LIVA

A Lite Version of Java

Shanqi Lu	Jiafei Song	Zihan Jiao	Yanan Zhang	Hyoyoon Kate Kim
sl4017	js4984	zj2203	yz3054	hk2870

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Chapter 1 Introduction

Liva is a general-purpose programming language and a lite version of Java. Having realized that the focus of this project should be applying compiler design theories in practice rather than innovation, we decided to develop a language that has the similar syntax and abstract data types in Java. Past projects related to general-purpose languages all have their own interesting features like Cpi (2013) implemented a data type called “struct” and Dice (2015) developed their own version of inheritance mechanism. Our preference is to develop some basic features and object-oriented model that resembles Java. This language is compiled down to LLVM.

Unlike domain-specific programming languages are designed for specific fields, our language is designed for general purpose, hence serving as a portable language that runs on many platforms as long as LLVM is runnable. Programs written in Liva will look like Java in many ways including variable declaration and class declaration. Common algorithms like GCD can be easily implemented using our language.

Chapter 2 Language Tutorial

2.1 Environment Setup

This compiler has been built and tested on Ubuntu 16.04 and OSX. Prerequisites include OCaml, LLVM, Opam, etc. Instructions on how to install the necessary packages under Ubuntu 16.04 is shown below:

```
sudo apt-get install -y ocaml m4 llvm opam
opam init
opam install llvm.3.6 ocamlfind
eval `opam config env`
```

For installation under OS X, please refer to the MicroC compiler’s README file which can be found at http://www.cs.columbia.edu/~sedwards/classes/2016/4115-summer/index.html

2.2 Run and test

First, make sure that you are in the “Liva” root directory. To test the compiler by using the test suit, follow the instructions below:
$ make liva
-ocamlfind ocamlopt -c -package llvm ast.ml

-ocamlfind ocamlopt -c -package llvm sast.ml
-ocamlyacc parser.mly
-ocamlc -c ast.ml
-ocamlc -c parser.mli
-ocamlfind ocamlopt -c -package llvm parser.ml
-ocamllex scanner.mll
127 states, 6605 transitions, table size 27182 bytes
-ocamlfind ocamlopt -c -package llvm scanner.ml
-ocamlfind ocamlopt -c -package llvm semant.ml
-ocamlfind ocamlopt -c -package llvm codegen.ml
-ocamlfind ocamlopt -c -package llvm liva.ml
-ocamlfind ocamlopt -linkpkg -package llvm -package llvm.analysis ast.cmx sast.cmx parser.cmx
-scanner.cmx semant.cmx codegen.cmx liva.cmx -o liva

You may need to run “chmod +x testall.sh” to unlock the shell script.
$ ./testall.sh
-n test-add...
OK
-n test-and...
OK
...
-n fail-sub...
OK
-n fail-while1...
OK

2.3 Hello World

To test a simple “Hello World” program, you need to:
1 compile the compiler (this have already been done using “make liva” in the previous step)
2 output generated LLVM IR code to a “*.ll” file
3 run “*.ll” file

hello_world.liva:

```
class test {
  void main () {
    print ("Hello World!\n");
  }
}
```

Copy the above code to an empty file named “hello_world.liva”, then run:

$ ./liva < hello_world.liva > hello_world.ll
$ lli hello_world.ll

This should print out the desired result “Hello World!”.

2.4 Another small program

This is an example to show that Liva supports object-oriented paradigm. Write another small program and test it.

test.liva:

```
class calculator{
    int addition(int x, int y){
        int z;
        z = x + y;
        return(z);
    }
}

class test {
    void main(){
        int result;
        class calculator obj = new calculator();
        result = obj.addition(31,79);
        print ("result=",result,"\n");
    }
}
```

$ ./liva < test.liva > test.ll
$ lli test.ll
result=110

Chapter 3 Language Manual

3.1 INTRODUCTION

Liva is a general purpose programming language and a lite version of Java. It is designed to let programmers who are familiar with class-based languages to feel comfortable with developing common algorithms like GCD. It is lite in the sense that it maintains some but not all features in Java. It has the similar syntax and abstract data types in Java and supports object-oriented paradigm and inheritance. However, generics and nested classes are beyond the scope of this project, hence they are not to be implemented.

The Liva programming language is strongly typed. The compiler checks whether arguments passed to a function match expected types and return an error if not. It is a portable language and compiled down to LLVM.

This language reference manual is organized as follows:

- Section 3.2 describes the lexical conventions of the Liva programming language.
- Section 3.3 describes types. Types are divided into two categories: primitive types and reference types.
- Section 3.4 describes classes including class declarations and inheritance.
- Section 3.5 describes statements.
- Section 3.6 describes expressions.

3.2 LEXICAL CONVENTIONS

This chapter specifies the lexical conventions of Liva programming language. A compiler takes a program which consists of a sequence of characters and reduce it to a sequence of elements, which are tokens, white space and comments. The tokens are identifiers, keywords, literals, separators, and operators.

Element:
    White Space| Comment| Token
Token:
    Identifier| Keyword| Literal| Separator| Operator

3.2.1 White Space

White space in Liva is defined as space character, tab character, form feed character(page-breaking) and line terminator character. White space characters are ignored by a compiler except as they serve to separate tokens.

3.2.2 Comments

There is one kind of comments:
/ text */*

All characters from “/*” to “*/” are ignored.

3.2.3 Identifiers

An identifier is a sequence of letters, digits and underscore ‘_’. It can only begin with a letter. Identifiers are the names of variables, methods and classes. They are case-sensitive.

3.2.4 Keyword

Keywords are reserved and cannot be used as identifiers.

- *Keyword:*

for	*new*	*if*	*boolean*	*this*	*break*
implements	*else*	*return*	*while*	*float*	*extends*
int	*char*	*void*	*class*		

3.2.5 Literals

Literals are syntactic representations of numeric, character, boolean or string data. They are used for representing values in programs.

3.2.5.1 Boolean Literals

There are two boolean literals:

- **`true`** represents a true Boolean value
- **`false`** represents a false Boolean value

3.2.5.2 Integer Literals

Integer numbers in Liva are in decimal format. Negative decimal numbers such as `-10` are actually expressions consisting of the operator ‘–’ and integer literal. The primitive type of integer literal is **`int`**.

3.2.5.3 Floating Point Literals

Floating point numbers are expressed as decimal fractions and consist of:

- an optional ‘+’ or ‘–’ sign; if omitted, the value is positive,
- the following format

Format			Example
integer digits	.	integer digits	17.31

3.2.5.4 Character Literals

Character literals are surrounded by single quotes: `'a'`, `'#'`

3.2.5.5 String Literals

String literals begin with a double quote character `"`, followed by zero or more characters and a terminating double quote `"`
Within string literals, there can be escape sequences but not unescaped newline.

3.2.5.6 Escape Sequences for Character and String Literals

An escape sequence is used to represent a special character. It begins with a backslash character (\), which indicates that the following character should be treated specially. Escape sequences are listed in the table below.

Name	Character
TAB	\t
newline	\n
double quote	\”
single quote	\’
backslash	\\

3.2.6 Separators

Separators are symbols used for separating tokens.

{ } ( ) ; , .

3.2.7 Operators

The expression section of this manual will explain behaviors of these operators. Here is a list of all the supported operators.

```
=    >    <    !    ==   >=
<=   !=   &   |   +    -
*     \    %
```

3.3 Types

The Liva programming language supports two kinds of types: primitive types and reference types. There are also two kinds of data values: primitive values and reference values accordingly.

Primitive types are boolean types and numeric types. Reference types are class types and array types.

3.3.1 Primitive Types

Primitive types are predefined by the Liva programming language. Their names are reserved keywords.

3.3.1.1 Integral Types

The integral types are int and char.

The integer data type is a 32-bit sequence of digits, which has a minimum value of -2^31 and a maximum value of 2^31-1. An integer literal is a sequence of digits preceded by an optional negative sign. A zero value cannot be preceded by a negative sign.

```
int x = 10;
int y = -50;
int z = 0;
```

3.3.1.2 Char Types

The char data type is a single 8-bit ASCII character. Their values range from ‘0x00’ to ‘0x7F’.

```
char x = 'a';
```

3.3.1.3 Floating-Point Types

The floating-point data type is a signed-precision 32-bit format values.

```
float x = 1.5;
float y = -5.1;
```

3.3.1.4 The Boolean Type

The boolean data type has two possible values: true and false. A boolean is its own type and cannot be compared to a non-boolean variable. Therefore, expression “true == 1” would lead to an error.

```
boolean x = true;
boolean y = false;
```

3.3.2 Reference Types

There are two kinds of reference types: class types and array types.

3.3.2.1 Class types

A class type consists of an identifier which is optionally followed by parameters. A class is an extensible template for creating objects. See Chapter 6 to get more explanation about class and object.

3.3.2.2 Array types

Array is a special type. An array contains a number of elements with primitive types. All elements in an array must have the same types.

```
int[] ai;
char[] ac = { 'a', 'b', 'c', ' ' };
```

3.3.2.3 Void type

The void type is used to indicate an empty return value from a function call. For example, a main function does not have a return value. It is declared in the following way.

```
void main{ }
```

3.4 Expressions

Much of the work in a program is done by evaluating *expressions*, such as assignments to variables, or for their values, which can be used as arguments or operands in larger expressions, or to affect the execution sequence in statements, or both. This chapter specifies the meanings of expressions and the rules for their evaluation.

3.4.1 Evaluation, Denotation, and Result

Liva evaluates a larger expression by evaluating smaller parts of it. When an expression in a program is *evaluated* (*executed*), the result denotes one of three things:

- A variable

```
int a = 1;
int b;
b = a + 1;  /* returns variable */
```

- A value

```
int foo (int a){
      return a + 1;
}
foo(3);      /*returns a value*/
```

- Nothing (for void functions and methods)

```
int x = 7;
void increase (int a) {
      x = x + a;
}
increase(2); /* returns nothing */
```

An expression denotes nothing if and only if it is a method invocation that invokes a method that does not return a value, that is, a method declared void. Such an expression can be used only as an expression statement (in statement chapter), because every other context in which an expression can appear requires the expression to denote something.

If an expression denotes a variable, and a value is required for use in further evaluation, then the value of that variable is used. In this context, if the expression denotes a variable or a value, we

may speak simply of the *value* of the expression. In this way, we may say each expression denotes a value in a certain type.

3.4.2 Type of an Expression

For an expression that denotes to a variable, the value stored in a variable is always compatible with the type of the variable. In other words, the value of an expression whose type is T is always suitable for assignment to a variable of type T.

The rules for determining the type of an expression that denotes to a value are explained separately below for each kind of expression. Including arithmetic operations, relation operations, bitwise/conditional operations, assignment.

3.4.3 Evaluation Order

Liva guarantees that the operands of operators are evaluated in a specific *evaluation order*, namely, from left to right.

3.4.3.1 Left-Hand Operand First

The left-hand operand of a binary operator is fully evaluated before any part of the right-hand operand is evaluated.

3.4.3.2 Evaluate Operands before Operation

Liva guarantees that every operand of an operator (except the conditional operators &, |) is fully evaluated before any part of the operation itself is performed.

For example, in an assignment expression, the assignment will not be evaluated until the right hand operands (if it is another expression) is evaluated.

3.4.3.3 Evaluation Respects Parentheses and Precedence

Liva respects the order of evaluation indicated explicitly by parentheses and implicitly by operator precedence.

3.4.4 Lexical Literals

A literal denotes a fixed, unchanging value. This kind of expression could be evaluated without

being broken into small expressions.

The type of a literal is determined has been defined previously. Evaluation of a lexical literal always completes normally.

3.4.5 The Arithmetic Operations

The operators +, -, *, /, and % are called the arithmetic operators. An expression concatenated by an arithmetic operator is called an arithmetic expression. The value of an arithmetic expression is numeric (int or double, depends on the operands, defined previously). They have precedence of two level: *, / and % are higher than + and -. They are syntactically left-associative (they group left-to-right). The type of the arithmetic expression is the promoted type of its operands.

The type of each of the operands of arithmetic operators must be a type that is convertible to a primitive numeric type, or a compile-time error occurs. For example: adding two objects of a user-defined class with "+" is prohibited.

+	Adds values on either side of the operator
-	Subtracts right hand operand from left hand operand
*****	Multiplies values on either side of the operator
/	Divides left hand operand by right hand operand
%	Divides left hand operand by right hand operand and returns remainder

3.4.6 The Relational Operations

The value of an equality expression is always boolean. The equality operators may be used to compare two operands that are convertible to numeric int type, or two operands of type boolean. Liva does not support character comparison. All other cases result in a compile-time error.

==	Checks if the values of two operands are equal or not, if values are equal then condition becomes true.
!=	Checks if the values of two operands are equal or not, if values are not equal then condition becomes true.
>	Checks if the value of left operand is greater than the value of right operand, if yes then condition becomes true.

<	Checks if the value of left operand is less than the value of right operand, if yes then condition becomes true.
>=	Checks if the value of left operand is greater than or equal to (no less than) the value of right operand, if yes then condition becomes true.
<=	Checks if the value of left operand is less than or equal to (no greater than) the value of right operand, if yes then condition becomes true.

3.4.7 The Bitwise and Conditional Operations:

Unlike Java, Liva uses &, |, ^, ~ for both bitwise and conditional operations. That depends on the operands. The operands of a Bitwise/Conditional Operation should both be `int` or `boolean`.

&	Binary AND if both operands are `int` type / Logic AND if both operands are `boolean` type
|	Binary OR if both operands are `int` type / Logic OR if both operands are `boolean` type
^	Binary XOR if both operands are `int` type / Logic XOR if both operands are `boolean` type
~	Binary Complement if both operands are `int` type / Logic INVERT if both operands are `boolean` type

3.4.8 Method Invocation Expressions

A method/function invocation expression is used to invoke an instance method (explanation about instance and method are in the class section). The result type of the chosen method is determined as follows: If the chosen method/function is declared with a return type of void, then the result is void. Otherwise, the result type is the method/function's declared return type.

3.4.9 Array Access Expressions

An array access expression contains two subexpressions, the *array reference expression* (before the left bracket) and the *index expression* (within the brackets).

```
a[10]

/* if a is an int array, then a[10] is an array access expression that returns
a variable with an int value. */
```

Note that the array reference expression may be a name or any primary expression that is not an

array creation expression. The type of the array reference expression must be an array type. For the index expression, the promoted type must be `int`, or a compile-time error occurs.

The result of an array access expression is a variable of type T or an object, namely the variable or the object within the array selected by the value of the index expression.

3.4.10 Assignment

In Liva, the only assignment operator is "=".

The result of the first operand of an assignment operator must be a variable. This operand may be a named variable, such as a local variable or a field of the current object or class, or it may be a computed variable, as can result from a field access or an array access (defined previously).

```
int a;
a = 1; /* variable assignment */

class foo {
      int value;
      constructor(int x) {
            this.value = x    /* class field assignment */
      }
}

class foo test = new foo (2);
test.value = 3; /* object properties assignment */
```

3.5 Statements

A statement forms a complete unit of execution. All expressions of statements are explained in the following. Except as indicated, statements are executed in sequence.

3.5.1 Expression Statements

Most statements are expression statements and expression statements are usually assignments or function calls. A function call is a call to a function along with its formal arguments

```
/* Object creation expressions */
class Student e1 = new Student ();

/* Assignment expressions */
c = 8933.234;
```

3.5.2 Declaration Statements

A declaration statement declares a variable by specifying its data type and name. It also could initialize the variable during the declaring.

```
/* declare a variable with data type and name */
char a;
int b =10;
float c;

int [] array1 = new int [10] ;
float n= 3.5;

boolean isMatch = false;
```

3.5.3 Control Flow Statements

3.5.3.1 If-then and If-then-else

There are two forms of conditional statements.

For the first If-then case, the conditional expression that is evaluated is enclosed in balanced parentheses. The section of code that is conditionally executed is specified as a sequence of statements enclosed in balanced braces. If the conditional expression evaluates to false, control jumps to the end of the if-then statement.

```
if (expression) {
      statement1
      statement2
      ...
}
```

In the second If-then-else case, the second sub-statement is executed if the expression is false. In liva, for a single statement, the brackets are optional.

```
if (expression) {
      statement1
} else {
      Statement2
}
```

The following example shows how to use if-then else statement:

```
if (true){
        print(42);
        print (100);
} else {
        print(8);
}
```

3.5.3.2 Looping: for

The ‘for’ condition will also run in a loop so long as the condition specified in the ‘for’ statement is true. The ‘for’ statement has the following format:

```
for (expression1; expression2; expression 3) {
      statement
 }
```

The first expression specifies initialization for the loop and it is executed once at the beginning of the 'for' statement (liva could not accept a statement for expression1 such as int i=0); the second specifies a Boolean expression, made before each iteration, such that the loop is terminated when the expression becomes false; the third expression specifies an operation which is performed after each iteration.

The following example uses a ‘for’ statement to print the numbers from 0 to 10:

```
int num;
for (num=0; num < 11; num ++) {

    print(num);
}
```

3.5.3.3 Looping: while

The ‘while’ statement has the form:

```
while(expression) {
      statement
}
```

The ‘while’ statement will be executed in a loop as long as the specified condition in the while statement is true. The expression must have type boolean, or a compile-time error occurs.

- If the value for expression is true, then the contained statement is executed
    - If execution of the statement completes normally, then the entire ‘while’ statement is executed again, beginning by re-evaluating the expression.
- If the value of the expression is false, no further action is taken and the ‘while’ statement completes normally.

The following example shows how to use ‘while’ statement:

```
int i=10;
while (i > 0) {
      print(i);
      i = i - 1;
}
```

3.5.3.4 Return

A ‘return’ returns to its caller by means of the ‘return’ statement, which has one of the forms:

```
return;
return(expression);
```

In the first case no value is returned when a method is declared void. For the first case, the users could specify no return statement for simplification. In the second case, simply put the value (or an expression that calculates the value) after the return Keyword, then the value of the expression is returned to the caller of the ‘return’.

3.5.4 Method Creation and Method Call

The user could write the user-defined methods.

```
returnType nameOfMethod (Parameter List) {
 /*method body*/
}
```

- `returnType:` Method may return a value.
- `nameOfMethod:` This is the method name. The method signature consists of the method name and the parameter list.

- `Parameter List:` The list of parameters, it is the type, order, and number of parameters of a method. These are optional, method may contain zero parameters. A usual format for the parameter list is (dataType Id, dataType Id …, dataType Id)
- `method body:` The method body defines what the method does with statements.

For using a method, it should be called. There are two ways in which a method is returned i.e. method returns a value or returning nothing (no return value). The method should be defined in a class.

Following is the example to demonstrate how to define a method and how to call it with a returned value in a class(refer to section 3.6):

```
class myclass{

    int calc (int x, int y){

        int z;
        z = x + y;
        return (z);
    }
}

class test {

    void main(){
        int x = 9;
        float y = 6.0;
        float z;

        class myclass obj = new myclass();
        z = obj.calc(x, y);

        print ("z=", z);
    }
}
```

3.5.5 Print to Console

The *print()* function takes one or more parameters and prints them one by one to standard output. The parameter type may be string, number. It is in the following form:

```
print (parameters);
```

Here is an example to accept an *int* and print the *int* to the console.

```
print (1);
```

Another example to accept a string and print the string to the console:

```
print (“CS4115 is fun!”)
```

3.5.6 Empty Statement

An empty statement does nothing and has the following form:

```
;
```

3.6 Classes

Classes and objects are highly related. A real world object has states and behaviors. For instance, a dog has states — name, breed, color as well as behaviors — barking, eating. An object in Liva also has states — stored in fields and behaviors — shown via methods. Fields are local variables stored inside a class and methods are functions that may be invoked by instances of that class. So class bodies consist of fields and methods. Actually, there is a special kind of methods called constructors which will be discussed in following sections. In a word, a class can be defined as a template that describes the states and behaviors that objects of its type support.

3.6.1 Class Declarations

A class declaration defines a new reference type and how it is implemented. A body of a class declaration contains field declarations and method declarations. Following is an example of how to define a class. Use the keyword “class” to indicate the start of a class declaration. In this example, “myclass” is the class name. It has two fields, one is an integer and the other is a character. One method “fuction1” is define and it simply returns integer 1.

```
class myclass {
    int field1;
    char field2;
    int function1(){
        return (1);
    }
}
```

3.6.2 Object Instantiation

The ‘new’ keyword is used to instantiate a new object by allocating memory for it. The ‘new’ requires a single argument: a *constructor method* for the object to be created. The constructor method is responsible for initializing the new object. In Liva, the name of constructor method for one class is defined as “constructor”. The user could define a constructor in the class. liva would create a default constructor for the class if the users do not explicitly define a constructor for a class. It is essentially a non-parameterized constructor without any arguments. The function of default constructor is to call the super class constructor and initialize all instance variables. When the keyword ‘this’ is used, it is replaced by an instance of the containing object at runtime.

The following example shows how to define a constructor method and initialize a new object:

```
/* User defined constructor*/

class myclass{
    int a;
    constructor(int x){
        this.a = x;
    }

}

class test {
    void main(){

        class myclass obj = new myclass(10);

        print ("a=", obj.a);
    }
}
```

3.6.3 Inheritance

Inheritance is that a subclass acquires all the behaviors and properties of a super class. A subclass inherits fields and methods from its parent class. The keyword “extends” is used to indicate a relationship between a subclass and a parent class like the following declaration.

```
class subclass extends myclass {

}
```

A subclass may override the methods of its parent class. If a method is overridden, an instance of the subclass can only access the new version but not the original method from the super class.

```
class myclass{
    int calc (int x, int y){
        int z;
        z = x + y;
        return (z);
    }
}
class subclass extends myclass{
    int calc (int x, int y){
        int z;
        z = x + y + 1;
        return (z);
    }
}
```

Chapter 4 Project Plan

4.1 Plan

Our group members worked collaboratively on Github. At the beginning, we studied the code of the MicroC languge to get more understanding about compiler design. We have met our TA every week to discuss our project and ask questions. After we got the “Hello Word” program successfully compiled, we worked together to add more features and fix bugs. Finally, in the last week, we asked our TA about the priority of the features we planned to add and implemented some of them with high priorities.

4.2 Timeline

July 6th - 11th	Brainstorm for language design and the proposal
July 11th – 20th	Determine language syntax and scope; Write Language Reference Manual
July 20th – July 25th	Scanner and Parser
July 25th – August 1st	Expressions, Print function and main function
August 1st	“Hello World !”
August 1st – August 8th	Add object-oriented features and array. Fix bugs

August 8th - August 11th	Report and presentation.

4.3 Roles and Responsibilities.

In our team, the role of each member was quite flexible. We worked together very often coding and fixing bugs. We have solved many problems together these days. Zihan and Shanqi mainly concentrated on implementing the code generator. Jiafei and Yanan focused on semantic check. Kate joined us from the middle of our project and she did some testing and document work.

4.4 Software Environment

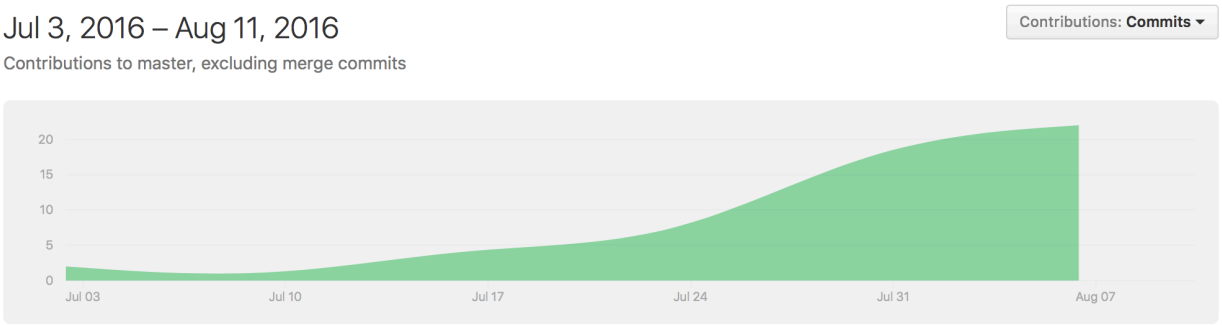
Ubuntu 16.04 – All our team members work on Ubuntu 16.4, the latest version to avoid unnecessary environment conflict. Our Ubuntu are powered by PD11 and VMware 12.

OS X – Meanwhile, we also try our language on OS X to ensure that LIVA is portable.

LLVM 3.6 - All our team members work with LLVM 3.6

Github – We work on the same branch in our Github repository.

4.5 Project Prolog



The commit curve from July 3 to Aug 11. It shows our work distributed evenly during the 30-day period. All our team members involved heavily in the development of LIVA.

Chapter 5 Architecture Design

5.1 Overview

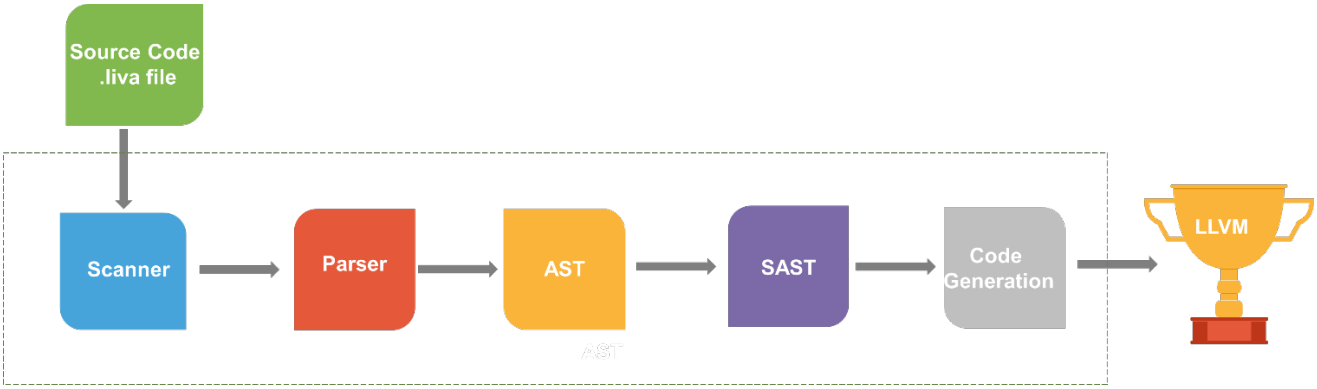


Figure 5.1 Overview of compiler architecture design

The compiler architectural design of Liva is shown in Figure 5.1. Overall, Liva follows a traditional compiler architecture design with a lexical scanner and parser at the front end, followed by generation of a Semantically Checked and Typed Abstract Syntax Tree (SAST) from an abstract syntax tree (AST) and finally LLVM IR code generation. We have a total of 5 modules which are codegen.ml, liva.ml, semant.ml, parser.mly, scanner.mll and 2 interfaces which are ast.ml and sast.ml.

5.2 The scanner

As the start of the front end, scanner reads a source file and convert it into tokens, and at the same time it checks whether each tokens is valid, if not, it will report the illegal character. Besides, it is also responsible for ignoring white space and comments which are not useful for Liva program.

5.3 The Parser

The tokens passed by the scanner are interpreted by the parser according to the precedence rules of Liva language and constructs an abstract syntax tree based on the definitions provided and the input tokens are constructed. The parser's main goal is to organize the tokens of the program into class declarations. The top level of the abstract syntax tree is a structure called Program which contains all classes. The fields, constructors and methods are declared within the classes. Specific to the method declarations record is the creation of an AST of functions from groups of statements, statements evaluating the results of expressions, and expressions formed from operations and assignments of variables, references and constants. The Parser produces the abstract syntax tree (AST) which is shown in Figure 5.1.

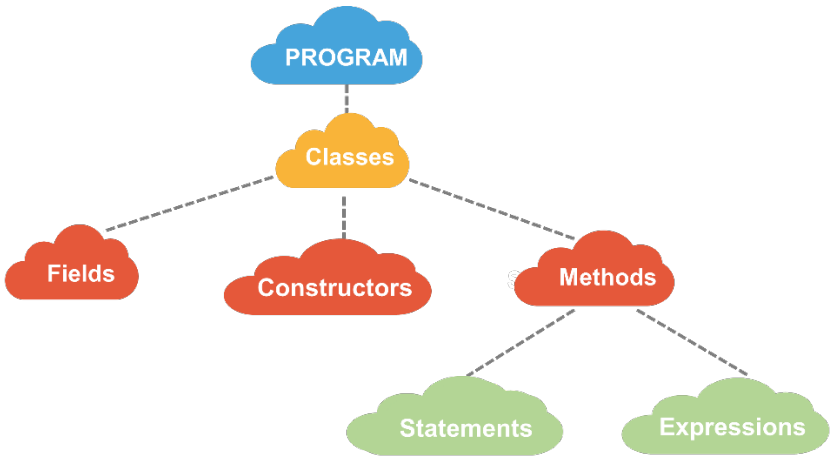


Figure 5.2 AST program representation.

5.4 The Semantic Checker

There are four kinds of work a semantic checker is responsible for. To begin with, it adds reserved functions as a part of the SAST shown in figure5.3, and these reserved functions can also help to check whether there are any functions use the same name as reserved ones which is not allowed in Liva. Next, semantic checker do some work concerning statistic semantic checking. It checks whether the source code is semantically correct from various aspects including whether there are duplicated fields or methods in one class, whether there are duplicated classes in one program and adds default constructor if there isn't user-defined constructor in one class. Thirdly, on the basis of the first two semantic checker deals with inheritance. Semantic checker finds all the inheritance relationship by looking through all the classes, if there is a inheritance relationship between two classes, semantic checker will add the fields and the methods of super class to subclass, but it the subclass declares fields or methods which share the same name as those of super class, subclass will override those fields and methods of super class. Finally, semantic checker converts its input, AST, to SAST which is helpful for code generator to generate LLVM IR code. Semantic checker separates the methods from classes, separates main method which is the entrance of Liva program from methods and add types to all the statements and expressions, in the meanwhile, it also do some work related with statistic semantic checking, including whether names or identifiers are defined before they are referred to, whether names or identifiers are used correctly, whether types are consistent and so on to make it as smooth as possible for code generator to generate code.

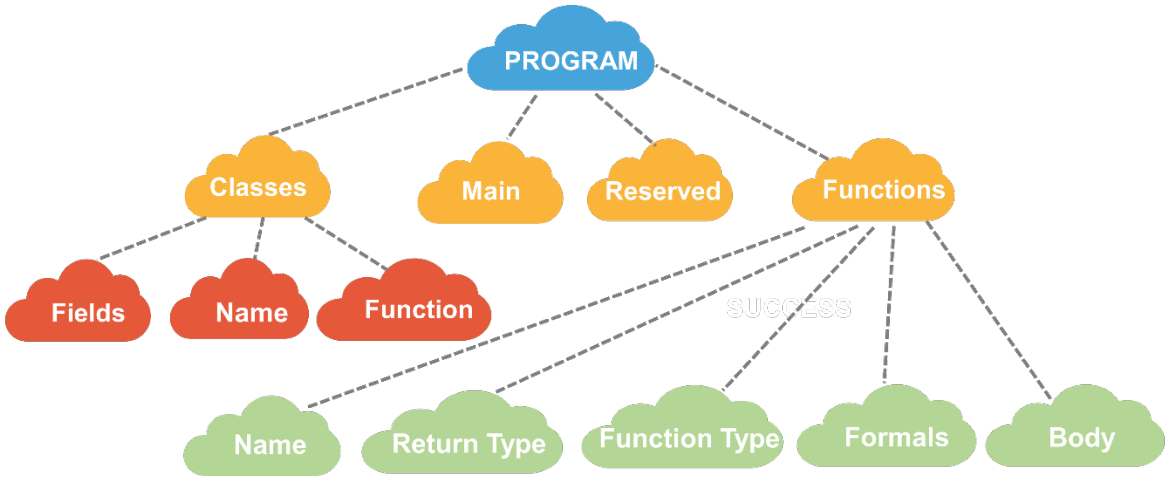


Figure 5.3 SAST representation.

5.5 The Code Generator

The main function of the compiler is to convert the abstract syntax tree into LLVM IR. After the semantic abstract syntax tree is generated, the semantic checker sends it to the code generator which construct the LLVM IR file which contains the final instructions for the program.

This code generation is written using the OCaml LLVM library, which uses OCaml functions to produce the desired LLVM code with the static variables used during code generation. Codegen.the_module is the top-level structure that the LLVM IR uses to contain code and it contains all of the functions and global variables in a chunk of code. The Codegen.builder object is a object that keeps track of the current place to insert instructions and has methods to create new instructions. The Codegen.named_values map keeps track of which values are defined in the current scope and what their LLVM representation is. After all of above is setup, the code generator iterates through the entire semantic abstract syntax tree and produces the necessary LLVM code for each function, statement, and expression.

Chapter 6 Test Plan

All the test cases used to test Liva are put into a folder named tests. The test cases which consist of unit tests, integration tests are designed to test all the features of Liva, from both positive way and negative way. All these various testing methods are used to create a robust testing environment for Liva language.

6.1 Reason for choosing test cases

All the tests were added as new language features were added, therefore, the language features decided the test cases we picked out to a large extent, and most of these tests are aimed at testing every aspect of Liva.

6.2 Unit testing

Unit testing was used to check whether small pieces of our language could behave as defined. The tests can be divided into two types: tests are meant to pass, tests are meant to fail, thereby utilizing positive and negative testing. Negative testing ensures that invalid input is not accepted, i.e. Liva is able to properly reject invalid input, while positive testing on the other hand allows us to assess whether Liva is able to behave and work out the result as defined.

6.3 Integration testing

Once smaller tests were verified to pass, they would be integrated into larger programs, so as to ensure whether Liva can manage to behave properly in more complex program. These integrated tests are the basis of our final interesting program.

6.4 Automation

Automation of testing becomes more and more necessary as the project moves forward, and it is an extremely useful tool for developing our language. Automation allows us to make sure that new added language features would not obstruct other features which have passed the tests. We created an automated regression test suite largely borrowed from the MicroC Compiler. The test cases meant to pass are written out using the notation ‘test-.liva’ and the corresponding output as ‘test-.out’, while the corresponding output of test cases meat to fail as ‘test-.err’. The test script is executed with the ./testall.sh command which will then display a list of tests that pass, fail, or produce a printed output that differs from the desired printed output.

6.5 Representative source programs

test-inheritance2.liva

```
class calculator {

    int add(int x, int y){
        int z = x + y;
        return(z);
    }
}

class my_calculator extends calculator{

}
```

```
class test {
   void main(){
      int x;
      int y;
      int z;
      x = 66;
      y = 98;
      class my_calculator obj = new my_calculator();
      z = obj.add(x,y);
      print ("z=",z);
   }
}
```

test-inheritance2.ll

```
; ModuleID = 'Liva'

%test = type <{ i32 }>
%my_calculator = type <{ i32 }>
%calculator = type <{ i32 }>

@tmp = private unnamed_addr constant [3 x i8] c"z=\00"
@tmp.1 = private unnamed_addr constant [5 x i8] c"%s%d\00"

declare i32 @printf(i8*, ...)

declare i8* @malloc(i32)

define i64* @lookup(i32 %c_index, i32 %f_index) {
entry:
  %tmp = alloca i64**, i32 3
  %tmp1 = alloca i64*, i32 0
  %tmp2 = getelementptr i64**, i64*** %tmp, i32 2
  store i64** %tmp1, i64*** %tmp2
  %tmp3 = alloca i64*
  %tmp4 = getelementptr i64*, i64** %tmp3, i32 0
  store i64* bitcast (i32 (%my_calculator*, i32, i32)* @my_calculator.add to i64*), i64** %tmp4
  %tmp5 = getelementptr i64**, i64*** %tmp, i32 1
  store i64** %tmp3, i64*** %tmp5
  %tmp6 = alloca i64*
  %tmp7 = getelementptr i64*, i64** %tmp6, i32 0
  store i64* bitcast (i32 (%calculator*, i32, i32)* @calculator.add to i64*), i64** %tmp7
  %tmp8 = getelementptr i64**, i64*** %tmp, i32 0
  store i64** %tmp6, i64*** %tmp8
  %tmp9 = getelementptr i64**, i64*** %tmp, i32 %c_index
  %tmp10 = load i64**, i64*** %tmp9
  %tmp11 = getelementptr i64*, i64** %tmp10, i32 %f_index
  %tmp12 = load i64*, i64** %tmp11
  ret i64* %tmp12
```

```
}

define %test* @test.constructor() {
entry:
  %this = alloca %test
  %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
  %tmp1 = bitcast i8* %tmp to %test*
  %tmp2 = load %test, %test* %tmp1
  store %test %tmp2, %test* %this
  %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
  store i32 2, i32* %.key
  ret %test* %this
}

define i32 @my_calculator.add(%my_calculator* %this, i32 %x, i32 %y) {
entry:
  %z = alloca i32
  %addtmp = add i32 %x, %y
  store i32 %addtmp, i32* %z
  %z1 = load i32, i32* %z
  ret i32 %z1
}

define %my_calculator* @my_calculator.constructor() {
entry:
  %this = alloca %my_calculator
  %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
  %tmp1 = bitcast i8* %tmp to %my_calculator*
  %tmp2 = load %my_calculator, %my_calculator* %tmp1
  store %my_calculator %tmp2, %my_calculator* %this
  %.key = getelementptr inbounds %my_calculator, %my_calculator* %this, i32 0, i32 0
  store i32 1, i32* %.key
  ret %my_calculator* %this
}

define i32 @calculator.add(%calculator* %this, i32 %x, i32 %y) {
entry:
  %z = alloca i32
  %addtmp = add i32 %x, %y
  store i32 %addtmp, i32* %z
  %z1 = load i32, i32* %z
  ret i32 %z1
}

define %calculator* @calculator.constructor() {
entry:
  %this = alloca %calculator
  %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
  %tmp1 = bitcast i8* %tmp to %calculator*
```

```
  %tmp2 = load %calculator, %calculator* %tmp1
  store %calculator %tmp2, %calculator* %this
  %.key = getelementptr inbounds %calculator, %calculator* %this, i32 0, i32 0
  store i32 0, i32* %.key
  ret %calculator* %this
}

define i32 @main() {
entry:
  %this = alloca %test
  %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
  %tmp1 = bitcast i8* %tmp to %test*
  %tmp2 = load %test, %test* %tmp1
  store %test %tmp2, %test* %this
  %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
  store i32 2, i32* %.key
  %x = alloca i32
  %y = alloca i32
  %z = alloca i32
  store i32 66, i32* %x
  store i32 98, i32* %y
  %obj = alloca %my_calculator
  %tmp3 = call %my_calculator* @my_calculator.constructor()
  %tmp4 = load %my_calculator, %my_calculator* %tmp3
  store %my_calculator %tmp4, %my_calculator* %obj
  %cindex = getelementptr inbounds %my_calculator, %my_calculator* %obj, i32 0, i32 0
  %cindex5 = load i32, i32* %cindex
  %fptr = call i64* @lookup(i32 %cindex5, i32 0)
  %my_calculator.add = bitcast i64* %fptr to i32 (%my_calculator*, i32, i32)*
  %x6 = load i32, i32* %x
  %y7 = load i32, i32* %y
  %tmp8 = call i32 %my_calculator.add(%my_calculator* %obj, i32 %x6, i32 %y7)
  store i32 %tmp8, i32* %z
  %z9 = load i32, i32* %z
  %tmp10 = call i32 (i8*, ...) @printf(i8* getelementptr inbounds ([5 x i8], [5 x i8]* @tmp.1, i32 0,
i32 0), i8* getelementptr inbounds ([3 x i8], [3 x i8]* @tmp, i32 0, i32 0), i32 %z9)
  ret i32 0
}
```

2.

test-while_for_nest.liva

```
class test {
  void main(){
        int i = 1;
        int j;
        while(i < 10)
        {
              j = 11;
              for(j = 11; j < 13; j = j + 1)
```

```
                print("i = ", i, " ", "j = ", j, "\n");
            i = i + 1;
        }
        print("\n\n");
        for(i = 1; i < 10; i = i + 1)
        {
            j = 11;
            while(j < 13)
            {
                print("i = ", i, " ", "j = ", j, "\n");
                j = j + 1;
            }
        }
  }
}
```

test-while_for_nest.ll

```
; ModuleID = 'Liva'

%test = type <{ i32 }>

@tmp = private unnamed_addr constant [5 x i8] c"i = \00"
@tmp.1 = private unnamed_addr constant [2 x i8] c" \00"
@tmp.2 = private unnamed_addr constant [5 x i8] c"j = \00"
@tmp.3 = private unnamed_addr constant [2 x i8] c"\0A\00"
@tmp.4 = private unnamed_addr constant [13 x i8] c"%s%d%s%s%d%s\00"
@tmp.5 = private unnamed_addr constant [3 x i8] c"\0A\0A\00"
@tmp.6 = private unnamed_addr constant [3 x i8] c"%s\00"
@tmp.7 = private unnamed_addr constant [5 x i8] c"i = \00"
@tmp.8 = private unnamed_addr constant [2 x i8] c" \00"
@tmp.9 = private unnamed_addr constant [5 x i8] c"j = \00"
@tmp.10 = private unnamed_addr constant [2 x i8] c"\0A\00"
@tmp.11 = private unnamed_addr constant [13 x i8] c"%s%d%s%s%d%s\00"

declare i32 @printf(i8*, ...)

declare i8* @malloc(i32)

define i64* @lookup(i32 %c_index, i32 %f_index) {
entry:
  %tmp = alloca i64**
  %tmp1 = alloca i64*, i32 0
  %tmp2 = getelementptr i64**, i64*** %tmp, i32 0
  store i64** %tmp1, i64*** %tmp2
  ret i64* null
}

define %test* @test.constructor() {
entry:
```

```
  %this = alloca %test
  %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
  %tmp1 = bitcast i8* %tmp to %test*
  %tmp2 = load %test, %test* %tmp1
  store %test %tmp2, %test* %this
  %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
  store i32 0, i32* %.key
  ret %test* %this
}

define i32 @main() {
entry:
  %this = alloca %test
  %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
  %tmp1 = bitcast i8* %tmp to %test*
  %tmp2 = load %test, %test* %tmp1
  store %test %tmp2, %test* %this
  %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
  store i32 0, i32* %.key
  %i = alloca i32
  store i32 1, i32* %i
  %j = alloca i32
  br label %cond

loop:                                             ; preds = %cond
  store i32 11, i32* %j
  store i32 11, i32* %j
  br label %cond5

loop3:                                            ; preds = %cond5
  %i7 = load i32, i32* %i
  %j8 = load i32, i32* %j
  %tmp9 = call i32 (i8*, ...) @printf(i8* getelementptr inbounds ([13 x i8], [13 x i8]* @tmp.4, i32
0, i32 0), i8* getelementptr inbounds ([5 x i8], [5 x i8]* @tmp, i32 0, i32 0), i32 %i7, i8*
getelementptr inbounds ([2 x i8], [2 x i8]* @tmp.1, i32 0, i32 0), i8* getelementptr inbounds ([5 x
i8], [5 x i8]* @tmp.2, i32 0, i32 0), i32 %j8, i8* getelementptr inbounds ([2 x i8], [2 x i8]* @tmp.3,
i32 0, i32 0))
  br label %step4

step4:                                            ; preds = %loop3
  %j10 = load i32, i32* %j
  %addtmp = add i32 %j10, 1
  store i32 %addtmp, i32* %j
  br label %cond5

cond5:                                            ; preds = %step4, %loop
  %j11 = load i32, i32* %j
  %lesstmp = icmp slt i32 %j11, 13
  br i1 %lesstmp, label %loop3, label %afterloop6
```

```
afterloop6:                                       ; preds = %cond5
  %i12 = load i32, i32* %i
  %addtmp13 = add i32 %i12, 1
  store i32 %addtmp13, i32* %i
  br label %step

step:                                             ; preds = %afterloop6
  br label %cond

cond:                                             ; preds = %step, %entry
  %i14 = load i32, i32* %i
  %lesstmp15 = icmp slt i32 %i14, 10
  br i1 %lesstmp15, label %loop, label %afterloop

afterloop:                                        ; preds = %cond
  %tmp16 = call i32 (i8*, ...) @printf(i8* getelementptr inbounds ([3 x i8], [3 x i8]* @tmp.6, i32 0,
i32 0), i8* getelementptr inbounds ([3 x i8], [3 x i8]* @tmp.5, i32 0, i32 0))
  store i32 1, i32* %i
  br label %cond19

loop17:                                           ; preds = %cond19
  store i32 11, i32* %j
  br label %cond23

loop21:                                           ; preds = %cond23
  %i25 = load i32, i32* %i
  %j26 = load i32, i32* %j
  %tmp27 = call i32 (i8*, ...) @printf(i8* getelementptr inbounds ([13 x i8], [13 x i8]* @tmp.11, i32
0, i32 0), i8* getelementptr inbounds ([5 x i8], [5 x i8]* @tmp.7, i32 0, i32 0), i32 %i25, i8*
getelementptr inbounds ([2 x i8], [2 x i8]* @tmp.8, i32 0, i32 0), i8* getelementptr inbounds ([5 x
i8], [5 x i8]* @tmp.9, i32 0, i32 0), i32 %j26, i8* getelementptr inbounds ([2 x i8], [2 x i8]*
@tmp.10, i32 0, i32 0))
  %j28 = load i32, i32* %j
  %addtmp29 = add i32 %j28, 1
  store i32 %addtmp29, i32* %j
  br label %step22

step22:                                           ; preds = %loop21
  br label %cond23

cond23:                                           ; preds = %step22, %loop17
  %j30 = load i32, i32* %j
  %lesstmp31 = icmp slt i32 %j30, 13
  br i1 %lesstmp31, label %loop21, label %afterloop24

afterloop24:                                      ; preds = %cond23
  br label %step18
```

```
step18:                                           ; preds = %afterloop24
  %i32 = load i32, i32* %i
  %addtmp33 = add i32 %i32, 1
  store i32 %addtmp33, i32* %i
  br label %cond19

cond19:                                           ; preds = %step18, %afterloop
  %i34 = load i32, i32* %i
  %lesstmp35 = icmp slt i32 %i34, 10
  br i1 %lesstmp35, label %loop17, label %afterloop20

afterloop20:                                      ; preds = %cond19
  ret i32 0
}
```

Test suites

fail-add.liva:

```
class arith {
        void main()
        {
                int i;
                i = "1" + 1;
                print(i);
        }
}
```

---

fail-array_access.liva:

```
class test {
        void main() {
                char b = 'a';
                float[] a = new float[10];
                print(a[b]);
        }
}
```

---

fail-array_access2.liva:

```
class test {
        void main() {
                float[] a = new float[10];
                print(a[1][1]);
        }
}
```

---

fail-array_init.liva:

```
class test {
        void main() {
                float[] a = new float[10.0];
```

```
	}
}
```

---

fail-diff.liva:

```
class arith {
	void main()
	{
		int i;
		i = "1" - 1;
		print(i);
	}
}
```

---

fail-div.liva:

```
class arith {
	void main()
	{
		int i;
		i = "4" / 2;
		print(i);
	}
}
```

---

fail-equal1.liva:

```
class test {
  void main(){
	float i = 1.0;
	if (i == 1.0) print(42);
	else print(8);

  }
}
```

---

fail-equal2.liva:

```
class test {
  void main(){
	float i = "123";
	if (i == true) print(42);
	else print(8);

  }
}
```

---

fail-for1.liva:

```
class test {


  void main(){
```

```
  int i;



  for (i = 0 ; i = 10 ; i = i + 1) {

  print(i);
            }

  }
}
```

---

fail-function.liva:

```
class myclass{

    int calc (int x, int y){

        int z;
        z = x + y;
        return (z);
    }
}

class test {

    void main(){
        int x = 9;
                    int y = 6;
        int z;

        class myclass obj = new myclass();
        z = obj.ca_lc(x, y);

        print ("z=",z);
    }
}
```

---

fail-function2.liva:

```
class myclass{

    int calc (int x, int y){

        int z;
        z = x + y;
        return (z);
    }
}

class test {

    void main(){
        int x = 9;
                    int y = 6;
        int z;

        class myclass obj = new myclass();
        z = obj.calc(x, x, y);

        print ("z=",z);
    }
}
```

---

fail-function3.liva:

```
class myclass{

    int calc (int x, int y){
```

```
        int z;
        z = x + y;
        return (z);
    }
}

class test {

    void main(){
        int x = 9;
                    float y = 6.0;
        float z;

        class myclass obj = new myclass();
        z = obj.calc(x, y);

        print ("z=",z);
    }
}
```

---

fail-hello.liva:

```
class test {

    print ("Hello World!");

    void main(){

    }
}
```

---

fail-hello2.liva:

```
class test {
    void main(){
        int a ;
        int b ;
        a=1.1;
        b=3;
        print ("multiple ", "params!", "\n", a, "\n" ,b, "\n");
    }
}
```

---

fail-if1.liva:

```
class test {

  void main(){
```

```
        if ("123") print(42);

  }
}
```

---

fail-mod.liva:

```
class arith {
        void main()
        {
                int i;
                i = "4" % 3;
                print(i);
        }
}
```

---

fail-mul.liva:

```
class arith {
        void main()
        {
                int i;
                i = "15" * 5;
                print(i);
        }
}
```

---

fail-not.liva:

```
class test {
  void main(){
        int i = 1;
        boolean j;
        j = !(i + 1);
  }
}
```

---

fail-obj_access.liva:

```
class test {
        void main() {
                int a;
                a.amethod;
        }
}
```

---

fail-obj_access2.liva:

```
class test {
        void main() {
                int a;
                (1+1).amethod;
        }
```

```
}
```

---

fail-obj_access3.liva:

```
class myclass{
    int a;
    constructor(int x){
        this.a = x;
    }
}

class test {

    void main(){
        class myclass obj = new myclass(10);
                    print ("b=",obj.b);
    }
}
```

---

fail-sub.liva:

```
class test {
  void main(){
          int j;
          j = -(true);
          print(j);
  }
}
```

---

fail-while1.liva:

```
class test {
          void main() {
            int i;
            i = 5;
            while (i = 1) {
              print(i);
              i = i - 1;
            }
            print(42);
          }
}
```

---

test-add.liva:

```
class arith {
          void main()
          {
                    int i;
                    i = 1 + 1;
                    print(i);
          }
}
```

---

test-and.liva:

```
class test {
  void main(){
        int i = 1;
        int j = 3;
        if (i == 1 & j == 3)
        {
                print(i, " ", j, "\n");
        }
  }
}
```

---

test-arith.liva:

```
class arith {
        void main()
        {
                int i;
                i = 1 + 3 * 4 % 7 - 4 / 2;
                print(i);
        }
}
```

---

test-array.liva:

```
class test {
        void main() {
                float[] a = new float[10];
                int[] b = new int[10];
                int i;
                a[0] = 1.0;
                b[0] = 1;
                for(i = 1; i < 10; i = i + 1)
                {
                        a[i] = a[i - 1] + 1.0;
                        b[i] = b[i - 1] + 1;
                }
      for(i = 0; i < 10; i = i + 1)
                        print("a[",i,"]"," = ",a[i]," , ", "b[",i,"]"," = ",b[i], "\n");
        }
}
```

---

test-array_object.liva:

```
class calculator{
   int g;
   int addition(int x, int y){
      this.g =9;
      int z;
      z = x + y;
      return(z);
   }
```

```
}

class test {
	void main() {
		class calculator c = new calculator();
		class calculator[] a = new class calculator[10];
		a[0] = c;
		print(a[0].addition(1,1));
	}
}
```

---

test-comments.liva:

```
class test {
  void main(){
	float i = 1.111;
	/*HAHAHAHA
		/* print(i);*/
	  BOOOO!%$#$^%^&^%g)__*%^#@...
	*/
	print(i);
  }
}
```

---

test-constructor.liva:

```
class myclass{
    int a;
    constructor(int x){
        this.a = x;
    }

}

class test {
    void main(){

        class myclass obj = new myclass(10);

        print ("a=",obj.a);
    }
}
```

---

test-diff.liva:

```
class arith {
        void main()
        {
                float i;
                i = 1.3 - 1.0;
                print(i);
        }
}
```

---

test-div.liva:

```
class arith {
        void main()
        {
                int i;
                i = 4 / 2;
                print(i);
        }
}
```

---

test-equal.liva:

```
class test {
  void main(){
        int i = 1;
        if (i == 1) print(42);
        else print(8);

  }
}
```

---

test-fib.liva:

```
class test {

        int fib (int x){
      int z;
      if (x <2) z=1;
        else z= this.fib(x-1) + this.fib(x-2);
      return (z);
      }

    void main(){
      int x;
      int y;
      int z;
        int m;
      x = 5;
      y = 6;
```

```
        z = this.fib (x);

           print (z);



    }
}
```

---

test-for1.liva:

```
class test {


  void main(){



  int i;



  for (i = 0 ; i < 10 ; i = i + 1) {

  print(i);
            }




  }
}
```

---

test-for_nest.liva:

```
class test {
  void main(){
          int i;
          int j;
          for(i = 0; i < 10; i = i + 1)
                    for(j = 11; j < 13; j = j + 1)
                              print("i = ", i, " ", "j = ", j, "\n");
  }
}
```

---

test-function.liva:

```
class myclass{

    int calc (int x, int y){
        int z;
        z = x + y;
        return (z);
    }

}


class test {
    void main(){
        int x;
        int y;
        int z;
        x = 9;
        y = 6;

        class myclass obj = new myclass();
        z = obj.calc(x, y);

        print ("z=",z);
    }
}
```

---

test-gcd.liva:

```
class gcd {
    void main(){
        int x;
        int y;
        int z;
        x = 66;
        y = 98;

        while(x != y){
            if(x > y){
                x = x - y;
            }
            else{
                y = y - x;
```

```
        }
      }
      print ("gcd=",x);
   }
}
```

---

test-geq.liva:

```
class test {
  void main(){
          int i = 1;
          int j = 1;
          if (i >= j) print("yes");
          else print("no");

  }
}
```

---

test-gt.liva:

```
class test {
  void main(){
          int i = 4;
          int j = 1;
          if (i > j) print(4);
          else print(8);

  }
}
```

---

test-hello.liva:

```
class test {

  void main(){

    print ("Hello World!");

  }
}
```

---

test-hello2.liva:

```
class test {
    void main(){
        int a ;
        int b ;
        a=1;
        b=3;
        print ("multiple ", "params!", "\n", a, "\n" ,b, "\n");
    }
}
```

---

test-if1.liva:

```
class test {

  void main(){




          print (100);

          if (true) print(42);
          else print(8);
          print(17);









  }
}
```

---

test-if_nest.liva:

```
class test {
  void main(){
          int i = 1;
          int j = 3;
          if (true)
          {
                  if(i == 1)
                  {
                          if(i < j)
                          {
                                  print(j);
                          }
                  }
```

```
        }
  }
}
```

---

test-inheritance.liva:

```
class myclass{
    int a;
    constructor(int x){
        this.a = x;
    }

}

class subclass extends myclass{
    constructor(int x){
        this.a = x;
    }
}

class test {
    void main(){

        class subclass obj = new subclass(10);

        print ("a=",obj.a);
    }
}
```

---

test-inheritance2.liva:

```
class calculator {

    int add(int x, int y){
        int z = x + y;
        return(z);
    }
}

class my_calculator extends calculator{

}
```

```
class test {
   void main(){
      int x;
      int y;
      int z;
      x = 66;
      y = 98;
      class my_calculator obj = new my_calculator();
      z = obj.add(x,y);
      print ("z=",z);
   }
}
```

---

test-leq.liva:

```
class test {
  void main(){
        int i = 1;
        int j = 1;
        if (i <= j) print(4);
        else print(8);

  }
}
```

---

test-lt.liva:

```
class test {
  void main(){
        int i = 3;
        int j = 1;
        if (i < j) print(4);
        else print(8);

  }
}
```

---

test-mod.liva:

```
class arith {
        void main()
        {
                int i;
                i = 4 % 3;
```

```
                print(i);
        }
}
```

---

test-mul.liva:

```
class arith {
        void main()
        {
                int i;
                i = 15 * 5;
                print(i);
        }
}
```

---

test-nequal.liva:

```
class test {
  void main(){
        int i = 3;
        if (i != 1) print(4);
        else print(8);

  }
}
```

---

test-not.liva:

```
class test {
  void main(){
        int i = 1;
        int j = 3;
        if (!(i != 1))
        {
                print("BOOO!");
        }
  }
}
```

---

test-obj.liva:

```
class myclass{
}

class test {
    void main(){

        class myclass obj = new myclass();

        print ("obj\n");
    }
}
```

---

test-or.liva:

```
class test {
  void main(){
          int i = 1;
          int j = 3;
          if (i != 1 | j == 3)
          {
                  print(i, " ", j, "\n");
          }
  }
}
```

---

test-override.liva:

```
class myclass{
    int a;
    int calc (int x, int y){
        int z;
        z = x + y;
        return (z);
    }

}

class subclass extends myclass{

    int calc (int x, int y){
        int z;
        z = x - y;
        return (z);
    }
}

class test {
    void main(){
        int x;
        int y;
        int z;
        x = 9;
        y = 6;

        class subclass obj = new subclass();
```

```
        z = obj.calc(x, y);

        print ("z=",z);
    }
}
```

---

test-sub.liva:

```
class test {
  void main(){
          int i = 3;
          int j;
          j = -(-(i) + i * i);
          print(j);
  }
}
```

---

test-while1.liva:

```
class test {
          void main() {
            int i;
            i = 5;
            while (i > 0) {
              print(i);
              i = i - 1;
            }
            print(42);
          }
}
```

---

test-while_for_nest.liva:

```
class test {
  void main(){
          int i = 1;
          int j;
          while(i < 10)
          {
                    j = 11;
                    for(j = 11; j < 13; j = j + 1)
                              print("i = ", i, " ", "j = ", j, "\n");
                    i = i + 1;
          }
```

```
        print("\n\n");
        for(i = 1; i < 10; i = i + 1)
        {
                j = 11;
                while(j < 13)
                {
                        print("i = ", i, " ", "j = ", j, "\n");
                        j = j + 1;
                }
        }
  }
}
```

Chapter 7 Lessons Learned

Shanqi:

Start early and do not surrender to difficult bugs. There is not much online community supports for OCaml Llvm API. I found this website helpful https://llvm.moe/ocaml-3.7/Llvm.html . However, this is not enough and you may want to refer to related past projects for some help. At the beginning, we all hated OCaml and found nothing worth in it. Now, I think that the most valuable thing about OCaml is the pattern matching. I cannot image how many switch statements would be used if we coded the compiler in Java.

First thing to do is to make sure that you understand the basic functions of the makefile and test shell in MicroC. They are useful during the development process. MicroC is a great example for beginners. After you understand it, you will know what is the basic steps of compiling a language. The parser file and the ast file are two highly related things. They only do one thing — reduce tokens according to the rules in parser to a single root element. In most cases, we call the root "program".

Semantic check and code generator are the most time-consuming parts. All difficult bugs appear here. Some of your group members may focus on semantic check and others on code generator. Ocaml has the magic "let rec…" binding which makes the following bindings start with "and let…" a connected block. A good software architecture can save time. Before starting your project, you may figure out what is the general structure of your semantic check and code generator. We have blocks to process statements and expressions and other sub-blocks as helpers.

Start early and keep going.

Jiafei:

This is my first time I have been in New York and studied in Columbia University as a visiting student. Frankly speaking, I have gained a lot from this course. First of all, I gained a deep understanding towards how languages and their features were implemented. Before this class, I always complain about the language I use about why it could not be more convenient for programmers to use, now I feel appreciate to those who designed these languages and respect these languages from the bottom of my heart. Besides, this is also my first time I have studied and used functional programming language, which offer me a precious opportunity to broaden my programming thinking. Additionally, this project made me realize the importance of a general view of the whole project. I was anxious to get down to coding as soon as I thought I was able to do something for the project, however, after several hours working I just deleted all my codes because I found them useless. After talking with one of the group member, I realized that I was lack of a general view of the whole project, which resulted in my difficulty in getting start in detail. I believe the general thinking I learned from this project will be of great importance to my future study.

There are two suggestion I would like to offer to future group. First, make a plan early and get to start early. This is significant to not just avoid last-minute crunch but complete a satisfying project and get the most out of this course. Secondly, teamwork is the next thing I would like to emphasize. At first, we had group meeting once a week, but later we found it was not enough and we had meeting several times a week, and in fact this increased our efficiency a lot. Whenever you encounter with difficulties, you could ask your group members for help, because the group can provide an important resource for the whole project, including asking questions as well as deciding on the best plan for implementing language features.

Zihan:

The most important thing I learned from this project is how to use Github to work together. I've never done such a large project like LIVA on Github. I think Gitbub is really a clear and efficient tool for team coding.

In addition, having a consistent coding style and naming convention is really important for a project team. Block comments above function definitions are critical. Wear sunscreen. Variable and function names should tell the reader what it is used for.

Ocaml is also an interesting programming language for me. Functional programming is impressive.

Yanan:

1. It is always better to start the project as early as you can. Time is every tight for summer session and one small issue could cost you a whole day to figure out. It is very

important to set up a suitable project plan and the deadline for each milestone. Follow up the timeline strictly and don't delay the subtask implementation.

2. Spend enough time in designing a suitable architecture at early stages. This could save a lot of time to avoid modifying the architecture for new features added in.
3. It is a good way to divide the total project into subtasks and assign the subtasks to the group members. But make sure to make active communication with other group members and have each member some familiarity to each part, making it easier to make changes iteratively.
4. GitHub is a good software development tool and it could improve the efficiency if we learn how to better use it. However, there could also be a big waste of time if we have a wrong operation such as pushing before commit or forgetting about pushing. We have met some problems with pushing new stuff to GitHub remotely. Some updates are missing and we were not sure what happened for this problem.
5. Avoid waste time on doing the duplicated work! Discuss with the group members and know each other's progress on the same task.
6. Trust our group members sincerely but also keep alert on every possible problem during the project development process.
7. I will not choose to compile our language to LLVM IR since there is so few reference on teaching how to use OCaml to write a LLVM IR code generator. It took us a lot of time to search for the good and useful references for this project.

Kate:

My most important lesson this term is to meet good teammates, for this was the first group project I participated in other than lab groups. To have good teammates, it is crucial to be the good teammate yourself, and despite my difficult situation, my teammates accepted me and helped me out greatly.

Chapter 8 Appendix

scanner.mll

```
{
        open Parser
        let depth = ref 0
```

```
        let unescape s =
                Scanf.sscanf ("\"" ^ s ^ "\"") "%S%!" (fun x -> x)
}

let whitespace = [' ' '\t'  '\r' '\n']
let ascii = ([' '-'!' '#'-'[' ']'-'~'])

let alpha = ['a'-'z' 'A'-'Z']
let digit = ['0'-'9']
let id = alpha (alpha | digit | '_')*
let int = digit+
let float = (digit+) '.' (digit+)
let char = ''' ( ascii) '''
let escape = '\\' ['\\' ''' '"' 'n' 'r' 't']
let escape_char = ''' (escape) '''
let string = '"' ( (ascii | escape)* as s) '"'


rule token = parse
        whitespace { token lexbuf }
  | "/*"      { incr depth; comment lexbuf }

  (* separator *)
  | '('     { LPAREN }
  | ')'     { RPAREN }
  | '{'     { LBRACE }
  | '}'     { RBRACE }
  | ';'     { SEMI }
  | ','     { COMMA }
  | '.'     { DOT }

  (* Operators *)
  | '+'     { PLUS }
  | '-'     { MINUS }
  | '*'     { TIMES }
  | '/'     { DIVIDE }
  | '%'     { MODULO }
  | '='     { ASSIGN }
  | "=="    { EQ }
  | "!="    { NEQ }
  | '<'     { LT }
  | "<="    { LEQ }
  | ">"     { GT }
```

```
  | ">="    { GEQ }
  | "&"     { AND }
  | "|"     { OR }
  | "!"     { NOT }
  | '['     { LBRACKET }
  | ']'     { RBRACKET }

  (* Branch Control *)
  | "if"    { IF }
  | "else"  { ELSE }
  | "for"   { FOR }
  | "while" { WHILE }
  | "return" { RETURN }

  (* Data Types *)
  | "int"      { INT }
  | "float"    { FLOAT }
  | "boolean"  { BOOLEAN }
  | "char"     { CHAR }
  | "void"     { VOID }
  | "null"     { NULL }
  | "true"     { TRUE }
  | "false"    { FALSE }

  (* Classes *)
  | "class"      { CLASS }
  | "constructor" { CONSTRUCTOR }
  | "extends"    { EXTENDS }
  | "this"       { THIS }
  | "new"                    { NEW }

  | int as lxm         { INT_LITERAL(int_of_string lxm) }
  | float as lxm       { FLOAT_LITERAL(float_of_string lxm) }
  | char as lxm        { CHAR_LITERAL(String.get lxm 1) }
  | escape_char as lxm  { CHAR_LITERAL(String.get (unescape lxm) 1) }
  | string          { STRING_LITERAL(unescape s) }
  | id as lxm          { ID(lxm) }
  | eof              { EOF }

  | _ as illegal  { raise (Failure("illegal character " ^ Char.escaped illegal )) }

and comment = parse
          "*/"     { decr depth; if !depth > 0 then comment lexbuf else token lexbuf }
```

```
  | "/*"           { incr depth; comment lexbuf }
  | _    { comment lexbuf }
```

ast.ml

```
type op = Add | Sub | Mult | Div | Equal | Neq | Less | Leq | Greater | Geq | And | Not | Or |
Mod

type primitive = Int_t | Float_t | Void_t | Bool_t | Char_t | String_t | Objecttype of string |
ConstructorType | Null_t

type datatype = Arraytype of primitive * int | Datatype of primitive |Any

type extends = NoParent | Parent of string
type fname = Constructor | FName of string
type formal = Formal of datatype * string | Many of datatype

type expr =
            Int_Lit of int
        |   Boolean_Lit of bool
        |   Float_Lit of float
        |   String_Lit of string
        |   Char_Lit of char
        |   This (*need to be implemented*)
        |   Id of string
        |   Binop of expr * op * expr
        |   Assign of expr * expr
        |   Noexpr
        |   ArrayCreate of datatype * expr list
        |   ArrayAccess of expr * expr list
        |   ObjAccess of expr * expr
        |   Call of string * expr list
        |  ObjectCreate of string * expr list
        |   Unop of op * expr
        |   Null

type stmt =
            Block of stmt list
        |   Expr of expr
        |   Return of expr
        |   If of expr * stmt * stmt
        |   For of expr * expr * expr * stmt
        |   While of expr * stmt
```

```
        |       Local of datatype * string * expr

type field = Field of datatype * string

type func_decl = {
        fname : fname;
        returnType : datatype;
        formals : formal list;
        body : stmt list;
        overrides : bool;
        rootcname : string option;

}

type cbody = {
        fields : field list;
        constructors : func_decl list;
        methods : func_decl list;
}

type class_decl = {
        cname : string;
        extends : extends;
        cbody: cbody;
}

type program = Program of class_decl list

(*get function name,tell constructor from ordinary functions*)
let string_of_fname = function
                Constructor -> "constructor"
        |       FName(s)        -> s

let string_of_primitive = function (*primitive type*)
                Int_t                   -> "int"
        |       Float_t                 -> "float"
        |       Void_t                  -> "void"
        |       Bool_t                  -> "bool"
        |       Char_t                  -> "char"
        |       Objecttype(s)  -> "class" ^ " " ^ s
        |       ConstructorType         -> "constructor"
        |       Null_t                  -> "null"
        |   String_t       -> "String"
```

```
let string_of_object = function
                Datatype(Objecttype(s))        -> s
        |       _ -> ""



let rec print_brackets = function
                1 -> "[]"
        |       a -> "[]" ^ print_brackets (a - 1)

let string_of_expr e = "remain to be completed"

let string_of_datatype = function (*datatype*)
                Arraytype(p, i) -> (string_of_primitive p) ^ (print_brackets i)
        |       Datatype(p)             -> (string_of_primitive p)
        |       Any                     -> "Any"

let string_of_op = function(*operator*)
                Add                     -> "+"
         |      Sub                     -> "-"
         |      Mult             -> "*"
         |      Div                     -> "/"
         |      Equal            -> "=="
         |      Neq                     -> "!="
         |      Less             -> "<"
         |      Leq                     -> "<="
         |      Greater                 -> ">"
         |      Geq                     -> ">="
         |      And                     -> "and"
         |      Not                     -> "not"
         |      Or                      -> "or"
         |      Mod              -> "%"


let string_of_boolean b = match b with
          true -> "true"
        | false -> "false"
```

parser.mly

```
%{  open Ast  %}

%token CLASS EXTENDS CONSTRUCTOR DOT THIS
%token INT FLOAT BOOLEAN CHAR VOID NULL TRUE FALSE
%token SEMI LPAREN RPAREN LBRACE RBRACE LBRACKET RBRACKET COMMA
%token AND NOT OR PLUS MINUS TIMES DIVIDE ASSIGN MODULO
%token EQ NEQ LT LEQ GT GEQ
%token RETURN IF ELSE FOR WHILE NEW
%token <int> INT_LITERAL
%token <float> FLOAT_LITERAL
%token <string> STRING_LITERAL
%token <string> ID
%token <char> CHAR_LITERAL
%token EOF

%nonassoc NOELSE
%nonassoc ELSE
%right ASSIGN
%left AND OR
%left EQ NEQ
%left LT GT LEQ GEQ
%left PLUS MINUS
%left TIMES DIVIDE MODULO
%right NOT
%right RBRACKET
%left LBRACKET
%right DOT

%start program
%type <Ast.program> program

%%

program:
                cdecls EOF { Program($1) }



/******************
 CLASSES
```

```
******************/
cdecls:
   cdecl_list    { List.rev $1 }

cdecl_list:
   cdecl          { [$1] }
  | cdecl_list cdecl  { $2::$1 }

cdecl:
                CLASS ID LBRACE cbody RBRACE { {
                        cname = $2;
                        extends = NoParent;
                        cbody = $4
                } }
        |       CLASS ID EXTENDS ID LBRACE cbody RBRACE { {
                        cname = $2;
                        extends = Parent($4);
                        cbody = $6
                } }

cbody:
                /* nothing */ { {
                        fields = [];
                        constructors = [];
                        methods = [];
                } }
        |       cbody field { {
                        fields = $2 :: $1.fields;
                        constructors = $1.constructors;
                        methods = $1.methods;
                } }
        |       cbody constructor { {
                        fields = $1.fields;
                        constructors = $2 :: $1.constructors;
                        methods = $1.methods;
                } }
        |       cbody fdecl { {
                        fields = $1.fields;
                        constructors = $1.constructors;
                        methods = $2 :: $1.methods;
                } }
```

```
/******************
 CONSTRUCTORS
******************/

constructor:
        CONSTRUCTOR LPAREN formals_opt RPAREN LBRACE stmt_list RBRACE {
                {

                        fname = Constructor;
                        returnType = Datatype(ConstructorType);
                        formals = $3;
                        body = List.rev $6;
                        overrides = false;
        rootcname = None;


                }
        }

/******************
 FIELDS
******************/



/* public UserObj name; */
field:
                datatype ID SEMI { Field($1, $2) }

/******************
 METHODS
******************/

fname:
        ID { $1 }

fdecl:
         datatype fname LPAREN formals_opt RPAREN LBRACE stmt_list RBRACE
        {
                {

                        fname = FName($2);
                        returnType = $1;
```

```
                        formals = $4;
                        body = List.rev $7;
                        overrides = false;
        rootcname = None;

                }
        }

/******************
 FORMALS/PARAMETERS & VARIABLES & ACTUALS
******************/

formals_opt:
                /* nothing */ { [] }
        |       formal_list   { List.rev $1 }

formal_list:
                formal                  { [$1] }
        |       formal_list COMMA formal { $3 :: $1 }

formal:
        datatype ID { Formal($1, $2) }

actuals_opt:
                /* nothing */ { [] }
        |       actuals_list  { List.rev $1 }

actuals_list:
                expr                { [$1] }
        |       actuals_list COMMA expr { $3 :: $1 }


/***************
        DATATYPES
***************/
primitive:
                INT             { Int_t }
        |       FLOAT           { Float_t }
        |       CHAR            { Char_t }
        |       BOOLEAN                 { Bool_t }
        |       VOID            { Void_t }

name:
```

```
        CLASS ID { Objecttype($2) }

type_tag:
                primitive { $1 }
        |       name    { $1 }

array_type:
        type_tag LBRACKET brackets RBRACKET { Arraytype($1, $3) }

datatype:
                type_tag   { Datatype($1) }
        |       array_type { $1 }

brackets:
                /* nothing */                   { 1 }
        |       brackets RBRACKET LBRACKET { $1 + 1 }

/******************
 EXPRESSIONS
******************/

stmt_list:
                /* nothing */  { [] }
        | stmt_list stmt { $2 :: $1 }

stmt:
                expr SEMI { Expr($1) }
        |       RETURN expr SEMI { Return($2) }
        |       RETURN SEMI             { Return(Noexpr) }
        |       LBRACE stmt_list RBRACE { Block(List.rev $2) }
        |       IF LPAREN expr RPAREN stmt %prec NOELSE { If($3, $5, Block([Expr(Noexpr)])) }
        |       IF LPAREN expr RPAREN stmt ELSE stmt    { If($3, $5, $7) }
        |       FOR LPAREN expr_opt SEMI expr_opt SEMI expr_opt RPAREN stmt
                 { For($3, $5, $7, $9) }
        |       WHILE LPAREN expr RPAREN stmt     { While($3, $5) }
        |   datatype ID SEMI                      { Local($1, $2, Noexpr) }
        |       datatype ID ASSIGN expr SEMI      { Local($1, $2, $4) }

expr_opt:
                /* nothing */ { Noexpr }
        |       expr        { $1 }

expr:
```

```
            literals                                        { $1 }
        |   expr PLUS   expr                                { Binop($1, Add,   $3) }
        |   expr MINUS  expr                                { Binop($1, Sub,   $3) }
        |   expr TIMES  expr                                { Binop($1, Mult,  $3) }
        |   expr DIVIDE expr                                { Binop($1, Div,   $3) }
        |   expr EQ     expr                                { Binop($1, Equal, $3) }
        |   expr NEQ    expr                                { Binop($1, Neq,   $3) }
        |   expr LT     expr                                { Binop($1, Less,  $3) }
        |   expr LEQ    expr                                { Binop($1, Leq,   $3) }
        |   expr GT     expr                                { Binop($1, Greater,  $3) }
        |   expr GEQ    expr                                { Binop($1, Geq,   $3) }
        |   expr AND    expr                                { Binop($1, And,   $3) }
        |   expr MODULO expr                                { Binop($1, Mod,   $3)}
        |   NOT  expr                                               { Unop (Not,   $2) }
        |   expr OR     expr                                { Binop($1, Or,    $3) }
        |   expr DOT    expr                                { ObjAccess($1, $3) }
        |   expr ASSIGN expr                                { Assign($1, $3) }

        |  MINUS expr                                               { Unop (Sub, $2) }
        |   ID LPAREN actuals_opt RPAREN            { Call($1, $3) }
        |   NEW ID LPAREN actuals_opt RPAREN        { ObjectCreate($2, $4) }
        |   NEW type_tag bracket_args RBRACKET      { ArrayCreate(Datatype($2), List.rev
$3) }
        |   expr bracket_args RBRACKET              { ArrayAccess($1, List.rev $2) }
        |   LPAREN expr RPAREN                              { $2 }

bracket_args:
            LBRACKET expr                                           { [$2] }
        |   bracket_args RBRACKET LBRACKET expr { $4 :: $1 }

literals:
         INT_LITERAL                { Int_Lit($1) }
        | FLOAT_LITERAL             { Float_Lit($1) }
        | TRUE                              { Boolean_Lit(true) }
        | FALSE                                     { Boolean_Lit(false) }
        | STRING_LITERAL            { String_Lit($1) }
        | CHAR_LITERAL                      { Char_Lit($1) }
        | THIS                              { This }
        | ID                                { Id($1) }
        | NULL                        { Null }
```

sast.ml

```
open Ast

type sexpr =
                SInt_Lit of int
        |       SBoolean_Lit of bool
        |       SFloat_Lit of float
        |       SString_Lit of string
        |       SChar_Lit of char
        |       SId of string * datatype
        |       SBinop of sexpr * op * sexpr * datatype
        |       SAssign of sexpr * sexpr * datatype
        |       SNoexpr
        |       SArrayCreate of datatype * sexpr list * datatype
        |       SArrayAccess of sexpr * sexpr list * datatype
        |       SObjAccess of sexpr * sexpr * datatype
        |       SCall of string * sexpr list * datatype * int
        |   SObjectCreate of string * sexpr list * datatype
        |       SArrayElements of sexpr list * datatype
        |       SUnop of op * sexpr * datatype
        |       SNull


type sstmt =
                SBlock of sstmt list
        |       SExpr of sexpr * datatype
        |       SReturn of sexpr  * datatype
        |       SIf of sexpr * sstmt * sstmt
        |       SFor of sexpr * sexpr * sexpr * sstmt
        |       SWhile of sexpr * sstmt
        |     SLocal of datatype * string * sexpr

type func_type = User | Reserved

type sfunc_decl = {
        sfname : fname;
        sreturnType : datatype;
        sformals : formal list;
        sbody : sstmt list;
        functype : func_type;
        source : string;
        overrides : bool;
}
```

```
type sclass_decl = {
	scname : string;
	sfields : field list;
	sfuncs: sfunc_decl list;
}

(* Class Declarations | All method declarations | Main entry method *)
type sprogram =  {
	classes : sclass_decl list;
	functions : sfunc_decl list;
	main : sfunc_decl;
	reserved : sfunc_decl list;
}
```

semant.ml

```
(* Semantic checking for the Liva compiler *)

open Ast
open Sast


(* Semantic checking of a program. Returns Sast if successful,
  throws an exception if something is wrong. *)

(*global variables and helpfer functions*)
module StringMap = Map.Make(String)
module StringSet = Set.Make (String)

module SS = Set.Make(
	struct
		let compare = Pervasives.compare
		type t = datatype
	end )

type classMap = {
	fieldMap		: Ast.field StringMap.t;
	functionMap		: Ast.func_decl StringMap.t;
	constructorMap		: Ast.func_decl StringMap.t;
	builtFuncMap  : sfunc_decl StringMap.t;
	cdecl				: Ast.class_decl;
}
```

```
type env ={

        envClassMaps: classMap StringMap.t;
        envName: string;
        envClassMap: classMap;
        envLocals: datatype StringMap.t;
        envParams: Ast.formal StringMap.t;
        envReturnType:datatype;
        envInFor: bool;
        envInWhile: bool;
        envBuiltIn:sfunc_decl list;
}

let updateEnv env envName =
{
        envClassMaps = env.envClassMaps;
        envName      = envName;
        envClassMap     = env.envClassMap;
        envLocals    = env.envLocals;
        envParams = env.envParams;
        envReturnType = env.envReturnType;
        envInFor    = env.envInFor;
        envInWhile   = env.envInWhile;
        envBuiltIn   = env.envBuiltIn;
}

let strucIndexes: (string, int) Hashtbl.t =  Hashtbl.create 10

let inheritanceRelation:(string, string list) Hashtbl.t = Hashtbl.create 10

let createStructIndexes cdecls=
        let classHandler index cdecl=
        Hashtbl.add strucIndexes cdecl.cname index in
        List.iteri classHandler cdecls

let defaultC =
{
        fname     = Ast.Constructor;
        returnType = Datatype(ConstructorType);
        formals    = [];
        body      = [];
        overrides                = false;
```

```
        rootcname               = None;
}

let getName cname fdecl = (*get the name of function,cname.constructor-> constructor /
cname.xxx-> normal_function / main*)
        let name = string_of_fname fdecl.fname (*tell constructor from normal function*)
        in
        match name with
         "main" -> "main"
        | _     -> cname ^ "." ^ name


let typOFSexpr = function(*get the type of sexpression*)
                SInt_Lit(_)                             -> Datatype(Int_t)
        |       SBoolean_Lit(_)                         -> Datatype(Bool_t)
        |       SFloat_Lit(_)                   -> Datatype(Float_t)
        |       SString_Lit(_)                  -> Arraytype(Char_t, 1)
        |       SChar_Lit(_)                    -> Datatype(Char_t)
        |       SId(_, d)                               -> d
        |       SBinop(_, _, _, d)              -> d
        |       SAssign(_, _, d)                -> d
        |       SNoexpr                                 -> Datatype(Void_t)
        |       SArrayCreate(_, _, d)  -> d
        |       SArrayAccess(_, _, d)  -> d
        |       SObjAccess(_, _, d)             -> d
        |       SCall(_, _, d,_)            -> d
        |   SObjectCreate(_, _, d)        -> d
        |       SArrayElements(_, d)  -> d
        |       SUnop(_, _, d)                  -> d
        |       SNull                                   -> Datatype(Null_t)


(**** Entry point for translating Ast to Sast *****)

let check program =

        (* add reserved built-in functions*)
        let storeBuiltinFunctions =
                let i32_t = Datatype(Int_t) and
                        void_t = Datatype(Void_t) and
                        str_t = Arraytype( Char_t, 1)
                in
                let mf t s = Formal(t, s)
```

```
		in
		let builtinStub fname returnType formals =
			{
				sfname = FName (fname);
				sreturnType = returnType;
				sformals= formals;
				functype= Sast.Reserved;
				sbody=[];
				overrides		= false;
				source= "NA"
			}
		in
		let builtinFunctions =[

			builtinStub "print"	(void_t)	([Many(Any)]);
			builtinStub "malloc"	(str_t)	([mf i32_t "size"]);
			builtinStub "cast"	(Any)		([mf Any "in"]);

			]
		in builtinFunctions
	in

	let builtinFunctions = storeBuiltinFunctions
	in

	(* create class maps*)
	let getConstructorName cname fdecl =
		let params = List.fold_left
			(fun s f -> match f with
					Formal(t, _) -> s ^ "." ^ string_of_datatype
t
				| _ -> "" ) "" fdecl.formals
		in
			let name = string_of_fname fdecl.fname
			in cname ^ "." ^ name ^ params
	in

	let mappingClass builtinFunctions cdecls =
		let builtFuncMap =
			List.fold_left (fun mp sfunc -> StringMap.add (string_of_fname
sfunc.sfname) sfunc mp) StringMap.empty builtinFunctions
		in
```

```
		let assistant mp cdecl =
			let fieldpart mp = function Field(d,n) ->
				if (StringMap.mem n mp)
					then raise (Failure ("Duplicated Field: " ^ n))
				else (StringMap.add n (Field(d, n)) mp)
			in

			let constructorpart condecl =
				if List.length condecl > 1
					then raise (Failure ("Duplicated Constructor"))
				else if List.length condecl = 0 (*default constructor*)
					then StringMap.add (getConstructorName cdecl.cname
defaultC) defaultC StringMap.empty
				else
					StringMap.add (getConstructorName cdecl.cname (List.hd
condecl)) (List.hd condecl) StringMap.empty

			in

			let funcpart m fdecl =
				let funname = getName cdecl.cname fdecl
				in

				if (StringMap.mem funname mp)
					then raise (Failure ("Duplicated Function: " ^ funname))
				else
					let strfunname = string_of_fname fdecl.fname
					in

					if (StringMap.mem strfunname builtFuncMap)
						then raise (Failure ("Cannot use the reserved buit-
in function name: " ^ strfunname))
					else (StringMap.add (getName cdecl.cname fdecl) fdecl m)
			in

			(if (StringMap.mem cdecl.cname mp)
				then raise (Failure ("Duplicated class name: " ^ cdecl.cname))
			else
				StringMap.add cdecl.cname
				{
					fieldMap = List.fold_left fieldpart StringMap.empty
cdecl.cbody.fields;
```

```
                                        constructorMap = constructorpart
cdecl.cbody.constructors;
                                        functionMap = List.fold_left funcpart StringMap.empty
cdecl.cbody.methods;
                                        builtFuncMap = builtFuncMap;
                                        cdecl = cdecl
                                } mp)
                in List.fold_left assistant StringMap.empty cdecls

        in

        match program with
        Program (classes) -> ignore (createStructIndexes classes);


        let classMaps = mappingClass builtinFunctions classes
        in

        (* convert statement in Ast to statement in Sast*)
        let rec exprToSexpr env = function
                Int_Lit i          -> SInt_Lit(i), env
        |   Boolean_Lit b      -> SBoolean_Lit(b), env
        |   Float_Lit f        -> SFloat_Lit(f), env
        |   String_Lit s       -> SString_Lit(s), env
        |   Char_Lit c         -> SChar_Lit(c), env
        |   This               -> SId("this", Datatype(Objecttype(env.envName))), env
        |   Id s               -> SId(s, getIDType env s), env
        |   Null               -> SNull, env
        |   Noexpr             -> SNoexpr, env
        |   ObjAccess(e1, e2)   -> checkObjAccess env e1 e2, env
        |   ObjectCreate(s, el) -> checkConstructor env s el, env
        |   Call(s, el)        -> checkCallType env s el, env
        |   ArrayCreate(d, el)  -> checkArrayInitialize env d el, env
        |   ArrayAccess(e, el)  -> checkArrayAccess env e el, env
        |   Assign(e1, e2)     -> checkAssign env e1 e2, env
        |   Unop(op, e)        -> checkUnop env op e, env
        |   Binop(e1, op, e2)   -> checkBinop env e1 op e2, env

        and exprsToSexprs env el = (*convert expression list to sexpression list*)
                let envref = ref env
                in
                        let rec assistant = function
                                h :: t -> let newh, env = exprToSexpr !envref h
```

```
                                                in(
                                                        envref := env;
                                                        newh :: (assistant t))
                                  | [] -> []
                                in
                                        (assistant el), !envref

        and getIDType env s =
                try
                        StringMap.find s env.envLocals
                with
                        | Not_found -> try let formal = StringMap.find s env.envParams
                                                        in (function   Formal(t, _) -> t
                                                                                | Many t -> t)
formal
                                                 with  | Not_found -> raise (Failure ("ID is
undefined: " ^ s))

        and checkArrayInitialize env d el =
                let arraySize = List.length el(*get the dimention of array*)
                in
                let checkIndexType e = (*check whether the type of index is int*)
                        let sexpr, _ = exprToSexpr env e (*convert expression to sexpression*)
                        in
                                let typ= typOFSexpr sexpr (*get the type of sexpression*)
                                in
                                        if typ = Datatype(Int_t)
                                                then sexpr
                                        else raise (Failure ("Invalid index type for array
initialization: " ^ string_of_datatype typ))
                in
                        let checkTyp = function(*check whether the type can be array type*)
                                  Datatype(x) -> Arraytype(x, arraySize)
                                | _ as t      -> raise (Failure ("Invalid array type: " ^
(string_of_datatype t)))
                        in
                                let typ = checkTyp d
                                in
                                        let sel = List.map checkIndexType  el
                                        in
                                                SArrayCreate(d, sel, typ)

        and checkArrayAccess env e el =
```

```
                let arraySize = List.length el (*get the size of array*)
                in
                        let checkIndexType arg = (*check whether the type of index is int*)
                                let sexpr, _ = exprToSexpr env arg (*convert expression to
sexpression*)
                                in
                                        let typ = typOFSexpr sexpr (*get the type of sexpression*)
                                        in
                                                if typ = Datatype(Int_t)
                                                        then sexpr
                                                else raise (Failure ("Invalid index type for array
access: " ^ string_of_datatype typ))
                                in
                                        let se, _ = exprToSexpr env e (*convert expression to
sexpression*)
                                        in
                                                let typ = typOFSexpr se (*get the type of sexpression*)
                                                in
                                                        let checkArraySize num = function
                                                                Arraytype(t, n) -> if num = n

        then Datatype(t)
                                                                                                else
raise (Failure ("Invalid demention for array access: " ^ (string_of_int num) ^ " > " ^
(string_of_int n)))
                                                                | _ as t        -> raise (Failure ("Invalid type
for array access: " ^ (string_of_datatype t)))
                                                        in
                                                                let typ = checkArraySize arraySize typ
                                                                in
                                                                        let sel = List.map checkIndexType el
                                                                        in SArrayAccess(se, sel, typ)

        and checkObjAccess env lhs rhs =

                let checkLHS = function(*check the expression before '.' and get sexpression*)
                          This   -> SId("this", Datatype(Objecttype(env.envName)))
                        | Id s   -> SId(s, getIDType env s)
                        | ArrayAccess(e, el)    -> checkArrayAccess env e el
                        | _      -> raise (Failure ("LHS of object access must be an instance of
certain class"))
                in
```

```
		let getCname lhsTyp = match lhsTyp with (*get the type of the expression before
'.', i.e. class name*)
					Datatype(Objecttype(name)) -> name
				|	_ as d 					-> raise (Failure
("Object access must have ObjectType: " ^ string_of_datatype d))
		in
		let rec checkRHS (env) lhsTyp=
			let classname = getCname lhsTyp (*get the class name*)
			in
				let search_classfield env (id) cname=
				let cmap = StringMap.find cname env.envClassMaps (*get the
class map of current class*)
				in
					let match_field  = function Field(d, _) -> d (*get datatype
of the expression after '.'*)
					in
						try match_field (StringMap.find id cmap.fieldMap)
						with | Not_found -> raise (Failure ("Unknown field
identifier for class: " ^ id ^ " -> " ^ cname))
				in
					function
					  Id s 		-> SId(s, (search_classfield env s
classname )), env (* Check fields*)
					|  Call(fname, el) -> let env = updateEnv env classname (*
Check functions*)
								in checkCallType env
fname el, env
					|  _ as e 			-> raise (Failure ("Invalid object
access: " ^ string_of_expr e))
		in

		let slhs= checkLHS lhs in

		let slhsTyp = typOFSexpr slhs in

		let lcname = getCname slhsTyp in

		let lhsenv = updateEnv env lcname in

		let srhs, _ = checkRHS lhsenv slhsTyp (*env*) rhs in

		let srhsTyp = typOFSexpr srhs in
```

```
            SObjAccess(slhs, srhs, srhsTyp )

        and checkCallType env fname el =
            let sel, env = exprsToSexprs env el(*convert expression list to sexpression list*)
            in
                let cmap = try StringMap.find env.envName env.envClassMaps (*check
whether the class has been defined*)
                                with | Not_found -> raise (Failure ("Undefined class: " ^
env.envName))
                in(*check type*)

                let check_pa_onebyone formal param = (*check parameter according to
type*)
                    let ftyp = match formal with
                        Formal(d, _) -> d
                        | _          -> Datatype(Void_t)
                    in

                    let ptyp = typOFSexpr param(*get the type of actual parameter*)
                    in
                        if ftyp = ptyp
                            then param
                        else raise (Failure ("Incompatible type for function: " ^
fname ^ "  " ^ string_of_datatype ptyp ^ " -> " ^ string_of_datatype ftyp))
                in


                let getIndex func funcName =
                    let cdecl = cmap.cdecl in

                    let fns = List.rev cdecl.cbody.methods in
                        let rec find x lst =
                            match lst with
                            | [] -> raise (Failure ("Could not find " ^ fname))
                            | fdecl :: t ->
                                let searchName = (getName env.envName
func) in

                                if x = searchName then 0
                                else if searchName = "main" then find x t
                                else 1 + find x t
                        in
                        find funcName fns
                in
```

```
                    let checkParams formals params = match formals, params with (*check
parameter according to amount*)
                            [Many(Any)], _                  -> params
                            | [], []            -> []
                            | _                 -> if List.length formals <> List.length params
                                                                    then raise (Failure
("Incorrect argument number for function: " ^ fname))
                                                                    else List.map2
check_pa_onebyone formals sel
                    in
                    try
                            let func = StringMap.find fname cmap.builtFuncMap
                            in
                            let actuals = checkParams func.sformals sel
                            in SCall(fname, actuals, func.sreturnType,0)
                    with | Not_found -> let sfname = env.envName ^ "." ^ fname
        in
            try let f = StringMap.find sfname cmap.functionMap
                    in
                    let actuals = checkParams f.formals sel in
                    let index = getIndex f sfname in
                    SCall(sfname, actuals, f.returnType, index)
            with | Not_found -> raise (Failure ("Function is not found: " ^ sfname))

        and checkConstructor env s el =
            let sel, env = exprsToSexprs env el
            in

            let params = List.fold_left
                    (fun s e -> s ^ "." ^ (string_of_datatype (typOFSexpr e))) "" sel
            in

            let constructorName = s ^ "." ^ "constructor" ^ params
            in

            let objectTyp = Datatype(Objecttype(s)) in

            SObjectCreate(constructorName, sel, objectTyp)

        and checkAssign env e1 e2 =
            let se1, env = exprToSexpr env e1(*convert expression to sexpression*)
            in
```

```
            let se2, env = exprToSexpr env e2
            in
            let type1 = typOFSexpr se1(*get the type of sexpression*)
            in
            let type2 = typOFSexpr se2
            in

            match (type1, se2) with
                    Datatype(Objecttype(_)), SNull -> SAssign(se1, se2, type1)
                  | _  ->
                          match type1, type2 with
                                  Datatype(Objecttype(d)), Datatype(Objecttype(t)) ->
                                                  if d = t
                                                          then SAssign(se1, se2, type1)
                                                  else raise (Failure ("Assignment types are
mismatched: " ^ string_of_datatype type1 ^ " <-> " ^ string_of_datatype type2))
                                        |  _ -> if type1 = type2
                                                  then SAssign(se1, se2, type1)
                                                  else raise (Failure ("Assignment types are
mismatched: " ^ string_of_datatype type1 ^ " <-> " ^ string_of_datatype type2))

        and checkUnop env op e =
            let checkNum t = function(*operator for number*)
                      Sub     -> t
                    |  _ as o  -> raise (Failure ("Invalid unary operation: " ^ string_of_op o))
            in
            let checkBool = function(*operator for bool*)
                      Not    -> Datatype(Bool_t)
                    |  _ as o -> raise (Failure ("Invalid unary operation: " ^ string_of_op o))
            in
            let se, env = exprToSexpr env e (*convert expression to sexpression*)
            in
            let st = typOFSexpr se (*get the type of sexpression*)
            in
                    match st with (*check the type of operand*)
                              Datatype(Int_t)
                            |  Datatype(Float_t) -> SUnop(op, se, checkNum st op)
                            |  Datatype(Bool_t)  -> SUnop(op, se, checkBool op)
                            |  _ as o          -> raise (Failure ("Invalid operant type for unary
operation: " ^ string_of_datatype o))

        and checkBinop env e1 op e2 =
            let getequal type1 type2 se1 se2 op =
```

```
                    if (type1 = Datatype(Float_t) || type2 = Datatype(Float_t)) (*unqualified
types*)
                        then raise (Failure ("Equality operation is not supported for Float
types"))
                    else
                        match type1, type2 with (*qualified types*)
                            Datatype(Objecttype(_)), Datatype(Null_t)
                          | Datatype(Null_t), Datatype(Objecttype(_)) ->
SBinop(se1, op, se2, Datatype(Bool_t))
                          | _                          -> if type1 = type2

                            then SBinop(se1, op, se2, Datatype(Bool_t))

                        else raise (Failure ("Invalid equality operator for these types: " ^
(string_of_datatype type1) ^ " <-> " ^ (string_of_datatype type2)))
            in

            let getlogic type1 type2 se1 se2 op =(*check operants and conver to sbinop*)
                match type1, type2 with
                    Datatype(Bool_t), Datatype(Bool_t) -> SBinop(se1, op, se2,
Datatype(Bool_t))
                  | _                        -> raise (Failure ("Invalid type for logical
operator" ^ (string_of_datatype type1) ^ "<->" ^ (string_of_datatype type2)))
            in

            let getcomp type1 type2 se1 se2 op =
                match type1, type2 with
                    Datatype(Int_t), Datatype(Float_t)
                  | Datatype(Float_t), Datatype(Int_t) -> SBinop(se1, op, se2,
Datatype(Bool_t))
                  | _                                                          -> if
type1 = type2

            then SBinop(se1, op, se2, Datatype(Bool_t))

        else raise (Failure ("Invalid type for comparison operator: " ^ (string_of_datatype type1)
^ "<->" ^ (string_of_datatype type2)))
            in

            let getarith type1 type2 se1 se2 op =
                match type1, type2 with (*qualified combination of operant type*)
                    Datatype(Int_t), Datatype(Float_t)
                  | Datatype(Float_t), Datatype(Int_t)
```

```
                        | Datatype(Float_t), Datatype(Float_t) -> SBinop(se1, op, se2,
Datatype(Float_t))
                        | Datatype(Int_t), Datatype(Int_t)    -> SBinop(se1, op, se2,
Datatype(Int_t))
                        | _ -> raise (Failure ("Invalid type for arithmetic operator: " ^
(string_of_datatype type1) ^ "<->" ^ (string_of_datatype type2)))
            in

            let se1, env = exprToSexpr env e1 (*convert expression to sexpression*)
            in
            let se2, env = exprToSexpr env e2 (*convert expression to sexpression*)
            in
            let type1 = typOFSexpr se1(*get the type of sexpression*)
            in
            let type2 = typOFSexpr se2(*get the type of sexpression*)
            in

                match op with(*check and convert binopexpression according to
binopexpression type*)
                        Equal | Neq             -> getequal type1 type2 se1 se2 op
                    |   And | Or                -> getlogic type1 type2 se1 se2 op
                    |   Less | Leq | Greater | Geq   -> getcomp type1 type2 se1
se2 op
                    |   Add | Mult | Sub | Div | Mod -> getarith type1 type2 se1
se2 op
                    |   _                   -> raise (Failure ("Invalid binop operator: "
^ (string_of_op op)))

    in

    let rec convertStmtsToSstmts env stmts =
        let envref = ref(env) in
            let rec iter = function
                 h::t -> let newh, newenv = checkStmt !envref h in
                                                    (envref := newenv;
newh::(iter t))
                    | [] -> []
            in
            let sstmts = (iter stmts), !envref in
            sstmts


    and checkExprStmt e env =
```

```
		let se, env = exprToSexpr env e
		in
			let typ = typOFSexpr se
			in
			SExpr(se, typ), env


	and checkIfStmt e s1 s2 env =
		let se, _ = exprToSexpr env e and
			ifbody, _ = checkStmt env s1 and
			elsebody, _ = checkStmt env s2
		in
		let typ = typOFSexpr se
		in
		match typ with
				Datatype(Bool_t)	-> SIf(se, ifbody, elsebody), env
			|   _					-> raise (Failure("invalid if type"))

	and checkForStmt e1 e2 e3 s env =

		let se1, _ = exprToSexpr env e1 and
			se2, _ = exprToSexpr env e2 and
			se3, _ = exprToSexpr env e3 and
			forBodyStmt, env = checkStmt env s
		in
		let cond = typOFSexpr se2
		in
		match cond with
				Datatype(Bool_t)	-> SFor(se1, se2, se3, forBodyStmt), env
			|	Datatype(Void_t)	-> SFor(se1, se2, se3, forBodyStmt), env
			|	_					-> raise (Failure("Invalid for
statement type"))


	and checkWhileStmt e s env =
		let se, _ = exprToSexpr env e and
			sstmt, _ = checkStmt env s
		in
		let typ = typOFSexpr se
		in
		match typ with
				Datatype(Bool_t)	-> SWhile(se, sstmt), env
			|	Datatype(Void_t)	-> SWhile(se, sstmt), env
```

```
                        |       _                                         -> raise (Failure("Invalid
while Statement Type"))

        and checkSblock sl env = match sl with
                  [] -> SBlock([SExpr(SNoexpr, Datatype(Void_t))]), env
                | _ -> let sl, _ = convertStmtsToSstmts env sl
                                in SBlock(sl), env

        and checkReturn e env =
                let se, env = exprToSexpr env e in
                let     typ = typOFSexpr se
                in
                match typ, env.envReturnType with
                          Datatype(Null_t), Datatype(Objecttype(_)) -> SReturn(se, typ), env
                        | _
->
                                if typ = env.envReturnType
                                        then SReturn(se, typ), env
                                        else raise (Failure ("Return type is mismatched!"))

        and checkLocal d s e env =
                if StringMap.mem s env.envLocals
                        then raise (Failure ("Duplicate Local variable defined: " ^ s))
                else
                        let se, env = exprToSexpr env e
                        in
                        let typ = typOFSexpr se
                        in
                        let update_env = {
                                        envClassMaps = env.envClassMaps;
                                        envName = env.envName;
                                        envClassMap = env.envClassMap;
                                        envLocals = StringMap.add s d env.envLocals; (* add new
locals *)
                                        envParams = env.envParams;
                                        envReturnType = env.envReturnType;
                                        envInFor = env.envInFor;
                                        envInWhile = env.envInWhile;
                                        envBuiltIn = env.envBuiltIn;
                                }
                        in
                        if typ = Datatype(Void_t) || typ = Datatype(Null_t) || typ = d
                                then
```

```
                                        match d with
                                                Datatype(Objecttype(x)) ->
                                                        if not (StringMap.mem
(Ast.string_of_object d) env.envClassMaps)
                                                                then raise (Failure ("Undefined
Class: " ^ string_of_object d ))
                                                        else
                                                                let local = SLocal(d, s, se)
                                                                in local, update_env
                                                | _ -> SLocal(d, s, se), update_env

                        else
                                raise (Failure("Local assignment type mismatch: " ^
Ast.string_of_datatype d ^ " <-> " ^ Ast.string_of_datatype typ))


        and  checkStmt env = function

                        Expr e                          -> checkExprStmt e env
                |       If(e, s1, s2)             -> checkIfStmt e s1 s2 env
                |   While(e, s)             -> checkWhileStmt e s env
                |       For(e1, e2, e3, e4) -> checkForStmt e1 e2 e3 e4 env
                |       Block sl                        -> checkSblock sl env
                |       Return e                        -> checkReturn e env
                |   Local(d, s, e)                -> checkLocal d s e env

        in

        (* about inheritance*)
        let rec manageInheritance classes classMaps =
                let inheritanceMap = getInheritanceMap classes classMaps in(*forest: father
class name -> [son class name]*)
                let allClassesM = getClassesForM classes inheritanceMap in(*all classes including
inherited classes which have been dealed with according to methods*)
                let classMethodMap = getClassMethodMap allClassesM in
                let allClassmapsF = getClassmapForF classMaps inheritanceMap in(* classmap
including inherited classes which have been dealed with according to field *)
                let finalMap = getFinalMap allClassmapsF allClassesM classMethodMap in
                finalMap, allClassesM

        and getInheritanceMap cdecls cmap =
                let handler a cdecl =
                        match cdecl.extends with
```

```
                        Parent(s)       ->
                                let new_list = if (StringMap.mem s a) then
                                        cdecl.cname::(StringMap.find s a)
                                else
                                        [cdecl.cname]
                                in
                                Hashtbl.add inheritanceRelation s new_list;
                                (StringMap.add s new_list a)
                |       NoParent       -> a
        in
        let forest = List.fold_left handler StringMap.empty cdecls in

        let handler key value =
                if not (StringMap.mem key cmap) then
                        raise (Failure("undefined class"))
        in
        ignore(StringMap.iter handler forest);
        forest

    and getClassesForM cdecls inheritanceMap =
        let cDataBase = List.fold_left (fun a litem -> StringMap.add litem.cname litem a)
StringMap.empty cdecls (*class name -> class declaration*)
        in
        let seperateInheritanceMap fathers sons sets =
                let fatherSet = StringSet.add fathers (fst sets) in
                let addSonList sndSet son = StringSet.add son sndSet in
                let sonSet = List.fold_left addSonList (snd sets) sons in
                (fatherSet, sonSet)
        in
        let sSet = StringSet.empty in
        let fatherAndson = StringMap.fold seperateInheritanceMap inheritanceMap
(sSet, sSet) in
        let noFather = StringSet.diff (fst fatherAndson) (snd fatherAndson) in
        let rec getNewClasses newMap father sons =
                let assistant newMap oneson =
                        let fatherCdecl = StringMap.find father newMap in (* class
declaration of father*)
                        let sonCdecl = StringMap.find oneson cDataBase in (* class
declaration of one son of father *)
                        let newSonCdecl = getNewSonCdecl fatherCdecl sonCdecl in
                        let newNewMap = (StringMap.add oneson newSonCdecl
newMap) in
                        if (StringMap.mem oneson inheritanceMap) then
```

```
                                        let sonsOFOneSon = StringMap.find oneson
inheritanceMap in
                                        getNewClasses newNewMap oneson sonsOFOneSon
                                else newNewMap
                        in
                        List.fold_left assistant newMap sons
                in
                let newClassMap =
                        let assistant noFather mp =
                                let sonOfSameFather = StringMap.find noFather inheritanceMap
in (*list: son classes for a certain father class*)
                                let noFatherMap = StringMap.add noFather (StringMap.find
noFather cDataBase) mp in(*stringmap: root class name -> class declaration*)
                                getNewClasses noFatherMap noFather sonOfSameFather
                        in
                        StringSet.fold assistant noFather StringMap.empty
                in
                let completeClasses cdecl mp =
                        let halfCompletedCMp =
                                try StringMap.find cdecl.cname newClassMap
                                with | Not_found -> cdecl
                        in
                        halfCompletedCMp::mp
                in
                let completedClassesM = List.fold_right completeClasses cdecls [] in
                completedClassesM


        and getNewSonCdecl fatherCdecl sonCdecl =
                let sonCBody =
                        {
                                fields = fatherCdecl.cbody.fields @ sonCdecl.cbody.fields;
                                constructors = sonCdecl.cbody.constructors;
                                methods = getFatherMethods fatherCdecl.cname
fatherCdecl.cbody.methods sonCdecl.cbody.methods
                        }
                        in
                        {
                                cname = sonCdecl.cname;
                                extends = sonCdecl.extends;
                                cbody = sonCBody
                        }
```

```
and getFatherMethods father fatherMethods sonMethods =
        let checkMethod sonMethod lists =
                let newSonMethods =
                        getNewSonMethod father (fst lists) sonMethod
                in
                if (fst lists) = newSonMethods
                        then ((fst lists), sonMethod::(snd lists))
                else (newSonMethods, (snd lists))
        in
        let allMethod =
                List.fold_right checkMethod sonMethods (fatherMethods, [])
        in
        (fst allMethod) @ (snd allMethod)

and getNewSonMethod father fatherMethods sonMethod =
        let replace fatherMethod sonMethodList =
                let getClassName = function
                        None -> Some(father)
                        | Some(x) -> Some(x)
                in
                let newSonMethod =
                        {
                                fname = sonMethod.fname;
                                returnType = sonMethod.returnType;
                                formals = sonMethod.formals;
                                body = sonMethod.body;
                                overrides = true;
                                rootcname = getClassName fatherMethod.rootcname;
                        }
                in
                if (getMethodName fatherMethod) = (getMethodName sonMethod)
                        then newSonMethod::sonMethodList
                        else fatherMethod::sonMethodList
        in
        List.fold_right replace fatherMethods []

and getMethodName fdecl =

        let params = List.fold_left
                (fun s ->
                        (function       Formal(t, _) -> s ^ "." ^ Ast.string_of_datatype t
                                        | _          -> "" ))
                "" fdecl.formals
```

```
            in
            let name = Ast.string_of_fname fdecl.fname in
            let ret_type = Ast.string_of_datatype fdecl.returnType in
            ret_type ^ "." ^ name ^ "." ^ params



    and getClassMethodMap allClasses =
        let getMethodMap cdecl = (*stringmap: method name -> function declaration*)
            let addMethod mp fdecl = StringMap.add (getName cdecl.cname fdecl)
fdecl mp in
            List.fold_left addMethod StringMap.empty cdecl.cbody.methods
        in
        let addClassMethodMap mp cdecl = StringMap.add cdecl.cname
(getMethodMap cdecl) mp in (*stringmap: class name -> function map (upper)*)
        List.fold_left addClassMethodMap StringMap.empty allClasses

    and getClassmapForF classMaps inheritanceMap =

        let seperateInheritanceMap fathers sons sets =
            let fatherSet = StringSet.add fathers (fst sets) in
            let addSonList sndSet son = StringSet.add son sndSet in
            let sonSet = List.fold_left addSonList (snd sets) sons in
            (fatherSet, sonSet)
        in
        let sSet = StringSet.empty in
        let fatherAndson = StringMap.fold seperateInheritanceMap inheritanceMap
(sSet, sSet) in
        let noFather = StringSet.diff (fst fatherAndson) (snd fatherAndson) in
        let rec getNewClassMap oldMap father sons =
            let assistant oldMap son =
                let fatherFieldMap = (StringMap.find father oldMap).fieldMap in
(* field_map of father *)
                let sonFieldMap = (StringMap.find son oldMap).fieldMap in (*
field_map son *)
                let newSonFieldMap = getNewSonFieldMap fatherFieldMap
sonFieldMap in
                let newMap = getNewMap newSonFieldMap son oldMap in
                if (StringMap.mem son inheritanceMap) then
                    let sonOfSon = StringMap.find son inheritanceMap in
                    getNewClassMap newMap son sonOfSon
                else newMap
            in
```

```
                List.fold_left assistant oldMap sons
        in
        let result = StringSet.fold (fun ns clp -> getNewClassMap clp ns (StringMap.find
ns inheritanceMap)) noFather classMaps
        in result

    and getNewSonFieldMap fatherFieldMap sonFieldMap = (* add father's fields to son *)
        StringMap.fold (fun fa fi sonmp -> StringMap.add fa fi sonmp) fatherFieldMap
sonFieldMap

    and getNewMap sonFieldMap son oldMap =
        let assistant m =
            {
                    fieldMap = sonFieldMap;
                    functionMap = m.functionMap;
                    constructorMap = m.constructorMap;
                    builtFuncMap = m.builtFuncMap;
                    cdecl = m.cdecl;
            }

        in
        let sonMap = StringMap.find son oldMap in
        let newSonMap = assistant sonMap in
        let newMap = StringMap.add son newSonMap oldMap in
        newMap

    and getFinalMap allClassmapsF allClassesM classMethodMap =
        let getCdecl cname =
            try List.find (fun cdecl -> cdecl.cname = cname) allClassesM
            with | Not_found -> raise (Failure("Class not found!")) (*impossible, has
been checked before*)
        in
        let assistant cname cmap =
            let mMap = StringMap.find cname classMethodMap in
            let cdecl = getCdecl cname in
            {
                fieldMap = cmap.fieldMap;
                functionMap = mMap;
                constructorMap = cmap.constructorMap;
                builtFuncMap = cmap.builtFuncMap;
                cdecl = cdecl;
            }
        in
```

```
            let updateCmap cname cmap mp = StringMap.add cname (assistant cname
cmap) mp in
            StringMap.fold updateCmap allClassmapsF StringMap.empty



        in

   let classMaps, cdecls = manageInheritance classes classMaps
        in

        let appendConstructor fbody cname returnType =
            let key = Hashtbl.find strucIndexes cname
            in
            let thisInit = [SLocal(
                                    returnType,
                                    "this",
                                    SCall(   "cast",
                                                [SCall("malloc",
                                                        [
                                                                SCall("sizeof", [SId("ignore",
returnType)], Datatype(Int_t),0)
                                                        ],
                                                        Arraytype(Char_t, 1),0)
                                                ],
                                                returnType,
                                                0
                                        )
                                    );
                                    SExpr(
                                            SAssign(
                                                    SObjAccess(
                                                            SId("this", returnType),
                                                            SId(".key", Datatype(Int_t)),
                                                            Datatype(Int_t)
                                                    ),
                                                    SInt_Lit(key),
                                                    Datatype(Int_t)
                                            ),
                                            Datatype(Int_t)
                                    )
                                ]
            in
```

```
		let returnThis =
					[
						SReturn(
							SId("this", returnType),
							returnType
						)
					]
		in
				thisInit @ fbody @ returnThis

	in

	let convertFuncToSfunc classMaps reserved classMap cname func=

		let appendMain fbodyStmt cname returnType =
			let key = Hashtbl.find strucIndexes cname in
			let thisInit = [SLocal(
				returnType,
				"this",
				SCall(   "cast",
						[SCall("malloc",
							[
								SCall("sizeof", [SId("ignore",
returnType)], Datatype(Int_t), 0)
							],
							Arraytype(Char_t, 1), 0)
						],
						returnType, 0
				)
			);
			SExpr(
				SAssign(
					SObjAccess(
						SId("this", returnType),
						SId(".key", Datatype(Int_t)),
						Datatype(Int_t)
					),
					SInt_Lit(key),
					Datatype(Int_t)
				),
				Datatype(Int_t)
			)
		]
```

```
                in
                thisInit  @ fbodyStmt
        in

        let rootClassName = match func.rootcname with
                Some(x) -> x
                | None -> cname
        in

        let classFormal =
                if func.overrides then
                        Ast.Formal(Datatype(Objecttype(rootClassName)), "this")
                else
                        Ast.Formal(Datatype(Objecttype(cname)), "this")
        in

        let envAssistant m fname = match fname with
                        Formal(d, s) -> (StringMap.add s fname m)
                |       _ -> m
        in
        let env_params = List.fold_left envAssistant StringMap.empty (classFormal ::
func.formals) in
        let env = {
                envClassMaps = classMaps;
                envName         = cname;
                envClassMap             = classMap;
                envLocals       = StringMap.empty;
                envParams       = env_params;
                envReturnType           = func.returnType;
                envInFor                = false;
                envInWhile      = false;
                envBuiltIn      = reserved;
        }

        in
        let fbody = fst (convertStmtsToSstmts env func.body) in
        let funcName = (getName cname func) in

        let fbody = if funcName= "main"
                then (appendMain fbody cname (Datatype(Objecttype(cname))))
                else fbody
        in
        {
```

```
                sfname                  = Ast.FName (getName cname func);
                sreturnType = func.returnType;
                sformals        = classFormal :: func.formals;
                sbody           = fbody;
                functype        = Sast.User;
                overrides   = func.overrides;
                source          = cname;
        }

    in

    let convertConstructorToSfunc classMaps reserved classMap cname constructor =


        let env = {
                envClassMaps = classMaps;
                envName     = cname;
                envClassMap         = classMap;
                envLocals       = StringMap.empty;
                envParams       = List.fold_left (fun m f -> match f with Formal(d, s) ->
(StringMap.add s f m) | _ -> m) StringMap.empty constructor.formals;
                envReturnType       = Datatype(Objecttype(cname));
                envInFor            = false;
                envInWhile      = false;
                envBuiltIn      = reserved;}
        in

        let fbody = fst (convertStmtsToSstmts env constructor.body)
        in
                {
                        sfname                  = Ast.FName(getConstructorName
cname constructor);
                        sreturnType = Datatype(Objecttype(cname));
                        sformals        = constructor.formals;
                        sbody           = appendConstructor fbody cname
(Datatype(Objecttype(cname)));
                        functype        = Sast.User;
                        overrides       = false;
                        source          = "NA";
                }
    in

    let converttosast classMaps builtinFunctions cdecls =
```

```
let deConstructorBody cname =
        let retyp = Datatype(Objecttype(cname)) in
        let fbody = [] in
        appendConstructor fbody cname retyp
in

let defaultSc cname =
{
        sfname                  = Ast.FName (cname ^ "." ^ "constructor");
        sreturnType = Datatype(Objecttype(cname));
        sformals        = [];
        sbody           = deConstructorBody  cname;
        functype        = Sast.User;
        overrides   = false;
        source          = "NA";
}
in

let convertClassToSast sfuncs cdecl =
        {scname =cdecl.cname;
         sfields =cdecl.cbody.fields;
         sfuncs= sfuncs;
        }
in

let isMain fdecl = fdecl.sfname = FName("main")
in
let checkMain fdecls =
        let mainFuncs = (List.filter isMain fdecls) in
                if List.length mainFuncs > 1
                        then raise (Failure("Multiple main functions are defined!"))
                else if List.length mainFuncs < 1
                        then raise (Failure("Main function is not defined!"))
                else List.hd mainFuncs
in
let removeMainFunc funcs = List.filter (fun func -> not(isMain func)) funcs
in
let handleClass cdecl =
let classMap =StringMap.find cdecl.cname classMaps
in
let sConstructors = match cdecl.cbody.constructors with
```

```
                                                                    [] ->
(defaultSc cdecl.cname) :: [](*no user defined constructor*)
                                                                | _ ->
List.map (convertConstructorToSfunc classMaps builtinFunctions classMap cdecl.cname)
cdecl.cbody.constructors
            in
            let funcs = List.fold_left (fun l f -> (convertFuncToSfunc classMaps
builtinFunctions classMap cdecl.cname f):: l) [] cdecl.cbody.methods
            in
                  let sfuncs = removeMainFunc funcs
                  in
                        let scdecl = convertClassToSast sfuncs cdecl
                        in
                              (scdecl, funcs @sConstructors)
      in
            let loopClass t c =
            let scdecl =handleClass c
            in (fst scdecl::fst t, snd scdecl @ snd t)
            in
                  let scdecls, funcs =List.fold_left loopClass ([],[]) cdecls
                  in
                        let mainFunc = checkMain funcs in
                              let funcs=  removeMainFunc funcs in
                                    {
                                          classes = scdecls;
                                          functions = funcs;
                                          main = mainFunc;
                                          reserved = builtinFunctions;
                                    }
      in
      let sast = converttosast classMaps builtinFunctions cdecls in
            sast
```

codegen.ml

```
(* Code generation: translate takes a semantically checked AST and
produces LLVM IR

LLVM tutorial: Make sure to read the OCaml version of the tutorial

http://llvm.org/docs/tutorial/index.html

Detailed documentation on the OCaml LLVM library:
```

```
http://llvm.moe/
http://llvm.moe/ocaml/
*)
open Llvm
open Hashtbl

open Ast
open Semant
open Sast

module L = Llvm

let context = L.global_context ()
let the_module = L.create_module context "Liva"
let builder = L.builder context

let i1_t = L.i1_type context
let i8_t = L.i8_type context;;
let i32_t = L.i32_type context;;
let i64_t = L.i64_type context;;
let f_t = L.double_type context;;

let str_t = L.pointer_type i8_t;;
let void_t = L.void_type context;;

let arr_type = Arraytype(Char_t, 1)

let local_var_table:(string, llvalue) Hashtbl.t = Hashtbl.create 100
let formals_table:(string, llvalue) Hashtbl.t = Hashtbl.create 100
let struct_typ_table:(string, lltype) Hashtbl.t = Hashtbl.create 100
let struct_field_idx_table:(string, int) Hashtbl.t = Hashtbl.create 100

(*~~~~~~~~~~~~~~~~ global functions: code generator utils ~~~~~~~~~~~~~~~~~~ *)
let rec get_llvm_type datatype = match datatype with
            Datatype(Int_t) -> i32_t
          | Datatype(Float_t) -> f_t
          | Datatype(Bool_t) -> i1_t
          | Datatype(Char_t) -> i8_t
          | Datatype(Void_t) -> void_t
          | Datatype(Null_t) -> i32_t
          | Datatype(Objecttype(name)) -> L.pointer_type(find_llvm_struct_type name)
          | Arraytype(t, i) -> get_arr_llvm_type (Arraytype(t, (i)))
```

```
        | _ -> raise(Failure ("Invalid DataType"))

and find_llvm_struct_type name =
        try Hashtbl.find struct_typ_table name
        with | Not_found -> raise(Failure ("undeclared struct"^ name))

and get_arr_llvm_type datatype = match datatype with
         Arraytype(t, 0) -> get_llvm_type (Datatype(t))
        | Arraytype(t, 1) -> L.pointer_type (get_llvm_type (Datatype(t)))
        | Arraytype(t, i) -> L.pointer_type (get_arr_llvm_type (Arraytype(t, (i-1))))
        | _ -> raise(Failure ("Invalid Array Pointer Type"))

let string_of_fname = function
         Constructor -> "constructor"
        | FName(s)     -> s

let find_func_in_module fname =
        match (L.lookup_function fname the_module) with
         None -> raise (Failure("Function NotFound in module: " ^ fname))
        | Some f -> f

(*~~~~~~~~~~~~~~~~~~~~~~~~~~~ code generator top level ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
*)
let translate sast =

        let classes = sast.classes in
        let functions = sast.functions in
   let main = sast.main in

        let util_func () =
                let printf_typ = L.var_arg_function_type i32_t [| pointer_type i8_t |] in
                let malloc_typ = L.function_type (str_t) [| i32_t |] in
                let lookup_typ = L.function_type (pointer_type i64_t) [| i32_t; i32_t |] in

                let _ = L.declare_function "printf" printf_typ the_module in
                let _ = L.declare_function "malloc" malloc_typ the_module in
                let _ = L.define_function "lookup" lookup_typ the_module in
                ()
        in
        let _ = util_func () in

        (*~~~~~~~~~~~~~~~~~~~~~~~~~~~ Generate class struct
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*)
```

```
let add_struct_typ_table cls =
        let struct_typ = L.named_struct_type context cls.scname in
        Hashtbl.add struct_typ_table cls.scname struct_typ
in

let _ = List.map add_struct_typ_table classes in

let class_struct_gen s =
        let struct_t = Hashtbl.find struct_typ_table s.scname in
        let type_list = List.map (function Field(d, _) -> get_llvm_type d) s.sfields in
        let name_list = List.map (function Field(_, s) -> s) s.sfields in
        let type_list = i32_t :: type_list in
        let name_list = ".key" :: name_list in
        let type_array = (Array.of_list type_list) in
        List.iteri (
                fun i f ->
      let n = s.scname ^ "." ^ f in
      Hashtbl.add struct_field_idx_table n i;
        )
    name_list;
        L.struct_set_body struct_t type_array true
in
let _ = List.map class_struct_gen classes in

(*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ define functions
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*)
let func_define sfdecl=

        let fname = sfdecl.sfname in
        let is_var_arg =ref false in
        let parameters = List.rev ( List.fold_left
        (fun l ->
                (function
                  Formal (t,_)-> get_llvm_type t::l
                | _ -> ignore(is_var_arg = ref true); l
                )
        )
        []  sfdecl.sformals)
        in

        let fty =
                if !is_var_arg
                        then L.var_arg_function_type (get_llvm_type sfdecl.sreturnType )
```

```
                    (Array.of_list parameters)
                else L.function_type (get_llvm_type sfdecl.sreturnType)
                    (Array.of_list parameters)
            in
            L.define_function (string_of_fname fname) fty the_module
    in
    let _ = List.map func_define functions in

    (*~~~~~~~~~~~~~~~~~~~~~~ function generation utils
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*)
    (*statement gengeration*)
    let rec stmt_gen llbuilder = function
             SBlock sl       ->        List.hd (List.map (stmt_gen llbuilder) sl)
            | SLocal (d, s, e) ->
                let local_gen datatype var_name expr llbuilder =
                    let t = match datatype with
                        Datatype(Objecttype(name)) -> find_llvm_struct_type
name
                        |  _ -> get_llvm_type datatype
                    in
                    let alloca = L.build_alloca t var_name llbuilder in
                    Hashtbl.add local_var_table var_name alloca;
                    let lhs = SId(var_name, datatype) in
                    match expr with
                        SNoexpr -> alloca
                    |       _ -> assign_gen lhs expr datatype llbuilder
                in
                local_gen d s e llbuilder

            | SReturn (e, d)   ->
                let return_gen d expr llbuilder =
                    match expr with
                         SId(name, d) ->
                            (match d with
                            | Datatype(Objecttype(_)) -> build_ret (id_gen false
false name d llbuilder) llbuilder
                            | _ -> build_ret (id_gen true true name d llbuilder)
llbuilder)
                        | SObjAccess(e1, e2, d) -> build_ret (obj_access_gen true
e1 e2 d llbuilder) llbuilder
                        | SNoexpr -> build_ret_void llbuilder
                        | _ -> build_ret (expr_gen llbuilder expr) llbuilder
```

```
                in
                return_gen d e llbuilder

        | SExpr (se, _)    ->      expr_gen llbuilder se

        (*control flow*)
        | SIf (e, s1, s2)  ->
                let if_gen exp then_stmt else_stmt llbuilder =
                        let condition= expr_gen llbuilder exp in
                        let start_block = L.insertion_block llbuilder in
                        let parent_function = L.block_parent start_block in
                        let then_block = L.append_block context "then" parent_function
in
                        L.position_at_end then_block llbuilder;

                        let then_val = stmt_gen llbuilder then_stmt in
                        let new_then_block = L.insertion_block llbuilder in
                        let else_block = L.append_block context "else" parent_function in
                        L.position_at_end else_block llbuilder;

                        let else_val= stmt_gen llbuilder else_stmt in
                        let new_else_block = L.insertion_block llbuilder in
                        let merge_block = L.append_block context "ifcont"
parent_function in
                        L.position_at_end merge_block builder;

                        let incoming = [(then_val, new_then_block); (else_val,
new_else_block)] in
                        let phi = L.build_phi incoming "iftmp" builder in
                        L.position_at_end start_block llbuilder;
                        ignore (build_cond_br condition then_block else_block llbuilder);
                        position_at_end new_then_block llbuilder; ignore (build_br
merge_block llbuilder);
                        position_at_end new_else_block llbuilder; ignore (build_br
merge_block llbuilder);
                        (* set the builder to the end of the merge block *)
                        L.position_at_end merge_block llbuilder;
                        phi
                in
                if_gen e s1 s2 llbuilder

        | SFor (se1, se2, se3, s) -> for_gen se1 se2 se3 s llbuilder
```

```
            | SWhile (se, s)   ->      while_gen se s llbuilder

        (*expression generation*)
        and expr_gen llbuilder = function
                SInt_Lit (i)     ->         L.const_int i32_t i
            | SBoolean_Lit (b) ->   if b then L.const_int i1_t 1 else L.const_int i1_t 0
            | SFloat_Lit (f)   ->      L.const_float f_t  f
            | SChar_Lit (c)    ->      L.const_int i8_t (Char.code c)
            | SString_Lit (s)  ->      L.build_global_stringptr s "tmp" llbuilder

            | SId (id, d)      -> id_gen true false id d llbuilder

            | SBinop (e1, op, e2, d) ->
                    let binop_gen e1 op e2 d llbuilder =
                            let type1 = Semant.typOFSexpr e1 in
                            let type2 = Semant.typOFSexpr e2 in
                            let e1 = expr_gen llbuilder e1 in
                            let e2 = expr_gen llbuilder e2 in
                            let float_ops op e1 e2 =
                                    match op with
                                     Add            -> L.build_fadd e1 e2 "flt_addtmp" llbuilder
                                    | Sub           -> L.build_fsub e1 e2 "flt_subtmp" llbuilder
                                    | Mult          -> L.build_fmul e1 e2 "flt_multmp" llbuilder
                                    | Div           -> L.build_fdiv e1 e2 "flt_divtmp" llbuilder
                                    | Mod           -> L.build_frem e1 e2 "flt_sremtmp"
llbuilder
                                    | Equal         -> L.build_fcmp Fcmp.Oeq e1 e2
"flt_eqtmp" llbuilder
                                    | Neq           -> L.build_fcmp Fcmp.One e1 e2
"flt_neqtmp" llbuilder
                                    | Less          -> L.build_fcmp Fcmp.Ult e1 e2
"flt_lesstmp" llbuilder
                                    | Leq           -> L.build_fcmp Fcmp.Ole e1 e2
"flt_leqtmp" llbuilder
                                    | Greater       -> L.build_fcmp Fcmp.Ogt e1 e2
"flt_sgttmp" llbuilder
                                    | Geq           -> L.build_fcmp Fcmp.Oge e1 e2
"flt_sgetmp" llbuilder
                                    | _             -> raise(Failure("Invalid operator for
floats"))
                            in
                            let int_ops op e1 e2 =
                                    match op with
```

```
                                    Add         -> L.build_add e1 e2 "addtmp" llbuilder
                                  | Sub         -> L.build_sub e1 e2 "subtmp" llbuilder
                                  | Mult        -> L.build_mul e1 e2 "multmp" llbuilder
                                  | Div         -> L.build_sdiv e1 e2 "divtmp" llbuilder
                                  | Mod         -> L.build_srem e1 e2 "sremtmp" llbuilder
                                  | Equal       -> L.build_icmp Icmp.Eq e1 e2 "eqtmp"
llbuilder
                                  | Neq         -> L.build_icmp Icmp.Ne e1 e2 "neqtmp"
llbuilder
                                  | Less        -> L.build_icmp Icmp.Slt e1 e2 "lesstmp"
llbuilder
                                  | Leq         -> L.build_icmp Icmp.Sle e1 e2 "leqtmp"
llbuilder
                                  | Greater     -> L.build_icmp Icmp.Sgt e1 e2 "sgttmp"
llbuilder
                                  | Geq         -> L.build_icmp Icmp.Sge e1 e2 "sgetmp"
llbuilder
                                  | And         -> L.build_and e1 e2 "andtmp" llbuilder
                                  | Or          -> L.build_or  e1 e2 "ortmp" llbuilder
                                  | _           -> raise(Failure("Invalid operator for
integers"))
                        in

                        let binop_type_cast lhs rhs lhsType rhsType llbuilder =
                                match (lhsType, rhsType) with
                                  Datatype(Int_t), Datatype(Int_t)    -> (lhs, rhs),
Datatype(Int_t)
                                  | Datatype(Int_t), Datatype(Char_t)   -> (build_uitofp lhs
i8_t "tmp" llbuilder, rhs), Datatype(Char_t)
                                  | Datatype(Int_t), Datatype(Float_t) -> (build_sitofp lhs f_t
"tmp" llbuilder, rhs), Datatype(Float_t)
                                  | Datatype(Char_t), Datatype(Int_t)  -> (lhs, build_uitofp
rhs i8_t "tmp" llbuilder), Datatype(Char_t)
                                  | Datatype(Char_t), Datatype(Char_t) -> (lhs, rhs),
Datatype(Char_t)
                                  | Datatype(Bool_t), Datatype(Bool_t) -> (lhs, rhs),
Datatype(Bool_t)
                                  | Datatype(Float_t), Datatype(Int_t) -> (lhs, build_sitofp
rhs f_t "tmp" llbuilder), Datatype(Float_t)
                                  | Datatype(Float_t), Datatype(Float_t)      -> (lhs, rhs),
Datatype(Float_t)
```

```
                                | Datatype(Objecttype(d)), Datatype(Null_t)-> (lhs, rhs),
lhsType
                                | Datatype(Null_t), Datatype(Objecttype(d)) -> (rhs, lhs),
rhsType
                                | Arraytype(d, s), Datatype(Null_t)     -> (lhs, rhs), lhsType
                                | Datatype(Null_t), Arraytype(d, s)  -> (rhs, lhs), rhsType

                                |          _ -> raise (Failure("binop type not supported"))
                        in

                        let (e1, e2), d = binop_type_cast e1 e2 type1 type2 llbuilder in
                        let type_handler d = match d with
                                        Datatype(Float_t)   -> float_ops op e1 e2
                                |       Datatype(Int_t)
                                |   Datatype(Bool_t)
                                |       Datatype(Char_t)       -> int_ops op e1 e2
                                |       Datatype(Objecttype(_))
                                |   _ -> raise (Failure("Invalid binop type"))
                        in
                        type_handler d
                in
                binop_gen e1 op e2 d llbuilder

        | SUnop (op, e, d)      ->
                let unop_gen op e d llbuilder =
                        let e_typ = Semant.typOFSexpr e in
                        let e = expr_gen llbuilder e in
                        let unops op e_typ e = match (op, e_typ) with
                                (Sub, Datatype(Int_t))          ->  L.build_neg e
"int_unoptmp" llbuilder
                                | (Sub, Datatype(Float_t))      ->      L.build_fneg e
"flt_unoptmp" llbuilder
                                | (Not, Datatype(Bool_t))       ->  L.build_not e
"bool_unoptmp" llbuilder
                                | _ -> raise (Failure("unop not supported"))  in

                        let unop_type_handler d = match d with
                                 Datatype(Float_t)
                                | Datatype(Int_t)
                                | Datatype(Bool_t)     -> unops op e_typ e
                                | _ -> raise (Failure("invalid unop type  "))
                        in
                        unop_type_handler d
```

```
                    in
                    unop_gen op e d llbuilder

            | SAssign (e1, e2, d) -> assign_gen e1 e2 d llbuilder
        | SCall (fname, expr_list, d, _) ->
            let reserved_func_gen llbuilder d expr_list = function
                        "print"         -> print_func_gen expr_list llbuilder
                    | "sizeof"        -> sizeof_func_gen expr_list llbuilder
                    | "cast"          -> cast_func_gen expr_list d llbuilder
                    | "malloc"        -> malloc_func_gen "malloc" expr_list d llbuilder
                    |  _ as call_name -> raise(Failure("function call not found: "^
call_name))
            in
            reserved_func_gen llbuilder d expr_list fname

        | SObjectCreate (id, el, d) ->
                    let create_obj_gen fname el d llbuilder =
                            let f = find_func_in_module fname in
                            let params = List.map (expr_gen llbuilder) el in
                            let obj = L.build_call f (Array.of_list params) "tmp" llbuilder in
                            obj
                    in
            create_obj_gen id el d llbuilder

            | SObjAccess (e1, e2, d)  -> obj_access_gen true e1 e2 d llbuilder

            | SArrayCreate (t, el, d) ->
                    let arr_create_gen llbuilder t expr_type el =
                            if(List.length el > 1) then raise(Failure("array not supported"))
                            else
                            match expr_type with
                             Arraytype(Char_t, 1) ->
                                    let e = List.hd el in
                                    let size = (expr_gen llbuilder e) in
                                    let t = get_llvm_type t in
                                    let arr = L.build_array_malloc t size "tmp" llbuilder in
                                    let arr = L.build_pointercast arr (pointer_type t) "tmp"
llbuilder in
                                    arr
                            | _ ->
                                    let e = List.hd el in
                                    let t = get_llvm_type t in
                                    let size = (expr_gen llbuilder e) in
```

```
                                let size_t = L.build_intcast (size_of t) i32_t "tmp" llbuilder
in
                                let size = L.build_mul size_t size "tmp" llbuilder in
                                let size_real = L.build_add size (const_int i32_t 1)
"arr_size" llbuilder in

                            let arr = L.build_array_malloc t size_real "tmp" llbuilder in
                                let arr = L.build_pointercast arr (pointer_type t) "tmp"
llbuilder in

                                let arr_len_ptr = L.build_pointercast arr (pointer_type
i32_t) "tmp" llbuilder in

                                ignore(build_store size_real arr_len_ptr llbuilder);
                                let init_array arr arr_len init_val start_pos llbuilder =
                                        let new_block label =
                                                let f = block_parent (insertion_block
llbuilder) in
                                                append_block (global_context ()) label f
                                        in
                                        let bbcurr = insertion_block llbuilder in
                                        let bbcond = new_block "array.cond" in
                                        let bbbody = new_block "array.init" in
                                        let bbdone = new_block "array.done" in
                                        ignore (L.build_br bbcond llbuilder);
                                        position_at_end bbcond llbuilder;

                                        let counter = L.build_phi [const_int i32_t start_pos,
bbcurr] "counter" llbuilder in
                                        add_incoming ((L.build_add counter (const_int
i32_t 1) "tmp" llbuilder), bbbody) counter;
                                        let cmp = L.build_icmp Icmp.Slt counter arr_len
"tmp" llbuilder in
                                        ignore (L.build_cond_br cmp bbbody bbdone
llbuilder);
                                        position_at_end bbbody llbuilder;

                                        let arr_ptr = L.build_gep arr [| counter |] "tmp"
llbuilder in
                                        ignore (L.build_store init_val arr_ptr llbuilder);
                                        ignore (L.build_br bbcond llbuilder);
                                        position_at_end bbdone llbuilder
                                in
```

```
                                        init_array arr_len_ptr size_real (const_int i32_t 0) 0
llbuilder;
                                        arr
                        in
                        arr_create_gen llbuilder t d el

                | SArrayAccess (e, el, d) -> arr_access_gen false e el d llbuilder

                | SNoexpr -> L.build_add (L.const_int i32_t 0) (L.const_int i32_t 0) "nop" llbuilder
                | _ -> raise(Failure("expression not match"))


        and print_func_gen expr_list llbuilder =
                let printf = find_func_in_module "printf" in
                let tmp_count = ref 0 in
                let incr_tmp = fun x -> incr tmp_count in
                let map_expr_to_printfexpr expr =
                        let exprType = Semant.typOFSexpr expr in
                        match exprType with
                        Datatype(Bool_t) ->
                                incr_tmp ();
                                let tmp_var = "tmp" ^ (string_of_int !tmp_count) in
                                let trueStr = SString_Lit("true") in
                                let falseStr = SString_Lit("false") in
                                let id = SId(tmp_var, arr_type) in
                                ignore(stmt_gen llbuilder (SLocal(arr_type, tmp_var, SNoexpr)));
                                ignore(
                                        stmt_gen llbuilder
                                        (
                                                SIf(
                                                        expr, SExpr(SAssign(id, trueStr, arr_type),
arr_type),
                                                        SExpr(SAssign(id, falseStr, arr_type),
arr_type)
                                                        )
                                        )
                                );
                                expr_gen llbuilder id
                        | _ -> expr_gen llbuilder expr
                in
                let params = List.map map_expr_to_printfexpr expr_list in
                let param_types = List.map (Semant.typOFSexpr) expr_list in
                let map_param_to_string = function
```

```
                 Arraytype(Char_t, 1)          -> "%s"
                | Datatype(Int_t)              -> "%d"
                | Datatype(Float_t)    -> "%f"
                | Datatype(Bool_t)             -> "%s"
                | Datatype(Char_t)             -> "%c"
                | _                                    -> raise (Failure("Print invalid type"))
                in
                let const_str = List.fold_left (fun s t -> s ^ map_param_to_string t) ""
param_types in
                let s = expr_gen llbuilder (SString_Lit(const_str)) in
                let zero = const_int i32_t 0 in
                let s = L.build_in_bounds_gep s [| zero |] "tmp" llbuilder in
                L.build_call printf (Array.of_list (s :: params)) "tmp" llbuilder

        and sizeof_func_gen el llbuilder =
                let type_of_sexpr = Semant.typOFSexpr (List.hd el) in
                let type_of_sexpr = get_llvm_type type_of_sexpr in
                let size_of_typ = L.size_of type_of_sexpr in
                L.build_intcast size_of_typ i32_t "tmp" llbuilder

        and cast_func_gen el d llbuilder =
                let cast_malloc_to_objtype lhs currType newType llbuilder = match newType
with
                         Datatype(Objecttype(x)) ->
                                let obj_type = get_llvm_type (Datatype(Objecttype(x))) in
                                L.build_pointercast lhs obj_type "tmp" llbuilder
                        | _ -> raise (Failure("cannot cast"))
                in
                let expr = List.hd el in
                let t = Semant.typOFSexpr expr in
                let lhs = match expr with
                        | Sast.SId(id, d) -> id_gen false false id d llbuilder
                        | SObjAccess(e1, e2, d) -> obj_access_gen false e1 e2 d llbuilder
                        | _ -> expr_gen llbuilder expr
                in
                cast_malloc_to_objtype lhs t d llbuilder

        and malloc_func_gen fname el d llbuilder =
                let f = find_func_in_module fname in
                let params = List.map (expr_gen llbuilder) el in
                match d with
                 Datatype(Void_t) -> L.build_call f (Array.of_list params) "" llbuilder
                | _ -> L.build_call f (Array.of_list params) "tmp" llbuilder
```

```
and id_gen deref checkParam id d llbuilder =
        if deref then
                try Hashtbl.find formals_table id
                with | Not_found ->
                        try let _val = Hashtbl.find local_var_table id in
                        build_load _val id llbuilder
                        with | Not_found -> raise (Failure("unknown variable id " ^ id))
        else
                try Hashtbl.find local_var_table id
                with | Not_found ->
                        try
                                let _val = Hashtbl.find formals_table id in
                                if checkParam then raise (Failure("cannot assign"))
                                else _val
                        with | Not_found -> raise (Failure("unknown variable id "^ id))

and assign_gen lhs rhs d llbuilder =
        let rhs_t = Semant.typOFSexpr rhs in
        let lhs, isObjAccess = match lhs with
                | Sast.SId(id, d) -> id_gen false false id d llbuilder, false
                | SObjAccess(e1, e2, d) -> obj_access_gen false e1 e2 d llbuilder, true
                | SArrayAccess(se, sel, d) -> arr_access_gen true se sel d llbuilder, true
                | _ -> raise (Failure("Left hand side must be assignable"))
        in
        let rhs = match rhs with
                | Sast.SId(id, d) -> id_gen false false id d llbuilder
                | SObjAccess(e1, e2, d) -> obj_access_gen true e1 e2 d llbuilder
                | _ -> expr_gen llbuilder rhs
        in
        let rhs = match d with
                 Datatype(Objecttype(_))      ->
                        if isObjAccess then rhs
                        else build_load rhs "tmp" llbuilder
                | Datatype(Null_t) -> L.const_null (get_llvm_type d)
                | _ -> rhs
        in
        let rhs = match d, rhs_t with
                 Datatype(Char_t), Datatype(Int_t) -> L.build_uitofp rhs i8_t "tmp"
llbuilder
                | Datatype(Int_t), Datatype(Char_t) -> L.build_uitofp rhs i32_t "tmp"
llbuilder
                | _ -> rhs
```

```
        in
        ignore(L.build_store rhs lhs llbuilder);
        rhs

and for_gen start cond step body llbuilder =
        let preheader_bb = L.insertion_block llbuilder in
        let the_function = L.block_parent preheader_bb  in
        let _ = expr_gen llbuilder start in
        let loop_bb = L.append_block context "loop" the_function in
        let step_bb = L.append_block context "step" the_function in
        let cond_bb = L.append_block context "cond" the_function in
        let after_bb = L.append_block context "afterloop" the_function in
        ignore (L.build_br cond_bb llbuilder);
        L.position_at_end loop_bb llbuilder;
        ignore (stmt_gen llbuilder body);

        let bb = L.insertion_block llbuilder in
        L.move_block_after bb step_bb;
        L.move_block_after step_bb cond_bb;
        L.move_block_after cond_bb after_bb;
        ignore(L.build_br step_bb llbuilder);
        L.position_at_end step_bb llbuilder;

        let _ = expr_gen  llbuilder step  in
        ignore(L.build_br cond_bb llbuilder);
        L.position_at_end cond_bb llbuilder;

        let cond_val = expr_gen llbuilder cond in
        ignore (L.build_cond_br cond_val loop_bb after_bb llbuilder);
        L.position_at_end after_bb llbuilder;
        const_null f_t

and while_gen pred body_stmt llbuilder =
        let null_sexpr = SInt_Lit(0) in
        for_gen null_sexpr pred null_sexpr body_stmt llbuilder

and obj_access_gen is_assign lhs rhs d llbuilder =
        let obj_func_gen param_ty fptr parent_expr el d llbuilder =
                let match_sexpr se = match se with
                        SId(id, d) ->
                                let deref = match d with
                                        Datatype(Objecttype(_)) -> false
                                      | _ -> true
```

```
                                        in
                                        id_gen deref false id d llbuilder
                                | se -> expr_gen llbuilder se
                        in
                        let parent_expr = build_pointercast parent_expr param_ty "tmp"
llbuilder in
                        let params = List.map match_sexpr el in
                        match d with
                                Datatype(Void_t) -> L.build_call fptr (Array.of_list (parent_expr ::
params)) "" llbuilder
                                | _ -> L.build_call fptr (Array.of_list (parent_expr :: params))
"tmp" llbuilder
                in

                let check_lhs = function
                        SId(s, d) -> id_gen false false s d llbuilder
                        | SArrayAccess(e, el, d) -> arr_access_gen false e el d llbuilder
                        | _ -> raise (Failure("check lhd error"))
                in

                let rec check_rhs parent_expr parent_type =
                        let parent_str = Ast.string_of_object parent_type in
                        function
                                SId(field, d) ->
                                        let search_term = (parent_str ^ "." ^ field) in
                                        let field_index = Hashtbl.find struct_field_idx_table
search_term in
                                        let _val = build_struct_gep parent_expr field_index field
llbuilder in
                                        let _val = match d with
                                                Datatype(Objecttype(_)) ->
                                                if not is_assign then _val
                                                else build_load _val field llbuilder
                                        | _ ->
                                        if not is_assign then
                                                _val
                                        else
                                                build_load _val field llbuilder
                                        in
                                        _val
                                | SCall(fname, el, d, index)     ->
                                        let index = const_int i32_t index in
```

```
                                        let c_index = build_struct_gep parent_expr 0 "cindex"
llbuilder in
                                        let c_index = build_load c_index "cindex" llbuilder in
                                        let lookup_func = find_func_in_module "lookup" in
                                        let fptr = L.build_call lookup_func [| c_index; index |]
"fptr" llbuilder in
                                        let fptr2 = find_func_in_module fname in
                                        let f_ty = type_of fptr2 in
                                        let param1 = param fptr2 0 in
                                        let param_ty = type_of param1 in
                                        let fptr = L.build_pointercast fptr f_ty fname llbuilder in
                                        let ret = obj_func_gen param_ty fptr parent_expr el d
llbuilder in
                                        let ret = ret in
                                        ret
                                | SObjAccess(e1, e2, _)         ->
                                        let e1_type = Semant.typOFSexpr e1 in
                                        let e1 = check_rhs parent_expr parent_type e1 in
                                        let e2 = check_rhs e1 e1_type e2 in
                                        e2
                                | _ -> raise (Failure("invalid access"))
                        in
                        let lhs_type = Semant.typOFSexpr lhs in
                        match lhs_type with
                                Arraytype(_, _) ->
                                        let lhs = expr_gen llbuilder lhs in
                                        let _val = build_gep lhs [| (const_int i32_t 0) |] "tmp" llbuilder in
                                        build_load _val "tmp" llbuilder
                                | _ ->
                                let lhs = check_lhs lhs in
                                let rhs = check_rhs lhs lhs_type rhs in
                                rhs

        and arr_access_gen is_assign e el d llbuilder =
                        let index = expr_gen llbuilder (List.hd el) in
                        let index = match d with
                                Datatype(Char_t) -> index
                                | _ -> L.build_add index (const_int i32_t 1) "tmp" llbuilder
                        in
                let arr = expr_gen llbuilder e in
                let _val = L.build_gep arr [| index |] "tmp" llbuilder in
                if is_assign
                        then _val
```

```
            else build_load _val "tmp" llbuilder
        in

        (*~~~~~~~~~~~~~~~~~~~~~~~~~~ function generation top-level
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~*)
        let build_func sfdecl =

            Hashtbl.clear local_var_table;
            Hashtbl.clear formals_table;
            let fname = string_of_fname sfdecl.sfname in
            let f =find_func_in_module fname in
            let llbuilder = L.builder_at_end context (L.entry_block f) in

            let init_formals f sformals =
                let sformals = Array.of_list (sformals) in
                Array.iteri (
                        fun i a ->
                let formal = sformals.(i) in
                let string_of_formal_name = function
                                        Formal(_, s) -> s
                                        | _ -> " "
                                in
                let formal_name = string_of_formal_name formal in
                L.set_value_name formal_name a;
                Hashtbl.add formals_table formal_name a;
              )
              (params f)
            in
            let _ = init_formals f sfdecl.sformals in

            let _ = if sfdecl.overrides then
                let this_param = Hashtbl.find formals_table "this" in
                let source = Datatype(Objecttype(sfdecl.source)) in
                let casted_param = L.build_pointercast this_param (get_llvm_type
source) "casted" llbuilder in
                Hashtbl.replace formals_table "this" casted_param;
            in

            let _  = stmt_gen llbuilder (SBlock (sfdecl.sbody)) in
            if sfdecl.sreturnType = Datatype (Void_t)
            then ignore (L.build_ret_void llbuilder);
            ()
        in
```

```
	let _ = List.map build_func functions in

	(*~~~~~~~~~~~~~~~~~~~~ main function generation top-level
~~~~~~~~~~~~~~~~~~~~~~~~~~~~*)
	let build_main main =
		Hashtbl.clear local_var_table;
		Hashtbl.clear formals_table;
	   let fty = L.function_type i32_t[||] in
		let f = L.define_function "main" fty the_module in
		let llbuilder = L.builder_at_end context (L.entry_block f) in

		let _ = stmt_gen llbuilder (SBlock (main.sbody)) in


		L.build_ret (L.const_int i32_t 0) llbuilder
	in
	let _ = build_main main in

	(*~~~~~~~~~~~~~~~~ virtual function table generation top-level
~~~~~~~~~~~~~~~~~~~~~~~~~~*)
	let build_vftable scdecls =
		let rt = L.pointer_type i64_t in
		let void_pt = L.pointer_type i64_t in
		let void_ppt = L.pointer_type void_pt in

		let f = find_func_in_module "lookup" in
		let llbuilder = L.builder_at_end context (entry_block f) in

		let len = List.length scdecls in
		let total_len = ref 0 in
		let scdecl_llvm_arr = L.build_array_alloca void_ppt (const_int i32_t len) "tmp"
llbuilder in

		let handle_scdecl scdecl =
			let index = Hashtbl.find Semant.strucIndexes scdecl.scname in
			let len = List.length scdecl.sfuncs in
			let sfdecl_llvm_arr = L.build_array_alloca void_pt (const_int i32_t len)
"tmp" llbuilder in

			let handle_fdecl i sfdecl =
				let fptr = find_func_in_module (Ast.string_of_fname
sfdecl.sfname) in
				let fptr = L.build_pointercast fptr void_pt "tmp" llbuilder in
```

```
                                let ep = L.build_gep sfdecl_llvm_arr [| (const_int i32_t i) |] "tmp"
llbuilder in
                                ignore(L.build_store fptr ep llbuilder);
                        in
                        List.iteri handle_fdecl scdecl.sfuncs;
                        total_len := !total_len + len;

                        let ep = L.build_gep scdecl_llvm_arr [| (const_int i32_t index) |] "tmp"
llbuilder in
                        ignore(build_store sfdecl_llvm_arr ep llbuilder);
                in
                List.iter handle_scdecl scdecls;

                let c_index = param f 0 in
                let f_index = param f 1 in
                L.set_value_name "c_index" c_index;
                L.set_value_name "f_index" f_index;

                if !total_len == 0 then
                        L.build_ret (const_null rt) llbuilder
                else
                        let vtbl = L.build_gep scdecl_llvm_arr [| c_index |] "tmp" llbuilder in
                        let vtbl = L.build_load vtbl "tmp" llbuilder in
                        let fptr = L.build_gep vtbl [| f_index |] "tmp" llbuilder in
                        let fptr = L.build_load fptr "tmp" llbuilder in

                        L.build_ret fptr llbuilder
        in
        let _ = build_vftable classes in

        the_module;
```

liva.ml

```
(* Top-level of the Liva compiler: scan & parse the input,
   check the resulting AST, generate LLVM IR, and dump the module *)
open Ast
open Sast


type action = Ast | LLVM_IR | Compile
```

```
let _ =
  let action = if Array.length Sys.argv > 1 then
    List.assoc Sys.argv.(1) [ ("-a", Ast);  (* Print the AST only *)
                              ("-l", LLVM_IR);  (* Generate LLVM, don't check *)
                              ("-c", Compile) ] (* Generate, check LLVM IR *)
  else Compile in
  let lexbuf = Lexing.from_channel stdin in
  let ast = Parser.program Scanner.token lexbuf in
  let sast = Semant.check ast in ();

  match action with
    Ast -> print_string ("not implemented")
  | LLVM_IR -> print_string (Llvm.string_of_llmodule (Codegen.translate sast))
  | Compile -> let m = Codegen.translate sast in
    Llvm_analysis.assert_valid_module m;
    print_string (Llvm.string_of_llmodule m)
```

Makefile

```
# Make sure ocamlbuild can find opam-managed packages: first run
#
# eval `opam config env`

# Easiest way to build: using ocamlbuild, which in turn uses ocamlfind

.PHONY : liva.native

liva.native :
	ocamlbuild -use-ocamlfind -pkgs llvm,llvm.analysis -cflags -w,+a-4 \
		liva.native

# "make clean" removes all generated files

.PHONY : clean
clean :
	ocamlbuild -clean
	rm -rf testall.log *.diff liva scanner.ml parser.ml parser.mli
	rm -rf *.cmx *.cmi *.cmo *.cmx *.o

# More detailed: build using ocamlc/ocamlopt + ocamlfind to locate LLVM

OBJS =  ast.cmx sast.cmx parser.cmx scanner.cmx semant.cmx codegen.cmx liva.cmx
```

```
liva : $(OBJS)
	ocamlfind ocamlopt -linkpkg -package llvm -package llvm.analysis $(OBJS) -o liva

scanner.ml : scanner.mll
	ocamllex scanner.mll

parser.ml parser.mli : parser.mly
	ocamlyacc parser.mly

%.cmo : %.ml
	ocamlc -c $<

%.cmi : %.mli
	ocamlc -c $<

%.cmx : %.ml
	ocamlfind ocamlopt -c -package llvm $<

### Generated by "ocamldep *.ml *.mli" after building scanner.ml and parser.ml
ast.cmo :
ast.cmx :

sast.cmo :
sast.cmx :

codegen.cmo : ast.cmo sast.cmo
codegen.cmx : ast.cmx ast.cmx
liva.cmo : semant.cmo scanner.cmo parser.cmi codegen.cmo ast.cmo sast.cmo
liva.cmx : semant.cmx scanner.cmx parser.cmx codegen.cmx ast.cmx sast.cmx
parser.cmo : ast.cmo sast.cmo parser.cmi
parser.cmx : ast.cmx sast.cmx parser.cmi
scanner.cmo : parser.cmi
scanner.cmx : parser.cmx
semant.cmo : ast.cmo sast.cmo
semant.cmx : ast.cmx sast.cmx
parser.cmi : ast.cmo

# Building the tarball

TESTS = add1 arith1 arith2 arith3 fib for1 for2 func1 func2 func3    \
  func4 func5 func6 func7 func8 gcd2 gcd global1 global2 global3  \
  hello if1 if2 if3 if4 if5 local1 local2 ops1 ops2 var1 var2             \
```

```
   while1 while2

FAILS = assign1 assign2 assign3 dead1 dead2 expr1 expr2 for1 for2\
   for3 for4 for5 func1 func2 func3 func4 func5 func6 func7 func8  \
   func9 global1 global2 if1 if2 if3 nomain return1 return2 while1   \
   while2

TESTFILES = $(TESTS:%=test-%.mc) $(TESTS:%=test-%.out) \
            $(FAILS:%=fail-%.mc) $(FAILS:%=fail-%.err)

TARFILES = asat.ml ast.ml codegen.ml Makefile liva.ml parser.mly README scanner.mll \
          semant.ml testall.sh $(TESTFILES:%=test/%)

liva-llvm.tar.gz : $(TARFILES)
          cd .. && tar czf liva-llvm/liva-llvm.tar.gz \
                    $(TARFILES:%=liva-llvm/%)



testall.sh
#!/bin/sh

# Regression testing script for Liva
# Step through a list of files
#  Compile, run, and check the output of each expected-to-work test
#  Compile and check the error of each expected-to-fail test

# Path to the LLVM interprete
LLI="lli"
#LLI="/usr/local/opt/llvm/bin/lli"

# Path to the liva compiler.  Usually "./liva.native"
# Try "_build/liva.native" if ocamlbuild was unable to create a symbolic link.
#LIVA="./liva.native"
LIVA="./liva"


# Set time limit for all operations
ulimit -t 30

globallog=testall.log
rm -f $globallog
error=0
```

```
globalerror=0

keep=0

Usage() {
   echo "Usage: testall.sh [options] [.liva files]"
   echo "-k    Keep intermediate files"
   echo "-h    Print this help"
   exit 1
}

SignalError() {
   if [ $error -eq 0 ] ; then
         echo "FAILED"
         error=1
   fi
   echo "  $1"
}

# Compare <outfile> <reffile> <difffile>
# Compares the outfile with reffile.  Differences, if any, written to difffile
Compare() {
   generatedfiles="$generatedfiles $3"
   echo diff -b $1 $2 ">" $3 1>&2
   diff -b "$1" "$2" > "$3" 2>&1 || {
         SignalError "$1 differs"
         echo "FAILED $1 differs from $2" 1>&2
   }
}

# Run <args>
# Report the command, run it, and report any errors
Run() {
   echo $* 1>&2
   eval $* || {
         SignalError "$1 failed on $*"
         return 1
   }
}

# RunFail <args>
# Report the command, run it, and expect an erro
RunFail() {
```

```
    echo $* 1>&2
    eval $* && {
        SignalError "failed: $* did not report an error"
        return 1
    }
    return 0
}

Check() {
    error=0
    basename=`echo $1 | sed 's/.*\\///
                        s/.liva//'`
    reffile=`echo $1 | sed 's/.liva$//'`
    basedir="`echo $1 | sed 's/\/[^\/]*$//'`/."

    echo -n "$basename..."

    echo 1>&2
    echo "###### Testing $basename" 1>&2

    generatedfiles=""

    generatedfiles="$generatedfiles ${basename}.ll ${basename}.out" &&
    Run "$LIVA" "<" $1 ">" "${basename}.ll" &&
    Run "$LLI" "${basename}.ll" ">" "${basename}.out" &&
    Compare ${basename}.out ${reffile}.out ${basename}.diff

    # Report the status and clean up the generated files

    if [ $error -eq 0 ] ; then
        if [ $keep -eq 0 ] ; then
            rm -f $generatedfiles
        fi
        echo "OK"
        echo "###### SUCCESS" 1>&2
    else
        echo "###### FAILED" 1>&2
        globalerror=$erro
    fi
}

CheckFail() {
    error=0
```

```
    basename=`echo $1 | sed 's/.*\\///
                        s/.liva//'`
    reffile=`echo $1 | sed 's/.liva$//'`
    basedir="`echo $1 | sed 's/\/[^\/]*$//'`/."

    echo -n "$basename..."

    echo 1>&2
    echo "###### Testing $basename" 1>&2

    generatedfiles=""

    generatedfiles="$generatedfiles ${basename}.err ${basename}.diff" &&
    RunFail "$LIVA" "<" $1 "2>" "${basename}.err" ">>" $globallog &&
    Compare ${basename}.err ${reffile}.err ${basename}.diff

    # Report the status and clean up the generated files

    if [ $error -eq 0 ] ; then
            if [ $keep -eq 0 ] ; then
               rm -f $generatedfiles
            fi
            echo "OK"
            echo "###### SUCCESS" 1>&2
    else
            echo "###### FAILED" 1>&2
            globalerror=$erro
    fi
}

while getopts kdpsh c; do
    case $c in
            k) # Keep intermediate files
               keep=1
               ;;
            h) # Help
               Usage
               ;;
    esac
done

shift `expr $OPTIND - 1`
```

```
LLIFail() {
  echo "Could not find the LLVM interpreter \"$LLI\"."
  echo "Check your LLVM installation and/or modify the LLI variable in testall.sh"
  exit 1
}

which "$LLI" >> $globallog || LLIFail


if [ $# -ge 1 ]
then
   files=$@
else
   files="tests/test-*.liva tests/fail-*.liva"
fi

for file in $files
do
   case $file in
          *test-*)
             Check $file 2>> $globallog
             ;;
          *fail-*)
             CheckFail $file 2>> $globallog
             ;;
          *)
             echo "unknown file type $file"
             globalerror=1
             ;;
   esac
done

exit $globalerro
```