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Alia Programming Language

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Introduction

The Alia programming language was built for the final project of the compiler construction course at the University of Twente. In this final project a programming language is specified and implemented in antlr (ANother Tool for Language Recognition). A compiler is built to translate code into a type of machine instructions. The type of machine instructions can vary from language to language. Over the first half of compiler construction course several parts of the design process of building a compiler are individually learned and tested. In the final project this is brought to culmination by going through the entire process from the specification, to in the end a usable programming language.

This document serves as a specification of the Alia Programming Language (Alia for short) as well as an explanation of the inner workings of the Alia compiler. In it we will give a short description of the Alia Programming Language in the context of programming languages, explain some of the problems faced during the construction of the Alia compiler, and our solutions. Give a specification of the Alia language with the help of the syntax, context-constraints and semantics. Also in this document are the transformations that show how the symbols of the language are turned into JVM instructions, a description of all the auxiliary Java code made for the compiler. A set of tests is described to give confidence in the correctness of the compiler. Lastly conclusions are drawn from the project.

The Alia source code repository is located at <https://github.com/JoostvDoorn/VertalerbouwEindproject>.

1 Alia Programming Language

The Alia programming language is an expression language with type inference. Alia code is compiled to Java bytecode using Jasmin and can be run using the Java Virtual Machine (JVM). As an expression language every statement has a return type. Functional statements such as print, read and conditional statements all return values. For example the print function may return a value which can be used in an assignment statement.

```
x = print(34) + 1 // x is assigned 35
```

Alia contains compound statement which are a series of statements with the last statement as return value, compound statements are used in conditional statements and can be explicitly used for scoping.

```
x = begin
  y = 3 // Only declared in this scope
  y + 1 // Return value for the compound statement
end
if y = true; y && x < 10 do // y here has a different scope
  print(y) // Print the value of y
  print('t')
end
```

Types in Alia are inferred and do not need explicit declarations. Types can be declared explicitly within an assignment statement, but are not required. In the current form of the programming language, type inference can always deduce the type of a declaration. However in an extended version of Alia with functions and procedures, explicit type declarations will be required in cases where type inference will not

be able to deduce the type of the variable or function return type. Type inference makes programming easier, it reduces the work of the programmer by making explicit type declarations optional, and reduces the amount of code required for variable declarations. Type checking is maintained and the programmer still has the option to add type declarations if it helps clarify the code.

```
x = 54 : int // x is assigned 54, and is explicitly declared as an int
```

2 Problems and solutions

During the construction of the Alia compiler we ran into some problems, as is to be expected during any first time construction of a compiler. In this section we will explain some of the bigger problems that we faced as well as the solutions that we applied.

2.1 Scope definition

Because we do not have explicit declarations we cannot redefine a variable inside a new scope. There would be no way to distinguish between redefining a variable in a new scope and reassigning the value that was given to a variable to be used later. With a new variable that overwrites an old one for a temporary scope you would need to assign a new space in memory. We have decided that we want this in our programming language, this is because if you can redeclare a variable inside a new scope then you are only making it more confusing for yourself as a coder. On the other hand not being able to assign a new value to a variable in a new scope destroys a large part of the functionality of language. For these reasons we have chosen to leave it as is.

2.2 String template expressions

StringTemplate does not allow you to evaluate an expression inside of a string template. This was purposefully implemented to stop you from putting a large part of the logic in the string template itself. The problem that we have with this is that there are issues that are specific to the creation of java bytecode that must now be evaluated in the antlr part of the program, and must be passed in the creation of any possible target platform. The first time this became a problem was what instructions to use for outputting any given number. A naive solution to this would be to always use the instruction for loading a large number like an integer. But java has special instructions for loading the numbers -1 through 5 and loading smaller numbers that fit on a byte or a short, so we wanted to use these. To solve this issue we created a function that calculated what type a number can fit into in the CodeGeneratorAux class which passes a number of booleans wrapped in a NumberType to the string template. We then use conditional templates to emit different instructions depending on the number to be put on the stack.

2.3 Constants

We chose to put the optimisation of replacing all constants by their actual reference in the checker stage. The choice was made because in the checker there is already a list of declared variables, and Java functions to do this. This made it very easy to implement this feature in the checker, and much more ugly to implement in the code generation. In an ideal world there would be a separate stage in-between the checker and the code generation that optimizes the abstract syntax tree, but this one feature was easily

done in the checker. We have also chosen to not support constants that can vary, being defined by another identifier. In the Alia programming language a constant can only be defined by a single primitive type.

3 Syntax, context-constraints and semantics

The syntax of Alia is defined as follows:

```

program = (func_def | (statement end_statement) | \n)*;

statements = (statement (end_statement statements)? | \n statements)?;
statements_cond = (statement (end_statement statements)? | \n statements_cond )?;

statement = (expr_assignment | const_assignment) (; type)?
| while_stmnt
;

end_statement = \n | ";" | EOF;

expr_assignment = (identifier "=") expr_assignment
| expr
;

const_assignment = CONST identifier "=" primitive;

expr = expr1 ((or | "||") expr1)*;
expr1 = expr2 ((and | "&&") expr2)*;
expr2 = expr3 ((" "> | ">=" | "<" | "<=" | "==" | "!=" ) ^ expr3)*;
expr3 = expr4 (("+" | "-") ^ expr4)*;
expr4 = expr5 (("*" | "/" | "%") ^ expr5)*;
expr5 = "!" operand | operand | expr_minus | expr_plus;
expr_minus = "-" operand;
expr_plus = "+" operand;
operand = read |
    print |
    if_stmnt |
    "(" expr ")" |
    compound_stmnt |
    primitive |
    func_identifier
;

compound_stmnt = begin statements end;

primitive = number | character | boolean;

func_identifier = identifier ( "(" exprlist? ")" )?;
```

```

while_stmnt = WHILE statements_cond DO statements END;

if_stmnt = IF statements_cond DO statements else_stmnt? END;

else_stmnt = ELSEIF statements_cond DO statements else_stmnt?
| (ELSE statements)
;

print = PRINT "(" exprlist ") ";
read = READ "(" varlist ") ";

varlist = identifier ("," identifier)*;
exprlist = expr ("," expr)*;

func_def = DEF identifier "(" varlist ")";

```

3.1 Semantics and context constraints:

The semantics and context constraints are defined using the abstract syntax of the Alia language.

Program

```
program = ((statement end_statement) | \n)*;
```

A program is run by executing a sequence of statements.

Statement

```

statements = (statement (end_statement statements)? | \n statements)?;
statements_conditional = (statement (end_statement statements)? | \n statements_cond )?;
end_statement = \n | ";" | EOF;
statement = while_stmnt
| (expr_assignment | const_assignment)
;
while_stmnt = WHILE statements_cond DO statements END;
if_stmnt = IF statements_cond DO statements else_stmnt? END;
else_stmnt = ELSEIF statements_cond DO statements else_stmnt?
| (ELSE statements);
compound_stmnt = begin statements end;

```

- A statements is a set of statements separated by an end statement.
- A conditional statements is a statements that is ment for conditional expressions.
- A statement can be ended by any of the above separators.

- The while statement 'while S1 do S2 end' is executed as follows. The statement S1 is evaluated, if its value is true then S2 is evaluated and the while statement is run again. If the value of S1 is false then the execution is completed. S1 must be of type boolean. This statement is of type void. Declarations made in S1 are valid in S1 and S2. The scope of declarations made in S2 is only S2.
- If statements of the form 'if S1 do S2 (elseif S3 do S4)* (else S5)?' are executed as follows. S1 is executed. If S1 is true, then S2 is evaluated. If S1 is false and there is an S3, then S3 is evaluated and if true S4 is executed. If the evaluated S3 is false there is another elseif statement then it is evaluated, same as an if statement is. If S1, S3 and all other elseifs have evaluated to false, then S5 is executed. If there is no S5, execution has completed. The type of S1 and S3 must be boolean. If there is no else part, the type of the statement is void. If there is an else part, then if all S2, S4, S5 are the same type, that is the type of the conditional statement. If S2, S4, S5 are not of the same type then the type of the statement is void. Special scope rules apply, a declaration in S1 or any S3 is valid in S2, S4, S5 as long as the declaration precedes the use.
- A compound statement is a closed set of statements. Any assignments made in the statements can not be used outside of the compound statement. The result and type of the compound statement are the same as the last statement in the compound statement.

Assignment

```
expr_assignment = identifier "=" expr_assignment
| expr (; type)?
;
```

```
const_assignment = CONST identifier "=" primitive(; type)?
```

- An expression assignment binds one or more identifiers to a value yielded by an expression E. If a type is included then the type and the type of the expression must match. The identifiers can thereafter be used in applied occurrences. The expression assignment yields the value of the expression.
- The expression 'const I = P (:T)?' is executed as follows. I is bound to the value P. If T was included, T and E must be of the same type. The expression is of type P. I can be used in applied occurrences. I can not be assigned a different value at a later time.

Expressions

```
expr = expr1 ((or | "|" | ") expr1)*;
expr1 = expr2 ((and | "&&") expr2)*;
expr2 = expr3 ((">" | ">=" | "<" | "<=" | "==" | "!=" ) ^ expr3)*;
expr3 = expr4 (("+ " | "- ") ^ expr4)*;
expr4 = expr5 ("*" | "/" | "%") ^ expr5)*;
expr5 = "!" operand | operand | expr_minus | expr_plus;
expr_minus = "-" operand;
expr_plus = "+" operand;
```

- The expressions 'or', '||', 'and', '&&' preceded by E1 and followed by E2 are evaluated by performing a logical or (True iff E1 or E2) in case of 'or' and '||'. In the case of 'and' and '&&' it is evaluated by performing a logical and on the two expressions (True iff E1 and E2). E1 and E2 must be of type boolean. The type of the expression is Boolean. These are the logical operators.
- The expression 'E1 == E2' is true iff E1 equals E2. 'E1 != E2' is true iff E1 is not equal to E2. 'E1 <= E2' is true iff E1 is smaller than or equal to E2. 'E1 >= E2' is true iff E1 greater than or equal to E2. 'E1 > E2' is true iff E1 is greater than E2. 'E1 < E2' is true iff E1 is smaller than E2. Of all these comparative operators, E1 and E2 must be of the same type. The type of the expressions is Boolean. These are the comparative operators.
- The expression 'E1 + E2' is executed as E1 plus E2. 'E1 - E2' is E1 minus E2. 'E1 * E2' is E1 times E2. 'E1 / E2' is E1 divided by E2, E2 is not allowed to be zero. '
- The operator O in '!O' is inverted. O must be of type boolean, the expression is of type boolean. The '+O' and '-O' are executed as follows. For '+O' nothing is done. For '-O' the operand is negated. O must be of type Int, the expression is of type Int. These are the unary operators.
- The previous expressions have the following priority, from highest to lowest. Unary operators (-, +, !), then *,/,

Operands

```
operand = READ "(" varlist ")" |
          PRINT "(" exprlist ")" |
          if_stmt |
          "(" expr ")" |
          compound_stmt |
          primitive |
          identifier
;
```

- The expression 'read VL' is executed as follows. The variable list evaluated. For every variable a line is read from the input, the first character of this line is assigned as value to the variable. The type of the expression is the type of VL.
- The expression 'print EL' is executed as follows. The expression list EL is evaluated. All evaluated expressions are then written to the output. The type of the expression is the type of EL.
- If statements are explained under statements.
- An operand can carry another expression as long as that expression is surrounded by brackets. The type and result are the same as the expression.
- Compound statements are explained under statements.
- A primitive is one of the three primitive types NUMBER, CHARACTER and BOOLEAN.
- The identifier operand points to a the value or variable bound to I. The operand I must have been previously declared. The type of the operand is the type of that value or variable.

lists

```
varlist = identifier ("," identifier)*;  
exprlist = expr ("," expr)*;
```

- The list 'I (I)*' evaluates to a list of identifiers. If there is one identifier the type of the list is the type of that identifier, and the result is its value. If there are 2 or more, the type is void and there is no result.
- The list 'E (E)*' evaluates to a list of expressions. None of the expressions may be void. If there is one expression, the list of the type of E, and the value is E. If there are 2 or more, the type is void, and thus there is no result.

types

```
primitive = NUMBER  
| CHARACTER  
| BOOLEAN  
;
```

- The operand 'N' evaluates to a number. N can be no larger than 2147483647 and no smaller than -2147483648. N is of type Int.
- The operand 'C' evaluates to a character. C is of type Char.
- The operand 'B' evaluates to a boolean, either true or false. C is of type Bool.

In Alia there are 4 types. 'int', 'char', 'boolean' and 'void'. If something is of type void it is an empty value that cannot be used.

4 Translation rules

The translation rules for Alia to Java bytecode are shown here. Some details have been abstracted away in favor of readability, these details include specific label names, translation rules which are dependent on the type of the expression (such as print and read), and some specific rules where pop statements are included.

Pop lines A pop line is included after every statement that returns a value but has no higher expression using it. The amount of variables generated on the stack are counted by the compiler and after each complete statement the leftover expressions are popped.

Translation rules

```
execute [I = E]  
    expr [E]  
    istore a // address of variable I  
    identifier [I]
```



```

expr [while C do S end] =
    goto COND
    WHILE:
    execute [S]
    COND:
    execute [C]
    ifne WHILE

expr [if C do S E end] =
    execute [C]
    ifeq ELSE
    execute [S]
    goto NEXT
    ELSE:
    exprElse [E]
    NEXT:

exprElse [elseif C do S E]
    execute [C]
    ifeq ELSE
    execute [S]
    goto NEXT
    ELSE:
    exprElse [E]
    NEXT:

exprElse [else S] =
    execute [S]

expr [E1 0 E2] =
    expr [E1]
    expr [E2]
    instruction [0] // The specific instruction, e.g. iadd etc.

expr [E1 0C E2] =
    expr [E1]
    expr [E2]
    if_icmp $+7 // Go to iconst_1 if it is true, this line contains the specific instruction
    iconst_0
    goto $+4 // Go to the line after iconst_1
    iconst_1

expr [-E]
    expr [E]
    ineg

```

```

expr [+E]
  expr [E]

expr [not E]
  expr[E]
  ifeq $+7
  iconst_0
  goto $+4
  iconst_1

expr [begin S end]
  execute [S]

print [S] =
  getstatic java/lang/System/out Ljava/io/PrintStream;
  execute [S]
  invokevirtual java/io/PrintStream/println(T)V

expr [print(S)] =
  getstatic java/lang/System/out Ljava/io/PrintStream;
  execute [S]
  istore_1
  iload_1
  invokevirtual java/io/PrintStream/println(T)V
  iload_1

expr [print(S, L)] =
  print [S]
  executePrint [L]

executePrint [S, L]
  print [S]
  executePrint [L]

executePrint [S]
  print [S]

read [] =
  invokestatic java/lang/System/console()Ljava/io/Console;
  invokevirtual java/io/Console/readLine()Ljava/lang/String;
  invokestatic java/lang/Type/parseType(Ljava/lang/String;)T

execute [read(I)] =
  read []
  istore_1

```

```

    iload_1
    istore a ; address of variable I
    execute [S]
    iload_1

execute [read(I, L)] =
    read []
    istore a ; address of variable I
    exprRead [L]

exprRead [I, L]
    read []
    istore a ; address of variable I
    exprRead [L]

exprRead [I]
    read []
    istore a ; address of variable I

execute [S \n S] =
    execute [S]
    execute [S]

execute [S ; S] =
    execute [S]
    execute [S]

execute [S] =
    expr [S]

identifier [I] =
    iload a // address of variable I

operand [I] =
    identifier [I]

operand [N] =
    number [N] // iconst n
operand [C] =
    bipush C

operand [true] =
    iconst_1

operand [false] =
    iconst_0

```

```

program [S] =
  .class public filename.j // target file
  .super java/lang/Object

  .method public \<init\>()V
    aload_0
    invokenonvirtual java/lang/Object/\<init\>()V
    return
  .end method

  .method public static main([Ljava/lang/String;)V
    .limit stack stackMax // stackMax = maximum size of the stack
    .limit locals localSize // localSize = amount of local variables required

    execute [S]

    return
  .end method

```

5 Java-code

The checker uses an auxiliary class `CheckerAux` that handles a large portion of the logic of the checking, such as if two types are the same. This class also declares variables and constants into the symbol table. `CheckerAux` also has methods to access the symbolTable so that it throws `AliaExceptions` instead of more general exceptions. The symbol table has a `HashMap` of Names, `IdEntries` and a `scopestack` that has all identifiers declared on a scope. Like every symbolTable it keeps track of what identifiers have been declared on what levels. The `IdEntries` also store information about whether the identifier is a constant and what type it is.

Most of the logic for type checking is implemented in `CheckerAux`, to do the type checking a set of type classes are used, such as `_Int` and `_Bool`. All of these classes inherit from `_Type` and have a string with their typename. We chose to make all types into distinct classes instead of an enum because this will allow for extension of say the `_Int` class with a `_Float` class or of the `_Char` class with a `_String` class. In this way we can more easily add additional types to `Alia` and a future `_Long` and `_Float` could be compared using inheritance.

The code generation makes use of `CodeGeneratorAux`. This separates some of the logic from the antlr files. In particular `CodeGeneratorAux` calculates what kind of java type can be used for any given number, this choice is explained in the problems section. To do this it uses the `NumberType` class, which acts as a container for a number of booleans so that they can be passed more elegantly. The other part that `CodeGeneratorAux` takes care of is the logic for the stack management, incrementing and decrementing the amount that is still to be pushed off the stack in the code generation.

For error handling `AliaException` and `AliaTypeException` are used. These exceptions are thrown in the checker when ever a type is violated. If there is a syntactical mistake then the classes generated by antlr will throw exceptions. For run time errors standard java exceptions are also used.

After the checking phase has been completed a decorated AST is returned. The decorated AST stores the type information that was found in the corresponding nodes, such as for all binary expressions. We also store the identifying numbers for all applied usages of identifiers (except for constants which are replaced), these ascending numbers are gotten from the IdEntries using CheckerAux and are stored with the nodes, for later use in the code generation.

6 Tests

The Alia programming language has been thoroughly tested using a collection of test programs. These test programs have been designed to check the correct workings of parser, checker and compiler of the Alia programming language. Unit tests have been build using JUnit, and are located in the src/tests/ folder of the Alia project. There are three type of errors which the compiler should check for.

1. Syntax: Incorrect syntax and typos should be reported.
2. Context: The context checker should type check the program, make sure all variables are declared before use, and enforce scoping rules.
3. Semantics: Runtime errors such as division by zero should be adequately handled by the compiler.

6.1 Tests

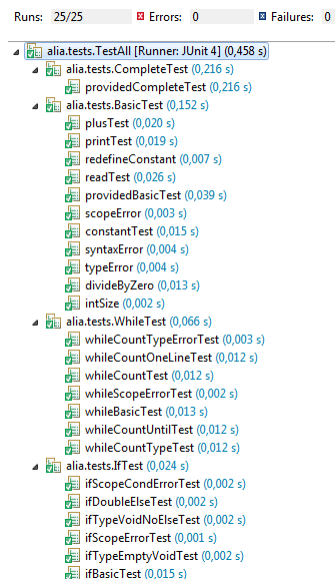
The tests have been constructed based on the requirements formulated in the compiler construction reader.

1. BasicTest.java: Contains tests for the basic expression language.
 - (a) providedBasicTest: Test with correct syntax which is checked for correct output.
 - (b) plusTest: Tests a basic arithmetic expression.
 - (c) printTest: Tests print expressions.
 - (d) readTest: Tests read expressions.
 - (e) constantTest: Tests constants.
 - (f) redefineConstant (Context): Checks if constants cannot be redefined.
 - (g) syntaxError (Syntax): Checks if syntax errors are properly detected.
 - (h) typeError (Context): Checks if type errors are properly detected.
 - (i) intSize (Context): Check if use of numbers above the maximum integer size are detected.
 - (j) scopeError (Context): Checks if references out of scope are valid.
 - (k) divideByZero (Semantics): Checks if divide by zero triggers a runtime error.
2. WhileTest.java: Contains tests for the while conditional statement.
 - (a) providedBasicTest (Syntax): Test with correct syntax which is checked for correct output.
 - (b) plusTest (Syntax): Tests a basic arithmetic expression.
 - (c) printTest (Syntax): Tests print expressions.

- (d) readTest (Syntax): Tests read expressions.
 - (e) constantTest (Syntax): Tests constants.
 - (f) redefineConstant (Context): Checks if constants cannot be redefined.
 - (g) syntaxError (Syntax): Checks if syntax errors are properly detected.
 - (h) typeError (Context): Checks if type errors are properly detected.
 - (i) intSize (Context): Check if use of numbers above the maximum integer size are detected.
 - (j) scopeError (Context): Checks if references out of scope are valid.
 - (k) divideByZero (Semantics): Checks if divide by zero triggers a runtime error.
3. IfTest.java: Contains test for the if conditional statement.
- (a) ifBasicTest (Syntax): Basic if statement test.
 - (b) ifTypeVoidNoElseTest (Context): Tests if type is void when else statement is not present.
 - (c) ifScopeErrorTest (Context): Tests the scope rules of the if statement.
 - (d) ifScopeCondErrorTest (Context): Tests the scope rules of the condition of the if statement.
 - (e) ifTypeEmptyVoidTest (Context): Tests if type is void when the if statement is empty.
 - (f) ifDoubleElseTest (Syntax): Test with two many else statements, checks correct syntax error.
4. CompleteTest.java: Contains all language constructs of the Alia programming language.
- (a) providedCompleteTest (Syntax): Test program with all language constructs.

6.2 Test results

The test program will output whether or not the tests have executed successfully. The tests results can be seen in the image below. All tests have been successfully run using JUnit. This gives a relatively high certainty that the programming language is correct.



7 Conclusion

8 Appendices

8.1 Complete functionality test

The following test is designed to test most of the programming language functionalities.

8.1.1 Alia code

```
1  ivar = begin
2      ivar1 = ivar2 = 0
3      read(ivar1, ivar2);
4      print(ivar1, ivar2);
5      const iconst1 = 1;
6      const iconst2 = 2;
7      ivar2 = ivar1 = +16 + 2 * -8;
8      print(ivar1 < ivar2 && iconst1 <= iconst2, iconst1 * iconst2 > ivar2 - ivar1);
9      ivar1 < read(ivar2) && iconst1 <= iconst2;
10     ivar2 = print(ivar2) + 1;
11     end + 1
12  bvar = begin
13     bvar = false
14     read(bvar);
15     print(bvar);
16     bvar = 12 / 5 * 5 + 12 % 5 == 12 && 6 >= 6;
17     const bconst = true;
18     print(!false && bvar == bconst || true != false);
19     end && true;
20  cvar = begin
21     cvar1 = 'c'
22     read(cvar1);
23     const cconst = 'c';
24     cvar2 = 'z';
25     print('a', cvar1 == cconst && cvar2 != 'b' || !true);
26     'b';
27     end;
28  print(ivar, bvar, cvar);
29
30  i = 0
31  z = 0
32  while x = 5; x > i do
33      print(i)
34      if z == 1 do
35          z = 0
36      elseif z == -1 do
37          z = 1
38      else
```



```
39     z = -1
40     i = i + 1
41 end
42 end
```

8.1.2 Jasmin bytecode

```
1 ; Jasmin JBC assembler code generated by
   AliaCodeGenerator
2 .class public Complete
3 .super java/lang/Object
4 .field private static in Ljava/io/BufferedReader;
5
6 .method static public <clinit>()V
7   .limit stack 5
8   new java/io/BufferedReader
9   dup
10  new java/io/InputStreamReader
11  dup
12  getstatic java/lang/System/in Ljava/io/
    InputStream;
13  invokespecial java/io/InputStreamReader/<init>(
    Ljava/io/InputStream;)V
14  invokespecial java/io/BufferedReader/<init>(Ljava
    /io/Reader;)V
15  putstatic Complete/in Ljava/io/BufferedReader;
16  return
17 .end method
18
19 .method public <init>()V
20   aload_0
21   invokenonvirtual java/lang/Object/<init>()V
22   return
23 .end method
24
25 .method public static main([Ljava/lang/String;)V
26   .limit stack 7
27   .limit locals 8
28
29   iconst_0
30   istore 2 ; store value into ivar2
31   iload 2 ; put value on the stack
32   istore 3 ; store value into ivar1
33   iload 3 ; put value on the stack
34   pop
35   getstatic Complete/in Ljava/io/BufferedReader;
36   invokevirtual java/io/BufferedReader/readLine()
    Ljava/lang/String;
37   invokestatic java/lang/Integer/parseInt(Ljava/
    lang/String;)I
38
39   istore_1
40   iload_1
41   istore 3 ; store value
42   getstatic Complete/in Ljava/io/BufferedReader;
43   invokevirtual java/io/BufferedReader/readLine()
    Ljava/lang/String;
44   invokestatic java/lang/Integer/parseInt(Ljava/
    lang/String;)I
45
46   istore 2 ; store value into ivar2
47   iload_1 ; repush the value to the stack if it is
    used again
48   pop
49   getstatic java/lang/System/out Ljava/io/
    PrintStream;
50   iload 3
51   invokevirtual java/io/PrintStream/println(I)V
52   getstatic java/lang/System/out Ljava/io/
    PrintStream;
53   iload 2
54   invokevirtual java/io/PrintStream/println(I)V ;
    add right constant pool reference bytes for
    println
55
56   ; does nothing, is feature
57   bipush 16 ; expr1
58   iconst_2 ; expr1
59   bipush 8
60   ineg ; expr2
61   imul ; expr2
62   iadd
63   istore 3 ; store value into ivar1
64   iload 3 ; put value on the stack
65   istore 2 ; store value into ivar2
66   iload 2 ; put value on the stack
67   pop
68   getstatic java/lang/System/out Ljava/io/
    PrintStream;
69   iload 3
70   iload 2
71   if_icmplt $+7 ; Go to iconst_1 if it is true
72   iconst_0
73   goto $+4 ; Go to the line after iconst_1
74   iconst_1 ; expr1
75   iconst_1
76   iconst_2
77   if_icmple $+7 ; Go to iconst_1 if it is true
78   iconst_0
79   goto $+4 ; Go to the line after iconst_1
80   iconst_1 ; expr2
81   iand
82   invokevirtual java/io/PrintStream/println(Z)V
83   getstatic java/lang/System/out Ljava/io/
    PrintStream;
84   iconst_1 ; expr1
85   iconst_2
86   ; expr2
87   imul
88   iload 2 ; expr1
89   iload 3 ; expr2
90   isub
91   if_icmpgt $+7 ; Go to iconst_1 if it is true
92   iconst_0
93   goto $+4 ; Go to the line after iconst_1
94   iconst_1
95   invokevirtual java/io/PrintStream/println(Z)V ;
    add right constant pool reference bytes for
    println
96
97   iload 3
98   getstatic Complete/in Ljava/io/BufferedReader;
99   invokevirtual java/io/BufferedReader/readLine()
    Ljava/lang/String;
100  invokestatic java/lang/Integer/parseInt(Ljava/
    lang/String;)I
101
102  istore_1
103  iload_1
104  istore 2 ; store value
105  iload_1 ; repush the value to the stack if it is
    used again
106  if_icmplt $+7 ; Go to iconst_1 if it is true
107  iconst_0
108  goto $+4 ; Go to the line after iconst_1
109  iconst_1 ; expr1
110  iconst_1
111  iconst_2
112  if_icmple $+7 ; Go to iconst_1 if it is true
113  iconst_0
114  goto $+4 ; Go to the line after iconst_1
115  iconst_1 ; expr2
116  iand
117  pop
118  getstatic java/lang/System/out Ljava/io/
    PrintStream;
119  iload 2
120  istore_1
121  iload_1
122  invokevirtual java/io/PrintStream/println(I)V
123
124  iload_1 ; repush the value to the stack if it is
    used again ; expr1
125  iconst_1 ; expr2
126  iadd
127  istore 2 ; store value into ivar2
128  iload 2 ; put value on the stack ; expr1
129  iconst_1 ; expr2
130  iadd
131  istore 2 ; store value into ivar
132  iload 2 ; put value on the stack
133  pop
134  iconst_0 ; Bool
135  istore 3 ; store value into bvar
```

136	iload 3 ; put value on the stack	209	bipush 99 ; Char
137	pop	210	istore 4 ; store value into cvar1
138	getstatic Complete/in Ljava/io/BufferedReader;	211	iload 4 ; put value on the stack
139	invokevirtual java/io/BufferedReader/readLine()	212	pop
	Ljava/lang/String;	213	getstatic Complete/in Ljava/io/BufferedReader;
140	invokestatic java/lang/Boolean/parseBoolean(214	invokevirtual java/io/BufferedReader/readLine()
	Ljava/lang/String;)Z		Ljava/lang/String;
141	istore_1	215	iconst_0
142	iload_1	216	invokevirtual java/lang/String/charAt(I)C
143	istore 3 ; store value	217	istore_1
144	iload_1 ; repush the value to the stack if it is	218	iload_1
	used again	219	istore 4 ; store value
145	pop	220	iload_1 ; repush the value to the stack if it is
146	getstatic java/lang/System/out Ljava/io/		used again
	PrintStream;	221	pop
147	iload 3	222	bipush 122 ; Char
148	istore_1	223	istore 6 ; store value into cvar2
149	iload_1	224	iload 6 ; put value on the stack
150	invokevirtual java/io/PrintStream/println(Z)V	225	pop
151		226	getstatic java/lang/System/out Ljava/io/
152	iload_1 ; repush the value to the stack if it is		PrintStream;
	used again	227	bipush 97 ; Char
153	pop	228	invokevirtual java/io/PrintStream/println(C)V
154	bipush 12 ; expr1	229	getstatic java/lang/System/out Ljava/io/
155	iconst_5		PrintStream;
156	; expr2	230	iload 4
157	idiv ; expr1	231	bipush 99 ; Char
158	iconst_5 ; expr2	232	if_icmpeq \$+7 ; Go to iconst_1 if it is true
159	imul ; expr1	233	iconst_0
160	bipush 12 ; expr1	234	goto \$+4 ; Go to the line after iconst_1
161	iconst_5 ; expr2	235	iconst_1 ; expr1
162	irem ; expr2	236	iload 6
163	iadd	237	bipush 98 ; Char
164	bipush 12	238	if_icmpne \$+7 ; Go to iconst_1 if it is true
165	if_icmpeq \$+7 ; Go to iconst_1 if it is true	239	iconst_0
166	iconst_0	240	goto \$+4 ; Go to the line after iconst_1
167	goto \$+4 ; Go to the line after iconst_1	241	iconst_1 ; expr2
168	iconst_1 ; expr1	242	iand ; expr1
169	bipush 6	243	iconst_1 ; Bool ; if x is 0 make it 1, if x is
170	bipush 6		1 make it 0
171	if_icmpge \$+7 ; Go to iconst_1 if it is true	244	ifeq \$+7 ; Go to iconst_1 if it is false
172	iconst_0	245	iconst_0
173	goto \$+4 ; Go to the line after iconst_1	246	goto \$+4 ; Go to the line after iconst_1
174	iconst_1 ; expr2	247	iconst_1 ; if original was 0, load 1 ; expr2
175	iand	248	ior
176	istore 3 ; store value into bvar	249	invokevirtual java/io/PrintStream/println(Z)V ;
177	iload 3 ; put value on the stack		add right constant pool reference bytes for
178	pop		println
179	getstatic java/lang/System/out Ljava/io/	250	
	PrintStream;	251	bipush 98 ; Char
180	iconst_0 ; Bool ; if x is 0 make it 1, if x is	252	istore 4 ; store value into cvar
	1 make it 0	253	iload 4 ; put value on the stack
181	ifeq \$+7 ; Go to iconst_1 if it is false	254	pop
182	iconst_0	255	getstatic java/lang/System/out Ljava/io/
183	goto \$+4 ; Go to the line after iconst_1		PrintStream;
184	iconst_1 ; if original was 0, load 1 ; expr1	256	iload 2
185	iload 3	257	invokevirtual java/io/PrintStream/println(I)V
186	iconst_1 ; Bool	258	getstatic java/lang/System/out Ljava/io/
187	if_icmpeq \$+7 ; Go to iconst_1 if it is true		PrintStream;
188	iconst_0	259	iload 3
189	goto \$+4 ; Go to the line after iconst_1	260	invokevirtual java/io/PrintStream/println(Z)V ;
190	iconst_1 ; expr2		add right constant pool reference bytes for
191	iand ; expr1		println
192	iconst_1 ; Bool	261	getstatic java/lang/System/out Ljava/io/
193	iconst_0 ; Bool		PrintStream;
194	if_icmpne \$+7 ; Go to iconst_1 if it is true	262	iload 4
195	iconst_0	263	invokevirtual java/io/PrintStream/println(C)V ;
196	goto \$+4 ; Go to the line after iconst_1		add right constant pool reference bytes for
197	iconst_1 ; expr2		println
198	ior	264	
199	istore_1	265	iconst_0
200	iload_1	266	istore 5 ; store value into i
201	invokevirtual java/io/PrintStream/println(Z)V	267	iload 5 ; put value on the stack
202		268	pop
203	iload_1 ; repush the value to the stack if it is	269	iconst_0
	used again ; expr1	270	istore 6 ; store value into z
204	iconst_1 ; Bool ; expr2	271	iload 6 ; put value on the stack
205	iand	272	pop
206	istore 3 ; store value into bvar	273	goto COND4 ; Jump to while condition
207	iload 3 ; put value on the stack	274	WHILE5:
208	pop	275	getstatic java/lang/System/out Ljava/io/

```

    PrintStream;
276   iload 5
277   istore_1
278   iload_1
279   invokevirtual java/io/PrintStream/println(I)V
280
281   iload_1 ; repush the value to the stack if it is
      used again
282   pop
283   iload 6
284   iconst_1
285   if_icmpeq $+7 ; Go to iconst_1 if it is true
286   iconst_0
287   goto $+4 ; Go to the line after iconst_1
288   iconst_1
289   ifeq ELSE2
290   iconst_0
291   istore 6 ; store value into z
292   iload 6 ; put value on the stack
293   goto NEXT3
294   ELSE2:
295       iload 6
296       iconst_1
297       ineg
298       if_icmpeq $+7 ; Go to iconst_1 if it is true
299       iconst_0
300       goto $+4 ; Go to the line after iconst_1
301       iconst_1
302       ifeq ELSE0
303       iconst_1
304       istore 6 ; store value into z
305       iload 6 ; put value on the stack

```

```

306   goto NEXT1
307   ELSE0:
308       iconst_1
309       ineg
310       istore 6 ; store value into z
311       iload 6 ; put value on the stack
312       pop
313       iload 5 ; expr1
314       iconst_1
315       ; expr2
316       iadd
317       istore 5 ; store value into i
318       iload 5 ; put value on the stack
319       NEXT1:
320       NEXT3:
321       pop
322       COND4:
323       iconst_5
324       istore 7 ; store value into x
325       iload 7 ; put value on the stack
326       pop
327       iload 7
328       iload 5
329       if_icmpgt $+7 ; Go to iconst_1 if it is true
330       iconst_0
331       goto $+4 ; Go to the line after iconst_1
332       iconst_1 ; Execute condition
333       ifne WHILE5 ; Jump to start of inner while
          statement
334
335       return
336   .end method

```