sclp: A Language Processor for a Subset of C

(version 0.1)

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About sclp

The language processor sclp has been implemented for UG courses cs302+cs316: Implementation of Programming Languages (theory and lab) at IIT Bombay. It is designed and implemented by Uday Khedker with the help of many students. Its immediate predecessor cfglp, which processed cfg output of gcc was implemented by Tanu Kanvar.

If you are new to the area of compilers, you may want to see this for an overview before proceeding further.

The main motivation behind this implementation has been to create a small well-crafted code base for a UG compiler construction class such that it can be enhanced systematically by the students. We begin with a *very* small language and enhance it using well defined increments. *Each step supports new source language features rather than a new phase in a compiler or an interpreter.* In other words, each step results in

- a complete working compiler which generates code which can be executed, and
- a complete working interpreter which executes all programs that can be written with the allowed source language features.

The complexity of understanding the complete compilation is controlled by restricting the input language instead of omitting phases or modules of the language processor. We believe that this provides a much better feel of an integrated working system than the traditional approach of enhancing the compiler phase-wise. What distinguishes sclp from cfglp is one more layer of modularity in the form of a well-chosen set of library support for different phases so that a student is not exposed to a large code base right in the beginning.

We welcome feedback and suggestions on improving sclp, as also bug reports.

Functionality of sclp

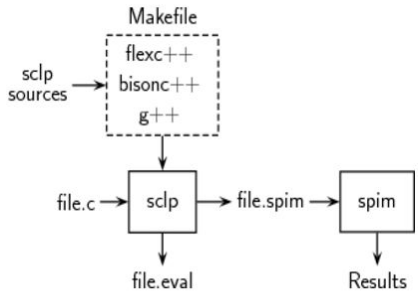
This language processor takes as input programs written in a subset of C (described below). Based on command line parameters, the read program is either interpreted or compiled to generate equivalent spim assembly language program.

The overall functionality supported by sclp is best described by the usage printed by it:

```
Usage: sclp [options] [file]
    Options:
        -help     Show this help
        -tokens   Show the tokens in file.toks (or out.toks)
        -parse    Stop processing after parsing. Do not perform semantic analysis
        -ast      Show abstract syntax trees in file.ast (or out.ast)
        -symtab   Show the symbol table of declarations in file.sym (or out.sym)
        -eval     Interpret the program and show a trace of the execution in file.eval (or out.eval)
        -compile  Compile the program and generate spim code in file.spim (or out.spim)
                  (-eval and -compile options are mutually exclusive)
                  (-compile is the default option)
        -lra      Do local register allocation to avoid redundant loads within a basic block
        -icode    Compile the program and show the intermediate code in file.ic (or out.ic)
                  (-eval and -icode options are mutually exclusive)
        -d        Demo version. Use stdout for the outputs instead of files
```

For simplicity, we have divided cfglp into two parts: Interpreter and Compiler.

A Schematic of sclp



sclp Levels

A subset of sclp code has been made available for level 1 in the form of some sclp files that need to be completed. The reference implementations in the form of binaries for subsequent levels (1, 2, and 3) will be made available for programming assignments

1. *Level 1.* (Sample files). This level consists of a (possibly empty) list of global declaration statements followed by the definition of the **`main`** procedure. No other procedure definition is allowed.
   - The lone **`main`** procedure has the following restrictions:
     - It consists of a (possibly empty) list of local declaration statements followed by a (possibly empty) list of assignment statements.
     - The declarations can introduce only integer variables (introduced by the type specifier **`int`**). No other type or data structure is allowed.
     - The list of statements does not have control flow statements or procedure calls.
   - An assignment statement has the following restrictions:
     - The right hand side must be an integer variable or an integer number.
   - All declaration statements precede any executable statements. Thus there are no assignments in declarations.
2. *Level 2.* (Sample files). This level extends level 1 in the following ways:
   - Apart from integers, single precision floating point types (introduced by the type specifier **`float`**) are supported.
   - Expressions appearing in the right hand side of an assignment or in comparisons may contain the following arithmetic operators: +, -, *, /, and unary minus. Note that the expressions do not have any side effects, i.e. pre- or post- increment or decrement operator (**`++`** or **`--`**) are not supported.
3. *Level 3.* (Sample files). This level extends level 2 by supporting intra-procedural control flow statements and evaluation of conditions in the following ways:
   - Conditional expression ***`e1?e2:e3`***, **`while`**, **`do-while`**, **`if`**, and **`if-else`** statements are allowed. Other statements such as **`for`**, **`switch`**, and **`goto`** are not supported. (You may support them for bonus marks).
   - The boolean conditions controlling the control flow consist of the six relational operators (<, <=, >, >=, ==, and !=) and three logical operators (**`&&`**, **`||`**, and **`!`**). This requires supporting relational expressions which can only take arithmetic expressions as operands to (internally) compute values true and false. Unlike C, arithmetic expressions cannot be used as boolean expressions (or operands) of boolean expressions; only relational expression can be used as boolean expressions or their operands. The above design decision has been motivated by a cleaner type system that avoids mixing values without introducing a **`bool`** type.
   - The right hand sides of assignment statements continue to remain arithmetic expressions only. Further, values of **`int`** and **`float`** type are not allowed to be mixed.
   - C++ style comments beginning with **`//`** and stretching upto the end of a line are supported.
   - Type declaration statement now may contain a comma separated list.
4. *Level 4.* (Sample files). This level extends Level 4 by supporting function calls (including recursion). In this level, we have multiple functions. Besides, the functions may take arguments and may return results. For simplicity, we assume that function calls do not appear as operands in expression; this requirement is met by first assigning the result of a function call to a source variable and then using the source variable as an operand in the expression at the required place.
5. *Level 5.* This level extends Level 4 by supporting data structures such as arrays and **`struct`**s.

Design of sclp level 1

sclp embodies object oriented design and implementation. The implementation language is C++. Bisonc++ and flexc++ have been used for parsing and scanning. Bisonc++ specifications create an object of class parser which is then invoked in the main function. The overall compilation flow is the classical sequence of

- parse and construct ASTs and symbol table (invoke the scanner when a token is needed, and typecheck during parsing), and
- evaluate (store the results in the symbol table) , or
- compile (assign offsets to variables, generate code in intermediate form by invoking optional register allocation, emit assembly instructions during compilation).

The main classes that constitute sclp are:

- program, procedure, basic block, abstract syntax trees
- symbol table (persistent as well as volatile symbol table for scope analysis)
- register and instruction descriptor
- intermediate code

Level 1 Grammar

A program consists of a **declaration_list** which is a list of (optional) global **variable_declaration_list**, and a **procedure_declaration**, followed by a **procedure_definition** (in level 1 we have a single procedure).

```
program                 :       declaration_list
                                procedure_definition
                        ;

declaration_list        :       procedure_declaration
                        |       variable_declaration_list
                                procedure_declaration
                        |       procedure_declaration
                                variable_declaration_list
                        ;
```

The associated action saves the list of global variables and checks that the names of the global variables and the procedure name are distinct. If no global variables are declared in the user program then the global variable list is **NULL**. Once the body of the procedure is processed, the procedure is added with its procedure name to a map of procedures (in level 1 we have only one procedure).

Note that there is a difference between a *procedure declaration* (**procedure_declaration** in the productions above) and a *procedure definition* (**procedure_definition** the productions below).

Our **declaration_list** indicates that the optional global variable list and the procedure prototype can exist in any order. In the **procedure_definition** the procedure does not have a return type associated with it (because it does not return a value) and does not have any parameters. The procedure body is enclosed in a pair of braces '{' and '}' and contains an **optional_variable_declaration_list** (local variables) followed by a **statement_list** (in case of level 1).

```
procedure_declaration   :       VOID NAME '(' ')' ';'
                        ;

procedure_definition    :       NAME '(' ')'
                                '{'
                                        optional_variable_declaration_list
                                        statement_list
                                '}'
                        ;
```

The action associated with this rule checks if the list of local variables have been declared in the user program, and saves the list of local variables and the basic block.

The **variable_declaration_list** is defined recursively as follows:

```
optional_variable_declaration_list      :       /* empty */
                                        |       variable_declaration_list
                                        ;

variable_declaration_list               :       variable_declaration
                                        |       variable_declaration_list
                                                variable_declaration
                                        ;

variable_declaration                    :       declaration ';'
                                        ;

declaration                             :       INTEGER NAME
                                        ;
```

Note that the same non-terminal is used for lists of global as well as local variables and the position where it occurs (inside of a procedure or outside it) tells us whether it is global or local. A declaration of a variable consists of the type name (only **INTEGER** in level 1) and the **NAME** of the variable followed by a semicolon (’**;**’). The action checks variables for possible redeclaration within the same scope. Variables thus recognized, are pushed in a symbol table.

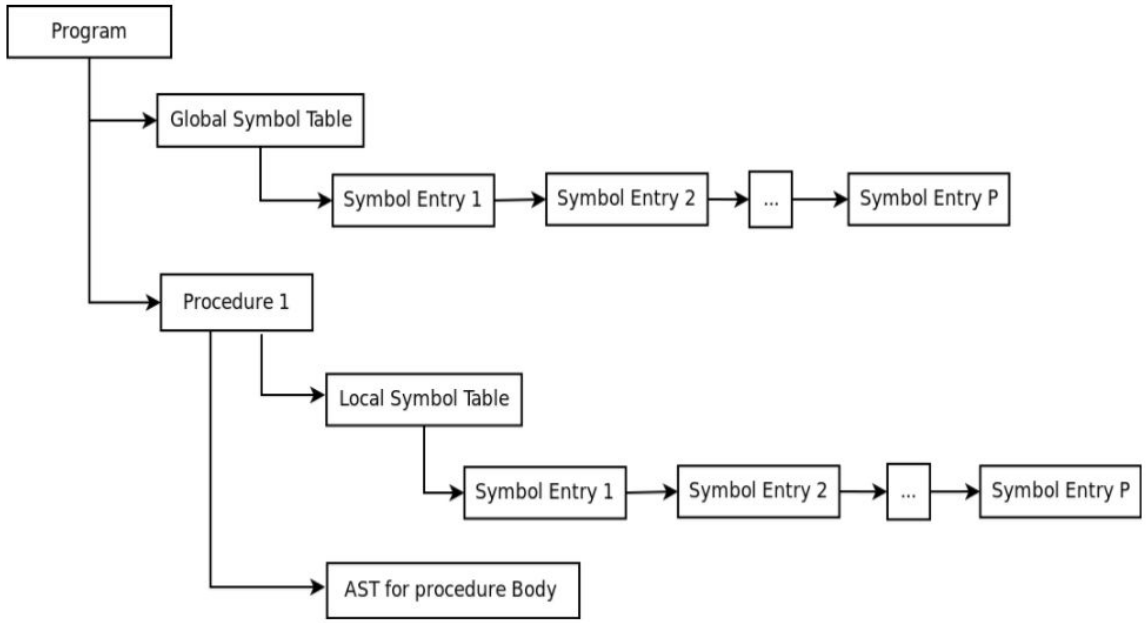
In level 1, we have only assignment statements. An assignment statement can involve only a variable or an integer number on the right hand side and only a variable on the left hand side.

```
statement_list          :       /* empty */
                        |       statement_list
                                assignment_statement
                        ;

 assignment_statement   :       variable ASSIGN variable ’;’
                        |       variable ASSIGN constant ’;’
                        ;

 variable               :       NAME
                        ;

 constant               :       INTEGER_NUMBER
                        ;
```

The associated actions check that a variable has been declared and the types of the left hand side and the right hand side are same.

Level 1 Data Structures

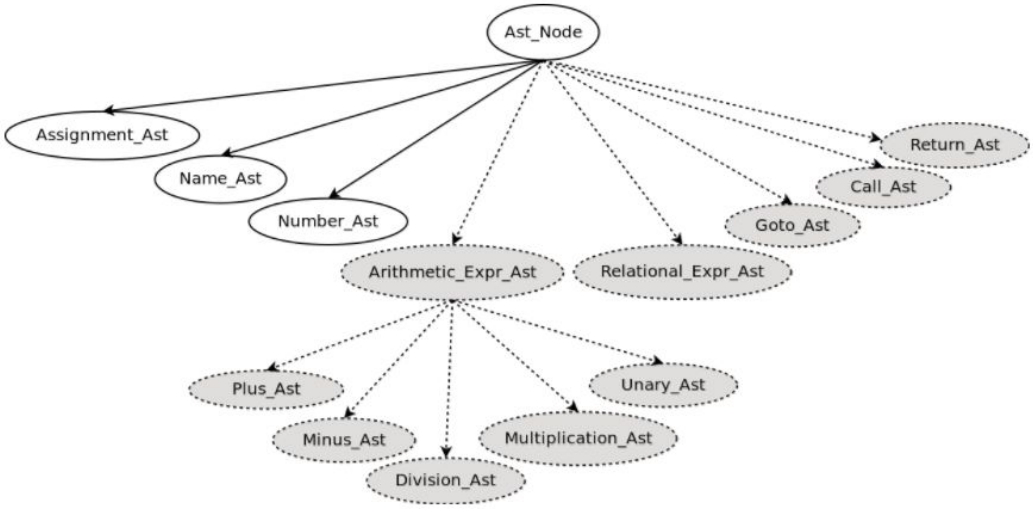
The data structure of the interpreter for Level 1 is as shown below. For simplicity, we first show the data structure restricted to a single parameterless procedure (as mandated by Level 1). Its extension for a compiler for higher levels is provided further below.



The **program** object is an instance of class **Program**. It contains:

- A **global_symbol_table** object which is an instance of class **Symbol_Table.** It is a list of **symbol_entry** objects which are instances of class **Symbol_Table_Entry**.
- A **procedure** object which is an instance of class **Procedure**. It contains
    - A **local_symbol_table** object which is an instance of class **Symbol_Table**. It is a list of **symbol_entry** objects which are instances of class **Symbol_Table_Entry**.
    - A **basic_block_list** object which is a list of pointers to instances of class **Basic_Block**.

      Each basic block contains a list of objects representing AST Statements (Abstract Syntax Tree). They are represented by an abstract class **Ast** as shown below. The following classes are derived from **Ast** in Level 1: **Name_Ast**, **Number_Ast**, **Assignment_Ast**, and **Return_Ast**.



The Ast classes described in gray colour are to be included in the subsequent levels.

Level 1 Interpretation

During interpretation, the local and global variables are copied into a separate data structure called the **`eval_env`** which is an instance of class **`Local_Environment`** which stores the variable names and their information for each procedure call (including recursive function calls). Note that this data structure is not necessary in level 1 because the values could be stored in the symbol table but this design has been chosen keeping in mind the enhancements in the subsequent levels.

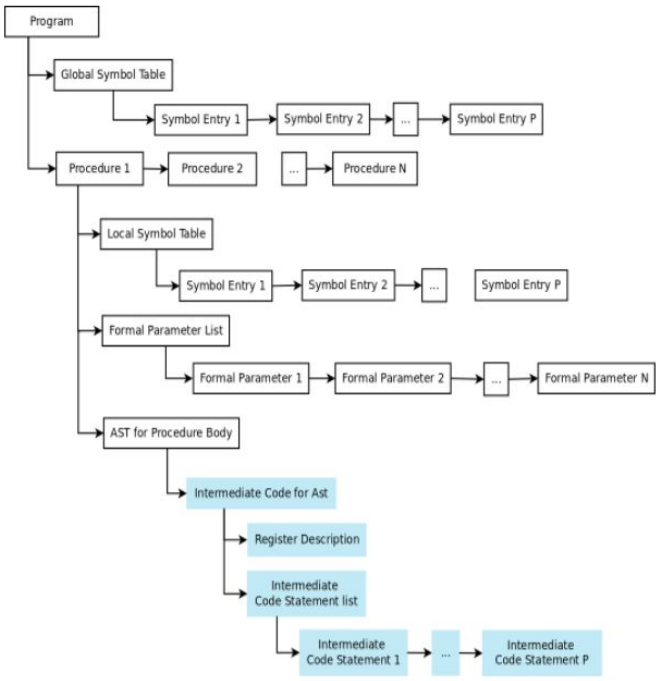
Interpretation is performed by traversing the basic blocks and visiting each AST in the basic block. Each AST is evaluated and the values of the variables in **`eval_env`** are updated. This requires recording the targets of goto statements also. Further, subsequent levels would need recording the values of floating point variables also. In order to implement a generic evaluate procedure across all ASTs, the values are stored using objects of a class called **`Eval_Result`**. We derive three classes **`Eval_Result_Value`** (used to store values of variables) and **`Eval_Result_Target`** (used to store the targets of gotos in level 3). We also derive classes **`Eval_Result_Value_Int`** and **`Eval_Result_Value_Float`** (this distinction will be required in level 3).

Level 1 Compilation

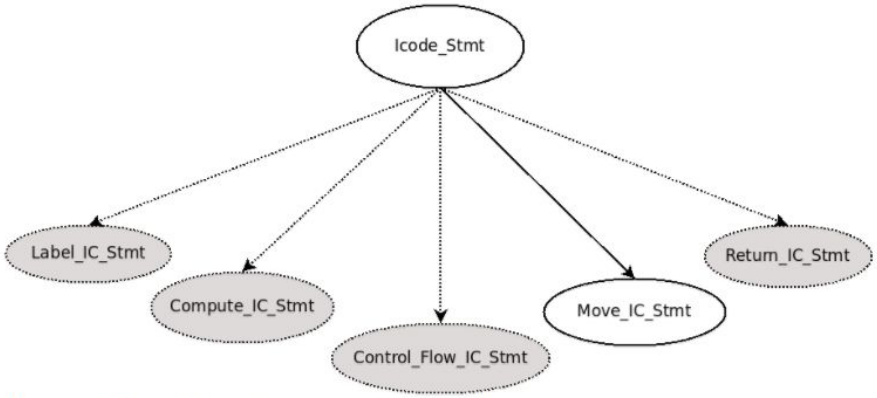
Compilation requires successful construction of ASTs for the entire program submitted to sclp and is performed by traversing the ASTs. It involves the following two steps.

- In the first step, an intermediate code is generated. The intermediate code is essentially a three address code with an operator, a result, and two operands. This step stores intermediate results into registers. The option **`-lra`** optimizes this local register allocation and tries to reuse registers by freeing registers of intermediate values earlier and by remembering and using variables for registers.
- In the second step, intermediate code is compiled to assembly code.In this step, local variables are assigned offsets, actual machine operations are identified, and appropriate assembly format is used for emitting the code.

The revised data structure (generalized to multiple procedures and procedures with parameters) now looks as shown below. The light blue boxes indicate additions required for compilation. The dashed lines indicate shared data structures that undergo a shallow copy and not a deep copy.



An intermediate code statement can be one of the following. **`Icode_Stmt`** is the base class and other classes are derived from it. In level 1, we have only move statements. The gray ovals indicate the statements that you will have to introduce in subsequent levels.



In order to understand the compilation, you basically need to understand the following:

1. Why multiple intermediate code statements may be generated for a single AST.
2. Why it is useful to also record the register that contains the final result of the computation described by a list of intermediate code statements.
3. How the register information has been encoded in the data structures.
4. How the statement categories (eg. register-to-memory, memory-to-register etc.) have been used for register allocation.
5. How offsets are assigned to variables.
6. The activation record structure.
7. How the machine instructions have been encoded in the data structures.

Points 1, 2, 5, and 6 are generic concepts that can be understood from the first principles. Points 3, 4, and 7 are specific sclp design. Points 1 and 2 implement the spirit of the syntax directed definition provided in Figure 6.19 (page 379) of the text book (Compilers: Principles, Techniques, and Tools by Aho, Lam, Sethi, and Ullman).

While understanding points 3, 4, 6, and 7, please keep the spim instruction set architecture in mind.

Current Limitations and Possible Improvements

The design and implementation of sclp has some limitations which we expect to overcome in subsequent versions. We welcome more additions to the following list.

- The use of a map to store symbol table details is fine for global and local variables where the order does not matter. However, for formal parameters, the order matters (because of positional correspondence between actual and formal parameters). I have been able to circumvent this problem by explicitly storing the sequence number but perhaps a better design is possible.
- We would like to introduce an optimizer generator which works with sclp to allow the users to specify analyses and transformations declaratively and automatically construct optimizers that work within cfglp.

Source Code of Level 1

Source code for Level 1 will be provided at a later stage.

Reference Implementations

Executables of reference implementation for different levels will be provided from time to time.

We would appreciate hearing about bugs if you come across any.

Using Flexc++ and Bisonc++

We use flexc++ and bisonc++ to generate C++ code for the scanner and parser. They provide a cleaner interface compared to flex and bison which generates C code by default but can be made to generate C++ code. For a detailed documentation, please visit the oringal flexc++ web page and the bisonc++ web page. They contain extensive documentation. Here we provide some details to help your understanding.

We introduce flexc++ and bisonc++ in three steps keeping the examples as simple as possible:

- First we construct a scanner to recognize numbers. This requires using flexc++ without bisonc++. Its complete tarball can be downloaded or files can be seen here.
- In the second step, we construct a scanner and a parser to recognize expressions. This requires cooperation between the scanner and parser in that the scanner must pass tokens to the parser. This equires us to modify the generated class descriptions. We use five grammars beginning with simplest of expressions to more complicated expressions. Its complete tarball can be downloaded or the files can be seen here.
- In the final step, we construct a calculator to compute the values of expressions. This requires further interaction between the scanner and the parser because apart from the tokens, the token values also need to be passed from the scanner to the parser. This requires us to change the classes further to share variables. Its complete tarball can be downloaded or the files can be seen.

We explain the interaction between the scanner and the parser in details in the third step.

Using Flexc++ to Create a Scanner to Recognize Numbers

We provide a simple example of using flexc++ to creare a standalone scanner. Since the generated scanner is called from main.cc rather than from within a parser, the class Scanner generated by flexc++ is sufficient and there is no need to manually change it unlike in the next two cases.
We reproduce the scanner script below. It defines tokens using regular expressions defined over character classes and prints the lexemes found along with the token that they match.

```
digit [0-9]
operator [-+*/]

%%
{digit}+    { std::cout << "Found a number whose lexeme is '" << matched() << "'\n"; }
{operator}  { std::cout << "Found an operator whose lexeme is '" << matched()[0] << "'\n"; }
.           { std::cout << "Found an unrecoganized character '" << matched()[0] << "'\n";
```

Please download the complete tarball or see the files. Please see the README file and Makefile for more details.

Using Flexc++ and Bisonc++ together to Recognize Expressions

We provide a simple example of using flexc++ and bisconc++ to creare a parser and scanner that recognize valid expressions. Now the scanne returns a token to the parser (eg. `return Parser::NUM;`).

Scanner script	Parser scripts

exp.ll

```
%%

[0-9]+  {
            return Parser::NUM;
        }

[-+*/]  {
            return matched()[0];
        }

\n      {
            return matched()[0];
        }

[ \t]   { }

%%
```

exp1.yy

```
%start E
%token NUM

%%

E : NUM       { cout << "found an expression consisting of a number\n"; }
  ;
```

exp2.yy

```
%start E
%token NUM

%%
E : NUM         { cout << "found an expression consisting of a number\n"; }
  | E '+' E     { cout << "found a plus expression\n"; }
  ;
```

exp3.yy

```
%start E
%token NUM
%left '+'

%%
E : NUM       { cout << "found an expression consisting of a number\n"; }
  | E '+' E   { cout << "found a plus expression\n"; }
  ;
```

exp4.yy

```
%start E
%token NUM
%left '+'
%left '*'

%%
E : NUM       { cout << "found an expression consisting of a number\n"; }
  | E '+' E   { cout << "found a plus expression\n"; }
  | E '*' E   { cout << "found a mult expression\n"; }
  ;
```

exp5.yy

```
%start E
%token NUM
%left '+' '-'
%left '*' '/'

%%
E : NUM       { cout << "found an expression consisting of a number\n"; }
  | E '+' E   { cout << "found a plus expression\n"; }
  | E '*' E   { cout << "found a mult expression\n"; }
  | E '-' E   { cout << "found a sub expression\n"; }
  | E '/' E   { cout << "found a div expression\n"; }
  ;
```

A Simple Expressions Calculator Example

We use a simple calculator program to explain the interaction between a scanner and a parser generated using flexc++ and bisonc++. The calculator computes the result of a single expression consisting of numbers and operators **+** and *****.

The the scanner and parser specificatons for our calculator, along with the associated actions to perform the computation are:

Scanner script

```
%%

[0-9]+  {
           ParserBase::STYPE__ *val = getSval();
          *val = atoi(matched().c_str());
           return Parser::NUM;
        }

[+*]    {  return matched()[0]; }

\n      {  return matched()[0]; }

[ \t]   { }
.       {
           string error_message;
           error_message =  "Illegal character `" + matched();
           error_message += "' on line " + lineNr();
          cerr << error_message;
           exit(1);
        }

%%
```

Parser script

```
%token NUM

%start Start

%left '+'
%left '*'

%%


Start : Expr '\n'         { cout << "\t= " << $1 << "\n"; }
      ;
Expr : Expr '+' Expr      { $$ = $1 + $3; }
     | Expr '*' Expr      { $$ = $1 + $3; }
     | NUM                { $$ = $1; }
     ;
```

In this grammar we have four terminals (or tokens): **NUM**, **+**, *, and **\n** and two non-terminals **Start** and **Expr**. The operators **+** and * have been declared to be left associative and * is declared to have a higher precedence than **+** (because its associativity specification appears lower). The action **$$ = $1 + $3** adds up the values associated with the two occurrences of **Expr** on the right hand side and assigns it to the value of the **Expr** appearing on the left hand side. The action **{ $$ = $1; }** assigns the value of **NUM** to **Expr**.

Passing different values derived from the lexemes from a scanner to a parser

The calculator example illustrates how an integer value can be passed from a scanner to a parser. In most cases, we need to pass more than one type of values. For this we declare a **union** of values in the parser, qualify the grammar symbols with the field names and set appropriate values using the field names in the scanner script.

The following example illustrates this. Our parser recognizes a list (non-terminal **List**) consisting of names (terminal **NAME**) and numbers (terminal **NUM**). In our scheme of things, the lexemes matching the token **NUM** represent integer values whereas the lexemes matching the token **NAME** represent string values. We specify this in the parser script as a C++ **union** of integer and a pointer to a string through the directive **%union**. This union is used to declare values of the type **STYPE__** internally by the parser. We have named the fields of the union as **integer_value** and **string_value**. The specifications of the terminals are qualified with appropriate field name (**integer_value** for token **NUM** and **string_value** for token **NAME**) in the parser script.

The values of the tokens are set by the scanner script using function **matched** which returns the actual lexeme matching the regular expression corresponding to the token identified. The values are set in two steps: First, we acquire a pointer to **STYPE__** using the **getSval** function in the **ScannerBase** class. Then we store the values using the appropriate field of the union (**integer_value** for token **NUM** and **string_value** for token **NAME**). Finally the tokens are returned to the parser.

Within the parser script, the values are directly available and can be accessed using the **$**i variable for the i^{th} grammar symbol on the RHS of a rule.

Scanner script

```
%%

[[:digit:]]+    {

          ParserBase::STYPE__ *val = getSval();
          val->integer_value = atoi(matched().c_str());
          return Parser::NUM;
        }

[[:alpha:]_][[:alpha:][:digit:]_]* {

          ParserBase::STYPE__ *val = getSval();
          val->string_value = new std::string(matched());
          return Parser::NAME;
        }
```

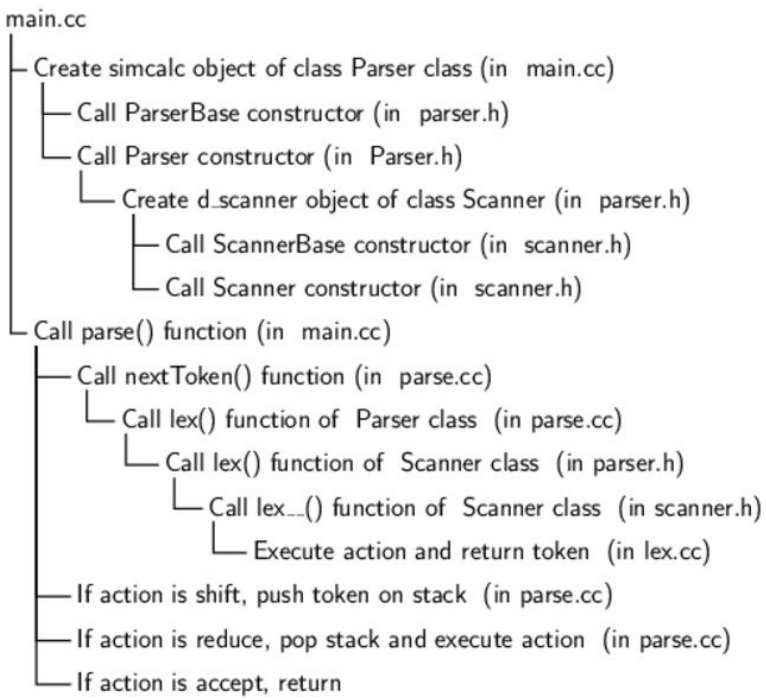
Parser script

```
%union
{
        int integer_value;
        std::string * string_value;
};

%token <integer_value> NUM
%token <string_value> NAME

%%

List    : List NUM   { cout << "Parser found a number " <<  $2
        | List NAME  { cout << "Parser found a name "   << *$2
        | NUM        { cout << "Parser found a number " <<  $1
        | NAME       { cout << "Parser found a name "   << *$1
        ;
```

This simple parser implementation can be downloaded for experimentation.

The internal details of the interaction between a scanner and a parser are as follows. The scanner is defined by an object of class **Scanner** which inherits from a base class **ScannerBase**. Similarly, the parser is defined by an object of class **Parser** which inherits from a base class **ParserBase**.

We create an object called **simcalc** as an instance of class **Parser** and then call its **parse()** function. The constructor of **Parser** creates an object called **d_scanner** as an instance of the **Scanner** class. The **parse()** function receives tokens from the **lex()** function and takes the parsing decisions. This has been illustrated below.



Since the the tokens are recognized by the scanner, and their values have to be passed by the scanner to the parser. In this case, after the scanner identifies a certain sequence of digits as a lexeme corresponding to the token **NUM**, it should also compute the value of the number from the lexeme and make it available to the parser. We explain this interaction below by first showing the default **Scanner** class generated by flexc++ and the default **Parser** class generated by bisonc++. Then we show how the classes are modified.

Automatically generated Scanner and Parser classes are as shown below

```
class Scanner: public ScannerBase
{
    public:
        explicit Scanner(std::istream &in = std::cin,
                         std::ostream &out = std::cout);

        Scanner(std::string const &infile,
                std::string const &outfile);

        // $insert lexFunctionDecl
        int lex();

    private:
        int lex__();
        int executeAction__(size_t ruleNr);

        void print();
        void preCode();
};
```

```
class Parser: public ParserBase
{
    // $insert scannerobject
    Scanner d_scanner;

    public:
        int parse();

    private:
        void error(char const *msg);
        int lex();

        void print();

    // support functions for parse():
        void executeAction(int ruleNr);
        void errorRecovery();
        int lookup(bool recovery);
        void nextToken();
};
```

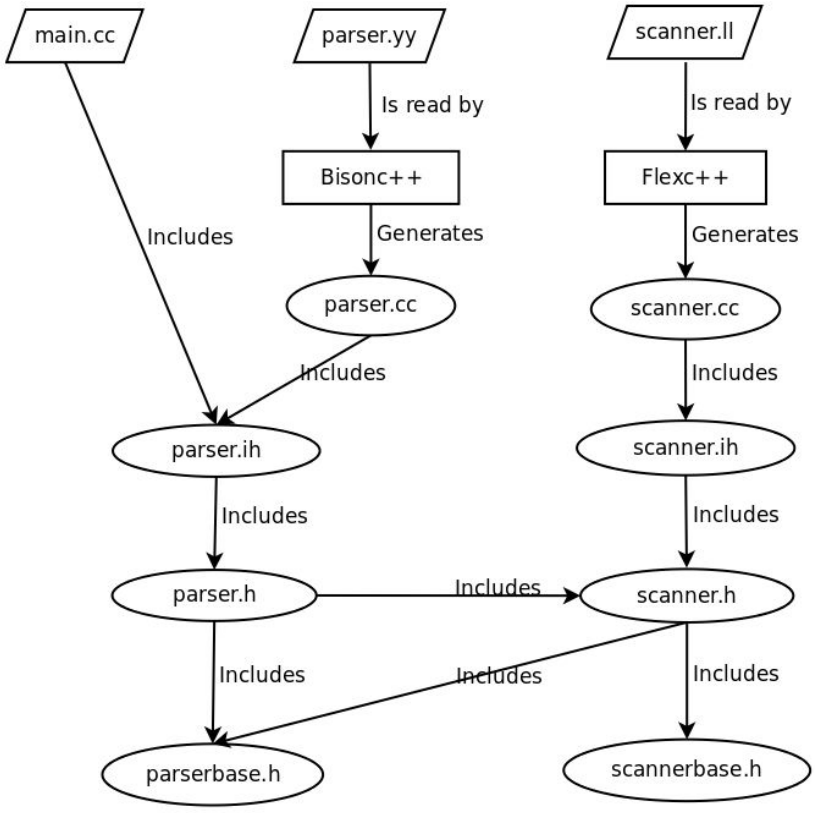
Manually updated classes (see the lines in red) to enable transfer of values from the Scanner to the Parser
(Our Makefile performs adds these lines automatically using sed commands Please see the explanation in the README file and the Makefile.)

```
class Scanner: public ScannerBase
{
    public:
        explicit Scanner(std::istream &in = std::cin,
                         std::ostream &out = std::cout);

        Scanner(std::string const &infile,
                         std::string const &outfile);

        // $insert lexFunctionDecl
        int lex();

    private:
        ParserBase::STYPE__ * dval;

        int lex__();
        int executeAction__(size_t ruleNr);

        void print();
        void preCode();


    public:
        void setSval(ParserBase::STYPE__ * val);
        ParserBase::STYPE__  * getSval();

};
```

```
class Parser: public ParserBase
{
    // $insert scannerobject
    Scanner d_scanner;

    public:
        Parser()
        {
                d_scanner.setSval(&d_val__);
        }

        int parse();

    private:
        void error(char const *msg);
        int lex();

        void print();
    // support functions for parse():
        void executeAction(int ruleNr);
        void errorRecovery();
        int lookup(bool recovery);
        void nextToken();
};
```

The class **`Parser`** has a protected member **`d_val__`** which it inherits from the base class **`ParserBase`**. We make the address of this variable available to the **`Scanner`** class by adding new constructor for the **`Parser`** class which calls the function **`d_scanner.setSval`** (**`d_scanner`** is the scanner object used by the parser object). This is a function that we have added in the **`Scanner`** class. This function store the pointer in a private variable **`dval`**. Whenever the script in **`scanner.ll`** has to make the value available to the parser, it gets the pointer using the function **`getSval`** and stores the value in the address which happens to be the address of the variable **`d_val__`** in an object of the **`Parser`** class.

The file inclusions are a little tricky and have been illustrated below. The files at the top are the files that we write. The **`parser.yy`** and **`scanner.ll`** are the scripts that are read by **`bisonc++`** and **`flexc++`** which then generate the `parser.cc` and **`scanner.cc`** files and the associated header files.



Installing Flexc++ and Bisonc++

On Ubuntu 14.04 and 16.04, a standard installation from the repositories using apt or synaptic work well.

For Ubuntu 12.04, the steps for installing Flexc++ and Bisonc++ on a 64 bit intel processor based machine have been given below. For a 32 bit intel processor based machine, please replace **amd64** by **i386** in the installation of **libbobcat** and **libbobcat-dev**.

We need to install the following packages. Note that the specific version numbers (or higher versions) are important. Wherever possible, we suggest using the **apt-get** command (synaptic package manger would do just as well) minimising the need of installation from **.deb** files or source files.

- **g++** version 4:4.6.3-1ubuntu5.
  - Use the command **sudo apt-get install g++**.
- **bisonc++** version 2.09.03-1.
  - Use the command **sudo apt-get install bisonc++**.
- **icmake** version 7.16.01-1ubuntu1
  - Use the command **sudo apt-get install icmake**.
- **libbobcat** version 3_3.01.00-1
  - Visit the site https://launchpad.net/ubuntu/quantal/amd64/libbobcat3/3.01.00-1.
  - Check for all dependencies and their versions listed on the site. You may want to use the synaptic package manager to find out whether the dependencies have been installed on your system. Install all missing dependencies.
  - Download the **libbobcat3_3.01.00-1_amd64.deb** file and use the command **sudo dpkg -i libbobcat3_3.01.00-1_amd64.deb**.
- **libbobcat-dev** version 3.01.00-1. These are the development libraries (note the suffix **-dev**).
  - Visit the site https://launchpad.net/ubuntu/raring/amd64/libbobcat-dev/3.01.00-1.
  - Check for all dependencies and their versions listed on the site. You may want to use the synaptic package manager to find out whether the dependencies have been installed on your system. Install all missing dependencies.
  - Download the **libbobcat-dev_3.01.00-1_amd64.deb** file and use the command **sudo dpkg -i libbobcat-dev_3.01.00-1_amd64.deb**.
- **flexc++** version 0.98.00.
  - Visit the site https://launchpad.net/ubuntu/+source/flexc++/0.98.00-1.
  - Check for all dependencies and their versions listed on the site. You may want to use the synaptic package manager to find out whether the dependencies have been installed on your system. Install all missing dependencies.
  - Download the source code archive file **flexc++_0.98.00.orig.tar.gz**.
  - Untar the source code using the command **tar zxvf flexc++_0.98.00.orig.tar.gz**.
  - Change the directory using **cd flexc++-0.98.00**.
  - Follow the steps given in the file **INSTALL**.