SLANG4.NET

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The Art of Compiler Construction using C#

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CHAPTER 1

Version 0.1

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The Art of Compiler Construction using C#

Thanks to the availability of information and better tools writing a compiler has become just an excersise in software engineering. The Compilers are not difficult programs to write. The various phases of compilers are easy to understand in an independent manner. The relationship is not purely sequential. It takes some time to put phases in perspective in the job of compilation of programs.

The task of writing a compiler can be viewed in a top down fashion as follows

Parsing => Creation of Abstract Syntax Tree => Tree Traversal to generate the Object code or
Recursive interpretation.

Abstract Syntax Tree

In computer science, an abstract syntax tree (AST), or just syntax tree, is a tree representation of the abstract (simplified) syntactic structure of source code written in a certain programming language. Each node of the tree denotes a construct occurring in the source code. The syntax is abstract in the sense that it does not represent every detail that appears in the real syntax. For instance, grouping parentheses is implicit in the tree structure, and a syntactic construct such as if cond then expr may be denoted by a single node with two branches.Most of you might not be aware of the fact that , programming languages are hierarchical in nature. We can model programming language constructs as classes. Trees are a natural data structure to represent most things hierarchical.

As a case in the point , let us look a simple expression evaluator . The expression evaluator will support double precision floating point value as the operands. The Operators supported are addition (+) , subtraction (-), multiplication (*) and division. The Object model support Unary operators (+ , -) as well. We are planning to use a composition model for modeling an expression.

In most imperative programming languages , an expression is something which u evaluate for it's value. Where as statements are something which you executes for it's effect.

let us define an abstract class for Exp

```
/// <summary>
///     Abstract for Expression evaluation
/// </summary>
abstract class Exp
 {
         public abstract double Evaluate(RUNTIME_CONTEXT cont);
 }
```

For the time being RUNTIME_CONTEXT is an empty class

```
/// <summary>
  ///     One can store the stack frame inside this class
  /// </summary>
  public class RUNTIME_CONTEXT
  {
     public RUNTIME_CONTEXT()
     {

     }
  }
```

Modeling Expression

Once u have declared the interface and it's parameters , we can create a hierarchy of classes to model an expression.

```
class Exp                          // Base class for Expression
   class  NumericConstant     //  Numeric Value
   class  BinaryExp               //  Binary Expression
   class  UnaryExp                //  Unary Expression
```

Take a look at the listing of NumericConstant class

```
/// <summary>
  ///     one can store number inside the class
  /// </summary>
 public class NumericConstant : Exp
  {
     private double _value;
     /// <summary>
     ///     Construction does not do much , just keeps the
     ///     value assigned to the private variable
     /// </summary>
     /// <param name="value"></param>

     public NumericConstant(double value)
     {
        _value = value;
     }
     /// <summary>
     ///     While evaluating a numeric constant , return the _value
     /// </summary>
     /// <param name="cont"></param>
     /// <returns></returns>
```

```
    public override double Evaluate(RUNTIME_CONTEXT cont)
    {
        return _value;
    }

  }
```

Since the class is derived from Exp , it ought to implement the Evaluate method. In the Numeric Constant node , we will store a IEEE 754 double precision value. While evaluating the tree , the node will return the value stored inside the object.

Binary Expression

In a Binary Expression , one will have two Operands (Which are themselves expressions of arbitary complexity) and an Operator.

```
/// <summary>
  ///     This class supports Binary Operators like + , - , / , *
  /// </summary>
  public class BinaryExp : Exp
  {
    private Exp _ex1, _ex2;
    private OPERATOR _op;
    /// <summary>
    ///
    /// </summary>
    /// <param name="a"></param>
    /// <param name="b"></param>
    /// <param name="op"></param>

    public BinaryExp(Exp a, Exp b, OPERATOR op)
    {
        _ex1 = a;
        _ex2 = b;
        _op = op;
    }

    /// <summary>
    ///     While evaluating apply the operator after evaluating the left and right operands
    /// </summary>
    /// <param name="cont"></param>
    /// <returns></returns>
    public override double Evaluate(RUNTIME_CONTEXT cont)
    {


        switch (_op)
        {
            case OPERATOR.PLUS:
                return _ex1.Evaluate(cont) + _ex2.Evaluate(cont);
            case OPERATOR.MINUS:
                return _ex1.Evaluate(cont) - _ex2.Evaluate(cont);
```

```
            case OPERATOR.DIV:
                return _ex1.Evaluate(cont) / _ex2.Evaluate(cont);
            case OPERATOR.MUL:
                return _ex1.Evaluate(cont) * _ex2.Evaluate(cont);

        }

        return Double.NaN;

    }

}
```

Unary Expression

In an unary expression , one will have an Operand (which can be an expression of arbitary complexity) and an Operator which can be applied on the Operand.

```
/// <summary>
 ///     This class supports Unary Operators like + , - , / , *
 /// </summary>
 public class UnaryExp : Exp
 {
     private Exp _ex1;
     private OPERATOR _op;
     /// <summary>
     ///
     /// </summary>
     /// <param name="a"></param>
     /// <param name="b"></param>
     /// <param name="op"></param>

     public UnaryExp(Exp a, OPERATOR op)
     {
         _ex1 = a;
         _op = op;
     }

     /// <summary>
     ///     While evaluating apply the unary operator after evaluating the operand.
     /// </summary>
     /// <param name="cont"></param>
     /// <returns></returns>
     public override double Evaluate(RUNTIME_CONTEXT cont)
     {

         switch (_op)
         {
```

```
            case OPERATOR.PLUS:
                return _ex1.Evaluate(cont);
            case OPERATOR.MINUS:
                return -_ex1.Evaluate(cont);
        }

        return Double.NaN;

    }

}
```

In the CallSLANG project, we will include the SLANG_DOT_NET assembly before composing the expression.

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using SLANG_DOT_NET; // include SLANG_DOT_NET assembly

namespace CallSLANG
{
   class Program
   {
      static void Main(string[] args)
      {
         // Abstract Syntax Tree (AST) for 5*10
         Exp e = new BinaryExp(new NumericConstant(5),
                        new NumericConstant(10),
                        OPERATOR.MUL);

         //
         // Evaluate the Expression
         //
         //
         Console.WriteLine(e.Evaluate(null));

         // AST for  (10 + (30 + 50 ) )

         e = new UnaryExp(
                  new BinaryExp(new NumericConstant(10),
                     new BinaryExp(new NumericConstant(30),
                           new NumericConstant(50),
                        OPERATOR.PLUS),
                  OPERATOR.PLUS),
```

```
                OPERATOR.MINUS);

            //
            // Evaluate the Expression
            //
            Console.WriteLine(e.Evaluate(null));

            //
            // Pause for a key stroke
            //
            Console.Read();

        }
    }
}
```

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CHAPTER 2

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INPUT Analysis

Compilers are programs which translate source language to a target language. The Source language can be a language like C,C++ or Lisp. The potential target languages are assembly languages , object code for the microprocessors like intel x86, itanium or power pc. There are programs which translate java to C++ and Lisp to C. In such case , target language is another programming language.

Any compiler has to understand the input. Once it has analyzed the input characters , it should convert the input into a form which is suitable for further processing.

Any input has to be parsed before the object code translation. To Parse means to understand.
The Parsing process works as follows

The characters are grouped together to find a token (or a word). Some examples of the tokens are '+','*',while , for , if etc. The module which reads character at a time and looks for legal token is called a lexical analyzer or Lexer. The input from the Lexer is passed into a module which identifies whether a group of tokens form a valid expression or a statement in the program. The module which determines the validity of expressions is called a parser. Rather than doing a lexical scan for the entire input , the parser requests the next token from the lexical analyzer. They act as if they are co-routines.

To put everything together let us write a small program which acts a four function calculator
The calculator is capable of evaluating mathematical expressions which contains four basic arithmetical operators , paranthesis to group the expression and unary operators.
Given below is the Lexical Specifications of the calculator.

```
TOK_PLUS – ‘+’
TOK_MUL  - ‘*’
TOK_SUB  - ‘-’
TOK_DIV  - '/'
TOK_OPAREN – ‘(‘
TOK_CPAREN – ‘)’
TOK_DOUBLE – [0-9]+
```

The stuff can be converted into C# as follows

```
/// <summary>
///   Enumeration for Tokens
/// </summary>
 public enum TOKEN  {
      ILLEGAL_TOKEN = -1, // Not a Token
      TOK_PLUS = 1, // '+'
      TOK_MUL, // '*'
      TOK_DIV, // '/'
      TOK_SUB, // '-'
      TOK_OPAREN, // '('
      TOK_CPAREN, // ')'
      TOK_DOUBLE, // '('
      TOK_NULL // End of string
   }
```

The Lexical Analysis Algorithm scans through the input and returns the token associated with the operator. If it has found out a number , returns the token associated with the number. There should be another mechanism to retrieve the actual number identified.

Following pseudo code shows the schema of the lexical analyzer

```
while ( there is input ) {
    switch(currentchar) {
    case Operands:
        advance input pointer
         return TOK_XXXX;
   case Number:
        Extract the number( Advance the input )
        return TOK_DOUBLE;
   default:
       error
   }
}
```

The following C# code is a literal translation of the above algorithm.

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;

namespace SLANG_DOT_NET
{
   /// <summary>
   ///   Enumeration for Tokens
   /// </summary>
   public enum TOKEN
   {
      ILLEGAL_TOKEN = -1, // Not a Token
      TOK_PLUS = 1, // '+'
      TOK_MUL, // '*'
      TOK_DIV, // '/'
      TOK_SUB, // '-'
      TOK_OPAREN, // '('
      TOK_CPAREN, // ')'
      TOK_DOUBLE, // '('
      TOK_NULL // End of string
   }

   /////////////////////////////////////////////////////////
   //
   // A naive Lexical analyzer which looks for operators , Parenthesis
   // and number. All numbers are treated as IEEE doubles. Only numbers
   // without decimals can be entered. Feel free to modify the code
   // to accomodate LONG and Double values
```

```
public class Lexer
{
   String IExpr; // Expression string
   int index; // index into a character
   int length; // Length of the string
   double number; // Last grabbed number from the stream
   /////////////////////////////////////////////
   //
   // Ctor
   //
   //
   public Lexer(String Expr)
   {
      IExpr = Expr;
      length = IExpr.Length;
      index = 0;
   }
   /////////////////////////////////////////////////////
   // Grab the next token from the stream
   //
   //
   //
   //
   public TOKEN GetToken()
   {
      TOKEN tok = TOKEN.ILLEGAL_TOKEN;
      ////////////////////////////////////////////////////////////
      //
      // Skip the white space
      //
      while (index < length &&
      (IExpr[index] == ' ' || IExpr[index] == '\t'))
         index++;
      //////////////////////////////////////////////
      //
      // End of string ? return NULL;
      //
      if (index == length)
         return TOKEN.TOK_NULL;
      /////////////////////////////////////////////////
      //
      //
      //
      switch (IExpr[index])
      {
         case '+':
            tok = TOKEN.TOK_PLUS;
            index++;
            break;
         case '-':
            tok = TOKEN.TOK_SUB;
            index++;
            break;
         case '/':
            tok = TOKEN.TOK_DIV;
            index++;
            break;
         case '*':
```

```
                tok = TOKEN.TOK_MUL;
                index++;
                break;
            case '(':
                tok = TOKEN.TOK_OPAREN;
                index++;
                break;
            case ')':
                tok = TOKEN.TOK_CPAREN;
                index++;
                break;
            case '0':
            case '1':
            case '2':
            case '3':
            case '4':
            case '5':
            case '6':
            case '7':
            case '8':
            case '9':
                {
                    String str = "";
                    while (index < length &&
                    (IExpr[index] == '0' ||
                    IExpr[index] == '1' ||
                    IExpr[index] == '2' ||
                    IExpr[index] == '3' ||
                    IExpr[index] == '4' ||
                    IExpr[index] == '5' ||
                    IExpr[index] == '6' ||
                    IExpr[index] == '7' ||
                    IExpr[index] == '8' ||
                    IExpr[index] == '9'))
                    {
                        str += Convert.ToString(IExpr[index]);
                        index++;
                    }
                    number = Convert.ToDouble(str);
                    tok = TOKEN.TOK_DOUBLE;
                }
                break;
            default:
                Console.WriteLine("Error While Analyzing Tokens");
                throw new Exception();
        }
        return tok;
    }
    public double GetNumber() { return number; }
  }
}
```

The Grammar
In computer science, a formal grammar (or grammar) is a set of formation rules (grammar) that describe which strings formed from the alphabet of a formal language are syntactically valid within the language. A grammar only addresses the location and manipulation of the strings of the language. It does not describe anything else about a language, such as its semantics (i.e. what the strings mean).

A context-free grammar is a grammar in which the left-hand side of each production rule consists of only a single nonterminal symbol. This restriction is non-trivial; not all languages can be generated by context-free grammars. Those that can are called context-free languages.

The Backus Naur Form (BNF) notation is used to specify grammars for programming languages , commnd line tools , file formats to name a few . The semantics of BNF is beyond the scope of this book.

Grammar of the expression evaluator

```
<Expr>  ::=  <Term> | Term { + | - } <Expr>
<Term> ::=  <Factor> | <Factor>  {*|/} <Term>
<Factor>::=  <number> | ( <expr> ) | {+|-} <factor>
```

There are two types of tokens in any grammar specifications. They are terminal tokens (terminals) or non terminals . In the above grammar , operators and <number> are the terminals. <Expr>,<Term>,<Factor> are non terminals. Non terminals will have at least one entry on the left side.

Conversion of Expression to the psuedo code

```
//   <Expr> ::=   <Term>  { + | - }  <Expr>
Void Expr() {
        Term();

        if ( Token == TOK_PLUS ||  Token == TOK_SUB    )
        {
                // Emit instructions
               //  and perform semantic operations

               Expr();    // recurse
        }
}
```

Converstion of term to the psuedo code

```
//   <Term> ::=   <Factor>  { * | / }  <Term>
Void Term() {
        Factor();
```

```
        if ( Token == TOK_MUL ||  Token == TOK_DIV    )
        {
                // Emit instructions
               //  and perform semantic operations

               Term();    // recurse
        }
}
```

The following psuedo code demonstrates how to map <Factor> into code

```
//   <Factor> ::=  <TOK_DOUBLE> | ( <expr> ) |  { + |- }  <Factor>
//
Void Factor() {
        switch(Token)
          case TOK_DOUBLE:
          //   push token to IL operand stack return
         case TOK_OPAREN:
               Expr();    //recurse
               // check for closing parenthesis and return
          case UNARYOP:
               Factor();   //recurse
           default:
               //Error
}
```

The class RDParser is derived from the Lexer class. By using an algorithm by the name Recursive descent parsing , we will evaluate the expression.A recursive descent parser is a top-down parser built from a set of mutually-recursive procedures where each such procedure usually implements one of the production rules of the grammar. Thus the structure of the resulting program closely mirrors that of the grammar it recognizes.

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;

namespace SLANG_DOT_NET
{
    /// <summary>
    ///
    /// </summary>
    public class RDParser : Lexer
```

```
{
    TOKEN Current_Token;


    public RDParser(String str)
        : base(str)
    {


    }

    /// <summary>
    ///
    /// </summary>
    /// <returns></returns>
    public Exp CallExpr()
    {
        Current_Token = GetToken();
        return Expr();
    }

    /// <summary>
    ///
    /// </summary>
    /// <returns></returns>
    public Exp Expr()
    {
        TOKEN l_token;
        Exp RetValue = Term();
        while (Current_Token == TOKEN.TOK_PLUS || Current_Token == TOKEN.TOK_SUB)
        {
            l_token = Current_Token;
            Current_Token = GetToken();
            Exp e1 = Expr();
            RetValue = new BinaryExp(RetValue, e1,
                l_token == TOKEN.TOK_PLUS ? OPERATOR.PLUS : OPERATOR.MINUS);

        }

        return RetValue;

    }
    /// <summary>
    ///
    /// </summary>
    public Exp Term()
    {
        TOKEN l_token;
        Exp RetValue = Factor();

        while (Current_Token == TOKEN.TOK_MUL || Current_Token == TOKEN.TOK_DIV)
        {
            l_token = Current_Token;
            Current_Token = GetToken();


            Exp e1 = Term();
            RetValue = new BinaryExp(RetValue, e1,
```

```
                l_token == TOKEN.TOK_MUL ? OPERATOR.MUL : OPERATOR.DIV);

            }

            return RetValue;
        }

        /// <summary>
        ///
        /// </summary>
        public Exp Factor()
        {
            TOKEN l_token;
            Exp RetValue = null;
            if (Current_Token == TOKEN.TOK_DOUBLE)
            {

                RetValue = new NumericConstant(GetNumber());
                Current_Token = GetToken();

            }
            else if (Current_Token == TOKEN.TOK_OPAREN)
            {

                Current_Token = GetToken();

                RetValue = Expr();  // Recurse

                if (Current_Token != TOKEN.TOK_CPAREN)
                {
                    Console.WriteLine("Missing Closing Parenthesis\n");
                    throw new Exception();

                }
                Current_Token = GetToken();
            }

            else if (Current_Token == TOKEN.TOK_PLUS || Current_Token == TOKEN.TOK_SUB)
            {
                l_token = Current_Token;
                Current_Token = GetToken();
                RetValue = Factor();

                RetValue = new UnaryExp(RetValue,
                     l_token == TOKEN.TOK_PLUS ? OPERATOR.PLUS : OPERATOR.MINUS);
            }
            else
            {

                Console.WriteLine("Illegal Token");
                throw new Exception();
            }

           return RetValue;

        }
    }
}
```

Using the Builder Pattern , we will encapsulate the Parser , Lexer class activities

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;

namespace SLANG_DOT_NET
{
   /// <summary>
   ///    Base class for all the Builders
   /// </summary>
   public class AbstractBuilder
   {

   }
   /// <summary>
   ///
   /// </summary>
   public class ExpressionBuilder : AbstractBuilder
   {
      public string _expr_string;
      public ExpressionBuilder(string expr)
      {
         _expr_string = expr;


      }
      /// <summary>
      ///
      /// </summary>
      /// <returns></returns>
      public Exp GetExpression()
      {
         try
         {
            RDParser p = new RDParser(_expr_string);
            return p.CallExpr();
         }
         catch (Exception)
         {

            return null;
         }
      }



   }

}
```

In the CallSLang Project , the expression compiler is invoked as follows

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using SLANG_DOT_NET;

namespace CallSLANG
{
   class Program
   {
      static void Main(string[] args)
      {
         ExpressionBuilder b = new ExpressionBuilder("-2*(3+3)");
         Exp e = b.GetExpression();
         Console.WriteLine(e.Evaluate(null));

         Console.Read();
      }
   }
}
```

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CHAPTER 3

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STATEMENTS

The crux of the SLANG4.net can be summed up in two sentences

Expression is what you evaluate for it's value

Statement is what you execute for it's effect (on variables)

The above two maxims can be converted into a computational structure as follows

A) Expression is what you evaluate for it's value

```
 /// <summary>
///      Abstract for Expression evaluation
///      Expression is what you evaluate for it's value
/// </summary>
public abstract class Exp
 {
    public abstract double Evaluate(RUNTIME_CONTEXT cont);
 }
```

B) Statement is what you execute for it's effect (on variables or lack of it)

```
/// <summary>
///   Statement is what you Execute for it's Effect
/// </summary>
public abstract class Stmt
{
    public abstract bool Execute(RUNTIME_CONTEXT con);
}
```

Let us implement a Print statement for the SLANG4.net compiler. The basic idea is as follows you add a class to model a statement and since the class has to inherit from the Stmt (abstract class) , it ought to implement Execute Method.

```
/// <summary>
    /// Implementation of Print Statement
    /// </summary>

    public class PrintStatement : Stmt
    {
        /// <summary>
        ///   At this point of time , Print will
        ///   spit the value of an Expression on the screen.
        /// </summary>
        private Exp _ex;
        /// <summary>
```

```
    ///   Ctor just stores the expression passed as parameter
    /// </summary>
    /// <param name="ex"></param>
    public PrintStatement(Exp ex)
    {
        _ex = ex;
    }

    /// <summary>
    ///   Execute method Evaluates the expression and
    ///   spits the value to the console using
    ///   Console.Write statement.
    /// </summary>
    /// <param name="con"></param>
    /// <returns></returns>
    public override bool Execute(RUNTIME_CONTEXT con)
    {
        double a = _ex.Evaluate(con);
        Console.Write(a.ToString());
        return true;
    }
  }
```

Let us add a PrintLine statement as well. PrintLine implementation is not different from Print statement. The only difference is it emits a new line after the expression value.

```
/// <summary>
  ///  Implementation of  PrintLine Statement
  /// </summary>
  public class PrintLineStatement : Stmt
  {
    private Exp _ex;

    public PrintLineStatement(Exp ex)
    {
        _ex = ex;
    }
    /// <summary>
    ///   Here we are calling Console.WriteLine to emit
    ///   an additional new line .
    /// </summary>
    /// <param name="con"></param>
    /// <returns></returns>
    public override bool Execute(RUNTIME_CONTEXT con)
    {
        double a = _ex.Evaluate(con);
        Console.WriteLine(a.ToString());
        return true;
    }
  }
```

Once we have created to classes to implement Print and PrintLine statement , we need to modify our parser (frontend) to support the statement in the language.

We are going to add few more tokens to support the Statements in the SLANG.

```
public enum TOKEN
  {
    ILLEGAL_TOKEN = -1, // Not a Token
    TOK_PLUS = 1, // '+'
    TOK_MUL, // '*'
    TOK_DIV, // '/'
    TOK_SUB, // '-'
    TOK_OPAREN, // '('
    TOK_CPAREN, // ')'
    TOK_DOUBLE, // 'number'
    TOK_NULL, // End of string
    TOK_PRINT, // Print Statement
    TOK_PRINTLN, // PrintLine
    TOK_UNQUOTED_STRING,
    TOK_SEMI // ;
  }
```

In the Lexer.cs module , we add a new data structure to be used for Keyword lookup.

```
/// <summary>
  ///     Keyword Table Entry
  /// </summary>
  ///
  public struct ValueTable
  {
    public TOKEN tok;          // Token id
    public String Value;       // Token string
    public ValueTable(TOKEN tok, String Value)
    {
      this.tok = tok;
      this.Value = Value;

    }
  }
```

In the ctor of Lexer.cs , we will populate an array of ValueTables with Token and it's textual representation as given below.

```
_val = new ValueTable[2];

_val[0] = new ValueTable(TOKEN.TOK_PRINT, "PRINT");

_val[1] = new ValueTable(TOKEN.TOK_PRINTLN, "PRINTLINE");
```

We need to add a new entrypoint into the RDParser.cs class to support statements. The grammar for the SLANG at this point of time (to support statement) is as given below.

```
 <stmtlist> :=  { statement }+

{statement}  :=  <printstmt> | <printlinestmt>

 <printstmt> :=  print   <expr >;

<printlinestmt>:= printline <expr>;

<Expr>  ::=  <Term> | Term { + | - } <Expr>
<Term> ::=  <Factor> | <Factor>  {*|/} <Term>
 <Factor>::=  <number> | ( <expr> ) | {+|-} <factor>
```

The new entry point to the parser module is as follows...

```
/// <summary>
///   The new Parser entry point
/// </summary>
/// <returns></returns>
public ArrayList Parse()
{
   GetNext();  // Get the Next Token
   //
   // Parse all the statements
   //
   return StatementList();
}
```

The StatementList method implements the grammar given above. The BNF to source code translation is very easy and without much explanation it is given below

```
/// <summary>
      ///  The Grammar is
      ///
      ///  <stmtlist> :=  { <statement> }+
      ///
      ///  {<statement> :=  <printstmt> | <printlinestmt>
      ///  <printstmt> :=  print   <expr >;
      ///
      /// <printlinestmt>:= printline <expr>;
      ///
      /// <Expr>  ::=  <Term> | <Term> { + | - } <Expr>
      /// <Term> ::=  <Factor> | <Factor>  {*|/} <Term>
      /// <Factor>::=  <number> | ( <expr> ) | {+|-} <factor>
      ///
      ///
      /// </summary>
```

```
    /// <returns></returns>
    private ArrayList StatementList()
    {
      ArrayList arr = new ArrayList();
      while (Current_Token != TOKEN.TOK_NULL)
      {
        Stmt temp = Statement();
        if (temp != null)
        {
          arr.Add(temp);
        }
      }
      return arr;
    }
```

The method Statement queries the statement type and parses the rest of the statement.

```
/// <summary>
    ///   This Routine Queries Statement Type
    ///   to take the appropriate Branch...
    ///   Currently , only Print and PrintLine statement
    ///   are supported..
    ///   if a line does not start with Print or PrintLine ..
    ///   an exception is thrown
    /// </summary>
    /// <returns></returns>
    private Stmt Statement()
    {
      Stmt retval = null;
      switch (Current_Token)
      {
        case TOKEN.TOK_PRINT:
          retval = ParsePrintStatement();
          GetNext();
          break;
        case TOKEN.TOK_PRINTLN:
          retval = ParsePrintLNStatement();
          GetNext();
          break;
        default:
          throw new Exception("Invalid statement");
          break;
      }
      return retval;
    }
    /// <summary>
    ///   Parse the Print Staement .. The grammar is
    ///   PRINT <expr> ;
    ///   Once you are in this subroutine , we are expecting
    ///   a valid expression ( which will be compiled ) and a
    ///   semi collon to terminate the line..
    ///   Once Parse Process is successful , we create a PrintStatement
    ///   Object..
    /// </summary>
    /// <returns></returns>
    private Stmt ParsePrintStatement()
```

```
{
   GetNext();
   Exp a = Expr();

   if (Current_Token != TOKEN.TOK_SEMI)
   {
      throw new Exception("; is expected");
   }
   return new PrintStatement(a);
}
/// <summary>
///    Parse the PrintLine Staement .. The grammar is
///    PRINTLINE <expr> ;
///    Once you are in this subroutine , we are expecting
///    a valid expression ( which will be compiled ) and a
///    semi collon to terminate the line..
///    Once Parse Process is successful , we create a PrintLineStatement
///    Object..
/// </summary>
/// <returns></returns>
private Stmt ParsePrintLNStatement()
{
   GetNext();
   Exp a = Expr();

   if (Current_Token != TOKEN.TOK_SEMI)
   {
      throw new Exception("; is expected");
   }
   return new PrintLineStatement(a);
}
```

Finally in the callSlang Project , I have invoked these routines to demonstrate how everything is put together.

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Collections;
using SLANG_DOT_NET;

namespace CallSLANG
{
   class Program
   {
      static void TestFirstScript()
      {
         string a = "PRINTLINE 2*10;" + "\r\n" + "PRINTLINE 10;\r\n PRINT 2*10;\r\n";
         RDParser p = new RDParser(a);
         ArrayList arr = p.Parse();
         foreach (object obj in arr)
         {
```

```
            Stmt s = obj as Stmt;
            s.Execute(null);
        }
    }
    /// <summary>
    ///
    /// </summary>
    static void TestSecondScript()
    {
        string a = "PRINTLINE -2*10;" + "\r\n" + "PRINTLINE -10*-1;\r\n PRINT 2*10;\r\n";
        RDParser p = new RDParser(a);
        ArrayList arr = p.Parse();
        foreach (object obj in arr)
        {
            Stmt s = obj as Stmt;
            s.Execute(null);
        }
    }
    /// <summary>
    ///
    /// </summary>
    /// <param name="args"></param>
    static void Main(string[] args)
    {
       // TestFirstScript();
        TestSecondScript();
        Console.Read();
    }
  }
}
```

SLANG4.NET

htttp://slangfordotnet.codeplex.com

The Art of Compiler Construction using C#

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CHAPTER 4

Version 0.1

Types, Variables and Assignment Statement

In this step , we will support data types and variables to SLANG. Assignment statement will also be implemented in this step.

The language supports only three data types viz

NUMERIC
STRING
BOOLEAN

Let us add an Enum for data types

```
 /// <summary>
/// Type info enumerations
/// </summary>
public enum TYPE_INFO
{
   TYPE_ILLEGAL = -1, // NOT A TYPE
   TYPE_NUMERIC,     // IEEE Double precision floating point
   TYPE_BOOL,        // Boolean Data type
   TYPE_STRING,      // String data type
}
```

Every variable will have a name , type and a slot for storing it's value in the symbol table. Moreover , Functions return SYMBOL_INFO.

```
 /// <summary>
///    Symbol Table entry for variable
///    using Attributes , one can optimize the
///    storage by simulating C/C++ union.
/// </summary>
public class SYMBOL_INFO
{
   public String SymbolName;   // Symbol Name
   public TYPE_INFO Type;      // Data type
   public String str_val;      // memory to hold string
   public double dbl_val;      // memory to hold double
   public bool bol_val;      // memory to hold boolean
}
```

The next step is to modify the Exp and Stmt interface to reflect the variable support.

```
/// <summary>
///     In  this Step , we add two more methods to the Exp class
///     TypeCheck => To do Type analysis
///     get_type  => Type of this node
/// </summary>
abstract class Exp
{
   public abstract SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont);
   public abstract TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont);
   public abstract TYPE_INFO get_type();

}
```

The class RunTime context contains the Symbol Table during interpretation.

```
/// <summary>
   ///   A Context is necessary for Variable scope...will be used later
   /// </summary>
  public class RUNTIME_CONTEXT
   {
      /// <summary>
      ///    Symbol Table for this context
      /// </summary>
      private SymbolTable m_dt;


      /// <summary>
      ///    Create an instance of Symbol Table
      /// </summary>
      public RUNTIME_CONTEXT()
      {
         m_dt = new SymbolTable();

      }



      /// <summary>
      ///    Property to retrieve Table
      /// </summary>
      public SymbolTable TABLE
      {

         get
         {
            return m_dt;
         }

         set
         {
            m_dt = value;
         }
      }



   }
```

```
/// <summary>
  ///   A Context is necessary for Variable scope...will be used later
  /// </summary>
  public class COMPILATION_CONTEXT
  {
     /// <summary>
     ///    Symbol Table for this context
     /// </summary>
     private SymbolTable m_dt;

     /// <summary>
     ///    Create an instance of Symbol Table
     /// </summary>
     public COMPILATION_CONTEXT()
     {
        m_dt = new SymbolTable();
     }

     /// <summary>
     ///    Property to retrieve Table
     /// </summary>
     public SymbolTable TABLE
     {

        get
        {
           return m_dt;
        }

        set
        {
           m_dt = value;
        }
     }



  }
```

Let us write the code for BooleanConstant node. This will store TRUE or FALSE value.

```
/// <summary>
 /// <summary>
  ///    Node for Boolean Constant ( TRUE, FALSE }
  ///    Value
  /// </summary>
  public class BooleanConstant : Exp
  {
     /// <summary>
     ///     Info Field
```

```
    /// </summary>
    private SYMBOL_INFO info;
    /// <summary>
    ///    Ctor
    /// </summary>
    /// <param name="pvalue"></param>

    public BooleanConstant(bool pvalue)
    {
       info = new SYMBOL_INFO();
       info.SymbolName = null;
       info.bol_val = pvalue;
       info.Type = TYPE_INFO.TYPE_BOOL;
    }
    /// <summary>
    ///    Evaluation of boolean will given the value
    /// </summary>
    /// <param name="local"></param>
    /// <param name="global"></param>
    /// <returns></returns>
    public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
    {
       return info;
    }
    /// <summary>
    ///
    /// </summary>
    /// <param name="local"></param>
    /// <param name="global"></param>
    /// <returns></returns>
    public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
    {
       return info.Type;
    }

    /// <summary>
    ///
    /// </summary>
    /// <returns></returns>
    public override TYPE_INFO get_type()
    {
       return info.Type;
    }
 }
```

The next thing which we should support is NumericConstant. This will store a IEEE 754 double precision floating point value.

```
/// <summary>
  ///
  /// </summary>
  public class NumericConstant : Exp
  {
    /// <summary>
    ///    Info field
    /// </summary>
    private SYMBOL_INFO info;
```

```
    /// <summary>
    ///
    /// </summary>
    /// <param name="pvalue"></param>
    public NumericConstant(double pvalue)
    {
       info = new SYMBOL_INFO();
       info.SymbolName = null;
       info.dbl_val = pvalue;
       info.Type = TYPE_INFO.TYPE_NUMERIC;

    }

    /// <summary>
    ///    Evaluation of boolean will given the value
    /// </summary>
    /// <param name="local"></param>
    /// <param name="global"></param>
    /// <returns></returns>
    public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
    {
       return info;
    }


    /// <summary>
    ///
    /// </summary>
    /// <param name="local"></param>
    /// <param name="global"></param>
    /// <returns></returns>
    public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
    {
       return info.Type;
    }
    /// <summary>
    ///
    /// </summary>
    /// <returns></returns>
    public override TYPE_INFO get_type()
    {
       return info.Type;
    }


  }
```

The AST node for storing String Literal is as given below

```
/// <summary>
  ///   To Store Literal string enclosed
  ///   in Quotes
  /// </summary>
 public class StringLiteral : Exp
```

```
{
   /// <summary>
   ///  info field
   /// </summary>
   private SYMBOL_INFO info;
   /// <summary>
   ///   Ctor
   /// </summary>
   /// <param name="pvalue"></param>
   public StringLiteral(string pvalue)
   {
      info = new SYMBOL_INFO();
      info.SymbolName = null;
      info.str_val = pvalue;
      info.Type = TYPE_INFO.TYPE_STRING;
   }

   /// <summary>
   ///    Evaluation of boolean will given the value
   /// </summary>
   /// <param name="local"></param>
   /// <param name="global"></param>
   /// <returns></returns>
   public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
   {
      return info;
   }


   /// <summary>
   ///
   /// </summary>
   /// <param name="local"></param>
   /// <param name="global"></param>
   /// <returns></returns>
   public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
   {
      return info.Type;
   }
   /// <summary>
   ///
   /// </summary>
   /// <returns></returns>
   public override TYPE_INFO get_type()
   {
      return info.Type;
   }

}
```

Addding support to variable is an involved activity. The code has been extensively commented to explain the rationale.

```
/// <summary>
  ///    Node to store Variables
  ///    The data types supported are
  ///      NUMERIC
```

```
///      STRING
///      BOOLEAN
///    The node store only the variable name , the
///    associated data will be found in the
///    Symbol Table attached to the
///      COMPILATION_CONTEXT
///
/// </summary>

public class Variable : Exp
{
    private string m_name;  // Var name
    TYPE_INFO _type;        // Type
    /// <summary>
    ///     this Ctor just stores the variable name
    /// </summary>
    /// <param name="inf"></param>
    public Variable(SYMBOL_INFO inf)
    {
        m_name = inf.SymbolName;

    }
    /// <summary>
    ///     Creates a new symbol and puts into the symbol table
    ///     and stores the key ( variable name )
    /// </summary>
    /// <param name="st"></param>
    /// <param name="name"></param>
    /// <param name="_value"></param>
    public Variable(COMPILATION_CONTEXT st, String name, double _value)
    {
        SYMBOL_INFO s = new SYMBOL_INFO();
        s.SymbolName = name;
        s.Type = TYPE_INFO.TYPE_NUMERIC;
        s.dbl_val = _value;
        st.TABLE.Add(s);
        m_name = name;
    }
    /// <summary>
    ///     Creates a new symbol and puts into the symbol table
    ///     and stores the key ( variable name )
    /// </summary>
    /// <param name="st"></param>
    /// <param name="name"></param>
    /// <param name="_value"></param>
    public Variable(COMPILATION_CONTEXT st, String name, bool _value)
    {
        SYMBOL_INFO s = new SYMBOL_INFO();
        s.SymbolName = name;
        s.Type = TYPE_INFO.TYPE_BOOL;
        s.bol_val = _value;
        st.TABLE.Add(s);
        m_name = name;
    }
    /// <summary>
    ///     Creates a new symbol and puts into the symbol table
    ///     and stores the key ( variable name )
    /// </summary>
```

```
/// <param name="st"></param>
/// <param name="name"></param>
/// <param name="_value"></param>
public Variable(COMPILATION_CONTEXT st, String name, string _value)
{
   SYMBOL_INFO s = new SYMBOL_INFO();
   s.SymbolName = name;
   s.Type = TYPE_INFO.TYPE_STRING;
   s.str_val = _value;
   st.TABLE.Add(s);
   m_name = name;
}

/// <summary>
///    Retrieves the name of the Variable ( method version )
/// </summary>
/// <returns></returns>

public string GetName()
{
   return m_name;
}

/// <summary>
///   Retrieves the name of the Variable ( property version )
/// </summary>
/// <returns></returns>
public string Name
{
   get
   {
      return m_name;
   }

   set
   {
      m_name = value;
   }
}

/// <summary>
///    To Evaluate a variable , we just need to do a lookup
///    in the Symbol table ( of RUNTIME_CONTEXT )
/// </summary>
/// <param name="st"></param>
/// <param name="glb"></param>
/// <returns></returns>
public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
{

   if (cont.TABLE == null)
   {
      return null;
   }
   else
   {
      SYMBOL_INFO a = cont.TABLE.Get(m_name);
      return a;
```

```
        }

    }

    /// <summary>
    ///     Look it up in the Symbol Table and
    ///     return the type
    /// </summary>
    /// <param name="local"></param>
    /// <param name="global"></param>
    /// <returns></returns>
    public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
    {

        if (cont.TABLE == null)
        {
            return TYPE_INFO.TYPE_ILLEGAL;
        }
        else
        {
            SYMBOL_INFO a = cont.TABLE.Get(m_name);
            if (a != null)
            {
                _type = a.Type;
                return _type;

            }


            return TYPE_INFO.TYPE_ILLEGAL;

        }

    }

    /// <summary>
    ///     this should only be called after the TypeCheck method
    ///     has been invoked on AST
    /// </summary>
    /// <returns></returns>
    public override TYPE_INFO get_type()
    {
        return _type;
    }


}
```

At this point of time Expression hierarchy (without operators) looks like as follows

```
class Exp
    class BooleanConstant
    class NumericConstant
    class StringLiteral
    class Variable
```

Once we have created nodes to represents constants of the type which we are planning to support , we created a variable node. The next challenge is to add support for the operators. Till now , I had UnaryExp and BinaryExp. For clarity , I will have classes like Plus (+) , Minus (-) , Div (/) and Mul (*) for BinaryExp and will have classes UnaryPlus (+) , UnaryMinus (-) for Unary operators

The first operator to be supported is Binary +

```
/// <summary>
  ///    the node to represent Binary +
  /// </summary>

  public class BinaryPlus : Exp
  {
     /// <summary>
     ///  Plus has got a left expression (exp1 )
     ///  and a right expression...
     ///  and a Associated type information
     /// </summary>
     private Exp exp1, exp2;
     TYPE_INFO _type;
     /// <summary>
     ///
     /// </summary>
     /// <param name="e1"></param>
     /// <param name="e2"></param>
     public BinaryPlus(Exp e1, Exp e2)
     {
        exp1 = e1; exp2 = e2;
     }
     /// <summary>
     ///
     /// </summary>
     /// <param name="cont"></param>
     /// <returns></returns>

     public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
     {
        SYMBOL_INFO eval_left = exp1.Evaluate(cont);
        SYMBOL_INFO eval_right = exp2.Evaluate(cont);

        if (eval_left.Type == TYPE_INFO.TYPE_STRING &&
           eval_right.Type == TYPE_INFO.TYPE_STRING)
```

```
        {
            SYMBOL_INFO ret_val = new SYMBOL_INFO();
            ret_val.str_val = eval_left.str_val + eval_right.str_val;
            ret_val.Type = TYPE_INFO.TYPE_STRING;
            ret_val.SymbolName = "";
            return ret_val;
        }
        else if (eval_left.Type == TYPE_INFO.TYPE_NUMERIC &&
            eval_right.Type == TYPE_INFO.TYPE_NUMERIC)
        {
            SYMBOL_INFO ret_val = new SYMBOL_INFO();
            ret_val.dbl_val = eval_left.dbl_val + eval_right.dbl_val;
            ret_val.Type = TYPE_INFO.TYPE_NUMERIC;
            ret_val.SymbolName = "";
            return ret_val;

        }
        else
        {
            throw new Exception("Type mismatch");
        }

    }


    /// <summary>
    ///
    /// </summary>
    /// <param name="local"></param>
    /// <param name="global"></param>
    /// <returns></returns>
    public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
    {
        TYPE_INFO eval_left = exp1.TypeCheck(cont);
        TYPE_INFO eval_right = exp2.TypeCheck(cont);

        if (eval_left == eval_right && eval_left != TYPE_INFO.TYPE_BOOL)
        {
            _type = eval_left;
            return _type;
        }
        else
        {
            throw new Exception("Type mismatch failure");

        }
    }




    public override TYPE_INFO get_type()
    {
        return _type;
    }

}
```

Where as Evaluate routine for StringLiteral , NumericConstant , BooleanConstant and Variable just involves returning the SYMBOL_INO , in the case of Operators things are bit evolved...

```
/// <summary>
    ///
    /// </summary>
    /// <param name="cont"></param>
    /// <returns></returns>

    public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
    {
      SYMBOL_INFO eval_left = exp1.Evaluate(cont);
      SYMBOL_INFO eval_right = exp2.Evaluate(cont);

      if (eval_left.Type == TYPE_INFO.TYPE_STRING &&
        eval_right.Type == TYPE_INFO.TYPE_STRING)
      {
        SYMBOL_INFO ret_val = new SYMBOL_INFO();
        ret_val.str_val = eval_left.str_val + eval_right.str_val;
        ret_val.Type = TYPE_INFO.TYPE_STRING;
        ret_val.SymbolName = "";
        return ret_val;
      }
      else if (eval_left.Type == TYPE_INFO.TYPE_NUMERIC &&
        eval_right.Type == TYPE_INFO.TYPE_NUMERIC)
      {
        SYMBOL_INFO ret_val = new SYMBOL_INFO();
        ret_val.dbl_val = eval_left.dbl_val + eval_right.dbl_val;
        ret_val.Type = TYPE_INFO.TYPE_NUMERIC;
        ret_val.SymbolName = "";
        return ret_val;

      }
      else
      {
        throw new Exception("Type mismatch");
      }

    }
```

In the above code snippet , Left and Right expressions are evaluated and the types are queried. In our compiler , operations involving numerics and strings are successful only if all the operands are of the same type.

The routine TypeCheck is similar to Evaluate. Only difference is that TypeCheck updates the type information of the nodes in a Recursive manner. The routine get_type is only valid once you have called TypeCheck routine.

BinaryMinus is similar to BinaryPlus. The only difference is only Numerics can be subtracted.

```
/// <summary>
  ///
  /// </summary>

  class BinaryMinus : Exp
  {
     private Exp exp1, exp2;
     TYPE_INFO _type;

     public BinaryMinus(Exp e1, Exp e2)
     {
        exp1 = e1; exp2 = e2;
     }


     public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
     {
        SYMBOL_INFO eval_left = exp1.Evaluate(cont);
        SYMBOL_INFO eval_right = exp2.Evaluate(cont);

        if (eval_left.Type == TYPE_INFO.TYPE_NUMERIC &&
           eval_right.Type == TYPE_INFO.TYPE_NUMERIC)
        {
           SYMBOL_INFO ret_val = new SYMBOL_INFO();
           ret_val.dbl_val = eval_left.dbl_val - eval_right.dbl_val;
           ret_val.Type = TYPE_INFO.TYPE_NUMERIC;
           ret_val.SymbolName = "";
           return ret_val;

        }
        else
        {
           throw new Exception("Type mismatch");
        }

     }


     /// <summary>
     ///
     /// </summary>
     /// <param name="local"></param>
     /// <param name="global"></param>
     /// <returns></returns>
     public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
     {
        TYPE_INFO eval_left = exp1.TypeCheck(cont);
        TYPE_INFO eval_right = exp2.TypeCheck(cont);

        if (eval_left == eval_right && eval_left == TYPE_INFO.TYPE_NUMERIC)
        {
           _type = eval_left;
           return _type;
        }
        else
```

```
        {
            throw new Exception("Type mismatch failure");

        }
    }

    public override TYPE_INFO get_type()
    {
        return _type;
    }



}
```

Multiplication and Division operators are only valid for Numeric Types. If you have understood the implementation of BinaryPlus , the Mul and Div operators are easy to follow

```
///
  /// <summary>
  ///
  /// </summary>

  class Mul : Exp
  {
    private Exp exp1, exp2;
    TYPE_INFO _type;

    public Mul(Exp e1, Exp e2)
    {
        exp1 = e1; exp2 = e2;
    }




    public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
    {
        SYMBOL_INFO eval_left = exp1.Evaluate(cont);
        SYMBOL_INFO eval_right = exp2.Evaluate(cont);

        if (eval_left.Type == TYPE_INFO.TYPE_NUMERIC &&
            eval_right.Type == TYPE_INFO.TYPE_NUMERIC)
        {
            SYMBOL_INFO ret_val = new SYMBOL_INFO();
            ret_val.dbl_val = eval_left.dbl_val * eval_right.dbl_val;
            ret_val.Type = TYPE_INFO.TYPE_NUMERIC;
            ret_val.SymbolName = "";
            return ret_val;

        }
        else
        {
            throw new Exception("Type mismatch");
```

```
        }

    }


    /// <summary>
    ///
    /// </summary>
    /// <param name="local"></param>
    /// <param name="global"></param>
    /// <returns></returns>
    public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
    {
        TYPE_INFO eval_left = exp1.TypeCheck(cont);
        TYPE_INFO eval_right = exp2.TypeCheck(cont);

        if (eval_left == eval_right && eval_left == TYPE_INFO.TYPE_NUMERIC)
        {
            _type = eval_left;
            return _type;
        }
        else
        {
            throw new Exception("Type mismatch failure");

        }
    }

    public override TYPE_INFO get_type()
    {
        return _type;
    }




}
/// <summary>
///
/// </summary>

class Div : Exp
{
    private Exp exp1, exp2;
    TYPE_INFO _type;

    public Div(Exp e1, Exp e2)
    {
        exp1 = e1; exp2 = e2;
    }


    public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
    {
        SYMBOL_INFO eval_left = exp1.Evaluate(cont);
        SYMBOL_INFO eval_right = exp2.Evaluate(cont);

        if (eval_left.Type == TYPE_INFO.TYPE_NUMERIC &&
```

```
            eval_right.Type == TYPE_INFO.TYPE_NUMERIC)
        {
            SYMBOL_INFO ret_val = new SYMBOL_INFO();
            ret_val.dbl_val = eval_left.dbl_val / eval_right.dbl_val;
            ret_val.Type = TYPE_INFO.TYPE_NUMERIC;
            ret_val.SymbolName = "";
            return ret_val;

        }
        else
        {
            throw new Exception("Type mismatch");
        }

    }


    /// <summary>
    ///
    /// </summary>
    /// <param name="local"></param>
    /// <param name="global"></param>
    /// <returns></returns>
    public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
    {
        TYPE_INFO eval_left = exp1.TypeCheck(cont);
        TYPE_INFO eval_right = exp2.TypeCheck(cont);

        if (eval_left == eval_right && eval_left == TYPE_INFO.TYPE_NUMERIC)
        {
            _type = eval_left;
            return _type;
        }
        else
        {
            throw new Exception("Type mismatch failure");

        }
    }

    public override TYPE_INFO get_type()
    {
        return _type;
    }



  }
```

UnaryPlus and UnaryMinus is also similar to the implementation of other operators. Both these operators are only applicable for Numeric data type.

```
/// <summary>
  ///    the node to represent Unary +
  /// </summary>

  class UnaryPlus : Exp
  {
     /// <summary>
     ///  Plus has got a right expression (exp1 )
     ///  and a Associated type information
     /// </summary>
     private Exp exp1;
     TYPE_INFO _type;
     /// <summary>
     ///
     /// </summary>
     /// <param name="e1"></param>
     /// <param name="e2"></param>
     public UnaryPlus(Exp e1)
     {
        exp1 = e1;
     }
     /// <summary>
     ///
     /// </summary>
     /// <param name="cont"></param>
     /// <returns></returns>

     public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
     {
        SYMBOL_INFO eval_left = exp1.Evaluate(cont);
        if (eval_left.Type == TYPE_INFO.TYPE_NUMERIC)
        {
           SYMBOL_INFO ret_val = new SYMBOL_INFO();
           ret_val.dbl_val = eval_left.dbl_val;
           ret_val.Type = TYPE_INFO.TYPE_NUMERIC;
           ret_val.SymbolName = "";
           return ret_val;

        }
        else
        {
           throw new Exception("Type mismatch");
        }

     }


     /// <summary>
     ///
     /// </summary>
     /// <param name="local"></param>
     /// <param name="global"></param>
     /// <returns></returns>
     public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
     {
```

```
        TYPE_INFO eval_left = exp1.TypeCheck(cont);


        if (eval_left == TYPE_INFO.TYPE_NUMERIC)
        {
            _type = eval_left;
            return _type;
        }
        else
        {
            throw new Exception("Type mismatch failure");

        }
    }




    public override TYPE_INFO get_type()
    {
        return _type;
    }

}

/// <summary>
///    the node to represent Unary -
/// </summary>

class UnaryMinus : Exp
{
    /// <summary>
    ///  Plus has got a right expression (exp1 )
    ///  and a Associated type information
    /// </summary>
    private Exp exp1;
    TYPE_INFO _type;
    /// <summary>
    ///
    /// </summary>
    /// <param name="e1"></param>
    /// <param name="e2"></param>
    public UnaryMinus(Exp e1)
    {
        exp1 = e1;
    }
    /// <summary>
    ///
    /// </summary>
    /// <param name="cont"></param>
    /// <returns></returns>

    public override SYMBOL_INFO Evaluate(RUNTIME_CONTEXT cont)
    {
        SYMBOL_INFO eval_left = exp1.Evaluate(cont);
        if (eval_left.Type == TYPE_INFO.TYPE_NUMERIC)
        {
            SYMBOL_INFO ret_val = new SYMBOL_INFO();
```

```
            ret_val.dbl_val = -eval_left.dbl_val;
            ret_val.Type = TYPE_INFO.TYPE_NUMERIC;
            ret_val.SymbolName = "";
            return ret_val;

        }
        else
        {
            throw new Exception("Type mismatch");
        }

    }


    /// <summary>
    ///
    /// </summary>
    /// <param name="local"></param>
    /// <param name="global"></param>
    /// <returns></returns>
    public override TYPE_INFO TypeCheck(COMPILATION_CONTEXT cont)
    {
        TYPE_INFO eval_left = exp1.TypeCheck(cont);


        if (eval_left == TYPE_INFO.TYPE_NUMERIC)
        {
            _type = eval_left;
            return _type;
        }
        else
        {
            throw new Exception("Type mismatch failure");

        }
    }




    public override TYPE_INFO get_type()
    {
        return _type;
    }

}
```

The statement related nodes are moved to a seperate module by the name AstForStatements.

In this step , we have added support for Variable Declaration and Assignment statement.

The AST for Variable declaration is given below

```
/// <summary>
   ///    Compile the Variable Declaration statements
   /// </summary>
   public class VariableDeclStatement : Stmt
   {
      /// <summary>
      ///
      /// </summary>
      SYMBOL_INFO m_inf = null;
      Variable var = null;
      /// <summary>
      ///
      /// </summary>
      /// <param name="inf"></param>
      public VariableDeclStatement(SYMBOL_INFO inf)
      {
         m_inf = inf;

      }
      /// <summary>
      ///
      /// </summary>
      /// <param name="cont"></param>
      /// <returns></returns>
      public override SYMBOL_INFO Execute(RUNTIME_CONTEXT cont)
      {
         cont.TABLE.Add(m_inf);
         var = new Variable(m_inf);
         return null;

      }



   }
```

In the parser , before we create VariableDeclStatement node , we need to insert the variable's SYMBOL_INFO into the SymbolTable of the COMPILATION_CONTEXT. The VariableDeclStatement node just stores the variable name in the Variable AST.

While Executing the VariableDeclStatement , a Variable is created in the Symbol table of RUNTIME_CONTEXT.

Both Compilation Context (COMPILATION_CONTEXT) and Run time Context (RUNTIME_CONTEXT) just contains references to respective symbol tables.

The AST for Assignment statement is given below

```
/// <summary>
  ///   Assignment Statement
  /// </summary>
  public class AssignmentStatement : Stmt
  {
     private Variable variable;
     private Exp exp1;

     public AssignmentStatement(Variable var, Exp e)
     {
        variable = var;
        exp1 = e;

     }

     public AssignmentStatement(SYMBOL_INFO var, Exp e)
     {
        variable = new Variable(var);
        exp1 = e;

     }
     public override SYMBOL_INFO Execute(RUNTIME_CONTEXT cont)
     {
        SYMBOL_INFO val = exp1.Evaluate(cont);
        cont.TABLE.Assign(variable, val);
        return null;
     }



  }
```

At this point of time , AST for Statements is as shown below

```
class Stmt
  class VariableDeclStatement
  class AssignmentStatement
  class PrintStatement
  class PrintLineStatement
```

The class SymbolTable is just a vector of name/value pair . The source code of the SymbolTable is given below.

```
/// <summary>
  ///   Symbol Table for Parsing and Type Analysis
  /// </summary>
  public class SymbolTable
  {
     /// <summary>
```

```
    ///   private data structure
    /// </summary>
    private System.Collections.Hashtable dt = new Hashtable();
    /// <summary>
    ///   Add a symbol to Symbol Table
    /// </summary>
    /// <param name="s"></param>
    /// <returns></returns>
    public bool Add(SYMBOL_INFO s)
    {
       dt[s.SymbolName] = s;
       return true;
    }

    /// <summary>
    ///   Retrieve the Symbol
    /// </summary>
    /// <param name="name"></param>
    /// <returns></returns>
    public SYMBOL_INFO Get(string name)
    {
       return dt[name] as SYMBOL_INFO;
    }

    /// <summary>
    ///   Assign to the Symbol Table
    /// </summary>
    /// <param name="var"></param>
    /// <param name="value"></param>
    public void Assign(Variable var, SYMBOL_INFO value)
    {
       value.SymbolName = var.GetName();
       dt[var.GetName()] = value;

    }
    /// <summary>
    ///  Assign to a variable
    /// </summary>
    /// <param name="var"></param>
    /// <param name="value"></param>
    public void Assign(string var, SYMBOL_INFO value)
    {
       dt[var] = value;
    }

  }
```

The class CsyntaxErrorLog and CsemanticErrorLog (in SupportClasses.cs) is meant for error logging while the compilation process is going on.....

Let us go back to Lexical Analysis stage once again. This time we have added lot of new keywords to the language and Token set has become bit larger than the previous step.

```
public enum TOKEN
  {
    ILLEGAL_TOKEN = -1, // Not a Token
    TOK_PLUS = 1, // '+'
    TOK_MUL, // '*'
    TOK_DIV, // '/'
    TOK_SUB, // '-'
    TOK_OPAREN, // '('
    TOK_CPAREN, // ')'

    TOK_NULL, // End of string
    TOK_PRINT, // Print Statement
    TOK_PRINTLN, // PrintLine
    TOK_UNQUOTED_STRING, // Variable name , Function name etc
    TOK_SEMI , // ;

    //---------- Addition in Step 4

    TOK_VAR_NUMBER,       // NUMBER data type
    TOK_VAR_STRING,       // STRING data type
    TOK_VAR_BOOL,         // Bool data type
    TOK_NUMERIC,          // [0-9]+
    TOK_COMMENT ,         // Comment Token ( presently not used )
    TOK_BOOL_TRUE,        // Boolean TRUE
    TOK_BOOL_FALSE ,      // Boolean FALSE
    TOK_STRING,           // String Literal
    TOK_ASSIGN            // Assignment Symbol =


  }
```

We have also moved couple of routines and state variables to Lexer class .

The two notable addition are

```
    /// <summary>
    ///    Current Token and Last Grabbed Token
    /// </summary>
    protected TOKEN Current_Token;  // Current Token
    protected TOKEN Last_Token;     // Penultimate token
```

Since we have added support for string type... , we need to support string literals (or the last grabbed string) in the lexical analyzer...

```
/// <summary>
    ///       last_str := Token assoicated with
    /// </summary>

    public String last_str; // Last grabbed String
```

We need to update the keyword table with additional key words supported by the compiler

```
     ////////////////////////////////////////////////////
     // Fill the Keywords
     //
     //
     keyword = new ValueTable[7];

     keyword[0] = new ValueTable(TOKEN.TOK_BOOL_FALSE, "FALSE");
     keyword[1] = new ValueTable(TOKEN.TOK_BOOL_TRUE, "TRUE");
     keyword[2] = new ValueTable(TOKEN.TOK_VAR_STRING, "STRING");
     keyword[3] = new ValueTable(TOKEN.TOK_VAR_BOOL, "BOOLEAN");
     keyword[4] = new ValueTable(TOKEN.TOK_VAR_NUMBER, "NUMERIC");
     keyword[5] = new ValueTable(TOKEN.TOK_PRINT, "PRINT");
     keyword[6] = new ValueTable(TOKEN.TOK_PRINTLN, "PRINTLINE");
```

The Parsing of the statements starts from Parse Routine of RDParser.cs

```
    / // <summary>
    ///   The new Parser entry point
    /// </summary>
    /// <returns></returns>
    public ArrayList Parse(COMPILATION_CONTEXT ctx)
    {
       GetNext();  // Get the Next Token
       //
       // Parse all the statements
       //
       return StatementList(ctx);
    }
```

Any variable encountered during the Parse Process will be put into the symbol table associated with Compilation Context.

The Logic of the StatementList is as follows,

while there is more statements
   Parse and Add Statements to the ArrayList

The Grammar supported is given as comments

```
/// <summary>
    ///  The Grammar is
    ///
    ///  <stmtlist> :=  { <statement> }+
    ///
    ///  {<statement> :=  <printstmt> | <printlinestmt>
    ///  <printstmt> :=   print   <expr >;
    ///  <vardeclstmt> := STRING <varname>;  |
    ///                   NUMERIC <varname>; |
    ///                   BOOLEAN <varname>;
    ///
    /// <printlinestmt>:= printline <expr>;
    ///
    /// <Expr>  ::=  <Term> | <Term> { + | - } <Expr>
    /// <Term> ::=  <Factor> | <Factor>  {*|/} <Term>
    /// <Factor>::=  <number> | ( <expr> ) | {+|-} <factor>
    ///              <variable> | TRUE | FALSE
    ///
    ///
    ///
    /// </summary>
    /// <returns></returns>
    private ArrayList StatementList(COMPILATION_CONTEXT ctx)
    {
       ArrayList arr = new ArrayList();
       while (Current_Token != TOKEN.TOK_NULL)
       {
          Stmt temp = Statement(ctx);
          if (temp != null)
          {
             arr.Add(temp);
          }
       }
       return arr;
    }
```

The Statement method just queries the statement type and calls the appropriate Parse Routines

```
/// <summary>
    ///   This Routine Queries Statement Type
    ///   to take the appropriate Branch...
    ///   Currently , only Print and PrintLine statement
    ///   are supported..
    ///   if a line does not start with Print or PrintLine ..
    ///   an exception is thrown
    /// </summary>
    /// <returns></returns>
    private Stmt Statement(COMPILATION_CONTEXT ctx)
```

```
    {
      Stmt retval = null;
      switch (Current_Token)
      {
        case TOKEN.TOK_VAR_STRING:
        case TOKEN.TOK_VAR_NUMBER:
        case TOKEN.TOK_VAR_BOOL:
          retval = ParseVariableStatement(ctx);
          GetNext();
          return retval;
        case TOKEN.TOK_PRINT:
          retval = ParsePrintStatement(ctx);
          GetNext();
          break;
        case TOKEN.TOK_PRINTLN:
          retval = ParsePrintLNStatement(ctx);
          GetNext();
          break;
        case TOKEN.TOK_UNQUOTED_STRING:
          retval = ParseAssignmentStatement(ctx);
          GetNext();
          return retval;

        default:
          throw new Exception("Invalid statement");

      }
      return retval;
    }
```

The Source code of the ParseVariableDeclStatement is as given below

```
/// <summary>
    ///   Parse Variable declaration statement
    /// </summary>
    /// <param name="type"></param>

    public Stmt ParseVariableDeclStatement(COMPILATION_CONTEXT ctx)
    {

      //--- Save the Data type
      TOKEN tok = Current_Token;

      // --- Skip to the next token , the token ought
      // to be a Variable name ( UnQouted String )
      GetNext();

      if (Current_Token == TOKEN.TOK_UNQUOTED_STRING)
      {
        SYMBOL_INFO symb = new SYMBOL_INFO();
        symb.SymbolName = base.last_str;
        symb.Type = (tok == TOKEN.TOK_VAR_BOOL) ?
        TYPE_INFO.TYPE_BOOL : (tok == TOKEN.TOK_VAR_NUMBER) ?
        TYPE_INFO.TYPE_NUMERIC : TYPE_INFO.TYPE_STRING;

        //---------- Skip to Expect the SemiColon
```

```
            GetNext();



            if (Current_Token == TOKEN.TOK_SEMI)
            {
                // ----------- Add to the Symbol Table
                // for type analysis
                ctx.TABLE.Add(symb);

                // --------- return the Object of type
                // --------- VariableDeclStatement
                // This will just store the Variable name
                // to be looked up in the above table
                return new VariableDeclStatement(symb);
            }
            else
            {
                CSyntaxErrorLog.AddLine("; expected");
                CSyntaxErrorLog.AddLine(GetCurrentLine(SaveIndex()));
                throw new CParserException(-100, ", or ; expected", SaveIndex());
            }
        }
        else
        {

            CSyntaxErrorLog.AddLine("invalid variable declaration");
            CSyntaxErrorLog.AddLine(GetCurrentLine(SaveIndex()));
            throw new CParserException(-100, ", or ; expected", SaveIndex());
        }
    }
```

Assignment statement is easy to parse as the required ground work has already been done... !

```
/// <summary>
    ///    Parse the Assignment Statement
    ///    <variable> = <expr>
    /// </summary>
    /// <param name="pb"></param>
    /// <returns></returns>
    public Stmt ParseAssignmentStatement(COMPILATION_CONTEXT ctx)
    {

        //
        // Retrieve the variable and look it up in
        // the symbol table ..if not found throw exception
        //
        string variable = base.last_str;
        SYMBOL_INFO s = ctx.TABLE.Get(variable);
        if (s == null)
        {
            CSyntaxErrorLog.AddLine("Variable not found  " + last_str);
            CSyntaxErrorLog.AddLine(GetCurrentLine(SaveIndex()));
            throw new CParserException(-100, "Variable not found", SaveIndex());

        }
```

```
        //------------ The next token ought to be an assignment
        // expression....

        GetNext();

        if (Current_Token != TOKEN.TOK_ASSIGN)
        {

            CSyntaxErrorLog.AddLine("= expected");
            CSyntaxErrorLog.AddLine(GetCurrentLine(SaveIndex()));
            throw new CParserException(-100, "= expected", SaveIndex());

        }

        //-------- Skip the token to start the expression
        // parsing on the RHS
        GetNext();
        Exp exp = Expr(ctx);

        //------------ Do the type analysis ...

        if (exp.TypeCheck(ctx) != s.Type)
        {
            throw new Exception("Type mismatch in assignment");

        }

        // -------------- End of statement ( ; ) is expected
        if (Current_Token != TOKEN.TOK_SEMI)
        {
            CSyntaxErrorLog.AddLine("; expected");
            CSyntaxErrorLog.AddLine(GetCurrentLine(SaveIndex()));
            throw new CParserException(-100, " ; expected", -1);

        }
        // return an instance of AssignmentStatement node..
        //   s => Symbol info associated with variable
        //   exp => to evaluated and assigned to symbol_info
        return new AssignmentStatement(s, exp);

    }
```

Parsing Expressions

The grammar for expression is given below

```
<Expr>  ::=  <Term> | <Term> { + | - } <Expr>
<Term> ::=  <Factor> | <Factor>  {*|/} <Term>
<Factor>::=  <number> | ( <expr> ) | {+|-} <factor>
             <variable> | TRUE | FALSE
```

Let us take a look at the Expression routine , ie the top most expression parsing routine at this point of time... (In future , when logical expressions and relational expressions are added , we modify the grammar)

```
/// <summary>
///    <Expr> ::= <Term> | <Term> { + | - } <Expr>
///
/// </summary>
/// <returns></returns>
public Exp Expr(COMPILATION_CONTEXT ctx)
{
   TOKEN l_token;
   Exp RetValue = Term(ctx);
   while (Current_Token == TOKEN.TOK_PLUS || Current_Token == TOKEN.TOK_SUB)
   {
      l_token = Current_Token;
      Current_Token = GetToken();
      Exp e1 = Expr(ctx);

      if (l_token == TOKEN.TOK_PLUS)
         RetValue = new BinaryPlus(RetValue, e1);
      else
         RetValue = new BinaryMinus(RetValue, e1);
   }

   return RetValue;

}
```

The Term routine handles the mul and the div operators

```
/// <summary>
/// <Term> ::= <Factor> | <Factor>  {*|/} <Term>
/// </summary>
public Exp Term(COMPILATION_CONTEXT ctx)
{
   TOKEN l_token;
   Exp RetValue = Factor(ctx);

   while (Current_Token == TOKEN.TOK_MUL || Current_Token == TOKEN.TOK_DIV)
   {
      l_token = Current_Token;
      Current_Token = GetToken();


      Exp e1 = Term(ctx);
      if (l_token == TOKEN.TOK_MUL)
         RetValue = new Mul(RetValue, e1);
      else
         RetValue = new Div(RetValue, e1);

   }

   return RetValue;
}
```

The factor routine is where we handle Variables , unary Operations , Constants etc....

```
/// <summary>
    ///    <Factor>::=  <number> | ( <expr> ) | {+|-} <factor>
    ///          <variable> | TRUE | FALSE
    /// </summary>
    public Exp Factor(COMPILATION_CONTEXT ctx)
    {
       TOKEN l_token;
       Exp RetValue = null;



       if (Current_Token == TOKEN.TOK_NUMERIC)
       {

          RetValue = new NumericConstant(GetNumber());
          Current_Token = GetToken();

       }
       else if (Current_Token == TOKEN.TOK_STRING)
       {
          RetValue = new StringLiteral(last_str);
          Current_Token = GetToken();
       }
       else if (Current_Token == TOKEN.TOK_BOOL_FALSE ||
               Current_Token == TOKEN.TOK_BOOL_TRUE)
       {
          RetValue = new BooleanConstant(
             Current_Token == TOKEN.TOK_BOOL_TRUE ? true : false);
          Current_Token = GetToken();
       }
       else if (Current_Token == TOKEN.TOK_OPAREN)
       {

          Current_Token = GetToken();

          RetValue = Expr(ctx);  // Recurse

          if (Current_Token != TOKEN.TOK_CPAREN)
          {
             Console.WriteLine("Missing Closing Parenthesis\n");
             throw new Exception();

          }
          Current_Token = GetToken();
       }

       else if (Current_Token == TOKEN.TOK_PLUS || Current_Token == TOKEN.TOK_SUB)
       {
          l_token = Current_Token;
          Current_Token = GetToken();
          RetValue = Factor(ctx);
          if (l_token == TOKEN.TOK_PLUS)
             RetValue = new UnaryPlus(RetValue);
          else
             RetValue = new UnaryMinus(RetValue);
```

```
        }
        else if (Current_Token == TOKEN.TOK_UNQUOTED_STRING)
        {
          ///
          ///  Variables
          ///
          String str = base.last_str;
          SYMBOL_INFO inf = ctx.TABLE.Get(str);

          if (inf == null)
            throw new Exception("Undefined symbol");

          GetNext();
          RetValue = new Variable(inf);
        }

       else
        {

          Console.WriteLine("Illegal Token");
          throw new Exception();
        }


        return RetValue;

      }
```

In the CallSlang Project , this is how we need to invoke the Script....

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Collections;
using System.IO;
using SLANG_DOT_NET;

namespace CallSLANG
{
  class Program
  {

    /// <summary>
    ///   Driver routine to call the program script
    /// </summary>
    static void TestFileScript(string filename)
    {

      if (filename == null)
          return;


      // -------------- Read the contents from the file
```

```
            StreamReader sr = new StreamReader(filename);
            string programs2 = sr.ReadToEnd();


            //---------------- Creates the Parser Object
            // With Program text as argument
            RDParser pars = null;
            pars = new RDParser(programs2);

            // Create a Compilation Context
            //
            //
            COMPILATION_CONTEXT ctx = new COMPILATION_CONTEXT();

            //
            // Call the top level Parsing Routine with
            // Compilation Context as the Argument
            //
            ArrayList stmts = pars.Parse(ctx);

            //
            // if we have reached here , the parse process
            // is successful... Create a Run time context and
            // Call Execute statements of each statement...
            //

            RUNTIME_CONTEXT f = new RUNTIME_CONTEXT();
            foreach(Object obj in stmts )
            {
                Stmt s = obj as Stmt;
                s.Execute(f);
            }

        }

        /// <summary>
        ///
        /// </summary>
        /// <param name="args"></param>
        static void Main(string[] args)
        {


            if (args == null ||
                 args.Length != 1)
            {
                Console.WriteLine("CallSlang <scriptname>\n");
                return;

            }
            TestFileScript(args[0]);
            //------------- Wait for the Key Press
            Console.Read();

        }
    }
}
```

First.sl (Slang script)

```
//////////////////////////////////
//
// A simple SLANG script
//
//    Sample #1
//
NUMERIC a;   // Declare a Numeric variable

a = 2*3+5* 30 + -(4*5+3);  // Assign

PRINTLINE a;  // Dump a

//----- String concatenation

PRINT "Hello " + "World";
//-------------- Write a new line

PRINTLINE "";
//-------------- string data type
STRING c;

c = "Hello ";  // assignment to string

//---------------- assignment and concatenation

C = C + "World";

PRINTLINE c;

//-------------- boolean variable

BOOLEAN d;

d= TRUE;

PRINTLINE d;

d= FALSE;

PRINTLINE d;
```

Second.sl

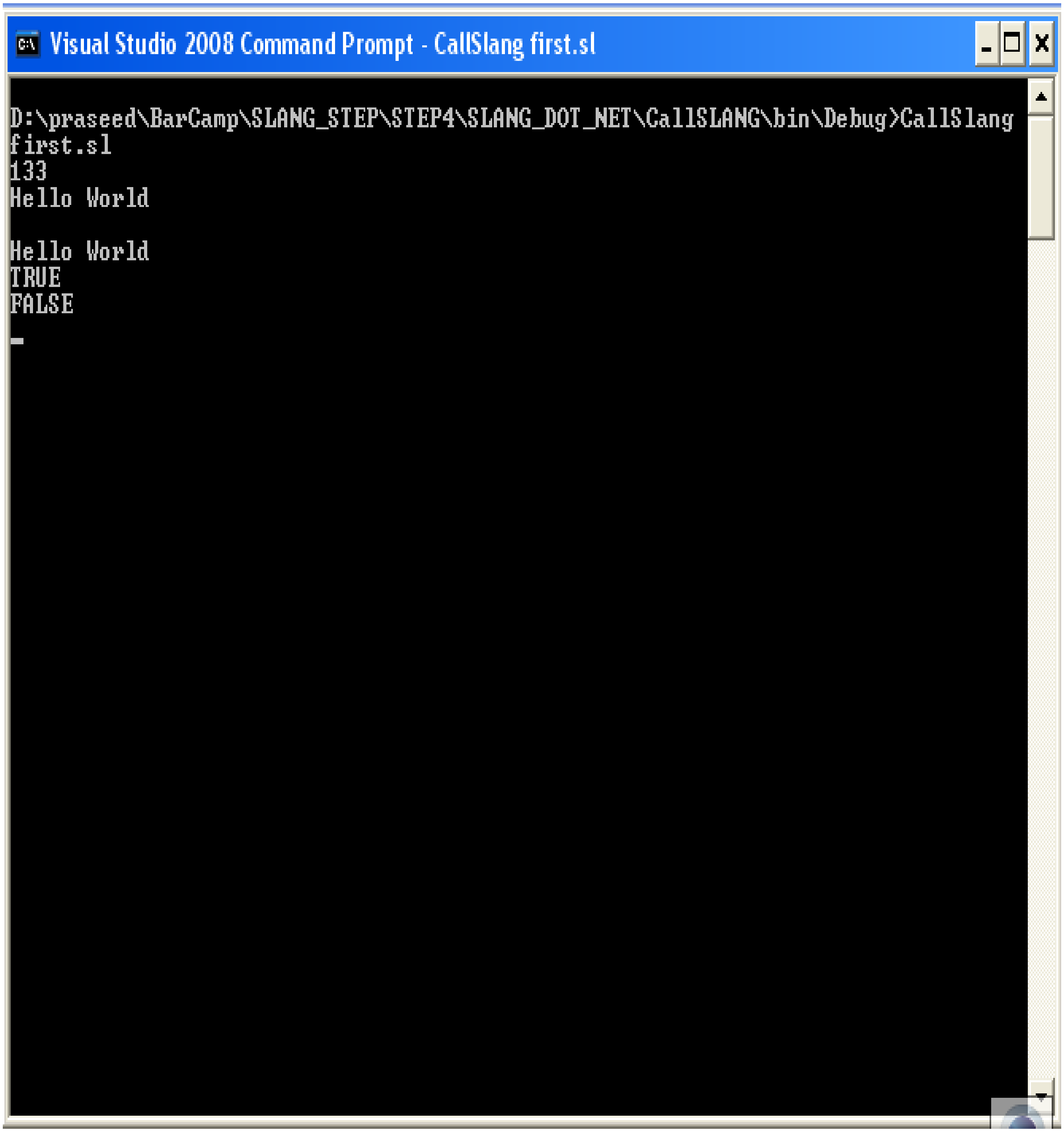
```
/////////////////////////////////////
//
// A slang script to test unary expression
//
//
//


Numeric a ;

a = -1 ;

a = -a;

Print a;
```

Third.sl

```
//////////////////////
//
//
//
//
//


Numeric a;

String b;


a = ---1;

PrintLine a*4 + 10;
```

You can go to the command line and invoke the CallSlang executable as follows....a screen snapshot is given in the next page

CallSlang first.sl
CallSlang second.sl
CallSlang third.sl


Visual Studio 2008 Command Prompt - CallSlang first.sl
D:\praseed\BarCamp\SLANG_STEP\STEP4\SLANG_DOT_NET\CallSLANG\bin\Debug>CallSlang first.sl
133
Hello World
Hello World
TRUE
FALSE