cfglp: A CFG (Control Flow Graph) Language Processor

(version 2.0)

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About cfglp

The language processor cfglp has been implemented for UG courses cs302+cs306: Language Processors (theory and lab) at IIT Bombay. It was designed and implemented by Uday Khedker. Tanu Kanvar refactored version 1.0 and revised it thoroughly to create version 2.0. This implementation has been made available purely for academic purposes without any warranty of any kind.

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 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.

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

Functionality of cfglp

This language processor takes as input GCC **`tree-cfg`** (control flow graph) dumps. 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 cfglp is best described by the usage printed by it:

```
 Usage: cfglp [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)
          -program  Show the complete program read by cfglp in file.prog (or
out.prog)
                    (-program option cannot be given with -tokens, -ast, or -symtab)
          -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.

Using cfglp

The required input for cfglp can be created by using GCC-4.6 by giving the command **`gcc -fdump-tree-cfg file.c`**. This would generate a dump file called **`file.c.013t.cfg`**. There are two limitations of the default cfg dump by GCC:

- GCC does not dump the declaration of global variables in the dump file.
- GCC introduces many temporary variables in the dump file
  - to hold the intermediate results so that the expressions can be broken down into smaller expressions, and

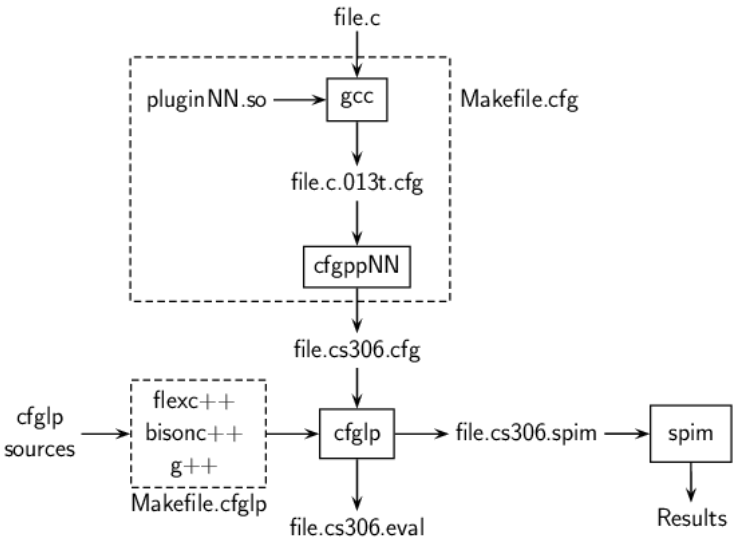
- to load the global variables and address taken variables (viewed as memory) into local variables (viewed as registers).

In order to simplify the input for cfglp, a dynamic plugin for GCC is used and the generated dump file is pre-processed using a pre-processor called cfgpp. We have provided binaries for these for both 32 bit intel based ubuntu as well as 64 bit intel based ubuntu.

Using cfglp involves the following three steps:

- Preparing the input for cfglp.
- Building cfglp.
- Executing cfglp.

These steps are illustrated in the figure below. The number NN appearing in the figure refer to 32 or 64 depending upon the word size of the machine.



The steps are explained below.

- *Preparing the input for cfglp*. This can be done using a makefile called **`Makefile.cfg`** which, given an input file **`test.c`**, invokes the dynamic plugin within GCC and pre-processes the dumps to eventually produce a cfg file called **`test.cs306.cfg`**. The Makefile assumes that **`test.c`** is present in a subdirectory called **`test_files`** and generates the **`test.cs306.cfg`** file in the same subdirectory. The command to invoke the makefile for input file **`test.c`** is: **`make FILE=test.c -f Makefile.cfg`**.

  Here is the makefile for 32 bit intel based ubuntu and for 64 bit intel based ubuntu. Note that we expect that you have gcc-4.6 installed on your machine. The dumps created by other versions of GCC may be slightly different and may have to be modified to meet the cfglp requirements.

- *Building cfglp*. This can be done using a makefile called **`Makefile.cfglp`**. The command to invoke this makefile is: **`make -f Makefile.cfglp`**.

  Here is the makefile for 32 bit intel based ubuntu and for 64 bit intel based ubuntu.

- Executing cfglp. The command to run cfglp on a cfg file generated in the first step is: **`./cfglp test_files/test.cs306.cfg`**.

Please see the **`README`** and **`USER-MANUAL`** files for more details.

Assignment Involving Enhancing cfglp 0

At the moment cfglp accepts *level 0* language that defines pre-processed cfg dumps corresponding to C programs that consist 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 can have a return statement but cannot return a value. Thus it does not have a return type.
  - 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 executatable statements. Thus there are no assignments in declarations.

For examples of valid and invalid inputs, please see the **test_files** directory.

- The **.c** files are valid test cases. These when passed through cfgpp produce a corresponding **.cs306.cfg** file. These files in turn when used as input to cfglp produce a valid output.
- The **.ecfg** file are invalid test cases. These have been created by manually editing the GCC generated files because GCC does not generate an invalid dump. The **.ecfg** files when passed as input to cfglp will either reject the files or will give invalid output.

The subsequent levels are defined by incrementally enhancing the input language given to GCC as follows:

1. *Level 1*. This level extends level 0 by supporting intraprocedural control flow statements and evaluation of conditions in the following ways:
    - Conditional expression ***e1?e2:e3***, **while**, **do-while**, **for**, **if**, and **if-else** statements may exists in the C source program.
    - **switch** and **goto** statements are not present in the C program.
    - The boolean conditions controlling the control flow consist of the six comparison operators (**<**, **<=**, **>**, **>=**, **==**, and **!=**) and three logical operators (**&&**, **||**, and **!**).
    - The values used for comparison are only integer values.
    - The comparison expressions can also appear on the right hand sides of assignment statements.
    - In some cases, GCC optimizes a statement
        - **A = (A < B) ? A : B;** to **A = MIN_EXPR <B, A>;**
        - **A = (A > B) ? A : B;** to **A = MAX_EXPR <B, A>;**

      such optimizations are not expected to be handled.

    Note that in the absence of expression computations (which are supported in level 2), loops in level 1 are not very meaningful logically because there is no way of maintaining loop counts.

2. *Level 2*. 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.
    - We restrict cfglp to only those input C programs in which,
        - arithmetic expressions using +, -, *, / and unary -, are translated by GCC in such a manner that the result expressions also contain only these operators. So the expressions for which gcc performs optimizations using bit wise operations (such as shifts, negates etc.) are excluded, and
        - no type casts exist in the C program. Note that type casts may exist in the **.cfg** file generated by GCC, and hence in the file generated by cfgpp).

3. *Level 3*. This level extends Level 2 by supporting function calls (including recursion). In this level, we have multiple functions. Besides, the functions may take arguments and may return results.

4. *Level 4*. This level extends Level 3 by supporting data and procedure encapsulation supported by classes.

It may be advisable to implement the above enhancements in smaller steps in the increasing order of complexity. A possible sequence of assignments focussed in each step could be defined as follows:

- Group A: Extend the interpreter to levels 1, 2, and 3.
- Group B: Extend the compiler to levels 1, 2, and 3.
- Group C: Extend the interpreter to level 4.
- Group D: Extend the compiler to level 4.

Reference Implementations

In order to help check your implementation, executables of reference implementation for different levels will be provided as the semester progresses. Currently, the reference implementation for Level 1 interpreter has been provided.

Level 1 Interpreter		***Level 2 Interpreter***		***Level 3 Interpreter***	
32 bit intel ubuntu	*64 bit intel ubuntu*	*32 bit intel ubuntu*	*64 bit intel ubuntu*	*32 bit intel ubuntu*	*64 bit intel ubuntu*
Tarball	Tarball	Tarball	Tarball	Tarball	Tarball
gcc-4.6 plugin	gcc-4.6 plugin	gcc-4.6 plugin	gcc-4.6 plugin	gcc-4.6 plugin	gcc-4.6 plugin
pre-processor cfgpp	pre-processor cfgpp	pre-processor cfgpp	pre-processor cfgpp	pre-processor cfgpp	pre-processor cfgpp
cfglp executable	cfglp executable	cfglp executable	cfglp executable	cfglp executable	cfglp executable
Makefile.cfg	Makefile.cfg	Makefile.cfg	Makefile.cfg	Makefile.cfg	Makefile.cfg
Test files	Test files	Test files	Test files	Test files	Test files

README file	README file	README file	README file	README file	README file
User Manual	User Manual	User Manual	User Manual	User Manual	User Manual

Level 1 Compiler	
32 bit intel ubuntu	*64 bit intel ubuntu*
Tarball	Tarball
gcc-4.6 plugin	gcc-4.6 plugin
pre-processor cfgpp	pre-processor cfgpp
cfglp executable	cfglp executable
Makefile.cfg	Makefile.cfg
Test files	Test files
README file	README file
User Manual	User Manual

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

Design of cfglp level 0

Cfglp 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 cfglp 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 0 Grammar

A program consists of a sequence of a declaration statement list which is a list of global variables, a procedure name, and finally the procedure body (in level 0 we have a single procedure).

```
program: declaration_statement_list
         procedure_name
         procedure_body
       | procedure_name
         procedure_body
       ;
```

The first rule matches if the program contains global variables, otherwise the second rule matches. 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 0 we have only one procedure).

Our procedure header indicates that 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
list of declarations followed by a list of basic blocks.

```
procedure_name: NAME '(' ')'
              ;

procedure_body: '{'
                    declaration_statement_list
                    basic_block_list
                '}'
              | '{'
                    basic_block_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 list of basic blocks.

The declaration statement list is defined recursively as follows:

```
declaration_statement_list: declaration_statement_list
                            declaration_statement
                          | declaration_statement
                          ;
     declaration_statement: 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 0) 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.

A basic block is a labelled list of groups of executable statements.

```
basic_block_list: basic_block_list
                  basic_block
                | basic_block
                ;
     basic_block: BB_NUMBER
                  executable_statement_list
                ;
```

In the current level we have only assignment statements and an optional return statement.

```
executable_statement_list: assignment_statement_list
                         | assignment_statement_list
                           RETURN
                         ;
```

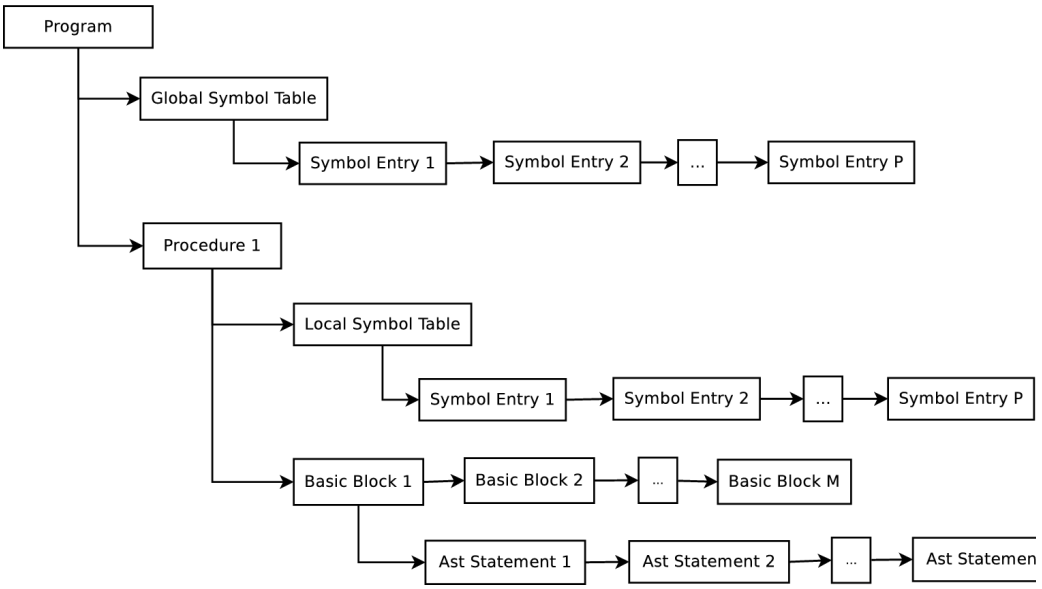
At level 0 an assignment statement can involve only a variable or an integer number on the right hand side and only a variable on the left hand side.

```
assignment_statement_list : /* empty */
                          | assignment_statement_list
                            assignment_statement
                          ;
     assignment_statement : variable ’=’ variable ’;’
                          | variable ’=’ 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 0 Data Structures

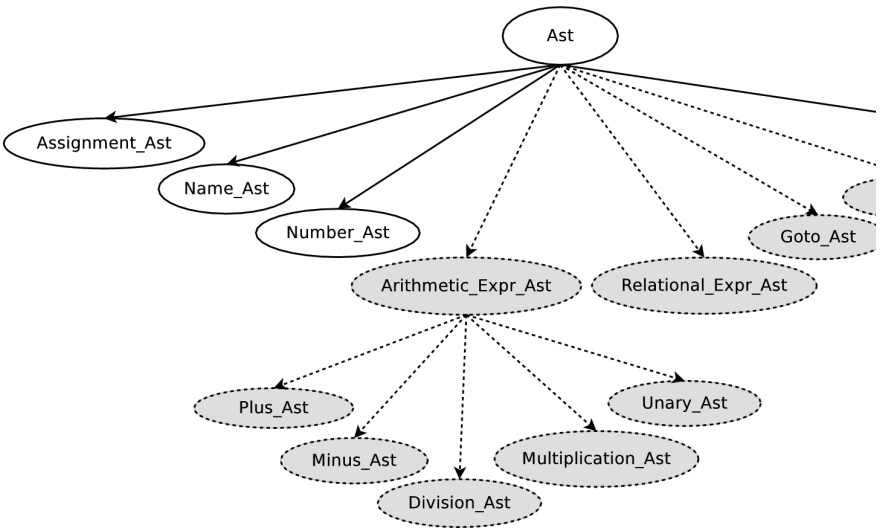
The data structure of the interpreter for Level 0 is as shown below:



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 0: **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 0 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 0 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_BB`** (used to store the targets of gotos in level 1). We also derive classes **`Eval_Result_Value_Int`** and **`Eval_Result_Value_Float`** (this distinction will be required in level 2).

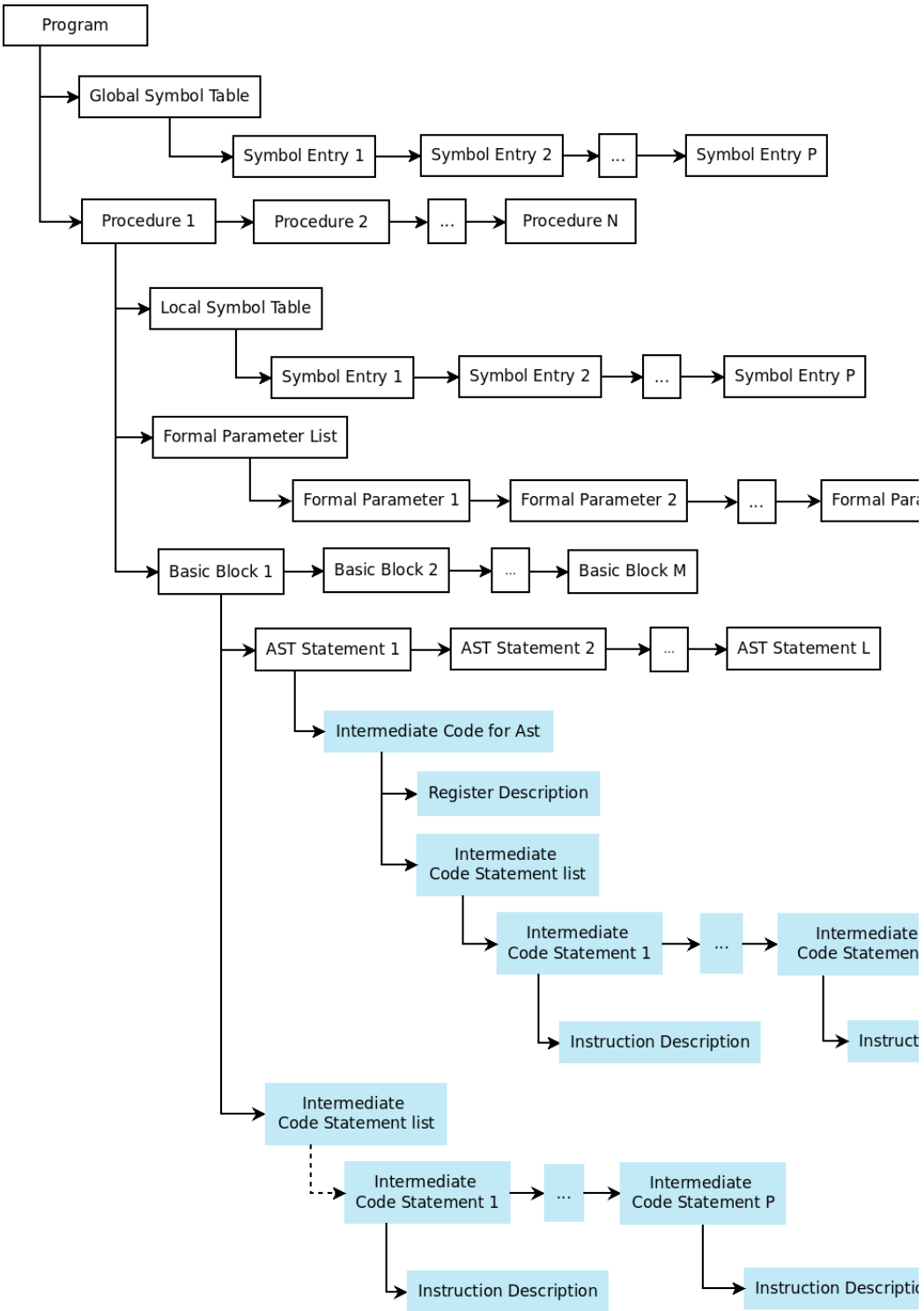
Level 0 Compilation

Compilation requires successful construction of ASTs for the entire program submitted to cfglp. It is performed by traversing the basic blocks and visiting each AST in the basic block. In interpretation, the next basic block to be interpreted depends on the result of interpretation of the current basic block. Compilation, on the other hand, follows the lexical ordering of basic block. (Similarly, when multiple function and function calls are included in cfglp level 3, inerpretation starts from the main function and the interpretation of caller and callee functions are interleaved. Compilation proceeds independently.)

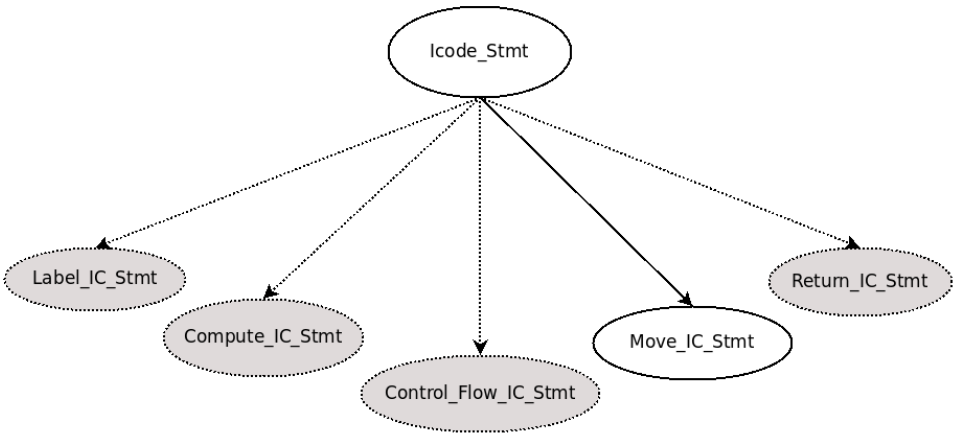
Compilation proceeds in two steps.

- 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 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 0, 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 activiation 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 cfglp 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 cfglp has some limitations which we expect to overcome in subsequent versions. We welcome more additions to the following list.

- Supporting loops in level 1 in the absence of expression computation is not something very meaningful. Ideally, loops should be moved from level 1 to level 2.
- 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 are not clear the extent to which the error files (**`.ecfg`** files) are useful because cfglp input is a generated file and trying to prohibit error situation seems to make the code very difficult to understand. We still don't know what is the golden mean.
- We would like to introduce an optimizer generator which works with cfglp to allow the users to specify analyses and transformations declaratively and automatically construct optimizers that work within cfglp.

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 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 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 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] << "'
.           { std::cout << "Found an unrecoganized character '" << matched()[0] << "'\
```

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

Using Flex++ 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 scanner 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 express`
	`;`

	exp2.yy
	`%start E`
	`%token NUM`
	`%%`
	`E : NUM { cout << "found an expres`
	`| E '+' E { cout << "found a plus ex`
	`;`

	exp3.yy
	`%start E`
	`%token NUM`
	`%left '+'`
	`%%`
	`E : NUM { cout << "found an express`
	`| E '+' E { cout << "found a plus exp`
	`;`

	exp4.yy
	`%start E`
	`%token NUM`
	`%left '+'`
	`%left '*'`
	`%%`
	`E : NUM { cout << "found an express`
	`| E '+' E { cout << "found a plus exp`
	`| E '*' E { cout << "found a mult exp`
	`;`

	exp5.yy
	`%start E`
	`%token NUM`
	`%left '+' '-'`
	`%left '*' '/'`
	`%%`
	`E : NUM { cout << "found an express`
	`| E '+' E { cout << "found a plus exp`
	`| E '*' E { cout << "found a mult exp`
	`| E '-' E { cout << "found a sub expr`
	`| E '/' E { cout << "found a div expr`

```
                                        ;
```

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

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);
        }

%%
```

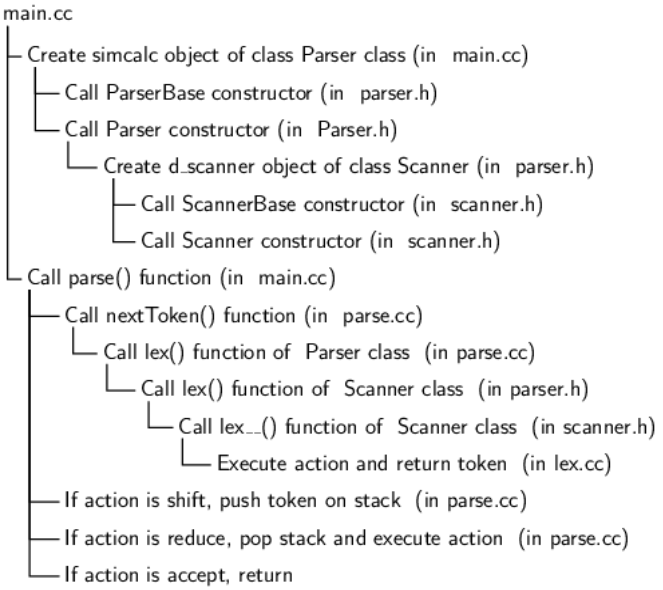
```
%token NUM

%start Start

%left '+'
%left '*'

%%

Start : Expr '\n'
      ;
Expr : Expr '+' Expr
     | Expr '*' Expr
     | NUM
     ;
```

Please download the tarball or see the files.

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**.

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 Parser
{
    // $insert scannerobjec
    Scanner d_scanner;

    public:
        int parse();

    private:
        void error(char con
        int lex();

        void print();

    // support functions fo
        void executeAction(
        void errorRecovery(
        int lookup(bool rec
        void nextToken();
};
```

Manually updated classes (see the lines in red) to enable transfer of values from the Scanner to t

```
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();
```

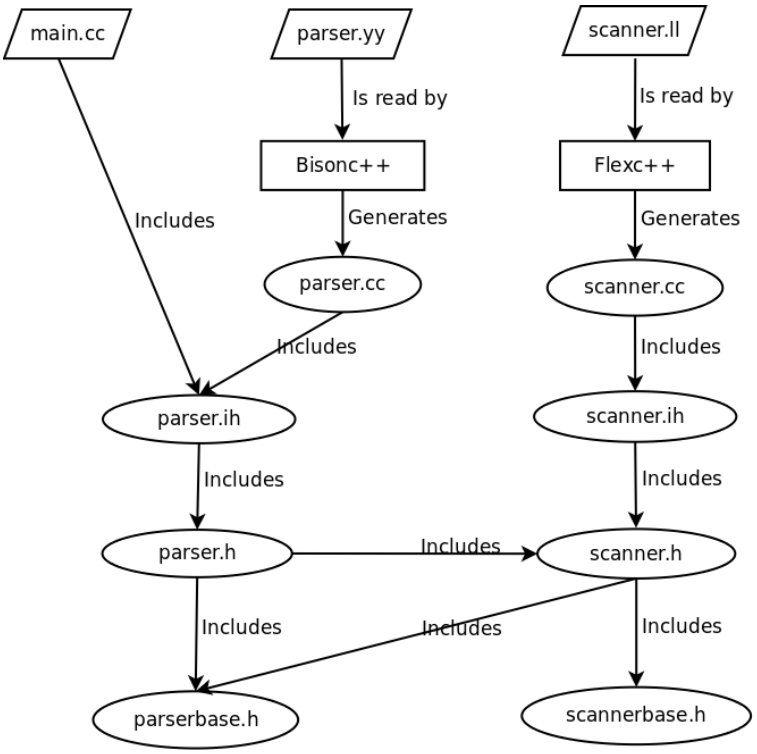
```
class Parser: public Parser
{
    // $insert scannerobjec
    Scanner d_scanner;

    public:
        Parser()
        {
                d_scanner.s
        }

        int parse();

    private:
        void error(char con
        int lex();

        void print();
    // support functions fo
        void executeAction(
        void errorRecovery(
```

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

};
```

```
        int lookup(bool rec
        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++

The only flip side of using flexc++ and bisonc++ is that they require multiple steps for installation. Our system administrators have installed them in all machines in NSL. If you want to install them on your machines, please read on.

The steps for installing Flexc++ and Bisonc++ on ubuntu (12.04+) 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**.