



Universidade do Minho

Escola de Engenharia

Departamento de Informática

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**Implementing a Syntax Directed Editor
for LISS.**

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ABSTRACT

The aim of this master work is to implement LISS language in ANTLR compiler generator system using an attribute grammar which create an abstract syntax tree (AST) and generate MIPS assembly code for MARS (MIPS Assembler and Runtime Simulator) . Using that AST, it is possible to create a Syntax Directed Editor (SDE) in order to provide the typical help of a structured editor which controls the writing according to language syntax as defined by the underlying context free grammar.

RESUMO

O tema desta dissertação é implementar a linguagem LISS em ANTLR com um gramática de atributos e no qual, irá criar uma árvore sintática abstrata e gerar MIPS assembly código para MARS (MIPS Assembler and Runtime Simulator). Usando esta árvore sintática abstrata, criaremos uma SDE (Editor Dirigido a Sintaxe) no qual fornecerá toda a ajuda típica de um editor estruturado que controlará a escrita de acordo com a gramática.

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¹ <http://www.biiet.org/blog/wp-content/uploads/2013/07/img028.jpg>

² [http://upload.wikimedia.org/wikipedia/commons/thumb/e/ea/MIPS_Architecture\(Pipelined\).svg/300px-MIPS_Architecture_\(Pipelined\).svg.png](http://upload.wikimedia.org/wikipedia/commons/thumb/e/ea/MIPS_Architecture(Pipelined).svg/300px-MIPS_Architecture_(Pipelined).svg.png)

³ ?

⁴ <http://www.alauda.ro/wp-content/uploads/2011/04/XCode-interface-e1302035068112.png>

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INTRODUCTION

In informatics, solving problems with computers is related to the necessity of helping the end-users, facilitating their life. And all these necessities pass through developers who creates programs for this purpose.

However, developing programs is a difficult task; analyzing problems, and debugging software takes effort and time.

And this is why we must find a solution for these problems.

Developing a software package requires tools to help the developers to maximize their programming productivity. These tools are: on one hand, compilers to generate lower-level code (machine code) from the high-level source code (the input program written in an high-level programming language); on the other hand, editors to create that source code. And to make easier and safer the programmers work, high-level programming languages were created for facilitating their work.

This is not enough to overcome all the difficulties for creating a program in a safety way and having a high level productivity!

This is why we need to have fresh ideas and to implement more features to help on solving these problems.

1.1 OBJECTIVES

In this work, this project aims to develop an editor with the concept of a SDE (Syntax Directed Editor).

It is intended that the editor works with language designed by the members of the Language Processing group at UM which is called LISS.

LISS language will be specified by an attribute grammar that will be passed, as input, to ANTLR. The compiler generated by ANTLR will generate MIPS assembly code (lower-level source code).

The front-end and the back-end of that compiler will be explained and detailed along the next pages.

1.2. Research Hypothesis

1.2 RESEARCH HYPOTHESIS

1.3 THESIS OUTCOMES

1.4 DOCUMENT STRUCTURE

In this section, the project planned for this master thesis will be explained.

First, create an ANTLR version of the CFG grammar for LISS language.

Second, extend the LISS CFG to an AG in order to specify throw it the generation of MIPS assembly code. To verify the correctness of the assembly code generated, a simple MIPS simulator, named MARS, will be selected to provide all the tools for checking it.

Third, the desired Structure-Editor, SDE, will be developed based on ANTLR. It will be implemented in with Java SWING because ANTLR has always been implemented via Java and it is said, also, to use Java target as a reference implementation mirrored by other targets. SWING is a GUI widget toolkit for Java which provides all the API for creating an interface with Java. At this phase, we will create an IDE similar to other platforms but with the capacity of being a syntax-directed editor.

Fourthly, to complete the SDE functionality, an incremental compiler shall be included. Incremental compilation (Reps et al., 1983; Holsti, 1986; Vogt et al., 1990) means that only the part that was changed must be processed again. And like that, both tasks (edition and compilation) are done synchronously at the same time and having an editor which compiles cleverly.

Finally, exhaustive and relevant tests will be made with the tool created and, the outcomes will be analyzed and discussed.

LANGUAGES AND GRAMMAR: CONCEPT & TOOLS

A grammar (Chomsky, 1962; Gaudel, 1983; Waite and Goos, 1984; Aho et al., 1986; Kastens, 1991b; Muchnick, 1997; Hopcroft et al., 2006; Grune et al., 2012) is a set of derivation rules (or production) that explains how words are used to build the sentences of a language.

A grammar (Deransart et al., 1988; Alblas, 1991; Kastens, 1991a; Swierstra and Vogt, 1991; Deransart and Jourdan, 1990; R  ih  , 1980; Fil  , 1983; Oliveira et al., 2010) is considered to be a language generator and also a language recognizer (checking if a sentence is correctly derived from the grammar).

The rules describe how a string is formed using the language alphabet, defining the sentences that are valid according to the language syntax.

One of the most important researchers in this area was Noam Chomsky. He defined the notion of grammar in computer science's field.

He described that a formal grammar is composed by a finite set of production rules
(left hand side \mapsto right hand side)

where each side is composed by a sequence of symbols.

These symbols are split into two sets : non terminals, terminals; the start symbol is a special non-terminal.

There is, always, at least one rule for the start symbol (see Figure 1) followed by other rules to derive each non-terminal. The non terminals are symbols which can be replaced and terminals are symbols which cannot be.

One valid sentences (Example in Figure 1), could be : bbebee .

In the compilers area two major classes of grammars are used : CFG (Context-free grammar) and AG (Attribute Grammar).

The difference between these two grammars are that a CFG is directed to define the syntax (only) and, AG contains semantic and syntax rules.

An AG is , basically, a CFG grammar extended with semantic definitions. It is a formal way to define attributes for the symbols that occur in each production of the underlying grammar. We can associate values to these attributes later, after processed with a parser; the evaluation will occur applying those semantic definition to any node of the abstract syntax tree. These attributes are divided into two groups: synthesized attributes and inherited attributes.

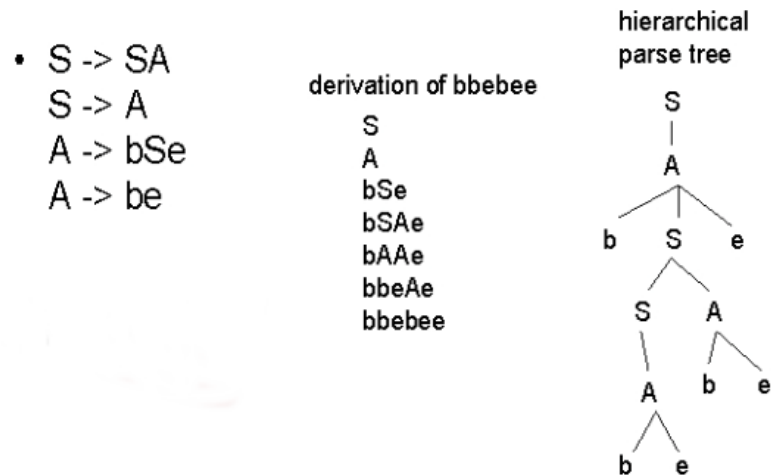


Figure 1.: CFG example ¹

The synthesized attributes are the result of the attribute evaluation rules for the root symbol of each subtree, and may also use the values of the inherited attributes. The inherited attributes are passed down from parent nodes to children or between siblings.

Like that it is possible to transport information anywhere in the abstract syntax tree which is one of the strength for using an AG (as seen on Listing 2.1).

```

1 facturas : fatura (facturas)*
2           ;
3
4 fatura : 'FATURA' cabec 'VENDAS' corpo {System.out.println("Total Factura
5           : " + $corpo.totOut);}
6           ;
7 cabec : idFat idForn 'CLIENTE' idClie {System.out.println("Factura n: " +
8           $idFat.text);}
9           ;
10 idFat : numFat ;
11
12 numFat : ID ;
13
14 idForn : nome morada 'NIF:' nif 'NIB:' nib
15           ;
16
17 idClie : nome morada 'NIF:' nif
18           ;
19
20 nome : STR ;

```

2.1. Formal Grammar

```
21
22 morada : STR;
23
24 nif : STR;
25
26 nib : STR;
27
28 corpo returns [int totOut]
29     : linha '.' {$totOut += $linha.linhatot;}
30     (linha '.' {$totOut += $linha.linhatot;})*
31     ;
32
33 linha returns [int linhatot]
34     : refProd '|' valUnit '|' quant {$linhatot = $valUnit.val * $quant.
35     quan;System.out.println("Ref: "+$refProd.text+" Total linha: "+(
36     $linhatot)+" Euros");}
37     ;
38
39     refProd : ID;
40
41 valUnit returns [int val]
42     : NUM {$val = $NUM.int;}
43     ;
44
45 quant returns [int quan]
46     : NUM {$quan = $NUM.int;}
47     ;
```

Listing 2.1: Example of an AG

In this way, an AG will be used to specify the translation from syntax tree directly into code for some specific machine or into another intermediate language. For our thesis, the AG will be processed by ANTLR tool in order to build automatically the parser, the attribute evaluator, and the code generation.

2.1 FORMAL GRAMMAR

According to Noam Chomsky, a classic formalization of generative grammars is composed by:

- A finite set N of nonterminals symbols.
- A finite set Σ of terminals symbols.
- A finite set P of production rules.

2.1. Formal Grammar

- A start symbol $S \in P$

A grammar is formally constructed by that tuple (N, Σ, P, S) .

Grammar is a set of productions rules which describes the syntax of the language (not semantic). Each grammar has only one start symbol production that defines where the grammar begins. And each production is composed by two things : LHS (Left Hand Side) and RHS (Right and Side). Left Hand Side represents the non terminal and the right hand side represents the behavior of the rule (composed by non terminal and terminal).

```
1    liss : 'program' identifier body
2          ;
```

Listing 2.2: A rule production

In 2.2, we can see that it is composed by two sides. The left hand side and the right hand side, delimited by ':'. On the LHS, 'liss' is a non-terminal and on the RHS, it is composed by the terminal 'program' followed by two non-terminals. This is the syntax of one production rule of the grammar.

Now let's speak about the entire syntax of the LISS.

LISS LANGUAGE

LISS (da Cruz and Henriques, 2007a) -that stands for Language of Integers, Sequences and Sets- is an imperative programming language, defined by the Language Processing members (Pedro Henriques and Leonor Barroca) at UM for teaching purposes (compiler course).

The idea behind the design of LISS language was to create a simplified version of the more usual imperative languages although combining functionalities from various languages.

It is designed to have atomic or structured integer values, as well as, control statements and block structure statements.

Now, let's explain the basic statements of the language and its data types as BNF grammar on the next section.

3.1 LISS DATA TYPES

There are 5 types available. From atomic to structured types, they are known as : integer, boolean, array, set and sequence.

Used for declaring a variable on the program, this gives us vital information for understanding what kind of type we are dealing it regarding a certain variable. Let's see deeper with one LISS code example:

```
1  a -> integer ;  
2  b -> boolean ;  
3  c -> array size 5,4;  
4  d -> set ;  
5  e -> sequence ;
```

Listing 3.1: Declaring a variable in LISS

As we can see in Listing 3.1, some variables ('a','b','c','d' and 'e') are being declared with his own types ('integer', 'boolean', 'array', 'set' and 'sequence'). Synthetically, in LISS, this

3.1. LISS Data types

is done by writing the variable name followed by an arrow and the type of the variable (see Listing 3.2).

```
1 variable_declaration : vars '→' type ';'
2                       ;
3 vars : var (',' var)*
4       ;
5 var : identifier value_var
6      ;
7 value_var :
8           | '=' inic_var
9           ;
10 type : 'integer'
11       | 'boolean'
12       | 'set'
13       | 'sequence'
14       | 'array' 'size' dimension
15       ;
16 dimension : number (',' number)*
17            ;
18 inic_var : constant
19           | array_definition
20           | set_definition
21           | sequence_definition
22           ;
23 constant : sign number
24           | 'true'
25           | 'false'
26           ;
27 sign :
28       | '+'
29       | '-'
30       ;
```

Listing 3.2: BNF of declaring a variable in LISS

Variables that are not initialized, have a default value (according to Table 1).

3.1. LISS Data types

Table 1.: LISS data types

| Type | Default Value |
|----------|---------------|
| boolean | false |
| integer | 0 |
| array | [0,...,0] |
| set | {} |
| sequence | nil |

Additionally, we may change the values of the variables by initializing them with a different value (see Listing 3.3). This can be made by putting an equal symbol after the variable name and, then, inserting the right value according to the type (see example in Listing 3.2).

```
1  a = 4, b -> integer ;
2  t = true -> boolean ;
3  vector1 = [1,2,3], vector2 -> array size 5;
4  a = { x | x<10} -> set ;
5  seq1 = <<10,20,30,40,50>>, seq3 = <<1,2>>, seq2 -> sequence ;
```

Listing 3.3: Initialize a variable

Now, let's see and list which type are, correctly, associated with the arithmetic symbols and functions in LISS (see Table 2).

3.1. LISS Data types

Table 2.: Operations and signatures in LISS

| Symbols & Functions | Signatures |
|---------------------|--|
| + | integer x integer -> integer |
| - | integer x integer -> integer |
| | boolean x boolean -> boolean |
| ++ | set x set -> set |
| / | integer x integer -> integer |
| * | integer x integer -> integer |
| && | boolean x boolean -> boolean |
| ** | set x set -> set |
| == | integer x integer -> boolean; boolean x boolean -> boolean |
| != | integer x integer -> boolean; boolean x boolean -> boolean |
| < | integer x integer -> boolean |
| > | integer x integer -> boolean |
| <= | integer x integer -> boolean |
| >= | integer x integer -> boolean |
| in | integer x set -> boolean |
| tail | sequence -> sequence |
| head | sequence -> integer |
| cons | integer x sequence -> sequence |
| delete | integer x sequence -> sequence |
| copy | sequence x sequence -> void |
| cat | sequence x sequence -> void |
| isEmpty | sequence -> boolean |
| length | sequence -> integer |
| isMember | integer x sequence -> boolean |

3.1. LISS Data types

So, in Table 2, we list the symbols and functions, who are available in LISS, and also its signature associated. In order to understand the table better, we will explain how to read the symbol and its signature with one example.

For example, the symbol '+' indicates that it can operate with, only, integers on each side of the symbol (separated by the symbol 'x') and that, the result of that operation, indicated by the symbol '->', will be an integer. Semantically, operations must be validated according to table 2, otherwise the operations would be incorrect and throw an error.

Arrays. LISS supports a way in indexing a collections of integer values such that each value is uniquely addressed (also it supports one great and most important property of being multidimensional).

Called as 'array', it is considered to be a static structured type due to the fact that his dimension and maximum size of elements is fixed at the declaration time.

And the operations defined over an array are basic in LISS:

1. *indexing*
2. *assignment*

Arrays can be initialized, in the declaration section, partially or completely the elements of each dimension. For example, consider an array of dimension 3x2 with the following way:

```
1 array1 = [[1,2],[5]] -> array size 3,2;
```

This is equivalent to the initialization below:

```
1 array1 = [[1,2],[5,0],[0,0]] -> array size 3,2;
```

Notice that the elements who weren't declared, are initialized with the value 0 (see Table 1).

The grammar who rules behind the syntax for array declaration and initialization is shown below.

```
1 array_definition : '[' array_initialization ']'
2                  ;
3
4 array_initialization : elem (',' elem)*
5                    ;
6
```

3.1. LISS Data types

```
7  elem : number
8      | array_definition
9      ;
```

Sets. The type *set* in LISS, is a collection of integers with no repeated numbers. It operates with a comprehension list instead of an enumeration. Set type can operate with two different ways. The first one is the empty value and this means that the set is empty. Syntactically, this is done by writing '{}'.

The other one is an 'identifier' separated by an explicit symbol '|' and an 'expression'. Expression is a set of operations that, at the end, result must be a boolean. Otherwise the set won't work

The operations defined for sets are :

1. *union*
2. *intersection*
3. *in*

Let's see an example of its syntax below:

```
1  set1 = {x | x < 6 && x > -7} -> set ;
```

This set explain us that only integers from -7 to 6 are valid and every others numbers are not included on the set.

The syntax for set declaration and initialization is :

```
1  set_definition : '{' set_initialization '}'
2                ;
3
4  set_initialization :
5                    | identifier '|' expression
6                    ;
```

Sequences. Considered as an array of one dimension, the type sequence is a collection of a list ordered integers. But, instead of the concept of an array, its size is not fixed; this means that it grows dynamically at run time like a linked list. There is two ways in defining

3.1. LISS Data types

sequences. The first way is declaring it with the empty value (syntactically done by writing '<<>>') and the second way is by defining with integers to the sequence. Let's see deeper with one example:

```
1  c=<<1,2,3>> -> sequence ;
```

Listing 3.4: Example of valid operations using sequence on LISS

So, the sequence example is defined by three numbers (3,2,1). Also some operations are defined for the sequence type and they are known as:

1. *tail*
2. *head*
3. *cons*
4. *delete*
5. *copy*
6. *cat*
7. *isEmpty*
8. *length*
9. *isMember*

Those operations will be explained further and deeper.

Now, the grammar behind the type sequence is defined by the follow one:

```
1  sequence_definition : '<<' sequence_initialization '>>'  
2                        ;  
3  
4  sequence_initialization :  
5                        | values  
6                        ;  
7  
8  values : number ( ',' number ) *  
9          ;
```

3.2. LISS blocks and statements

3.2 LISS BLOCKS AND STATEMENTS

A LISS program is always composed of two parts: declarations and statements (a program block). LISS language is structured with ease and simple hierarchy. And this is done by structuring LISS code as a block.

It begins by creating our program with a name, succeeding by implementing the declaration of variables and then the flow of the program by writing statements. Let's see a deeper look with one example (see Listing 3.5).

```
1 program sum{  
2     declarations  
3         int=2 -> integer;  
4     statements  
5         writeln(int+3);  
6 }
```

Listing 3.5: The structure of a LISS program (example)

So a program in LISS, begins by, syntactically, writing 'program' and then the name of the program (in this case, the name is 'sum'). Then appears some braces that delimits the contents of the program which is done by opening it after the name of the program and closing it at the end of the program. After those braces, there is one important part to alert the user with the way of declaring variables and statements.

As in a traditional imperative language (let's compare 'C language'), if we don't take the habits of implementing the variable always in a certain part of the code. We may be confused by implementing and finding them randomly in the code. And this makes the life harder to the programmer in understanding the code when the code is quite long/bigger.

So, in LISS, we always declare variable declarations firstly (syntactically written by 'declarations') and then the statements secondly (syntactically written by 'statements'). This is due to the fact that LISS want to help the user by creating solid and correctness code. And in this case, the user will always know that all the variable declarations will be always at the top of the statements and not randomly everywhere.

Then, comes the part where we implement the flow of the program under the section of 'statements'.

3.2.1 Statements

As said previously, under the statements part, we control and implement the flow of LISS program. In LISS, we may write none or multiple statements consecutively and notice that the same behavior is, also, done for declaring variables.

3.2. LISS blocks and statements

Every statements ends with a semicolon unless two type of statements (conditional and cyclic/iterative statement) (as shown in Listing 3.6).

```
1 statements : statement*
2           ;
3 statement : assignment ';'
4           | write_statement ';'
5           | read_statement ';'
6           | conditional_statement
7           | iterative_statement
8           | function_call ';'
9           | succ_or_pred ';'
10          | copy_statement ';'
11          | cat_statement ';'
12          ;
```

Listing 3.6: BNF of statements in LISS

Let's see one example of a LISS program which shows how it is done (see in Listing 3.7).

```
1 program factorial{
2   declarations
3     res=1, i=5 -> integer;
4   statements
5     writeln(res);
6     for(j in 1..i){
7       res=res*j;
8     }
9     writeln(res);
10 }
```

Listing 3.7: Example of using statements in LISS

3.2.2 Control statements

LISS language includes some statements for controlling the execution flow at runtime with two different kind of behavior.

The first one is called conditional statement and it has only one variant in LISS language (see Listing 3.8).

But the second one is called cyclic statement or iterative statement, and it has two cyclic different variants (see Listing 3.8).

```
1 conditional_statement : if_then_else_stat
```


3.2. LISS blocks and statements

```
2           ;  
3 iterative_statement : for_stat  
4                   | while_stat  
5           ;
```

Listing 3.8: BNF of control statements in LISS

These control statements, mimics the syntax and the behavior, nearly, of other modern imperative language. But, we should take a look on the behavior of one of the control statement in order to understand its role deeper.

The 'for' statement has two different ways for defining his comportment. Normally, in a conventional way, the for-loop has a control variable which takes a value in a given range and step up or step down by a default or a explicit value.

In LISS, the control variable is set in a given integer interval defined by the lower and upper bounds. Therefore, by default, the step is incremented by one but it is possible to increment or decrease it by setting it explicitly. Additionally, we may write a condition for filtering on each step the for-loop statement, like setting an if-condition. This can be done with the following syntax:

```
1 for(a in 1..10) stepUp 2 satisfying array[a]==1{  
2     ...  
3 }
```

Listing 3.9: LISS syntax of a for-loop statement

In Listing 3.9, the control variable 'a' is set to a range by 1 to 10 and would be increased (due to 'stepUp' syntax) by 2. Also there is a filter condition which is applied after the 'satisfying' syntax and it will be tested on each step of the for-loop statement. Notice that the filter condition must boolean and that if it pass the condition, then the inner content of the for-loop statement would be executed.

Otherwise the control variable would be incremented with the explicit value 2 and the filter condition tested again. This is the first example, about expressing in a way the for-loop statement. Let's see the second way on the next lines.

There is also the possibility for ease use, in expressing a for-each statement on a array. And this is done by calling a simple syntax in LISS.

```
1 for(b inArray array){  
2     ...  
3 }
```

Listing 3.10: LISS syntax of a for-each statement on array

3.3. Subprograms

In Listing 3.10, the control variable 'b' is assigned with all of the elements of the array and begins with his lower index (zero) until his upper index (size of the array minus one). Notice that, in this case, we cannot apply an increment or decrement behavior and also a filter condition.

The next grammar fragment describes the cycle for in LISS:

```
1 for_stat : 'for' '(' interval ')' step satisfy
2           '{' statements '}'
3           ;
4 interval : identifier type_interval
5           ;
6 type_interval : 'in' range
7               | 'inArray' identifier
8               ;
9 range : minimum '..' maximum
10        ;
11 minimum : number
12          | identifier
13          ;
14 maximum : number
15          | identifier
16          ;
17 step :
18       | up_down number
19       ;
20 up_down : 'stepUp'
21          | 'stepDown'
22          ;
23 satisfy :
24          | 'satisfying' expression
25          ;
```

Listing 3.11: BNF of for statement in LISS

3.3 SUBPROGRAMS

In LISS, it is possible to organize your code by splitting a portion of your code into sub-programs. This allows to the programmer to reuse or give more clarity to his code by creating functions or doing some procedure. Also, it is possible to create sub-programs into sub-programs by using a nesting strategy.

The syntax who defines a sub-program in LISS is shown in Listing 3.12.

3.3. Subprograms

```
1 subprogram_definition: 'subprogram' identifier '(' formal_args ')'
   return_type f_body
2
   ;
3 f_body : '{'
4         'declarations' declarations
5         'statements' statements
6         returnSubPrg
7         '}'
8
   ;
9 formal_args :
10             | f_args
11
   ;
12 f_args : formal_arg (',' formal_arg)*
13
   ;
14 formal_arg : identifier '->' type
15
   ;
16 return_type :
17             | '->' typeReturnSubProgram
18
   ;
19 returnSubPrg :
20             | 'return' expression ';'
21
   ;
```

Listing 3.12: BNF of block structure in LISS

Note that every variable, who are declared inside of a sub-program, are local, and they can be access to others nested sub-program of a sub-program. However, variables declared in the program (not in a sub-program) are considered global and not local.

3.4. Evolution of LISS syntax

3.4 EVOLUTION OF LISS SYNTAX

Due to the maturity of the language already done by the professors whom invented, we have added some few but extra changes for a better experience of the programming language. The syntax of the LISS language (Figure A), has been constructed with ANTLR which is ANother Tool for Language Recognition where it collaborates with the Java platform.

One of the first objectives is that we have changed the format of the syntax. We have translated the old LISS language to a brand new extended BNF format (as shown in Figure A).

Then we have added some better clarification syntactically of the programming language which was by not mixing functions and variable declarations between them (See Figure 3.4). Like that we, indirectly, teach the programmer by doing it in the right way. So we declare, firstly, the variables and then the functions.

```
1 declaration : variable_declaration * subprogram_definition *  
2           ;
```

Another objectives was to add punctuation after each line of any statements (See Figure 3.13).

```
1 statement : assignment ';'   
2           | write_statement ';'   
3           | read_statement ';'   
4           | conditional_statement   
5           | iterative_statement   
6           | function_call ';'   
7           | succ_or_pred ';'   
8           | copy_statement ';'   
9           | cat_statement ';'   
10          ;
```

Listing 3.13: Function statement

As adding also a 'cat_statement' rule which works with only sets. It concatenate sets with another sets.

Regarding to the arrays, it was previously able to add some expressions over the access elements of the array. But these access were able to use some boolean expression which was non sense regarding to the semantic. So we changed and allowed any other expressions less than boolean expression (See figure 3.14).

```
1 elem_array : single_expression ( ',' s2=single_expression ) *  
2           ;
```

3.4. Evolution of LISS syntax

Listing 3.14: Rule element of array

In the previous version of the LISS, it was allowed to create a big boolean expression, but we decided to change that and only able to create one boolean expression (See figure 3.15). It was a non sense of having an expression like that : '3 == 4 == 5 != 6'.

```
1 expression : single_expression (rel_op single_expression )?
2           ;
```

Listing 3.15: Rule expression

We added the possibility of using some parenthesis over expressions (See figure 3.16).

```
1 factor: '(' expression ')'
2       ;
```

Listing 3.16: Rule factor

We changed the rules of two functions: 'cons' and 'del'. These functions were working with both in the same way. Waiting for an expression and a variable as arguments. Now, we decided to change that and giving more powers of expressivity to those functions 3.17.

```
1 cons // integer x sequence -> sequence
2     : 'cons' '(' expression ',' expression ')'
3     ;
4
5 delete // del : integer x sequence -> sequence
6       : 'del' '(' expression ',' expression ')'
7       ;
```

Listing 3.17: Rule cons and delete

Beside of adding some improvements to the grammar, we additionally deleted a rule which we thought it wasn't necessary to have (see figure 3.18).

```
1 type_interval : 'in' range
2               | 'inArray' identifier
3               //| 'inFunction' identifier
4               ;
```

Listing 3.18: Rule type interval

Last but not least, we also added the way of adding some comments to the programming language. Giving more power for the user in giving some informations about his code.

3.4. Evolution of LISS syntax

```
1 fragment
2 COMMENT
3   : '/*'.*?'*'/ /* multiple comments*/
4   | '//'~('\'r' | '\n')* /* single comment*/
5   ;
```

Listing 3.19: Rule comment

TARGET MACHINE

4.1 MIPS

MIPS, from Microprocessor without Interlocked Pipeline Stages, is a reduced instruction set computer (RISC) developed by MIPS Technologies.

The architecture of MIPS is composed by 5 stages (see Figure 2).

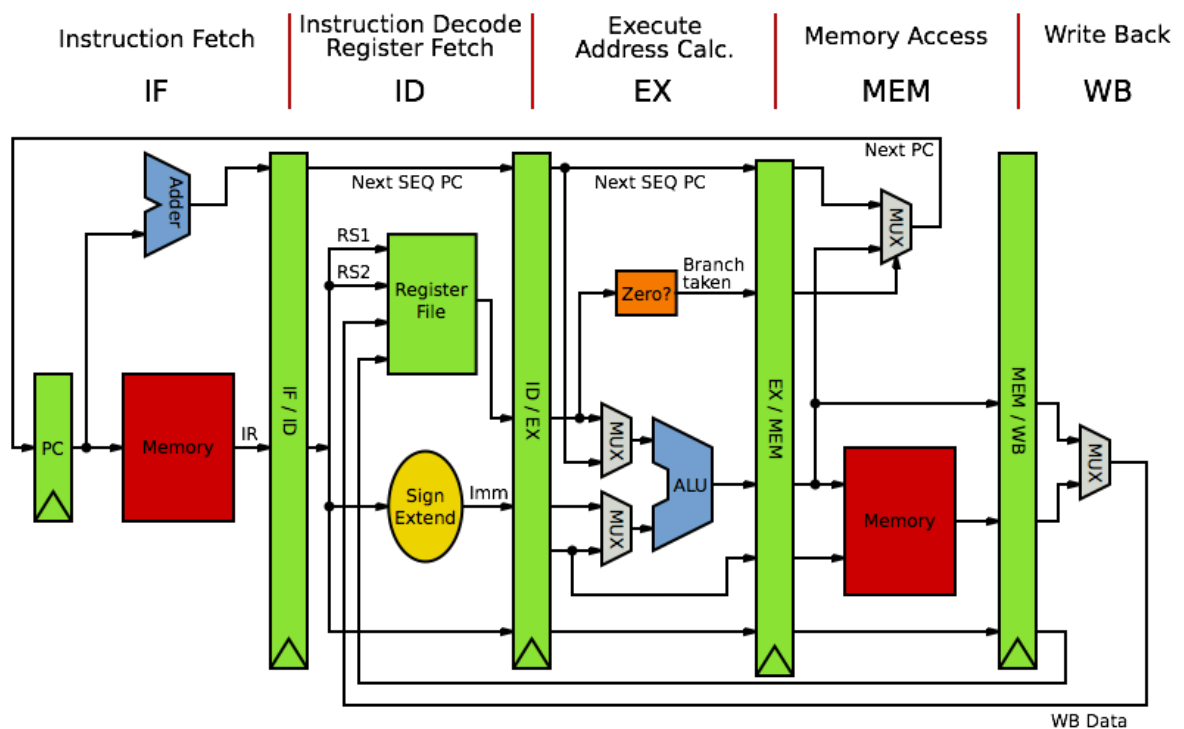


Figure 2.: MIPS architecture ¹

4.1. MIPS

It has 32 registers and 5 type of instructions :

- instructions for data transfer
- instructions for arithmetic
- instructions for logical
- instructions for conditional branch
- instructions for unconditional jump

It uses a mnemonic to represent each low-level machine instruction or operation. Operations require three operands in order to form a complete instruction in MIPS assembly code, the address for the result and the address of the two operands.

A simple example of a complete instruction can be seen in Listing 4.1.

```
1 add $s1,$s2,$s3
```

Listing 4.1: Sum of two registers in MIPS assembly code

The instruction shown in Listing 4.1, means that register \$s2 shall be added to register \$s3 and their sum (the result) stored in \$s1 register (note that each operand is represented by \$ sign).

As mentioned in the previous section, the AG processed by the compiler generator ANTLR will compose MIPS assembly. The MIPS assembly instructions generated so far will be converted into executable machine code by an assembler included in MARS environment (a MIPS simulator and debugger) according to the process depicted in Figure 3.

After presenting in the previous chapter the essential definitions for the intended work, in this chapter the project planned for this master thesis will be explained.

First, create an ANTLR version of the CFG grammar for LISS language.

Second, extend the LISS CFG to an AG in order to specify throw it the generation of MIPS assembly code. To verify the correctness of the assembly code generated, a simple MIPS simulator, named MARS, will be selected to provide all the tools for checking it.

Third, the desired Structure-Editor, SDE, will be developed based on ANTLR. It will be implemented in with Java SWING because ANTLR has always been implemented via Java and it is said, also, to use Java target as a reference implementation mirrored by other targets. SWING is a GUI widget toolkit for Java which provides all the API for creating an interface with Java. At this phase, we will create an IDE similar to other platforms but with the capacity of being a syntax-directed editor.

Fourthly, to complete the SDE functionality, an incremental compiler shall be included. Incremental compilation (Reps et al., 1983; Holsti, 1986; Vogt et al., 1990) means that only

4.1. MIPS

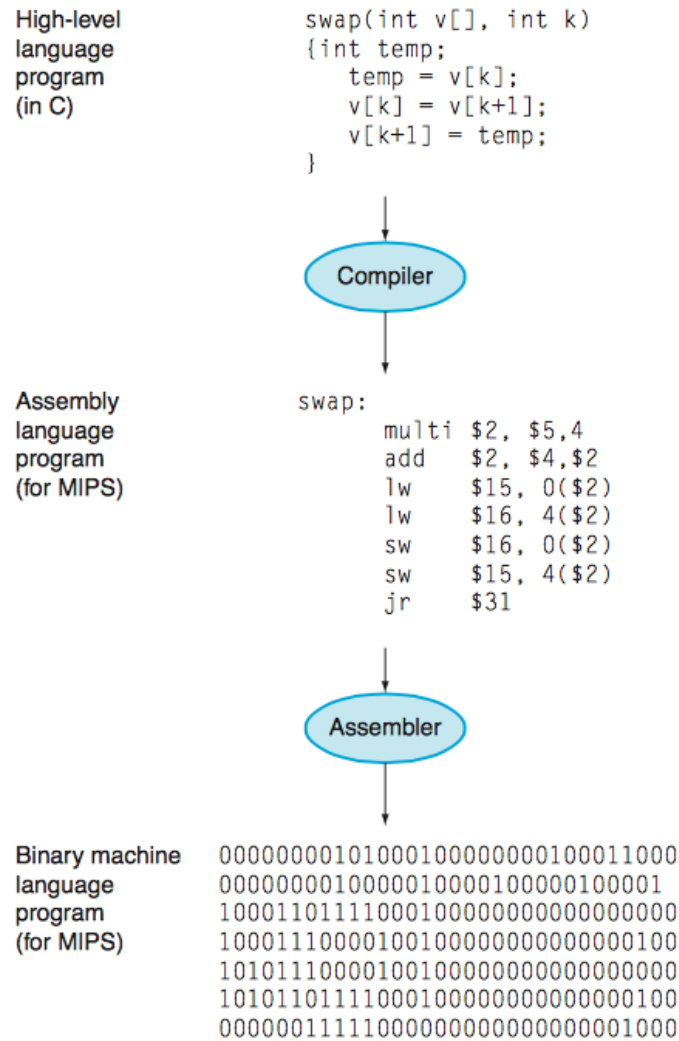


Figure 3.: Stages converting high-level language into binary machine language ²

the part that was changed must be processed again. And like that, both tasks (edition and compilation) are done synchronously at the same time and having an editor which compiles cleverly.

Finally, exhaustive and relevant tests will be made with the tool created and, the outcomes will be analyzed and discussed.

COMPILER DEVELOPMENT

Earlier in the history of computers, software was primarily written in assembly language. Due to the low productivity of programming assembly code, researchers invented a way that add some more productivity and flexibility for programmers; they created the compiler allowing to wire programs in high level programming languages.

A compiler is a software program which converts a high-level programming language (source code) into a lower level programing language for the target machine (known as machine code or assembly language).

The compiler task is divided into several steps (see Figure 4):

1. Lexical analysis
2. Syntactic analysis or parsing
3. Semantic analysis
4. Optimization
5. Code generation

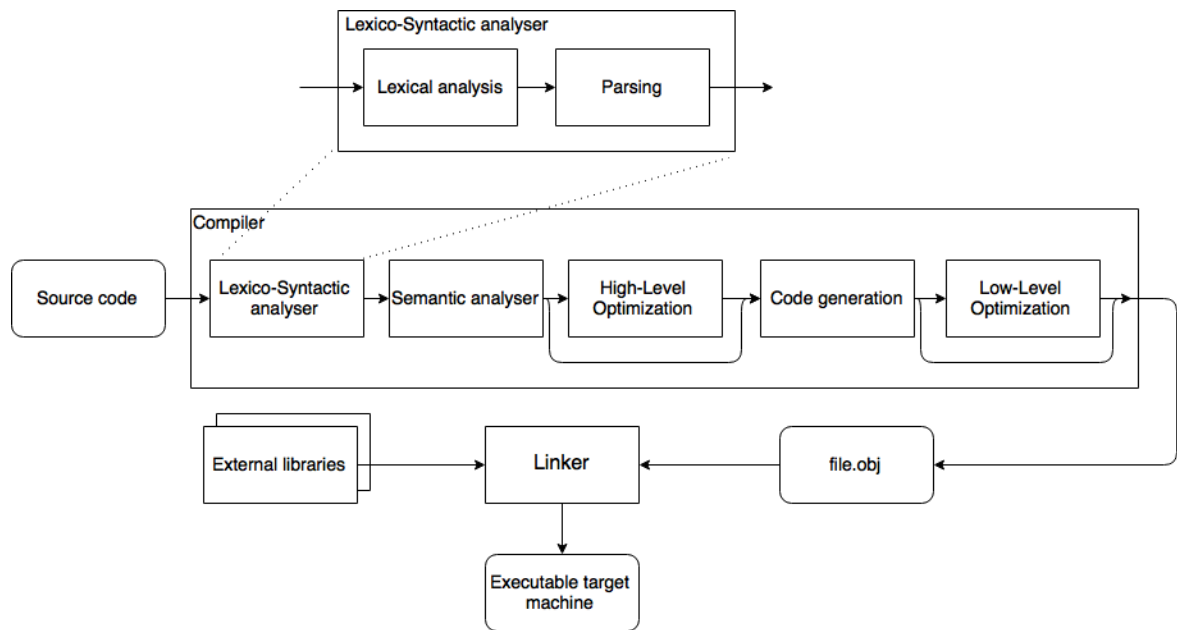


Figure 4.: Traditional compiler

The task of constructing a compiler for a particular source language is complex. Firstly, the lexical analysis must recognize words; these words are a string of symbols each of which is a letter, a digit or a special character.

The Lexical analysis divides program text into "words" or "tokens" and once words are identified, the next step is to understand sentence structure (role of the parser). We can think the parsing as an analogy of our world by constructing phrases which requires a subject, verb and object. So, basically, the parser do a diagramming of sentences (see Figure 5). Once the sentence structure is understood, we must extract the "meaning" with the semantic analyzer. The duty of the semantic analyzer is to perform some semantic analysis to catch some inconsistencies. Finally, after that, it may or may not have some optimization regarding the source code. Then the code generator translates the intermediate representation of the high-level programming into assembly code (lower level programming).

5.1. Compiler generation with ANTLR

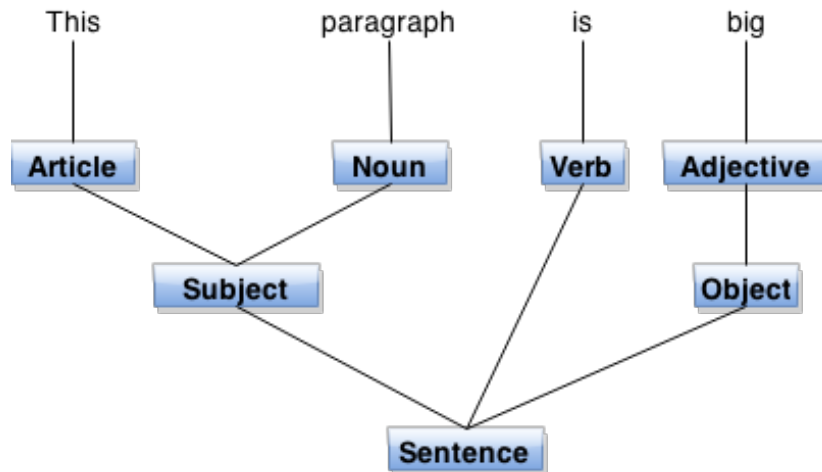


Figure 5.: Parsing

5.1 COMPILER GENERATION WITH ANTLR

Terence Parr, the man who is behind ANTLR (ANother Tool for Language Recognition (Parr, 2007, 2005)) made a parser (or more precisely, a compiler) generator that reads a context free grammar, a translation grammar, or an attribute grammar and produces automatically a processor (based on a LL(k) recursive-descent parser) for the language defined by the input grammar.

An ANTLR specification is composed by two parts : the one with all the grammar rules and the other one with lexer grammar.

Listing 5.1 is the one with the grammar rules; in that case it is an example of an AG.

```
1 facturas : fatura +
2          ;
3 fatura   : 'FATURA' cabec 'VENDAS' corpo
4          ;
5 cabec    : numFat idForn 'CLIENTE' idClie
6          { System.out.println("FATURA num: " + $numFat.text); }
7          ;
8 numFat   : ID
9          ;
10 idForn   : nome morada 'NIF:' nif 'NIB:' nib
```

Listing 5.1: AG representation on ANTLR

On the other hand, the lexer grammar defines the lexical rules which are regular expressions as can be seen in Listing 5.2. They define the set of possible character sequences that

5.1. Compiler generation with ANTLR

are used to form individual tokens. A lexer recognizes strings and for each string found, it produces the respective tokens.

```

1  /*----- Lexer -----*/
2
3  ID   :   ( 'a' .. 'z' | 'A' .. 'Z' | '_' ) ( 'a' .. 'z' | 'A' .. 'Z' | '0' .. '9' | '_' | '-' ) *
4
5
6  NUM :   '0' .. '9' +

```

Listing 5.2: Lexer representation

The parser generator by ANTLR will be able to create an abstract syntax tree (AST) which is a tree representation of the abstract syntactic structure of source code written in a programming language (see Figure 6).

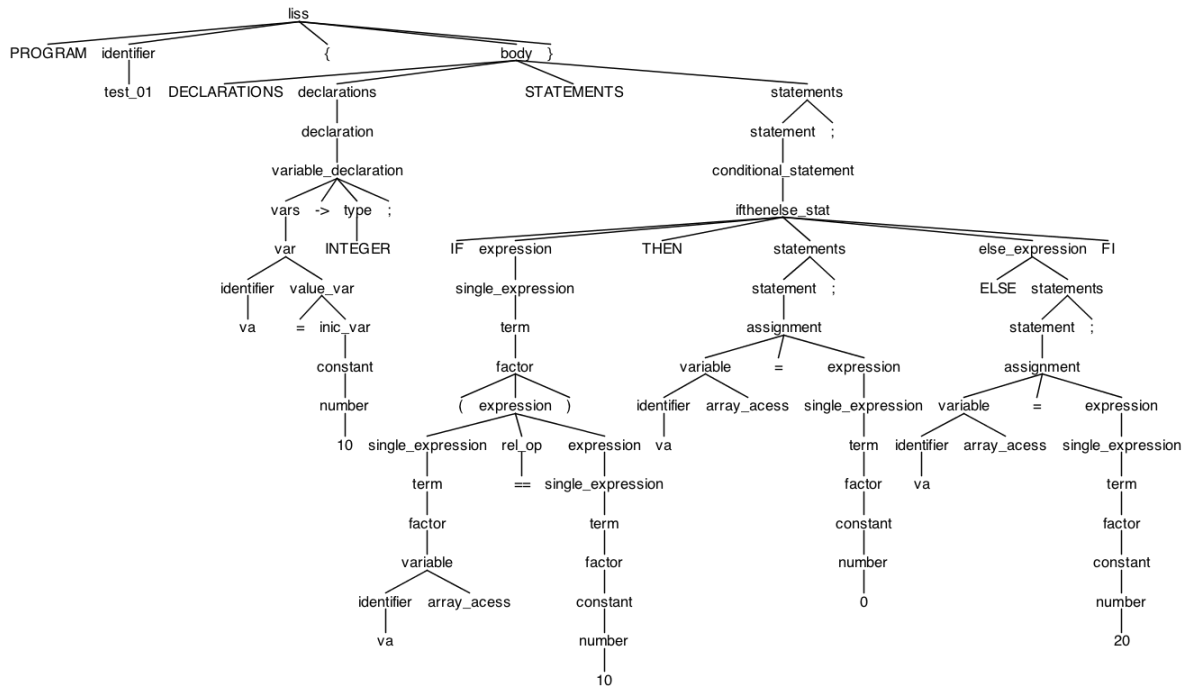


Figure 6.: AST representation

ANTLR will be used to generate MIPS assembly code according to the semantic rule specified in the AG for LISS language.

SDE: DEVELOPMENT

Before we try to explain the concept of a Syntax-Directed Editor (SDE) (Reps and Teitelbaum, 1989b; Ko et al., 2005; MI-students et al., 2010; Teitelbaum and Reps, 1981; Reps et al., 1986; Reps and Teitelbaum, 1989a; Arefi et al., 1989), let's start defining what is an Integrated Development Environment (IDE).

An IDE is described as a software application that provides facilities to computer programmers for software development. It consists, normally, of a source code editor, a compiler, a debugger, and others tools. IDEs are designed for maximizing the productivity of programmers with visual interface and contains, normally, an interpreter, a compiler or both (see Figure 7).

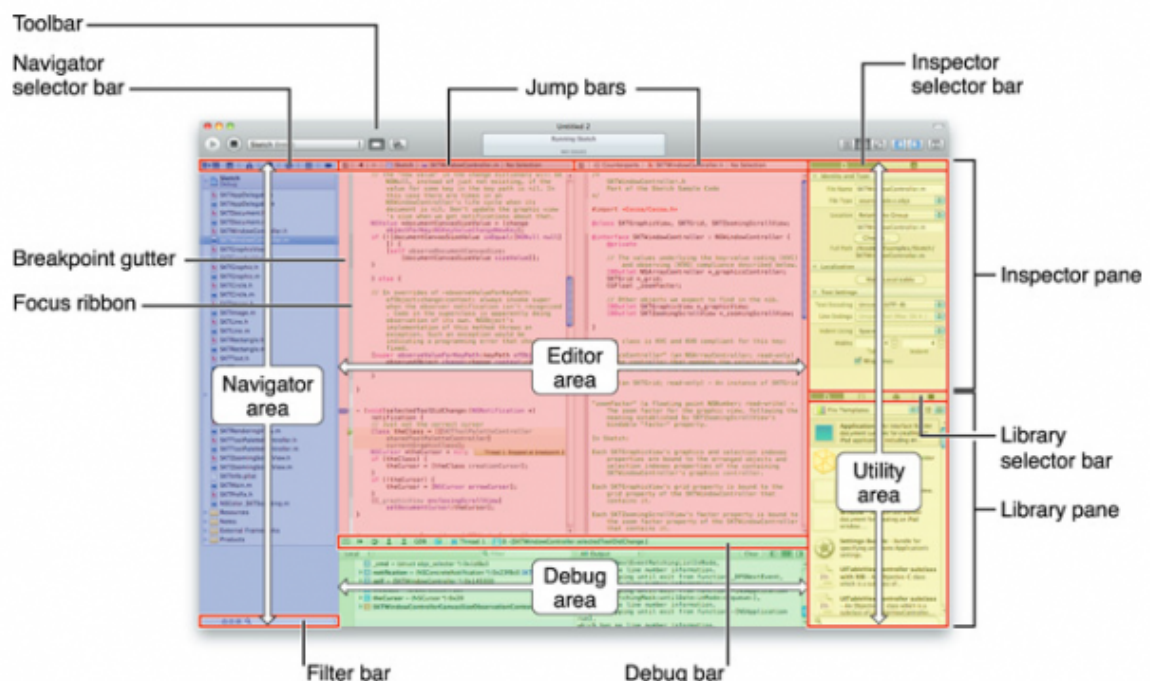


Figure 7.: Example of an IDE visual interface (XCode) ¹

6.1. What is a template?

Programs are created top down in the editor sections by inserting statements and expressions at the right cursor position of the current syntactic template and we can, by the cursor, change simply from one line of text to another one.

A SDE has the same approach of an IDE which is (as said above) an interactive programming environment with integrated facilities to create, edit, execute and debugging programs. The difference between them is that SDE encourages the program writing at a high level of abstraction, and promotes the programming based on a step by step refinement process.

It liberates the user from knowing the language syntactic details while editing programs.

SDE is basically guided by the syntactic structure of a programming language in both editing and execution. It is a hybrid system between a tree editor and a text editor.

The notion of cursor is really important in the context of SDE because, when the editing mode is on, the cursor is always located in a placeholder of a correct template (see next section) and the programmer may only change to another correct template at that placeholder or to its constituents.

It reinforces the idea that the program is a hierarchical composition of syntactic objects, rather than a sequence of characters.

6.1 WHAT IS A TEMPLATE?

The grammar of a programming language is a collection of production (or derivation rules) that state how a non-terminal symbol (LHS) is decomposed in a sequence of other symbols (RHS). A template is just the RHS of a grammar rule. Templates cannot be altered, they have placeholders for inserting a phrase or another template and they are generated by editor commands, according to the grammar production.

```
1 IF( condition )  
2   THEN statement  
3   ELSE statement
```

Listing 6.1: Example of a IF Conditional template

In Listing 6.1 we can see the editor template for the if-statement, where *condition* and *statement* are placeholders.

The notion of template is very important because templates are always syntactically correct for two reasons:

1. First, the command is validated to guarantee that it inserts a template permitted.
2. Second, the template is not typed, so it contains no lexical errors.

6.2. Conception of the SDE

So a correct program (i.e., a valid sentence of the programming language) is created by choosing templates and replacing placeholders by others templates or by concrete values (numeric or string constants or identifiers).

To clarify the definition of SDE, we will explain it with the help of an example.

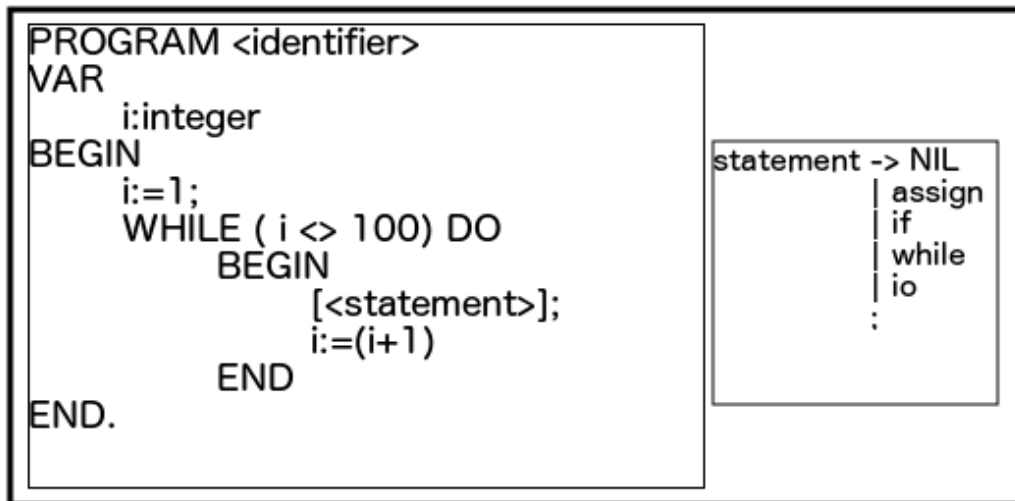


Figure 8.: SDE example

Figure 8 shows the main window of a standard Syntax-Directed Editor. In this figure, two boxes are displayed. The left one is the editor window where we code the program, and the right one exhibits templates choices.

Every <...> tag represents a placeholder, and [...] represents the actual cursor position.

As the cursor changes its position, moving from one placeholder to another placeholder, the right box will be updated according to the grammar rules in the context of the new cursor position. In this example, the cursor in Figure 8 is placed at the placeholder corresponding to a *statement*; at the same time, the right box will be updated with all the possible templates according to the *statement* derivation rules (RHS).

To sum up, this is how a SDE works.

6.2 CONCEPTION OF THE SDE

CONCLUSION

7.1 FUTUR WORK

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LISS CONTEXT FREE GRAMMAR

LISS (da Cruz and Henriques, 2007a) is an imperative programming language, defined by the Language Processing members (Pedro Henriques and Leonor Barroca) at UM for teaching purposes. It allows handling integers, sets of integers, dynamic sequences, complex numbers, polynomials, etc., etc (da Cruz and Henriques, 2007b,a, 2006a,b, 2005).

The idea behind the design of LISS language was to create a simplified version of the more usual imperative languages although combining functionalities from various languages.

```
1 grammar LissGIC ;
2
3 /* ***** Program ***** */
4
5 liss : 'program' identifier body
6      ;
7
8
9 body : '{'
10      'declarations' declarations
11      'statements' statements
12      '}'
13      ;
14
15 /* ***** Declarations ***** */
16
17 declarations : variable_declaration* subprogram_definition*
18              ;
19
20 /* ***** Variables ***** */
21
22 variable_declaration : vars '->' type ';'
23                      ;
24
```

```

25 vars : var ( ' , ' var ) *
26     ;
27
28 var : identifier value_var
29     ;
30
31 value_var :
32     | '=' inic_var
33     ;
34
35 type : 'integer '
36     | 'boolean '
37     | 'set '
38     | 'sequence '
39     | 'array ' 'size ' dimension
40     ;
41
42 typeReturnSubProgram : 'integer '
43                     | 'boolean '
44                     ;
45
46 dimension : number ( ' , ' number ) *
47     ;
48
49 inic_var : constant
50     | array_definition
51     | set_definition
52     | sequence_definition
53     ;
54
55 constant : sign number
56     | 'true '
57     | 'false '
58     ;
59
60 sign :
61     | '+'
62     | '-'
63     ;
64
65 /* ***** Array definition ***** */
66
67 array_definition : '[' array_initialization ']'

```

```

68         ;
69
70 array_initialization : elem (',' elem)*
71                     ;
72
73 elem : number
74     | array_definition
75     ;
76
77 /* ***** Sequence definition ***** */
78
79 sequence_definition : '<<' sequence_initialization '>>'
80                     ;
81
82 sequence_initialization :
83                         | values
84                         ;
85
86 values : number (',' number )*
87         ;
88
89 /* ***** Set definition ***** */
90
91 set_definition : '{' set_initialization '}'
92               ;
93
94 set_initialization :
95                     | identifier '|' expression
96                     ;
97
98 /* ***** SubProgram definition ***** */
99
100 subprogram_definition: 'subprogram' identifier '(' formal_args ')'
101                      return_type f_body
102                      ;
103
104 f_body : '{'
105         'declarations' declarations
106         'statements' statements
107         returnSubPrg
108         '}'
109         ;

```

```

110 /* ***** Formal args ***** */
111
112 formal_args :
113     | f_args
114     ;
115
116 f_args : formal_arg (',' formal_arg)*
117     ;
118
119 formal_arg : identifier '->' type
120     ;
121
122 /* ***** Return type ***** */
123
124 return_type :
125     | '->' typeReturnSubProgram
126     ;
127
128 /* ***** Return ***** */
129
130 returnSubPrg :
131     | 'return' expression ';'
132     ;
133
134 /* ***** Statements ***** */
135
136 statements : statement*
137     ;
138
139 statement : assignment ';'
140     | write_statement ';'
141     | read_statement ';'
142     | conditional_statement
143     | iterative_statement
144     | function_call ';'
145     | succ_or_pred ';'
146     | copy_statement ';'
147     | cat_statement ';'
148     ;
149
150 /* ***** Assignment ***** */
151
152 assignment : designator '=' expression

```



```

153         ;
154
155 /* ***** Designator ***** */
156
157 designator : identifier array_access
158             ;
159
160 array_access :
161             | '[' elem_array ']'
162             ;
163
164 elem_array : single_expression (',' single_expression)*
165             ;
166
167 /* ***** Function call ***** */
168
169 function_call : identifier '(' sub_prg_args ')'
170               ;
171
172 sub_prg_args :
173             | args
174             ;
175
176 args : expression (',' expression)*
177       ;
178
179 /* ***** Expression ***** */
180
181 expression : single_expression ( rel_op single_expression )?
182            ;
183
184 /* ***** Single expression ***** */
185
186 single_expression : term ( add_op term )*
187                   ;
188
189 /* ***** Term ***** */
190
191 term : factor ( mul_op factor )*
192       ;
193
194 /* ***** Factor ***** */
195
196 factor : inic_var

```

```

196         | designator
197         | '(' expression ')'
198         | '!' factor
199         | function_call
200         | specialFunctions
201     ;
202
203 specialFunctions : tail
204                 | head
205                 | cons
206                 | member
207                 | is_empty
208                 | length
209                 | delete
210             ;
211
212 /* ***** add_op , mul_op , rel_op ***** */
213
214 add_op : '+'
215       | '-'
216       | '||'
217       | '++'
218     ;
219
220 mul_op : '*'
221       | '/'
222       | '&&'
223       | '**'
224     ;
225
226 rel_op : '=='
227       | '!='
228       | '<'
229       | '>'
230       | '<='
231       | '>='
232       | 'in'
233     ;
234
235 /* ***** Write statement ***** */
236
237 write_statement : write_expr '(' print_what ')'
238               ;

```

```

239
240 write_expr : 'write'
241             | 'writeln'
242             ;
243
244 print_what :
245             | expression
246             ;
247
248 /* ***** Read statement ***** */
249
250 read_statement : 'input' '(' identifier ')'
251                ;
252
253 /* ***** Conditional & Iterative ***** */
254
255 conditional_statement : if_then_else_stat
256                      ;
257
258 iterative_statement : for_stat
259                     | while_stat
260                     ;
261
262 /* ***** if_then_else_stat ***** */
263
264 if_then_else_stat : 'if' '(' expression ')'
265                   'then' '{' statements '}'
266                   else_expression
267                   ;
268
269 else_expression :
270                 | 'else' '{' statements '}'
271                 ;
272
273 /* ***** for_stat ***** */
274
275 for_stat : 'for' '(' interval ')' step satisfy
276           '{' statements '}'
277           ;
278
279 interval : identifier type_interval
280           ;
281

```

```

282 type_interval : 'in' range
283               | 'inArray' identifier
284               ;
285
286 range : minimum '..' maximum
287       ;
288
289 minimum : number
290         | identifier
291         ;
292
293 maximum : number
294         | identifier
295         ;
296
297 step :
298     | up_down number
299     ;
300
301 up_down : 'stepUp'
302         | 'stepDown'
303         ;
304
305 satisfy :
306         | 'satisfying' expression
307         ;
308
309 /* ***** While_Stat ***** */
310 while_stat : 'while' '(' expression ')'
311            '{' statements '}'
312            ;
313
314 /* ***** Succ_Or_Predd ***** */
315
316 succ_or_pred : succ_pred identifier
317             ;
318
319 succ_pred : 'succ'
320           | 'pred'
321           ;
322
323 /* ***** SequenceOper ***** */
324

```

```

325 tail // tail : sequence -> sequence
326       : 'tail' '(' expression ')'
327       ;
328
329 head // head : sequence -> integer
330       : 'head' '(' expression ')'
331       ;
332
333 cons // integer x sequence -> sequence
334       : 'cons' '(' expression ',' expression ')'
335       ;
336
337 delete // del : integer x sequence -> sequence
338         : 'del' '(' expression ',' expression ')'
339         ;
340
341 copy_statement // copy_statement : seq x seq -> void
342               : 'copy' '(' identifier ',' identifier ')'
343               ;
344
345 cat_statement // cat_statement : seq x seq -> void
346              : 'cat' '(' identifier ',' identifier ')'
347              ;
348
349 is_empty // is_empty : sequence -> boolean
350          : 'isEmpty' '(' expression ')'
351          ;
352
353 length // length : sequence -> integer
354        : 'length' '(' expression ')'
355        ;
356
357 /* ***** set_oper ***** */
358
359 member // isMember : integer x sequence -> boolean
360        : 'isMember' '(' expression ',' identifier ')'
361        ;
362
363
364
365 /*
+++++
*/

```

```

366
367 string : STR
368         ;
369
370 number : NBR
371         ;
372
373 identifier : ID
374           ;
375 /*
376     ++++++
377     */
378 /* ***** Lexer ***** */
379
380 NBR : ( '0' .. '9' )+
381       ;
382
383 ID : ( 'a' .. 'z' | 'A' .. 'Z' ) ( 'a' .. 'z' | 'A' .. 'Z' | '0' .. '9' | '-' ) * //removi o uso
384       do signal '-' conflitos com os valores do signal
385       ;
386
387 WS : ( [ \t\r\n ] | COMMENT ) -> skip
388
389 STR : ' ' ( ESC_SEQ | ~( ' ' ) ) * ' '
390       ;
391
392
393 fragment
394 COMMENT
395     : '/*'.*?'*/' /* multiple comments */
396     | '//' ~( '\r' | '\n' ) * /* single comment */
397     ;
398
399 fragment
400 ESC_SEQ
401     : '\\ ' ( 'b' | 't' | 'n' | 'f' | 'r' | '\"' | '\ ' | '\\ ' )
402     ;

```

lissGIC.g4

Auxiliary results which are not main-stream; or

Details of results whose length would compromise readability of main text; or
Specifications and Code Listings: should this be the case; or
Tooling: Should this be the case.

NB: place here information about funding, FCT project, etc in which the work is framed. Leave empty otherwise.