

Dice Project Report



"Java, but worse"

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1. INTRODUCTION

The Dice programming language is an object-oriented, general purpose programming language. It is designed to let programmers who are more familiar with object oriented programming languages to feel comfortable with common design patterns to build useful applications. The syntax of Dice resembles the Java programming language. Dice compiles down to LLVM IR which is a cross-platform runtime environment. This allows Dice code to work on any system as long as there is an LLVM port for it, which includes Windows, Mac OS X, and Linux or various processor architectures such as x86, MIPS, and ARM¹.

Dice lays programs out the same way a Java program would. Variables and methods of a class can be declared with private scope. There is a simple to use inheritance that allows for multiple children inheriting the fields and methods of its parent. Dice also allows for convenient use of functions that exist in C, such as malloc, open, and write. This allows the user to construct objects and call c functions using those objects.

Background

Object-oriented programming (OOP) is a programming paradigm based on the concept of "objects". These objects are data structures that contain data, in the form of fields, often known as attributes. The code itself are contained within methods in the code which are compiled to varying subroutines. The most useful aspect of OOP is that these methods and fields can modify one another allowing for a rich and varied use case.

Class based OOP specifically creates instances of classes, referred to as objects, which have their values modified at runtime. There are many languages that implement their language this way including Java and C#.

Inheritance is when an object or class is based on another class using the same implementation. This allows for a class to serve as a blueprint for subclasses. Polymorphism allows an object to take on many forms. This may include an object being assigned to a type that is a class it inherits from, or being used in place of a class it inherits from.

We want to leverage these capabilities using LLVM code to produce a syntactically Java-like language but offer a cross platform solution that is simple and easy to use. Implementing inheritance and objects in a c-like context like LLVM allows for fine control over the code.

Related Work

Object-oriented programming languages have existed since the late 20th century. Java, C#, C++, Objective-C, Python, and many more languages have facilities for defining custom user classes and manipulating them at runtime.

¹<http://llvm.org/>

Implementing an object-oriented paradigm using C is a well-known solution, but compiling object-oriented code down to LLVM is not publicly available. We want to contribute to the LLVM community by adding additional information regarding the creation of a compiler using OCaml that compiles to LLVM code.

Goals

Cross-Platform

Utilizing the LLVM IR we are able to compile the source once and have it work on multiple architectures without fail.

Flexibility

Allowing the user to define their own classes and offering them the ability to inherit functionality from other user defined types offer a wide range of possibilities for their programs and also saves the user time when implementing large programs.

Transparency

Using the LLVM IR allows the user to see exactly what the program is doing after the compiler is done. For a more optimal result it can then be compiled to bitcode representation using the LLVM compiler.

Familiarity

Incorporate familiar primitive data types most commonly found in languages such as C, C++, and Java such as int, char, float, and bool.

2. LANGUAGE TUTORIAL

Environment Setup

The compiler has been built and tested using an Ubuntu 15.10 virtual machine. The ISO for downloading Ubuntu 15.10 can be found [here](#)¹. This is followed by downloading virtualbox and following the corresponding tutorial for setting up a custom Ubuntu VM [here](#)². Once inside the VM there are a series of packages that need to be installed before you can compile the compiler. Run the following commands to install the corresponding packages:

```
>sudo apt-get install m4 clang-3.7 clang-3.7-doc libclang-common-3.7-dev libclang-3.7-dev
↪ libclang1-3.7 libclang1-3.7-dbg libllvm-3.7-ocaml-dev libllvm3.7 libllvm3.7-dbg
↪ lldb-3.7 llvm-3.7 llvm-3.7-dev llvm-3.7-doc llvm-3.7-examples llvm-3.7-runtime
↪ clang-modernize-3.7 clang-format-3.7 python-clang-3.7 lldb-3.7-dev liblldb-3.7-dbg
↪ opam llvm-runtime
```

copy the tutorial from <https://github.com/DavidWatkins/Dice>

Using the Compiler

Inside the directory 'Dice' type **make**. This creates the dice compiler that takes in '.dice' files and compiles them to corresponding '.ll' files corresponding to LLVM IR. The syntax for running the dice executable is: **dice [optional-option] <source file>**. There are also additional flags with respect to the compiler that allow for additional options.

- **-h** - Print help text
- **-tendl** - Prints tokens with newlines intact
- **-t** - Prints token stream
- **-p** - Pretty prints Ast as a program
- **-ast** - Prints abstract syntax tree as json
- **-sast** - Prints semantically checked syntax tree as json
- **-c** - Compiles source and prints result to stdout
- **-f** - Compiles source to file (`<filename>.<ext> → <filename>.ll`)

The following sample dice code demonstrates the following features:

- The mandatory main function that exists within **only** one class. The syntax for a main declaration is **public void main(char[] args)**
- Calling the built-in print function, which takes an arbitrary list of primitive values, including char[].

¹<http://www.ubuntu.com/>

²<http://www.wikihow.com/Install-Ubuntu-on-VirtualBox>

- A string literal with escape characters
- Defining a base class with one or more fields.

```
1      class example1 {  
2          public void main(char[] [] args) {  
3              print("This is example 1\n");  
4          }  
5      }
```

To compile the sample code above, type:

```
> ./dice example1.dice
```

The output will be:

```
>lli example1.ll  
This is example 1  
>
```

Defining methods

Control Flow

Defining custom classes

Using Inheritance

3. LANGUAGE REFERENCE MANUAL

Introduction

Dice is a general purpose, object-oriented programming language. The principal is simplicity, pulling many themes of the language from Java. Dice is a high level language that utilizes LLVM IR to abstract away hardware implementation of code. Utilizing the LLVM as a backend allows for automatic garbage collection of variables as well.

Dice is a strongly typed programming language, meaning that at compile time the language will be type-checked, thus preventing runtime errors of type.

This language reference manual is organized as follows:

- Chapter 2 Describes types, values, and variables, subdivided into primitive types and reference types
- Chapter 3 Describes the lexical structure of Dice, based on Java. The language is written in the ASCII character set
- Chapter 4 Describes the expressions and operators that are available to be used in the language
- Chapter 5 Describes different statements and how to invoke them
- Chapter 6 Describes the structure of a program and how to determine scope
- Chapter 7 Describes classes, how they are defined, fields of classes or their variables, and their methods
- Chapter 8 Discusses the different library classes provided with the compiler and their definitions

The syntax of the language is meant to be reminiscent of Java, thereby allowing ease of use for the programmer.

Types

There are two kinds of types in the Dice programming language: primitive types and non-primitive types. There are, correspondingly, two kinds of data values that can be stored in variables, passed as arguments, returned by methods, and operated on: primitive values and non-primitive values.

Type:

PrimitiveType

NonprimitiveType

There is also a special null type, the type of the expression *null*, which has no name. Because the null type has no name, it is impossible to declare a variable of the null type. The null reference is the only possible value of an expression of null type. The null reference can always undergo a widening reference conversion to any reference type. In practice, the programmer can ignore the null type and just pretend that *null* is merely a special literal that can be of any reference type.

Primitive Types and Values

A primitive type is predefined by the Dice programming language and named by its reserved keyword.

```
PrimitiveType:
  NumericType
  bool
NumericType:
  IntegralType
  float
IntegralType: one of
  int char
```

int

A value of type *int* is stored as a 32-bit signed two's-complement integer. The *int* type can hold values ranging from -2,147,483,648 to 2,147,483,647, inclusive.

float

The float type stores the given value in 64 bits. The *float* type can hold values ranging from 1e-37 to 1e37. Since all values are represented in binary, certain floating point values must be approximated.

char

The *char* data type is a 8-bit ASCII character. A *char* value maps to an integral ASCII code. The decimal values 0 through 31, and 127, represent non-printable control characters. All other characters can be printed by the computer, i.e. displayed on the screen or printed on printers, and are called printable characters. The character 'A' has the code value of 65, 'B' has the value 66, and so on. The ASCII values of letters 'A' through 'Z' are in a contiguous increasing numeric sequence. The values of the lower case letters 'a' through 'z' are also in a contiguous increasing sequence starting at the code value 97. Similarly, the digit symbol characters '0' through '9' are also in an increasing contiguous sequence starting at the code value 48.

bool

A variable of type *bool* can take one of two values, *true* or *false*. A bool could also be *null*.

Non-Primitive Types

Non-primitive types include arrays and classes.

Arrays

An array stores one or more values of the same type contiguously in memory. The type of an array can be any primitive or an array type. This allows the creation of an n-dimensional array, the members of which can be accessed by first indexing to the desired element of the outermost array, which is of type *array*, and then accessing into the desired element of the immediately nested array, and continuing n-1 times.

Classes

Classes are user-defined types. See chapter 7 to learn about the usage of objects.

Casting

Casting is not supported in this language. There are interesting behaviors between ints and float defined in the section on operators that imitate casting, but there is no syntax to support casting between types directly.

Lexical Conventions

This chapter describes the lexical elements that make up Dice source code. These elements are called tokens. There are six types of tokens: identifiers, keywords, literals, separators, and operators. White space, sometimes required to separate tokens, is also described in this chapter.

Identifiers

Identifiers are sequences of characters used for naming variables, functions and new data types. Valid identifier characters include ASCII letters, decimal digits, and the underscore character '_'. The first character must be alphabetic.

An identifier cannot have the same spelling (character sequence) as a keyword, boolean or null literal, a compile-time error occurs. Lowercase letters and uppercase letters are distinct, such that foo and Foo are two different identifiers.

```
ID = "[ 'a'-'z' 'A'-'Z' ] ( [ 'a'-'z' 'A'-'Z' ] | [ '0'-'9' ] | '\textunderscore' ) *"
```

Keywords

Keywords are special identifiers reserved for use as part of the programming language itself. You cannot use them for any other purpose. Dice recognizes the following keywords:

if	else	for	while	
break	continue	return		
int	float	bool	char	void
null	true	false	class	constructor
public	private	extends	include	this

Literals

A literal is the source code representation of a value of a primitive type or the null type.

Integer Literals

An integer literal is expressed in decimal (base 10). It is represented with either the single ASCII digit 0, representing the integer zero, or an ASCII digit from 1 to 9 optionally followed by one or more ASCII digits from 0 to 9.

```
INT = "[ '0'-'9' ] +"
```

Float Literals

A float literal has the following parts: an integer part, a decimal point (represented by an ASCII period character), and a fraction part. The integer and fraction parts are defined by a single digit 0 or one digit from 1-9 followed by more ASCII digits from 0 to 9.

```
FLOAT = "[ '0'-'9' ] + [ '.' ] [ '0'-'9' ] +"
```


Boolean Literals

The boolean type has two values, represented by the boolean literals `true` and `false`, formed from ASCII letters.

```
BOOL = "true|false"
```

Character Literals

A character literal is always of type `char`, and is formed by an ascii character appearing between two single quotes. The following characters are represented with an escape sequence, which consists of a backslash and another character:

- `'\'` - backslash
- `'\"'` - double-quote
- `'\''` - single-quote
- `'\n'` - newline
- `'\r'` - carriage return
- `'\t'` - tab character

It is a compile-time error for the character following the character literal to be other than a single-quote character `'`.

```
CHAR = "\' ( ([\' \-!\' \'#\'-\' [\' \']\'-\'~\' ] | \'\\\' [ \'\\\' \'\"\' \'n\' \'r\' \'t\' ]) )\' "
```

String Literals

A string literal is always of type `char[]` and is initialized with zero or more characters or escape sequences enclosed in double quotes.

```
char[] x = "abcdef\n";
```

```
STRING = "\"( ([\' \-!\' \'#\'-\' [\' \']\'-\'~\' ] | \'\\\' [ \'\\\' \'\"\' \'n\' \'r\' \'t\' ]) )*\\""
```

Separators

A separator separates tokens. White space is a separator but it is not a token. The other separators are all single-character tokens themselves: `() [] ; , .`

<code>'('</code>	{ LPAREN }
<code>')'</code>	{ RPAREN }
<code>'{'</code>	{ LBRACE }
<code>'}'</code>	{ RBRACE }
<code> ';'</code>	{ SEMI }
<code> ','</code>	{ COMMA }
<code>'['</code>	{ LBRACKET }
<code>']'</code>	{ RBRACKET }
<code> '.'</code>	{ DOT }

Operators

The following operators are reserved lexical elements in the language. See the expression and operators section for more detail on their defined behavior.

+	-	*	/	=
==	!=	<	<=	>
>=				

White Space

White space refers to one or more of the following characters:

- the ASCII SP character, also known as "space"
- the ASCII HT character, also known as "horizontal tab"
- the ASCII FF character, also known as "form feed"
- LineTerminator

White space is ignored, except when it is used to separate tokens. Aside from its use in separating tokens, it is optional. Hence, the following two snippets of source code are equivalent.

```
public int foo()
{
    print( "hello, world\n" );
    return 0;
}

public int foo(){print("hello, world\n"); return 0;}
```

WHITESPACE = "[' ' '\t' '\r' '\n']"

Comments

The characters `(*` introduce a comment, which terminates with the characters `*)`. Multiline comments can be distinguished from code by preceding each line of the comment with a `*` similar to the following:

```
(* This is a long comment
 * that spans multiple lines because
 * there is a lot to say. *)
```

COMMENT = "(* [^ *])* *"

Expressions and Operators

The precedence of expression operators is the same as the order of the major subsections of this section (highest precedence first). Within each subsection, the operators have the same precedence. Left- or right-associativity is specified in each subsection for the operators discussed therein.

Primary Expressions

Primary expressions involving `.`, subscripting, and function calls group left to right.

Identifier

An identifier is a primary expression, provided it has been suitably declared as discussed below. Its type is specified by its declaration.

Literal

Any of the literal types discussed in Chapter 3 is a primary expression, which evaluates to the type of the literal.

(expression)

A parenthesized expression is a primary expression whose type and value are identical to those of the unadorned expression. The presence of parentheses does not affect whether the expression is an lvalue.

primary-expression [expression]

A primary expression followed by an expression in square brackets is a primary expression. The intuitive meaning is that of a subscript. The primary expression has type *array* of . . . and the type of the result is The type of the subscript expression must be a type that is convertible to an integral type, or a compile-time error occurs.

primary-expression (expression-list-opt)

A function call is a primary expression followed by parentheses containing a possibly empty, comma-separated list of expressions which constitute the actual arguments to the function. The result of the function call is the function's return type. Recursive calls to any function are permissible.

primary-lvalue . member-of-structure

An lvalue expression followed by a dot followed by the name of a class member is a primary expression. The object referred to by the lvalue is assumed to be an instance of the class defining the class member. The given lvalue can be an instance of any user-defined class.

Unary operators

Expressions with unary operators group right-to-left.

expression

The result is the negative of the expression, and has the same type. The type of the expression must be *char*, *int*, or *float*.

not expression

The result of the logical negation operator *not* is *true* if the value of the expression is *false*, *false* if the value of the expression is *true*. The type of the result is *bool*. This operator is applicable only to operands that evaluate to *bool*.

Multiplicative operators

The multiplicative operators *** and */* group left-to-right.

expression * expression

The binary `*` operator indicates multiplication. Operands of *int*, *float*, and *char* types are allowed. If both operands are of type ..., the result is type If the operands are of two different types of the ones listed above, the result is the type of the left-most operand.

expression / expression

The binary `/` operator indicates division. The same type considerations as for multiplication apply.

Additive operators

The additive operators `+` and `-` group left-to-right.

expression + expression

The value of the result is the sum of the expressions. The same type considerations as for multiplication apply. Overflow of a *char* type during an addition operation results in wraparound.

expression - expression

The value of the result is the difference of the expressions. The same type considerations as for multiplication apply.

Relational operators

The relational operators group left-to-right.

expression < expression**expression > expression****expression <= expression****expression >= expression**

The operators `<` (less than), `>` (greater than), `<=` (less than or equal to) and `>=` (greater than or equal to) all yield *true* if the specified relation is true and *false* otherwise. The same type considerations as for multiplication apply.

Equality operators**expression == expression****expression != expression**

The `==` (equal to) and the `!=` (not equal to) operators are exactly analogous to the relational operators except for their lower precedence.

Logical operators**expression and expression**

Both operands must evaluate to a value of type *bool*. The *and* operator returns *true* if both its operands evaluate to *true*, *false* otherwise. The second expression is not evaluated if the first evaluates to *false*.

expression or expression

Both operands must evaluate to a value of type *bool*. The *or* operator returns *true* if either of its operands evaluate to *true*, and *false* otherwise. The second operand is not evaluated if the value of the first operand evaluates to *true*.

Assignment operators

lvalue = expression

The value of the expression replaces that of the object referred to by the lvalue. Both operands must have the same type.

Statements

A statement forms a complete unit of execution.

Include Statement

If a .dice file contains a statement of the following form:

```
include(mylib)
```

then all classes defined in *mylib* are available to be used in definitions of classes in the .dice file in which the include statement appears.

Expression Statements

An expression statement consists of an expression followed by a semicolon. The execution of such a statement causes the associated expression to be evaluated. The following types of expressions can be made into a statement by terminating the expression with a semicolon (;):

```
(* Assignment expressions *)
aValue = 8933.234;
(* Method invocations *)
game.updateScore(Player1, 5);
(* Object creation expressions *)
Bicycle myBike = Bicycle();
```

Declaration Statements

A declaration statement declares a variable by specifying its data type and name.

```
float aValue;
```

Control Flow Statements

The statements inside source files are generally executed from top to bottom, in the order that they appear. Control flow statements, however, break up the flow of execution by employing decision making, looping, and branching, enabling your program to conditionally execute particular blocks of code. This section describes the decision-making statements (if-then, if-then-else), the looping statements (for, while), and the branching statements (break, continue, return) supported by the Dice programming language.

if-then, if-then-else

The 'if-then' statement tells the program to execute a certain section of code only if a particular test evaluates to true. 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 (condition) {
    <stmt>
}

if (not condition) {
    <stmt>
} (* if statement is skipped *)
```

The 'if-then-else' statement provides an alternate path of execution when "if" clause evaluates to false. This alternate path of execution is denoted by a sequence of statements enclosed in balanced braces, in the same format as the path of execution to take if the conditional evaluates to true, prefixed by the keyword "else".

```
if (condition) {
    <stmt>
} else {
    <stmt2>
} (* <stmt2> executed when not condition *)
```

Looping: for, while

The 'for' statement allows the programmer to iterate over a range of values. The 'for' statement has the following format:

```
for (initialization; termination; update) { <stmt> }
```

- The 'initialization' expression initializes the loop counter. It is executed once at the beginning of the 'for' statement
- When the 'termination' expression evaluates to false, the loop terminates.
- The 'update' expression is invoked after each iteration and can either increment or decrement the value of the loop counter.

The following example uses a 'for' statement to print the numbers from 1 to 10:

```
int loopCounter;
for (loopCounter=1; loopCounter<11; loopCounter++) {
    print(loopCounter);
}
```

The 'while' statement executes a user-defined block of statements as long as a particular conditional expression evaluates to true. The syntax of a 'while' statement is:

```
while (expression) {
    <stmt>
}
```

The following example uses a 'while' statement to print the numbers from 1 to 10:

```
int loopCounter;
loopCounter = 1;
while (loopCounter < 11) {
    print(loopCounter);
    loopCounter = loopCounter + 1;
}
```

Branching: break, continue, return

If a 'break' statement is included within either a 'for' or 'while' statement, then it terminates execution of the innermost looping statement it is nested within. All break statements have the same syntax:

```
break;
```

In the following example, the 'break' statement terminates execution of the inner 'while' statement and does not prevent the 'for' statement from executing its block of statements for all iterations of i from 1 to 10. This results in the the values of j from 100 to 110 being printed, in each of the 10 iterations of the 'for' loop.

```
int i;
int j;
for (i=1; i<11; i++) {
    j = 100;
    while (j<120) {
        if (j>110) {
            break;
        }
        print(j);
        j = j + 1;
    }
}
```

In the following example, the 'break' statement terminates execution of the inner 'for' statement and does not prevent the 'while' statement from executing its block of statements for all iterations of i from 1 to 1000. This results in the the values of j from 100 to 110 being printed, in each of the 1000 iterations of the 'while' loop.

```
int i;
int j;

i = 1;
while (i<1001) {
    for (j=100; j<120; j++) {
        if (j>110) {
            break;
        }
    }
    i = i + 1;
}
```

The continue statement skips the current iteration of a 'for' or 'while' statement, causing the flow of execution to skip to the end of the innermost loop's body and evaluate the conditional expression that controls the loop. The following example uses a 'continue' statement within a 'for' loop to print only the odd integers

between 1 and 10. The code prints "hello" 1000 times and on each of the 1000 'while' loop iterations, prints the odd integers.

```
int i;
int counter;
counter = 1;
while (counter < 1001) {
    print("hello");
    for (i=1; i<11; i++) {
        if (i - 2*(i/2) == 0) {
            continue;
        } else {
            print(i);
        }
    }
    counter = counter + 1;
}
```

The 'return' statement exits from the current method, and control flow returns to where the method was invoked. To return a value, simply put the value (or an expression that calculates the value) after the return keyword:

```
return count + 4;
```

The data type of the returned value must match the type of the method's declared return value. When a method is declared void, either no return statement is needed or the following 'return' statement is used:

```
return;
```

Blocks

A block is a group of zero or more statements between balanced braces and can be used anywhere a single statement is allowed. The following example, BlockDemo, illustrates the use of blocks:

```
class BlockDemo {
    public void main(char[], args) {
        bool condition;
        condition = true;
        if (condition) { (* begin block 1 *)
            print("Condition is true.");
        } (* end block one *)
        else { (* begin block 2 *)
            print("Condition is false.");
        } (* end block 2 *)
    }
}
```

Dice Functions

There are several reserved functions in Dice that cannot be overridden and follow a particular syntax and return type.

File I/O

Manipulating files is an important aspect of any programming languages. Open files are denoted by a particular *int fd*; that can be used to read or write from a file. A file must be closed by the end of a program or else undefined behavior may occur.

int fopen(char[] filename, bool isWriteEnabled)

Accepts a filename and a flag to determine whether the file will be written to. If the file exists, it will be opened in append mode, otherwise a new file will be created. If it is in read mode, it will return a file descriptor as normal, or if the file doesn't exist will return '-1'. Likewise for write enabled, if there is an error it will return -1.

```
int fd;
fd = fopen("hello.txt", false);
```

bool fwrite(int fd, char[] values, int num, int offset)

Accepts an array of values to be written to a file, the number of characters it should write, and the offset into the value array it should write from. If there is an error, returns false, otherwise returns true.

```
bool success;
success = fwrite(fd, "This should work", 4, 1); (* Writes "his " to a file *)
```

bool fread(int fd, char[] storage, int num)

Accepts an array to store values from the file that are to be read, and will read in num bytes. Returns true on success and false on error.

```
char[] a;
bool success;

a = char[100];
success = fread(fd, a, 20);
```

bool fclose(int fd)

Closes a file. Returns true on success, false on error.

```
bool success;
success = fclose(fd);
```

Reading and Writing from Console

Reading and writing to the console is defined by two simple to use functions that cannot be overridden.

void print(char[] string)

Accepts a char array and prints the string to the console.

```
print("hello world");
```

void print(int num)

Accepts an int and prints the int to the console.

```
print(1);
```

`void input(char[] buf)`

Accepts a `buf` that will hold read bytes from the console. Then it will write those bytes to the array passed. Terminates when a user enters a newline or an EOF.

```
char[] a;  
a = char[100];  
input(a);
```

Program Structure and Scope

Program structure and scope define what variables are accessible and where. When inside a class, there are many different cases of scope, however those are better defined in chapter 7.

Program Structure

A Dice program may exist either within one source file or spread among multiple files which can be linked at compile-time. An example of such a linked file is the standard library, or *stdlib.dice*. When an include statement is executed at compile time, it will load in the files mentioned at the includes and insert the code at that location as if it were part of the head source file. Therefore at compilation, one only needs to compile with *dicecmaster.dice*. If an included module defines a class that has the same name as one of the classes defined in the including module, then the compiler throws an error. The compiler does not resolve recursive includes; if *foo.dice* includes *bar.dice* and *bar.dice* includes *foo.dice*, the compiler throws an error.

A program consists of zero or more include statements, followed by one or more class definitions. Each class defined in a module must have a distinct name. Only one class out of all classes may have a main method, defined with *public void main(char[][] args)* which designates the entry point for a program to begin executing code. All Dice files are expected to end with the file extension *.dice* and follow the following syntactic layout.

```
include(stdlib)  
include(mylib)  
  
class FOO {  
  
    (* my code *)  
  
}  
  
class BAR {  
  
    (* my code *)  
  
    public void main(char[] [] args)  
  
}
```

Scope

Scope refers to which variables, methods, and classes are available at any given time in the program. All classes are available to all other classes regardless of their relative position in a program or library. Variable

scope falls into two categories: fields (instance variables) which are defined at the top of a class, and local variables, which are defined within a method. Fields can be public or private. If a field is public then it is accessible whenever an instance of that class is instantiated. For instance, if I have a class X, then class Y can be defined as follows:

```
class Y {  
  
    public int num;  
  
    constructor() {  
  
        X myObj;  
        myObj = X();  
        this.num = myObj.number;  
    }  
}  
  
class X {  
  
    public int number;  
  
}
```

In this example, class Y has one field which is an int. In its constructor, an instance of class X is declared, and a public field within that object is used to set the value for the given int. If a field is declared private, however, it can only be accessed by the methods in the same class. For example, if there is a class Y with a private field, the following is valid:

```
class Y {  
  
    private int num;  
  
    constructor() {  
  
        this.num = 5;  
    }  
  
    private int getNum() {  
  
        return this.num;  
    }  
}
```

However, if I have a class X, that class cannot access the private field within Y. The following is invalid:

```
class X {  
  
    public int number;  
  
    constructor() {
```

```
Y myObj;  
myObj = Y();  
(* This code is invalid since num is a private field within Y *)  
this.number = myObj.num;  
}  
}
```

Methods are also declared as public or private, and their accessibility is the same as fields. They must have a scope defined on them.

Local variables are variables that are declared inside of a method. Local variables are only accessible within the same method in which they are declared, and they may have the same name as fields within the same class since fields in a class are only accessible by calling the *this* keyword.

Classes

Classes are the constructs whereby a programmer defines their own types. All state changes in a Dice program must happen in the context of changes in state maintained by an object that is an instance of a user-defined class.

Class definition

A class definition starts with the keyword 'class' followed by the class name (see identifiers in chapter 2) and the class body. The class body, enclosed by a pair of curly braces, declares one or more of each of the following: fields, methods, and constructors.

The members of a class type are all of the following:

- Members inherited from its ancestors (its direct superclass and its ancestors)
- Members declared in the body of the class, with the exception of constructors

Access modifiers

Class member declarations must include access modifiers but the class declaration itself does not; there is no notion of a private class in Dice. Field and method declarations must include one of the access modifiers: *public* or *private*. Fields and methods with the access modifier *public* can be accessed by methods defined in any class. Fields and methods with the access modifier *private* can be accessed by methods defined either in the same class or in successor classes (classes derived directly from that class and their successors).

Fields

The only fields that can be declared are instance variables, which are freshly incarnated for each instance of the class. Field declarations have the following format:

```
<access modifier> <type> <VariableDeclaratorId>;  
(* Example *) private int myInstanceVariable;
```

All instance variables must be declared before methods and constructors.

Methods

A method declares executable code that can be invoked, passing a fixed number of values as arguments. The only methods that can be declared are the 'main' method and instance methods. Instance methods are invoked with respect to some particular object that is an instance of a class type.

Method declarations constitute a method header followed by a method body. The method header has the following format:

```
<access modifier> <return type> <method name> <comma-separated list of parameters>
(* Example *) public double amountPaid(double wage, int duration)
```

The method body contains, enclosed between the ASCII characters '{' and '}', zero or more variable declarations followed by zero or more statements. If the type of the return value is not void, then the method body must include a return statement.

One and only one of the classes to be compiled must contain a definition for a method named "main" that executes when the program runs. The *main* method is not callable as an instance method. The *main* method must have a void return type and accept a single parameter of type `char[][]`. Hence, its signature must be:

```
public void main (char[] [] args)
```

If either zero or more than one class contains a definition for a method with the signature above, this results in a compile-time error.

Methods can be overloaded: If two methods of a class (whether both declared in the same class, or both inherited by a class, or one declared and one inherited) have the same name but signatures that are not equivalent, then the method name is said to be overloaded. There can be multiple methods with the same name defined for a class, as long as each has a different number and/or type of parameters. The *main* method can never be overloaded because it has one and only one accepted signature. If two methods in the same class have the same signature, the compiler throws an error.

Constructors

Constructors are similar to methods but cannot be invoked as an instance method; they are used to initialize new class instances. A constructor has no return type and its formal parameters are identical in syntax and semantics to those of a method. A constructor definition has the following format:

```
constructor (<comma-separated formal arguments>) {
    <list of variable declarations>
    <list of statements>
}
(* Example *) constructor (int a, char[] b) {...}
```

Unlike fields and methods, access to constructors is not governed by access modifiers. Constructors are accessible from any class.

Constructor declarations are never inherited and therefore are not subject to overriding.

If no constructors are defined, the compiler defines a default constructor. Like methods, they may be overloaded. It is a compile-time error to declare two constructors with equivalent signatures in a class.


```

8  let char = ''' ( ascii | digit ) '''
9  let float = (digit+) [ '.' ] digit+
10 let int = digit+
11
12 | '('      { LPAREN }
13 | ')'      { RPAREN }
14 | '{'      { LBRACE }
15 | '}'      { RBRACE }
16 | ';'      { SEMI }
17 | ','      { COMMA }
18 | '+'      { PLUS }
19 | '-'      { MINUS }
20 | '*'      { TIMES }
21 | '/'      { DIVIDE }
22 | '%'      { MODULO }
23 | '='      { ASSIGN }
24 | "=="     { EQ }
25 | "!="     { NEQ }
26 | '<'      { LT }
27 | "<="     { LEQ }
28 | ">"      { GT }
29 | ">="     { GEQ }
30 | "and"     { AND }
31 | "or"      { OR }
32 | "not"     { NOT }
33 | '.'      { DOT }
34 | '['      { LBRACKET }
35 | ']'      { RBRACKET }
36 | '|'      { BAR }
37 | "if"      { IF }
38 | "else"    { ELSE }
39 | "for"     { FOR }
40 | "while"   { WHILE }
41 | "return"  { RETURN }
42 | "int"     { INT }
43 | "float"   { FLOAT }
44 | "bool"    { BOOL }
45 | "char"    { CHAR }
46 | "void"    { VOID }
47 | "null"    { NULL }
48 | "true"    { TRUE }
49 | "false"   { FALSE }
50 | "class"   { CLASS }
51 | "constructor" { CONSTRUCTOR }
52 | "public"  { PUBLIC }
53 | "private" { PRIVATE }
54 | "extends" { EXTENDS }
55 | "include" { INCLUDE }
56 | "this"    { THIS }

```

```

57 | "break"           { BREAK }
58 | "continue"       { CONTINUE }
59 | "new"             { NEW }
60 | "delete"         { DELETE }
61
62 | int as lxm         { INT_LITERAL(int_of_string lxm) }
63 | float as lxm      { FLOAT_LITERAL(float_of_string lxm) }
64 | char as lxm       { CHAR_LITERAL( String.get lxm 1 ) }
65 | escape_char as lxm{ CHAR_LITERAL( String.get (unescape lxm) 1) }
66 | string            { STRING_LITERAL(unescape s) }
67 | id as lxm         { ID(lxm) }
68 | eof              { EOF }
69
70 | (* *) {COMMENT*}

```

It should be noted that comments were handled to allow for nested comments. Therefore this cannot be captured strictly using a grammar, and instead is better shown in the scanner.mll documentation at the end of this document. The following grammar is the same as the grammar shown in parser.mly at the end of this document except it does not have the rules it will turn into regarding OCaml code. This is very similar to the syntax for ocaml yacc.

```

1  program:
2      includes cdecls EOF
3
4  includes:
5      /* nothing */
6      |      include_list
7
8  include_list:
9      include_decl
10     |      include_list include_decl
11
12 include_decl:
13     INCLUDE LPAREN STRING_LITERAL RPAREN SEMI
14
15 cdecls:
16     cdecl_list
17
18 cdecl_list:
19     cdecl
20     |      cdecl_list cdecl
21
22 cdecl:
23     CLASS ID LBRACE cbody RBRACE
24     |      CLASS ID EXTENDS ID LBRACE cbody RBRACE
25
26 cbody:
27     /* nothing */
28     |      cbody field
29     |      cbody constructor

```



```
30         |          cbody fdecl
31
32 constructor:
33     CONSTRUCTOR LPAREN formals_opt RPAREN LBRACE stmt_list RBRACE
34
35 scope:
36     PRIVATE
37     |
38     PUBLIC
39
40 field:
41     scope datatype ID SEMI
42
43 fname:
44     ID
45
46 fdecl:
47     scope datatype fname LPAREN formals_opt RPAREN LBRACE stmt_list RBRACE
48
49 formals_opt:
50     /* nothing */
51     |
52     formal_list
53
54 formal_list:
55     formal
56     |
57     formal_list COMMA formal
58
59 formal:
60     datatype ID
61
62 actuals_opt:
63     /* nothing */
64     |
65     actuals_list
66
67 actuals_list:
68     expr
69     |
70     actuals_list COMMA expr
71
72 primitive:
73     INT
74     |
75     FLOAT
76     |
77     CHAR
78     |
79     BOOL
80     |
81     VOID
82
83 name:
84     CLASS ID
85
86 type_tag:
87     primitive
```

```

79         |         name
80
81 array_type:
82     type_tag LBRACKET brackets RBRACKET
83
84 datatype:
85     type_tag
86     |         array_type
87
88 brackets:
89     /* nothing */
90     |         brackets RBRACKET LBRACKET
91
92 stmt_list:
93     /* nothing */
94     |         stmt_list stmt
95
96 stmt:
97     expr SEMI
98     |         RETURN expr SEMI
99     |         RETURN SEMI
100    |         LBRACE stmt_list RBRACE
101    |         IF LPAREN expr RPAREN stmt
102    |         IF LPAREN expr RPAREN stmt ELSE stmt
103    |         FOR LPAREN expr_opt SEMI expr_opt SEMI expr_opt RPAREN stmt
104    |         WHILE LPAREN expr RPAREN stmt
105    |         BREAK SEMI
106    |         CONTINUE SEMI
107    |         datatype ID SEMI
108    |         datatype ID ASSIGN expr SEMI
109
110 expr_opt:
111     /* nothing */
112     |         expr
113
114 expr:
115     literals
116     |         expr PLUS expr
117     |         expr MINUS expr
118     |         expr TIMES expr
119     |         expr DIVIDE expr
120     |         expr EQ expr
121     |         expr NEQ expr
122     |         expr LT expr
123     |         expr LEQ expr
124     |         expr GT expr
125     |         expr GEQ expr
126     |         expr AND expr
127     |         expr MODULO expr

```

```
128         |      NOT  expr
129         |      expr OR   expr
130         |      expr DOT  expr
131         |      expr ASSIGN expr
132         |      DELETE expr
133         |  MINUS  expr
134         |      ID LPAREN actuals_opt RPAREN
135         |      NEW ID LPAREN actuals_opt RPAREN
136         |      NEW type_tag bracket_args RBRACKET
137         |      expr bracket_args RBRACKET
138         |      LPAREN expr RPAREN
139
140 bracket_args:
141     LBRACKET expr
142     |      bracket_args RBRACKET LBRACKET expr
143
144 literals:
145     INT_LITERAL
146     |      FLOAT_LITERAL
147     |      TRUE
148     |      FALSE
149     |      STRING_LITERAL
150     |      CHAR_LITERAL
151     |      THIS
152     |      ID
153     |      NULL
154     |      BAR array_prim BAR
155
156 array_prim:
157     expr
158     |      array_prim COMMA expr
```

4. PROJECT PLAN

Planning Process

Throughout the project we embodied the principles of agile development. At any point in time during our development we had working code on the master branch and every member of the team was brought up to speed with what has been completed and worked on. All goals for the project were put on Github and as they were resolved they were cleared. We created several milestones which captured our goals for completing the parser, scanner, analyzer, codegen, and final report milestones. We also worked closely with Professor Edwards at Columbia University to receive guidance on how best to implement this language. The following milestones were created and cleared over the course of the semester:

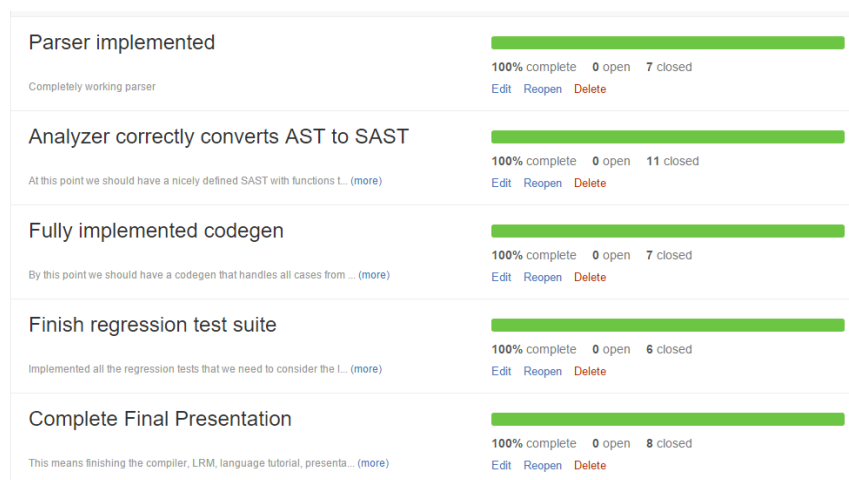


Figure 4.1: Milestoning on Github.

Specification Process

At the beginning of the semester we had originally intended our language to be a distributed software solution that would conveniently allow the developer to distribute tasks to various slave machines that had compiled the tasks to LLVM IR. After discussing this with professor Edwards we then decided to opt for an object oriented programming language that specifically compiled to LLVM IR. This way we as a team could learn more about making compilers and showing the power of LLVM.

Once we decided on the theme of Dice, we met to discuss the features we wanted most in our object oriented language. In our case we wanted arrays, inheritance, objects, and file IO to be some of the key highlights of our language. We then built up the scanner and parser to get a more solid idea as to what the language would look like, and by November 15th we had solidified our plans to implement the aforementioned features.

Development Process

Implementation was very dependent on the course deadlines. We started with the scanner and parser specifically so the language reference manual was better defined. This was completed by October 26th. We then iterated on the analyzer and codegen until it was capable of producing hello world. This was completed on November 15th. The month afterwards was spent implementing inheritance and arrays until they were finally completed on December 18th.

Testing Process

Throughout the development process we had numerous tests. The plan was to always have tests that were non-functional so a feature could then be implemented to get them working. If we encountered an error that we were unsure of how to fix, we added more error messages in our compiler until we could exactly pinpoint where the error was occurring. We also made a rule for our team to handle each and every exception that could occur as a custom error message to be printed out by the compiler.

Team Responsibilities

Team responsibilities were divided up and evenly distributed amongst the four group members. While we could not adhere to a strict division of labor based on group member titles, every member contributed to the codebase.

Team Member	Responsibility
David Watkins	Scanner, Parser, Analyzer, Codegen, Utils, LRM, Final Report, Latex, Code cleanup
Emily Chen	Inheritance in Analyzer, Expression types in Analyzer, LRM
Khaled Atef	Test Suite, Binary and unary expression evaluation in codegen
Phillip Schiffrin	Standard Library, Class map generation

Github Usernames

The following Github usernames correspond to the following group members:

- Emily Chen - six5532one, ec2805
- Khaled Atef - KhaledAtef
- David Watkins - DavidWatkins
- Phillip Schiffrin - nethacker11

Project Log

To demonstrate our timeline we captured the number of git commits over time for our project.

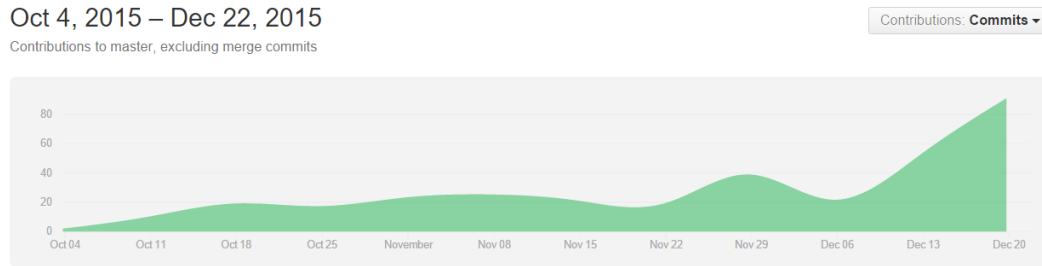


Figure 4.2: Commit timeline on Github.

The timeline shows that we have been diligent at constantly working on the project since the beginning of the semester. All group members have contributed to this project. The following issues are a list of git issues that were cleared as part of our project, as well as the person who closed the issue. We did not have a rule for who closed an issue so sometimes the person who completed the issue may not have been the one to close it.

- #71 Should not be able to access variables outside of scope
- #137 Awesome!
- #134 Subclass assignment [by @six5532one, @DavidWatkins]
- #133 string length tests
- #132 fix delete test, no multiple arrays
- #131 this should raise no exceptions
- #130 Expected stderr: "exception Exceptions.LocalAssignTypeMismatch("B", "C")"
- #129 passing in an inherited class for classes
- #128 E-test-privateFieldsAccess.dice
- #127 Create test for cyclical inheritance
- #126 Add error message for assigning parameters
- #125 test-gcd.dice Bug. You cannot assign values to parameters
- #124 test-constructor1.dice is written incorrectly
- #123 Maximum float is limited to 6 digits after the decimal
- #122 char[][] args does not work in main
- #121 Test max/min floats
- #120 Test default constructor
- #119 Test overloading std-lib functions
- #118 Exit not working in runtime
- #117 Test args

- #116 assign ints to floats
- #115 Integer toString generates string twice
- #114 concat adds an extra character to the string
- #113 Test exit
- #111 Errors.log from script output isn't working properly
- #110 add teststdlib .out
- #109 Add Test returning objects
- #108 add tests for empty blocks
- #107 For inheritance of functions we should have an id to determine which function to call
- #106 Includes should check with String_lit not ID
- #105 Odd invalid numbering of blocks bug
- #104 Fix parameters on library functions
- #103 Get Dice exec working so tests can run again.
- #102 "Get the t-shirts made"
- #101 Adapt codegen to changes in analyzer that add inherited fields to sprogram.classes
- #100 Need to test includes
- #99 add test for empty conditionals
- #98 add empty for loop test
- #97 Add nested comments
- #96 test order of fdecl,fields,constructor in classes
- #95 primitive type limit tests
- #94 test constructors
- #93 test private scope function
- #92 Help needed: env.env_class_maps seems correct but exception is raised when I try to access an inherited field
- #91 default constructors
- #90 Need to add an environment variable to point to the includes
- #89 Strings need to be initialized and accessed differently from normal arrays
- #88 This should raise "UndefinedClass: H"
- #87 Use of Delete
- #86 add static scoping test
- #85 Add applicative order test

- #84 Add delete command to free memory
- #82 Add exit call
- #81 return statements in branches aren't recognized
- #80 dice executable doesn't run without any args
- #79 Kappa [by @DavidWatkins]
- #78 Add tests for recursion
- #77 Obj access [by @DavidWatkins]
- #75 Test invalid functions
- #74 Test multiple classes
- #73 Parent cannot have fields of type of its children
- #72 Cannot call return inside of a constructor
- #135 check for overridden methods takes ret type into account [by @six5532one, @DavidWatkins]
- #69 Casting rules questions
- #68 Kappa [by @DavidWatkins]
- #67 Floats print with extra trailing zeros. Kinda ugly.
- #66 Emily [by @six5532one, @DavidWatkins]
- #65 local decl (primitives): stderr should be "DuplicateLocal: myc"
- #64 object creation: this should raise no exception
- #63 object creation: this should raise no exceptions
- #62 Compiler doesn't allow formal to be an object
- #61 object creation: This should throw no exceptions
- #60 Object creation: this should raise "ConstructorNotFound: Foo.constructor.int.bool.char.float"
- #59 object decl without assignment expr: This should throw no exceptions
- #58 This should throw exception "UndefinedClass: Baz"
- #57 incorrect check for duplicate constructors
- #56 Emily [by @six5532one, @DavidWatkins]
- #55 Create arith tests that have signed values
- #54 Parser issue with reading user-defined objects.
- #53 Emily [by @six5532one]
- #52 Decide whether to promote all ints to floats in binops
- #51 Consecutive print statements don't work. Compiler only outputs first print statement.

- #50 Epsilon [by @six5532one]
- #49 Reorganize object accesses for functions
- #46 Kreygasm [by @DavidWatkins]
- #45 Add shakespeare and stephen number to tester
- #44 Create symbol table for cdecls, fdecls, fields
- #39 static analysis checks for variable access
- #38 use 'new' keyword for object and array instantiation
- #37 support addition of chars and ints
- #36 Update LRM: support addition of chars and ints
- #35 Change parser array create type to type tag and not primitive
- #34 Evaluate whether to add new as a keyword to object initialization
- #33 Exceptions, try, catch?
- #32 Implement basic primitive expressions for codegen
- #31 Should we add continuous checking even when an illegal character/parser error occurs like java?
- #30 Add annotation for source code position to AST
- #29 We should evaluate whether we want to move variable declarations to stmts
- #28 Do we need to add an additional layer of abstraction from SAST to Codegen?
- #27 Complete pretty printing abstract syntax tree to Utils
- #26 How does LLVM handle allocating on the heap
- #24 Strings with escape characters are not being displayed properly
- #23 Create OCamlDoc Documentation
- #22 Should we switch the llvm package to ollvm?
- #21 Add file operator functions to Codegen
- #20 Write the File class
- #19 Write the String class
- #18 Write the Math class
- #17 Add support for utilizing line number and character number in Analyzer
- #16 Add class name and function name collision detection
- #15 Add testing for arrays
- #14 Evaluate the type of an expression in Analyzer.get_expr_type
- #13 Add testing for extends

- #12 Add mentioning of unary minus to LRM
- #11 Remove '-' symbol from regex in floats and ints of LRM
- #10 Convert AST.cdecl to SAST.cdecl
- #9 Convert AST.expr to SAST.expr in Analyzer.convert_expr
- #8 Analyzer.process_includes does not check absolute path
- #7 Delta [by @DavidWatkins]
- #6 Delta [by @DavidWatkins]
- #5 Special chars (tabs/newlines/etc) aren't getting tokenized properly
- #4 float limit
- #3 David fix [by @DavidWatkins]
- #2 Merge pull request #1 from DavidWatkins/DavidFix [by @DavidWatkins]
- #1 David fix [by @DavidWatkins]

Git Commit History

Here are all of the commits as performed by the team. Everyone contributed to the project.

- EDIT ME

Software Development Environment

From the beginning of the project we agreed to the following development environment with the following software versions:

- **Ubuntu 15.10** - Very simple to use linux distribution that had the LLVM software and OCaml software easily accessible. Ubuntu was used within Virtualbox to ensure consistency across hardware as well.
- **LLVM-3.7** - The latest version of LLVM and allowed for easy code generation in OCaml using the LLVM module
- **OCaml Packages** - There were some features, such as JSON manipulation, that required additional OCaml packages. Therefore we included the following four OCaml packages in our development process: core, batteries, llvm, and yojson.
- **Slack** - We agreed that the Slack chat messaging platform was the most convenient and efficient way to share code snippets and communicate. It also brought up morale in the group in the form of emojis.
- **Github** - In order to version control our software and maintain a working version at any time, we used Github as our go to source code repository. It made integration with the team simpler and everyone was able to view the repository conveniently in their browser.
- **Latex** - In order to compile the documentation we made sure to all use Latex to ensure high quality material being produced for the project.
- **Vim/Sublime** - We could not create a consensus on which text editor to use, but in the end it did not matter to much which members used which.

Programming Style Guide

We adhered to the following style guide as much as possible:

- No lines greater than 80 characters
- Ensure that pattern matches are on the same indent with respect to each other
- Use tabbed indentation as opposed to spaces. Ensure that the tab width is 4 spaces.

5. ARCHITECTURE

The Compiler

To give a quick overview of our compiler, we have a total of 8 modules:

- **analyzer.ml** - Semantically checks incoming AST representation to make sure that it includes existing files, adheres to the rules of inheritance, and expressions are properly type-checked
- **codegen.ml** - Converts a semantically checked AST into a working LLVM code by producing LLVM IR.
- **dice.ml** - Main module that calls on all the other modules depending on compiler flags passed to it
- **filepath.ml** - Uses system calls to determine the absolute path to any file in the system. Useful for uniquely checking if an include statement refers to the same files
- **parser.mly** - Reads in tokens from the scanner to produce an AST representation of the program
- **processor.ml** - Handles communication between scanner and parser so that error messages regarding invalid input can be handled better
- **scanner.mll** - Reads a source file and tokenizes it to the corresponding token output.
- **utils.ml** - Contains several functions for printing out the string representation of various intermediate representations in our language. Most critically used for debugging.

and we have 4 interfaces

- **ast.ml** - Representation of program after parser
- **conf.ml** - Contains paths for accessing standard library and bindings
- **exceptions.ml** - All exceptions in the compiler
- **sast.ml** - The semantically checked representation of the language

and we have 2 library files

- **bindings.c** - A c file containing critical functions written in c that are usable in the language. This is compiled to LLVM bitcode and then linked with all source files compiled in our language
- **stdlib.dice** - A file containing user defined classes written in dice that are usable by the user

The Scanner

The Scanner scans through the input file and tokenizes the input, discarding characters which are no longer need such as whitespace.

The Parser

The parser scans the tokens passed to it by the scanner and constructs an abstract syntax tree based on the definitions provided and the input tokens. The top level of the abstract syntax tree is a structure containing all classes and a structure containing all include statements.

The Semantic Analyzer

The first job of the Analyzer is to run the Scanner and Parser on any files contained in the includes statements of the given abstract syntax tree. The process of building an abstract syntax tree is the same for these files as for the originally compiled file. If any of these new abstract syntax trees contain include statements, the same process is run until there are no more includes. Similarly, each time a new included file's abstract syntax tree is passed to the Analyzer, all classes contained in the class structure of the new abstract syntax tree are appended to the original class list contained in the original class structure which was in the original abstract syntax tree. Once this process is complete, the analyzer is left with a class structure which contains every class defined in every file which was included with the originally compiled file.

Next, the Analyzer performs an inheritance analysis by looking through the class list contained in the class structure and performs an analysis to determine whether any classes are children or parents of other classes. If there are any such relationships, the fields of each parent class are added to the front of its child's fields list, and the methods of each parent class are added to the child's method's list. However, if the child has declared a method or field which shares the same name as the parent's field or method, the child's field or method is not overwritten by the parent. As the inheritance analysis is performed, the list of fields for each class is also assigned a integer key beginning with 0 which will serve as the key to a lookup table which, at runtime, contains pointers to every function for each class.

Once the inheritance analysis is performed, semantic analysis is performed on each statement and expression in each block of code in every method for every class. This semantic analysis consists of making sure that types are consistent in every expression, making sure variables are declared and in the proper scope, and making sure that variables are only declared once. For instance, if an integer x is declared and x is assigned to the return of a method, the analyzer checks that the called method returns the type of x, namely an integer.

As this analysis is performed, the analyzer is simultaneously constructing a semantic abstract syntax tree. The purpose of this new data structure is to provide the code generator with data that is organized more similarly to the LLVM code that it will eventually produce. Thus, instead of classes containing methods and fields, the top level program structure now contains separate sections for methods and fields. This is useful for the code generator because the LLVM code that is produced uses structs to store the fields of a class and functions to store the code within a class's methods. Thus, there is no inherent connection between the functions and the structs in LLVM. However, the analyzer modifies each method so that an instance of the structure containing the fields of the given class is passed in as the first argument to every function for that class. In this way, functions can access each field of a given class by accessing the data inside of the structure.

The Code Generator

The code generator uses the semantic abstract syntax tree passed to it by the analyzer to construct the LLVM IR file which contains the final instructions for the program. Along with the code produced from the semantic abstract syntax tree, the code generator also output boiler-plate code for Dice's built-in functions and the virtual table. Definitions for built-in functions are hard-coded in the code generator. The codegen uses those definitions to write the declarations that LLVM needs to call those built in functions from the C standard library. The virtual table is an LLVM function called `lookup()`. Every time a user function is called in the semantic abstract syntax tree, the code generator instead produces a call to the lookup function,

which constructs the virtual table and indexes into it in order to find the desired function. When this is found, the corresponding function pointer is returned.

Once the boiler-plate code is generated, the code generator iterates through the entire semantic abstract syntax tree and produces the necessary LLVM code for each function, statement, and expression. This code generation is done using the `llvm.moe` library, which uses ocaml functions to produce the desired LLVM code.

Structs and Inheritance

All structs are given an integer key at the beginning of their definition which will allow them to directly get their own virtual function table. Even if a subclass inherits from a parent class

The Virtual Function Table

At compile time, an intermediate representation of the virtual function table is produced in LLVM IR. It is a function defined as "lookup" that is able to lookup a classes virtual function array by its class index and a

The Utilities

Pretty printing, token printing, JSON printing

Supplementary Code

The Standard Library

The standard library was written in order to provide the user with a solid foundation on which to start writing interesting programs. To that end we provide for basic file i/o and string and integer manipulation.

String

Provide useful functionality for string manipulation.

Fields

String has no public fields. Private fields include a char array `my_string` which stores the given string and an int to store the length of the string.

Constructors

String(char[] a) Accepts a char array, such as a string literal or a char array. This string is copied into the `my_string` field of the object and the private `length()` method is run to get the length of the input string.

Methods

private int length_internal(char[] input) Returns the length of the given char array.

private char[] copy_internal(char[] input) Creates a new char array into which it copies the given char array.

public char[] string() Returns the char array contained in the `my_string` field.

public char getChar(int index) Returns the char contained at the given index in the my_string field.

public int length() Returns the length of the my_string field

public int toInteger() Converts the char array in the my_string field to an integer and returns that int. If the char array contained in the my_string field is not a string representation of an int, the behavior is undefined.

public int toDigit(char digit) Returns the integer corresponding to the character passed in.

public class String copy(class String input) Returns a copy of the current object.

public int indexOf(char input) Returns the index of the input character in the my_string field. Returns -1 if the character is not found in the field.

public class String reverse() Returns a string object with the my_string field containing the reverse of the current my_string char array.

public class String concat(class String temp) Returns a string object with the my_string field containing the concatenation of the current my_string field with the temp's my_string field.

public bool compare(class String input) Returns true if the my_string field of the input String is equal to the my_string field of the current String object.

public bool contains(class String check) Returns true if the my_string field of the input String is contained in the my_string field of the current String object.

public void free() Frees the memory for the my_string field of the current String object.

File

The File class constructor takes two arguments: a char[] that points to an already opened file on which the user wishes to operate and a boolean indicating whether the user wishes to open the file for writing. If the boolean is true the file is opened for reading and writing, and if false the file is opened as read only. The constructor stores the given path in a field and then calls open() on the given path and, if successful, sets the object's file descriptor field to the return of open(). If open() fails, the program exits with error.

Fields

File has no public fields. Private fields are the class String filePath, private bool isWriteEnabled, and the private int fd.

Constructors

File(char[] path, bool isWriteEnabled) Accepts a char array to open a file on, then creates a file object with the file descriptor. isWriteEnabled is a parameter that is used to determine whether the file can be written to or just read from.

Methods

private int **openfile**(class **String** **path**, **bool** **isWriteEnabled**) Returns the file descriptor of the opened file if successful, and -1 otherwise.

public char[] **readfile**(**int** **num**) Reads num bytes from the open file and returns the bytes in a char array.

public int **writefile**(**char[]** **arr**, **int** **offset**) Writes the contents of the **char[]** array to the file. If offset is -1 the write starts at the beginning of the file, if 0 it starts at the end of the file, and with any other positive integer it starts writing offset bytes from the beginning of the file.

public void **closefile**() Closes the open file. On error, the program exits with error.

Integer

The Integer class provides for integers to be converted to char arrays.

Fields

Integer has no public fields. There is one private field **my_int** which stores the given integer.

Constructors

Integer(int input) Accepts an integer which is stored in the field **my_int**.

Methods

public int **num**() Returns the integer stored in the **my_int** field.

public char **toChar(int digit)** Returns in teh input digit as a character.

public class String **toString**() Converts the integer stored in the **my_int** field into a string using the **toChar()** method. Returns a string object.

Built-in Functions

These are functions which are mapped from Dice to the C standard library, which is accessed through LLVM IR. The following function names may not be declared by the user since they are reserved. These are the only functions in dice which are not called as the method of an object; instead the user calls them directly with no dot operator.

int **print(...)**

The print function can take a char array, int, float and boolean. For char arrays, the contents of the array are printed to stdout. For every other type, the type is converted to the proper variable identifier as used in the C standard library printf function, and then the identifier is replaced with the value of the passed in type when the string is printed to standard out. Arguments can be in any order and must be comma separated.

char[] **malloc(int size)**

Returns a char pointer to an area of allocated memory on the heap of size bytes.

int open(char[] path)

Attempts to open the file located at the path specified and, if successful, returns a file descriptor to the open file. Returns -1 on failure.

int close(int fd)

Closes the open file identified by the integer fd. Returns 0 if successful and -1 on error.

int read(int fd, char[] buf, int num)

Reads num bytes from the open file identified by fd and stores the resulting string in the char array buf. If successful the number of bytes read is returned. Otherwise returns -1.

int write(int fd, char[] buf, int size)

Writes the contents of the char array buf, which contains size bytes, to the open file identified by fd. If successful the number of bytes written is returned. Otherwise returns -1.

int lseek(int fd, int offset, int whence)

The lseek() function repositions the offset of the open file associated with the file descriptor fd to the argument offset according to the directive whence as follows: 0 - the offset is set to offset bytes, 1 - The offset is set to its current location plus offset bytes, 2 - The offset is set to the size of the file plus offset bytes.

void exit(int flag)

Exits the program. Program exits without error if flag is 0 and exits with error if flag is set to any other integer.

int getchar()

Gets a character from stdin. Returns the character cast to an int.

Functions Implemented in C

With LLVM IR dice is able to compile functions written in C to LLVM. The following functions for dice were written in C.

Declarations

char[] input()

The input function reads from stdin with the C standard library getchar() function, storing each character in a malloc'd char array, until a newline character is read. The resulting array is returned.

long[] init_arr(int[] dims, int dimc)

Takes a list of dimensions in the form of ints and initialize a dimc-dimensional array in a one-dimension malloc call. To access element arr[1][2], first dereference a[1], and cast the value to a long*, which is an address to the array at position 1. Then dereference arr[2] and then cast that to a long* and the value is located at that position. This function is implemented in bindings.c, but was never incorporated directly into the language.

6. TEST PLAN

We embodied a "Test Driven Development" approach while creating our programming language. This process entailed writing tests for specific features of our language before starting to implement them. Every test should start by failing in an automated script and then the script should be executed after every modification to any portion of the compiler (from scanner to code generation). This way the team members would know if any modifications made resulted in other tests failing that had previously passed.

The majority of the test cases in our suite check the code generation through a comparison of print statement outputs from the code and our expected output. We created a test for every component of our language from basic variable declaration and assignment to class inheritance and method overriding. If it's in our language, there's a test case for it.

Testing Phases

Unit Testing

In the beginning of the testing process, we set out to thoroughly check the scanner and parser; however, the course instructor suggested we focus on the overall output of the project because testing end-to-end flow was his recommendation. To simplify checking of the Abstract Syntax Tree (AST) and the semantically checked AST (SAST), our manager created a pretty printer that would output the trees in a Javascript Object Notation (JSON) format for quick visual confirmation of their structure. In addition to quick visual feedback JSON objects provide, we also considered using an OCaml JSON visualization package known as `yojson` to render a visual tree of the data. We then compared the results of this output to the expected results based on the input.

Integration Testing

In addition to running the test suite routinely, we streamlined creation of new test cases by allowing any member of the team to create a git issue (labeled with "Testing") whenever a test case idea came to mind. Khaled (Test Suite Creator) would then screen all the open testing issues and add/modify the test according to schedule set by the manager.

During the development process, we also realized that in addition to checking proper output from our programs, we should also check if our analyzer was correctly identifying semantically invalid code. For example, if trying to assign a float type number to an integer variable (a feature we do not support), the analyzer should throw the proper exception. We accounted for these cases and placed all the tests in a separate folder with an identifying prefix to easily determine the category of test case.

Automation

Testing was very simple using `./tester.sh`. We can verify that a test works individually by running `lli` on the outputted `ll` file

Test Suites

We created a total of 121 tests divided into two categories. One checks that the compiler is properly recognizing invalid code. The other checks that the compiler accepts valid code and tests the output program.

Dice to LL IR

The following code examples are dice source files that compile to an associated LLVM IR file.

Hello World Example

The following "Hello, World!" program is the first program we got running in our language.

test-hello.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print("Hello, World!");
4      }
```

test-hello.ll

```
1  ; ModuleID = 'Dice Codegen'
2  target datalayout = "e-m:e-i64:64-f80:128-n8:16:32:64-S128"
3  target triple = "x86_64-pc-linux-gnu"
4
5  %test = type <{ i32 }>
6
7  @tmp = private unnamed_addr constant [14 x i8] c"Hello, World!\00"
8  @tmp.1 = private unnamed_addr constant [3 x i8] c"%s\00"
9
10 declare i32 @printf(i8*, ...)
11
12 declare noalias i8* @malloc(i32)
13
14 declare i32 @open(i8*, i32)
15
16 declare i32 @close(i32)
17
18 declare i32 @read(i32, i8*, i32)
19
20 declare i32 @write(i32, i8*, i32)
21
22 declare i32 @lseek(i32, i32, i32)
23
24 declare void @exit(i32)
25
26 declare i8* @realloc(i8*, i32)
27
28 declare i32 @getchar()
```

```

29
30 define i64* @lookup(i32 %c_index, i32 %f_index) {
31 entry:
32     %tmp = alloca i64**
33     %tmp1 = alloca i64*, i32 0
34     %tmp2 = getelementptr i64**, i64*** %tmp, i32 0
35     store i64** %tmp1, i64*** %tmp2
36     ret i64* null
37 }
38
39 define %test* @test.constructor() {
40 entry:
41     %this = alloca %test
42     %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to
43         ↪ i32))
44     %tmp1 = bitcast i8* %tmp to %test*
45     %tmp2 = load %test, %test* %tmp1
46     store %test %tmp2, %test* %this
47     %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
48     store i32 0, i32* %.key
49     ret %test* %this
50 }
51
52 define i32 @main(i32 %argc, i8** %argv) {
53 entry:
54     %arr_size = add i32 %argc, 1
55     %mallocsize = mul i32 %arr_size, ptrtoint (i1** getelementptr (i1*, i1** null, i32 1)
56         ↪ to i32)
57     %malloccall = tail call i8* @malloc(i32 %mallocsize)
58     %args = bitcast i8* %malloccall to i8***
59     %args1 = bitcast i8*** %args to i8**
60     %argc_len = bitcast i8** %args1 to i32*
61     %arr_1 = getelementptr i8*, i8** %args1, i32 1
62     store i32 %argc, i32* %argc_len
63     br label %args.cond
64
65 args.cond:                                     ; preds = %args.init, %entry
66     %counter = phi i32 [ 0, %entry ], [ %tmp, %args.init ]
67     %tmp = add i32 %counter, 1
68     %tmp2 = icmp slt i32 %counter, %argc
69     br i1 %tmp2, label %args.init, label %args.done
70
71 args.init:                                     ; preds = %args.cond
72     %tmp3 = getelementptr i8*, i8** %arr_1, i32 %counter
73     %tmp4 = getelementptr i8*, i8** %argv, i32 %counter
74     %tmp5 = load i8*, i8** %tmp4
75     store i8* %tmp5, i8** %tmp3
76     br label %args.cond

```

```

76  args.done:                                ; preds = %args.cond
77  %this = alloca %test
78  %tmp6 = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to
    ↪ i32))
79  %tmp7 = bitcast i8* %tmp6 to %test*
80  %tmp8 = load %test, %test* %tmp7
81  store %test %tmp8, %test* %this
82  %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
83  store i32 0, i32* %.key
84  %tmp9 = call i32 (i8*, ...) @printf(i8* getelementptr inbounds ([3 x i8], [3 x i8]*
    ↪ @tmp.1, i32 0, i32 0), i8* getelementptr inbounds ([14 x i8], [14 x i8]* @tmp, i32
    ↪ 0, i32 0))
85  ret i32 0
86  }
87
88  ; Function Attrs: nounwind uwtable
89  define i8* @input() #0 {
90      %initial_size = alloca i32, align 4
91      %str = alloca i8*, align 8
92      %index = alloca i32, align 4
93      %tmp = alloca i8, align 1
94      store i32 100, i32* %initial_size, align 4
95      %1 = load i32, i32* %initial_size, align 4
96      %2 = sext i32 %1 to i64
97      %3 = call noalias i8* bitcast (i8* (i32)* @malloc to i8* (i64*)(i64 %2)) #1
98      store i8* %3, i8** %str, align 8
99      store i32 0, i32* %index, align 4
100     store i8 48, i8* %tmp, align 1
101     br label %4
102
103     ; <label>:4                                ; preds = %20, %0
104     %5 = call i32 @getchar()
105     %6 = trunc i32 %5 to i8
106     store i8 %6, i8* %tmp, align 1
107     %7 = sext i8 %6 to i32
108     %8 = icmp ne i32 %7, 10
109     br i1 %8, label %9, label %27
110
111     ; <label>:9                                ; preds = %4
112     %10 = load i32, i32* %index, align 4
113     %11 = load i32, i32* %initial_size, align 4
114     %12 = sub nsw i32 %11, 1
115     %13 = icmp sge i32 %10, %12
116     br i1 %13, label %14, label %20
117
118     ; <label>:14                                ; preds = %9
119     %15 = load i8*, i8** %str, align 8
120     %16 = load i32, i32* %initial_size, align 4
121     %17 = mul nsw i32 %16, 2

```

```

122     store i32 %17, i32* %initial_size, align 4
123     %18 = sext i32 %17 to i64
124     %19 = call i8* @bitcast (i8* (i8*, i32)* @realloc to i8* (i8*, i64)*) (i8* %15, i64 %18)
        ↪ #1
125     store i8* %19, i8** %str, align 8
126     br label %20
127
128 ; <label>:20                                ; preds = %14, %9
129     %21 = load i8, i8* %tmp, align 1
130     %22 = load i32, i32* %index, align 4
131     %23 = add nsw i32 %22, 1
132     store i32 %23, i32* %index, align 4
133     %24 = sext i32 %22 to i64
134     %25 = load i8*, i8** %str, align 8
135     %26 = getelementptr inbounds i8, i8* %25, i64 %24
136     store i8 %21, i8* %26, align 1
137     br label %4
138
139 ; <label>:27                                ; preds = %4
140     %28 = load i32, i32* %index, align 4
141     %29 = sext i32 %28 to i64
142     %30 = load i8*, i8** %str, align 8
143     %31 = getelementptr inbounds i8, i8* %30, i64 %29
144     store i8 0, i8* %31, align 1
145     %32 = load i8*, i8** %str, align 8
146     ret i8* %32
147 }
148
149 ; Function Attrs: nounwind uwtable
150 define void @rec_init(i64* %arr, i32 %curr_offset, i32* %static_offsets, i32* %indexes,
        ↪ i32* %dims, i32 %dimc, i32 %dim_curr) #0 {
151     %1 = alloca i64*, align 8
152     %2 = alloca i32, align 4
153     %3 = alloca i32*, align 8
154     %4 = alloca i32*, align 8
155     %5 = alloca i32*, align 8
156     %6 = alloca i32, align 4
157     %7 = alloca i32, align 4
158     %static_offset = alloca i32, align 4
159     %dynamic_offset = alloca i32, align 4
160     %i = alloca i32, align 4
161     %tmp = alloca i32, align 4
162     %j = alloca i32, align 4
163     %i1 = alloca i32, align 4
164     %offset = alloca i32, align 4
165     %sub = alloca i64*, align 8
166     store i64* %arr, i64** %1, align 8
167     store i32 %curr_offset, i32* %2, align 4
168     store i32* %static_offsets, i32** %3, align 8

```

```

169 store i32* %indexes, i32** %4, align 8
170 store i32* %dims, i32** %5, align 8
171 store i32 %dimc, i32* %6, align 4
172 store i32 %dim_curr, i32* %7, align 4
173 %8 = load i32, i32* %7, align 4
174 %9 = sext i32 %8 to i64
175 %10 = load i32*, i32** %5, align 8
176 %11 = getelementptr inbounds i32, i32* %10, i64 %9
177 %12 = load i32, i32* %11, align 4
178 %13 = sext i32 %12 to i64
179 %14 = load i32, i32* %2, align 4
180 %15 = sext i32 %14 to i64
181 %16 = load i64*, i64** %1, align 8
182 %17 = getelementptr inbounds i64, i64* %16, i64 %15
183 store i64 %13, i64* %17, align 8
184 %18 = load i32, i32* %7, align 4
185 %19 = add nsw i32 %18, 1
186 %20 = load i32, i32* %6, align 4
187 %21 = icmp sge i32 %19, %20
188 br i1 %21, label %22, label %23
189
190 ; <label>:22                                ; preds = %0
191 br label %115
192
193 ; <label>:23                                ; preds = %0
194 %24 = load i32, i32* %7, align 4
195 %25 = sext i32 %24 to i64
196 %26 = load i32*, i32** %3, align 8
197 %27 = getelementptr inbounds i32, i32* %26, i64 %25
198 %28 = load i32, i32* %27, align 4
199 store i32 %28, i32* %static_offset, align 4
200 store i32 0, i32* %dynamic_offset, align 4
201 store i32 0, i32* %i, align 4
202 br label %29
203
204 ; <label>:29                                ; preds = %60, %23
205 %30 = load i32, i32* %i, align 4
206 %31 = load i32, i32* %7, align 4
207 %32 = icmp slt i32 %30, %31
208 br i1 %32, label %33, label %63
209
210 ; <label>:33                                ; preds = %29
211 %34 = load i32, i32* %i, align 4
212 %35 = sext i32 %34 to i64
213 %36 = load i32*, i32** %4, align 8
214 %37 = getelementptr inbounds i32, i32* %36, i64 %35
215 %38 = load i32, i32* %37, align 4
216 store i32 %38, i32* %tmp, align 4
217 %39 = load i32, i32* %i, align 4

```

```

218  %40 = add nsw i32 %39, 1
219  store i32 %40, i32* %j, align 4
220  br label %41
221
222  ; <label>:41                                ; preds = %53, %33
223  %42 = load i32, i32* %j, align 4
224  %43 = load i32, i32* %7, align 4
225  %44 = icmp sle i32 %42, %43
226  br i1 %44, label %45, label %56
227
228  ; <label>:45                                ; preds = %41
229  %46 = load i32, i32* %j, align 4
230  %47 = sext i32 %46 to i64
231  %48 = load i32*, i32** %5, align 8
232  %49 = getelementptr inbounds i32, i32* %48, i64 %47
233  %50 = load i32, i32* %49, align 4
234  %51 = load i32, i32* %tmp, align 4
235  %52 = mul nsw i32 %51, %50
236  store i32 %52, i32* %tmp, align 4
237  br label %53
238
239  ; <label>:53                                ; preds = %45
240  %54 = load i32, i32* %j, align 4
241  %55 = add nsw i32 %54, 1
242  store i32 %55, i32* %j, align 4
243  br label %41
244
245  ; <label>:56                                ; preds = %41
246  %57 = load i32, i32* %tmp, align 4
247  %58 = load i32, i32* %dynamic_offset, align 4
248  %59 = add nsw i32 %58, %57
249  store i32 %59, i32* %dynamic_offset, align 4
250  br label %60
251
252  ; <label>:60                                ; preds = %56
253  %61 = load i32, i32* %i, align 4
254  %62 = add nsw i32 %61, 1
255  store i32 %62, i32* %i, align 4
256  br label %29
257
258  ; <label>:63                                ; preds = %29
259  store i32 0, i32* %i1, align 4
260  br label %64
261
262  ; <label>:64                                ; preds = %112, %63
263  %65 = load i32, i32* %i1, align 4
264  %66 = load i32, i32* %7, align 4
265  %67 = sext i32 %66 to i64
266  %68 = load i32*, i32** %5, align 8

```



```
267 %69 = getelementptr inbounds i32, i32* %68, i64 %67
268 %70 = load i32, i32* %69, align 4
269 %71 = icmp slt i32 %65, %70
270 br i1 %71, label %72, label %115
271
272 ; <label>:72                                ; preds = %64
273 %73 = load i32, i32* %static_offset, align 4
274 %74 = load i32, i32* %dynamic_offset, align 4
275 %75 = load i32, i32* %i1, align 4
276 %76 = add nsw i32 %74, %75
277 %77 = load i32, i32* %7, align 4
278 %78 = add nsw i32 %77, 1
279 %79 = sext i32 %78 to i64
280 %80 = load i32*, i32** %5, align 8
281 %81 = getelementptr inbounds i32, i32* %80, i64 %79
282 %82 = load i32, i32* %81, align 4
283 %83 = add nsw i32 %82, 1
284 %84 = mul nsw i32 %76, %83
285 %85 = add nsw i32 %73, %84
286 store i32 %85, i32* %offset, align 4
287 %86 = load i64*, i64** %1, align 8
288 %87 = load i32, i32* %offset, align 4
289 %88 = sext i32 %87 to i64
290 %89 = getelementptr inbounds i64, i64* %86, i64 %88
291 store i64* %89, i64** %sub, align 8
292 %90 = load i64*, i64** %sub, align 8
293 %91 = ptrtoint i64* %90 to i64
294 %92 = load i32, i32* %2, align 4
295 %93 = add nsw i32 %92, 1
296 %94 = load i32, i32* %i1, align 4
297 %95 = add nsw i32 %93, %94
298 %96 = sext i32 %95 to i64
299 %97 = load i64*, i64** %1, align 8
300 %98 = getelementptr inbounds i64, i64* %97, i64 %96
301 store i64 %91, i64* %98, align 8
302 %99 = load i32, i32* %i1, align 4
303 %100 = load i32, i32* %7, align 4
304 %101 = sext i32 %100 to i64
305 %102 = load i32*, i32** %4, align 8
306 %103 = getelementptr inbounds i32, i32* %102, i64 %101
307 store i32 %99, i32* %103, align 4
308 %104 = load i64*, i64** %1, align 8
309 %105 = load i32, i32* %offset, align 4
310 %106 = load i32*, i32** %3, align 8
311 %107 = load i32*, i32** %4, align 8
312 %108 = load i32*, i32** %5, align 8
313 %109 = load i32, i32* %6, align 4
314 %110 = load i32, i32* %7, align 4
315 %111 = add nsw i32 %110, 1
```

```

316     call void @rec_init(i64* %104, i32 %105, i32* %106, i32* %107, i32* %108, i32 %109, i32
    ↪ %111)
317     br label %112
318
319 ; <label>:112                                     ; preds = %72
320     %113 = load i32, i32* %i1, align 4
321     %114 = add nsw i32 %113, 1
322     store i32 %114, i32* %i1, align 4
323     br label %64
324
325 ; <label>:115                                     ; preds = %22, %64
326     ret void
327 }
328
329 ; Function Attrs: nounwind uwtable
330 define i64* @init_arr(i32* %dims, i32 %dimc) #0 {
331     %1 = alloca i32*, align 8
332     %2 = alloca i32, align 4
333     %3 = alloca i8*
334     %total = alloca i32, align 4
335     %i = alloca i32, align 4
336     %j = alloca i32, align 4
337     %i1 = alloca i32, align 4
338     %length = alloca i32, align 4
339     %i2 = alloca i32, align 4
340     %tmp = alloca i32, align 4
341     %j3 = alloca i32, align 4
342     %arr = alloca i64*, align 8
343     %i4 = alloca i32, align 4
344     store i32* %dims, i32** %1, align 8
345     store i32 %dimc, i32* %2, align 4
346     %4 = load i32, i32* %2, align 4
347     %5 = zext i32 %4 to i64
348     %6 = call i8* @llvm.stacksave()
349     store i8* %6, i8** %3
350     %7 = alloca i32, i64 %5, align 16
351     store i32 0, i32* %total, align 4
352     store i32 0, i32* %i, align 4
353     br label %8
354
355 ; <label>:8                                         ; preds = %56, %0
356     %9 = load i32, i32* %i, align 4
357     %10 = load i32, i32* %2, align 4
358     %11 = icmp slt i32 %9, %10
359     br i1 %11, label %12, label %59
360
361 ; <label>:12                                       ; preds = %8
362     %13 = load i32, i32* %i, align 4
363     %14 = sext i32 %13 to i64

```

```
364 %15 = getelementptr inbounds i32, i32* %7, i64 %14
365 store i32 1, i32* %15, align 4
366 store i32 0, i32* %j, align 4
367 br label %16
368
369 ; <label>:16                                ; preds = %31, %12
370 %17 = load i32, i32* %j, align 4
371 %18 = load i32, i32* %i, align 4
372 %19 = icmp slt i32 %17, %18
373 br i1 %19, label %20, label %34
374
375 ; <label>:20                                ; preds = %16
376 %21 = load i32, i32* %j, align 4
377 %22 = sext i32 %21 to i64
378 %23 = load i32*, i32** %1, align 8
379 %24 = getelementptr inbounds i32, i32* %23, i64 %22
380 %25 = load i32, i32* %24, align 4
381 %26 = load i32, i32* %i, align 4
382 %27 = sext i32 %26 to i64
383 %28 = getelementptr inbounds i32, i32* %7, i64 %27
384 %29 = load i32, i32* %28, align 4
385 %30 = mul nsw i32 %29, %25
386 store i32 %30, i32* %28, align 4
387 br label %31
388
389 ; <label>:31                                ; preds = %20
390 %32 = load i32, i32* %j, align 4
391 %33 = add nsw i32 %32, 1
392 store i32 %33, i32* %j, align 4
393 br label %16
394
395 ; <label>:34                                ; preds = %16
396 %35 = load i32, i32* %i, align 4
397 %36 = sext i32 %35 to i64
398 %37 = load i32*, i32** %1, align 8
399 %38 = getelementptr inbounds i32, i32* %37, i64 %36
400 %39 = load i32, i32* %38, align 4
401 %40 = add nsw i32 %39, 1
402 %41 = load i32, i32* %i, align 4
403 %42 = sext i32 %41 to i64
404 %43 = getelementptr inbounds i32, i32* %7, i64 %42
405 %44 = load i32, i32* %43, align 4
406 %45 = mul nsw i32 %44, %40
407 store i32 %45, i32* %43, align 4
408 %46 = load i32, i32* %total, align 4
409 %47 = load i32, i32* %i, align 4
410 %48 = sext i32 %47 to i64
411 %49 = getelementptr inbounds i32, i32* %7, i64 %48
412 %50 = load i32, i32* %49, align 4
```

```

413 %51 = add nsw i32 %50, %46
414 store i32 %51, i32* %49, align 4
415 %52 = load i32, i32* %i, align 4
416 %53 = sext i32 %52 to i64
417 %54 = getelementptr inbounds i32, i32* %7, i64 %53
418 %55 = load i32, i32* %54, align 4
419 store i32 %55, i32* %total, align 4
420 br label %56
421
422 ; <label>:56                                ; preds = %34
423 %57 = load i32, i32* %i, align 4
424 %58 = add nsw i32 %57, 1
425 store i32 %58, i32* %i, align 4
426 br label %8
427
428 ; <label>:59                                ; preds = %8
429 %60 = load i32, i32* %2, align 4
430 %61 = zext i32 %60 to i64
431 %62 = alloca i32, i64 %61, align 16
432 store i32 0, i32* %i1, align 4
433 br label %63
434
435 ; <label>:63                                ; preds = %71, %59
436 %64 = load i32, i32* %i1, align 4
437 %65 = load i32, i32* %2, align 4
438 %66 = icmp slt i32 %64, %65
439 br i1 %66, label %67, label %74
440
441 ; <label>:67                                ; preds = %63
442 %68 = load i32, i32* %i1, align 4
443 %69 = sext i32 %68 to i64
444 %70 = getelementptr inbounds i32, i32* %62, i64 %69
445 store i32 0, i32* %70, align 4
446 br label %71
447
448 ; <label>:71                                ; preds = %67
449 %72 = load i32, i32* %i1, align 4
450 %73 = add nsw i32 %72, 1
451 store i32 %73, i32* %i1, align 4
452 br label %63
453
454 ; <label>:74                                ; preds = %63
455 store i32 0, i32* %length, align 4
456 store i32 0, i32* %i2, align 4
457 br label %75
458
459 ; <label>:75                                ; preds = %108, %74
460 %76 = load i32, i32* %i2, align 4
461 %77 = load i32, i32* %2, align 4

```

```
462 %78 = icmp slt i32 %76, %77
463 br i1 %78, label %79, label %111
464
465 ; <label>:79                                ; preds = %75
466 store i32 1, i32* %tmp, align 4
467 %80 = load i32, i32* %i2, align 4
468 %81 = sub nsw i32 %80, 1
469 store i32 %81, i32* %j3, align 4
470 br label %82
471
472 ; <label>:82                                ; preds = %93, %79
473 %83 = load i32, i32* %j3, align 4
474 %84 = icmp sge i32 %83, 0
475 br i1 %84, label %85, label %96
476
477 ; <label>:85                                ; preds = %82
478 %86 = load i32, i32* %j3, align 4
479 %87 = sext i32 %86 to i64
480 %88 = load i32*, i32** %1, align 8
481 %89 = getelementptr inbounds i32, i32* %88, i64 %87
482 %90 = load i32, i32* %89, align 4
483 %91 = load i32, i32* %tmp, align 4
484 %92 = mul nsw i32 %91, %90
485 store i32 %92, i32* %tmp, align 4
486 br label %93
487
488 ; <label>:93                                ; preds = %85
489 %94 = load i32, i32* %j3, align 4
490 %95 = add nsw i32 %94, -1
491 store i32 %95, i32* %j3, align 4
492 br label %82
493
494 ; <label>:96                                ; preds = %82
495 %97 = load i32, i32* %i2, align 4
496 %98 = sext i32 %97 to i64
497 %99 = load i32*, i32** %1, align 8
498 %100 = getelementptr inbounds i32, i32* %99, i64 %98
499 %101 = load i32, i32* %100, align 4
500 %102 = add nsw i32 %101, 1
501 %103 = load i32, i32* %tmp, align 4
502 %104 = mul nsw i32 %103, %102
503 store i32 %104, i32* %tmp, align 4
504 %105 = load i32, i32* %tmp, align 4
505 %106 = load i32, i32* %length, align 4
506 %107 = add nsw i32 %106, %105
507 store i32 %107, i32* %length, align 4
508 br label %108
509
510 ; <label>:108                                ; preds = %96
```

```

511  %109 = load i32, i32* %i2, align 4
512  %110 = add nsw i32 %109, 1
513  store i32 %110, i32* %i2, align 4
514  br label %75
515
516  ; <label>:111                                ; preds = %75
517  %112 = load i32, i32* %length, align 4
518  %113 = sext i32 %112 to i64
519  %114 = call noalias i8* @bitcast (i8* (i32)* @malloc to i8* (i64*)) (i64 %113) #1
520  %115 = bitcast i8* %114 to i64*
521  store i64* %115, i64** %arr, align 8
522  store i32 0, i32* %i4, align 4
523  br label %116
524
525  ; <label>:116                                ; preds = %125, %111
526  %117 = load i32, i32* %i4, align 4
527  %118 = load i32, i32* %length, align 4
528  %119 = icmp slt i32 %117, %118
529  br i1 %119, label %120, label %128
530
531  ; <label>:120                                ; preds = %116
532  %121 = load i32, i32* %i4, align 4
533  %122 = sext i32 %121 to i64
534  %123 = load i64*, i64** %arr, align 8
535  %124 = getelementptr inbounds i64, i64* %123, i64 %122
536  store i64 0, i64* %124, align 8
537  br label %125
538
539  ; <label>:125                                ; preds = %120
540  %126 = load i32, i32* %i4, align 4
541  %127 = add nsw i32 %126, 1
542  store i32 %127, i32* %i4, align 4
543  br label %116
544
545  ; <label>:128                                ; preds = %116
546  %129 = load i64*, i64** %arr, align 8
547  %130 = load i32*, i32** %1, align 8
548  %131 = load i32, i32* %2, align 4
549  call void @rec_init(i64* %129, i32 0, i32* %7, i32* %62, i32* %130, i32 %131, i32 0)
550  %132 = load i64*, i64** %arr, align 8
551  %133 = load i8*, i8** %3
552  call void @llvm.stackrestore(i8* %133)
553  ret i64* %132
554 }
555
556 ; Function Attrs: nounwind
557 declare i8* @llvm.stacksave() #1
558
559 ; Function Attrs: nounwind

```

```
560 declare void @llvm.stackrestore(i8*) #1
561
562 attributes #0 = { nounwind uwtable "disable-tail-calls"="false"
↳ "less-precise-fpmad"="false" "no-frame-pointer-elim"="true"
↳ "no-frame-pointer-elim-non-leaf" "no-infs-fp-math"="false" "no-nans-fp-math"="false"
↳ "stack-protector-buffer-size"="8" "target-cpu"="x86-64"
↳ "target-features"="+sse,+sse2" "unsafe-fp-math"="false" "use-soft-float"="false" }
563 attributes #1 = { nounwind }
564
565 !llvm.ident = !{!0}
566
567 !0 = !{"Ubuntu clang version 3.7.0-2ubuntu1 (tags/RELEASE_370/final) (based on LLVM
↳ 3.7.0)"}
```

Class Extends Example

The following test checks if a child class inherits the parent's fields:

test-classExtends.dice

```
1  class shape {
2      public float xCoord;
3      public float yCoord;
4  }
5
6  class circle extends shape {
7      public float radius;
8  }
9
10 class test {
11     public void main(char[] [] args) {
12         class circle a = new circle();
13         a.xCoord = 1.5;
14         print(a.xCoord);
15     }
16 }
```

test-classExtends.ll

```
1      ; ModuleID = 'Dice Codegen'
2      target datalayout = "e-m:e-i64:64-f80:128-n8:16:32:64-S128"
3      target triple = "x86_64-pc-linux-gnu"
4
5      %test = type <{ i32 }>
6      %circle = type <{ i32, double, double, double }>
7      %shape = type <{ i32, double, double }>
8
9      @tmp = private unnamed_addr constant [3 x i8] c"%f\00"
10
11      declare i32 @printf(i8*, ...)
12
13      declare noalias i8* @malloc(i32)
14
15      declare i32 @open(i8*, i32)
16
17      declare i32 @close(i32)
18
19      declare i32 @read(i32, i8*, i32)
20
21      declare i32 @write(i32, i8*, i32)
22
23      declare i32 @lseek(i32, i32, i32)
24
25      declare void @exit(i32)
```



```

26
27     declare i8* @realloc(i8*, i32)
28
29     declare i32 @getchar()
30
31     define i64* @lookup(i32 %c_index, i32 %f_index) {
32     entry:
33         %tmp = alloca i64**, i32 3
34         %tmp1 = alloca i64*, i32 0
35         %tmp2 = getelementptr i64**, i64*** %tmp, i32 2
36         store i64** %tmp1, i64*** %tmp2
37         %tmp3 = alloca i64*, i32 0
38         %tmp4 = getelementptr i64**, i64*** %tmp, i32 1
39         store i64** %tmp3, i64*** %tmp4
40         %tmp5 = alloca i64*, i32 0
41         %tmp6 = getelementptr i64**, i64*** %tmp, i32 0
42         store i64** %tmp5, i64*** %tmp6
43         ret i64* null
44     }
45
46     define %test* @test.constructor() {
47     entry:
48         %this = alloca %test
49         %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
50         %tmp1 = bitcast i8* %tmp to %test*
51         %tmp2 = load %test, %test* %tmp1
52         store %test %tmp2, %test* %this
53         %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
54         store i32 2, i32* %.key
55         ret %test* %this
56     }
57
58     define %circle* @circle.constructor() {
59     entry:
60         %this = alloca %circle
61         %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
62         %tmp1 = bitcast i8* %tmp to %circle*
63         %tmp2 = load %circle, %circle* %tmp1
64         store %circle %tmp2, %circle* %this
65         %.key = getelementptr inbounds %circle, %circle* %this, i32 0, i32 0
66         store i32 1, i32* %.key
67         ret %circle* %this
68     }
69
70     define %shape* @shape.constructor() {
71     entry:
72         %this = alloca %shape
73         %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
74         %tmp1 = bitcast i8* %tmp to %shape*

```

```

75 %tmp2 = load %shape, %shape* %tmp1
76 store %shape %tmp2, %shape* %this
77 %.key = getelementptr inbounds %shape, %shape* %this, i32 0, i32 0
78 store i32 0, i32* %.key
79 ret %shape* %this
80 }
81
82 define i32 @main(i32 %argc, i8** %argv) {
83 entry:
84 %arr_size = add i32 %argc, 1
85 %mallocsize = mul i32 %arr_size, ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to
    ↪ i32)
86 %malloccall = tail call i8* @malloc(i32 %mallocsize)
87 %args = bitcast i8* %malloccall to i8***
88 %args1 = bitcast i8*** %args to i8**
89 %argc_len = bitcast i8** %args1 to i32*
90 %arr_1 = getelementptr i8*, i8** %args1, i32 1
91 store i32 %argc, i32* %argc_len
92 br label %args.cond
93
94 args.cond:                                     ; preds = %args.init, %entry
95 %counter = phi i32 [ 0, %entry ], [ %tmp, %args.init ]
96 %tmp = add i32 %counter, 1
97 %tmp2 = icmp slt i32 %counter, %argc
98 br i1 %tmp2, label %args.init, label %args.done
99
100 args.init:                                     ; preds = %args.cond
101 %tmp3 = getelementptr i8*, i8** %arr_1, i32 %counter
102 %tmp4 = getelementptr i8*, i8** %argv, i32 %counter
103 %tmp5 = load i8*, i8** %tmp4
104 store i8* %tmp5, i8** %tmp3
105 br label %args.cond
106
107 args.done:                                     ; preds = %args.cond
108 %this = alloca %test
109 %tmp6 = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to
    ↪ i32))
110 %tmp7 = bitcast i8* %tmp6 to %test*
111 %tmp8 = load %test, %test* %tmp7
112 store %test %tmp8, %test* %this
113 %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
114 store i32 2, i32* %.key
115 %a = alloca %circle
116 %tmp9 = call %circle* @circle.constructor()
117 %tmp10 = load %circle, %circle* %tmp9
118 store %circle %tmp10, %circle* %a
119 %xCoord = getelementptr inbounds %circle, %circle* %a, i32 0, i32 2
120 store double 1.500000e+00, double* %xCoord
121 %xCoord11 = getelementptr inbounds %circle, %circle* %a, i32 0, i32 2

```

```

122 %xCoord12 = load double, double* %xCoord11
123 %tmp13 = call i32 (i8*, ...) @printf(i8* getelementptr inbounds ([3 x i8], [3 x i8]*
    ↪ @tmp, i32 0, i32 0), double %xCoord12)
124 ret i32 0
125 }
126
127 ; Function Attrs: nounwind uwtable
128 define i8* @input() #0 {
129     %initial_size = alloca i32, align 4
130     %str = alloca i8*, align 8
131     %index = alloca i32, align 4
132     %tmp = alloca i8, align 1
133     store i32 100, i32* %initial_size, align 4
134     %1 = load i32, i32* %initial_size, align 4
135     %2 = sext i32 %1 to i64
136     %3 = call noalias i8* bitcast (i8* (i32)* @malloc to i8* (i64)*) (i64 %2) #1
137     store i8* %3, i8** %str, align 8
138     store i32 0, i32* %index, align 4
139     store i8 48, i8* %tmp, align 1
140     br label %4
141
142     ; <label>:4                                ; preds = %20, %0
143     %5 = call i32 @getchar()
144     %6 = trunc i32 %5 to i8
145     store i8 %6, i8* %tmp, align 1
146     %7 = sext i8 %6 to i32
147     %8 = icmp ne i32 %7, 10
148     br i1 %8, label %9, label %27
149
150     ; <label>:9                                ; preds = %4
151     %10 = load i32, i32* %index, align 4
152     %11 = load i32, i32* %initial_size, align 4
153     %12 = sub nsw i32 %11, 1
154     %13 = icmp sge i32 %10, %12
155     br i1 %13, label %14, label %20
156
157     ; <label>:14                               ; preds = %9
158     %15 = load i8*, i8** %str, align 8
159     %16 = load i32, i32* %initial_size, align 4
160     %17 = mul nsw i32 %16, 2
161     store i32 %17, i32* %initial_size, align 4
162     %18 = sext i32 %17 to i64
163     %19 = call i8* bitcast (i8* (i8*, i32)* @realloc to i8* (i8*, i64)*) (i8* %15, i64
    ↪ %18) #1
164     store i8* %19, i8** %str, align 8
165     br label %20
166
167     ; <label>:20                               ; preds = %14, %9
168     %21 = load i8, i8* %tmp, align 1

```

```

169     %22 = load i32, i32* %index, align 4
170     %23 = add nsw i32 %22, 1
171     store i32 %23, i32* %index, align 4
172     %24 = sext i32 %22 to i64
173     %25 = load i8*, i8** %str, align 8
174     %26 = getelementptr inbounds i8, i8* %25, i64 %24
175     store i8 %21, i8* %26, align 1
176     br label %4
177
178     ; <label>:27                                ; preds = %4
179     %28 = load i32, i32* %index, align 4
180     %29 = sext i32 %28 to i64
181     %30 = load i8*, i8** %str, align 8
182     %31 = getelementptr inbounds i8, i8* %30, i64 %29
183     store i8 0, i8* %31, align 1
184     %32 = load i8*, i8** %str, align 8
185     ret i8* %32
186 }
187
188 ; Function Attrs: nounwind uwtable
189 define void @rec_init(i64* %arr, i32 %curr_offset, i32* %static_offsets, i32* %indexes,
190     ↪ i32* %dims, i32 %dimc, i32 %dim_curr) #0 {
191     %1 = alloca i64*, align 8
192     %2 = alloca i32, align 4
193     %3 = alloca i32*, align 8
194     %4 = alloca i32*, align 8
195     %5 = alloca i32*, align 8
196     %6 = alloca i32, align 4
197     %7 = alloca i32, align 4
198     %static_offset = alloca i32, align 4
199     %dynamic_offset = alloca i32, align 4
200     %i = alloca i32, align 4
201     %tmp = alloca i32, align 4
202     %j = alloca i32, align 4
203     %i1 = alloca i32, align 4
204     %offset = alloca i32, align 4
205     %sub = alloca i64*, align 8
206     store i64* %arr, i64** %1, align 8
207     store i32 %curr_offset, i32* %2, align 4
208     store i32* %static_offsets, i32** %3, align 8
209     store i32* %indexes, i32** %4, align 8
210     store i32* %dims, i32** %5, align 8
211     store i32 %dimc, i32* %6, align 4
212     store i32 %dim_curr, i32* %7, align 4
213     %8 = load i32, i32* %7, align 4
214     %9 = sext i32 %8 to i64
215     %10 = load i32*, i32** %5, align 8
216     %11 = getelementptr inbounds i32, i32* %10, i64 %9
217     %12 = load i32, i32* %11, align 4

```

```

217 %13 = sext i32 %12 to i64
218 %14 = load i32, i32* %2, align 4
219 %15 = sext i32 %14 to i64
220 %16 = load i64*, i64** %1, align 8
221 %17 = getelementptr inbounds i64, i64* %16, i64 %15
222 store i64 %13, i64* %17, align 8
223 %18 = load i32, i32* %7, align 4
224 %19 = add nsw i32 %18, 1
225 %20 = load i32, i32* %6, align 4
226 %21 = icmp sge i32 %19, %20
227 br i1 %21, label %22, label %23
228
229 ; <label>:22                                ; preds = %0
230 br label %115
231
232 ; <label>:23                                ; preds = %0
233 %24 = load i32, i32* %7, align 4
234 %25 = sext i32 %24 to i64
235 %26 = load i32*, i32** %3, align 8
236 %27 = getelementptr inbounds i32, i32* %26, i64 %25
237 %28 = load i32, i32* %27, align 4
238 store i32 %28, i32* %static_offset, align 4
239 store i32 0, i32* %dynamic_offset, align 4
240 store i32 0, i32* %i, align 4
241 br label %29
242
243 ; <label>:29                                ; preds = %60, %23
244 %30 = load i32, i32* %i, align 4
245 %31 = load i32, i32* %7, align 4
246 %32 = icmp slt i32 %30, %31
247 br i1 %32, label %33, label %63
248
249 ; <label>:33                                ; preds = %29
250 %34 = load i32, i32* %i, align 4
251 %35 = sext i32 %34 to i64
252 %36 = load i32*, i32** %4, align 8
253 %37 = getelementptr inbounds i32, i32* %36, i64 %35
254 %38 = load i32, i32* %37, align 4
255 store i32 %38, i32* %tmp, align 4
256 %39 = load i32, i32* %i, align 4
257 %40 = add nsw i32 %39, 1
258 store i32 %40, i32* %j, align 4
259 br label %41
260
261 ; <label>:41                                ; preds = %53, %33
262 %42 = load i32, i32* %j, align 4
263 %43 = load i32, i32* %7, align 4
264 %44 = icmp sle i32 %42, %43
265 br i1 %44, label %45, label %56

```

```
266
267 ; <label>:45 ; preds = %41
268 %46 = load i32, i32* %j, align 4
269 %47 = sext i32 %46 to i64
270 %48 = load i32*, i32** %5, align 8
271 %49 = getelementptr inbounds i32, i32* %48, i64 %47
272 %50 = load i32, i32* %49, align 4
273 %51 = load i32, i32* %tmp, align 4
274 %52 = mul nsw i32 %51, %50
275 store i32 %52, i32* %tmp, align 4
276 br label %53
277
278 ; <label>:53 ; preds = %45
279 %54 = load i32, i32* %j, align 4
280 %55 = add nsw i32 %54, 1
281 store i32 %55, i32* %j, align 4
282 br label %41
283
284 ; <label>:56 ; preds = %41
285 %57 = load i32, i32* %tmp, align 4
286 %58 = load i32, i32* %dynamic_offset, align 4
287 %59 = add nsw i32 %58, %57
288 store i32 %59, i32* %dynamic_offset, align 4
289 br label %60
290
291 ; <label>:60 ; preds = %56
292 %61 = load i32, i32* %i, align 4
293 %62 = add nsw i32 %61, 1
294 store i32 %62, i32* %i, align 4
295 br label %29
296
297 ; <label>:63 ; preds = %29
298 store i32 0, i32* %i1, align 4
299 br label %64
300
301 ; <label>:64 ; preds = %112, %63
302 %65 = load i32, i32* %i1, align 4
303 %66 = load i32, i32* %7, align 4
304 %67 = sext i32 %66 to i64
305 %68 = load i32*, i32** %5, align 8
306 %69 = getelementptr inbounds i32, i32* %68, i64 %67
307 %70 = load i32, i32* %69, align 4
308 %71 = icmp slt i32 %65, %70
309 br i1 %71, label %72, label %115
310
311 ; <label>:72 ; preds = %64
312 %73 = load i32, i32* %static_offset, align 4
313 %74 = load i32, i32* %dynamic_offset, align 4
314 %75 = load i32, i32* %i1, align 4
```

```

315 %76 = add nsw i32 %74, %75
316 %77 = load i32, i32* %7, align 4
317 %78 = add nsw i32 %77, 1
318 %79 = sext i32 %78 to i64
319 %80 = load i32*, i32** %5, align 8
320 %81 = getelementptr inbounds i32, i32* %80, i64 %79
321 %82 = load i32, i32* %81, align 4
322 %83 = add nsw i32 %82, 1
323 %84 = mul nsw i32 %76, %83
324 %85 = add nsw i32 %73, %84
325 store i32 %85, i32* %offset, align 4
326 %86 = load i64*, i64** %1, align 8
327 %87 = load i32, i32* %offset, align 4
328 %88 = sext i32 %87 to i64
329 %89 = getelementptr inbounds i64, i64* %86, i64 %88
330 store i64* %89, i64** %sub, align 8
331 %90 = load i64*, i64** %sub, align 8
332 %91 = ptrtoint i64* %90 to i64
333 %92 = load i32, i32* %2, align 4
334 %93 = add nsw i32 %92, 1
335 %94 = load i32, i32* %i1, align 4
336 %95 = add nsw i32 %93, %94
337 %96 = sext i32 %95 to i64
338 %97 = load i64*, i64** %1, align 8
339 %98 = getelementptr inbounds i64, i64* %97, i64 %96
340 store i64 %91, i64* %98, align 8
341 %99 = load i32, i32* %i1, align 4
342 %100 = load i32, i32* %7, align 4
343 %101 = sext i32 %100 to i64
344 %102 = load i32*, i32** %4, align 8
345 %103 = getelementptr inbounds i32, i32* %102, i64 %101
346 store i32 %99, i32* %103, align 4
347 %104 = load i64*, i64** %1, align 8
348 %105 = load i32, i32* %offset, align 4
349 %106 = load i32*, i32** %3, align 8
350 %107 = load i32*, i32** %4, align 8
351 %108 = load i32*, i32** %5, align 8
352 %109 = load i32, i32* %6, align 4
353 %110 = load i32, i32* %7, align 4
354 %111 = add nsw i32 %110, 1
355 call void @rec_init(i64* %104, i32 %105, i32* %106, i32* %107, i32* %108, i32 %109, i32
    ↪ %111)
356 br label %112
357
358 ; <label>:112                                ; preds = %72
359 %113 = load i32, i32* %i1, align 4
360 %114 = add nsw i32 %113, 1
361 store i32 %114, i32* %i1, align 4
362 br label %64

```

```

363
364 ; <label>:115                                ; preds = %22, %64
365 ret void
366 }
367
368 ; Function Attrs: nounwind uwtable
369 define i64* @init_arr(i32* %dims, i32 %dimc) #0 {
370 %1 = alloca i32*, align 8
371 %2 = alloca i32, align 4
372 %3 = alloca i8*
373 %total = alloca i32, align 4
374 %i = alloca i32, align 4
375 %j = alloca i32, align 4
376 %i1 = alloca i32, align 4
377 %length = alloca i32, align 4
378 %i2 = alloca i32, align 4
379 %tmp = alloca i32, align 4
380 %j3 = alloca i32, align 4
381 %arr = alloca i64*, align 8
382 %i4 = alloca i32, align 4
383 store i32* %dims, i32** %1, align 8
384 store i32 %dimc, i32* %2, align 4
385 %4 = load i32, i32* %2, align 4
386 %5 = zext i32 %4 to i64
387 %6 = call i8* @llvm.stacksave()
388 store i8* %6, i8** %3
389 %7 = alloca i32, i64 %5, align 16
390 store i32 0, i32* %total, align 4
391 store i32 0, i32* %i, align 4
392 br label %8
393
394 ; <label>:8                                    ; preds = %56, %0
395 %9 = load i32, i32* %i, align 4
396 %10 = load i32, i32* %2, align 4
397 %11 = icmp slt i32 %9, %10
398 br i1 %11, label %12, label %59
399
400 ; <label>:12                                    ; preds = %8
401 %13 = load i32, i32* %i, align 4
402 %14 = sext i32 %13 to i64
403 %15 = getelementptr inbounds i32, i32* %7, i64 %14
404 store i32 1, i32* %15, align 4
405 store i32 0, i32* %j, align 4
406 br label %16
407
408 ; <label>:16                                    ; preds = %31, %12
409 %17 = load i32, i32* %j, align 4
410 %18 = load i32, i32* %i, align 4
411 %19 = icmp slt i32 %17, %18

```



```
412 br i1 %19, label %20, label %34
413
414 ; <label>:20                                ; preds = %16
415 %21 = load i32, i32* %j, align 4
416 %22 = sext i32 %21 to i64
417 %23 = load i32*, i32** %1, align 8
418 %24 = getelementptr inbounds i32, i32* %23, i64 %22
419 %25 = load i32, i32* %24, align 4
420 %26 = load i32, i32* %i, align 4
421 %27 = sext i32 %26 to i64
422 %28 = getelementptr inbounds i32, i32* %7, i64 %27
423 %29 = load i32, i32* %28, align 4
424 %30 = mul nsw i32 %29, %25
425 store i32 %30, i32* %28, align 4
426 br label %31
427
428 ; <label>:31                                ; preds = %20
429 %32 = load i32, i32* %j, align 4
430 %33 = add nsw i32 %32, 1
431 store i32 %33, i32* %j, align 4
432 br label %16
433
434 ; <label>:34                                ; preds = %16
435 %35 = load i32, i32* %i, align 4
436 %36 = sext i32 %35 to i64
437 %37 = load i32*, i32** %1, align 8
438 %38 = getelementptr inbounds i32, i32* %37, i64 %36
439 %39 = load i32, i32* %38, align 4
440 %40 = add nsw i32 %39, 1
441 %41 = load i32, i32* %i, align 4
442 %42 = sext i32 %41 to i64
443 %43 = getelementptr inbounds i32, i32* %7, i64 %42
444 %44 = load i32, i32* %43, align 4
445 %45 = mul nsw i32 %44, %40
446 store i32 %45, i32* %43, align 4
447 %46 = load i32, i32* %total, align 4
448 %47 = load i32, i32* %i, align 4
449 %48 = sext i32 %47 to i64
450 %49 = getelementptr inbounds i32, i32* %7, i64 %48
451 %50 = load i32, i32* %49, align 4
452 %51 = add nsw i32 %50, %46
453 store i32 %51, i32* %49, align 4
454 %52 = load i32, i32* %i, align 4
455 %53 = sext i32 %52 to i64
456 %54 = getelementptr inbounds i32, i32* %7, i64 %53
457 %55 = load i32, i32* %54, align 4
458 store i32 %55, i32* %total, align 4
459 br label %56
460
```

```
461 ; <label>:56 ; preds = %34
462 %57 = load i32, i32* %i, align 4
463 %58 = add nsw i32 %57, 1
464 store i32 %58, i32* %i, align 4
465 br label %8
466
467 ; <label>:59 ; preds = %8
468 %60 = load i32, i32* %2, align 4
469 %61 = zext i32 %60 to i64
470 %62 = alloca i32, i64 %61, align 16
471 store i32 0, i32* %i1, align 4
472 br label %63
473
474 ; <label>:63 ; preds = %71, %59
475 %64 = load i32, i32* %i1, align 4
476 %65 = load i32, i32* %2, align 4
477 %66 = icmp slt i32 %64, %65
478 br i1 %66, label %67, label %74
479
480 ; <label>:67 ; preds = %63
481 %68 = load i32, i32* %i1, align 4
482 %69 = sext i32 %68 to i64
483 %70 = getelementptr inbounds i32, i32* %62, i64 %69
484 store i32 0, i32* %70, align 4
485 br label %71
486
487 ; <label>:71 ; preds = %67
488 %72 = load i32, i32* %i1, align 4
489 %73 = add nsw i32 %72, 1
490 store i32 %73, i32* %i1, align 4
491 br label %63
492
493 ; <label>:74 ; preds = %63
494 store i32 0, i32* %length, align 4
495 store i32 0, i32* %i2, align 4
496 br label %75
497
498 ; <label>:75 ; preds = %108, %74
499 %76 = load i32, i32* %i2, align 4
500 %77 = load i32, i32* %2, align 4
501 %78 = icmp slt i32 %76, %77
502 br i1 %78, label %79, label %111
503
504 ; <label>:79 ; preds = %75
505 store i32 1, i32* %tmp, align 4
506 %80 = load i32, i32* %i2, align 4
507 %81 = sub nsw i32 %80, 1
508 store i32 %81, i32* %j3, align 4
509 br label %82
```

```

510
511 ; <label>:82                                ; preds = %93, %79
512 %83 = load i32, i32* %j3, align 4
513 %84 = icmp sge i32 %83, 0
514 br i1 %84, label %85, label %96
515
516 ; <label>:85                                ; preds = %82
517 %86 = load i32, i32* %j3, align 4
518 %87 = sext i32 %86 to i64
519 %88 = load i32*, i32** %1, align 8
520 %89 = getelementptr inbounds i32, i32* %88, i64 %87
521 %90 = load i32, i32* %89, align 4
522 %91 = load i32, i32* %tmp, align 4
523 %92 = mul nsw i32 %91, %90
524 store i32 %92, i32* %tmp, align 4
525 br label %93
526
527 ; <label>:93                                ; preds = %85
528 %94 = load i32, i32* %j3, align 4
529 %95 = add nsw i32 %94, -1
530 store i32 %95, i32* %j3, align 4
531 br label %82
532
533 ; <label>:96                                ; preds = %82
534 %97 = load i32, i32* %i2, align 4
535 %98 = sext i32 %97 to i64
536 %99 = load i32*, i32** %1, align 8
537 %100 = getelementptr inbounds i32, i32* %99, i64 %98
538 %101 = load i32, i32* %100, align 4
539 %102 = add nsw i32 %101, 1
540 %103 = load i32, i32* %tmp, align 4
541 %104 = mul nsw i32 %103, %102
542 store i32 %104, i32* %tmp, align 4
543 %105 = load i32, i32* %tmp, align 4
544 %106 = load i32, i32* %length, align 4
545 %107 = add nsw i32 %106, %105
546 store i32 %107, i32* %length, align 4
547 br label %108
548
549 ; <label>:108                               ; preds = %96
550 %109 = load i32, i32* %i2, align 4
551 %110 = add nsw i32 %109, 1
552 store i32 %110, i32* %i2, align 4
553 br label %75
554
555 ; <label>:111                               ; preds = %75
556 %112 = load i32, i32* %length, align 4
557 %113 = sext i32 %112 to i64
558 %114 = call noalias i8* @bitcast (i8* (i32)* @malloc to i8* (i64*)(i64 %113)) #1

```

```

559 %115 = bitcast i8* %114 to i64*
560 store i64* %115, i64** %arr, align 8
561 store i32 0, i32* %i4, align 4
562 br label %116
563
564 ; <label>:116                                ; preds = %125, %111
565 %117 = load i32, i32* %i4, align 4
566 %118 = load i32, i32* %length, align 4
567 %119 = icmp slt i32 %117, %118
568 br i1 %119, label %120, label %128
569
570 ; <label>:120                                ; preds = %116
571 %121 = load i32, i32* %i4, align 4
572 %122 = sext i32 %121 to i64
573 %123 = load i64*, i64** %arr, align 8
574 %124 = getelementptr inbounds i64, i64* %123, i64 %122
575 store i64 0, i64* %124, align 8
576 br label %125
577
578 ; <label>:125                                ; preds = %120
579 %126 = load i32, i32* %i4, align 4
580 %127 = add nsw i32 %126, 1
581 store i32 %127, i32* %i4, align 4
582 br label %116
583
584 ; <label>:128                                ; preds = %116
585 %129 = load i64*, i64** %arr, align 8
586 %130 = load i32*, i32** %1, align 8
587 %131 = load i32, i32* %2, align 4
588 call void @rec_init(i64* %129, i32 0, i32* %7, i32* %62, i32* %130, i32 %131, i32 0)
589 %132 = load i64*, i64** %arr, align 8
590 %133 = load i8*, i8** %3
591 call void @llvm.stackrestore(i8* %133)
592 ret i64* %132
593 }
594
595 ; Function Attrs: nounwind
596 declare i8* @llvm.stacksave() #1
597
598 ; Function Attrs: nounwind
599 declare void @llvm.stackrestore(i8*) #1
600
601 attributes #0 = { nounwind uwtable "disable-tail-calls"="false"
  ↳ "less-precise-fpmad"="false" "no-frame-pointer-elim"="true"
  ↳ "no-frame-pointer-elim-non-leaf" "no-infs-fp-math"="false" "no-nans-fp-math"="false"
  ↳ "stack-protector-buffer-size"="8" "target-cpu"="x86-64"
  ↳ "target-features"="+sse,+sse2" "unsafe-fp-math"="false" "use-soft-float"="false" }
602 attributes #1 = { nounwind }
603

```

```
604  !llvm.ident = !{!0}
605
606  !0 = !{"Ubuntu clang version 3.7.0-2ubuntu1 (tags/RELEASE_370/final) (based on LLVM
↪    3.7.0)"}
```

For Loop Test

The following test is the first of several for loop checks. This one ensures that the correct amount of iterations are complete for the specified block within the curly braces:

test-for1.dice

```
1      class test {
2          public void main(char[] [] args) {
3              int i;
4              for (i = 0 ; i < 5 ; i = i + 1) {
5                  print(i);
6              }
7              print(42);
8          }
9      }
```

test-for1.ll

```
1      ; ModuleID = 'Dice Codegen'
2      target datalayout = "e-m:e-i64:64-f80:128-n8:16:32:64-S128"
3      target triple = "x86_64-pc-linux-gnu"
4
5      %test = type <{ i32 }>
6
7      @tmp = private unnamed_addr constant [3 x i8] c"%d\00"
8      @tmp.1 = private unnamed_addr constant [3 x i8] c"%d\00"
9
10     declare i32 @printf(i8*, ...)
11
12     declare noalias i8* @malloc(i32)
13
14     declare i32 @open(i8*, i32)
15
16     declare i32 @close(i32)
17
18     declare i32 @read(i32, i8*, i32)
19
20     declare i32 @write(i32, i8*, i32)
21
22     declare i32 @lseek(i32, i32, i32)
23
24     declare void @exit(i32)
25
26     declare i8* @realloc(i8*, i32)
27
28     declare i32 @getchar()
29
30     define i64* @lookup(i32 %c_index, i32 %f_index) {
31     entry:
```

```

32     %tmp = alloca i64**
33     %tmp1 = alloca i64*, i32 0
34     %tmp2 = getelementptr i64**, i64*** %tmp, i32 0
35     store i64** %tmp1, i64*** %tmp2
36     ret i64* null
37 }
38
39 define %test* @test.constructor() {
40 entry:
41     %this = alloca %test
42     %tmp = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to i32))
43     %tmp1 = bitcast i8* %tmp to %test*
44     %tmp2 = load %test, %test* %tmp1
45     store %test %tmp2, %test* %this
46     %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
47     store i32 0, i32* %.key
48     ret %test* %this
49 }
50
51 define i32 @main(i32 %argc, i8** %argv) {
52 entry:
53     %arr_size = add i32 %argc, 1
54     %mallocsize = mul i32 %arr_size, ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to
55     ↪ i32)
56     %malloccall = tail call i8* @malloc(i32 %mallocsize)
57     %args = bitcast i8* %malloccall to i8***
58     %args1 = bitcast i8*** %args to i8**
59     %argc_len = bitcast i8** %args1 to i32*
60     store i32 %argc, i32* %argc_len
61     br label %args.cond
62
63 args.cond:                                     ; preds = %args.init, %entry
64     %counter = phi i32 [ 0, %entry ], [ %tmp, %args.init ]
65     %tmp = add i32 %counter, 1
66     %tmp2 = icmp slt i32 %counter, %argc
67     br i1 %tmp2, label %args.init, label %args.done
68
69 args.init:                                     ; preds = %args.cond
70     %tmp3 = getelementptr i8*, i8** %arr_1, i32 %counter
71     %tmp4 = getelementptr i8*, i8** %argv, i32 %counter
72     %tmp5 = load i8*, i8** %tmp4
73     store i8* %tmp5, i8** %tmp3
74     br label %args.cond
75
76 args.done:                                     ; preds = %args.cond
77     %this = alloca %test
78     %tmp6 = call i8* @malloc(i32 ptrtoint (i1** getelementptr (i1*, i1** null, i32 1) to
79     ↪ i32))

```

```

79 %tmp7 = bitcast i8* %tmp6 to %test*
80 %tmp8 = load %test, %test* %tmp7
81 store %test %tmp8, %test* %this
82 %.key = getelementptr inbounds %test, %test* %this, i32 0, i32 0
83 store i32 0, i32* %.key
84 %i = alloca i32
85 store i32 0, i32* %i
86 br label %cond
87
88 loop:                                     ; preds = %cond
89 %i9 = load i32, i32* %i
90 %tmp10 = call i32 @i8*, ... @printf(i8* getelementptr inbounds ([3 x i8], [3 x i8]*
    ↪ @tmp, i32 0, i32 0), i32 %i9)
91 br label %inc
92
93 inc:                                     ; preds = %loop
94 %i11 = load i32, i32* %i
95 %addtmp = add i32 %i11, 1
96 store i32 %addtmp, i32* %i
97 br label %cond
98
99 cond:                                   ; preds = %inc, %args.done
100 %i12 = load i32, i32* %i
101 %lesstmp = icmp slt i32 %i12, 5
102 br i1 %lesstmp, label %loop, label %afterloop
103
104 afterloop:                             ; preds = %cond
105 %tmp13 = call i32 @i8*, ... @printf(i8* getelementptr inbounds ([3 x i8], [3 x i8]*
    ↪ @tmp.1, i32 0, i32 0), i32 42)
106 ret i32 0
107 }
108
109 ; Function Attrs: nounwind uwtable
110 define i8* @input() #0 {
111     %initial_size = alloca i32, align 4
112     %str = alloca i8*, align 8
113     %index = alloca i32, align 4
114     %tmp = alloca i8, align 1
115     store i32 100, i32* %initial_size, align 4
116     %1 = load i32, i32* %initial_size, align 4
117     %2 = sext i32 %1 to i64
118     %3 = call noalias i8* bitcast (i8* (i32)* @malloc to i8* (i64)*) (i64 %2) #1
119     store i8* %3, i8** %str, align 8
120     store i32 0, i32* %index, align 4
121     store i8 48, i8* %tmp, align 1
122     br label %4
123
124     ; <label>:4                               ; preds = %20, %0
125     %5 = call i32 @getchar()

```



```

126     %6 = trunc i32 %5 to i8
127     store i8 %6, i8* %tmp, align 1
128     %7 = sext i8 %6 to i32
129     %8 = icmp ne i32 %7, 10
130     br i1 %8, label %9, label %27
131
132     ; <label>:9                                ; preds = %4
133     %10 = load i32, i32* %index, align 4
134     %11 = load i32, i32* %initial_size, align 4
135     %12 = sub nsw i32 %11, 1
136     %13 = icmp sge i32 %10, %12
137     br i1 %13, label %14, label %20
138
139     ; <label>:14                                ; preds = %9
140     %15 = load i8*, i8** %str, align 8
141     %16 = load i32, i32* %initial_size, align 4
142     %17 = mul nsw i32 %16, 2
143     store i32 %17, i32* %initial_size, align 4
144     %18 = sext i32 %17 to i64
145     %19 = call i8* @bitcast (i8* (i8*, i32)* @realloc to i8* (i8*, i64)*) (i8* %15, i64
        ↪ %18) #1
146     store i8* %19, i8** %str, align 8
147     br label %20
148
149     ; <label>:20                                ; preds = %14, %9
150     %21 = load i8, i8* %tmp, align 1
151     %22 = load i32, i32* %index, align 4
152     %23 = add nsw i32 %22, 1
153     store i32 %23, i32* %index, align 4
154     %24 = sext i32 %22 to i64
155     %25 = load i8*, i8** %str, align 8
156     %26 = getelementptr inbounds i8, i8* %25, i64 %24
157     store i8 %21, i8* %26, align 1
158     br label %4
159
160     ; <label>:27                                ; preds = %4
161     %28 = load i32, i32* %index, align 4
162     %29 = sext i32 %28 to i64
163     %30 = load i8*, i8** %str, align 8
164     %31 = getelementptr inbounds i8, i8* %30, i64 %29
165     store i8 0, i8* %31, align 1
166     %32 = load i8*, i8** %str, align 8
167     ret i8* %32
168 }
169
170 ; Function Attrs: nounwind uwtable
171 define void @rec_init(i64* %arr, i32 %curr_offset, i32* %static_offsets, i32* %indexes,
        ↪ i32* %dims, i32 %dimc, i32 %dim_curr) #0 {
172 %1 = alloca i64*, align 8

```

```

173 %2 = alloca i32, align 4
174 %3 = alloca i32*, align 8
175 %4 = alloca i32*, align 8
176 %5 = alloca i32*, align 8
177 %6 = alloca i32, align 4
178 %7 = alloca i32, align 4
179 %static_offset = alloca i32, align 4
180 %dynamic_offset = alloca i32, align 4
181 %i = alloca i32, align 4
182 %tmp = alloca i32, align 4
183 %j = alloca i32, align 4
184 %i1 = alloca i32, align 4
185 %offset = alloca i32, align 4
186 %sub = alloca i64*, align 8
187 store i64* %arr, i64** %1, align 8
188 store i32 %curr_offset, i32* %2, align 4
189 store i32* %static_offsets, i32** %3, align 8
190 store i32* %indexes, i32** %4, align 8
191 store i32* %dims, i32** %5, align 8
192 store i32 %dimc, i32* %6, align 4
193 store i32 %dim_curr, i32* %7, align 4
194 %8 = load i32, i32* %7, align 4
195 %9 = sext i32 %8 to i64
196 %10 = load i32*, i32** %5, align 8
197 %11 = getelementptr inbounds i32, i32* %10, i64 %9
198 %12 = load i32, i32* %11, align 4
199 %13 = sext i32 %12 to i64
200 %14 = load i32, i32* %2, align 4
201 %15 = sext i32 %14 to i64
202 %16 = load i64*, i64** %1, align 8
203 %17 = getelementptr inbounds i64, i64* %16, i64 %15
204 store i64 %13, i64* %17, align 8
205 %18 = load i32, i32* %7, align 4
206 %19 = add nsw i32 %18, 1
207 %20 = load i32, i32* %6, align 4
208 %21 = icmp sge i32 %19, %20
209 br i1 %21, label %22, label %23
210
211 ; <label>:22                                ; preds = %0
212 br label %115
213
214 ; <label>:23                                ; preds = %0
215 %24 = load i32, i32* %7, align 4
216 %25 = sext i32 %24 to i64
217 %26 = load i32*, i32** %3, align 8
218 %27 = getelementptr inbounds i32, i32* %26, i64 %25
219 %28 = load i32, i32* %27, align 4
220 store i32 %28, i32* %static_offset, align 4
221 store i32 0, i32* %dynamic_offset, align 4

```

```
222 store i32 0, i32* %i, align 4
223 br label %29
224
225 ; <label>:29                                ; preds = %60, %23
226 %30 = load i32, i32* %i, align 4
227 %31 = load i32, i32* %7, align 4
228 %32 = icmp slt i32 %30, %31
229 br i1 %32, label %33, label %63
230
231 ; <label>:33                                ; preds = %29
232 %34 = load i32, i32* %i, align 4
233 %35 = sext i32 %34 to i64
234 %36 = load i32*, i32** %4, align 8
235 %37 = getelementptr inbounds i32, i32* %36, i64 %35
236 %38 = load i32, i32* %37, align 4
237 store i32 %38, i32* %tmp, align 4
238 %39 = load i32, i32* %i, align 4
239 %40 = add nsw i32 %39, 1
240 store i32 %40, i32* %j, align 4
241 br label %41
242
243 ; <label>:41                                ; preds = %53, %33
244 %42 = load i32, i32* %j, align 4
245 %43 = load i32, i32* %7, align 4
246 %44 = icmp sle i32 %42, %43
247 br i1 %44, label %45, label %56
248
249 ; <label>:45                                ; preds = %41
250 %46 = load i32, i32* %j, align 4
251 %47 = sext i32 %46 to i64
252 %48 = load i32*, i32** %5, align 8
253 %49 = getelementptr inbounds i32, i32* %48, i64 %47
254 %50 = load i32, i32* %49, align 4
255 %51 = load i32, i32* %tmp, align 4
256 %52 = mul nsw i32 %51, %50
257 store i32 %52, i32* %tmp, align 4
258 br label %53
259
260 ; <label>:53                                ; preds = %45
261 %54 = load i32, i32* %j, align 4
262 %55 = add nsw i32 %54, 1
263 store i32 %55, i32* %j, align 4
264 br label %41
265
266 ; <label>:56                                ; preds = %41
267 %57 = load i32, i32* %tmp, align 4
268 %58 = load i32, i32* %dynamic_offset, align 4
269 %59 = add nsw i32 %58, %57
270 store i32 %59, i32* %dynamic_offset, align 4
```

```
271 br label %60
272
273 ; <label>:60                                ; preds = %56
274 %61 = load i32, i32* %i, align 4
275 %62 = add nsw i32 %61, 1
276 store i32 %62, i32* %i, align 4
277 br label %29
278
279 ; <label>:63                                ; preds = %29
280 store i32 0, i32* %i1, align 4
281 br label %64
282
283 ; <label>:64                                ; preds = %112, %63
284 %65 = load i32, i32* %i1, align 4
285 %66 = load i32, i32* %7, align 4
286 %67 = sext i32 %66 to i64
287 %68 = load i32*, i32** %5, align 8
288 %69 = getelementptr inbounds i32, i32* %68, i64 %67
289 %70 = load i32, i32* %69, align 4
290 %71 = icmp slt i32 %65, %70
291 br i1 %71, label %72, label %115
292
293 ; <label>:72                                ; preds = %64
294 %73 = load i32, i32* %static_offset, align 4
295 %74 = load i32, i32* %dynamic_offset, align 4
296 %75 = load i32, i32* %i1, align 4
297 %76 = add nsw i32 %74, %75
298 %77 = load i32, i32* %7, align 4
299 %78 = add nsw i32 %77, 1
300 %79 = sext i32 %78 to i64
301 %80 = load i32*, i32** %5, align 8
302 %81 = getelementptr inbounds i32, i32* %80, i64 %79
303 %82 = load i32, i32* %81, align 4
304 %83 = add nsw i32 %82, 1
305 %84 = mul nsw i32 %76, %83
306 %85 = add nsw i32 %73, %84
307 store i32 %85, i32* %offset, align 4
308 %86 = load i64*, i64** %1, align 8
309 %87 = load i32, i32* %offset, align 4
310 %88 = sext i32 %87 to i64
311 %89 = getelementptr inbounds i64, i64* %86, i64 %88
312 store i64* %89, i64** %sub, align 8
313 %90 = load i64*, i64** %sub, align 8
314 %91 = ptrtoint i64* %90 to i64
315 %92 = load i32, i32* %2, align 4
316 %93 = add nsw i32 %92, 1
317 %94 = load i32, i32* %i1, align 4
318 %95 = add nsw i32 %93, %94
319 %96 = sext i32 %95 to i64
```

```

320 %97 = load i64*, i64** %1, align 8
321 %98 = getelementptr inbounds i64, i64* %97, i64 %96
322 store i64 %91, i64* %98, align 8
323 %99 = load i32, i32* %i1, align 4
324 %100 = load i32, i32* %7, align 4
325 %101 = sext i32 %100 to i64
326 %102 = load i32*, i32** %4, align 8
327 %103 = getelementptr inbounds i32, i32* %102, i64 %101
328 store i32 %99, i32* %103, align 4
329 %104 = load i64*, i64** %1, align 8
330 %105 = load i32, i32* %offset, align 4
331 %106 = load i32*, i32** %3, align 8
332 %107 = load i32*, i32** %4, align 8
333 %108 = load i32*, i32** %5, align 8
334 %109 = load i32, i32* %6, align 4
335 %110 = load i32, i32* %7, align 4
336 %111 = add nsw i32 %110, 1
337 call void @rec_init(i64* %104, i32 %105, i32* %106, i32* %107, i32* %108, i32 %109, i32
    ↪ %111)
338 br label %112
339
340 ; <label>:112                                ; preds = %72
341 %113 = load i32, i32* %i1, align 4
342 %114 = add nsw i32 %113, 1
343 store i32 %114, i32* %i1, align 4
344 br label %64
345
346 ; <label>:115                                ; preds = %22, %64
347 ret void
348 }
349
350 ; Function Attrs: nounwind uwtable
351 define i64* @init_arr(i32* %dims, i32 %dimc) #0 {
352 %1 = alloca i32*, align 8
353 %2 = alloca i32, align 4
354 %3 = alloca i8*
355 %total = alloca i32, align 4
356 %i = alloca i32, align 4
357 %j = alloca i32, align 4
358 %i1 = alloca i32, align 4
359 %length = alloca i32, align 4
360 %i2 = alloca i32, align 4
361 %tmp = alloca i32, align 4
362 %j3 = alloca i32, align 4
363 %arr = alloca i64*, align 8
364 %i4 = alloca i32, align 4
365 store i32* %dims, i32** %1, align 8
366 store i32 %dimc, i32* %2, align 4
367 %4 = load i32, i32* %2, align 4

```

```

368 %5 = zext i32 %4 to i64
369 %6 = call i8* @llvm.stacksave()
370 store i8* %6, i8** %3
371 %7 = alloca i32, i64 %5, align 16
372 store i32 0, i32* %total, align 4
373 store i32 0, i32* %i, align 4
374 br label %8
375
376 ; <label>:8                                ; preds = %56, %0
377 %9 = load i32, i32* %i, align 4
378 %10 = load i32, i32* %2, align 4
379 %11 = icmp slt i32 %9, %10
380 br i1 %11, label %12, label %59
381
382 ; <label>:12                                ; preds = %8
383 %13 = load i32, i32* %i, align 4
384 %14 = sext i32 %13 to i64
385 %15 = getelementptr inbounds i32, i32* %7, i64 %14
386 store i32 1, i32* %15, align 4
387 store i32 0, i32* %j, align 4
388 br label %16
389
390 ; <label>:16                                ; preds = %31, %12
391 %17 = load i32, i32* %j, align 4
392 %18 = load i32, i32* %i, align 4
393 %19 = icmp slt i32 %17, %18
394 br i1 %19, label %20, label %34
395
396 ; <label>:20                                ; preds = %16
397 %21 = load i32, i32* %j, align 4
398 %22 = sext i32 %21 to i64
399 %23 = load i32*, i32** %1, align 8
400 %24 = getelementptr inbounds i32, i32* %23, i64 %22
401 %25 = load i32, i32* %24, align 4
402 %26 = load i32, i32* %i, align 4
403 %27 = sext i32 %26 to i64
404 %28 = getelementptr inbounds i32, i32* %7, i64 %27
405 %29 = load i32, i32* %28, align 4
406 %30 = mul nsw i32 %29, %25
407 store i32 %30, i32* %28, align 4
408 br label %31
409
410 ; <label>:31                                ; preds = %20
411 %32 = load i32, i32* %j, align 4
412 %33 = add nsw i32 %32, 1
413 store i32 %33, i32* %j, align 4
414 br label %16
415
416 ; <label>:34                                ; preds = %16

```

```

417 %35 = load i32, i32* %i, align 4
418 %36 = sext i32 %35 to i64
419 %37 = load i32*, i32** %1, align 8
420 %38 = getelementptr inbounds i32, i32* %37, i64 %36
421 %39 = load i32, i32* %38, align 4
422 %40 = add nsw i32 %39, 1
423 %41 = load i32, i32* %i, align 4
424 %42 = sext i32 %41 to i64
425 %43 = getelementptr inbounds i32, i32* %7, i64 %42
426 %44 = load i32, i32* %43, align 4
427 %45 = mul nsw i32 %44, %40
428 store i32 %45, i32* %43, align 4
429 %46 = load i32, i32* %total, align 4
430 %47 = load i32, i32* %i, align 4
431 %48 = sext i32 %47 to i64
432 %49 = getelementptr inbounds i32, i32* %7, i64 %48
433 %50 = load i32, i32* %49, align 4
434 %51 = add nsw i32 %50, %46
435 store i32 %51, i32* %49, align 4
436 %52 = load i32, i32* %i, align 4
437 %53 = sext i32 %52 to i64
438 %54 = getelementptr inbounds i32, i32* %7, i64 %53
439 %55 = load i32, i32* %54, align 4
440 store i32 %55, i32* %total, align 4
441 br label %56
442
443 ; <label>:56                                ; preds = %34
444 %57 = load i32, i32* %i, align 4
445 %58 = add nsw i32 %57, 1
446 store i32 %58, i32* %i, align 4
447 br label %8
448
449 ; <label>:59                                ; preds = %8
450 %60 = load i32, i32* %2, align 4
451 %61 = zext i32 %60 to i64
452 %62 = alloca i32, i64 %61, align 16
453 store i32 0, i32* %i1, align 4
454 br label %63
455
456 ; <label>:63                                ; preds = %71, %59
457 %64 = load i32, i32* %i1, align 4
458 %65 = load i32, i32* %2, align 4
459 %66 = icmp slt i32 %64, %65
460 br i1 %66, label %67, label %74
461
462 ; <label>:67                                ; preds = %63
463 %68 = load i32, i32* %i1, align 4
464 %69 = sext i32 %68 to i64
465 %70 = getelementptr inbounds i32, i32* %62, i64 %69

```

```

466 store i32 0, i32* %70, align 4
467 br label %71
468
469 ; <label>:71                                ; preds = %67
470 %72 = load i32, i32* %i1, align 4
471 %73 = add nsw i32 %72, 1
472 store i32 %73, i32* %i1, align 4
473 br label %63
474
475 ; <label>:74                                ; preds = %63
476 store i32 0, i32* %length, align 4
477 store i32 0, i32* %i2, align 4
478 br label %75
479
480 ; <label>:75                                ; preds = %108, %74
481 %76 = load i32, i32* %i2, align 4
482 %77 = load i32, i32* %2, align 4
483 %78 = icmp slt i32 %76, %77
484 br i1 %78, label %79, label %111
485
486 ; <label>:79                                ; preds = %75
487 store i32 1, i32* %tmp, align 4
488 %80 = load i32, i32* %i2, align 4
489 %81 = sub nsw i32 %80, 1
490 store i32 %81, i32* %j3, align 4
491 br label %82
492
493 ; <label>:82                                ; preds = %93, %79
494 %83 = load i32, i32* %j3, align 4
495 %84 = icmp sge i32 %83, 0
496 br i1 %84, label %85, label %96
497
498 ; <label>:85                                ; preds = %82
499 %86 = load i32, i32* %j3, align 4
500 %87 = sext i32 %86 to i64
501 %88 = load i32*, i32** %1, align 8
502 %89 = getelementptr inbounds i32, i32* %88, i64 %87
503 %90 = load i32, i32* %89, align 4
504 %91 = load i32, i32* %tmp, align 4
505 %92 = mul nsw i32 %91, %90
506 store i32 %92, i32* %tmp, align 4
507 br label %93
508
509 ; <label>:93                                ; preds = %85
510 %94 = load i32, i32* %j3, align 4
511 %95 = add nsw i32 %94, -1
512 store i32 %95, i32* %j3, align 4
513 br label %82
514

```



```

515 ; <label>:96                                ; preds = %82
516 %97 = load i32, i32* %i2, align 4
517 %98 = sext i32 %97 to i64
518 %99 = load i32*, i32** %1, align 8
519 %100 = getelementptr inbounds i32, i32* %99, i64 %98
520 %101 = load i32, i32* %100, align 4
521 %102 = add nsw i32 %101, 1
522 %103 = load i32, i32* %tmp, align 4
523 %104 = mul nsw i32 %103, %102
524 store i32 %104, i32* %tmp, align 4
525 %105 = load i32, i32* %tmp, align 4
526 %106 = load i32, i32* %length, align 4
527 %107 = add nsw i32 %106, %105
528 store i32 %107, i32* %length, align 4
529 br label %108
530
531 ; <label>:108                                ; preds = %96
532 %109 = load i32, i32* %i2, align 4
533 %110 = add nsw i32 %109, 1
534 store i32 %110, i32* %i2, align 4
535 br label %75
536
537 ; <label>:111                                ; preds = %75
538 %112 = load i32, i32* %length, align 4
539 %113 = sext i32 %112 to i64
540 %114 = call noalias i8* @bitcast (i8* (i32)* @malloc to i8* (i64*)) (i64 %113) #1
541 %115 = bitcast i8* %114 to i64*
542 store i64* %115, i64** %arr, align 8
543 store i32 0, i32* %i4, align 4
544 br label %116
545
546 ; <label>:116                                ; preds = %125, %111
547 %117 = load i32, i32* %i4, align 4
548 %118 = load i32, i32* %length, align 4
549 %119 = icmp slt i32 %117, %118
550 br i1 %119, label %120, label %128
551
552 ; <label>:120                                ; preds = %116
553 %121 = load i32, i32* %i4, align 4
554 %122 = sext i32 %121 to i64
555 %123 = load i64*, i64** %arr, align 8
556 %124 = getelementptr inbounds i64, i64* %123, i64 %122
557 store i64 0, i64* %124, align 8
558 br label %125
559
560 ; <label>:125                                ; preds = %120
561 %126 = load i32, i32* %i4, align 4
562 %127 = add nsw i32 %126, 1
563 store i32 %127, i32* %i4, align 4

```

```
564 br label %116
565
566 ; <label>:128                                ; preds = %116
567 %129 = load i64*, i64** %arr, align 8
568 %130 = load i32*, i32** %1, align 8
569 %131 = load i32, i32* %2, align 4
570 call void @rec_init(i64* %129, i32 0, i32* %7, i32* %62, i32* %130, i32 %131, i32 0)
571 %132 = load i64*, i64** %arr, align 8
572 %133 = load i8*, i8** %3
573 call void @llvm.stackrestore(i8* %133)
574 ret i64* %132
575 }
576
577 ; Function Attrs: nounwind
578 declare i8* @llvm.stacksave() #1
579
580 ; Function Attrs: nounwind
581 declare void @llvm.stackrestore(i8*) #1
582
583 attributes #0 = { nounwind uwtable "disable-tail-calls"="false"
  ↳ "less-precise-fpmad"="false" "no-frame-pointer-elim"="true"
  ↳ "no-frame-pointer-elim-non-leaf" "no-infs-fp-math"="false" "no-nans-fp-math"="false"
  ↳ "stack-protector-buffer-size"="8" "target-cpu"="x86-64"
  ↳ "target-features"="+sse,+sse2" "unsafe-fp-math"="false" "use-soft-float"="false" }
584 attributes #1 = { nounwind }
585
586 !llvm.ident = !{!0}
587
588 !0 = !{"Ubuntu clang version 3.7.0-2ubuntu1 (tags/RELEASE_370/final) (based on LLVM
  ↳ 3.7.0)"}

```

7. LESSONS LEARNED

David

Most critically I learned that if you want to make something good, put as much effort as physically possible into it. I was told frequently "get started early" with respect to this project. After starting early I also learned that working often and with purpose helped not only myself get through the project but also the rest of my team.

As project manager the most critical decision I made was to gain consensus on the development environment that each team member was using. My main takeaway was to make sure that everyone agrees to use the same tools and systems. Having incompatible hardware/software can create unnecessary tension in what is already a stressful situation.

One final note is that I really did not know what to expect from OCaml coming into this class. It seemed very mysterious at first, but after looking through previous examples of compilers from other groups and writing out the Analyzer for my language, I quickly grew to enjoy the language. It certainly was not as daunting as it seemed at first.

Emily

Khaled

Read the lessons learned from previous projects and prioritize (with your group) which of them you will implement. You will not be able to do them all, but if you can agree as a group on which mistakes you can avoid, you're already ahead. For our group, we determined that we will ACTUALLY start early, which we did.

Fortunately, we had a very organized and decisive manager that made sure we were all on track throughout the semester. Make sure you nominate a person with same qualities if you don't want to spend the last week of the semester pulling all-nighters for this project (save that for your other exams).

Track tasks with Github's issue tracking. Keep this issue tracker open during meetings with the Professor/TAs in order to avoid forgetting discussed to-do items. Ensure the manager of the group delegates through this system.

To spare your team members pain, don't use the diff command's output in your test script. Just label the program's output and your expected output and place them on top of each other for easy reading.

Phillip

8. CODE LISTING

`_tags`

```
1 <filepath.*> or <*/*.native> or <*/*.byte>: package(unix)
```

analyzer.ml

```
1  open Sast
2  open Ast
3  open Processor
4  open Utils
5  open Filepath
6  open Conf
7
8  module StringMap = Map.Make (String)
9
10 module StringSet = Set.Make (String)
11
12 let struct_indexes:(string, int) Hashtbl.t = Hashtbl.create 10
13 let predecessors:(string, string list) Hashtbl.t = Hashtbl.create 10
14
15 module SS = Set.Make(
16   struct
17   let compare = Pervasives.compare
18   type t = datatype
19   end )
20
21 type class_map = {
22   field_map      : Ast.field StringMap.t;
23   func_map       : Ast.func_decl StringMap.t;
24   constructor_map : Ast.func_decl StringMap.t;
25   reserved_map   : sfunc_decl StringMap.t;
26   cdecl          : Ast.class_decl;
27 }
28
29 type env = {
30   env_class_maps: class_map StringMap.t;
31   env_name      : string;
32   env_cmap      : class_map;
33   env_locals    : datatype StringMap.t;
34   env_parameters: Ast.formal StringMap.t;
35   env_returnType: datatype;
36   env_in_for    : bool;
37   env_in_while  : bool;
38   env_reserved  : sfunc_decl list;
39 }
40
41 let update_env_name env env_name =
42 {
43   env_class_maps = env.env_class_maps;
44   env_name       = env_name;
45   env_cmap       = env.env_cmap;
46   env_locals     = env.env_locals;
47   env_parameters = env.env_parameters;
```

```

48     env_returnType = env.env_returnType;
49     env_in_for      = env.env_in_for;
50     env_in_while    = env.env_in_while;
51     env_reserved    = env.env_reserved;
52 }
53
54 let update_call_stack env in_for in_while =
55 {
56     env_class_maps = env.env_class_maps;
57     env_name       = env.env_name;
58     env_cmap       = env.env_cmap;
59     env_locals     = env.env_locals;
60     env_parameters = env.env_parameters;
61     env_returnType = env.env_returnType;
62     env_in_for     = in_for;
63     env_in_while   = in_while;
64     env_reserved   = env.env_reserved;
65 }
66
67 let append_code_to_constructor fbody cname ret_type =
68 let key = Hashtbl.find struct_indexes cname in
69 let init_this = [SLocal(
70 ret_type,
71 "this",
72 SCall(      "cast",
73 [SCall("malloc",
74 [
75 SCall("sizeof", [SId("ignore", ret_type)], Datatype(Int_t), 0)
76 ],
77 Arraytype(Char_t, 1), 0)
78 ],
79 ret_type,
80 0
81 )
82 );
83 SExpr(
84 SAssign(
85 SObjAccess(
86 SId("this", ret_type),
87 SId(".key", Datatype(Int_t)),
88 Datatype(Int_t)
89 ),
90 SInt_Lit(key),
91 Datatype(Int_t)
92 ),
93 Datatype(Int_t)
94 )
95 ]
96 in

```

```

97 let ret_this =
98 [
99 SReturn(
100 SId("this", ret_type),
101 ret_type
102 )
103 ]
104 in
105 (* Need to check for duplicate default constructs *)
106 (* Also need to add malloc around other constructors *)
107 init_this @ fbody @ ret_this
108
109 let default_constructor_body cname =
110 let ret_type = Datatype(Objecttype(cname)) in
111 let fbody = [] in
112 append_code_to_constructor fbody cname ret_type
113
114 let default_sc cname =
115 {
116     sfname                = Ast.FName (cname ^ "." ^ "constructor");
117     sreturnType           = Datatype(Objecttype(cname));
118     sformals              = [];
119     sbody                 = default_constructor_body cname;
120     func_type             = Sast.User;
121     overrides             = false;
122     source                = "NA";
123 }
124
125 let default_c cname =
126 {
127     scope                 = Ast.Public;
128     fname                 = Ast.Constructor;
129     returnType            = Datatype(ConstructorType);
130     formals               = [];
131     body                  = [];
132     overrides             = false;
133     root_cname            = None;
134 }
135
136 let process_includes filename includes classes =
137 (* Bring in each include *)
138 let processInclude include_statement =
139 let file_in = open_in include_statement in
140 let lexbuf = Lexing.from_channel file_in in
141 let token_list = Processor.build_token_list lexbuf in
142 let program = Processor.parser include_statement token_list in
143 ignore(close_in file_in);
144 program
145 in

```

```

146 let rec iterate_includes classes m = function
147 [] -> classes
148 | (Include h) :: t ->
149 let h = if h = "stdlib" then Conf.stdlib_path else h in
150 (* Check each include against the map *)
151 let realpath = Filepath.realpath h in
152 if StringMap.mem realpath m then
153 iterate_includes (classes) (m) (t)
154 else
155 let result = processInclude realpath in
156 match result with Program(i,c) ->
157 iterate_includes (classes @ c) (StringMap.add realpath 1 m) (i @ t)
158 in
159 iterate_includes classes (StringMap.add (Filepath.realpath filename) 1 StringMap.empty)
  ↪ includes
160
161 let get_name cname fdecl =
162 (* We use '.' to separate types so llvm will recognize the function name and it won't
  ↪ conflict *)
163 (* let params = List.fold_left (fun s -> (function Formal(t, _) -> s ^ "." ^
  ↪ Utils.string_of_datatype t | _ -> "" )) "" fdecl.formals in *)
164 let name = Utils.string_of_fname fdecl.fname in
165 if name = "main"
166 then "main"
167 else cname ^ "." ^ name(* ^ params *)
168
169 let get_constructor_name cname fdecl =
170 let params = List.fold_left (fun s -> (function Formal(t, _) -> s ^ "." ^
  ↪ Utils.string_of_datatype t | _ -> "" )) "" fdecl.formals in
171 let name = Utils.string_of_fname fdecl.fname in
172 cname ^ "." ^ name ^ params
173
174 let get_name_without_class fdecl =
175 (* We use '.' to separate types so llvm will recognize the function name and it won't
  ↪ conflict *)
176 let params = List.fold_left (fun s -> (function Formal(t, _) -> s ^ "." ^
  ↪ Utils.string_of_datatype t | _ -> "" )) "" fdecl.formals in
177 let name = Utils.string_of_fname fdecl.fname in
178 let ret_type = Utils.string_of_datatype fdecl.returnType in
179 ret_type ^ "." ^ name ^ "." ^ params
180
181 (* Generate list of all classes to be used for semantic checking *)
182 let build_class_maps reserved cdecls =
183 let reserved_map = List.fold_left (fun m f -> StringMap.add (Utils.string_of_fname
  ↪ f.sfname) f m) StringMap.empty reserved in
184 let helper m (cdecl:Ast.class_decl) =
185 let fieldfun = (fun m -> (function Field(s, d, n) -> if (StringMap.mem (n) m) then
  ↪ raise(Exceptions.DuplicateField) else (StringMap.add n (Field(s, d, n)) m))) in
186 let funcname = get_name cdecl.cname in

```



```

187 let funcfun m fdecl =
188   if (StringMap.mem (funcname fdecl) m)
189   then raise(Exceptions.DuplicateFunction(funcname fdecl))
190   else if (StringMap.mem (Utils.string_of_fname fdecl.fname) reserved_map)
191   then raise(Exceptions.CannotUseReservedFuncName(Utils.string_of_fname fdecl.fname))
192   else (StringMap.add (funcname fdecl) fdecl m)
193   in
194   let constructor_name = get_constructor_name cdecl.cname in
195   let constructorfun m fdecl =
196     if fdecl.formals = [] then m
197     else if StringMap.mem (constructor_name fdecl) m
198     then raise(Exceptions.DuplicateConstructor)
199     else (StringMap.add (constructor_name fdecl) fdecl m)
200     in
201     let default_c = default_c cdecl.cname in
202     let constructor_map = StringMap.add (get_constructor_name cdecl.cname default_c)
203       ↪ default_c StringMap.empty in
204     (if (StringMap.mem cdecl.cname m) then raise (Exceptions.DuplicateClassName(cdecl.cname))
205       ↪ else
206       StringMap.add cdecl.cname
207       {
208         field_map = List.fold_left fieldfun StringMap.empty cdecl.cbody.fields;
209         func_map = List.fold_left funcfun StringMap.empty cdecl.cbody.methods;
210         constructor_map = List.fold_left constructorfun constructor_map
211           ↪ cdecl.cbody.constructors;
212         reserved_map = reserved_map;
213         cdecl = cdecl }
214       m) in
215   List.fold_left helper StringMap.empty cdecls
216
217 let rec get_all_descendants cname accum =
218   if Hashtbl.mem predecessors cname then
219     let direct_descendants = Hashtbl.find predecessors cname in
220     let add_childs_descendants desc_set direct_descendant =
221       get_all_descendants direct_descendant (StringSet.add direct_descendant desc_set)
222     in
223     List.fold_left add_childs_descendants accum direct_descendants
224   else accum
225
226 let inherited potential_predec potential_child =
227   match potential_predec, potential_child with
228   | Datatype(Objecttype(predec_cname)), Datatype(Objecttype(child_cname)) ->
229     let descendants = get_all_descendants predec_cname StringSet.empty in
230     if (predec_cname = child_cname) || (StringSet.mem child_cname descendants) then true
231     else raise (Exceptions.LocalAssignTypeMismatch(predec_cname, child_cname))
232   | _ , _ -> false
233
234 let get_equality_binop_type type1 type2 se1 se2 op =
235   (* Equality op not supported for float operands. The correct way to test floats
236    for equality is to check the difference between the operands in question *)

```

```

233 if (type1 = Datatype(Float_t) || type2 = Datatype(Float_t)) then raise
    ↪ (Exceptions.InvalidBinopExpression "Equality operation is not supported for Float
    ↪ types")
234 else
235 match type1, type2 with
236 Datatype(Char_t), Datatype(Int_t)
237 |      Datatype(Int_t), Datatype(Char_t)
238 |      Datatype(Objecttype(_), Datatype(Null_t))
239 |      Datatype(Null_t), Datatype(Objecttype(_))
240 |      Datatype(Null_t), Arraytype(_, _)
241 |      Arraytype(_, _), Datatype(Null_t) -> SBinop(se1, op, se2, Datatype(Bool_t))
242 | _ ->
243 if type1 = type2 then SBinop(se1, op, se2, Datatype(Bool_t))
244 else raise (Exceptions.InvalidBinopExpression "Equality operator can't operate on
    ↪ different types, with the exception of Int_t and Char_t")
245
246 let get_logical_binop_type se1 se2 op = function
247 (Datatype(Bool_t), Datatype(Bool_t)) -> SBinop(se1, op, se2, Datatype(Bool_t))
248 | _ -> raise (Exceptions.InvalidBinopExpression "Logical operators only operate on Bool_t
    ↪ types")
249
250 let get_comparison_binop_type type1 type2 se1 se2 op =
251 let numerics = SS.of_list [Datatype(Int_t); Datatype(Char_t); Datatype(Float_t)]
252 in
253 if SS.mem type1 numerics && SS.mem type2 numerics
254 then SBinop(se1, op, se2, Datatype(Bool_t))
255 else raise (Exceptions.InvalidBinopExpression "Comparison operators operate on numeric
    ↪ types only")
256
257
258 let get_arithmetic_binop_type se1 se2 op = function
259 (Datatype(Int_t), Datatype(Float_t))
260 |      (Datatype(Float_t), Datatype(Int_t))
261 |      (Datatype(Float_t), Datatype(Float_t)) -> SBinop(se1, op, se2,
    ↪ Datatype(Float_t))
262
263 |      (Datatype(Int_t), Datatype(Char_t))
264 |      (Datatype(Char_t), Datatype(Int_t))
265 |      (Datatype(Char_t), Datatype(Char_t)) -> SBinop(se1, op, se2,
    ↪ Datatype(Char_t))
266
267 |      (Datatype(Int_t), Datatype(Int_t)) -> SBinop(se1, op, se2,
    ↪ Datatype(Int_t))
268
269 | _ -> raise (Exceptions.InvalidBinopExpression "Arithmetic operators don't support these
    ↪ types")
270
271 let rec get_ID_type env s =
272 try StringMap.find s env.env_locals

```

```

273 with | Not_found ->
274 try let formal = StringMap.find s env.env_parameters in
275 (function Formal(t, _) -> t | Many t -> t ) formal
276 with | Not_found -> raise (Exceptions.UndefinedID s)
277
278 and check_array_primitive env el =
279 let rec iter t sel = function
280 [] -> sel, t
281 | e :: el ->
282 let se, _ = expr_to_sexpr env e in
283 let se_t = get_type_from_sexpr se in
284 if t = se_t
285 then iter t (se :: sel) el
286 else
287 let t1 = Utils.string_of_datatype t in
288 let t2 = Utils.string_of_datatype se_t in
289 raise (Exceptions.InvalidArrayPrimitiveConsecutiveTypes(t1, t2))
290 in
291 let se, _ = expr_to_sexpr env (List.hd el) in
292 let el = List.tl el in
293 let se_t = get_type_from_sexpr se in
294 let sel, t = iter se_t ([se]) el in
295 let se_t = match t with
296 Datatype(x) -> Arraytype(x, 1)
297 | Arraytype(x, n) -> Arraytype(x, n+1)
298 | _ as t -> raise (Exceptions.InvalidArrayPrimitiveType(Utils.string_of_datatype
  ↪ t))
299 in
300 SArrayPrimitive(sel, se_t)
301
302 and check_array_init env d el =
303 (* Get dimension size for the array being created *)
304 let array_complexity = List.length el in
305 let check_elem_type e =
306 let sexpr, _ = expr_to_sexpr env e in
307 let sexpr_type = get_type_from_sexpr sexpr in
308 if sexpr_type = Datatype(Int_t)
309 then sexpr
310 else raise (Exceptions.MustPassIntegerTypeToArrayCreate)
311 in
312 let convert_d_to_arraytype = function
313 Datatype(x) -> Arraytype(x, array_complexity)
314 | _ as t ->
315 let error_msg = Utils.string_of_datatype t in
316 raise (Exceptions.ArrayInitTypeInvalid(error_msg))
317 in
318 let sexpr_type = convert_d_to_arraytype d in
319 let sel = List.map check_elem_type el in
320 SArrayCreate(d, sel, sexpr_type)

```

```

321
322 and check_array_access env e el =
323   (* Get dimensions of array, ex: foo[10][4][2] is dimen=3 *)
324   let array_dimensions = List.length el in
325   (* Check every e in el is of type Datatype(Int_t). Ensure all indices are ints *)
326   let check_elem_type arg =
327     let sexpr, _ = expr_to_sexpr env arg in
328     let sexpr_type = get_type_from_sexpr sexpr in
329     if sexpr_type = Datatype(Int_t)
330     then sexpr
331     else raise (Exceptions.MustPassIntegerTypeToArrayAccess)
332   in
333   (* converting e to se also checks if the array id has been declared *)
334   let se, _ = expr_to_sexpr env e in
335   let se_type = get_type_from_sexpr se in
336
337   (* Check that e has enough dimens as e's in el. Return overall datatype of access*)
338   let check_array_dim_vs_params num_params = function
339     Arraytype(t, n) ->
340     if num_params < n then
341       Arraytype(t, (n-num_params))
342     else if num_params = n then
343       Datatype(t)
344     else
345       raise (Exceptions.ArrayAccessInvalidParamLength(string_of_int num_params, string_of_int
346         ↪ n))
347   | _ as t ->
348   let error_msg = Utils.string_of_datatype t in
349   raise (Exceptions.ArrayAccessExpressionNotArray(error_msg))
350   in
351   let sexpr_type = check_array_dim_vs_params array_dimensions se_type in
352   let sel = List.map check_elem_type el in
353   SArrayAccess(se, sel, sexpr_type)
354
355 and check_obj_access env lhs rhs =
356   let check_lhs = function
357     This -> SId("this", Datatype(Objecttype(env.env_name)))
358     | Id s -> SId(s, get_ID_type env s)
359     | ArrayAccess(e, el) -> check_array_access env e el
360     | _ as e -> raise (Exceptions.LHSofRootAccessMustBeIDorFunc
361       ↪ (Utils.string_of_expr e))
362   in
363   let ptype_name parent_type = match parent_type with
364     Datatype(Objecttype(name)) -> name
365     | _ as d -> raise
366       ↪ (Exceptions.ObjAccessMustHaveObjectType (Utils.string_of_datatype d))
367   in
368   let rec check_rhs (env) parent_type (top_level_env) =

```

```

367 let pt_name = ptype_name parent_type in
368 let get_id_type_from_object env (id) cname tlenv =
369 let cmap = StringMap.find cname env.env_class_maps in
370 let match_field f = match f with
371 Field(scope, d, n) ->
372 (* Have to update this with all parent classes checks *)
373 if scope = Ast.Private && tlenv.env_name <> env.env_name then
374 raise (Exceptions.CannotAccessPrivateFieldInNonProperScope(n, env.env_name,
375 ↪ tlenv.env_name))
376 else d
377 in
378 try match_field (StringMap.find id cmap.field_map)
379 with | Not_found -> raise (Exceptions.UnknownIdentifierForClass(id, cname))
380 in
381 function
382 (* Check fields in parent *)
383 Id s                                     -> SId(s, (get_id_type_from_object env s pt_name
384 ↪ top_level_env)), env
385 (* Check functions in parent *)
386 | Call(fname, e1)                       ->
387 let env = update_env_name env pt_name in
388 check_call_type top_level_env true env fname e1, env
389 (* Set parent, check if base is field *)
390 | ObjAccess(e1, e2)                     ->
391 let old_env = env in
392 let lhs, env = check_rhs env parent_type top_level_env e1 in
393 let lhs_type = get_type_from_sexpr lhs in
394
395 let pt_name = ptype_name lhs_type in
396 let lhs_env = update_env_name env pt_name in
397
398 let rhs, env = check_rhs lhs_env lhs_type top_level_env e2 in
399 let rhs_type = get_type_from_sexpr rhs in
400 SObjAccess(lhs, rhs, rhs_type), old_env
401 | _ as e                                 -> raise (Exceptions.InvalidAccessLHS
402 ↪ (Utils.string_of_expr e))
403 in
404 let arr_lhs, _ = expr_to_sexpr env lhs in
405 let arr_lhs_type = get_type_from_sexpr arr_lhs in
406 match arr_lhs_type with
407 Arraytype(Char_t, 1) -> raise (Exceptions.CannotAccessLengthOfCharArray)
408 | Arraytype(_, _) ->
409 let rhs = match rhs with
410 Id("length") -> SId("length", Datatype(Int_t))
411 | _ -> raise (Exceptions.CanOnlyAccessLengthOfArray)
412 in
413 SObjAccess(arr_lhs, rhs, Datatype(Int_t))
414 | _ ->
415 let lhs = check_lhs lhs in

```

```

413 let lhs_type = get_type_from_sexpr lhs in
414
415 let ptype_name = ptype_name lhs_type in
416 let lhs_env = update_env_name env ptype_name in
417
418 let rhs, _ = check_rhs lhs_env lhs_type env rhs in
419 let rhs_type = get_type_from_sexpr rhs in
420 SObjAccess(lhs, rhs, rhs_type)
421
422 and check_call_type top_level_env isObjAccess env fname el =
423 let sel, env = expr1_to_sexpr1 env el in
424 (* check that 'env.env_name' is in the list of defined classes *)
425 let cmap =
426 try StringMap.find env.env_name env.env_class_maps
427 with | Not_found -> raise (Exceptions.UndefinedClass env.env_name)
428 in
429
430 let handle_param formal param =
431 let fty = match formal with Formal(d, _) -> d | _ -> Datatype(Void_t) in
432 let pty = get_type_from_sexpr param in
433 match fty, pty with
434 Datatype(Objecttype(f)), Datatype(Objecttype(p)) ->
435 if f <> p then
436 try let descendants = Hashtbl.find predecessors f in
437 let _ = try List.find (fun d -> p = d) descendants
438 with | Not_found -> raise (Exceptions.CannotPassNonInheritedClassesInPlaceOfOthers(f, p))
439 in
440 let rt = Datatype(Objecttype(f)) in
441 SCall("cast", [param; SId("ignore", rt)], rt, 0)
442 with | Not_found -> raise (Exceptions.ClassIsNotExtendedBy(f, p))
443 else param
444 | _ -> if fty = pty then param else
445   ↪ raise (Exceptions.IncorrectTypePassedToFunction(fname, Utils.string_of_datatype pty))
446 in
447
448 let index fdecl fname =
449 let cdecl = cmap.cdecl in
450 (* Have to update this with all parent classes checks *)
451 let _ =
452 if fdecl.scope = Ast.Private && top_level_env.env_name <> env.env_name then
453 raise (Exceptions.CannotAccessPrivateFunctionInNonProperScope(get_name env.env_name fdecl,
454   ↪ env.env_name, top_level_env.env_name))
455 in
456 (* Not exactly sure why there needs to be a list.rev *)
457 let fns = List.rev cdecl.cbody.methods in
458 let rec find x lst =
459 match lst with
460 | [] -> raise (Failure ("Could not find " ^ fname))
461 | fdecl :: t ->

```

```

460 let search_name = (get_name env.env_name fdecl) in
461 if x = search_name then 0
462 else if search_name = "main" then find x t
463 else 1 + find x t
464 in
465 find fname fns
466 in
467
468 let handle_params (formals) params =
469 match formals, params with
470 [Many(Any)], _ -> params
471 | [], [] -> []
472 | [], _
473 | _, [] -> raise (Exceptions.IncorrectTypePassedToFunction(fname,
  ↳ Utils.string_of_datatype (Datatype(Void_t))))
474 | _ ->
475 let len1 = List.length formals in
476 let len2 = List.length params in
477 if len1 <> len2 then raise (Exceptions.IncorrectNumberOfArguments(fname, len1, len2))
478 else
479 List.map2 handle_param formals sel
480 in
481
482 let sfname = env.env_name ^ "." ^ fname in
483 try let func = StringMap.find fname cmap.reserved_map in
484 let actuals = handle_params func.sformals sel in
485 SCall(fname, actuals, func.sreturnType, 0)
486 with | Not_found ->
487 try let f = StringMap.find sfname cmap.func_map in
488 let actuals = handle_params f.formals sel in
489 let index = index f sfname in
490 SCall(sfname, actuals, f.returnType, index)
491 with | Not_found -> raise (Exceptions.FunctionNotFound(env.env_name, sfname)) | _ as ex ->
  ↳ raise ex
492
493 and check_object_constructor env s el =
494 let sel, env = expr1_to_sexpr1 env el in
495 (* check that 'env.env_name' is in the list of defined classes *)
496 let cmap =
497 try StringMap.find s env.env_class_maps
498 with | Not_found -> raise (Exceptions.UndefinedClass s)
499 in
500 (* get a list of the types of the actuals to match against defined function formals *)
501 let params = List.fold_left (fun s e -> s ^ "." ^ (Utils.string_of_datatype
  ↳ (get_type_from_sexpr e))) "" sel in
502 let constructor_name = s ^ "." ^ "constructor" ^ params in
503 let _ =
504 try StringMap.find constructor_name cmap.constructor_map
505 with | Not_found -> raise (Exceptions.ConstructorNotFound constructor_name)

```

```

506 in
507 let ftype = Datatype(Objecttype(s)) in
508 (* Add a reference to the class in front of the function call *)
509 (* Must properly handle the case where this is a reserved function *)
510 SObjectCreate(constructor_name, se1, ftype)
511
512 and check_assign env e1 e2 =
513 let se1, env = expr_to_sexpr env e1 in
514 let se2, env = expr_to_sexpr env e2 in
515 let type1 = get_type_from_sexpr se1 in
516 let type2 = get_type_from_sexpr se2 in
517 match (type1, se2) with
518 Datatype(Objecttype(_)), SNull
519 |      Arraytype(_, _), SNull -> SAssign(se1, se2, type1)
520 |      _ ->
521 match type1, type2 with
522 Datatype(Char_t), Datatype(Int_t)
523 |      Datatype(Int_t), Datatype(Char_t) -> SAssign(se1, se2, type1)
524 |      Datatype(Objecttype(d)), Datatype(Objecttype(t)) ->
525 if d = t then SAssign(se1, se2, type1)
526 else if inherited type1 type2 then
527 SAssign(se1, SCall("cast", [se2; SId("ignore", type1)], type1, 0), type1)
528 else raise (Exceptions.AssignmentTypeMismatch(Utls.string_of_datatype type1,
529   ↪ Utls.string_of_datatype type2))
529 | _ ->
530 if type1 = type2
531 then SAssign(se1, se2, type1)
532 else raise (Exceptions.AssignmentTypeMismatch(Utls.string_of_datatype type1,
533   ↪ Utls.string_of_datatype type2))
534
535 and check_unop env op e =
536 let check_num_unop t = function
537 Sub      -> t
538 |      _      -> raise(Exceptions.InvalidUnaryOperation)
539 in
540 let check_bool_unop = function
541 Not      -> Datatype(Bool_t)
542 |      _      -> raise(Exceptions.InvalidUnaryOperation)
543 in
544 let se, env = expr_to_sexpr env e in
545 let t = get_type_from_sexpr se in
546 match t with
547 Datatype(Int_t)
548 |      Datatype(Float_t)      -> SUnop(op, se, check_num_unop t op)
549 |      Datatype(Bool_t)      -> SUnop(op, se, check_bool_unop op)
550 |      _ -> raise(Exceptions.InvalidUnaryOperation)
551
552 and check_binop env e1 op e2 =
553 let se1, env = expr_to_sexpr env e1 in

```



```

553 let se2, env = expr_to_sexpr env e2 in
554 let type1 = get_type_from_sexpr se1 in
555 let type2 = get_type_from_sexpr se2 in
556 match op with
557 | Equal | Neq -> get_equality_binop_type type1 type2 se1 se2 op
558 | And | Or -> get_logical_binop_type se1 se2 op (type1, type2)
559 | Less | Leq | Greater | Geq -> get_comparison_binop_type type1 type2 se1 se2 op
560 | Add | Mult | Sub | Div | Mod -> get_arithmetic_binop_type se1 se2 op (type1, type2)
561 | _ -> raise (Exceptions.InvalidBinopExpression ((Utils.string_of_op op) ^ " is not a
    ↪ supported binary op"))
562
563 and check_delete env e =
564 let se, _ = expr_to_sexpr env e in
565 let t = get_type_from_sexpr se in
566 match t with
567 | Arraytype(_, _) | Datatype(Objecttype(_)) -> SDelete(se)
568 | _ -> raise (Exceptions.CanOnlyDeleteObjectsOrArrays)
569
570 and expr_to_sexpr env = function
571 | Int_Lit i -> SInt_Lit(i), env
572 | Boolean_Lit b -> SBoolean_Lit(b), env
573 | Float_Lit f -> SFloat_Lit(f), env
574 | String_Lit s -> SString_Lit(s), env
575 | Char_Lit c -> SChar_Lit(c), env
576 | This -> SId("this", Datatype(Objecttype(env.env_name))), env
577 | Id s -> SId(s, get_ID_type env s), env
578 | Null -> SNull, env
579 | Noexpr -> SNoexpr, env
580
581 | ObjAccess(e1, e2) -> check_obj_access env e1 e2, env
582 | ObjectCreate(s, el) -> check_object_constructor env s el, env
583 | Call(s, el) -> check_call_type env false env s el, env
584
585 | ArrayCreate(d, el) -> check_array_init env d el, env
586 | ArrayAccess(e, el) -> check_array_access env e el, env
587 | ArrayPrimitive el -> check_array_primitive env el, env
588
589 | Assign(e1, e2) -> check_assign env e1 e2, env
590 | Unop(op, e) -> check_unop env op e, env
591 | Binop(e1, op, e2) -> check_binop env e1 op e2, env
592 | Delete(e) -> check_delete env e, env
593
594
595 and get_type_from_sexpr = function
596 | SInt_Lit(_) -> Datatype(Int_t)
597 | SBoolean_Lit(_) -> Datatype(Bool_t)
598 | SFloat_Lit(_) -> Datatype(Float_t)
599 | SString_Lit(_) -> Arraytype(Char_t, 1)
600 | SChar_Lit(_) -> Datatype(Char_t)

```

```

601 |         SId(_, d)                                -> d
602 |         SBinop(_, _, _, d)                        -> d
603 |         SAssign(_, _, d)                          -> d
604 |         SNoexpr                                    -> Datatype(Void_t)
605 |         SArrayCreate(_, _, d)                     -> d
606 |         SArrayAccess(_, _, d)                     -> d
607 |         SObjAccess(_, _, d)                       -> d
608 |         SCall(_, _, d, _)                         -> d
609 |     SObjectCreate(_, _, d)                        -> d
610 |         SArrayPrimitive(_, d)                     -> d
611 |         SUnop(_, _, d)                            -> d
612 |         SNull                                       -> Datatype(Null_t)
613 |         SDelete _                                 -> Datatype(Void_t)
614
615 and expr1_to_sexpr1 env e1 =
616 let env_ref = ref(env) in
617 let rec helper = function
618 head::tail ->
619 let a_head, env = expr_to_sexpr !env_ref head in
620 env_ref := env;
621 a_head::(helper tail)
622 | [] -> []
623 in (helper e1), !env_ref
624
625 let rec local_handler d s e env =
626 if StringMap.mem s env.env_locals
627 then raise (Exceptions.DuplicateLocal s)
628 else
629 let se, env = expr_to_sexpr env e in
630 let t = get_type_from_sexpr se in
631 if t = Datatype(Void_t) || t = Datatype(Null_t) || t = d || (inherited d t)
632 then
633 let new_env = {
634     env_class_maps = env.env_class_maps;
635     env_name = env.env_name;
636     env_cmap = env.env_cmap;
637     env_locals = StringMap.add s d env.env_locals;
638     env_parameters = env.env_parameters;
639     env_returnType = env.env_returnType;
640     env_in_for = env.env_in_for;
641     env_in_while = env.env_in_while;
642     env_reserved = env.env_reserved;
643 } in
644 (* if the user-defined type being declared is not in global classes map, it is an
645 ↳ undefined class *)
646 (match d with
647 Datatype(Objecttype(x)) ->
648 (if not (StringMap.mem (Utils.string_of_object d) env.env_class_maps)
649 then raise (Exceptions.UndefinedClass (Utils.string_of_object d))

```

```

649 else
650 let local = if inherited d t then SLocal(t, s, se) else SLocal(d, s, se)
651 in local, new_env)
652 | _ -> SLocal(d, s, se), new_env)
653 else
654 (let type1 = (Utils.string_of_datatype t) in
655 let type2 = (Utils.string_of_datatype d) in
656 let ex = Exceptions.LocalAssignTypeMismatch(type1, type2) in
657 raise ex)
658
659 let rec check_sblock s1 env = match s1 with
660 [] -> SBlock([SExpr(SNoexpr, Datatype(Void_t))]), env
661 | _ ->
662 let s1, _ = convert_stmt_list_to_sstmt_list env s1 in
663 SBlock(s1), env
664
665 and check_expr_stmt e env =
666 let se, env = expr_to_sexpr env e in
667 let t = get_type_from_sexpr se in
668 SExpr(se, t), env
669
670 and check_return e env =
671 let se, _ = expr_to_sexpr env e in
672 let t = get_type_from_sexpr se in
673 match t, env.env_returnType with
674 Datatype(Null_t), Datatype(Objecttype(_))
675 | Datatype(Null_t), Arraytype(_, _) -> SReturn(se, t), env
676 | _ ->
677 if t = env.env_returnType
678 then SReturn(se, t), env
679 else raise (Exceptions.ReturnTypeMismatch(Utils.string_of_datatype t,
680 ↪ Utils.string_of_datatype env.env_returnType))
681
682 and check_if e s1 s2 env =
683 let se, _ = expr_to_sexpr env e in
684 let t = get_type_from_sexpr se in
685 let ifbody, _ = parse_stmt env s1 in
686 let elsebody, _ = parse_stmt env s2 in
687 if t = Datatype(Bool_t)
688 then SIf(se, ifbody, elsebody), env
689 else raise Exceptions.InvalidIfStatementType
690
691 and check_for e1 e2 e3 s env =
692 let old_val = env.env_in_for in
693 let env = update_call_stack env true env.env_in_while in
694
695 let se1, _ = expr_to_sexpr env e1 in
696 let se2, _ = expr_to_sexpr env e2 in
697 let se3, _ = expr_to_sexpr env e3 in

```

```

697 let forbody, _ = parse_stmt env s in
698 let conditional = get_type_from_sexpr se2 in
699 let sfor =
700   if (conditional = Datatype(Bool_t) || conditional = Datatype(Void_t))
701   then SFor(se1, se2, se3, forbody)
702   else raise Exceptions.InvalidForStatementType
703   in
704
705 let env = update_call_stack env old_val env.env_in_while in
706 sfor, env
707
708 and check_while e s env =
709   let old_val = env.env_in_while in
710   let env = update_call_stack env env.env_in_for true in
711
712   let se, _ = expr_to_sexpr env e in
713   let t = get_type_from_sexpr se in
714   let sstmt, _ = parse_stmt env s in
715   let swhile =
716     if (t = Datatype(Bool_t) || t = Datatype(Void_t))
717     then SWhile(se, sstmt)
718     else raise Exceptions.InvalidWhileStatementType
719     in
720
721   let env = update_call_stack env env.env_in_for old_val in
722   swhile, env
723
724 and check_break env =
725   if env.env_in_for || env.env_in_while then
726     SBreak, env
727   else
728     raise Exceptions.CannotCallBreakOutsideOfLoop
729
730 and check_continue env =
731   if env.env_in_for || env.env_in_while then
732     SContinue, env
733   else
734     raise Exceptions.CannotCallContinueOutsideOfLoop
735
736 and parse_stmt env = function
737   Block s1                                -> check_sblock s1 env
738   | Expr e                                -> check_expr_stmt e env
739   | Return e                              -> check_return e env
740   | If(e, s1, s2)                          -> check_if e s1 s2      env
741   | For(e1, e2, e3, e4)                    -> check_for e1 e2 e3 e4 env
742   | While(e, s)                            -> check_while e s env
743   | Break                                  -> check_break env (* Need to
  ↪ check if in right context *)

```

```

744 |   Continue                                     -> check_continue env (* Need to check if in
    |   ↪ right context *)
745 |   Local(d, s, e)                               -> local_handler d s e env
746
747 (* Update this function to return an env object *)
748 and convert_stmt_list_to_sstmt_list env stmt_list =
749 let env_ref = ref(env) in
750 let rec iter = function
751 head::tail ->
752 let a_head, env = parse_stmt !env_ref head in
753 env_ref := env;
754 a_head::(iter tail)
755 | [] -> []
756 in
757 let sstmt_list = (iter stmt_list), !env_ref in
758 sstmt_list
759
760 let append_code_to_main fbody cname ret_type =
761 let key = Hashtbl.find struct_indexes cname in
762 let init_this = [SLocal(
763 ret_type,
764 "this",
765 SCall(
766 "cast",
767 [SCall("malloc",
768 [
769 SCall("sizeof", [SId("ignore", ret_type)], Datatype(Int_t), 0)
770 ],
771 Arraytype(Char_t, 1), 0)
772 ],
773 ret_type, 0
774 )
775 );
776 SExpr(
777 SAssign(
778 SObjAccess(
779 SId("this", ret_type),
780 SId(".key", Datatype(Int_t)),
781 Datatype(Int_t)
782 ),
783 SInt_Lit(key),
784 Datatype(Int_t)
785 ),
786 Datatype(Int_t)
787 )
788 in
789 init_this @ fbody
790
791 let convert_constructor_to_sfdecl class_maps reserved class_map cname constructor =

```

```

792 let env = {
793     env_class_maps      = class_maps;
794     env_name            = cname;
795     env_cmap            = class_map;
796     env_locals          = StringMap.empty;
797     env_parameters      = List.fold_left (fun m f -> match f with Formal(d, s) ->
798         ↪ (StringMap.add s f m) | _ -> m) StringMap.empty constructor.formals;
799     env_returnType      = Datatype(Objecttype(cname));
800     env_in_for          = false;
801     env_in_while        = false;
802     env_reserved        = reserved;
803 } in
804 let fbody = fst (convert_stmt_list_to_sstmt_list env constructor.body) in
805 {
806     sfname              = Ast.FName (get_constructor_name cname constructor);
807     sreturnType         = Datatype(Objecttype(cname));
808     sformals            = constructor.formals;
809     sbody               = append_code_to_constructor fbody cname
810         ↪ (Datatype(Objecttype(cname)));
811     func_type           = Sast.User;
812     overrides           = false;
813     source              = "NA";
814 }
815
816 let check_fbody fname fbody returnType =
817 let len = List.length fbody in
818 if len = 0 then () else
819 let final_stmt = List.hd (List.rev fbody) in
820 match returnType, final_stmt with
821 Datatype(Void_t), _ -> ()
822 | _, SReturn(_, _) -> ()
823 | _ -> raise(Exceptions.AllNonVoidFunctionsMustEndWithReturn(fname))
824
825 let convert_fdecl_to_sfdecl class_maps reserved class_map cname fdecl =
826 let root_cname = match fdecl.root_cname with
827 Some(x) -> x
828 | None -> cname
829 in
830 let class_formal =
831 if fdecl.overrides then
832 Ast.Formal(Datatype(Objecttype(root_cname)), "this")
833 else
834 Ast.Formal(Datatype(Objecttype(cname)), "this")
835 in
836 let env_param_helper m fname = match fname with
837 Formal(d, s) -> (StringMap.add s fname m)
838 | _ -> m
839 in

```

```

838 let env_params = List.fold_left env_param_helper StringMap.empty (class_formal ::
    ↪ fdecl.formals) in
839 let env = {
840     env_class_maps      = class_maps;
841     env_name            = cname;
842     env_cmap            = class_map;
843     env_locals          = StringMap.empty;
844     env_parameters      = env_params;
845     env_returnType      = fdecl.returnType;
846     env_in_for          = false;
847     env_in_while        = false;
848     env_reserved        = reserved;
849 }
850 in
851 let fbody = fst (convert_stmt_list_to_sstmt_list env fdecl.body) in
852 let fname = (get_name cname fdecl) in
853 ignore(check_fbody fname fbody fdecl.returnType);
854 let fbody = if fname = "main"
855 then (append_code_to_main fbody cname (Datatype(Objecttype(cname))))
856 else fbody
857 in
858 (* We add the class as the first parameter to the function for codegen *)
859 {
860     sfname                = Ast.FName (get_name cname fdecl);
861     sreturnType           = fdecl.returnType;
862     sformals              = class_formal :: fdecl.formals;
863     sbody                 = fbody;
864     func_type             = Sast.User;
865     overrides             = fdecl.overrides;
866     source                = cname;
867 }
868
869 let convert_cdecl_to_sast sfdecls (cdecl:Ast.class_decl) =
870 {
871     scname = cdecl.cname;
872     sfields = cdecl.cbody.fields;
873     sfuncs = sfdecls;
874 }
875
876 (*
877  * Given a list of func_decls for the base class and a single func_decl
878  * for the child class, replaces func_decls for the base class if any of them
879  * have the same method signature
880  *)
881 let replace_fdecl_in_base_methods base_cname base_methods child_fdecl =
882 let replace base_fdecl accum =
883 let get_root_cname = function
884 None -> Some(base_cname)
885 | Some(x) -> Some(x)

```

```

886 in
887 let modify_child_fdecl =
888 {
889     scope = child_fdecl.scope;
890     fname = child_fdecl.fname;
891     returnType = child_fdecl.returnType;
892     formals = child_fdecl.formals;
893     body = child_fdecl.body;
894     overrides = true;
895     root_cname = get_root_cname base_fdecl.root_cname;
896 }
897 in
898 if (get_name_without_class base_fdecl) = (get_name_without_class child_fdecl)
899 then modify_child_fdecl::accum
900 else base_fdecl::accum
901 in
902 List.fold_right replace base_methods []
903
904 let merge_methods base_cname base_methods child_methods =
905 let check_overrides child_fdecl accum =
906 let base_checked_for_overrides =
907 replace_fdecl_in_base_methods base_cname (fst accum) child_fdecl
908 in
909 if (fst accum) = base_checked_for_overrides
910 then ((fst accum), child_fdecl::(snd accum))
911 else (base_checked_for_overrides, (snd accum))
912 in
913 let updated_base_and_child_fdecls =
914 List.fold_right check_overrides child_methods (base_methods, [])
915 in
916 (fst updated_base_and_child_fdecls) @ (snd updated_base_and_child_fdecls)
917
918 let merge_cdecls base_cdecl child_cdecl =
919 (* return a cdecl in which cdecl.cbody.fields contains the fields of
920 the extended class, concatenated by the fields of the child class *)
921 let child_cbody =
922 {
923     fields = base_cdecl.cbody.fields @ child_cdecl.cbody.fields;
924     constructors = child_cdecl.cbody.constructors;
925     methods = merge_methods base_cdecl.cname base_cdecl.cbody.methods
926         ↪ child_cdecl.cbody.methods
927 }
928 in
929 {
930     cname = child_cdecl.cname;
931     extends = child_cdecl.extends;
932     cbody = child_cbody
933 }

```



```

934  (* returns a list of cdecls that contains inherited fields *)
935  let inherit_fields_cdecls cdecls inheritance_forest =
936  (* iterate through cdecls to make a map for lookup *)
937  let cdecl_lookup = List.fold_left (fun a litem -> StringMap.add litem.cname litem a)
    ↪ StringMap.empty cdecls in
938  let add_key key pred maps =
939  let elem1 = StringSet.add key (fst maps) in
940  let accum acc child = StringSet.add child acc in
941  let elem2 = List.fold_left (accum) (snd maps) pred in
942  (elem1, elem2)
943  in
944  let empty_s = StringSet.empty in
945  let res = StringMap.fold add_key inheritance_forest (empty_s, empty_s) in
946  let roots = StringSet.diff (fst res) (snd res) in
947  let rec add_inherited_fields predec desc map_to_update =
948  let merge_fields accum descendant =
949  let updated_predec_cdecl = StringMap.find predec accum in
950  let descendant_cdecl_to_update = StringMap.find descendant cdecl_lookup in
951  let merged = merge_cdecls updated_predec_cdecl descendant_cdecl_to_update in
952  let updated = (StringMap.add descendant merged accum) in
953  if (StringMap.mem descendant inheritance_forest) then
954  let descendants_of_descendant = StringMap.find descendant inheritance_forest in
955  add_inherited_fields descendant descendants_of_descendant updated
956  else updated
957  in
958  List.fold_left merge_fields map_to_update desc
959  in
960  (* map class name of every class_decl in 'cdecls' to its inherited cdecl *)
961  let inherited_cdecls =
962  let traverse_tree tree_root accum =
963  let tree_root_descendant = StringMap.find tree_root inheritance_forest in
964  let accum_with_tree_root_mapping = StringMap.add tree_root (StringMap.find tree_root
    ↪ cdecl_lookup) accum in
965  add_inherited_fields tree_root tree_root_descendant accum_with_tree_root_mapping
966  in
967  StringSet.fold traverse_tree roots StringMap.empty
968  in
969  (* build a list of updated cdecls corresponding to the sequence of cdecls in 'cdecls' *)
970  let add_inherited_cdecl cdecl accum =
971  let inherited_cdecl =
972  try StringMap.find cdecl.cname inherited_cdecls
973  with | Not_found -> cdecl
974  in
975  inherited_cdecl::accum
976  in
977  let result = List.fold_right add_inherited_cdecl cdecls [] in
978  result
979
980  let convert_cdecls_to_sast class_maps reserved (cdecls:Ast.class_decl list) =

```

```

981 let find_main = (fun f -> match f.sfname with FName n -> n = "main" | _ -> false) in
982 let get_main func_list =
983 let mains = (List.find_all find_main func_list) in
984 if List.length mains < 1 then
985 raise Exceptions.MainNotDefined
986 else if List.length mains > 1 then
987 raise Exceptions.MultipleMainsDefined
988 else List.hd mains
989 in
990 let remove_main func_list =
991 List.filter (fun f -> not (find_main f)) func_list
992 in
993 let find_default_constructor cdecl clist =
994 let default_cname = cdecl.cname ^ "." ^ "constructor" in
995 let find_default_c f =
996 match f.sfname with FName n -> n = default_cname | _ -> false
997 in
998 try let _ = List.find find_default_c clist in
999 clist
1000 with | Not_found ->
1001 let default_c = default_sc cdecl.cname in
1002 default_c :: clist
1003 in
1004 let handle_cdecl cdecl =
1005 let class_map = StringMap.find cdecl.cname class_maps in
1006 let sconstructor_list = List.fold_left (fun l c -> (convert_constructor_to_sfdecl
  ↪ class_maps reserved class_map cdecl.cname c) :: l) [] cdecl.cbody.constructors in
1007 let sconstructor_list = find_default_constructor cdecl sconstructor_list in
1008 let func_list = List.fold_left (fun l f -> (convert_fdecl_to_sfdecl class_maps reserved
  ↪ class_map cdecl.cname f) :: l) [] cdecl.cbody.methods in
1009 let sfunc_list = remove_main func_list in
1010 let scdecl = convert_cdecl_to_sast sfunc_list cdecl in
1011 (scdecl, func_list @ sconstructor_list)
1012 in
1013 let iter_cdecls t c =
1014 let scdecl = handle_cdecl c in
1015 (fst scdecl :: fst t, snd scdecl @ snd t)
1016 in
1017 let scdecl_list, func_list = List.fold_left iter_cdecls ([], []) cdecls in
1018 let main = get_main func_list in
1019 let funcs = remove_main func_list in
1020 (* let funcs = (add_default_constructors cdecls class_maps) @ funcs in *)
1021 {
1022     classes          = scdecl_list;
1023     functions        = funcs;
1024     main             = main;
1025     reserved         = reserved;
1026 }
1027

```

```

1028 let add_reserved_functions =
1029 let reserved_stub name return_type formals =
1030 {
1031     sfname                = FName(name);
1032     sreturnType           = return_type;
1033     sformals              = formals;
1034     sbody                 = [];
1035     func_type             = Sast.Reserved;
1036     overrides             = false;
1037     source                = "NA";
1038 }
1039 in
1040 let i32_t = Datatype(Int_t) in
1041 let void_t = Datatype(Void_t) in
1042 let str_t = Arraytype(Char_t, 1) in
1043 let mf t n = Formal(t, n) in (* Make formal *)
1044 let reserved = [
1045     reserved_stub "print"      (void_t)      ([Many(Any)]);
1046     reserved_stub "malloc"    (str_t)        ([mf i32_t "size"]);
1047     reserved_stub "cast"      (Any)          ([mf Any "in"]);
1048     reserved_stub "sizeof"    (i32_t)        ([mf Any "in"]);
1049     reserved_stub "open"      (i32_t)        ([mf str_t "path"; mf i32_t "flags"]);
1050     reserved_stub "close"     (i32_t)        ([mf i32_t "fd"]);
1051     reserved_stub "read"      (i32_t)        ([mf i32_t "fd"; mf str_t "buf"; mf i32_t
1052     ↪ "nbyte"]);
1052     reserved_stub "write"     (i32_t)        ([mf i32_t "fd"; mf str_t "buf"; mf i32_t
1053     ↪ "nbyte"]);
1053     reserved_stub "lseek"     (i32_t)        ([mf i32_t "fd"; mf i32_t "offset"; mf
1054     ↪ i32_t "whence"]);
1054     reserved_stub "exit"      (void_t)        ([mf i32_t "status"]);
1055     reserved_stub "getchar"   (i32_t)        ([]);
1056     reserved_stub "input"     (str_t)        ([]);
1057 ] in
1058 reserved
1059
1060 let build_inheritance_forest cdecls cmap =
1061 let handler a cdecl =
1062 match cdecl.extends with
1063 Parent(s)      ->
1064 let new_list = if (StringMap.mem s a) then
1065 cdecl.cname::(StringMap.find s a)
1066 else
1067 [cdecl.cname]
1068 in
1069 Hashtbl.add predecessors s new_list;
1070 (StringMap.add s new_list a)
1071 |      NoParent      -> a
1072 in
1073 let forest = List.fold_left handler StringMap.empty cdecls in

```

```

1074
1075 let handler key value =
1076 if not (StringMap.mem key cmap) then
1077 raise (Exceptions.UndefinedClass key)
1078 in
1079 ignore(StringMap.iter handler forest);
1080 forest
1081
1082 let merge_maps m1 m2 =
1083 StringMap.fold (fun k v a -> StringMap.add k v a) m1 m2
1084
1085 let update_class_maps map_type cmap_val cname cmap_to_update =
1086 let update m map_type =
1087 if map_type = "field_map" then
1088 {
1089     field_map = cmap_val;
1090     func_map = m.func_map;
1091     constructor_map = m.constructor_map;
1092     reserved_map = m.reserved_map;
1093     cdecl = m.cdecl;
1094 }
1095 else m
1096 in
1097 let updated = StringMap.find cname cmap_to_update in
1098 let updated = update updated map_type in
1099 let updated = StringMap.add cname updated cmap_to_update in
1100 updated
1101
1102 let inherit_fields class_maps predecessors =
1103 (* Get basic inheritance map *)
1104 let add_key key pred map = StringMap.add key pred map in
1105 let cmap_inherit = StringMap.fold add_key class_maps StringMap.empty in
1106 (* Perform accumulation of child classes *)
1107 let add_key key pred maps =
1108 let elem1 = StringSet.add key (fst maps) in
1109 let accum acc child = StringSet.add child acc in
1110 let elem2 = List.fold_left (accum) (snd maps) pred in
1111 (elem1, elem2)
1112 in
1113 let empty_s = StringSet.empty in
1114 let res = StringMap.fold add_key predecessors (empty_s, empty_s) in
1115 let roots = StringSet.diff (fst res) (snd res) in
1116 (*in let _ = print_set_members roots*)
1117 let rec add_inherited_fields predec desc cmap_to_update =
1118 let cmap_inherit accum descendant =
1119 let predec_field_map = (StringMap.find predec accum).field_map in
1120 let desc_field_map = (StringMap.find descendant accum).field_map in
1121 let merged = merge_maps predec_field_map desc_field_map in
1122 let updated = update_class_maps "field_map" merged descendant accum in

```

```

1123 if (StringMap.mem descendant predecessors) then
1124 let descendants_of_descendant = StringMap.find descendant predecessors in
1125 add_inherited_fields descendant descendants_of_descendant updated
1126 else updated
1127 in
1128 List.fold_left cmap_inherit cmap_to_update desc
1129 (* end of add_inherited_fields *)
1130 in
1131 let result = StringSet.fold (fun x a -> add_inherited_fields x (StringMap.find x
  ↪ predecessors) a) roots cmap_inherit
1132 (*in let _ = print_map result*)
1133 in result
1134
1135 (* TODO Check that this actually works *)
1136 let check_cyclical_inheritance cdecls predecessors =
1137 let handle_predecessor cdecl parent predecessor =
1138 if cdecl.cname = predecessor then
1139 raise(Exceptions.CyclicalDependencyBetween(cdecl.cname, parent))
1140 in
1141 let handle_cdecl cdecl =
1142 if StringMap.mem cdecl.cname predecessors
1143 then
1144 let pred_list = StringMap.find cdecl.cname predecessors in
1145 List.iter (handle_predecessor cdecl (List.hd pred_list)) pred_list
1146 else ()
1147 in
1148 List.iter handle_cdecl cdecls
1149
1150 let build_func_map_inherited_lookup cdecls_inherited =
1151 let build_func_map cdecl =
1152 let add_func m fdecl = StringMap.add (get_name cdecl.cname fdecl) fdecl m in
1153 List.fold_left add_func StringMap.empty cdecl.cbody.methods
1154 in
1155 let add_class_func_map m cdecl = StringMap.add cdecl.cname (build_func_map cdecl) m in
1156 List.fold_left add_class_func_map StringMap.empty cdecls_inherited
1157
1158 let add_inherited_methods cmap cdecls func_maps_inherited =
1159 let find_cdecl cname =
1160 try List.find (fun cdecl -> cdecl.cname = cname) cdecls
1161 with | Not_found -> raise Not_found
1162 in
1163 let update_with_inherited_methods cname cmap =
1164 let fmap = StringMap.find cname func_maps_inherited in
1165 let cdecl = find_cdecl cname in
1166 {
1167     field_map = cmap.field_map;
1168     func_map = fmap;
1169     constructor_map = cmap.constructor_map;
1170     reserved_map = cmap.reserved_map;

```

```

1171         cdecl = cdecl;
1172     }
1173     in
1174     let add_updated_cmap cname cmap accum = StringMap.add cname
1175     ↪ (update_with_inherited_methods cname cmap) accum in
1176     StringMap.fold add_updated_cmap cmaps StringMap.empty
1177
1178     let handle_inheritance cdecls class_maps =
1179     let predecessors = build_inheritance_forest cdecls class_maps in
1180     let cdecls_inherited = inherit_fields_cdecls cdecls predecessors in
1181     let func_maps_inherited = build_func_map_inherited_lookup cdecls_inherited in
1182     ignore(check_cyclical_inheritance cdecls predecessors);
1183     let cmaps_with_inherited_fields = inherit_fields class_maps predecessors in
1184     let cmaps_inherited = add_inherited_methods cmaps_with_inherited_fields cdecls_inherited
1185     ↪ func_maps_inherited in
1186     cmaps_inherited, cdecls_inherited
1187
1188     let generate_struct_indexes cdecls =
1189     let cdecl_handler index cdecl =
1190     Hashtbl.add struct_indexes cdecl.cname index
1191     in
1192     List.iteri cdecl_handler cdecls
1193
1194     (* Main method for analyzer *)
1195     let analyze filename program = match program with
1196     Program(includes, classes) ->
1197     (* Include code from external files *)
1198     let cdecls = process_includes filename includes classes in
1199     ignore(generate_struct_indexes cdecls);
1200
1201     (* Add built-in functions *)
1202     let reserved = add_reserved_functions in
1203     (* Generate the class_maps for look up in checking functions *)
1204     let class_maps = build_class_maps reserved cdecls in
1205     let class_maps, cdecls = handle_inheritance cdecls class_maps in
1206     let sast = convert_cdecls_to_sast class_maps reserved cdecls in
1207     sast

```

ast.ml

```

1  type op = Add | Sub | Mult | Div | Equal | Neq | Less | Leq | Greater | Geq | And | Not |
    ↪ Or | Mod
2  type scope = Private | Public
3  type primitive = Int_t | Float_t | Void_t | Bool_t | Char_t | Objecttype of string |
    ↪ ConstructorType | Null_t
4  type datatype = Arraytype of primitive * int | Datatype of primitive | Any
5
6  type extends = NoParent | Parent of string
7  type fname = Constructor | FName of string
8  type formal = Formal of datatype * string | Many of datatype
9
10 type expr =
11 Int_Lit of int
12 |
13   Boolean_Lit of bool
14 |
15   Float_Lit of float
16 |
17   String_Lit of string
18 |
19   Char_Lit of char
20 |
21   This
22 |
23   Id of string
24 |
25   Binop of expr * op * expr
26 |
27   Assign of expr * expr
28 |
29   Noexpr
30 |
31   ArrayCreate of datatype * expr list
32 |
33   ArrayAccess of expr * expr list
34 |
35   ObjAccess of expr * expr
36 |
37   Call of string * expr list
38 |
39   ObjectCreate of string * expr list
40 |
41   ArrayPrimitive of expr list
42 |
43   Unop of op * expr
44 |
45   Null
46 |
47   Delete of expr
48
49 type stmt =
50 Block of stmt list
51 |
52   Expr of expr
53 |
54   Return of expr
55 |
56   If of expr * stmt * stmt
57 |
58   For of expr * expr * expr * stmt
59 |
60   While of expr * stmt
61 |
62   Break
63 |
64   Continue
65 |
66   Local of datatype * string * expr
67
68 type field = Field of scope * datatype * string
69 type include_stmt = Include of string
70
71 type func_decl = {

```

```
46     scope : scope;
47     fname : fname;
48     returnType : datatype;
49     formals : formal list;
50     body : stmt list;
51     overrides : bool;
52     root_cname : string option;
53 }
54
55 type cbody = {
56     fields : field list;
57     constructors : func_decl list;
58     methods : func_decl list;
59 }
60
61 type class_decl = {
62     cname : string;
63     extends : extends;
64     cbody: cbody;
65 }
66
67 type program = Program of include_stmt list * class_decl list
```


bindings.c

```
1  #include <stdio.h>
2  #include <stdlib.h>
3
4  #define INIT_SIZE 100
5
6  struct s {
7      int x;
8      int y;
9  };
10
11 char* input() {
12     int initial_size = INIT_SIZE;
13     char* str = malloc(initial_size);
14     int index = 0;
15     char tmp = '0';
16     while((tmp = getchar()) != '\n') {
17         if(index >= initial_size - 1) {
18             str = realloc(str, initial_size *= 2);
19         }
20         str[index++] = tmp;
21     }
22     str[index] = '\0';
23     return str;
24 }
25
26 void rec_init(long* arr, int curr_offset, int* static_offsets, int* indexes, int* dims,
27 ↪ int dimc, int dim_curr) {
28
29     //Assign length
30     arr[curr_offset] = dims[dim_curr];
31
32     if(dim_curr + 1 >= dimc)
33         return;
34
35     //Determine the static offset and the dynamic offset
36     int static_offset = static_offsets[dim_curr];
37     int dynamic_offset = 0;
38     for(int i = 0; i < dim_curr; i++) {
39         int tmp = indexes[i];
40         for(int j = i + 1; j <= dim_curr; j++) {
41             tmp *= dims[j];
42         }
43         dynamic_offset += tmp;
44     }
45
46     //Iterate through position and initialize subarrays
47     //Set local indexes to pointers to the subarrays
```

```
47     for(int i = 0; i < dims[dim_curr]; i++) {
48         int offset = (static_offset + (dynamic_offset + i) * (dims[dim_curr + 1]
49             ↪ + 1));
50
51         long* sub = arr + offset;
52         arr[curr_offset + 1 + i] = (long) sub;
53
54         indexes[dim_curr] = i;
55         rec_init(arr, offset, static_offsets, indexes, dims, dimc, dim_curr + 1);
56     }
57 }
58 long* init_arr(int* dims, int dimc) {
59
60     int static_offsets[dimc];
61     int total = 0;
62     for(int i = 0; i < dimc; i++) {
63         static_offsets[i] = 1;
64         for(int j = 0; j < i; j++) {
65             static_offsets[i] *= dims[j];
66         }
67         static_offsets[i] *= dims[i] + 1;
68         static_offsets[i] += total;
69         total = static_offsets[i];
70     }
71
72     int indexes[dimc];
73     for(int i = 0; i < dimc; i++) {
74         indexes[i] = 0;
75     }
76
77     //Get total length of array
78     int length = 0;
79     for(int i = 0; i < dimc; i++) {
80         int tmp = 1;
81         for(int j = i - 1; j >= 0; j--) {
82             tmp *= dims[j];
83         }
84         tmp *= dims[i] + 1;
85         length += tmp;
86     }
87
88     //Malloc array
89     long* arr = malloc(length);
90
91     //Set all values to 0 initially
92     for(int i = 0 ; i < length; i++) {
93         arr[i] = 0;
94     }
```

```
95
96     //Initialize the entire array
97     rec_init(arr, 0, static_offsets, indexes, dims, dimc, 0);
98
99     return arr;
100 }
101
102 // int main() {
103
104     //         //Array creation
105     //         int dims[5] = {2, 3, 4, 5, 6};
106     //         int dimc = 5;
107
108     //         long* arr = init_arr(dims, dimc);
109
110     //         //Get total length of array
111     //         int length = 0;
112     //         for(int i = 0; i < dimc; i++) {
113     //             //             int tmp = 1;
114     //             //             for(int j = i - 1; j >= 0; j--) {
115     //                 //                 tmp *= dims[j];
116     //                 //             }
117     //             //             tmp *= dims[i] + 1;
118     //             //             length += tmp;
119     //         }
120
121     //         for(int i = 0; i < length; i++) {
122     //             //             printf("val: %ld | addr: %ld\n", arr[i], (long) arr +
123     //                 ↪ i);
124     //             //             }
125     //         printf("\n");
126     //     }
```

```
* =====
* Code Generation
*=====*)

open Lllvm
open Ast
open Sast
open Analyzer
open Exceptions
open Batteries
open Hashtbl
open Conf


open Lllvm.MemoryBuffer
open Lllvm_bitreader


let context = global_context ()
let the_module = create_module context "Dice Codegen"
let builder = builder context
let named_values:(string, llvalue) Hashtbl.t = Hashtbl.create 50
let named_params:(string, llvalue) Hashtbl.t = Hashtbl.create 50
let struct_types:(string, lltype) Hashtbl.t = Hashtbl.create 10
let struct_field_indexes:(string, int) Hashtbl.t = Hashtbl.create 50


let i32_t = i32_type context;;
let i8_t = i8_type context;;
let f_t = double_type context;;
let i1_t = i1_type context;;
let str_t = pointer_type i8_t;;
let i64_t = i64_type context;;
let void_t = void_type context;;


let str_type = Arraytype(Char_t, 1)


let (br_block) = ref (block_of_value (const_int i32_t 0))
let (cont_block) = ref (block_of_value (const_int i32_t 0))
let is_loop = ref false


let debug = fun s ->
print_endline ("^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^s");
dump_module the_module;
print_endline ("^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^s");
()


let rec get_ptr_type datatype = match datatype with
Arraytype(t, 0) -> get_type (Datatype(t))
|          Arraytype(t, 1) -> pointer_type (get_type (Datatype(t)))
```

```

48 |         Arraytype(t, i) -> pointer_type (get_ptr_type (Arraytype(t, (i-1))))
49 |         _ -> raise(Exceptions.InvalidStructType "Array Pointer Type")
50
51 and find_struct name =
52 try Hashtbl.find struct_types name
53 with | Not_found -> raise(Exceptions.InvalidStructType name)
54
55 and get_type (datatype:Ast.datatype) = match datatype with
56 Datatype(Int_t) -> i32_t
57 |   Datatype(Float_t) -> f_t
58 |   Datatype(Bool_t) -> i1_t
59 |   Datatype(Char_t) -> i8_t
60 |   Datatype(Void_t) -> void_t
61 |   Datatype(Null_t) -> i32_t
62 |   Datatype(Objecttype(name)) -> pointer_type(find_struct name)
63 |   Arraytype(t, i) -> get_ptr_type (Arraytype(t, (i)))
64 |   d -> raise(Exceptions.InvalidStructType (Utils.string_of_datatype d))
65
66 (* cast will return an llvalue of the desired type *)
67 (* The commented out casts are unsupported actions in Dice *)
68 let cast lhs rhs lhsType rhsType llbuilder =
69 match (lhsType, rhsType) with
70 (* int to, __ ) ( using const_sitofp for signed ints *)
71 (Datatype(Int_t), Datatype(Int_t))                -> (lhs, rhs),
72   ↪ Datatype(Int_t)
73 |   (Datatype(Int_t), Datatype(Char_t))                ->
74   ↪ (build_uitofp lhs i8_t "tmp" llbuilder, rhs), Datatype(Char_t)
75 (* /           (Datatype(Int_t), Datatype(Bool_t))                ->
76   ↪ (lhs, const_zext rhs i32_t) *)
77 |   (Datatype(Int_t), Datatype(Float_t))                -> (build_sitofp lhs f_t
78   ↪ "tmp" llbuilder, rhs), Datatype(Float_t)
79
80 (* char to, __ ) ( using uitofp since char isn't signed *)
81 |   (Datatype(Char_t), Datatype(Int_t))                -> (lhs, build_uitofp rhs
82   ↪ i8_t "tmp" llbuilder), Datatype(Char_t)
83 |   (Datatype(Char_t), Datatype(Char_t))                -> (lhs, rhs),
84   ↪ Datatype(Char_t)
85 (* /           (Datatype(Char_t), Datatype(Bool_t))                -> (lhs,
86   ↪ const_zext rhs i8_t) *)
87 (* /           (Datatype(Char_t), Datatype(Float_t))                ->
88   ↪ (const_uitofp lhs f_t, rhs) *)
89
90 (* bool to, __ ) ( zext fills the empty bits with zeros, zero extension *)
91 (* /           (Datatype(Bool_t), Datatype(Int_t))                -> (const_zext
92   ↪ lhs i32_t, rhs) *)
93 (* /           (Datatype(Bool_t), Datatype(Char_t))                -> (const_zext
94   ↪ lhs i8_t, rhs) *)
95 |   (Datatype(Bool_t), Datatype(Bool_t))                -> (lhs, rhs),
96   ↪ Datatype(Bool_t)

```

```

86  (* /          (Datatype(Bool_t), Datatype(Float_t))          ->
   ↪  (const_uitofp lhs f_t, rhs) *)
87
88  (* float to, __) ( using fptosi for signed ints *)
89  |  (Datatype(Float_t), Datatype(Int_t))          -> (lhs, build_sitofp
   ↪  rhs f_t "tmp" llbuilder), Datatype(Float_t)
90  (* /          (Datatype(Float_t), Datatype(Char_t))          -> (lhs,
   ↪  const_uitofp rhs f_t) *)
91  (* /          (Datatype(Float_t), Datatype(Bool_t))          -> (lhs,
   ↪  const_uitofp rhs f_t) *)
92  |  (Datatype(Float_t), Datatype(Float_t))          -> (lhs, rhs),
   ↪  Datatype(Float_t)
93
94  |  Datatype(Objecttype(d)), Datatype(Null_t)          -> (lhs, rhs), lhsType
95  |  Datatype(Null_t), Datatype(Objecttype(d))          -> (rhs, lhs), rhsType
96  |  Datatype(Objecttype(d)), t          ->
   ↪  raise(Exceptions.CanOnlyCompareObjectsWithNull(d, (Utils.string_of_datatype t)))
97
98  |  Arraytype(d, s), Datatype(Null_t)          -> (lhs, rhs),
   ↪  lhsType
99  |  Datatype(Null_t), Arraytype(d, s)          -> (rhs, lhs),
   ↪  rhsType
100 |  Arraytype(d, _), t          ->
   ↪  raise(Exceptions.CanOnlyCompareArraysWithNull(Utils.string_of_primitive d,
   ↪  (Utils.string_of_datatype t)))
101
102 |  _
   ↪
   ↪  raise (Exceptions.CannotCastTypeException(Utils.string_of_datatype lhsType,
   ↪  Utils.string_of_datatype rhsType))
103
104 let rec handle_binop e1 op e2 d llbuilder =
105   (* Get the types of e1 and e2 *)
106   let type1 = Analyzer.get_type_from_sexpr e1 in
107   let type2 = Analyzer.get_type_from_sexpr e2 in
108
109   (* Generate llvalues from e1 and e2 *)
110
111   let e1 = codegen_sexpr llbuilder e1 in
112   let e2 = codegen_sexpr llbuilder e2 in
113
114   let float_ops op e1 e2 =
115     match op with
116     Add          -> build_fadd e1 e2 "flt_addtmp" llbuilder
117     |  Sub          -> build_fsub e1 e2 "flt_subtmp" llbuilder
118     |  Mult         -> build_fmul e1 e2 "flt_multmp" llbuilder
119     |  Div          -> build_fdiv e1 e2 "flt_divtmp" llbuilder
120     |  Mod          -> build_frem e1 e2 "flt_sremtmp" llbuilder
121     |  Equal        -> build_fcmp Fcmp.Oeq e1 e2 "flt_eqtmp" llbuilder

```

```

122 |         Neq                -> build_fcmp Fcmp.One e1 e2 "flt_neqtmp" llbuilder
123 |         Less              -> build_fcmp Fcmp.Ult e1 e2 "flt_lesstmp" llbuilder
124 |         Leq               -> build_fcmp Fcmp.Ole e1 e2 "flt_leqtmp" llbuilder
125 |         Greater           -> build_fcmp Fcmp.Ogt e1 e2 "flt_sgttmp" llbuilder
126 |         Geq               -> build_fcmp Fcmp.Oge e1 e2 "flt_sgetmp" llbuilder
127 |         _                  -> raise Exceptions.FloatOpNotSupported
128
129 in
130
131 (* chars are considered ints, so they will use int_ops as well*)
132 let int_ops op e1 e2 =
133 match op with
134 Add                -> build_add e1 e2 "addtmp" llbuilder
135 |         Sub          -> build_sub e1 e2 "subtmp" llbuilder
136 |         Mult         -> build_mul e1 e2 "multmp" llbuilder
137 |         Div          -> build_sdiv e1 e2 "divtmp" llbuilder
138 |         Mod          -> build_srem e1 e2 "sremtmp" llbuilder
139 |         Equal        -> build_icmp Icmp.Eq e1 e2 "eqtmp" llbuilder
140 |         Neq          -> build_icmp Icmp.Ne e1 e2 "neqtmp" llbuilder
141 |         Less         -> build_icmp Icmp.Slt e1 e2 "lesstmp" llbuilder
142 |         Leq          -> build_icmp Icmp.Sle e1 e2 "leqtmp" llbuilder
143 |         Greater      -> build_icmp Icmp.Sgt e1 e2 "sgtmp" llbuilder
144 |         Geq          -> build_icmp Icmp.Sge e1 e2 "sgetmp" llbuilder
145 |         And          -> build_and e1 e2 "andtmp" llbuilder
146 |         Or           -> build_or e1 e2 "ortmp" llbuilder
147 |         _            -> raise Exceptions.IntOpNotSupported
148 in
149
150 let obj_ops op e1 e2 =
151 match op with
152 Equal -> build_is_null e1 "tmp" llbuilder
153 |     Neq -> build_is_not_null e1 "tmp" llbuilder
154 |     _   -> raise (Exceptions.ObjOpNotSupported(Utils.string_of_op op))
155 in
156
157 let (e1, e2), d = cast e1 e2 type1 type2 llbuilder in
158
159 let type_handler d = match d with
160 Datatype(Float_t) -> float_ops op e1 e2
161 | Datatype(Int_t)
162 | Datatype(Bool_t)
163 | Datatype(Char_t) -> int_ops op e1 e2
164 | Datatype(Objecttype(_))
165 | Arraytype(_, _) -> obj_ops op e1 e2
166 | _ -> raise Exceptions.InvalidBinopEvaluationType
167 in
168
169 type_handler d
170

```

```

171 and handle_unop op e d llbuilder =
172   (* Get the type of e *)
173   let eType = Analyzer.get_type_from_sexpr e in
174   (* Get llvalue *)
175   let e = codegen_sexpr llbuilder e in
176
177   let unops op eType e = match (op, eType) with
178   (Sub, Datatype(Int_t))          -> build_neg e "int_unoptmp" llbuilder
179   | (Sub, Datatype(Float_t))      -> build_fneg e "flt_unoptmp" llbuilder
180   | (Not, Datatype(Bool_t))      -> build_not e "bool_unoptmp" llbuilder
181   | _                            -> raise Exceptions.UnopNotSupported in
182
183   let unop_type_handler d = match d with
184   Datatype(Float_t)
185   | Datatype(Int_t)
186   | Datatype(Bool_t)      -> unops op eType e
187   | _ -> raise Exceptions.InvalidUnopEvaluationType
188   in
189
190   unop_type_handler d
191
192   and func_lookup fname =
193   match (lookup_function fname the_module) with
194   None          -> raise (Exceptions.LLVMFunctionNotFound fname)
195   | Some f      -> f
196
197   and codegen_print el llbuilder =
198   let printf = func_lookup "printf" in
199   let tmp_count = ref 0 in
200   let incr_tmp = fun x -> incr tmp_count in
201
202   let map_expr_to_printfexpr expr =
203   let exprType = Analyzer.get_type_from_sexpr expr in
204   match exprType with
205   Datatype(Bool_t) ->
206   incr_tmp ();
207   let tmp_var = "tmp" ^ (string_of_int !tmp_count) in
208   let trueStr = SString_Lit("true") in
209   let falseStr = SString_Lit("false") in
210   let id = SId(tmp_var, str_type) in
211   ignore(codegen_stmt llbuilder (SLocal(str_type, tmp_var, SNoexpr)));
212   ignore(codegen_stmt llbuilder (SIf(expr,
213   SExpr(SAssign(id, trueStr, str_type), str_type),
214   SExpr(SAssign(id, falseStr, str_type), str_type)
215   )));
216   codegen_sexpr llbuilder id
217   | _ -> codegen_sexpr llbuilder expr
218   in
219

```



```

220 let params = List.map map_expr_to_printfexpr el in
221 let param_types = List.map (Analyzer.get_type_from_sexpr) el in
222
223 let map_param_to_string = function
224 Arraytype(Char_t, 1)          -> "%s"
225 |      Datatype(Int_t)         -> "%d"
226 |      Datatype(Float_t)       -> "%f"
227 |      Datatype(Bool_t)        -> "%s"
228 |      Datatype(Char_t)        -> "%c"
229 |      _                       -> raise
    ↪ (Exceptions.InvalidTypePassedToPrintf)
230 in
231 let const_str = List.fold_left (fun s t -> s ^ map_param_to_string t) "" param_types in
232 let s = codegen_sexpr llbuilder (SString_Lit(const_str)) in
233 let zero = const_int i32_t 0 in
234 let s = build_in_bounds_gep s [| zero |] "tmp" llbuilder in
235 build_call printf (Array.of_list (s :: params)) "tmp" llbuilder
236
237 and codegen_func_call fname el d llbuilder =
238 let f = func_lookup fname in
239 let params = List.map (codegen_sexpr llbuilder) el in
240 match d with
241 Datatype(Void_t) -> build_call f (Array.of_list params) "" llbuilder
242 |      _ ->
    build_call f (Array.of_list params) "tmp"
    ↪ llbuilder
243
244 and codegen_sizeof el llbuilder =
245 let type_of = Analyzer.get_type_from_sexpr (List.hd el) in
246 let type_of = get_type type_of in
247 let size_of = size_of type_of in
248 build_bitcast size_of i32_t "tmp" llbuilder
249
250 and codegen_cast el d llbuilder =
251 let cast_malloc_to_objtype lhs currType newType llbuilder = match newType with
252 Datatype(Objecttype(x)) ->
253 let obj_type = get_type (Datatype(Objecttype(x))) in
254 build_pointercast lhs obj_type "tmp" llbuilder
255 |      _ as t -> raise (Exceptions.CannotCastTypeException(Utills.string_of_datatype
    ↪ currType, Utills.string_of_datatype t))
256 in
257 let expr = List.hd el in
258 let t = Analyzer.get_type_from_sexpr expr in
259 let lhs = match expr with
260 |      Sast.SId(id, d) -> codegen_id false false id d llbuilder
261 |      SObjAccess(e1, e2, d) -> codegen_obj_access false e1 e2 d llbuilder
262 |      SArrayAccess(se, sel, d) -> codegen_array_access true se sel d llbuilder
263 |      _ -> codegen_sexpr llbuilder expr
264 in
265 cast_malloc_to_objtype lhs t d llbuilder

```

```

266
267 and codegen_call llbuilder d el = function
268 "print"      -> codegen_print el llbuilder
269 |           "sizeof"      -> codegen_sizeof el llbuilder
270 |           "cast"        -> codegen_cast el d llbuilder
271 |           "malloc"      -> codegen_func_call "malloc" el d llbuilder
272 |           "open"        -> codegen_func_call "open" el d llbuilder
273 |           "write"       -> codegen_func_call "write" el d llbuilder
274 |           "close"       -> codegen_func_call "close" el d llbuilder
275 |           "read"        -> codegen_func_call "read" el d llbuilder
276 |           "lseek"       -> codegen_func_call "lseek" el d llbuilder
277 |           "exit"        -> codegen_func_call "exit" el d llbuilder
278 |           "input"       -> codegen_func_call "input" el d llbuilder
279 |           "getchar"     -> codegen_func_call "getchar" el d llbuilder
280 |           _ as fname    -> raise (Exceptions.UnableToCallFunctionWithoutParent
↳ fname)(* codegen_func_call fname el llbuilder *)
281
282 and codegen_id isDeref checkParam id d llbuilder =
283 if isDeref then
284 try Hashtbl.find named_params id
285 with | Not_found ->
286 try let _val = Hashtbl.find named_values id in
287 build_load _val id llbuilder
288 with | Not_found -> raise (Exceptions.UnknownVariable id)
289 else
290 try Hashtbl.find named_values id
291 with | Not_found ->
292 try
293 let _val = Hashtbl.find named_params id in
294 if checkParam then raise (Exceptions.CannotAssignParam id)
295 else _val
296 with | Not_found -> raise (Exceptions.UnknownVariable id)
297
298 and codegen_assign lhs rhs d llbuilder =
299 let rhsType = Analyzer.get_type_from_sexpr rhs in
300 (* Special case '=' because we don't want to emit the LHS as an
301 * expression. *)
302 let lhs, isObjAccess = match lhs with
303 | Sast.SId(id, d) -> codegen_id false false id d llbuilder, false
304 | SObjAccess(e1, e2, d) -> codegen_obj_access false e1 e2 d llbuilder, true
305 | SArrayAccess(se, sel, d) -> codegen_array_access true se sel d llbuilder, true
306 | _ -> raise Exceptions.AssignLHSMustBeAssignable
307 in
308 (* Codegen the rhs. *)
309 let rhs = match rhs with
310 | Sast.SId(id, d) -> codegen_id false false id d llbuilder
311 | SObjAccess(e1, e2, d) -> codegen_obj_access true e1 e2 d llbuilder
312 | _ -> codegen_sexpr llbuilder rhs
313 in

```

```

314 let rhs = match d with
315 Datatype(Objecttype(_))      ->
316 if isObjAccess then rhs
317 else build_load rhs "tmp" llbuilder
318 |      Datatype(Null_t) -> const_null (get_type d)
319 | _ -> rhs
320 in
321 let rhs = match d, rhsType with
322 Datatype(Char_t), Datatype(Int_t) -> build_uitofp rhs i8_t "tmp" llbuilder
323 |      Datatype(Int_t), Datatype(Char_t) -> build_uitofp rhs i32_t "tmp" llbuilder
324 |      _ -> rhs
325 in
326 (* Lookup the name. *)
327 ignore(build_store rhs lhs llbuilder);
328 rhs
329
330 and deref ptr t llbuilder =
331 build_gep ptr (Array.of_list [ptr]) "tmp" llbuilder
332
333 and codegen_obj_access isAssign lhs rhs d llbuilder =
334 let codegen_func_call param_ty fptr parent_expr el d llbuilder =
335 let match_sexpr se = match se with
336 SId(id, d) -> let isDeref = match d with
337 Datatype(Objecttype(_)) -> false
338 |      _ -> true
339 in codegen_id isDeref false id d llbuilder
340 |      se -> codegen_sexpr llbuilder se
341 in
342 let parent_expr = build_pointercast parent_expr param_ty "tmp" llbuilder in
343 let params = List.map match_sexpr el in
344 match d with
345 Datatype(Void_t) -> build_call fptr (Array.of_list (parent_expr :: params)) "" llbuilder
346 |      _ -> build_call fptr (Array.of_list (parent_expr :: params)) "tmp" llbuilder
347 in
348 let check_lhs = function
349 SId(s, d)                                -> codegen_id false false s d llbuilder
350 |      SArrayAccess(e, el, d)             -> codegen_array_access false e el d llbuilder
351 |      se                                  -> raise (Exceptions.LHSofRootAccessMustBeIDorFunc
352 ↪ (Utils.string_of_sexpr se))
353 in
354 (* Needs to be changed *)
355 let rec check_rhs isLHS parent_expr parent_type =
356 let parent_str = Utils.string_of_object parent_type in
357 function
358 (* Check fields in parent *)
359 SId(field, d) ->
360 let search_term = (parent_str ^ "." ^ field) in
361 let field_index = Hashtbl.find struct_field_indexes search_term in
362 let _val = build_struct_gep parent_expr field_index field llbuilder in

```

```

362 let _val = match d with
363 Datatype(Objecttype(_)) ->
364 if not isAssign then _val
365 else build_load _val field llbuilder
366 | _ ->
367 if not isAssign then
368 _val
369 else
370 build_load _val field llbuilder
371 in
372 _val
373
374 |          SArrayAccess(e, e1, d) ->
375
376 let ce = check_rhs false parent_expr parent_type e in
377 let index = codegen_sexpr llbuilder (List.hd e1) in
378 let index = match d with
379 Datatype(Char_t) -> index
380 |          _ -> build_add index (const_int i32_t 1) "tmp" llbuilder
381 in
382 let _val = build_gep ce [| index |] "tmp" llbuilder in
383 if isLHS && isAssign
384 then _val
385 else build_load _val "tmp" llbuilder
386
387 (* Check functions in parent *)
388 |          SCall(fname, e1, d, index)          ->
389 let index = const_int i32_t index in
390 let c_index = build_struct_gep parent_expr 0 "cindex" llbuilder in
391 let c_index = build_load c_index "cindex" llbuilder in
392 let lookup = func_lookup "lookup" in
393 let fptr = build_call lookup [| c_index; index |] "fptr" llbuilder in
394 let fptr2 = func_lookup fname in
395 let f_ty = type_of fptr2 in
396 let param1 = param fptr2 0 in
397 let param_ty = type_of param1 in
398 let fptr = build_pointercast fptr f_ty fname llbuilder in
399 let ret = codegen_func_call param_ty fptr parent_expr e1 d llbuilder in
400 let ret = ret
401 (* if not isLHS && not isAssign then
402 build_load ret "tmp" llbuilder
403 else
404 ret *)
405 in
406 ret
407 (* Set parent, check if base is field *)
408 |          SObjAccess(e1, e2, d)          ->
409 let e1_type = Analyzer.get_type_from_sexpr e1 in
410 let e1 = check_rhs true parent_expr parent_type e1 in

```

```

411 let e2 = check_rhs true e1 e1_type e2 in
412 e2
413 | _ as e -> raise (Exceptions.InvalidAccessLHS (Utils.string_of_sexpr e))
414 in
415 let lhs_type = Analyzer.get_type_from_sexpr lhs in
416 match lhs_type with
417 | Arraytype(_, _) ->
418   let lhs = codegen_sexpr llbuilder lhs in
419   let _ = match rhs with
420   | SId("length", _) -> "length"
421   | _ -> raise (Exceptions.CanOnlyAccessLengthOfArray)
422   in
423   let _val = build_gep lhs [| (const_int i32_t 0) |] "tmp" llbuilder in
424   build_load _val "tmp" llbuilder
425 | _ ->
426   let lhs = check_lhs lhs in
427   let rhs = check_rhs true lhs lhs_type rhs in
428   rhs
429
430 and codegen_obj_create fname e1 d llbuilder =
431   let f = func_lookup fname in
432   let params = List.map (codegen_sexpr llbuilder) e1 in
433   let obj = build_call f (Array.of_list params) "tmp" llbuilder in
434   obj
435
436 and codegen_string_lit s llbuilder =
437   if s = "true" then build_global_stringptr "true" "tmp" llbuilder
438   else if s = "false" then build_global_stringptr "false" "tmp" llbuilder
439   else build_global_stringptr s "tmp" llbuilder
440
441 and codegen_array_access isAssign e1 d llbuilder =
442   let index = codegen_sexpr llbuilder (List.hd e1) in
443   let index = match d with
444   | Datatype(Char_t) -> index
445   | _ -> build_add index (const_int i32_t 1) "tmp" llbuilder
446   in
447   let arr = codegen_sexpr llbuilder e in
448   let _val = build_gep arr [| index |] "tmp" llbuilder in
449   if isAssign
450   then _val
451   else build_load _val "tmp" llbuilder
452
453 and initialise_array arr arr_len init_val start_pos llbuilder =
454   let new_block label =
455     let f = block_parent (insertion_block llbuilder) in
456     append_block (global_context ()) label f
457   in
458   let bbcurr = insertion_block llbuilder in
459   let bbcond = new_block "array.cond" in

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```

460 let bbbbody = new_block "array.init" in
461 let bbdone = new_block "array.done" in
462 ignore (build_br bbcond llbuilder);
463 position_at_end bbcond llbuilder;
464
465 (* Counter into the length of the array *)
466 let counter = build_phi [const_int i32_t start_pos, bbcurr] "counter" llbuilder in
467 add_incoming ((build_add counter (const_int i32_t 1) "tmp" llbuilder), bbbbody) counter;
468 let cmp = build_icmp Icmp.Slt counter arr_len "tmp" llbuilder in
469 ignore (build_cond_br cmp bbbbody bbdone llbuilder);
470 position_at_end bbbbody llbuilder;
471
472 (* Assign array position to init_val *)
473 let arr_ptr = build_gep arr [| counter |] "tmp" llbuilder in
474 ignore (build_store init_val arr_ptr llbuilder);
475 ignore (build_br bbcond llbuilder);
476 position_at_end bbdone llbuilder
477
478 and codegen_array_create llbuilder t expr_type el =
479 if(List.length el > 1) then raise(Exceptions.ArrayLargerThan1Unsupported)
480 else
481 match expr_type with
482 Arraytype(Char_t, 1) ->
483 let e = List.hd el in
484 let size = (codegen_sexpr llbuilder e) in
485 let t = get_type t in
486 let arr = build_array_malloc t size "tmp" llbuilder in
487 let arr = build_pointercast arr (pointer_type t) "tmp" llbuilder in
488 (* initialise_array arr size (const_int i32_t 0) 0 llbuilder; *)
489 arr
490 | _ ->
491 let e = List.hd el in
492 let t = get_type t in
493
494 (* This will not work for arrays of objects *)
495 let size = (codegen_sexpr llbuilder e) in
496 let size_t = build_intcast (size_of t) i32_t "tmp" llbuilder in
497 let size = build_mul size_t size "tmp" llbuilder in
498 let size_real = build_add size (const_int i32_t 1) "arr_size" llbuilder in
499
500 let arr = build_array_malloc t size_real "tmp" llbuilder in
501 let arr = build_pointercast arr (pointer_type t) "tmp" llbuilder in
502
503 let arr_len_ptr = build_pointercast arr (pointer_type i32_t) "tmp" llbuilder in
504
505 (* Store length at this position *)
506 ignore(build_store size_real arr_len_ptr llbuilder);
507 initialise_array arr_len_ptr size_real (const_int i32_t 0) 0 llbuilder;
508 arr

```

```

509
510 and codegen_array_prim d el llbuilder =
511 let t = d in
512 let size = (const_int i32_t ((List.length el))) in
513 let size_real = (const_int i32_t ((List.length el) + 1)) in
514 let t = get_type t in
515 let arr = build_array_malloc t size_real "tmp" llbuilder in
516 let arr = build_pointercast arr t "tmp" llbuilder in
517 let size_casted = build_bitcast size t "tmp" llbuilder in
518 ignore(if d = Arraytype(Char_t, 1) then ignore(build_store size_casted arr llbuilder));
519   ↪  (* Store length at this position *)
520   (* initialise_array arr size_real (const_int i32_t 0) 1 llbuilder; *)
521
522 let llvalues = List.map (codegen_sexpr llbuilder) el in
523 List.iteri (fun i llval ->
524 let arr_ptr = build_gep arr [] (const_int i32_t (i+1)) [] "tmp" llbuilder in
525 ignore(build_store llval arr_ptr llbuilder); ) llvalues;
526 arr
527
528 and codegen_delete e llbuilder =
529 let ce = match e with
530 SId(id, d) -> codegen_id false false id d llbuilder
531 | _ -> codegen_sexpr llbuilder e
532 in
533 build_free ce llbuilder
534
535 and codegen_sexpr llbuilder = function
536 SInt_Lit(i) -> const_int i32_t i
537 | SBoolean_Lit(b) -> if b then const_int i1_t 1 else const_int
538   ↪ i1_t 0
539 | SFloat_Lit(f) -> const_float f_t f
540 | SString_Lit(s) -> codegen_string_lit s llbuilder
541 | SChar_Lit(c) -> const_int i8_t (Char.code c)
542 | SId(id, d) -> codegen_id true false id d llbuilder
543 | SBinop(e1, op, e2, d) -> handle_binop e1 op e2 d llbuilder
544 | SAssign(e1, e2, d) -> codegen_assign e1 e2 d llbuilder
545 | SNoexpr -> build_add (const_int i32_t 0) (const_int i32_t 0)
546   ↪ "nop" llbuilder
547 | SArrayCreate(t, el, d) -> codegen_array_create llbuilder t d el
548 | SArrayAccess(e, el, d) -> codegen_array_access false e el d llbuilder
549 | SObjAccess(e1, e2, d) -> codegen_obj_access true e1 e2 d llbuilder
550 | SCall(fname, el, d, _) -> codegen_call llbuilder d el fname
551 | SObjectCreate(id, el, d) -> codegen_obj_create id el d llbuilder
552 | SArrayPrimitive(el, d) -> codegen_array_prim d el llbuilder
553 | SUnop(op, e, d) -> handle_unop op e d llbuilder
554 | SNull -> const_null i32_t
555 | SDelete e -> codegen_delete e
556   ↪ llbuilder

```

```

554 and codegen_if_stmt exp then_ (else_:Sast.sstmt) llbuilder =
555 let cond_val = codegen_sexpr llbuilder exp in
556
557 (* Grab the first block so that we might later add the conditional branch
558 * to it at the end of the function. *)
559 let start_bb = insertion_block llbuilder in
560 let the_function = block_parent start_bb in
561
562 let then_bb = append_block context "then" the_function in
563
564 (* Emit 'then' value. *)
565 position_at_end then_bb llbuilder;
566 let _(* then_val *) = codegen_stmt llbuilder then_ in
567
568 (* Codegen of 'then' can change the current block, update then_bb for the
569 * phi. We create a new name because one is used for the phi node, and the
570 * other is used for the conditional branch. *)
571 let new_then_bb = insertion_block llbuilder in
572
573 (* Emit 'else' value. *)
574 let else_bb = append_block context "else" the_function in
575 position_at_end else_bb llbuilder;
576 let _(* else_val *) = codegen_stmt llbuilder else_ in
577
578 (* Codegen of 'else' can change the current block, update else_bb for the
579 * phi. *)
580 let new_else_bb = insertion_block llbuilder in
581
582
583 let merge_bb = append_block context "ifcont" the_function in
584 position_at_end merge_bb llbuilder;
585 (* let then_bb_val = value_of_block new_then_bb in *)
586 let else_bb_val = value_of_block new_else_bb in
587 (* let incoming = [(then_bb_val, new_then_bb); (else_bb_val, new_else_bb)] in *)
588 (* let phi = build_phi incoming "iftmp" llbuilder in *)
589
590 (* Return to the start block to add the conditional branch. *)
591 position_at_end start_bb llbuilder;
592 ignore (build_cond_br cond_val then_bb else_bb llbuilder);
593
594 (* Set a unconditional branch at the end of the 'then' block and the
595 * 'else' block to the 'merge' block. *)
596 position_at_end new_then_bb llbuilder; ignore (build_br merge_bb llbuilder);
597 position_at_end new_else_bb llbuilder; ignore (build_br merge_bb llbuilder);
598
599 (* Finally, set the builder to the end of the merge block. *)
600 position_at_end merge_bb llbuilder;
601
602 else_bb_val (* phi *)

```



```
603
604 and codegen_for init_ cond_ inc_ body_ llbuilder =
605 let old_val = !is_loop in
606 is_loop := true;
607
608 let the_function = block_parent (insertion_block llbuilder) in
609
610 (* Emit the start code first, without 'variable' in scope. *)
611 let _ = codegen_sexpr llbuilder init_ in
612
613 (* Make the new basic block for the loop header, inserting after current
614 * block. *)
615 let loop_bb = append_block context "loop" the_function in
616 (* Insert maintenance block *)
617 let inc_bb = append_block context "inc" the_function in
618 (* Insert condition block *)
619 let cond_bb = append_block context "cond" the_function in
620 (* Create the "after loop" block and insert it. *)
621 let after_bb = append_block context "afterloop" the_function in
622
623 let _ = if not old_val then
624   cont_block := inc_bb;
625   br_block := after_bb;
626 in
627
628 (* Insert an explicit fall through from the current block to the
629 * loop_bb. *)
630 ignore (build_br cond_bb llbuilder);
631
632 (* Start insertion in loop_bb. *)
633 position_at_end loop_bb llbuilder;
634
635 (* Emit the body of the loop. This, like any other expr, can change the
636 * current BB. Note that we ignore the value computed by the body, but
637 * don't allow an error *)
638 ignore (codegen_stmt llbuilder body_);
639
640 let bb = insertion_block llbuilder in
641 move_block_after bb inc_bb;
642 move_block_after inc_bb cond_bb;
643 move_block_after cond_bb after_bb;
644 ignore (build_br inc_bb llbuilder);
645
646 (* Start insertion in loop_bb. *)
647 position_at_end inc_bb llbuilder;
648 (* Emit the step value. *)
649 let _ = codegen_sexpr llbuilder inc_ in
650 ignore (build_br cond_bb llbuilder);
651
```

```

652 position_at_end cond_bb llbuilder;
653
654 let cond_val = codegen_sexpr llbuilder cond_ in
655 ignore (build_cond_br cond_val loop_bb after_bb llbuilder);
656
657 (* Any new code will be inserted in after_bb. *)
658 position_at_end after_bb llbuilder;
659
660 is_loop := old_val;
661
662 (* for expr always returns 0.0. *)
663 const_null f_t
664
665 and codegen_while cond_ body_ llbuilder =
666 let null_sexpr = SInt_Lit(0) in
667 codegen_for null_sexpr cond_ null_sexpr body_ llbuilder
668
669 and codegen_alloca datatype var_name expr llbuilder =
670 let t = match datatype with
671 Datatype(Objecttype(name)) -> find_struct name
672 | _ -> get_type datatype
673 in
674 let alloca = build_alloca t var_name llbuilder in
675 Hashtbl.add named_values var_name alloca;
676 let lhs = SId(var_name, datatype) in
677 match expr with
678 SNoexpr -> alloca
679 | _ -> codegen_assign lhs expr datatype llbuilder
680
681 and codegen_ret d expr llbuilder =
682 match expr with
683 SId(name, d) ->
684 (match d with
685 | Datatype(Objecttype(_)) -> build_ret (codegen_id false false name d llbuilder)
686   ↳ llbuilder
687 | _ -> build_ret (codegen_id true true name d llbuilder) llbuilder)
688 | SObjAccess(e1, e2, d) -> build_ret (codegen_obj_access true e1 e2 d llbuilder)
689   ↳ llbuilder
690 | SNoexpr -> build_ret_void llbuilder
691 | _ -> build_ret (codegen_sexpr llbuilder expr) llbuilder
692
693 and codegen_break llbuilder =
694 let block = fun () -> !br_block in
695 build_br (block ()) llbuilder
696
697 and codegen_continue llbuilder =
698 let block = fun () -> !cont_block in
699 build_br (block ()) llbuilder
700
701

```

```

699 and codegen_stmt llbuilder = function
700 SBlock s1                                -> List.hd(List.map (codegen_stmt llbuilder) s1)
701 | SExpr(e, d)                             -> codegen_sexpr llbuilder e
702 | SReturn(e, d)                           -> codegen_ret d e llbuilder
703 | SIf (e, s1, s2)                          -> codegen_if_stmt e s1 s2 llbuilder
704 | SFor (e1, e2, e3, s)                     -> codegen_for e1 e2 e3 s llbuilder
705 | SWhile (e, s)                            -> codegen_while e s llbuilder
706 | SBreak                                  -> codegen_break llbuilder
707 | SContinue                               -> codegen_continue llbuilder
708 | SLocal(d, s, e)                         -> codegen_alloca d s e llbuilder
709
710 let codegen_funcstub sfdecl =
711 let fname = (Utils.string_of_fname sfdecl.sfname) in
712 let is_var_arg = ref false in
713 let params = List.rev (List.fold_left (fun l -> (function Formal(t, _) -> get_type t :: l
714   ↪ | _ -> is_var_arg := true; l )) [] sfdecl.sformals) in
714 let fty = if !is_var_arg
715 then var_arg_function_type (get_type sfdecl.sreturnType) (Array.of_list params)
716 else function_type (get_type sfdecl.sreturnType) (Array.of_list params)
717 in
718 define_function fname fty the_module
719
720 let init_params f formals =
721 let formals = Array.of_list (formals) in
722 Array.iteri (fun i a ->
723 let n = formals.(i) in
724 let n = Utils.string_of_formal_name n in
725 set_value_name n a;
726 Hashtbl.add named_params n a;
727 ) (params f)
728
729 let codegen_func sfdecl =
730 Hashtbl.clear named_values;
731 Hashtbl.clear named_params;
732 let fname = (Utils.string_of_fname sfdecl.sfname) in
733 let f = func_lookup fname in
734 let llbuilder = builder_at_end context (entry_block f) in
735 let _ = init_params f sfdecl.sformals in
736 let _ = if sfdecl.overrides then
737 let this_param = Hashtbl.find named_params "this" in
738 let source = Datatype(Objecttype(sfdecl.source)) in
739 let casted_param = build_pointercast this_param (get_type source) "casted" llbuilder in
740 Hashtbl.replace named_params "this" casted_param;
741 in
742 let _ = codegen_stmt llbuilder (SBlock (sfdecl.sbody)) in
743 if sfdecl.sreturnType = Datatype(Void_t)
744 then ignore(build_ret_void llbuilder);
745 ()
746

```

```

747 let codegen_vtbl sdecls =
748 let rt = pointer_type i64_t in
749 let void_pt = pointer_type i64_t in
750 let void_ppt = pointer_type void_pt in
751
752 let f = func_lookup "lookup" in
753 let llbuilder = builder_at_end context (entry_block f) in
754
755 let len = List.length sdecls in
756 let total_len = ref 0 in
757 let sdecl_llvm_arr = build_array_alloca void_ppt (const_int i32_t len) "tmp" llbuilder
  ↪ in
758
759 let handle_sdecl sdecl =
760 let index = Hashtbl.find Analyzer.struct_indexes sdecl.sname in
761 let len = List.length sdecl.sfuncs in
762 let sfdecl_llvm_arr = build_array_alloca void_pt (const_int i32_t len) "tmp" llbuilder in
763
764 let handle_fdecl i sfdecl =
765 let fptr = func_lookup (Utils.string_of_fname sfdecl.sfname) in
766 let fptr = build_pointercast fptr void_pt "tmp" llbuilder in
767
768 let ep = build_gep sfdecl_llvm_arr [| (const_int i32_t i) |] "tmp" llbuilder in
769 ignore(build_store fptr ep llbuilder);
770 in
771 List.iteri handle_fdecl sdecl.sfuncs;
772 total_len := !total_len + len;
773
774 let ep = build_gep sdecl_llvm_arr [| (const_int i32_t index) |] "tmp" llbuilder in
775 ignore(build_store sfdecl_llvm_arr ep llbuilder);
776 in
777 List.iter handle_sdecl sdecls;
778
779 let c_index = param f 0 in
780 let f_index = param f 1 in
781 set_value_name "c_index" c_index;
782 set_value_name "f_index" f_index;
783
784 if !total_len == 0 then
785 build_ret (const_null rt) llbuilder
786 else
787 let vtbl = build_gep sdecl_llvm_arr [| c_index |] "tmp" llbuilder in
788 let vtbl = build_load vtbl "tmp" llbuilder in
789 let fptr = build_gep vtbl [| f_index |] "tmp" llbuilder in
790 let fptr = build_load fptr "tmp" llbuilder in
791
792 build_ret fptr llbuilder
793
794 let codegen_library_functions () =

```

```

795 (* C Std lib functions *)
796 let printf_ty = var_arg_function_type i32_t [| pointer_type i8_t |] in
797 let _ = declare_function "printf" printf_ty the_module in
798 let malloc_ty = function_type (str_t) [| i32_t |] in
799 let _ = declare_function "malloc" malloc_ty the_module in
800 let open_ty = function_type i32_t [| (pointer_type i8_t); i32_t |] in
801 let _ = declare_function "open" open_ty the_module in
802 let close_ty = function_type i32_t [| i32_t |] in
803 let _ = declare_function "close" close_ty the_module in
804 let read_ty = function_type i32_t [| i32_t; pointer_type i8_t; i32_t |] in
805 let _ = declare_function "read" read_ty the_module in
806 let write_ty = function_type i32_t [| i32_t; pointer_type i8_t; i32_t |] in
807 let _ = declare_function "write" write_ty the_module in
808 let lseek_ty = function_type i32_t [| i32_t; i32_t; i32_t |] in
809 let _ = declare_function "lseek" lseek_ty the_module in
810 let exit_ty = function_type void_t [| i32_t |] in
811 let _ = declare_function "exit" exit_ty the_module in
812 let realloc_ty = function_type str_t [| str_t; i32_t |] in
813 let _ = declare_function "realloc" realloc_ty the_module in
814 let getchar_ty = function_type (i32_t) [| |] in
815 let _ = declare_function "getchar" getchar_ty the_module in
816
817 (* Dice defined functions *)
818 let fty = function_type (pointer_type i64_t) [| i32_t; i32_t |] in
819 let _ = define_function "lookup" fty the_module in
820 let rec_init_ty = function_type void_t [| (pointer_type i64_t); i32_t; (pointer_type
  ↪ i32_t); (pointer_type i32_t); (pointer_type i32_t); i32_t; i32_t |] in
821 let _ = declare_function "rec_init" rec_init_ty the_module in
822 let init_arr_ty = function_type (pointer_type i64_t) [| (pointer_type i32_t); i32_t |] in
823 let _ = declare_function "init_arr" init_arr_ty the_module in
824 let input_ty = function_type str_t [| |] in
825 let _ = declare_function "input" input_ty the_module in
826 ()
827
828 let codegen_struct_stub s =
829 let struct_t = named_struct_type context s.scname in
830 Hashtbl.add struct_types s.scname struct_t
831
832 let codegen_struct s =
833 let struct_t = Hashtbl.find struct_types s.scname in
834 let type_list = List.map (function Field(_, d, _) -> get_type d) s.sfields in
835 let name_list = List.map (function Field(_, _, s) -> s) s.sfields in
836
837 (* Add key field to all structs *)
838 let type_list = i32_t :: type_list in
839 let name_list = ".key" :: name_list in
840
841 let type_array = (Array.of_list type_list) in
842 List.iteri (fun i f ->

```

```

843 let n = s.scname ^ "." ^ f in
844 Hashtbl.add struct_field_indexes n i;
845 ) name_list;
846 struct_set_body struct_t type_array true
847
848 let init_args argv args argc llbuilder =
849 let new_block label =
850 let f = block_parent (insertion_block llbuilder) in
851 append_block (global_context ()) label f
852 in
853 let bbcurr = insertion_block llbuilder in
854 let bbcond = new_block "args.cond" in
855 let bbbody = new_block "args.init" in
856 let bbdone = new_block "args.done" in
857 ignore (build_br bbcond llbuilder);
858 position_at_end bbcond llbuilder;
859
860 (* Counter into the length of the array *)
861 let counter = build_phi [const_int i32_t 0, bbcurr] "counter" llbuilder in
862 add_incoming ((build_add counter (const_int i32_t 1) "tmp" llbuilder), bbbody) counter;
863 let cmp = build_icmp Icmp.Slt counter argc "tmp" llbuilder in
864 ignore (build_cond_br cmp bbbody bbdone llbuilder);
865 position_at_end bbbody llbuilder;
866
867 (* Assign array position to init_val *)
868 let arr_ptr = build_gep args [| counter |] "tmp" llbuilder in
869 let argv_val = build_gep argv [| counter |] "tmp" llbuilder in
870 let argv_val = build_load argv_val "tmp" llbuilder in
871 ignore (build_store argv_val arr_ptr llbuilder);
872 ignore (build_br bbcond llbuilder);
873 position_at_end bbdone llbuilder
874
875 let construct_args argc argv llbuilder =
876 let str_pt = pointer_type str_t in
877 let size_real = build_add argc (const_int i32_t 1) "arr_size" llbuilder in
878
879 let arr = build_array_malloc str_pt size_real "args" llbuilder in
880 let arr = build_pointercast arr str_pt "args" llbuilder in
881 let arr_len_ptr = build_pointercast arr (pointer_type i32_t) "argc_len" llbuilder in
882 let arr_1 = build_gep arr [| const_int i32_t 1 |] "arr_1" llbuilder in
883
884 (* Store length at this position *)
885 ignore (build_store argc arr_len_ptr llbuilder);
886 ignore (init_args argv arr_1 argc llbuilder);
887 arr
888
889 let codegen_main main =
890 Hashtbl.clear named_values;
891 Hashtbl.clear named_params;

```

```
892 let fty = function_type i32_t [| i32_t; pointer_type str_t |] in
893 let f = define_function "main" fty the_module in
894 let llbuilder = builder_at_end context (entry_block f) in
895
896 let argc = param f 0 in
897 let argv = param f 1 in
898 set_value_name "argc" argc;
899 set_value_name "argv" argv;
900 let args = construct_args argc argv llbuilder in
901 Hashtbl.add named_params "args" args;
902
903 let _ = codegen_stmt llbuilder (SBlock (main.sbody)) in
904 build_ret (const_int i32_t 0) llbuilder
905
906 let linker filename =
907 let llctx = Llvm.global_context () in
908 let llmem = Llvm.MemoryBuffer.of_file filename in
909 let llm = Llvm_bitreader.parse_bitcode llctx llmem in
910 ignore(Llvm_linker.link_modules the_module llm)
911
912 let codegen_sprogram sprogram =
913 let _ = codegen_library_functions () in
914 let _ = List.map (fun s -> codegen_struct_stub s) sprogram.classes in
915 let _ = List.map (fun s -> codegen_struct s) sprogram.classes in
916 let _ = List.map (fun f -> codegen_funcstub f) sprogram.functions in
917 let _ = List.map (fun f -> codegen_func f) sprogram.functions in
918 let _ = codegen_main sprogram.main in
919 let _ = codegen_vtbl sprogram.classes in
920 let _ = linker Conf.bindings_path in
921 the_module
922
923 (* Need to handle assignment of two different types *)
924 (* Need to handle private/public access *)
```

conf.ml

```
1 let bindings_path = "_includes/bindings.bc"
2 let stdlib_path = "_includes/stdlib.dice"
```


dice.ml

```

1  open Llvml
2  open Llvml_analysis
3  open Analyzer
4  open Utils
5  open Ast
6  open Yojson
7  open Exceptions
8  open Filepath
9
10 type action = Tokens | TokenEndl | PrettyPrint | Ast | Sast | Compile | CompileToFile |
    ↳ Help
11
12 let get_action = function
13   "-tendl"      -> TokenEndl
14   | "-t"         -> Tokens
15   | "-p"         -> PrettyPrint
16   | "-ast"       -> Ast
17   | "-sast"      -> Sast
18   | "-h"         -> Help
19   | "-c"         -> Compile
20   | "-f"         -> CompileToFile
21   | _ as s       -> raise (Exceptions.InvalidCompilerArgument s)
22
23 let check_single_argument = function
24   "-h"          -> Help, ""
25   | "-tendl"
26   | "-t"
27   | "-p"
28   | "-ast"
29   | "-sast"
30   | "-c"
31   | "-f"         -> raise (Exceptions.NoFileArgument)
32   | _ as s       -> CompileToFile, s
33
34 let dice_name filename =
35   let basename = Filename.basename filename in
36   let filename = Filename.chop_extension basename in
37   filename ^ ".ll"
38
39 let help_string = (
40   "Usage: dice [optional-option] <source file>\n" ^
41   "optional-option:\n" ^
42   "\t-h: Print help text\n" ^
43   "\t-tendl: Prints tokens with newlines intact\n" ^
44   "\t-t: Prints token stream\n" ^
45   "\t-p: Pretty prints Ast as a program\n" ^
46   "\t-ast: Prints abstract syntax tree as json\n" ^

```

```

47 "\t-sast: Prints semantically checked syntax tree as json\n" ^
48 "\t-c: Compiles source\n" ^
49 "\t-f: Compiles source to file (<filename>.<ext> -> <filename>.ll)\n" ^
50 "Option defaults to \"-f"\n"
51 )
52
53 let _ =
54 ignore(Printexc.record_backtrace true);
55 try
56 let action, filename =
57 if Array.length Sys.argv = 1 then
58 Help, ""
59 else if Array.length Sys.argv = 2 then
60 check_single_argument (Sys.argv.(1))
61 else if Array.length Sys.argv = 3 then
62 get_action Sys.argv.(1), Sys.argv.(2)
63 else raise (Exceptions.InvalidNumberCompilerArguments (Array.length Sys.argv))
64 in
65 (* Added fun () -> <x> so that each is evaluated only when requested *)
66 let filename = Filepath.realpath filename in
67 let file_in = fun () -> open_in filename in
68 let lexbuf = fun () -> Lexing.from_channel (file_in ()) in
69 let token_list = fun () -> Processor.build_token_list (lexbuf ()) in
70 let program = fun () -> Processor.parser filename (token_list ()) in
71 let sprogram = fun () -> Analyzer.analyze filename (program ()) in
72 let llm = fun () -> Codegen.codegen_sprogram (sprogram ()) in
73 (* let _ = Llvmanalysis.assert_valid_module llm in *)
74 match action with
75 Help -> print_string help_string
76 | Tokens -> print_string (Utils.token_list_to_string
77   ↪ (token_list ()))
78 | TokenEndl -> print_string (Utils.token_list_to_string_endl
79   ↪ (token_list ()))
80 | Ast -> print_string (pretty_to_string
81   ↪ (Utils.print_tree (program ())))
82 | Sast -> print_string (pretty_to_string
83   ↪ (Utils.map_sprogram_to_json (sprogram ())))
84 | PrettyPrint -> print_string (Utils.string_of_program (program ()))
85 | Compile -> dump_module (llm ())
86 | CompileToFile -> print_module (dice_name filename) (llm ())
87 with
88 Exceptions.IllegalCharacter(filename, c, ln) ->
89 print_string
90 (
91 "In \"^ filename ^ "\", Illegal Character, '\" ^
92 Char.escaped c ^ '\", line \" ^ string_of_int ln ^ "\n"
93 )
94 | Exceptions.UnmatchedQuotation(ln) -> print_endline("Unmatched
95   ↪ Quotation, line \" ^ string_of_int ln)

```

```

91 |         Exceptions.IllegalToken(tok)                -> print_endline("Illegal token "
    ↪ ^ tok)
92 |         Exceptions.MissingEOF                        -> print_endline("Missing
    ↪ EOF")
93 |         Parsing.Parse_error ->
94 print_string
95 (
96 "File \"\" ^ !Processor.filename ^ "\", " ^
97 "line " ^ string_of_int !Processor.line_number ^ ", " ^
98 "character " ^ string_of_int !Processor.char_num ^ ", " ^
99 "Syntax Error, token " ^ Utils.string_of_token !Processor.last_token ^ "\n"
100 )
101
102 |         Exceptions.InvalidNumberCompilerArguments i -> print_endline ("Invalid
    ↪ argument passed " ^ (string_of_int i)); print_string help_string
103 |         Exceptions.InvalidCompilerArgument s        -> print_endline ("Invalid
    ↪ argument passed " ^ s); print_string help_string
104 |         Exceptions.NoFileArgument                    ->
    ↪ print_string ("Must include file argument\n" ^ help_string)
105
106 |         Exceptions.IncorrectNumberOfArgumentsException ->
    ↪ print_endline("Incorrect number of arguments passed to function")
107 |         Exceptions.ConstructorNotFound(cname)
    ↪ -> print_endline("Constructor" ^ cname ^ "
    ↪ not found")
108 |         Exceptions.DuplicateClassName(cname)        ->
    ↪ print_endline("Class " ^ cname ^ " not found")
109 |         Exceptions.DuplicateField
    ↪ ->
    ↪ print_endline("Duplicate field defined")
110 |         Exceptions.DuplicateFunction(fname)          ->
    ↪ print_endline("Duplicate function defined " ^ fname)
111 |         Exceptions.DuplicateConstructor
    ↪ -> print_endline("Duplicate
    ↪ constructor found")
112 |         Exceptions.DuplicateLocal(lname)
    ↪ -> print_endline("Duplicate local
    ↪ variable defined " ^ lname)
113 |         Exceptions.UndefinedClass(cname)
    ↪ -> print_endline("Undefined class " ^
    ↪ cname)
114 |         Exceptions.UnknownIdentifier(id)
    ↪ -> print_endline("Unkown identifier "
    ↪ ^ id)
115 |         Exceptions.InvalidBinopExpression(binop)     ->
    ↪ print_endline("Invalid binary expression " ^ binop)
116 |         Exceptions.InvalidIfStatementType
    ↪ -> print_endline("Invalid type passed
    ↪ to if statement, must be bool")

```

```

117 |         Exceptions.InvalidForStatementType
    ↪                                     -> print_endline("Invalid type passed
    ↪ to for loop, must be bool")
118 |         Exceptions.ReturnTypeMismatch(t1, t2)                                     ->
    ↪ print_endline("Incorrect return type " ^ t1 ^ " expected " ^ t2)
119 |         Exceptions.MainNotDefined
    ↪                                     ->
    ↪ print_endline("Main not found in program")
120 |
    ↪         Exceptions.MultipleMainsDefined                                     ->
    ↪ print_endline("Multiple mains defined, can only define 1")
121 |         Exceptions.InvalidWhileStatementType                                     ->
    ↪ print_endline("Invalid type passed to while loop, must be bool")
122 |         Exceptions.LocalAssignTypeMismatch(t1, t2)                             ->
    ↪ print_endline("Invalid assignment of " ^ t1 ^ " to " ^ t2)
123 |         Exceptions.InvalidUnaryOperation
    ↪                                     -> print_endline("Invalid unary
    ↪ operator")
124 |         Exceptions.AssignmentTypeMismatch(t1, t2)                             ->
    ↪ print_endline("Invalid assignment of " ^ t1 ^ " to " ^ t2)
125 |         Exceptions.FunctionNotFound(fname, scope)                             ->
    ↪ print_endline("function " ^ fname ^ " not found in scope " ^ scope)
126 |         Exceptions.UndefinedID(id)
    ↪                                     ->
    ↪ print_endline("Undefined id " ^ id)
127 |         Exceptions.InvalidAccessLHS(t)
    ↪                                     -> print_endline("Invalid LHS
    ↪ expression of dot operator with " ^ t)
128 |         Exceptions.LHSofRootAccessMustBeIDorFunc(lhs)                         ->
    ↪ print_endline("Dot operator expects ID, not " ^ lhs)
129 |         Exceptions.ObjAccessMustHaveObjectType(t)                             ->
    ↪ print_endline("Can only dereference objects, not " ^ t)
130 |         Exceptions.UnknownIdentifierForClass(c, id)                           ->
    ↪ print_endline("Unknown id " ^ id ^ " for class " ^ c)
131 |         Exceptions.CannotUseReservedFuncName(f)                               ->
    ↪ print_endline("Cannot use name " ^ f ^ " because it is reserved")
132 |         Exceptions.InvalidArrayPrimitiveConsecutiveTypes(t1,t2)               ->
    ↪ print_endline("Array primitive types must be equal, not " ^ t1 ^ " " ^ t2)
133 |         Exceptions.InvalidArrayPrimitiveType(t)                               ->
    ↪ print_endline("Array primitive type invalid, " ^ t)
134 |         Exceptions.MustPassIntegerTypeToArrayCreate                           ->
    ↪ print_endline("Only integer types can be passed to an array initializer")
135 |         Exceptions.ArrayInitTypeInvalid(t)
    ↪                                     -> print_endline("Only integer types
    ↪ can be passed to an array initializer, not " ^ t)
136 |         Exceptions.MustPassIntegerTypeToArrayAccess                           ->
    ↪ print_endline("Only integer types can be passed to an array access")
137 |         Exceptions.ArrayAccessInvalidParamLength(o,a)                         ->
    ↪ print_endline("Only arrays can have access to length, not " ^ o ^ " " ^ a)

```

```

138 |         Exceptions.ArrayAccessExpressionNotArray(a)                                ->
    ↪ print_endline("This expression is not an array " ^ a)
139 |         Exceptions.CanOnlyAccessLengthOfArray
    ↪                                     -> print_endline("Can only access the length
    ↪ of an array")
140 |         Exceptions.CanOnlyDeleteObjectsOrArrays                                ->
    ↪ print_endline("Can only delete objects or arrays")
141 |         Exceptions.CannotAccessLengthOfCharArray                                ->
    ↪ print_endline("Cannot access the length of a char array")
142 |         Exceptions.AllNonVoidFunctionsMustEndWithReturn(f)                    ->
    ↪ print_endline("Non-void function " ^ f ^ " does not end in return")
143 |         Exceptions.CyclicalDependencyBetween(c1, c2)                          ->
    ↪ print_endline("Class " ^ c1 ^ " and " ^ c2 ^ " have a cylical dependence")
144 |         Exceptions.CannotAccessPrivateFieldInNonProperScope(f, cp, cc) ->
    ↪ print_endline("Cannot access private field " ^ f ^ " in scope " ^ cp ^ " from object
    ↪ " ^ cc)
145 |         Exceptions.CannotCallBreakOutsideOfLoop                                ->
    ↪ print_endline("Cannot call break outside of loop")
146 |         Exceptions.CannotCallContinueOutsideOfLoop                            ->
    ↪ print_endline("Cannot call continue outside of loop")
147 |         Exceptions.CannotAccessPrivateFunctionInNonProperScope(f, cp, cc) ->
    ↪ print_endline("Cannot access private function " ^ f ^ " in scope " ^ cp ^ " from
    ↪ object " ^ cc)
148 |         Exceptions.CannotPassNonInheritedClassesInPlaceOfOthers(c1, c2)        ->
    ↪ print_endline("Cannot pass non-inherited classe" ^ c1 ^ " to parameter " ^ c2)
149 |         Exceptions.IncorrectTypePassedToFunction(id, t)
    ↪                                     -> print_endline("Canot pass type " ^ t ^ "
    ↪ to " ^ id)
150 |         Exceptions.IncorrectNumberOfArguments(f, a1, a2) -> print_endline("Cannot pass
    ↪ " ^ string_of_int a1 ^ " args when expecting " ^ string_of_int a2 ^ " in " ^ f)
151 |         Exceptions.ClassIsNotExtendedBy(c1, c2)                                ->
    ↪ print_endline("Class " ^ c1 ^ " not extended by " ^ c2)
152 |
153 |         Exceptions.InvalidTypePassedToPrintf                                ->
    ↪ print_endline("Invalid type passed to print")
154 |         Exceptions.InvalidBinaryOperator                                        ->
    ↪ print_endline("Invalid binary operator")
155 |         Exceptions.UnknownVariable(id)
    ↪                                     -> print_endline("Unknown variable "
    ↪ ^ id)
156 |         Exceptions.AssignLHSMustBeAssignable                                ->
    ↪ print_endline("Assignment lhs must be assignable")
157 |         Exceptions.CannotCastTypeException(t1, t2)                            ->
    ↪ print_endline("Cannot cast " ^ t1 ^ " to " ^ t2)
158 |         Exceptions.InvalidBinopEvaluationType                                ->
    ↪ print_endline("Invalid binary expression evaluation type")
159 |         Exceptions.FloatOpNotSupported
    ↪                                     -> print_endline("Float operation not
    ↪ supported")

```

```

160 |         Exceptions.IntOpNotSupported                                ->
    ↪ print_endline("Integer operation not supported")
161 |         Exceptions.LLVMFunctionNotFound(f)                        ->
    ↪ print_endline("LLVM function " ^ f ^ " not found")
162 |         Exceptions.InvalidStructType(t)                            ->
    ↪ print_endline("Invalid structure type " ^ t)
163 |         Exceptions.UnableToCallFunctionWithoutParent(f)           ->
    ↪ print_endline("Unable to call function " ^ f ^ " without parent")
164 |         Exceptions.CannotAssignParam(p)                            ->
    ↪ print_endline("Cannot assign to param " ^ p)
165 |         Exceptions.InvalidUnopEvaluationType                       ->
    ↪ print_endline("Invalid unary expression evaluation type")
166 |         Exceptions.UnopNotSupported                                ->
    ↪ print_endline("Unary operator not supported")
167 |         Exceptions.ArrayLargerThan1Unsupported                    ->
    ↪ print_endline("Array dimensions greater than 1 not supported")
168 |         Exceptions.CanOnlyCompareObjectsWithNull(e1, e2)          -> print_endline("Can
    ↪ only compare objects with null " ^ e1 ^ " " ^ e2)
169 |         Exceptions.ObjOpNotSupported(op)                           ->
    ↪ print_endline("Object operator not supported " ^ op)
170 |         Exceptions.CanOnlyCompareArraysWithNull(e1, e2)           -> print_endline("Can
    ↪ only compare arrays with null " ^ e1 ^ " " ^ e2)

```

exceptions.ml

```
1  (* Dice Exceptions *)
2  exception InvalidNumberCompilerArguments of int
3  exception InvalidCompilerArgument of string
4  exception NoFileArgument
5
6  (* Processor Exceptions *)
7  exception MissingEOF
8
9  (* Scanner Exceptions *)
10 exception IllegalCharacter of string * char * int
11 exception UnmatchedQuotation of int
12 exception IllegalToken of string
13
14 (* Analyzer Exceptions *)
15 exception IncorrectNumberOfArgumentsException
16 exception ConstructorNotFound of string
17 exception DuplicateClassName of string
18 exception DuplicateField
19 exception DuplicateFunction of string
20 exception DuplicateConstructor
21 exception DuplicateLocal of string
22 exception UndefinedClass of string
23 exception UnknownIdentifier of string
24 exception InvalidBinopExpression of string
25 exception InvalidIfStatementType
26 exception InvalidForStatementType
27 exception ReturnTypeError of string * string
28 exception MainNotDefined
29 exception MultipleMainsDefined
30 exception InvalidWhileStatementType
31 exception LocalAssignTypeMismatch of string * string
32 exception InvalidUnaryOperation
33 exception AssignmentTypeMismatch of string * string
34 exception FunctionNotFound of string * string
35 exception UndefinedID of string
36 exception InvalidAccessLHS of string
37 exception LHSofRootAccessMustBeIDorFunc of string
38 exception ObjAccessMustHaveObjectType of string
39 exception UnknownIdentifierForClass of string * string
40 exception CannotUseReservedFuncName of string
41 exception InvalidArrayPrimitiveConsecutiveTypes of string * string
42 exception InvalidArrayPrimitiveType of string
43 exception MustPassIntegerTypeToArrayCreate
44 exception ArrayInitTypeInvalid of string
45 exception MustPassIntegerTypeToArrayAccess
46 exception ArrayAccessInvalidParamLength of string * string
47 exception ArrayAccessExpressionNotArray of string
```

```
48 exception CanOnlyAccessLengthOfArray
49 exception CanOnlyDeleteObjectsOrArrays
50 exception CannotAccessLengthOfCharArray
51 exception AllNonVoidFunctionsMustEndWithReturn of string
52 exception CyclicalDependencyBetween of string * string
53 exception CannotAccessPrivateFieldInNonProperScope of string * string * string
54 exception CannotCallBreakOutsideOfLoop
55 exception CannotCallContinueOutsideOfLoop
56 exception CannotAccessPrivateFunctionInNonProperScope of string * string * string
57 exception CannotPassNonInheritedClassesInPlaceOfOthers of string * string
58 exception IncorrectTypePassedToFunction of string * string
59 exception IncorrectNumberOfArguments of string * int * int
60 exception ClassIsNotExtendedBy of string * string
61
62 (* Codegen Exceptions *)
63 exception InvalidTypePassedToPrintf
64 exception InvalidBinaryOperator
65 exception UnknownVariable of string
66 exception AssignLHSMustBeAssignable
67 exception CannotCastTypeException of string * string
68 exception InvalidBinopEvaluationType
69 exception FloatOpNotSupported
70 exception IntOpNotSupported
71 exception LLVMFunctionNotFound of string
72 exception InvalidStructType of string
73 exception UnableToCallFunctionWithoutParent of string
74 exception CannotAssignParam of string
75 exception InvalidUnopEvaluationType
76 exception UnopNotSupported
77 exception ArrayLargerThan1Unsupported
78 exception CanOnlyCompareObjectsWithNull of string * string
79 exception ObjOpNotSupported of string
80 exception CanOnlyCompareArraysWithNull of string * string
```


filepath.ml

```

1  open Filename
2  open Unix
3
4  exception Safe_exception of (string * string list ref)
5
6  let raise_safe fmt =
7  let do_raise msg = raise @@ Safe_exception (msg, ref []) in
8  Printf.ksprintf do_raise fmt
9
10 let reraise_with_context ex fmt =
11 let do_raise context =
12 let () = match ex with
13 | Safe_exception (_, old_contexts) -> old_contexts := context :: !old_contexts
14 | _ -> Printf.eprintf "warning: Attempt to add note '%s' to non-Safe_exception!" context
15 in
16 raise ex
17 in Printf.ksprintf do_raise fmt
18
19 module StringMap = struct
20 include Map.Make(String)
21 let find_nf = find
22 let find_safe key map = try find key map with Not_found -> raise_safe "BUG: Key '%s' not
    ↳ found in StringMap!" key
23 let find key map = try Some (find key map) with Not_found -> None
24 let map_bindings fn map = fold (fun key value acc -> fn key value :: acc) map []
25 end
26
27 type path_component =
28 | Filename of string    (* foo/ *)
29 | ParentDir            (* ../ *)
30 | CurrentDir           (* ./ *)
31 | EmptyComponent       (* / *)
32
33 type filepath = string
34
35
36 let on_windows = Filename.dir_sep <> "/"
37
38 let path_is_absolute path = not (Filename.is_relative path)
39
40 let string_tail s i =
41 let len = String.length s in
42 if i > len then failwith ("String '\" ^ s ^ \"' too short to split at " ^ (string_of_int
    ↳ i))
43 else String.sub s i (len - i)
44
45 let split_path_str path =

```

```

46 let l = String.length path in
47 let is_sep c = (c = '/' || (on_windows && c = '\\')) in
48
49 (* Skip any leading slashes and return the rest *)
50 let rec find_rest i =
51   if i < 1 then (
52     if is_sep path.[i] then find_rest (i + 1)
53     else string_tail path i
54   ) else (
55     ""
56   ) in
57
58 let rec find_slash i =
59   if i < 1 then (
60     if is_sep path.[i] then (String.sub path 0 i, find_rest (i + 1))
61     else find_slash (i + 1)
62   ) else (
63     (path, "")
64   )
65 in
66 find_slash 0
67
68 let split_first path =
69   if path = "" then
70     (CurrentDir, "")
71   else (
72     let (first, rest) = split_path_str path in
73     let parsed =
74       if first = Filename.parent_dir_name then ParentDir
75       else if first = Filename.current_dir_name then CurrentDir
76       else if first = "" then EmptyComponent
77       else Filename first in
78     (parsed, rest)
79   )
80
81 let normpath path : filepath =
82 let rec explode path =
83   match split_first path with
84   | CurrentDir, "" -> []
85   | CurrentDir, rest -> explode rest
86   | first, "" -> [first]
87   | first, rest -> first :: explode rest in
88
89 let rec remove_parents = function
90   | checked, [] -> checked
91   | (Filename _name :: checked), (ParentDir :: rest) -> remove_parents (checked, rest)
92   | checked, (first :: rest) -> remove_parents ((first :: checked), rest) in
93
94 let to_string = function

```

```

95 | Filename name -> name
96 | ParentDir -> Filename.parent_dir_name
97 | EmptyComponent -> ""
98 | CurrentDir -> assert false in
99 String.concat Filename.dir_sep @@ List.rev_map to_string @@ remove_parents ([], explode
   ↪ path)
100
101
102 let abspath path =
103 let (+/) = Filename.concat in
104 normpath (
105 if path_is_absolute path then path
106 else (Sys.getcwd ()) +/ path
107 )
108
109 let realpath path =
110 let (+/) = Filename.concat in    (* Faster version, since we know the path is relative *)
111
112 (* Based on Python's version *)
113 let rec join_realpath path rest seen =
114 (* Printf.printf "join_realpath <%s> + <%s>\n" path rest; *)
115 (* [path] is already a realpath (no symlinks). [rest] is the bit to join to it. *)
116 match split_first rest with
117 | Filename name, rest -> (
118 (* path + name/rest *)
119 let newpath = path +/ name in
120 let link = try Some (Unix.readlink newpath) with Unix.Unix_error _ -> None in
121 match link with
122 | Some target ->
123 (* path + symlink/rest *)
124 begin match StringMap.find newpath seen with
125 | Some (Some cached_path) -> join_realpath cached_path rest seen
126 | Some None -> (normpath (newpath +/ rest), false)    (* Loop; give up *)
127 | None ->
128 (* path + symlink/rest -> realpath(path + target) + rest *)
129 match join_realpath path target (StringMap.add newpath None seen) with
130 | path, false ->
131 (normpath (path +/ rest), false)    (* Loop; give up *)
132 | path, true -> join_realpath path rest (StringMap.add newpath (Some path) seen)
133 end
134 | None ->
135 (* path + name/rest -> path/name + rest (name is not a symlink) *)
136 join_realpath newpath rest seen
137 )
138 | CurrentDir, "" ->
139 (path, true)
140 | CurrentDir, rest ->
141 (* path + ./rest *)
142 join_realpath path rest seen

```

```
143 | ParentDir, rest ->
144 (* path + ../rest *)
145 if String.length path > 0 then (
146 let name = Filename.basename path in
147 let path = Filename.dirname path in
148 if name = Filename.parent_dir_name then
149 join_realpath (path +/ name +/ name) rest seen    (* path/.. + ../rest -> path/../../ +
↳ rest *)
150 else
151 join_realpath path rest seen                        (* path/name + ../rest -> path + rest
↳ *)
152 ) else (
153 join_realpath Filename.parent_dir_name rest seen    (* "" + ../rest -> .. + rest *)
154 )
155 | EmptyComponent, rest ->
156 (* [rest] is absolute; discard [path] and start again *)
157 join_realpath Filename.dir_sep rest seen
158 in
159
160 try
161 if on_windows then
162 abspath path
163 else (
164 fst @@ join_realpath (Sys.getcwd ()) path StringMap.empty
165 )
166 with Safe_exception _ as ex -> reraise_with_context ex "... in realpath(%s)" path
```

Makefile

```
1 TARGET=src/dice
2 LIBS=-I,/usr/lib/ocaml/
3 FLAGS= -j 0 -r -use-ocamlfind -pkg
  ↪ yojson,llvm,llvm.analysis,llvm.bitwriter,llvm.bitreader,llvm.linker,llvm.target,batteries
4 OCAMLBUILD=ocamlbuild
5 OPAM=opam config env
6 CLIBEXT=_includes
7
8
9 all: native
10     @clang-3.7 -c -emit-llvm src/bindings.c
11     @mkdir -p $(CLIBEXT)
12     @mv bindings.bc $(CLIBEXT)/bindings.bc
13     @cp src/stdlib.dice $(CLIBEXT)/stdlib.dice
14     @mv dice.native dice
15     @echo Compilation Complete
16
17 clean:
18     @cd src
19     $(OCAMLBUILD) -clean
20     @cd ..
21     @rm -rf $(CLIBEXT)
22     @echo cleaning complete
23
24 native:
25     @cd src
26     @eval `opam config env`
27     $(OCAMLBUILD) $(FLAGS) $(TARGET).native
28     @cd ..
29
30 byte:
31     $(OCAMLBUILD) $(FLAGS) $(TARGET).byte
32
33 depend:
34     echo "Not needed."
```

parser.mly

```
1  %{  open Ast  %}
2
3  %token CLASS EXTENDS CONSTRUCTOR INCLUDE DOT THIS PRIVATE PUBLIC
4  %token INT FLOAT BOOL CHAR VOID NULL TRUE FALSE
5  %token SEMI LPAREN RPAREN LBRACE RBRACE LBRACKET RBRACKET COMMA
6  %token AND NOT OR PLUS MINUS TIMES DIVIDE ASSIGN MODULO
7  %token EQ NEQ LT GT LEQ GEQ BAR
8  %token RETURN IF ELSE FOR WHILE BREAK CONTINUE NEW DELETE
9  %token <int> INT_LITERAL
10 %token <float> FLOAT_LITERAL
11 %token <string> STRING_LITERAL
12 %token <string> ID
13 %token <char> CHAR_LITERAL
14 %token EOF
15
16 %nonassoc NOELSE
17 %nonassoc ELSE
18 %right ASSIGN
19 %left AND OR
20 %left EQ NEQ
21 %left LT GT LEQ GEQ
22 %left PLUS MINUS
23 %left TIMES DIVIDE MODULO
24 %right NOT
25 %right DELETE
26 %right RBRACKET
27 %left LBRACKET
28 %right DOT
29
30 %start program
31 %type <Ast.program> program
32
33 %%
34
35 program:
36 includes cdecls EOF { Program($1, $2) }
37
38 /*****
39 INCLUDE
40 *****/
41
42 includes:
43 /* nothing */ { [] }
44 |          include_list { List.rev $1 }
45
46 include_list:
47 include_decl          { [$1] }
```

```

48 |         include_list include_decl { $2::$1 }
49
50 include_decl:
51 INCLUDE LPAREN STRING_LITERAL RPAREN SEMI { Include($3) }
52
53
54 /*****
55 CLASSES
56 *****/
57 cdecls:
58 cdecl_list    { List.rev $1 }
59
60 cdecl_list:
61 cdecl         { [$1] }
62 | cdecl_list cdecl { $2::$1 }
63
64 cdecl:
65 CLASS ID LBRACE cbody RBRACE { {
66     cname = $2;
67     extends = NoParent;
68     cbody = $4
69 } }
70 | CLASS ID EXTENDS ID LBRACE cbody RBRACE { {
71     cname = $2;
72     extends = Parent($4);
73     cbody = $6
74 } }
75
76 cbody:
77 /* nothing */ { {
78     fields = [];
79     constructors = [];
80     methods = [];
81 } }
82 | cbody field { {
83     fields = $2 :: $1.fields;
84     constructors = $1.constructors;
85     methods = $1.methods;
86 } }
87 | cbody constructor { {
88     fields = $1.fields;
89     constructors = $2 :: $1.constructors;
90     methods = $1.methods;
91 } }
92 | cbody fdecl { {
93     fields = $1.fields;
94     constructors = $1.constructors;
95     methods = $2 :: $1.methods;
96 } }

```

```

97
98
99  /*****
100  CONSTRUCTORS
101  *****/
102
103  constructor:
104  CONSTRUCTOR LPAREN formals_opt RPAREN LBRACE stmt_list RBRACE {
105      {
106          scope = Public;
107          fname = Constructor;
108          returnType = Datatype(ConstructorType);
109          formals = $3;
110          body = List.rev $6;
111          overrides = false;
112          root_cname = None;
113      }
114  }
115
116  /*****
117  FIELDS
118  *****/
119
120  scope:
121  PRIVATE { Private }
122  |      PUBLIC { Public }
123
124  /* public UserObj name; */
125  field:
126  scope datatype ID SEMI { Field($1, $2, $3) }
127
128  /*****
129  METHODS
130  *****/
131
132  fname:
133  ID { $1 }
134
135  fdecl:
136  scope datatype fname LPAREN formals_opt RPAREN LBRACE stmt_list RBRACE
137  {
138      {
139          scope = $1;
140          fname = FName($3);
141          returnType = $2;
142          formals = $5;
143          body = List.rev $8;
144          overrides = false;
145          root_cname = None;

```



```

146         }
147     }
148
149     /*****
150     FORMALS/PARAMETERS & VARIABLES & ACTUALS
151     *****/
152
153     forms_opt:
154     /* nothing */ { [] }
155     |          formal_list   { List.rev $1 }
156
157     formal_list:
158     formal           { [$1] }
159     |          formal_list COMMA formal { $3 :: $1 }
160
161     formal:
162     datatype ID { Formal($1, $2) }
163
164     actuals_opt:
165     /* nothing */ { [] }
166     |          actuals_list   { List.rev $1 }
167
168     actuals_list:
169     expr           { [$1] }
170     |          actuals_list COMMA expr { $3 :: $1 }
171
172
173     /*****
174     DATATYPES
175     *****/
176     primitive:
177     INT           { Int_t }
178     |          FLOAT           { Float_t }
179     |          CHAR           { Char_t }
180     |          BOOL           { Bool_t }
181     |          VOID           { Void_t }
182
183     name:
184     CLASS ID { Objecttype($2) }
185
186     type_tag:
187     primitive { $1 }
188     |          name           { $1 }
189
190     array_type:
191     type_tag LBRACKET brackets RBRACKET { Arraytype($1, $3) }
192
193     datatype:
194     type_tag { Datatype($1) }

```

```

195 |         array_type { $1 }
196
197 brackets:
198 /* nothing */ { 1 }
199 |         brackets RBRACKET LBRACKET { $1 + 1 }
200
201 /*****
202 EXPRESSIONS
203 *****/
204
205 stmt_list:
206 /* nothing */ { [] }
207 | stmt_list stmt { $2 :: $1 }
208
209 stmt:
210 expr SEMI { Expr($1) }
211 |     RETURN expr SEMI { Return($2) }
212 |     RETURN SEMI { Return(Noexpr) }
213 |     LBRACE stmt_list RBRACE { Block(List.rev $2) }
214 |     IF LPAREN expr RPAREN stmt %prec NOELSE { If($3, $5, Block([Expr(Noexpr)])) }
215 |     IF LPAREN expr RPAREN stmt ELSE stmt { If($3, $5, $7) }
216 |     FOR LPAREN expr_opt SEMI expr_opt SEMI expr_opt RPAREN stmt
217 { For($3, $5, $7, $9) }
218 |     WHILE LPAREN expr RPAREN stmt { While($3, $5) }
219 |     BREAK SEMI { Break }
220 |     CONTINUE SEMI { Continue }
221 |     datatype ID SEMI { Local($1, $2, Noexpr) }
222 |     datatype ID ASSIGN expr SEMI { Local($1, $2, $4) }
223
224 expr_opt:
225 /* nothing */ { Noexpr }
226 |     expr { $1 }
227
228 expr:
229 literals { $1 }
230 |     expr PLUS expr { Binop($1, Add, $3)
231   ↪ }
232 |     expr MINUS expr { Binop($1, Sub, $3)
233   ↪ }
234 |     expr TIMES expr { Binop($1, Mult, $3)
235   ↪ }
236 |     expr DIVIDE expr { Binop($1, Div, $3)
237   ↪ }
238 |     expr EQ expr { Binop($1, Equal, $3)
239   ↪ }
240 |     expr NEQ expr { Binop($1, Neq, $3)
241   ↪ }
242 |     expr LT expr { Binop($1, Less, $3)
243   ↪ }

```

```

237 |      expr LEQ      expr      { Binop($1, Leq,   $3)
    ↳ }
238 |      expr GT      expr      { Binop($1, Greater,
    ↳ $3) }
239 |      expr GEQ      expr      { Binop($1, Geq,   $3)
    ↳ }
240 |      expr AND      expr      { Binop($1, And,   $3)
    ↳ }
241 |      expr MODULO   expr      { Binop($1, Mod,
    ↳ $3)}
242 |      NOT expr      { Unop (Not,
    ↳ $2) }
243 |      expr OR      expr      { Binop($1, Or,    $3)
    ↳ }
244 |      expr DOT      expr      { ObjAccess($1, $3) }
245 |      expr ASSIGN   expr      { Assign($1, $3) }
246 |      DELETE expr    { Delete($2) }
247 |      MINUS expr    { Unop (Sub, $2) }
248 |      ID LPAREN actuals_opt RPAREN { Call($1, $3) }
249 |      NEW ID LPAREN actuals_opt RPAREN { ObjectCreate($2, $4) }
250 |      NEW type_tag bracket_args RBRACKET { ArrayCreate(Datatype($2), List.rev
    ↳ $3) }
251 |      expr bracket_args RBRACKET { ArrayAccess($1, List.rev
    ↳ $2) }
252 |      LPAREN expr RPAREN { $2 }
253
254 bracket_args:
255 LBRACKET expr { [$2] }
256 |      bracket_args RBRACKET LBRACKET expr { $4 :: $1 }
257
258 literals:
259 INT_LITERAL { Int_Lit($1) }
260 | FLOAT_LITERAL { Float_Lit($1) }
261 | TRUE { Boolean_Lit(true) }
262 | FALSE { Boolean_Lit(false) }
263 | STRING_LITERAL { String_Lit($1) }
264 | CHAR_LITERAL { Char_Lit($1) }
265 | THIS { This }
266 | ID { Id($1) }
267 | NULL { Null }
268 | BAR array_prim BAR { ArrayPrimitive($2) }
269
270 /* ARRAY LITERALS */
271
272 array_prim:
273 expr { [$1] }
274 |      array_prim COMMA expr { $3 :: $1 }

```

processor.ml

```
1  open Parser
2
3  type token_attr = {
4      lineno: int;
5      cnum: int;
6  }
7
8  let line_number = ref 1
9  let last_token = ref EOF
10 let char_num = ref 1
11 let filename = ref ""
12
13 let build_token_list lexbuf =
14   Scanner.filename := !filename;
15   let rec helper prev_cnum prev_lineno lexbuf token_list =
16     let token = Scanner.token lexbuf in
17     let lineno = !Scanner.lineno in
18     let cnum = (Lexing.lexeme_start_p lexbuf).Lexing.pos_cnum in
19     let prev_cnum = if lineno > prev_lineno then cnum else prev_cnum in
20     let cnum = cnum - prev_cnum in
21     match token with
22     EOF as eof -> (eof, { lineno = lineno; cnum = cnum })::token_list
23     | t          -> (t, { lineno = lineno; cnum = cnum })::(helper prev_cnum lineno lexbuf
24       ↪ token_list)
25   in helper 0 0 lexbuf []
26
27 let parser filen token_list =
28   let token_list = ref(token_list) in
29   let tokenizer _ =
30     match !token_list with
31     | (head, curr) :: tail ->
32       filename := filen;
33       line_number := curr.lineno;
34       char_num := curr.cnum;
35       last_token := head;
36       token_list := tail;
37       head
38   | [] -> raise (Exceptions.MissingEOF)
39   in
40   let program = Parser.program tokenizer (Lexing.from_string "") in
41   program
```

sast.ml

```

1  open Ast
2
3  type sexpr =
4  SInt_Lit of int
5  |
6    SBoolean_Lit of bool
7  |
8    SFloat_Lit of float
9  |
10   SString_Lit of string
11 |
12   SChar_Lit of char
13 |
14   SId of string * datatype
15 |
16   SBinop of sexpr * op * sexpr * datatype
17 |
18   SAssign of sexpr * sexpr * datatype
19 |
20   SNoexpr
21 |
22   SArrayCreate of datatype * sexpr list * datatype
23 |
24   SArrayAccess of sexpr * sexpr list * datatype
25 |
26   SObjAccess of sexpr * sexpr * datatype
27 |
28   SCall of string * sexpr list * datatype * int
29 |
30   SObjectCreate of string * sexpr list * datatype
31 |
32   SArrayPrimitive of sexpr list * datatype
33 |
34   SUNop of op * sexpr * datatype
35 |
36   SNull
37 |
38   SDelete of sexpr
39
40 type sstmt =
41 SBlock of sstmt list
42 |
43   SExpr of sexpr * datatype
44 |
45   SReturn of sexpr * datatype
46 |
47   SIf of sexpr * sstmt * sstmt
48 |
49   SFor of sexpr * sexpr * sexpr * sstmt
50 |
51   SWhile of sexpr * sstmt
52 |
53   SBreak
54 |
55   SContinue
56 |
57   SLocal of datatype * string * sexpr
58
59 type func_type = User | Reserved
60
61 type sfunc_decl = {
62   sfname : fname;
63   sreturnType : datatype;
64   sformals : formal list;
65   sbody : sstmt list;
66   func_type : func_type;
67   source : string;
68   overrides : bool;
69 }
70
71 type sclass_decl = {
72   scname : string;

```

```
48         sfields : field list;
49         sfuncs: sfunc_decl list;
50     }
51
52     (* Class Declarations / All method declarations / Main entry method *)
53     type sprogram = {
54         classes : sclass_decl list;
55         functions : sfunc_decl list;
56         main : sfunc_decl;
57         reserved : sfunc_decl list;
58     }
```

scanner.mll

```

1  {
2      open Parser
3      let lineno = ref 1
4      let depth = ref 0
5      let filename = ref ""
6
7      let unescape s =
8          Scanf.sscanf ("\"\" ^ s ^ \"\"") "%S%!" (fun x -> x)
9  }
10
11 let alpha = ['a'-'z' 'A'-'Z']
12 let escape = '\\\' ['\\\' ' ' ' ' ' ' 'n' 'r' 't']
13 let escape_char = ' ' (escape) ' '
14 let ascii = ([ ' ' '!' ' #' ' ' [ ' ' ] ' ' '~ ' ])
15 let digit = ['0'-'9']
16 let id = alpha (alpha | digit | '_' ) *
17 let string = ' ' ( (ascii | escape) * as s ) ' '
18 let char = ' ' ( ascii | digit ) ' '
19 let float = (digit+) [ '.' ] digit+
20 let int = digit+
21 let whitespace = [ ' ' '\t' '\r' ]
22 let return = '\n'
23
24 rule token = parse
25 whitespace { token lexbuf }
26 | return      { incr lineno; token lexbuf }
27 | "(*"       { incr depth; comment lexbuf }
28
29 | '('        { LPAREN }
30 | ')'        { RPAREN }
31 | '{'        { LBRACE }
32 | '}'        { RBRACE }
33 | ';'        { SEMI }
34 | ','        { COMMA }
35
36 (* Operators *)
37 | '+'        { PLUS }
38 | '-'        { MINUS }
39 | '*'        { TIMES }
40 | '/'        { DIVIDE }
41 | '%'        { MODULO }
42 | '='        { ASSIGN }
43 | "=="       { EQ }
44 | "!="       { NEQ }
45 | '<'        { LT }
46 | "<="       { LEQ }
47 | ">"        { GT }

```

```

48 | ">="      { GEQ }
49 | "and"     { AND }
50 | "or"      { OR }
51 | "not"     { NOT }
52 | ' .'      { DOT }
53 | '['       { LBRACKET }
54 | ']'       { RBRACKET }
55 | '|'       { BAR }
56
57 (* Branch Control *)
58 | "if"      { IF }
59 | "else"    { ELSE }
60 | "for"     { FOR }
61 | "while"   { WHILE }
62 | "return"  { RETURN }
63
64 (* Data Types *)
65 | "int"     { INT }
66 | "float"   { FLOAT }
67 | "bool"    { BOOL }
68 | "char"    { CHAR }
69 | "void"    { VOID }
70 | "null"    { NULL }
71 | "true"    { TRUE }
72 | "false"   { FALSE }
73
74 (* Classes *)
75 | "class"   { CLASS }
76 | "constructor" { CONSTRUCTOR }
77 | "public"  { PUBLIC }
78 | "private" { PRIVATE }
79 | "extends" { EXTENDS }
80 | "include" { INCLUDE }
81 | "this"    { THIS }
82 | "break"   { BREAK }
83 | "continue" { CONTINUE }
84 | "new"     { NEW }
85 | "delete"  { DELETE }
86
87 | int as lxm          { INT_LITERAL(int_of_string lxm) }
88 | float as lxm        { FLOAT_LITERAL(float_of_string lxm) }
89 | char as lxm         { CHAR_LITERAL( String.get lxm 1 ) }
90 | escape_char as lxm { CHAR_LITERAL( String.get (unescape lxm) 1) }
91 | string              { STRING_LITERAL(unescape s) }
92 | id as lxm           { ID(lxm) }
93 | eof                 { EOF }
94
95 | '""'               { raise (Exceptions.UnmatchedQuotation(!lineno)) }
96 | _ as illegal      { raise (Exceptions.IllegalCharacter(!filename, illegal, !lineno)) }

```

```
97
98 and comment = parse
99 return      { incr lineno; comment lexbuf }
100 |          "*"      { decr depth; if !depth > 0 then comment lexbuf else token lexbuf }
101 |          "("      { incr depth; comment lexbuf }
102 |          _        { comment lexbuf }
```

stdlib.dice

```
1  class Integer {
2
3      private int my_int;
4
5      constructor(int input) {
6          this.my_int = input;
7      }
8
9      public int num() {
10         return this.my_int;
11     }
12
13
14     public char toChar(int digit) {
15
16         if (digit == 0) {
17             return '0';
18         } else if (digit == 1) {
19             return '1';
20         } else if (digit == 2) {
21             return '2';
22         } else if (digit == 3) {
23             return '3';
24         } else if (digit == 4) {
25             return '4';
26         } else if (digit == 5) {
27             return '5';
28         } else if (digit == 6) {
29             return '6';
30         } else if (digit == 7) {
31             return '7';
32         } else if (digit == 8) {
33             return '8';
34         } else if (digit == 9) {
35             return '9';
36         }
37
38         return 'z';
39     }
40
41
42
43
44
45     public class String toString() {
46
47         (* integer cannot be greater than 10 digits in 32 bit *)
```

```
48     int temp = this.my_int;
49     int i = 0;
50     char[] str = new char[9];
51
52     int digit = temp % 10;
53     str[i] = this.toChar(digit);
54     i = i + 1;
55     temp = temp / 10;
56     while (temp > 0) {
57
58         digit = temp % 10;
59         str[i] = this.toChar(digit);
60         temp = temp / 10;
61         i = i + 1;
62     }
63
64     str[i] = 0;
65     class String newString = new String(str);
66     class String a = newString.reverse();
67     return newString.reverse();
68 }
69 }
70
71
72
73 class String {
74
75     private char[] my_string;
76     private int length;
77
78     constructor(char[] input) {
79
80         this.my_string = this.copy_internal(input);
81
82         this.length = this.length();
83     }
84
85     (* PRIVATE CLASSES ----- *)
86
87     private int length_internal(char[] input) {
88         int length = 0;
89
90         while(input[length] != 0) {
91             length = length + 1;
92         }
93
94         return length;
95     }
96 }
```

```
97     private char[] copy_internal(char[] input) {
98
99         char[] newString = new char[this.length_internal(input) + 1];
100
101         int i = 0;
102         for (; input[i] != 0; i = i + 1) {
103             newString[i] = input[i];
104         }
105
106         newString[i] = 0;
107         return newString;
108     }
109
110     (* PUBLIC CLASSES ----- *)
111
112     public char[] string() {
113         return this.my_string;
114     }
115
116     public char getChar(int index) {
117
118         return this.my_string[index];
119     }
120
121     public int length() {
122
123         int length = 0;
124
125         while(this.my_string[length] != 0){
126             length = length + 1;
127         }
128
129         return length;
130     }
131
132     public int toInteger() {
133
134         char[] temp = this.string();
135         int ndigit = 0;
136         int i;
137         int j;
138         for (i = 0; i < this.length; i = i + 1) {
139
140             int exp = 1;
141             int xdigit = this.toDigit(temp[i]);
142             for (j = 0; j < (this.length-i-1); j = j + 1) {
143                 exp = exp * 10;
144             }
145             xdigit = xdigit * exp;
```

```
146         ndigit = ndigit + xdigit;
147     }
148
149     return ndigit;
150 }
151
152 public int toDigit(char digit) {
153
154     if (digit == '0') {
155         return 0;
156     } else if (digit == '1') {
157         return 1;
158     } else if (digit == '2') {
159         return 2;
160     } else if (digit == '3') {
161         return 3;
162     } else if (digit == '4') {
163         return 4;
164     } else if (digit == '5') {
165         return 5;
166     } else if (digit == '6') {
167         return 6;
168     } else if (digit == '7') {
169         return 7;
170     } else if (digit == '8') {
171         return 8;
172     } else if (digit == '9') {
173         return 9;
174     }
175
176     return -1;
177 }
178
179
180 public class String copy(class String input) {
181
182     char[] newArray = this.copy_internal(input.string());
183     class String newString = new String(newArray);
184     return newString;
185 }
186
187 public int indexOf(char x) {
188
189     int i = 0;
190     for (; this.getChar(i) != x and this.getChar(i) != 0; i = i + 1) {
191     }
192
193     (* If the char was not found, return -1 *)
194     if (i == this.length()) {
```

```
195         return -1;
196     }
197
198     return i;
199 }
200
201 public class String reverse() {
202
203     class String newString;
204
205     char[] temp = new char[this.length + 1];
206     int i = this.length;
207     for (; i > 0; i = i - 1) {
208
209         temp[this.length - i] = this.getChar(i-1);
210     }
211     temp[this.length] = 0;
212     newString = new String(temp);
213     return newString;
214 }
215
216 public class String concat(class String temp) {
217
218     char[] temparray = new char[this.length() + temp.length() + 1];
219
220     (* Copy over the current string into a new char array *)
221     int i = 0;
222     for (; this.getChar(i) != 0; i = i + 1) {
223         temparray[i] = this.getChar(i);
224     }
225
226     (* Append the new string *)
227     int j = 0;
228     for (; temp.getChar(j) != 0; j = j + 1) {
229         temparray[i+j] = temp.getChar(j);
230     }
231
232     temparray[this.length() + temp.length()] = 0;
233     class String newString = new String(temparray);
234     return newString;
235 }
236
237 public bool compare(class String check) {
238
239     if (check.length != this.length) {
240         return false;
241     }
242
243     int i = 0;
```

```
244
245     for (; i < check.length(); i = i + 1) {
246
247         if (check.getChar(i) != this.getChar(i)) {
248             return false;
249         }
250     }
251
252     return true;
253 }
254
255 public bool contains(class String check) {
256
257
258     if (this.length < check.length) {
259         return false;
260     } else if (this.compare(check)) {
261         return true;
262     } else {
263
264         int diff = this.length - check.length + 1;
265         int i;
266         int j;
267         for ( i = 0; i < diff; i = i + 1)
268
269         for ( j = 0; j < check.length; j = j + 1) {
270
271             if (this.getChar(i+j) != check.getChar(j)) {
272                 break;
273             }
274
275             if (j == check.length - 1) {
276                 return true;
277             }
278         }
279     }
280     return false;
281 }
282
283 public void free() {
284
285     delete(this.my_string);
286 }
287
288 }
289
290
291
292 class File {
```

```
293
294     private class String filePath;
295     private bool isWriteEnabled;
296     private int fd;
297
298     constructor(char[] path, bool isWriteEnabled) {
299
300         this.filePath = new String(path);
301         this.isWriteEnabled = isWriteEnabled;
302         class String a = this.filePath;
303         this.fd = this.openfile(a, this.isWriteEnabled);
304         if (this.fd < 0) {
305             print("open failed");
306             exit(1);
307         }
308     }
309
310     (* PRIVATE CLASSES ----- *)
311
312     private int openfile(class String path, bool isWriteEnabled) {
313
314         if (isWriteEnabled) {
315             (* 2 is the value for O_RDWR *)
316             return open(path.string(), 2);
317         }
318
319         (* 0 is the value for O_RDONLY *)
320         return open(path.string(), 0);
321     }
322
323     (* PUBLIC CLASSES ----- *)
324
325     public void closefile() {
326
327         if (close(this.fd) < 0) {
328             print("close failed");
329         }
330     }
331
332     public char[] readfile(int bytes) {
333
334         char[] buf = new char[bytes];
335
336         int ret = read(this.fd, buf, bytes);
337
338         if (ret < 0) {
339             print("read failed");
340         }
341     }
```



```
342         return buf;
343     }
344
345     public int writefile(char[] buf, int offset) {
346
347         class String temp = new String(buf);
348         int err;
349         (* seek to desired offset from beginning of file *)
350         if (offset > 0) {
351             err = lseek(this.fd, offset, 0);
352         } else if (offset == -1) {
353             err = lseek(this.fd, 0, 0);
354         } else {
355             (* Seek to the end of the file by default *)
356             err = lseek(this.fd, 0, 2);
357         }
358
359         if (err < 0) {
360             print("seek failed");
361         }
362
363         err = write(this.fd, temp.string(), temp.length());
364         if (err < 0) {
365             print("write failed");
366         }
367         return err;
368     }
369
370 }
```

utils.ml

```

1  (* Pretty Printer *)
2  open Ast
3  open Sast
4  open Parser
5  open Processor
6  open Yojson
7
8  let save file string =
9  let channel = open_out file in
10 output_string channel string;
11 close_out channel
12
13 let replace input output =
14 Str.global_replace (Str.regexp_string input) output
15
16 (* Print data types *)
17
18 let string_of_scope = function
19 Public      -> "public"
20 |          Private -> "private"
21
22 let string_of_primitive = function
23 Int_t                -> "int"
24 |          Float_t    -> "float"
25 |          Void_t     -> "void"
26 |          Bool_t     -> "bool"
27 |          Char_t     -> "char"
28 |          Objecttype(s) -> "class " ^ s
29 |          ConstructorType -> "constructor"
30 |          Null_t      -> "null"
31
32 let string_of_object = function
33 Datatype(Objecttype(s)) -> s
34 |          _ -> ""
35
36 let rec print_brackets = function
37 1 -> "[]"
38 |          a -> "[" ^ print_brackets (a - 1)
39
40 let string_of_datatype = function
41 Arraytype(p, i) -> (string_of_primitive p) ^ (print_brackets i)
42 |          Datatype(p) -> (string_of_primitive p)
43 |          Any -> "Any"
44
45 (* Print expressions *)
46
47 let string_of_op = function

```

```

48 Add                                -> "+"
49 |      Sub                          -> "-"
50 |      Mult                         -> "*"
51 |      Div                          -> "/"
52 |      Equal                       -> "=="
53 |      Neq                         -> "!="
54 |      Less                        -> "<"
55 |      Leq                         -> "<="
56 |      Greater                     -> ">"
57 |      Geq                         -> ">="
58 |      And                         -> "and"
59 |      Not                         -> "not"
60 |      Or                          -> "or"
61 |      Mod                         -> "%"
62
63 let rec string_of_bracket_expr = function
64 []                                -> ""
65 |      head :: tail                -> "[" ^ (string_of_expr head) ^ "]" ^
  ↪ (string_of_bracket_expr tail)
66 and string_of_array_primitive = function
67 []                                -> ""
68 |      [last]                     -> (string_of_expr last)
69 |      head :: tail                -> (string_of_expr head) ^ ", " ^
  ↪ (string_of_array_primitive tail)
70 and string_of_expr = function
71 Int_Lit(i)                        -> string_of_int i
72 |      Boolean_Lit(b)              -> if b then "true" else "false"
73 |      Float_Lit(f)                -> string_of_float f
74 |      String_Lit(s)                -> "\"" ^ (String.escaped s) ^ "\""
75 |      Char_Lit(c)                  -> Char.escaped c
76 |      This                        -> "this"
77 |      Id(s)                       -> s
78 |      Binop(e1, o, e2)             -> (string_of_expr e1) ^ " " ^ (string_of_op o)
  ↪ ^ " " ^ (string_of_expr e2)
79 |      Assign(e1, e2)               -> (string_of_expr e1) ^ " = " ^
  ↪ (string_of_expr e2)
80 |      Noexpr                       -> ""
81 |      ObjAccess(e1, e2)            -> (string_of_expr e1) ^ "." ^ (string_of_expr
  ↪ e2)
82 |      Call(f, el)                  -> f ^ "(" ^ String.concat ", "
  ↪ (List.map string_of_expr el) ^ ")"
83 |      ArrayPrimitive(el)           -> "[" ^ (string_of_array_primitive el) ^ "]"
84 |      Unop(op, e)                  -> (string_of_op op) ^ "(" ^
  ↪ string_of_expr e ^ ")"
85 |      Null                         -> "null"
86 |      ArrayCreate(d, el)           -> "new " ^ string_of_datatype d ^ string_of_bracket_expr
  ↪ el
87 |      ArrayAccess(e, el)           -> (string_of_expr e) ^ (string_of_bracket_expr el)

```

```

88 |   ObjectCreate(s, el)          -> "new " ^ s ^ "(" ^ String.concat ", " (List.map
   ↪   string_of_expr el) ^ ")"
89 |   Delete(e)                   -> "delete (" ^ (string_of_expr e) ^
   ↪   ")"
90 ;;
91
92 let rec string_of_bracket_sexpr = function
93 | []                           -> ""
94 | head :: tail                 -> "[" ^ (string_of_sexpr head) ^ "]" ^
   ↪   (string_of_bracket_sexpr tail)
95 and string_of_sarray_primitive = function
96 | []                           -> ""
97 | [last]                      -> (string_of_sexpr last)
98 | head :: tail                -> (string_of_sexpr head) ^ ", " ^
   ↪   (string_of_sarray_primitive tail)
99 and string_of_sexpr = function
100 SInt_Lit(i)                   -> string_of_int i
101 | SBoolean_Lit(b)              -> if b then "true" else "false"
102 | SFloat_Lit(f)                -> string_of_float f
103 | SString_Lit(s)               -> "\"" ^ (String.escaped s) ^
   ↪   "\""
104 | SChar_Lit(c)                 -> Char.escaped c
105 | SId(s, _)                    -> s
106 | SBinop(e1, o, e2, _)         -> (string_of_sexpr e1) ^ " " ^
   ↪   (string_of_op o) ^ " " ^ (string_of_sexpr e2)
107 | SAssign(e1, e2, _)          -> (string_of_sexpr e1) ^ " = " ^
   ↪   (string_of_sexpr e2)
108 | SNoexpr                      -> ""
109 | SObjAccess(e1, e2, _)        -> (string_of_sexpr e1) ^ "." ^
   ↪   (string_of_sexpr e2)
110 | SCall(f, el, _, _)           -> f ^ "(" ^ String.concat ", "
   ↪   (List.map string_of_sexpr el) ^ ")"
111 | SArrayPrimitive(el, _)       -> "|" ^ (string_of_sarray_primitive el) ^
   ↪   "|"
112 | SUNop(op, e, _)              -> (string_of_op op) ^ "(" ^
   ↪   string_of_sexpr e ^ ")"
113 | SNull                        -> "null"
114 | SArrayCreate(d, el, _)       -> "new " ^ string_of_datatype d ^
   ↪   string_of_bracket_sexpr el
115 | SArrayAccess(e, el, _)       -> (string_of_sexpr e) ^ (string_of_bracket_sexpr el)
116 | SObjectCreate(s, el, _)      -> "new " ^ s ^ "(" ^ String.concat ", " (List.map
   ↪   string_of_sexpr el) ^ ")"
117 | SDelete(e)                  -> "delete (" ^
   ↪   (string_of_sexpr e) ^ ")"
118 ;;
119
120 let string_of_local_expr = function
121 Noexpr -> ""
122 | e          -> " = " ^ string_of_expr e

```

```

123
124 (* Print statements *)
125
126 let rec string_of_stmt indent =
127 let indent_string = String.make indent '\t' in
128 let get_stmt_string = function
129
130 Block(stmts)                                ->
131 indent_string ^ "{\n" ^
132     String.concat "" (List.map (string_of_stmt (indent+1)) stmts) ^
133     indent_string ^ "}\n"
134
135 | Expr(expr)                                ->
136 indent_string ^ string_of_expr expr ^ ";\n";
137
138 | Return(expr)                                ->
139 indent_string ^ "return " ^ string_of_expr expr ^ ";\n";
140
141 | If(e, s, Block([Expr(Noexpr)]))            ->
142 indent_string ^ "if (" ^ string_of_expr e ^ ")\n" ^
143 (string_of_stmt (indent+1) s)
144
145 | If(e, s1, s2)                                ->
146 indent_string ^ "if (" ^ string_of_expr e ^ ")\n" ^
147 string_of_stmt (indent+1) s1 ^
148 indent_string ^ "else\n" ^
149 string_of_stmt (indent+1) s2
150
151 | For(e1, e2, e3, s)                            ->
152 indent_string ^ "for (" ^ string_of_expr e1 ^ " ; " ^ string_of_expr e2 ^ " ; " ^
153     ↪ string_of_expr e3 ^ ")\n" ^
154 string_of_stmt (indent) s
155
156 | While(e, s)                                    ->
157 indent_string ^ "while (" ^ string_of_expr e ^ ")\n" ^
158 string_of_stmt (indent) s
159
160 | Break                                            -> indent_string ^ "break;\n"
161 | Continue                                        -> indent_string ^ "continue;\n"
162 | Local(d, s, e)                                -> indent_string ^ string_of_datatype d ^ " "
163     ↪ ^ s ^ string_of_local_expr e ^ ";\n"
164 in get_stmt_string
165
166 let string_of_local_sexpr = function
167 SNoexpr                                -> ""
168 | e                                    -> " = " ^ string_of_sexpr e
169
170 let rec string_of_sstmt indent =
171 let indent_string = String.make indent '\t' in

```

```

170 let get_stmt_string = function
171
172   SBlock(stmts)                                ->
173   indent_string ^ "{\n" ^
174     String.concat "" (List.map (string_of_sstmt (indent+1)) stmts) ^
175     indent_string ^ "}\n"
176
177   | SExpr(expr, _)                             ->
178   indent_string ^ string_of_sexpr expr ^ ";\n";
179
180   | SReturn(expr, _)                           ->
181   indent_string ^ "return " ^ string_of_sexpr expr ^ ";\n";
182
183   | SIf(e, s, SBlock([SExpr(SNoexpr, _)]))      ->
184   indent_string ^ "if (" ^ string_of_sexpr e ^ ")\n" ^
185   (string_of_sstmt (indent+1) s)
186
187   | SIf(e, s1, s2)                             ->
188   indent_string ^ "if (" ^ string_of_sexpr e ^ ")\n" ^
189   string_of_sstmt (indent+1) s1 ^
190   indent_string ^ "else\n" ^
191   string_of_sstmt (indent+1) s2
192
193   | SFor(e1, e2, e3, s)                         ->
194   indent_string ^ "for (" ^ string_of_sexpr e1 ^ " ; " ^ string_of_sexpr e2 ^ " ; " ^
195   ↪ string_of_sexpr e3 ^ ")\n" ^
196   string_of_sstmt (indent) s
197
198   | SWhile(e, s)                               ->
199   indent_string ^ "while (" ^ string_of_sexpr e ^ ")\n" ^
200   string_of_sstmt (indent) s
201
202   | SBreak                                     -> indent_string ^ "break;\n"
203   | SContinue                                -> indent_string ^ "continue;\n"
204   | SLocal(d, s, e)                          -> indent_string ^ string_of_datatype d ^ " "
205   ↪ ^ s ^ string_of_local_sexpr e ^ ";\n"
206
207 in get_stmt_string
208
209 (* Print Function *)
210
211 let string_of_fname = function
212   Constructor -> "constructor"
213   | FName(s)   -> s
214
215 let string_of_formal = function
216   Formal(d, s) -> (string_of_datatype d) ^ " " ^ s
217   | _          -> ""
218
219 let string_of_formal_name = function

```

```

217 Formal(_, s) -> s
218 |      _ -> ""
219
220 let string_of_func_decl fdecl =
221   "" ^ (string_of_scope fdecl.scope) ^ " " ^ (string_of_datatype fdecl.returnType) ^ " " ^
222   ↪ (string_of_fname fdecl.fname) ^ " " ^
223   (* Formals *)
224   "(" ^ String.concat "," (List.map string_of_formal fdecl.formals) ^ ")" {\n" ^
225   (* body *)
226   String.concat "" (List.map (string_of_stmt 2) fdecl.body) ^
227   "\t}\n\n"
228   (* Class Printing *)
229
230 let string_of_extends = function
231   NoParent      -> ""
232 |      Parent(s)      -> "extends " ^ s ^ " "
233 let string_of_field = function
234   Field(s, d, id) -> (string_of_scope s) ^ " " ^ (string_of_datatype d) ^ " " ^ id ^ ";\n"
235
236 let string_of_cbody cbody =
237   String.concat "" (List.map (fun s -> "\t" ^ s) (List.map string_of_field cbody.fields)) ^
238   String.concat "" (List.map (fun s -> "\t" ^ s) (List.map string_of_func_decl
239   ↪ cbody.constructors)) ^
240   String.concat "" (List.map (fun s -> "\t" ^ s) (List.map string_of_func_decl
241   ↪ cbody.methods))
242
243 let string_of_class_decl cdecl =
244   "class " ^ cdecl.cname ^ " " ^ (string_of_extends cdecl.extends) ^ "{\n" ^
245   (string_of_cbody cdecl.cbody) ^
246   "}\n"
247
248 (* Include Printing *)
249
250 let rec string_of_include = function
251   Include(s) -> "include(" ^ s ^ ");\n"
252
253 (* Print whole program *)
254
255 let string_of_program = function
256   Program(includes, cdecls) ->
257   String.concat "" (List.map string_of_include includes) ^ "\n" ^
258   String.concat "\n" (List.map string_of_class_decl cdecls)
259
260 (* Print AST tree representation *)
261
262 let includes_tree includes =
263   'List (List.map (function Include s -> 'String s) includes)

```

```

263 let map_fields_to_json fields =
264   'List (List.map (function Field(scope, datatype, s) ->
265     'Assoc [
266       ("name", 'String s);
267       ("scope", 'String (string_of_scope scope));
268       ("datatype", 'String (string_of_datatype datatype));
269     ]) fields)
270
271 let map_formals_to_json formals =
272   'List (List.map (function Formal(d, s) -> 'Assoc [
273     ("name", 'String s);
274     ("datatype", 'String (string_of_datatype d));
275   ]
276   | Many d -> 'Assoc [("Many", 'String (string_of_datatype d));]
277   ) formals)
278
279 let rec map_expr_to_json = function
280   Int_Lit(i) -> 'Assoc [("int_lit", 'Int i)]
281   | Boolean_Lit(b) -> 'Assoc [("bool_lit", 'Bool b)]
282   | Float_Lit(f) -> 'Assoc [("float_lit", 'Float f)]
283   | String_Lit(s) -> 'Assoc [("string_lit", 'String s)]
284   | Char_Lit(c) -> 'Assoc [("char_lit", 'String
    ↪ (Char.escaped c))]
285   | This -> 'String "this"
286   | Id(s) -> 'Assoc [("id", 'String s)]
287   | Binop(e1, o, e2) -> 'Assoc [("binop", 'Assoc [("lhs",
    ↪ map_expr_to_json e1); ("op", 'String (string_of_op o)); ("rhs", map_expr_to_json
    ↪ e2)]]]
288   | Assign(e1, e2) -> 'Assoc [("assign", 'Assoc [("lhs",
    ↪ map_expr_to_json e1); ("op", 'String "="); ("rhs", map_expr_to_json e2)]]]
289   | Noexpr -> 'String "noexpr"
290   | ObjAccess(e1, e2) -> 'Assoc [("objaccess", 'Assoc [("lhs",
    ↪ map_expr_to_json e1); ("op", 'String "."); ("rhs", map_expr_to_json e2)]]]
291   | Call(f, el) -> 'Assoc [("call", 'Assoc [("name",
    ↪ 'String f); ("params", 'List (List.map map_expr_to_json el)); ] ) ]
292   | ArrayPrimitive(el) -> 'Assoc [("arrayprimitive", 'List(List.map
    ↪ map_expr_to_json el))]
293   | Unop(op, e) -> 'Assoc [("Unop", 'Assoc [("op",
    ↪ 'String (string_of_op op)); ("operand", map_expr_to_json e)]]]
294   | Null -> 'String "null"
295   | ArrayCreate(d, el) -> 'Assoc [("arraycreate", 'Assoc [("datatype", 'String
    ↪ (string_of_datatype d)); ("args", 'List (List.map map_expr_to_json el)]]]
296   | ArrayAccess(e, el) -> 'Assoc [("arrayaccess", 'Assoc [("array",
    ↪ map_expr_to_json e); ("args", 'List (List.map map_expr_to_json el)]]]
297   | ObjectCreate(s, el) -> 'Assoc [("objectcreate", 'Assoc [("type", 'String s);
    ↪ ("args", 'List (List.map map_expr_to_json el)]]]
298   | Delete(e) -> 'Assoc [("delete", 'Assoc
    ↪ [("expr", map_expr_to_json e)]]]
299

```



```

300 let rec map_stmt_to_json = function
301 Block(stmts)                -> 'Assoc [("block", 'List (List.map
    ↪ (map_stmt_to_json) stmts))]
302 |      Expr(expr)            -> 'Assoc [("expr", map_expr_to_json
    ↪ expr)]
303 |      Return(expr)          -> 'Assoc [("return", map_expr_to_json
    ↪ expr)]
304 |      If(e, s1, s2)          -> 'Assoc [("if", 'Assoc [("cond",
    ↪ map_expr_to_json e); ("ifbody", map_stmt_to_json s1)]; ("else", map_stmt_to_json
    ↪ s2)]
305 |      For(e1, e2, e3, s)     -> 'Assoc [("for", 'Assoc [("init",
    ↪ map_expr_to_json e1); ("cond", map_expr_to_json e2); ("inc", map_expr_to_json e3);
    ↪ ("body", map_stmt_to_json s))]]
306 |      While(e, s)           -> 'Assoc [("while", 'Assoc [("cond",
    ↪ map_expr_to_json e); ("body", map_stmt_to_json s)]]]
307 |      Break                 -> 'String "break"
308 |      Continue              -> 'String "continue"
309 |      Local(d, s, e)         -> 'Assoc [("local", 'Assoc [("datatype",
    ↪ 'String (string_of_datatype d)); ("name", 'String s); ("val", map_expr_to_json e)]]]
310
311 let map_methods_to_json methods =
312 'List (List.map (fun (fdecl:Ast.func_decl) ->
313 'Assoc [
314 ("name", 'String (string_of_fname fdecl.fname));
315 ("scope", 'String (string_of_scope fdecl.scope));
316 ("returnType", 'String (string_of_datatype fdecl.returnType));
317 ("formals", map_formals_to_json fdecl.formals);
318 ("body", 'List (List.map (map_stmt_to_json) fdecl.body));
319 ]) methods)
320
321
322 let cdecls_tree cdecls =
323 let map_cdecl_to_json cdecl =
324 'Assoc [
325 ("cname", 'String cdecl.cname);
326 ("extends", 'String (string_of_extends cdecl.extends));
327 ("fields", map_fields_to_json cdecl.cbody.fields);
328 ("methods", map_methods_to_json cdecl.cbody.methods);
329 ("constructors", map_methods_to_json cdecl.cbody.constructors)
330 ]
331 in
332 'List (List.map (map_cdecl_to_json) cdecls)
333
334 let print_tree = function
335 Program(includes, cdecls) ->
336 'Assoc [("program",
337 'Assoc([
338 ("includes", includes_tree includes);
339 ("classes", cdecls_tree cdecls)

```

```

340  ])
341  ])
342
343  (* Print SAST tree representation *)
344
345  let rec map_sexpr_to_json =
346  let datatype d = [("datatype", 'String (string_of_datatype d))] in
347  function
348  SInt_Lit(i)          -> 'Assoc [("int_lit", 'Assoc ([("val", 'Int i)] @ (datatype
    ↪ (Datatype(Int_t)))))]
349  | SBoolean_Lit(b)    -> 'Assoc [("bool_lit", 'Assoc ([("val", 'Bool b)] @
    ↪ (datatype (Datatype(Bool_t)))))]
350  | SFloat_Lit(f)      -> 'Assoc [("float_lit", 'Assoc ([("val", 'Float f)] @
    ↪ (datatype (Datatype(Float_t)))))]
351  | SString_Lit(s)     -> 'Assoc [("string_lit", 'Assoc ([("val", 'String s)] @
    ↪ (datatype (Arraytype(Char_t, 1)))))]
352  | SChar_Lit(c)       -> 'Assoc [("char_lit", 'Assoc ([("val", 'String
    ↪ (Char.escaped c))] @ (datatype (Datatype(Char_t)))))]
353  | SId(s, d)          -> 'Assoc [("id", 'Assoc ([("name", 'String s)] @ (datatype
    ↪ d)))]
354  | SBinop(e1, o, e2, d) -> 'Assoc [("binop", 'Assoc ([("lhs", map_sexpr_to_json e1);
    ↪ ("op", 'String (string_of_op o)); ("rhs", map_sexpr_to_json e2)] @ (datatype d)))]
355  | SAssign(e1, e2, d)  -> 'Assoc [("assign", 'Assoc ([("lhs", map_sexpr_to_json e1);
    ↪ ("op", 'String "="); ("rhs", map_sexpr_to_json e2)] @ (datatype d)))]
356  | SNoexpr            -> 'Assoc [("noexpr", 'Assoc (datatype
    ↪ (Datatype(Void_t)))))]
357  | SArrayCreate(t, e1, d) -> 'Assoc [("arraycreate", 'Assoc ([("datatype", 'String
    ↪ (string_of_datatype d)); ("args", 'List (List.map map_sexpr_to_json e1))] @ (datatype
    ↪ d)))]
358  | SArrayAccess(e, e1, d) -> 'Assoc [("arrayaccess", 'Assoc ([("array",
    ↪ map_sexpr_to_json e); ("args", 'List (List.map map_sexpr_to_json e1))] @ (datatype
    ↪ d)))]
359  | SObjAccess(e1, e2, d) -> 'Assoc [("objaccess", 'Assoc ([("lhs", map_sexpr_to_json
    ↪ e1); ("op", 'String "."); ("rhs", map_sexpr_to_json e2)] @ (datatype d)))]
360  | SCall(fname, e1, d, i) -> 'Assoc [("call", 'Assoc ([("name", 'String fname);
    ↪ ("params", 'List (List.map map_sexpr_to_json e1)); ("index", 'Int i) ] @ (datatype
    ↪ d) )]
361  | SObjectCreate(s, e1, d) -> 'Assoc [("objectcreate", 'Assoc ([("type", 'String s);
    ↪ ("args", 'List (List.map map_sexpr_to_json e1))] @ (datatype d)))]
362  | SArrayPrimitive(e1, d) -> 'Assoc [("arrayprimitive", 'Assoc ([("expressions",
    ↪ 'List(List.map map_sexpr_to_json e1))] @ (datatype d)))]
363  | SUnop(op, e, d)     -> 'Assoc [("Unop", 'Assoc ([("op", 'String (string_of_op
    ↪ op)); ("operand", map_sexpr_to_json e)] @ (datatype d)))]
364  | SNull              -> 'Assoc [("null", 'Assoc (datatype
    ↪ (Datatype(Void_t)))))]
365  | SDelete(e)          -> 'Assoc [("delete", 'Assoc
    ↪ ([("expr", map_sexpr_to_json e)] @ (datatype (Datatype(Void_t)))))]
366
367  let rec map_sstmt_to_json =

```

```

368 let datatype d = [("datatype", 'String (string_of_datatype d))] in
369 function
370 SBlock s1                                -> 'Assoc [("sblock", 'List (List.map
    ↪ (map_sstmt_to_json) s1))]
371 | SExpr(e, d)                            -> 'Assoc [("sexpr", 'Assoc [("expr",
    ↪ map_sexpr_to_json e)] @ (datatype d)))]
372 | SReturn(e, d)                         -> 'Assoc [("sreturn", 'Assoc [("return",
    ↪ map_sexpr_to_json e)] @ (datatype d)))]
373 | SIf (e, s1, s2)                       -> 'Assoc [("sif", 'Assoc [("cond",
    ↪ map_sexpr_to_json e); ("ifbody", map_sstmt_to_json s1)]; ("selse", map_sstmt_to_json
    ↪ s2)]
374 | SFor (e1, e2, e3, s)                  -> 'Assoc [("sfor", 'Assoc [("init",
    ↪ map_sexpr_to_json e1); ("cond", map_sexpr_to_json e2); ("inc", map_sexpr_to_json e3);
    ↪ ("body", map_sstmt_to_json s)))]
375 | SWhile (e, s)                         -> 'Assoc [("swhile", 'Assoc [("cond",
    ↪ map_sexpr_to_json e); ("body", map_sstmt_to_json s)))]
376 | SBreak                               -> 'String "sbreak"
377 | SContinue                             -> 'String "scontinue"
378 | SLocal(d, s, e)                       -> 'Assoc [("slocal", 'Assoc [("datatype",
    ↪ 'String (string_of_datatype d)); ("name", 'String s); ("val", map_sexpr_to_json e)))]
379
380 let string_of_func_type = function
381 User -> "user" | Reserved -> "reserved"
382
383 let map_sfdecl_to_json sfdecl =
384 'Assoc[("sfdecl", 'Assoc[
385 ("sfname", 'String (string_of_fname sfdecl.sfname));
386 ("sreturnType", 'String (string_of_datatype sfdecl.sreturnType));
387 ("sformals", map_formals_to_json sfdecl.sformals);
388 ("sbody", 'List (List.map (map_sstmt_to_json) sfdecl.sbody));
389 ("func_type", 'String(string_of_func_type sfdecl.func_type));
390 ])]
391
392 let map_sfdecls_to_json sfdecls =
393 'List(List.map map_sfdecl_to_json sfdecls)
394
395 let map_scdecls_to_json scdecls =
396 'List(List.map (fun scdecl ->
397 'Assoc [("scdecl",
398 'Assoc[
399 ("scname", 'String scdecl.scname);
400 ("sfields", map_fields_to_json scdecl.sfields);
401 ("sfuncs", map_sfdecls_to_json scdecl.sfuncs);
402 ])]
403 ])
404 scdecls)
405
406 let map_sprogram_to_json sprogram =
407 'Assoc [("sprogram", 'Assoc [

```

```

408 ("classes", map_scdecls_to_json sprogram.classes);
409 ("functions", map_sfdecls_to_json sprogram.functions);
410 ("main", map_sfdecl_to_json sprogram.main);
411 ("reserved", map_sfdecls_to_json sprogram.reserved);
412 ])]
413
414 (* Print tokens *)
415
416 let string_of_token = function
417 LPAREN                                -> "LPAREN"
418 |   RPAREN                            -> "RPAREN"
419 |   LBRACE                             -> "LBRACE"
420 |   RBRACE                             -> "RBRACE"
421 |   SEMI                              -> "SEMI"
422 |   COMMA                             -> "COMMA"
423 |   PLUS                              -> "PLUS"
424 |   MINUS                             -> "MINUS"
425 |   TIMES                             -> "TIMES"
426 |   DIVIDE                            -> "DIVIDE"
427 |   ASSIGN                            -> "ASSIGN"
428 |   EQ                                -> "EQ"
429 |   NEQ                               -> "NEQ"
430 |   LT                                -> "LT"
431 |   LEQ                               -> "LEQ"
432 |   GT                                -> "GT"
433 |   GEQ                               -> "GEQ"
434 |   AND                               -> "AND"
435 |   OR                                -> "OR"
436 |   NOT                               -> "NOT"
437 |   DOT                               -> "DOT"
438 |   LBRACKET                          -> "LBRACKET"
439 |   RBRACKET                          -> "RBRACKET"
440 |   BAR                                -> "BAR"
441 |   IF                                 -> "IF"
442 |   ELSE                              -> "ELSE"
443 |   FOR                                -> "FOR"
444 |   WHILE                             -> "WHILE"
445 |   RETURN                            -> "RETURN"
446 |   INT                               -> "INT"
447 |   FLOAT                             -> "FLOAT"
448 |   BOOL                              -> "BOOL"
449 |   CHAR                              -> "CHAR"
450 |   VOID                              -> "VOID"
451 |   NULL                              -> "NULL"
452 |   TRUE                              -> "TRUE"
453 |   FALSE                             -> "FALSE"
454 |   CLASS                             -> "CLASS"
455 |   CONSTRUCTOR                       -> "CONSTRUCTOR"
456 |   PUBLIC                            -> "PUBLIC"

```

```

457 |         PRIVATE                                -> "PRIVATE"
458 |         EXTENDS                                -> "EXTENDS"
459 |         INCLUDE                                -> "INCLUDE"
460 |         THIS                                    -> "THIS"
461 |         BREAK                                  -> "BREAK"
462 |         CONTINUE                               -> "CONTINUE"
463 |     NEW                                         -> "NEW"
464 |         INT_LITERAL(i)                        -> "INT_LITERAL(" ^ string_of_int i ^ ")"
465 |         FLOAT_LITERAL(f)                      -> "FLOAT_LITERAL(" ^ string_of_float f ^ ")"
466 |         CHAR_LITERAL(c)                       -> "CHAR_LITERAL(" ^ Char.escaped c ^ ")"
467 |         STRING_LITERAL(s)                     -> "STRING_LITERAL(" ^ s ^ ")"
468 |         ID(s)                                 -> "ID(" ^ s ^ ")"
469 |         DELETE                                -> "DELETE"
470 |         MODULO                                 -> "MODULO"
471 |         EOF                                    -> "EOF"
472 |
473 | let string_of_token_no_id = function
474 | LPAREN                                         -> "LPAREN"
475 |         RPAREN                                -> "RPAREN"
476 |         LBRACE                                -> "LBRACE"
477 |         RBRACE                                -> "RBRACE"
478 |         SEMI                                  -> "SEMI"
479 |         COMMA                                 -> "COMMA"
480 |         PLUS                                  -> "PLUS"
481 |         MINUS                                 -> "MINUS"
482 |         TIMES                                 -> "TIMES"
483 |         DIVIDE                                -> "DIVIDE"
484 |         ASSIGN                                -> "ASSIGN"
485 |         EQ                                    -> "EQ"
486 |         NEQ                                    -> "NEQ"
487 |         LT                                    -> "LT"
488 |         LEQ                                    -> "LEQ"
489 |         GT                                    -> "GT"
490 |         GEQ                                    -> "GEQ"
491 |         AND                                    -> "AND"
492 |         OR                                    -> "OR"
493 |         NOT                                    -> "NOT"
494 |         DOT                                    -> "DOT"
495 |         LBRACKET                             -> "LBRACKET"
496 |         RBRACKET                             -> "RBRACKET"
497 |         BAR                                    -> "BAR"
498 |         IF                                    -> "IF"
499 |         ELSE                                  -> "ELSE"
500 |         FOR                                    -> "FOR"
501 |         WHILE                                 -> "WHILE"
502 |         RETURN                                -> "RETURN"
503 |         INT                                    -> "INT"
504 |         FLOAT                                 -> "FLOAT"
505 |         BOOL                                  -> "BOOL"

```

```

506 |         CHAR                -> "CHAR"
507 |         VOID                -> "VOID"
508 |         NULL                -> "NULL"
509 |         TRUE                -> "TRUE"
510 |         FALSE               -> "FALSE"
511 |         CLASS               -> "CLASS"
512 |         CONSTRUCTOR         -> "CONSTRUCTOR"
513 |         PUBLIC              -> "PUBLIC"
514 |         PRIVATE             -> "PRIVATE"
515 |         EXTENDS             -> "EXTENDS"
516 |         INCLUDE             -> "INCLUDE"
517 |         THIS                -> "THIS"
518 |         BREAK               -> "BREAK"
519 |         CONTINUE            -> "CONTINUE"
520 |     NEW                     -> "NEW"
521 |         INT_LITERAL(i)      -> "INT_LITERAL"
522 |         FLOAT_LITERAL(f)    -> "FLOAT_LITERAL"
523 |         CHAR_LITERAL(c)     -> "CHAR_LITERAL"
524 |         STRING_LITERAL(s)   -> "STRING_LITERAL"
525 |         ID(s)               -> "ID"
526 |         DELETE              -> "DELETE"
527 |         MODULO              -> "MODULO"
528 |         EOF                 -> "EOF"
529
530 let token_list_to_string_endl token_list =
531 let rec helper last_line_number = function
532 (token, curr)::tail ->
533 let line = curr.lineno in
534 (if line != last_line_number then "\n" ^ string_of_int line ^ ". " else " ") ^
535 string_of_token token ^ helper line tail
536 | [] -> "\n"
537 in helper 0 token_list
538
539 let token_list_to_string token_list =
540 let rec helper = function
541 (token, line)::tail ->
542 string_of_token_no_id token ^ " " ^ helper tail
543 | [] -> "\n"
544 in helper token_list

```

Test Suite Code

tester.sh

```
1  #!/bin/bash
2  # This script must reside in the "Test Suite" directory of the project
3  # Make sure the "dice" executable is in the "Compiler" directory
4
5  diceExecPath=./dice
6  testOption=$1 #stores the test flag since functions can't see the £1
7  vFlag=$2 #stores the -v flag since functions can't see it with £2
8  pass=0
9  fail=0
10 RED='\033[0;31m'
11 GREEN='\033[0;32m'
12 CYAN='\033[0;36m'
13 NC='\033[0m'
14 errorFile=errors.log
15 excpTestFlag=0
16
17 # Set time limit for all operations
18 ulimit -t 30
19
20 usage(){
21     echo "Usage: $0 [test flag] [other]";
22     echo "";
23     echo "[test flag] = -c    Test Compiler (default if test flag not selected)";
24     echo "                -d    Test Compiler and display Dice Compiler messages";
25     echo "                -s    Test Scanner";
26     echo "                -m    Run script without compiling Dice executable";
27     echo "[other]      = -v    Verbose (prints log results)";
28     exit 1;
29 }
30
31 confirmation(){
32     #£? is the exit code for diff, if 0, then test output matched!
33     if [ $? -eq 0 ];
34     then
35         echo -e "${GREEN}$filename passed!${NC}" >> session_file
36         echo -e "${GREEN}$filename passed!${NC}"
37         ((pass++))
38     else
39
40         echo -e "${RED}$filename FAILED${NC}" >> session_file
41         echo -e "${RED}$filename FAILED${NC}"
42
43         #print out expected output and result
44         echo "Expected Output:" >> session_file
45
```

```

46         if [ $excpTestFlag -eq 0 ];           then
47             cat "$testPath"$filename$testExtension >> session_file
48         else
49             cat "$testExceptionsPath"$filename$testExtension >>
               ↪ session_file
50         fi
51         echo "" >> session_file
52         echo "Generated Output:" >> session_file
53         cat temp_Dice_Tester >> session_file
54         echo "" >> session_file
55         ((fail++))
56     fi
57 }
58
59 header(){
60     echo ""
61     echo "*****" >> session_file
62     echo "Dice Test Script Results:" >> session_file
63     date >> session_file
64     echo "" >> session_file
65 }
66
67 test_function(){
68     header #func
69
70     for testFile in "$testPath"*.dice; do
71
72         filename=$(basename "$testFile")
73
74         echo "=====" >> session_file
75         echo "Testing: $filename" >> session_file
76
77         if [ "$testOption" == "-s" ]; then
78             #Create file to be tested (with tokens)
79             $diceExecPath $diceOption "$testFile" > temp_Dice_Tester
80             #Test output differences use the diff command and neglect screen
81             ↪ output
82             diff temp_Dice_Tester "$testPath"$filename$testExtension >
               ↪ /dev/null
83             confirmation #function
84         else #Only other option is -c or -d which perform the same function
85             ↪ except where noted below
86             #extract filename without extension for executable
87             name=$(echo $filename | cut -f 1 -d '.')
88
89             if [ "$testOption" == "-d" ]; then
90                 #run the executable and port output (stderr) to temp test
91                 ↪ file
92                 #port stdout (compiler msgs) to screen with color

```



```

90         echo -e -n "${CYAN}"
91         $diceExecPath $diceOption "$testFile" 2> temp.ll
92         echo -e -n "${NC}"
93         echo ""
94
95     else
96         #Create header for any messages coming from Dice compiler
97
98         echo -e "${CYAN}Dice Compiler Messages (if any):" >>
99         ↪ session_file
100        #run the executable and port output (stderr) to temp test
101        ↪ file
102        #port stdout (compiler msgs) to log file
103        $diceExecPath $diceOption "$testFile" 2> temp.ll 1>>
104        ↪ session_file
105        echo -e "${NC}">> session_file
106        echo "" >> session_file
107    fi
108
109    #Run the llvm executable and port output to temp test file
110    lli temp.ll > temp_Dice_Tester
111
112    #Send all error messages this script generates (if any) to error
113    ↪ log file
114    exec 2> $errorFile
115
116    #Perform comparison of outputs
117    diff temp_Dice_Tester "$testPath"$filename$testExtension >
118    ↪ /dev/null
119    confirmation #function
120
121    fi
122done
123
124#The following portion is only to test compiler errors
125if [ "$testOption" == "-c" ] || [ "$testOption" == "-d" ] || [ "$testOption" ==
126↪ "-m" ] || [ $# -eq 0 ]; then
127
128    #set flag to prevent
129    excpTestFlag=1
130    for testFile in "$testExceptionsPath"*.dice; do
131
132        filename=$(basename "$testFile")
133
134        echo "===== " >> session_file
135        echo "Testing: $filename" >> session_file
136
137        #Only other option is -c or -d which perform the same function
138        ↪ except where noted below
139        #extract filename without extension for executable

```

```
132         name=$(echo $filename | cut -f 1 -d '.')
133
134         #run the executable and port error output (stdout) to temp test
135         ↪ file
136         #port stdout (compiler msgs) to log file
137         $diceExecPath $diceOption "$testFile" 1> temp_Dice_Tester
138         ↪ 2>/dev/null
139
140         #Perform comparison of outputs
141         diff temp_Dice_Tester
142         ↪ "$testExceptionsPath"$filename$testExtension >> /dev/null
143         confirmation #function
144     done
145
146     #Test if our executable can take in command line arguments:
147     filename=test-args.dice
148     $diceExecPath $diceOption "$argsPath"test-args.dice 2>temp.ll
149     lli temp.ll david emily phil > tempArgs
150     diff tempArgs "$argsPath"test-args.dice.out >/dev/null
151     confirmation
152     rm tempArgs
153
154 fi
155 echo "" >> session_file
156
157 #Verbose flag actuated
158 if [ "$vFlag" == "-v" ]; then
159     cat session_file
160 fi
161
162 #Copy session output to historical log
163 cat session_file >> "$logFile"
164
165 #Test status output
166 echo ""
167 echo -e "${GREEN}Tests Passed: $pass ${NC}"
168 echo -e "${RED}Tests Failed: $fail ${NC}"
169 echo "View $logFile for more information"
170
171 #Clean up temp files
172 rm temp_Dice_Tester;
173 rm session_file;
174 }
175
176 createDice(){
177     echo "Compiling dice executable"
178     cd ..
179     make clean 2>&1 > /dev/null
180     make
```

```
178     #cp dice ../Test\ Suite/Hello_World_Demo/dice
179     # cd Test\ Suite
180     echo "Compilation of dice executable complete"
181 }
182
183 #-----Script starts flag checking here -----
184 if [ "$testOption" == "-s" ]; then
185     echo "Scanner Test Started"
186     createDice
187     logFile=Test\ Suite/scanner_tests.log
188     testPath=Test\ Suite/Scanner\ Test\ Suite/
189     diceOption=-tendl
190     testExtension=.ManualTokens
191     test_function
192
193 elif [ "$testOption" == "-c" ] || [ "$testOption" == "-d" ] || [ "$testOption" == "-m" ]
194 ↪ || [ $# -eq 0 ]; then
195     echo "Compiler Test Started"
196
197     if [ "$testOption" == "-m" ]; then
198         if [ -f ../dice ]; then
199             echo "Skipping Dice recompilation"
200             cd ..
201         else
202             createDice
203         fi
204     else
205         createDice
206     fi
207
208     logFile=Test\ Suite/compiler_tests.log
209     testPath=Test\ Suite/Compiler_Test_Suite/
210     testExceptionsPath=Test\ Suite/Compiler_Test_Suite/Exceptions/
211     argsPath=Test\ Suite/Compiler_Test_Suite/Args/
212     diceOption=-c
213     testExtension=.out
214     test_function
215     rm temp.ll;
216
217 else
218     usage
219 fi
220
221 #Print out number of bash script errors and
222 if [ "$testOption" != "-s" ]; then
223     errorLines=$(cat $errorFile | wc -l)
224     mv $errorFile Test\ Suite/$errorFile
225     if [ $errorLines -ne 0 ]; then
```

```
226     echo "$errorLines lines of script errors reported. Please check $errorFile!"
227     else
228         mv Test\ Suite/$errorFile
229     fi
230 fi
231
232 exit 0
```

test-var1.dice.out

1 42

test-stdlib-stringclass.dice.out

```
1  hi
```

test-stdlib-integerclass1.dice

```
1  include("stdlib");
2
3  class Two {
4      public void main(char[] [] args) {
5          class Integer x = new Integer(128);
6          print(x.num(), "\n");
7      }
8  }
```

test-constructorInherited.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      constructor(){
6          this.xCoord = 0;
7          this.yCoord = 0;
8      }
9
10     constructor(int x, int y){
11         this.xCoord = x;
12         this.yCoord = y;
13     }
14 }
15
16 class circle extends shape {
17     public int radius;
18
19     constructor(){
20         this.radius = 0;
21     }
22     constructor(int r){
23         this.radius = r;
24     }
25     constructor(int x, int y, int r){
26         this.radius = r;
27         this.xCoord = x;
28         this.yCoord = y;
29     }
30 }
31
32 class test {
33     public void main(char[] [] args) {
34         class circle a = new circle(0,0,7);
35         print(a.xCoord);
36         print(a.yCoord);
37         print(a.radius);
38     }
39 }
```


test-ifEmptyBlock2.dice.out

1 17

test-global1.dice.out

1 42214322

test-if7.dice

```
1  class test {
2      public void main(char[] [] args) {
3
4          if(false) {
5              print("if");
6          }
7
8          else if(false) {
9              print("elseif");
10         }
11
12         else if(false) {
13             print("elseif2");
14         }
15
16         else {
17             print("else");
18         }
19     }
20 }
```

test-var3.dice

```
1  class test {
2
3      public int a;
4
5      public void print2(int x, int y) {
6          print(x);
7          print(y);
8      }
9
10     public void main(char[] [] args) {
11         int b;
12         this.a = 42;
13         b = 57;
14         this.print2(this.a + b * 3, 77);
15     }
16 }
```

test-classFunctionOverload1.dice.out

1 10

test-applicative.dice

```
1  class test {
2
3      public int p(int i){
4          print(i);
5          return i;
6      }
7
8      public void q(int a, int b, int c){
9          int total = a ;
10         print(b);
11         total = total + c ;
12     }
13
14     public void main(char[] [] args) {
15         this.q( this.p(1), 2, this.p(3));
16     }
17 }
```

test-forEmptyBlock2.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int i;
4          for (i = 0 ; i < 5 ; i = i + 1) {
5              (*empty block*) null;
6          }
7          print(1);
8      }
9  }
```

test-if1.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          if (true) print(42);  
4          print(17);  
5      }  
6  }
```


test-func5.dice

```
1  class test {
2
3      public void foo(int a, int b){
4          int c;
5          int d;
6          int e;
7          print(a);
8          e = a + b + 10;
9          print(e);
10     }
11
12     public void main(char[][] args) {
13         this.foo(1,2);
14     }
15
16 }
```

test-arith5.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(15-5);  
4      }  
5  }
```

test-bool5.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(1==2);  
4          print(1==1);  
5      }  
6  }
```

test-constructor2.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      constructor(int x, int y){
6          this.xCoord = x;
7          this.yCoord = y;
8      }
9
10     constructor(float x, float y){
11         this.xCoord = 0;
12         this.yCoord = 0;
13     }
14 }
15
16 class test {
17     public void main(char[][] args) {
18         class shape a = new shape(5,10);
19         print (a.xCoord);
20         print (a.yCoord);
21     }
22 }
```

test-arithSigned2.dice.out

1 -3-3-3.000000-3.000000

test-classExtends2.dice

```
1  class person {
2      public int ssn;
3  }
4
5  class worker extends person {
6      public int workid;
7  }
8
9  class programmer extends worker {
10     public int nerdCred;
11 }
12
13 class test {
14     public void main(char[] [] args) {
15         class programmer david = new programmer();
16         david.ssn = 123456789;
17         david.workid = 57;
18         david.nerdCred = 99;
19
20         print(david.ssn);
21         print(david.workid);
22         print(david.nerdCred);
23     }
24 }
```

test-arithSigned1.dice.out

1 -5-5-5.000000-5.000000

test-forEmptyBlock.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          int i;  
4          for (i = 0 ; i < 5 ; i = i + 1) {  
5              (*empty block*)  
6          }  
7          print(1);  
8      }  
9  }
```


test-func5.dice.out

1 113

test-float.dice.out

1 1.500000

test-stdlib-integerclass1.dice.out

1 128

test-for2.dice.out

1 5432142

test-if4.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          if (false)  
4              print(42);  
5          else  
6              print(8);  
7          print(17);  
8      }  
9  }
```

test-arith7.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(15/5);  
4      }  
5  }
```

test-if5.dice

```
1  class test {
2      public void main(char[] [] args) {
3          this.foo(3,5,6);
4      }
5
6      public void foo(int a, int b, int c) {
7          int d;
8          if (a == 3)
9              d = b;
10         else
11             d = c;
12         print(d);
13     }
14 }
```

test-arithSigned3.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(-1+3);
4          print(1+-3);
5          print(-1.0+3.0);
6          print(1.0+-3.0);
7      }
8  }
```


test-if7.dice.out

```
1  else
```

test-classGetter.dice.out

1 13

test-stdlib-compare.dice

```
1 include("stdlib");
2
3 class Two {
4     public void main(char[] [] args) {
5         class String b = new String("phil");
6         class String c = new String("khal");
7         class String d = c.copy(c);
8         print(b.string(), " == ", c.string(), " is ", b.compare(c));
9         print(c.string(), " == ", d.string(), " is ", c.compare(d));
10    }
11 }
```

test-class.dice.out

1 13

test-for1.dice.out

1 0123442

test-classInheritanceArgument.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4  }
5
6  class circle extends shape {
7      public int radius;
8  }
9
10 class test {
11
12     public void main(char[] [] args) {
13         class circle a = new circle();
14         this.inheritanceTest(a);
15     }
16
17     public void inheritanceTest(class shape a){
18         print("pass");
19     }
20
21 }
```

test-whileBreak.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int i;
4          i = 5;
5          while (i > 0) {
6              print(i);
7              if(i==3){
8                  break;
9              }
10             i = i - 1;
11         }
12     }
13 }
```

test-while1.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int i;
4          i = 5;
5          while (i > 0) {
6              print(i);
7              i = i - 1;
8          }
9          print(42);
10     }
11 }
```


test-fileio.dice.out

```
1  include("stdlib");
2
3  class Two {
4
5      public void main(char[] [] args) {
6          class File a = new File("Test Suite/Compiler_Test_Suite/test-fileio.dice", true);
7          char[] buf = a.readfile(243);
8          a.closefile();
9          print(buf);
10         }
11     }
```

test-classExtends2.dice.out

1 1234567895799

test-forContinue.dice.out

1 23420

test-fib.dice

```
1  class test {
2
3      public int fib(int x) {
4          if (x < 2)
5              return 1;
6          return this.fib(x-1) + this.fib(x-2);
7      }
8
9      public void main(char[] [] args) {
10         print(this.fib(0));
11         print(this.fib(1));
12         print(this.fib(2));
13         print(this.fib(3));
14         print(this.fib(4));
15         print(this.fib(5));
16     }
17 }
```

test-bool1.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(1<2);
4          print(1.0<2);
5          print(1<2.0);
6          print(1.0<2.0);
7      }
8  }
```

test-forBreak.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int i;
4          for (i = 0 ; i < 5 ; i = i + 1) {
5              if(i==3){
6                  break;
7              }
8              print(i);
9          }
10         print(100);
11     }
12 }
```

test-bool6.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(1!=2);  
4          print(1!=1);  
5      }  
6  }
```

test-bool4.dice.out

```
1  truetruetruefalse
```


test-stdlib-stringclassContains2.dice

```
1  include("stdlib");
2
3  class Two {
4      public void main(char[] [] args) {
5          class String b = new String("philkhal");
6          class String c = new String("butts");
7          print(b.contains(c));
8      }
9  }
```

test-classGetter.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      public int getX(){
6          return this.xCoord;
7      }
8      public int getY(){
9          return this.yCoord;
10     }
11
12 }
13
14 class test {
15     public void main(char[] [] args) {
16         class shape a = new shape();
17         a.xCoord = 1;
18         a.yCoord = 3;
19         print(a.getX());
20         print(a.getY());
21     }
22 }
```

test-var3.dice.out

1 21377

test-forContinue.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int i;
4          for (i = 0 ; i < 5 ; i = i + 1) {
5              if(i<2){ continue; }
6              else{
7                  print(i);
8              }
9          }
10         print(20);
11     }
12 }
```

test-stdlib-stringclassReverse.dice.out

```
1  olleh
```

test-while1.dice.out

1 5432142

test-float.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          float a = 1.5;  
4          print(a);  
5  
6      }  
7  }
```

test-arith5.dice.out

1 10

test-array4.dice

```
1  class shape {
2      public int x;
3      public int y;
4
5      constructor(int a, int b){
6          this.x = a;
7          this.y = b;
8      }
9
10 }
11
12 class test {
13     public void main(char[] [] args) {
14         class shape[] a = new class shape[5];
15         class shape b = new shape(2,3);
16         a[1] = b;
17         print(a[1].x);
18     }
19 }
```

test-arithSigned1.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(-15/3);
4          print(15/-3);
5          print(-15.0/3.0);
6          print(15.0/-3.0);
7      }
8  }
```

test-if2.dice.out

1 4217

test-stdlib-concat.dice

```
1  include("stdlib");
2
3  class Two {
4      public void main(char[] [] args) {
5          class String b = new String("phil");
6          class String c = new String("khal");
7          class String a = b.concat(c);
8          print(b.string(), "\n");
9          print(c.string(), "\n");
10         print(a.string(), "\n");
11     }
12 }
```

test-classReturnObjects.dice.out

1 12

test-if8.dice

```
1  class test {
2      public void main(char[] [] args) {
3
4          if(false) {
5              print("if");
6          }
7
8          else if(true) {
9              print("elseif");
10         }
11
12         else if(false) {
13             print("elseif2");
14         }
15
16         else {
17             print("else");
18         }
19     }
20 }
```

test-stmts1.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(this.foo(1,42));
4          print(this.foo(0,37));
5      }
6
7      public int foo(int a, int b) {
8          int i;
9          int j = b;
10         if ( a == 1)
11             return b + 3;
12         else
13             for (i = 0 ; i < 5 ; i = i + 1)
14                 j = j + 5;
15         return j;
16     }
17 }
```

test-if6.dice.out

1 42278

test-classExtendsGetter.dice.out

1 13

test-ops1.dice.out

```
1 3-125099falsetrue99truefalse99truefalse99truetruefalse99falsetrue99falsetruetrue
```

test-arith4.dice

```
1  (* Test side-effect sequence in a series of statement *)
2
3  class test {
4      public int g;
5
6      public void main(char[] [] args) {
7
8          int l;
9          l = 1;
10         print(l);
11
12         this.g = 3;
13         print(this.g);
14
15         l = 5;
16         print(l+100);
17
18         this.g = 7;
19         print(this.g+100);
20     }
21 }
```

test-func3.dice.out

1 42171928

test-class.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      constructor (){
6      }
7  }
8
9  class test {
10     public void main(char[] [] args) {
11         class shape a = new shape();
12         a.xCoord = 1;
13         a.yCoord = 3;
14         print(a.xCoord);
15         print(a.yCoord);
16     }
17 }
```

test-bool9.dice.out

```
1  truetruetruefalsefalsefalse
```

test-whileContinue.dice.out

1 543

test-stdlib-copy.dice.out

1 philkhalkhal

test-stdlib-integerclass2.dice.out

1 128

test-classExtends.dice

```
1  class shape {
2      public float xCoord;
3      public float yCoord;
4  }
5
6  class circle extends shape {
7      public float radius;
8  }
9
10 class test {
11     public void main(char[] [] args) {
12         class circle a = new circle();
13         a.xCoord = 1.5;
14         print(a.xCoord);
15     }
16 }
```

test-if3.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          if (false)  
4              print(42);  
5          print(17);  
6      }  
7  }
```

test-bool8.dice.out

```
1  falsetrue
2  falsefalse
```

test-scope.dice.out

1 12321

test-constructor1.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      constructor(){
6          this.xCoord = 0;
7          this.yCoord = 0;
8      }
9
10     constructor(int x, int y){
11         this.xCoord = x;
12         this.yCoord = y;
13     }
14 }
15
16 class test {
17     public void main(char[][] args) {
18         class shape a = new shape();
19         class shape b = new shape(5,10);
20         print (a.xCoord);
21         print (a.yCoord);
22         print (b.xCoord);
23         print (b.yCoord);
24     }
25 }
```

test-stdlib-concat.dice.out

```
1  phil
2  khal
3  philkhal
```

test-forEmptyBlock2.dice.out

1 1

test-if4.dice.out

1 817

test-array.dice.out

1 04

test-array2.dice.out

```
1 1.5000004.500000
```

test-objectDeclarationInheritance.dice.out

1 pass

test-if5.dice.out

1 5

test-forEmptyBlock.dice.out

1 1

test-var4.dice.out

1 1242

test-whileContinue.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int i;
4          i = 6;
5          while (i > 0) {
6              i = i - 1;
7
8              if(i<3){
9                  continue;
10             }
11
12             print(i);
13         }
14     }
15 }
```


test-array3.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int[] a = new int[10];
4          a[0] = 1;
5          print(a[0]);
6          a[0] = 10;
7          print(a[0]);
8          a[9] = 2;
9          print(a[9]);
10     }
11 }
```

test-if3.dice.out

1 17

test-arith6.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(10*5);  
4      }  
5  }
```

test-helloTwice.dice.out

```
1 Hello, World!  
2 Professor Edwards favorite number is: 42!
```

test-stdlib-stringclassLength.dice.out

1 9

test-bool3.dice.out

```
1  false true false true
```

test-hello.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print("Hello, World!");  
4      }  
5  }
```

test-array.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int[] a = |0,1,2,3,4|;
4          print(a[0]);
5          print(a[4]);
6      }
7  }
```


test-exit.dice

```
1  class test {
2      public void main(char[] [] args) {
3
4          print(1);
5          exit(1);
6          print(2);
7
8      }
9  }
```

test-helloTwice.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print("Hello, World!\n");
4          print("Professor Edwards favorite number is: 42!\n");
5      }
6  }
```

test-arithSigned2.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(-1*3);
4          print(1*-3);
5          print(-1.0*3.0);
6          print(1.0*-3.0);
7      }
8  }
```

test-cyclicalIncludes2.dice

```
1  include("Test Suite/Compiler_Test_Suite/test-cyclicalIncludes.dice");
2
3  class test2 {
4      constructor(){
5          this.output2();
6      }
7      public void output2(){
8          print("b");
9      }
10 }
```

test-if2.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          if (true) print(42);  
4          else print(8);  
5          print(17);  
6      }  
7  }
```

test-constructorDefault.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5  }
6
7  class test {
8      public void main(char[] [] args) {
9          class shape a = new shape();
10         a.xCoord = 5;
11         print (a.xCoord);
12     }
13 }
```

test-var1.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3  
4          int a;  
5          a = 42;  
6          print(a);  
7      }  
8  }
```

test-arithSigned4.dice.out

1 -44-4.0000004.000000

test-ifEmptyBlock.dice.out

1 17

test-stdlib-compare.dice.out

```
1  phil == khal is falsekhal == khal is true
```

test-cyclicalIncludes.dice.out

1 ba

test-bool7.dice.out

```
1 truefalsefalsefalse
2 truetruetruefalse
```

test-classSetter.dice.out

1 13

test-stdlib-stringclassReverse.dice

```
1  include("stdlib");
2
3  class Test {
4      public void main(char[] [] args) {
5          class String a = new String("hello");
6          class String reverse = a.reverse();
7
8          print(reverse.string());
9      }
10 }
```

test-factorialRecursive.dice

```
1  class Factorial {
2
3      public void main(char[] [] args) {
4          print(this.factorial(5));
5      }
6
7      public int factorial(int n) {
8          int temp;
9          if(n <= 1) return 1;
10         temp = n * this.factorial(n - 1);
11         return temp;
12     }
13 }
```

test-classInheritanceArgument.dice.out

1 pass

test-ctorInherited.dice.out

1 007

test-bool8.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(not true);
4          print(not false);
5          print("\n");
6          print(not true and true);
7          print(not (true and true));
8      }
9  }
```

test-classFunctionOverload.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      constructor(){
6          this.xCoord = 0;
7          this.yCoord = 0;
8      }
9
10     constructor(int x, int y){
11         this.xCoord = x;
12         this.yCoord = y;
13     }
14
15     public int getArea(){
16         return 10;
17     }
18 }
19
20 class circle extends shape {
21     public int radius;
22
23     constructor(){
24         this.radius = 0;
25     }
26     constructor(int r){
27         this.radius = r;
28     }
29     constructor(int x, int y, int r){
30         this.radius = r;
31         this.xCoord = x;
32         this.yCoord = y;
33     }
34
35     public int getArea(){
36         return 3*this.radius*this.radius;
37     }
38 }
39
40 class test {
41     public void main(char[][] args) {
42         class circle a = new circle(0,0,2);
43         print(a.getArea());
44     }
45 }
```

test-stdlib-stringclassContains.dice.out

```
1 true
```

test-arith8.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(15+5.0);
4          print("\n");
5          print(1.5+1);
6      }
7  }
```

test-array4.dice.out

1 2

test-stdlib-copy.dice

```
1  include("stdlib");
2
3  class Two {
4      public void main(char[] [] args) {
5          class String b = new String("phil");
6          class String c = new String("khal");
7          class String d = c.copy(c);
8          print(b.string());
9          print(c.string());
10         print(d.string());
11     }
12 }
```

test-arith7.dice.out

1 3

test-classFunctionOverload1.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      constructor(){
6          this.xCoord = 0;
7          this.yCoord = 0;
8      }
9
10     constructor(int x, int y){
11         this.xCoord = x;
12         this.yCoord = y;
13     }
14
15     public int getArea(){
16         return 10;
17     }
18 }
19
20 class circle extends shape {
21     public int radius;
22
23     constructor(){
24         this.radius = 0;
25     }
26     constructor(int r){
27         this.radius = r;
28     }
29     constructor(int x, int y){
30         this.radius = 0;
31         this.xCoord = x;
32         this.yCoord = y;
33     }
34
35     public int getArea(){
36         return 3*this.radius*this.radius;
37     }
38 }
39
40 class test {
41     public void main(char[] [] args) {
42         class shape a = new shape(0,0);
43         print(a.getArea());
44     }
45 }
```

test-stdlib-stringclassContains.dice

```
1 include("stdlib");
2
3 class Two {
4     public void main(char[] [] args) {
5         class String b = new String("philkhal");
6         class String c = new String("khal");
7         print(b.contains(c));
8     }
9 }
```

test-factorialRecursive.dice.out

1 120

test-stdlib-integerclass2.dice

```
1  include("stdlib");
2
3  class Two {
4      public void main(char[] [] args) {
5          class Integer x = new Integer(128);
6          class String str = x.toString();
7          print(str.string(), "\n");
8      }
9  }
```

test-bool6.dice.out

```
1 truefalse
```

test-cyclicalIncludes.dice

```
1  include("Test Suite/Compiler_Test_Suite/test-cyclicalIncludes2.dice");
2
3  class test {
4      public void main(char[] [] args) {
5          class test2 a = new test2();
6          this.output();
7      }
8
9      public void output(){
10         print("a");
11     }
12 }
```


test-stdlib-stringclass3.dice

```
1  include("stdlib");
2
3  class test{
4
5      private class String x;
6
7      public void main(char[] [] args) {
8
9          class String a = new String("goodBye");
10         this.x = a;
11         print(this.x.string());
12
13     }
14 }
```


test-arith3.dice

```
1  (* Test left-to-right evaluation of expressions *)
2
3  class test {
4
5      public int a; (* Global variable *)
6
7      public int inca() {
8          this.a = this.a + 1;  (* Increment a; return its new value *)
9          return this.a;
10     }
11
12     public void main(char[][] args) {
13         this.a = 42;  (* Initialize a *)
14         print(this.inca() + this.a);
15     }
16 }
```

test-emptyBlock.dice

```
1  class test {
2      public void main(char[] [] args) {
3          {
4              (* Nothing in the following blocks*) {} {}
5          }
6          { null; }
7          print(1);
8      }
9  }
```

test-intOverflow.dice.out

1 passpass

test-stdlib.dice.out

```
1  hi
```

test-classFunctionOverload.dice.out

1 12

test-exit.dice.out

1 1

test-if1.dice.out

1 4217

test-stdlib-stringclass2.dice

```
1 include("stdlib");
2
3 class test {
4     public void main(char[] [] args) {
5         class String s = new String("StringDoesn'tStartWithH");
6         print(s.string());
7     }
8 }
```


test-arith6.dice.out

1 50

test-stdlib-stringclassLength.dice

```
1  include("stdlib");
2
3  class Two {
4      public void main(char[] [] args) {
5          class String s = new String("123456789");
6          print(s.length());
7      }
8  }
```

test-stdlib-stringclassContains2.dice.out

1 false

test-ops1.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(1 + 2);
4          print(1 - 2);
5          print(1 * 2);
6          print(100 / 2);
7          print(99);
8          print(1 == 2);
9          print(1 == 1);
10         print(99);
11         print(1 != 2);
12         print(1 != 1);
13         print(99);
14         print(1 < 2);
15         print(2 < 1);
16         print(99);
17         print(1 <= 2);
18         print(1 <= 1);
19         print(2 <= 1);
20         print(99);
21         print(1 > 2);
22         print(2 > 1);
23         print(99);
24         print(1 >= 2);
25         print(1 >= 1);
26         print(2 >= 1);
27     }
28 }
```

test-stdlib-stringclass.dice

```
1  include("stdlib");
2
3  class Two {
4      public void main(char[] [] args) {
5          class String s = new String("hi");
6          print(s.string());
7      }
8  }
```

test-arith2.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(1 + 2 * 3 + 4);  
4      }  
5  }
```

test-float-max.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          float a = 0.01175494;  
4          float b = 1010123.45;  
5          print(a);  
6          print("\n");  
7          print(b);  
8      }  
9  }  
10 }
```

test-arith1.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(5+15);  
4      }  
5  }
```


test-stdlib-stringclass3.dice.out

```
1  goodBye
```

test-ifEmptyBlock2.dice

```
1  class test {
2      public void main(char[] [] args) {
3          if (false){}
4          else {}
5          print(17);
6      }
7  }
```

test-array3.dice.out

1 1102

test-arithSigned4.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(-1-3);
4          print(1--3);
5          print(-1.0-3.0);
6          print(1.0--3.0);
7      }
8  }
```

test-classSetter.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      public void setX(int x){
6          this.xCoord = x;
7      }
8      public void setY(int y){
9          this.yCoord = y;
10     }
11
12 }
13
14 class test {
15     public void main(char[] [] args) {
16         class shape a = new shape();
17         a.setX(1);
18         a.setY(3);
19         print(a.xCoord);
20         print(a.yCoord);
21     }
22 }
```

test-classExtendsSetter.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      public void setX(int x){
6          this.xCoord = x;
7      }
8      public void setY(int y){
9          this.yCoord = y;
10     }
11
12 }
13
14 class circle extends shape {
15     public int radius;
16
17 }
18
19 class test {
20     public void main(char[] [] args) {
21         class circle a = new circle();
22         a.setX(1);
23         a.setY(3);
24         print(a.xCoord);
25         print(a.yCoord);
26     }
27 }
```

test-gcd.dice

```
1  class test {
2
3      public void main(char[] [] args) {
4          print(this.gcd(2,14));
5          print(this.gcd(3,15));
6          print(this.gcd(99,121));
7      }
8
9      public int gcd(int x, int y){
10         int a = x;
11         int b = y;
12         while (a != b) {
13             if (a > b)
14                 a = a - b;
15             else
16                 b = b - a;
17         }
18         return a;
19     }
20 }
```

test-bool7.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(true and true);
4          print(false and true);
5          print(true and false);
6          print(false and false);
7          print("\n");
8          print(true or true);
9          print(false or true);
10         print(true or false);
11         print(false or false);
12     }
13 }
```


test-classExtendsGetter.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      public int getX(){
6          return this.xCoord;
7      }
8      public int getY(){
9          return this.yCoord;
10     }
11
12 }
13
14 class circle extends shape {
15     public int radius;
16
17 }
18
19 class test {
20     public void main(char[] [] args) {
21         class circle a = new circle();
22         a.xCoord = 1;
23         a.yCoord = 3;
24         print(a.getX());
25         print(a.getY());
26     }
27 }
```

test-func4.dice.out

1 371

test-constructor1.dice.out

1 00510

test-fib.dice.out

1 112358

test-forBreak.dice.out

1 012100

test-func3.dice

```
1  class test {
2      public void main(char[] [] args) {
3          this.printem(42,17,192,8);
4      }
5
6      public void printem(int a, int b, int c, int d) {
7          print(a);
8          print(b);
9          print(c);
10         print(d);
11     }
12 }
```

test-scope.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int a;
4          a = 1;
5          {
6              int b = 2;
7              {
8                  int c = 3;
9                  print(a);
10                 print(b);
11                 print(c);
12             }
13             print(b);
14         }
15         print(a);
16     }
17 }
```

test-objectDeclarationInheritance.dice

```
1  class A {}
2  class B extends A {}
3  class C extends B {}
4
5  class test {
6
7      public void main(char[] [] args) {
8          class A myCObj = new C();
9          print("pass");
10     }
11 }
```


test-bool9.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(true, true, true, false, false, true, true, false, "\n");  
4      }  
5  }
```

test-if8.dice.out

```
1 elseif
```

test-hello.dice.out

```
1 Hello, World!
```

test-fileio.dice

```
1  include("stdlib");
2
3  class Two {
4
5      public void main(char[] [] args) {
6          class File a = new File("Test Suite/Compiler_Test_Suite/test-fileio.dice", true);
7          char[] buf = a.readfile(243);
8          a.closefile();
9          print(buf);
10         }
11     }
```

test-arith3.dice.out

1 86

test-float-max.dice.out

```
1 0.011755
2 1010123.450000
```

test-var4.dice

```
1  class test {
2      public int a;
3
4      public void foo(int b) {
5          int c;
6          c = this.a;
7          print(c);
8          this.a = b;
9          print(this.a);
10     }
11
12     public void main(char[][] args) {
13         this.a = 12;
14         this.foo(42);
15     }
16 }
```

test-cyclicalIncludes2.dice.out

1 ba

test-classExtendsSetter.dice.out

1 13

test-bool4.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(1<=2);  
4          print(1<=1);  
5          print(1<=2.0);  
6          print(2.1<=2.0);  
7      }  
8  }
```

test-bool2.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(1>2);
4          print(1.0>2);
5          print(1>2.0);
6          print(1.0>2.0);
7      }
8  }
```

test-classExtends.dice.out

1 1.500000

test-gcd.dice.out

1 2311

test-bool2.dice.out

```
1 falsefalsefalsefalse
```

test-func4.dice

```
1  class test {
2      public int a;
3
4      constructor() {}
5
6      public int inca() {
7          this.a = 124;
8          return this.a + 124;
9      }
10
11     public int add2(int x, int y) {
12         return x + y;
13     }
14
15     public void main(char[] [] args) {
16         class test b = new test();
17         print(b.add2(b.inca(), 123));
18     }
19 }
```

test-emptyBlock.dice.out

1 1

test-constructor2.dice.out

1 510

test-for2.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          int i;  
4          for ( i = 5 ; i > 0 ; i = i - 1 )  
5              print(i);  
6          print(42);  
7      }  
8  }
```

test-array2.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          float[] a = |1.0,1.5,2.5,3.5,4.5|;  
4          print(a[1]);  
5          print(a[4]);  
6      }  
7  }
```

test-**constructorDefault.dice.out**

1 5

test-applicative.dice.out

1 132

test-stmts1.dice.out

1 4562

test-global1.dice

```
1  class test {
2      public int a;
3      public int b;
4
5      public void printa(){
6          print(this.a);
7      }
8
9      public void printb(){
10         print(this.b);
11     }
12
13     public void incab(){
14         this.a = this.a + 1;
15         this.b = this.b + 1;
16     }
17
18     public void main(char[] [] args) {
19         this.a = 42;
20         this.b = 21;
21         this.printa();
22         this.printb();
23         this.incab();
24         this.printa();
25         this.printb();
26     }
27 }
```

test-intOverflow.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int a = 2147483648; (*More than an int can hold should overflow*)
4          if(a<2147483647){
5              print("pass");
6          }
7          else{
8              print(a);
9          }
10
11         int b = -2147483649; (*More than an int can hold should overflow*)
12         if(b>-2147483648){
13             print("pass");
14         }
15         else{
16             print(b);
17         }
18     }
19 }
```


test-if6.dice

```
1  class test {
2      public void main(char[] [] args) {
3          if (true){
4              if(true)
5                  print(42);
6                  print(27);
7          }
8          else
9              print(8);
10
11         if (false){
12             if(true)
13                 print(42);
14                 print(27);
15         }
16         else
17             print(8);
18     }
19 }
20 }
```

test-ifEmptyBlock.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          if (true){}  
4          print(17);  
5      }  
6  }
```

test-arith1.dice.out

1 20

test-arith4.dice.out

1 13105107

test-whileBreak.dice.out

1 543

test-classReturnObjects.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      constructor (){
6          this.xCoord = 1;
7          this.yCoord = 2;
8      }
9
10 }
11
12 class test {
13     public void main(char[] [] args) {
14         class shape a = this.returnMe();
15         print(a.xCoord);
16         print(a.yCoord);
17     }
18
19     public class shape returnMe(){
20         class shape b = new shape();
21         return b;
22     }
23 }
```

test-stdlib-stringclass2.dice.out

```
1 StringDoesn'tStartWithH
```

test-intMax.dice.out

```
1 2147483647
2 -2147483648
```


test-arith2.dice.out

1 11

test-for1.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int i;
4          for (i = 0 ; i < 5 ; i = i + 1) {
5              print(i);
6          }
7          print(42);
8      }
9  }
```

test-bool3.dice

```
1  class test {
2      public void main(char[] [] args) {
3          print(1>=2);
4          print(1>=1);
5          print(1>=2.0);
6          print(2.0>=2.0);
7      }
8  }
```

test-arithSigned3.dice.out

1 2-22.000000-2.000000

test-arith8.dice.out

```
1 20.000000
2 2.500000
```

test-intMax.dice

```
1  class test {
2      public void main(char[] [] args) {
3          int a = 2147483647;
4          int b = -2147483648;
5          print(a);
6          print("\n");
7          print(b);
8      }
9  }
```

test-bool5.dice.out

```
1  falsetrue
```

test-args.dice.out

```
1  davidemilyphil4
```


test-args.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print(args[1]);  
4          print(args[2]);  
5          print(args[3]);  
6          print(args.length);  
7      }  
8  }
```

E-test-cyclicalIncludesDuplicate.dice.out

```
1 Exceptions.DuplicateClassName(test)
```

E-test-objectCreation2.dice.out

1

E-test-scope3.dice

```
1  class test {  
2  
3      public void main(char[] [] args) {  
4          int x;  
5          for(x = 0; x < 3; x = x+1){  
6              int y = 10;  
7              print(y);  
8          }  
9          print(y);  
10     }  
11 }
```

E-test-objectCreation2.dice

```
1  class Bar {
2  constructor(char c, float f) {}
3  }
4
5  class Foo {
6  constructor(bool b, char c, float f) {}
7  constructor(int a, bool b, char c, float f) {}
8  }
9
10 class test {
11 public void main(char[] [] args) {
12 char myc = 'z';
13 float myf = 4.5;
14 class Bar myb = new Bar(myc, myf);
15 class Foo myFooObj = new Foo(5, true, myc, myf);
16 }
17 }
```

E-test-objectAssignMismatch.dice.out

```
1 LocalAssignTypeMismatch(B,C)
```

E-test-cyclicalIncludes.dice.out

```
1 Exceptions.DuplicateClassName(test)
```

E-test-scope1.dice.out

1 UndefinedID(x)

E-test-objectCreation1.dice.out

1

E-test-scope2.dice.out

1 UndefinedID(x)

E-test-assignMismatch.dice.out

```
1 AssignmentTypeMismatch (float,int)
```

E-test-duplicate.dice

```
1  class test {  
2  public void main(char[] [] args) {  
3  char myc = 'z';  
4  int myc = 2;  
5  float myf = 4.5;  
6  }  
7  }
```

E-test-scope3.dice.out

```
1 UndefinedID(y)
```

E-test-objectCreation4.dice

```
1  class Bar {
2  constructor(char c, float f) {}
3  constructor(bool b, char c, float f) {}
4  }
5  class Foo {
6  constructor(int a, bool b, char c, float f) {}
7  }
8  class test {
9  public void main(char[] [] args) {
10 char myc = 'z';
11 float myf = 4.5;
12 class Bar myb = new Bar(myc, myf);
13 class Foo myFooObj = new Foo(5, true, myc, myf);
14 }
15 }
```

E-test-constructor.dice

```
1  class Foo {
2  constructor(char c, float f) {}
3  constructor(bool b, char c, float f) {}
4  }
5
6  class test {
7  public void main(char[] [] args) {
8  int mya = 2;
9  bool myb = false;
10 char myc = 'z';
11 float myf = 3.5;
12 class Foo myFooObj = new Foo(mya, myb, myc, myf);
13 }
14 }
```

E-test-scope2.dice

```
1  class test {  
2  
3      public void main(char[] [] args) {  
4          if(true){  
5              int x = 10;  
6              print(x);  
7          }  
8          print(x);  
9      }  
10 }
```


E-test-constructor.dice.out

```
1 ConstructorNotFound: Foo.constructor.int.bool.char.float
```

E-test-noReturn.dice

```
1  class test {
2
3      public int increment(int x){
4          x = x+1;
5      }
6      public void main(char[] [] args) {
7          int x = this.increment(5);
8      }
9  }
```

E-test-cyclicalIncludesDuplicate2.dice.out

```
1 Exceptions.DuplicateClassName(test)
```

E-test-objectCreation1.dice

```
1  class Bar {
2  constructor(char c, float f) {}
3  constructor(bool b, char c, float f) {}
4  }
5
6  class Foo {
7  constructor(bool a, int b) {}
8  constructor(int a, bool b, char c, float f) {}
9  }
10
11  class test {
12  public void main(char[] [] args) {
13  int mya = 2;
14  bool myb = false;
15  char myc = 'z';
16  float myf = 3.5;
17  class Foo myFooObj = new Foo(mya, myb, myc, myf);
18  }
19  }
```

E-test-cyclicalIncludes.dice

```
1  include("Test Suite/Compiler_Test_Suite/test-cyclicalIncludes.dice");
2
3  class test {
4      public void main(char[] [] args) {
5          this.output();
6      }
7
8      public void output(){
9          print("a");
10     }
11 }
```

E-test-undefinedClass2.dice

```
1  class Foo {}
2
3  class Bar {}
4
5  class test {
6  public void main(char[] [] args) {
7  class Baz b;
8  }
9  }
```

E-test-mainClassNotDefined.dice

```
1  class test{  
2  
3  }
```

E-test-privateFieldsAccess.dice

```
1  class shape {
2      private int area;
3
4      constructor(){
5          this.area = 100;
6      }
7
8      public void setArea(int x){
9          this.area = x;
10     }
11
12     public int getArea(){
13         return this.area;
14     }
15 }
16
17
18 class test {
19     public void main(char[][] args) {
20         class shape a = new shape();
21         a.area = 50;
22
23     }
24 }
```


E-test-duplicate.dice.out

```
1 DuplicateLocal: myc
```

E-test-stdlib-overload.dice.out

```
1  CannotUseReservedFuncName(print)
```

E-test-noReturn.dice.out

```
1 Exceptions.AllNonVoidFunctionsMustEndWithReturn(test.increment)
```

E-test-undefinedClass.dice

```
1  class D {  
2      public void main(char[] [] args) {}  
3  }  
4  class A extends B {}  
5  class B extends C {}  
6  class C extends D {}  
7  class G extends H {}  
8  class I extends H {}
```

E-test-objectAssignMistmatch.dice

```
1  class A {}
2  class B extends A {}
3  class C {}
4  class test {
5  public void main(char[] [] args) {
6  class A myBObj = new B();
7    class B mySecondBObj = new C();
8  }
9  }
```

E-test-privateFunctionAccess.dice.out

```
1  CannotAccessPrivateFunctionInNonProperScope(something.hi,something,test)
```

E-test-objectCreation3.dice.out

1

E-test-objectCreation3.dice

```
1  class Foo {}
2
3  class Baz {}
4
5  class test {
6  public void main(char[] [] args) {
7    class Baz b;
8  }
9  }
```


E-test-privateFieldsAccess.dice.out

```
1  CannotAccessPrivateFieldInNonProperScope(area,shape,test)
```

E-test-assignMismatch2.dice.out

```
1 AssignmentTypeMismatch (int,float)
```

E-test-scope1.dice

```
1  class test {  
2  
3      public void main(char[] [] args) {  
4          {  
5              int x = 10;  
6              print(x);  
7          }  
8          print(x);  
9      }  
10 }
```

E-test-stdlib-overload.dice

```
1  class test {  
2  
3      public void print(){  
4  
5      }  
6  
7  public void main(char[] [] args) {  
8  
9      }  
10 }
```

E-test-objectCreation4.dice.out

1

E-test-cyclicalIncludesDuplicate.dice

```
1  include("Test
   ↪ Suite/Compiler_Test_Suite/Exceptions/E-test-cyclicalIncludesDuplicate2.dice");
2
3  class test {
4      public void main(char[] [] args) {
5
6      }
7  }
```

E-test-undefinedClass2.dice.out

```
1 UndefinedClass: Baz
```

E-test-cyclicalIncludesDuplicate2.dice

```
1  include("Test
   ↪ Suite/Compiler_Test_Suite/Exceptions/E-test-cyclicalIncludesDuplicate.dice");
2
3  class test {
4
5  }
```


E-test-assignMismatch2.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          int a;  
4          a = 1.0;  
5          print(a);  
6      }  
7  }
```

E-test-privateFunctionAccess.dice

```
1  class shape {  
2  }  
3  
4  class something {  
5  
6      private void hi(){  
7          }  
8  }  
9  
10 class test {  
11     public void main(char[] [] args) {  
12         class something a = new something();  
13         a.hi();  
14     }  
15 }
```

E-test-constructor1.dice

```
1  class shape {
2      public int xCoord;
3      public int yCoord;
4
5      constructor(int x, int y){
6          xCoord = 0;
7          yCoord = 0;
8      }
9
10     constructor(int x, int y){
11         xCoord = x;
12         yCoord = y;
13     }
14 }
15
16 class test {
17     public void main(char[][] args) {
18         (* Constructor clash *)
19     }
20 }
```

E-test-assignMismatch.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          float a;  
4          a = 1;  
5          print(a);  
6      }  
7  }
```

E-test-mainClassNotDefined.dice.out

1 MainNotDefined

E-test-undefinedClass.dice.out

```
1 UndefinedClass: H
```

E-test-constructor1.dice.out

```
1 DuplicateConstructor
```

test_pretty.dice

```
1  class test {
2      public void main (char[][] args) {
3          print("Hello World");
4      }
5  }
```


test.dice

```
1  class test {  
2      public void main(char[] [] args) {  
3          print("Hello World");  
4      }  
5  }
```

primitives.dice

```
1  class testPrims {
2      public int a;
3      public float b;
4      private char c;
5      private bool d;
6      public void main(char[] [] args) {
7          int e;
8          float f;
9          char g;
10         bool h;
11         a = -2147483648;
12         e = 2147483647;
13         b = 1.0;
14         f = 2.222222;
15         c = '0';
16         g = '\t';
17         d = true;
18         h = false;
19     }
20 }
```

test_pretty.dice.ManualTokens

```
1 1. CLASS ID(test) LBRACE
2 2. PUBLIC VOID ID(main) LPAREN CHAR LBRACKET RBRACKET LBRACKET RBRACKET ID(args) RPAREN
   ↪ LBRACE
3 3. ID(print) LPAREN STRING_LITERAL(Hello World) RPAREN SEMI
4 4. RBRACE
5 5. RBRACE
6 6. EOF
```

primitives.dice.ManualTokens

```
1 1. CLASS ID(testPrims) LBRACE
2 2. PUBLIC INT ID(a) SEMI
3 3. PUBLIC FLOAT ID(b) SEMI
4 4. PRIVATE CHAR ID(c) SEMI
5 5. PRIVATE BOOL ID(d) SEMI
6 6. PUBLIC VOID ID(main) LPAREN CHAR LBRACKET RBRACKET LBRACKET RBRACKET ID(args) RPAREN
   ↪ LBRACE
7 7. INT ID(e) SEMI
8 8. FLOAT ID(f) SEMI
9 9. CHAR ID(g) SEMI
10 10. BOOL ID(h) SEMI
11 11. ID(a) ASSIGN MINUS INT_LITERAL(2147483648) SEMI
12 12. ID(e) ASSIGN INT_LITERAL(2147483647) SEMI
13 13. ID(b) ASSIGN FLOAT_LITERAL(1.) SEMI
14 14. ID(f) ASSIGN FLOAT_LITERAL(2.222222) SEMI
15 15. ID(c) ASSIGN CHAR_LITERAL(0) SEMI
16 16. ID(g) ASSIGN CHAR_LITERAL(\\t) SEMI
17 17. ID(d) ASSIGN TRUE SEMI
18 18. ID(h) ASSIGN FALSE SEMI
19 19. RBRACE
20 20. RBRACE EOF
```

test.dice.ManualTokens

```
1 1. CLASS ID(test) LBRACE
2 2. PUBLIC VOID ID(main) LPAREN CHAR LBRACKET RBRACKET LBRACKET RBRACKET ID(args) RPAREN
   ↪ LBRACE
3 3. ID(print) LPAREN STRING_LITERAL(Hello World) RPAREN SEMI
4 4. RBRACE
5 5. RBRACE EOF
```

Demo_Animals.dice

```
1  include("stdlib");
2
3  class Animal{
4      public int weight;
5      constructor(){
6          this.weight = 0;
7      }
8
9      constructor(int w){
10         this.weight = w;
11     }
12
13     public void move(){
14         print("Animals move in many ways");
15     }
16 }
17
18 class Bird extends Animal {
19     public int maxFlyingHeight;
20
21     constructor(){
22         this.weight = 0;
23         this.maxFlyingHeight = 0;
24     }
25
26     constructor(int w, int h){
27         this.weight = w;
28         this.maxFlyingHeight = h;
29     }
30
31     public void move(){
32         print("Birds fly!");
33     }
34 }
35
36
37 class Dog extends Animal {
38     public int speed;
39
40     constructor(){
41         this.weight = 0;
42         this.speed = 0;
43     }
44
45     constructor(int w, int s){
46         this.weight = w;
47         this.speed = s;
```

```
48     }
49
50     public void move(){
51         print("Dogs run!");
52     }
53 }
54
55 class Stephen extends Animal {
56     private bool isDone;
57
58     constructor() {
59         this.isDone = true;
60     }
61
62     constructor(bool isDone) {
63         this.isDone = isDone;
64     }
65
66     public void move() {
67         if(not this.isDone) {
68             print("I am a techer!");
69         } else {
70             print("Also my favorite number is 42");
71         }
72         this.isDone = true;
73     }
74 }
75
76
77 class Snake extends Animal {
78     public int slitherSpeed;
79
80     constructor(){
81         this.weight = 0;
82         this.slitherSpeed = 0;
83     }
84
85     constructor(int w, int s){
86         this.weight = w;
87         this.slitherSpeed = s;
88     }
89
90     public void move(){
91         print("Snakes slither!");
92     }
93 }
94
95 class Marnie extends Dog {
96     public int cuteness;
```

```
97
98     constructor(){
99         this.weight = 0;
100         this.speed = 0;
101     }
102
103     constructor(int w, int s){
104         this.weight = w;
105         this.speed = s;
106     }
107
108     constructor(int w, int s, int c){
109         this.weight = w;
110         this.speed = s;
111         this.cuteness = c;
112     }
113
114     public void move(){
115         class File a = new File("Demo/marnie1.txt", true);
116         char[] buf = a.readfile(4500);
117         a.closefile();
118         print(buf);
119         print("\n");
120     }
121 }
122
123 class test {
124     private bool isDone;
125     public void main(char[] [] args) {
126         this.logo();
127         this.isDone = false;
128
129         bool keepGoing = true;
130         while(keepGoing){
131             this.animalsToChoose();
132             char[] buf = input();
133             print("\n");
134
135             int choice = this.getInt(buf[0]);
136
137             if(choice==5)
138                 break;
139             else
140                 this.printMovement(choice);
141
142             print("\n");
143         }
144
145         class Marnie a = new Marnie();
```



```
146     a.move();
147 }
148
149 public int getInt(char num){
150     if(num=='1')
151         return 1;
152     else if(num=='2')
153         return 2;
154     else if(num=='3')
155         return 3;
156     else if(num=='4')
157         return 4;
158     else if(num=='5')
159         return 5;
160
161     return 0;
162
163 }
164
165 public void printMovement(int choice){
166
167     class Animal b = new Bird();
168     class Animal d = new Dog();
169     class Animal s = new Snake();
170     class Animal stephen = new Stephen(this.isDone);
171
172     if(choice == 1)
173         b.move();
174     else if(choice == 2)
175         d.move();
176     else if(choice == 3)
177         s.move();
178     else if(choice == 4) {
179         stephen.move();
180         this.isDone = true;
181     }
182     else
183         print("Animal not selected!\n");
184
185     print("\n");
186 }
187
188 public void animalsToChoose(){
189     print("1-Bird\n2-Dog\n3-Snake\n4-Stephen\n5-Exit\nPlease choose an animal
190     ↪ or exit(by selecting a number):");
191 }
192
193 public void logo(){
```

```
194         class File a = new File("Demo/logo.txt", true);
195         char[] buf = a.readfile(4500);
196         a.closefile();
197         print(buf);
198
199         int i;
200         for(i=0;i<3;i=i+1){
201             print("\n");
202         }
203
204         print("Welcome to the animal farm!\n\n");
205     }
206 }
```

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