provided in the report will not be assessed.
- You are welcome to share ideas and suggestions. However, under no circumstances should code be shared among students. Please remember that plagiarism will not be tolerated; the final submission must be entirely your work.
- You are to allocate approximately **40** hours for this assignment.

Description

In this assignment you are to develop a lexer, parser, and interpreter for the programming language *MiniLang*. The specification of this language can be found in the next sections. The assignment is composed of four major parts: i) a FSA-based lexer and hand-crafted top-down parser, ii) visitor classes to perform semantic analysis and execution on the abstract syntax tree (AST) produced by the parser, iii) a REPL (Read-Evaluate-Print-Loop) for the language and iv) a report detailing how you designed and implemented the different tasks. All tasks are explained in detail in the Task Breakdown section.

MiniLang is an expression-based strongly-typed programming language. The language has C-style comments, that is, `//...` for line comments and `/*...*/` for block comments. The language is case-sensitive and each function is expected to return a value. MiniLang has 4 types: 'real', 'int', 'bool' and 'string'. Binary operators, such as '+', require that the operands have matching types and the language does not perform any implicit/automatic typecast.

The following is a syntactically and semantically correct MiniLang program:

```
def funcSquare(x:real) : real {
        return x*x;
}

def funcGreaterThan(x:real, y:real) : bool {
        var ans : bool = true;
        if (y > x) { set ans = false; }
        return ans;
}

var x : real = 2.4;
var y : real = funcSquare(2.5);
print y;                                          //6.25
print funcGreaterThan(x, 2.3);                    //true
print funcGreaterThan(x, funcSquare(1.555));      //false
```

MiniLang (in EBNF)

⟨*Letter*⟩ ::= [A-Za-z]

⟨*Digit*⟩ ::= [0-9]

⟨*Printable*⟩ ::= [\x20-\x7E]

⟨*Type*⟩ ::= '`real`' | '`int`' | '`bool`' | '`string`'

⟨*BooleanLiteral*⟩ ::= '`true`' | '`false`'

⟨*IntegerLiteral*⟩ ::= ⟨*Digit*⟩ { ⟨*Digit*⟩ }

⟨*RealLiteral*⟩ ::= ⟨*Digit*⟩ { ⟨*Digit*⟩ } '`.`' ⟨*Digit*⟩ { ⟨*Digit*⟩ }

⟨*StringLiteral*⟩ ::= '`"`' { ⟨*Printable*⟩ } '`"`'

⟨*Literal*⟩ ::= ⟨*BooleanLiteral*⟩
| ⟨*IntegerLiteral*⟩
| ⟨*RealLiteral*⟩
| ⟨*StringLiteral*⟩

⟨*Identifier*⟩ ::= ('`_`' | ⟨*Letter*⟩) { '`_`' | ⟨*Letter*⟩ | ⟨*Digit*⟩ }

⟨*MultiplicativeOp*⟩ ::= '`*`' | '`/`' | '`and`'

⟨*AdditiveOp*⟩ ::= '`+`' | '`-`' | '`or`'

⟨*RelationalOp*⟩ ::= '`<`' | '`>`' | '`==`' | '`!=`' | '`<=`' | '`>=`'

⟨*ActualParams*⟩ ::= ⟨*Expression*⟩ { '`,`' ⟨*Expression*⟩ }

⟨*FunctionCall*⟩ ::= ⟨*Identifier*⟩ '`(`' [⟨*ActualParams*⟩] '`)`'

⟨*SubExpression*⟩ ::= '`(`' ⟨*Expression*⟩ '`)`'

⟨*Unary*⟩ ::= ('`-`' | '`not`') ⟨*Expression*⟩

⟨*Factor*⟩ ::= ⟨*Literal*⟩
| ⟨*Identifier*⟩
| ⟨*FunctionCall*⟩
| ⟨*SubExpression*⟩
| ⟨*Unary*⟩

⟨*Term*⟩ ::= ⟨*Factor*⟩ { ⟨*MultiplicativeOp*⟩ ⟨*Factor*⟩ }

⟨*SimpleExpression*⟩ ::= ⟨*Term*⟩ { ⟨*AdditiveOp*⟩ ⟨*Term*⟩ }

⟨*Expression*⟩ ::= ⟨*SimpleExpression*⟩ { ⟨*RelationalOp*⟩ ⟨*SimpleExpression*⟩ }

⟨*Assignment*⟩ ::= '`set`' ⟨*Identifier*⟩ '`=`' ⟨*Expression*⟩

⟨*VariableDecl*⟩ ::= '`var`' ⟨*Identifier*⟩ '`:`' ⟨*Type*⟩ '`=`' ⟨*Expression*⟩

⟨*PrintStatement*⟩ ::= '`print`' ⟨*Expression*⟩

⟨*ReturnStatement*⟩ ::= '`return`' ⟨*Expression*⟩

⟨*IfStatement*⟩ ::= '`if`' '`(`' ⟨*Expression*⟩ '`)`' ⟨*Block*⟩ ['`else`' ⟨*Block*⟩]

⟨*WhileStatement*⟩ ::= '`while`' '`(`' ⟨*Expression*⟩ '`)`' ⟨*Block*⟩

⟨*FormalParam*⟩ ::= ⟨*Identifier*⟩ '`:`' ⟨*Type*⟩

⟨*FormalParams*⟩ ::= ⟨*FormalParam*⟩ { '`,`' ⟨*FormalParam*⟩ }

⟨*FunctionDecl*⟩ ::= '`def`' ⟨*Identifier*⟩ '`(`' [⟨*FormalParams*⟩] '`)`' '`:`' ⟨*Type*⟩ ⟨*Block*⟩

⟨*Statement*⟩ ::= ⟨*VariableDecl*⟩ '`;`'
| ⟨*Assignment*⟩ '`;`'
| ⟨*PrintStatement*⟩ '`;`'
| ⟨*IfStatement*⟩
| ⟨*WhileStatement*⟩
| ⟨*ReturnStatement*⟩ '`;`'
| ⟨*FunctionDecl*⟩
| ⟨*Block*⟩

⟨*Block*⟩ ::= '`{`' { ⟨*Statement*⟩ } '`}`'

⟨*Program*⟩ ::= { ⟨*Statement*⟩ }

Task Breakdown

Task 1 - A table-driven lexer in C++

In this first task you are to develop the lexer for the *MiniLang* language using the C++ programming language. The lexer is to be implemented using the table-driven approach, which encodes the DFA transition function of the *MiniLang* micro-syntax. The lexer should be able to report any lexical errors in the input program.

[Marks: 20%]

Task 2 - Hand-crafted recursive descent parser in C++

In this task you are to develop a hand-crafted predictive parser for the *MiniLang* language using the C++ programming language. The Lexer and Parser classes interact through the function *GetNextToken*() which the parser uses to get the next valid token from the lexer. The parser should be able to report any syntax errors in the input program. A successful parse of the input should produce an abstract syntax tree (AST) describing the structure of the program.

[Marks: 30%]

Task 3 - Generate XML of AST

In OOP programming, the Visitor design pattern is used to describe an operation to be performed on the elements of an object structure without changing the classes on which it operates. In our case this object structure is the AST produced by the parser in Task 2. For this task you are to implement a visitor class to output a properly indented XML representation of the generated AST.

```
var x : real = 8.1 + 2.2;

<Decl>
    <Id Type="real">x</Id>
    <BinExprNode Op="+">
        <Real>8.1</Real>
        <Real>2.2</Real>
    </BinExprNode>
</Decl>
```

[Marks: 5%]

Task 4 - Semantic Analysis Pass

For this task, you are to implement another visitor class to traverse the AST and perform type-checking (e.g. checking that variables are assigned to appropriately typed expressions, variables are not declared multiple times in the same scope, etc.). In addition to the global program scope, scopes are created whenever a block is entered and destroyed when control leaves the block.

[Marks: 10%]

Task 5 - Interpreter Execution Pass

For this task, you are to implement another visitor class to traverse the AST and execute the program. The *'print'* <Expression> statement can be used in your test programs to output the value of <Expression> to the console and determine whether the computation carried out by the interpreter visitor is correct.

[Marks: 20%]

Task 6 - The REPL

The language is designed in such a way that one statement is a valid program by itself. This fact makes it easier for the interpreter (Task 5) to run in an interactive mode. Thus a REPL (Read-Execute-Print-Loop) environment can be implemented by creating a main class called, say *MiniLangI* (MiniLang Interactive), which acts as an interactive console class. *MiniLangI* is to wrap an instance of the parser and an instance of the symbol table. Note that for any direct *MiniLangI* commands (e.g. *#load*, *#st*) a parser is not required, a simple string comparison is enough.

When *MiniLangI* is started, a prompt is presented to the user for him/her to type in statements/expressions to be executed. Once the statement is input, *MiniLangI* is required to run the parser, the type-checker and the interpreter respectively and output the result of the computation. It is convenient that the interpreter maintains a special variable (in some languages this is usually called "it" or "ans" which holds the last result computed. Below is an example of an interactive session.

```
MLi> let x : real = 8 + 2;    // Creates variable 'x' with value 10
Val ans : real = 10

MLi> 24 + 12;                 // Computes expression and stores it in ans
Val ans : int = 36

MLi> let y : bool = ans * 2;        // Error since the types do not match
Type mismatch:  real is assigned to a bool variable

MLi> #load "factorial.prog"

MLi> funcFactorial(5);
Ans : int = 120
```

[Marks: 15%]

Report

In addition to the source and class files, you are to deliver a report. Tasks 1 to 6 for which no information is provided in the report will not be assessed. In your report include any deviations from the original EBNF, the salient points on how you developed the lexer / parser / interpreter (and reasons behind any decisions you took) including semantic rules and code execution, and any sample *MiniLang* programs you developed for testing the outcome of your compiler. In your report, state what you are testing for, insert the program AST and the outcome of your test. As an example, the *MiniLang* source script below, computes the answer of a real number raised to an integer power:

```
//Function definition for Power
def funcPow( x : real, n : int ) : real
{
    var y : real = 1.0;         //Declare y and set it to 1.0
    if( n>0 )
    {
        while(n>0)
        {
            set y = y * x;          //Assignment y = y * x;
            set n = n - 1;          //Assignment n = n - 1;
        }
    }
    else
    {
        while(n<0)
        {
            set y = y / x;          //Assignment y = y / x;
            set n = n + 1;          //Assignment n = n + 1;
        }
    }
    return y;                       //return y as the result
}
```