1. Introduction:

1.1 Motivation

Matrices are a useful tool to represent finite sets of data across a wide range of subject matter, including the hard sciences, mathematics, engineering, and computer science. Moreover, basic matrix operations, including matrix multiplication, summation, subtraction, inversion, and finding the transpose, eigenvalues, and eigenvectors of matrices, have been unusually difficult to perform without the use of external packages in languages like Python and R. The purpose of our language, The MatriCs, is to not only simplify these computations, but also to reduce the running time of matrix operations. Using C-like syntax, our language is tailored for programmers familiar with C, but not necessarily familiar with popular “data science” packages, like SciPy (Python), NumPy (Python), and Matrix (R).

1.2 Background

MatriCs is a strongly typed language that combines a C-like syntax with a whole host of special operators. These operators enable the user to perform fundamental computations involving linear algebra, including but not limited to calculating a matrix’s transpose and inverse, carrying out matrix multiplication, and extracting submatrices through slicing. At the very core of our language is the special data type: matrix. MatriCs will compile to LLVM.

2. Language Tutorial:

2.1 Setting Up the Environment

In order to use MatriCs in the appropriate environment please follow the steps provided in the official Github page of MatriCs. The link is given below:

https://github.com/mannykoum/MatriCs/tree/dev/microc-llvm

Please note that different operating systems have different have separate instructions. Upon successful completion of the environment setup, the configuration files can be found here:

https://github.com/mannykoum/MatriCs/tree/dev

The configuration files should be cloned from the official Github site to ensure that the language runs without any problems.

2.2 Building and Using the Language

2.2.1 Building

Upon complete and successful installation of the MatriCs environment, the language is ready for building. Before using the language, the configuration files have to be built. In order to do this, simply run the following command:

```
> ./build.sh
```

After successful build, the compiler will output a “Build successful” message.

2.2.2 Compiling

MatriCs compiler supports three different kinds of compilation flags:

```
-a : Prints the AST
-l  : Generates LLVM but doesn’t check it
-c  : Generates LLVM and compiles the given file
```

If the file is compiled successfully, the following command should generate the LLVM output of the input file:

```
./neo.native -c hello.neo > hello.ll
```

2.3 Basics of MatriCs

MatriCs has the following data types that must be declared at the beginning of body of the function:

- Integers
- Booleans
- Strings
- Voids
- N dimensional Matrices

An example of a variable declaration is given below:

```
int main (){

        bool x; //declaration of variable x with data type boolean
        x = true; //setting x is equal to true - note that this done on a seperate
        printb(x); //printing x to the standard output
        return 0;
}
```

2.3.1 Global Variables

Global variables are allowed in MatriCs and therefore any global variable declared outside of the scope of any function will be accessed by any of the functions in the program. For instance, in the following example, x can be reached from any of the functions:

```
int x;
int main(){

	int y;
	y = 0;
	if(y == 1){
		x = 1;
	}
	else{
		x = 2;
	}

	return 0;

}
```

2.3.2 Operators

MatriCs supports the following binary operators:

- Arithmetic (+, -, *, /, %)
- Relational (==, !=, <, <=, >, >=)
- Logical (!, &&, ||)

… and the following unary operators:

- Negation (!)
- Increment/Decrement (++, --)

For a detailed set of examples about the implementation of operators please check the test codes attached.

2.3.3 Vectors and Matrices

MatriCs provides its user the ease of manipulating vectors and matrices of any dimension. While most of the operators are designed for two dimensional matrices or below, the user is given the freedom to declare, define and print matrices of any dimension.

An example matrix and vector declaration is given below. Note that the matrices and vectors support only the integer or float data types. Other data types are not supported.

```
#include <stdlib.neo>

int main() {
   int[2,2,2] a;
   a = [[[1,2], [3,4]],
       [[5,6], [7,8]]];
   print3d(a);
}
```

The function given above declares and defines a three dimensional 2x2x2 matrix and calls the standard library function print3d to print the matrix in a formatted way.

2.3.4 Standard Library

The MatriCs standard library contains many matrix manipulation functions to give its user to ease of working with matrices. Standard library functions include transpose, add, subtract, identity for two dimensional matrices and print function for up to three dimensional matrices.The user must include the header “#include <stdlib.neo>” to make use of the matrix functions.

2.3.5 Control Flow

Control flow is exactly the same as the C syntax and includes if/else/else if statements, while and for loops as well as return. The following programs display the simple statements and loops:

```
//while loop
int main() {
        int i;
        i = 1;
        while (i < 5) {
                print_int(i);
```

```
		i = i + 1;
	}
	return 0;
}

//if statement
int main() {
	int[4] a;
	a = [1, 2, 3, 4];

	if (a[1] == 2) {
		printb(true);
	}
	else {
		printb(false);
	}
	return 0;
}

//for loop
int main(){
	int i;
	for(i = 0; i < 5; i++){
		print(“High five”);
	}
	return 0;
}
```

2.3.6 Defining Functions

MatriCs allows its users to define and use their own functions. Function declaration and definition are same as the C syntax. Functions can return void, string. int and float data types. An example function and its calling in the main is given below:

```
void print3d(int[2,2,2] c) {
int i;
int j;
int k;
    for(i = 0; i < 2; i++) {
        print("[");
        for(j = 0; j < 2; j++) {
            print("[");
            for(k = 0; k < 2; k++) {
                if(k != 1) {
                    print_int(c[i,j,k]);
                    print(",");
                } else {
                    print_int(c[i,j,k]);
                }
            }
            if(j != 1) {
                print("], ");
            } else {
                print("]");
            }
        }
        print("]\n");
    }
}

int main() {
    int[2,2,2] a;
    a = [[[1,2], [3,4]],
         [[5,6], [7,8]]];
    print3d(a);
}
```

3. Language Reference Manual:

3.1 Lexical Elements

3.1.1 Tokens
Our language can be broken down into six categories of tokens: identifiers, keywords, literals, operators, punctuation, and comments. Whitespace is used to separate tokens but otherwise will be ignored. Indentation should be used for stylistic purposes but is not necessary for the proper functioning of MatriCs programs.

3.1.2 Identifiers
Identifiers are strings used for naming different elements, such as variables and

functions. Identifiers must begin with a letter, but can contain digits and underscores as well.

These rules are described by the definitions involving regular expressions below:
identifier := (letter) (letter | digit | underscore)*
digit := ‘0’ - ‘9’
letter := uppercase_letter | lowercase_letter
uppercase_letter := ‘A’ - ‘Z’
lowercase_letter := ‘a’ - ‘z’

3.1.3 Keywords

The following literals cannot be used as identifiers. They are also case sensitive.

Syntax	*Description*
if	Similar to C conditional
else if	Similar to C conditional
else	Similar to C conditional
for	Similar to C for loop
while	Similar to C while loop
return	Return from function
null	No data
void	Returns nothing
import	Import external libraries for extended functions

3.1.4 Punctuation

Symbol	*Purpose*
;	Used to end a statement, as well as to define each row of a matrix.
{ }	Curly brackets are used to enclose functions, while and for loops, and if statements. In other words, they are used to delineate the scope of blocks of code in the program. They are also used to define the special data type, matrix.

( )	Use to specify and pass arguments for a function and the precedence of operators. Also used to enclose conditions in for and while loops and if statements.
[ ]	Use to specify dimension of the matrix data-type when it is declared. Also used to access elements in the array at a given position. ‘
,	Used to separate function arguments and to separate different in a specific row in a given matrix.
“ ”	Used to declare a variable of string data type
//	Inline comment
/* */	Block comment

3.2 Operators and Expressions

3.2.1 Standard Operators

Name	*Syntax*	*Example*
Addition,Subtraction, Multiplication, Division, Modulo*	+,-,*,/,%	int a = 5 + 8 //a = 13

Additive, Subtractive, Multiplicative, Divisive, Modular Assignment*	+=, -=, *=, /=, %=	int a = 4;
		a += 2;
		//a = 6

Assignment	=	int a = 7 //a has a value of 7
Equality check	==	7 == 7 //Returns 1
Greater than	>	6 > 5 //Returns 1
Less than	<	5 < 3 //Returns 0
Greater than or equal to	=>	5 => 4 //Returns 1

Less than or equal to	<=	5 <= 5 //Returns 1
Not equal	!=	5 != 3 // Returns 1

Logical Not	!	int a = 1;
		int b = 0;
		!(a && b) //Returns 1

Logical AND	&&	//with the values from the example above a && b //Returns 0
Logical OR	||	//with the values from the example above a || b //Returns 1

*Note that these operations are automatically casted into float when an int and a float are used in an operation.

3.2.2 Matrix Operators

Note that all of these operations are implemented in the standard library, stdlib.neo.

Name	*Description*	*Syntax*	*Example*

Scalar Multiplication, Scalar Division, Scalar Power	Element-wise multiplication/ division or scalar multiplication/ division/power	.*, ./, .^	mat int C = A.*B;
			mat int C = A./B;
			mat int C = A.*2;
			mat int C = A./2;
			mat int C = A.^2;

Matrix Multiplication, Matrix Division	Matrix multiplication/ division.Operation is not commutative.
	If at least one input is scalar, then A*B is equivalent to A.*B and is commutative.
		*, /	mat int C = A*B;
			mat int C = A/B;
			mat int C = A*3;
			mat int C = A/3;

Addition, Subtraction	Addition/ subtraction, scalar or element-wise	+, -	mat int C = A+B;
			mat int C = A+2;
			mat int C = A+B;
			mat int C = A-2;

Transpose	Returns the	’	mat int B = A’;

	transpose of a matrix		
Indexing	Returns the element in the specified row and column of a given matrix	matr_x[*row_index*][*column_index*]	matr_x[2][4] //returns the element in the 3rd row and 5th column of the given matrix

3.2.3 Expressions

Expressions are made of at least one operand and zero or more operators. Innermost expressions are evaluated first and the priority of an expression is determined by parentheses. The direction of evaluation is from left to right.

3.3 Literals

3.3.1 String Literals

String literals are a sequence of zero or more letters, spaces, digits, other ASCII characters numbers 32 to 126, excluding the double quote. These strings should be enclosed in double quotes. For example: “Hello, world”.

3.3.2 Integer Literals

Integer literals are one or more number digits, in succession with no whitespace or punctuation character in between them. For example: 42, 666, 2.

3.3.3 Floating-Point Literals

Floating-point literals are decimal numbers. A decimal number is a fraction whose denominator is a power of ten and whose numerator is expressed by figures placed to the right of a decimal point. The integer part is expressed by figures placed to the left of a decimal point. Similarly to integer literals whitespace is not allowed to separate digits or digits and the decimal point `.`. For example: 4.2, 5.0, 222.666

3.3.4 Matrix Literals

Matrix literals can be integer or floating-point numbers. Matrices can only be composed of entirely integers or floating-point numbers.

3.4 Data Types

3.4.1 Primitive Data Types

MatriCs provides primitive data types that are common to many high level languages. The full list of primitive data types is given below:

Type	*Description*	*Syntax*	*Range of Values*	*Example*
integer	Used to define integer types	int	-2,147,483,648 to 2,147,483,648	int a = 5;
float	32-bit floating number	float	±1.79769313486 231570E+308	float a = 5.0;
bool	Used to define boolean types (true and false)	bool	True, False	bool flag = true;
string	Used to define strings of characters	string	Any string of ASCII characters enclosed, excluding double quotes.	string str = “abcd1234” ;

3.4.2: Non-Primitive Data Types

3.4.2.1 Matrices

Note that MatriCs doesn’t have a data type called arrays and therefore the matrix data type can be used to declare/define an array of any dimensions (i.e. the matrix data type can be used to declare/define one dimensional array).

Type	*Description*	*Syntax*	*Example*
matrix	Defines a matrix	typeofmatrix[row][column] nameofmatrix; nameofmatrix = [elm1,elm2, .. ; elmn,elm(n+1)];	Int[3,3] matr_x; matr_x =[[1,2,3; 4,5,6] [7,8,9]];

3.4.2.2: Vectors

Vectors are basically 1 dimensional matrices and are declared and defined as follows:

Type	*Description*	*Syntax*	*Example*

vector	Defines a vector	typeofvector[size] nameofvector;
		nameofvector = [elm1, elm2, …];
			int[5] v;
			v = [1, 2, 3, 4, 5];

3.4.2.3 Declaring Matrices

A matrix is declared by first typing the data type to be stored in the matrix, the name of the matrix, and the dimensions of the matrix enclosed by square brackets. An example is given below:

```
int matr_x [2,5];  //returns a 2 by 5 uninitialized matrix holding values of type int
int matr_x = [[0, 0, 0] 0, 0, 0]; //defines a 2 by 3 and initializes its values to zero
```

3.4.2.4 Accessing and Setting Array Elements

A matrix element can be accessed by simply typing the name of the matrix and the dimensions of the element desired to be accessed inside square brackets.

```
int elmt;
elmt = matr_x[2,5];
//elmt is equal to 6 - i.e. the element in the second row and fifth column of “matr_x”
```

Array elements can be set either in the declaration stage or later on. Simultaneous declaration and definition is demonstrated in the example below:

```
int matr_x = [[1,2,3], [4,5,6], [7,8,9]];
```

Array elements can also be set after declaration. An example is given below:

```
matr_x[2][5] = 99
```

3.5 Statements

3.5.1 The if Statement

Format:

```
if(condition){
	action1;
}else if(condition){
	action2;
}else{
	action3
}
```

Description:
The if statement consists of a block of code that only executes if the condition enclosed within the parentheses is true. If not, the block of code is ignored and the program jumps to the next line. Optional additions include else if, which contains another condition to be checked, and else, which executes in the case that none of the conditions above are met. These additions are not required, but if an else statement is used, then it should be the last element of the statement.

3.5.2 The while Loop

Format:

```
while(condition){
	action;
}
```

Description:

The while loop consists of a block of code that repeatedly executes as long as the condition enclosed within the parentheses is true. If the condition is not true when the code is first encountered, then the program jumps over the block entirely. Furthermore, if the condition is true and remains true indefinitely, then the code gets caught in an infinite loop and the program never continues beyond the block.

3.5.3 The for Loop

Format:

```
for(variable initialization; condition; increment step){
	action;
}
```

Description:

The for loop is a generalization of the while loop. Within the parentheses there are three distinct parts, separated by semicolons. The first part, variable initialization, runs once when the for loop is first encountered. The second part is a condition checked on every iteration to determine whether the block of code inside the loop should be executed. If it is executed, the third part then increments (or decrements) and the condition is re-evaluated. The initialization, condition, and increment can be any expressions.

3.6 Functions

3.6.1 Function Definitions

Function definition consists of the type of value returned by the function followed by the name of the function and the set of parameters and types enclosed in parentheses. The scope of the function will be defined by the opening and the closing curly braces, one placed after the function declaration and the other placed after the block of code defining the function is finished. An example of a function is given below:

```
int determinant(mat int m){
   int det;
   int sign;
   det = 0;
   sign = 1;

   if(rows(m) == 1) {    // base case, dimensional array
     return m[0,0];
   }
```

3.6.2 Calling Functions

A function can be called by its name followed by its parameters. Note that there is no need to specify the type of the parameter when calling the function. An example is given below:

```
sum (2, 4) //returns the sum of 2 and 4
```

3.7 Program Structure and Scope

3.7.1 Program Structure

MatriCs program are found on a single source file. The major components of a MatriCs program are matrix declarations, matrix specifications, and function declarations in this specific order.

3.7.2 Scope

Declarations made within a while/for loop, if statement, or any function are available only by reference within this specific block of code. Ones that are made outside of while/for loops, if statement, or any function are available by reference throughout the rest of the code.

3.8 Built-in Functions

3.8.1 The print Function

void print(string str): prints string str on the console, similarly print_int(int a), printb(bool b), and print_float(float a) prints their data types to the console

3.9 Standard Library

The standard library is not a part of MatriCs, but an environment that supports standard MatriCs will provide the function declarations and type and macro definitions of this library. The standard library is invoked by calling “include stdlib.neo”. Currently, the MatriCs standard library contains the functions listed in part 3.2.2.

Appendix A Sample Code

Methods may be used recursively:

```
int determinant(int m){
       int det;
       int sign;
       int rows;
       int cols;
       int smaller_m[(rows(m))-1][(cols(m))-1];
       det = 0;
       sign = 1;

     if(rows(m) == 1) {     // base case, dimensional array
       return m[0][0];
     }

     // lib functions to get # of rows and columns in m
     // (actually the values should be the same anyway)
     rows = rows(m);
     cols = cols(m);
```

```
    // finds determinant using row-by-row expansion
    for(int i = 0; i < rows; i++){

      // keep decomposing the matrix by 1 dimension


      for(int a = 1; a < rows; a++){
        for(int b = 0; b < cols; b++){

          if(b < i){
            smaller_m[a-1][b] = m[a][b];
          }
          elif(b > i){
            smaller_m[a-1][b-1] = m[a][b];
          }
        }
      }

      if (i%2 == 0){    // sign changes based on i
        sign = 1;
      }
      else{
        sign = -1;
      }
      det += sign*m[0][i]*determinant(smaller_m); // rec call for det
    }
    return det;
}


int transpose(int m) {
     int rows;
     int cols;
     int m_transpose[cols(m)][rows(m)];

     rows = rows(m);
     cols = cols(m);



    for(int i = 0; i < rows; i++) {
        for(int j = 0; j < cols; j++) {
            m_transpose[j][i] = m[i][j];
        }
    }
    return m_transpose;
}


int sum_matrix(int m) {
     int sum;
     int cols;
     int rows;
     sum = 0;

     cols = cols(m);
     rows = rows(m);

     for(int i = 0; i < rows; rows++) {
           for(int j = o; j < cols; cols++){      //Will go through all
     elements
           sum += m;
     }
     return sum;
}
```

Appendix B Context-Free Grammar

program → **ε** | program vdecl | program fdecl

fdecl → **id** (formals) { vdecls stmts }

formals → **id** |formals , **id**

vdecls → vdecl | vdecls vdecl

vdecl → type **id**; | type **id** = expr; | matrix **id** | matrix **id** = matexpr;

stmts → **ε** | stmts stmt

stmt → expr ; | return expr ; | { stmts } | if (expr) stmt else_if | if (expr) stmt else_if
else stmt | while (expr) stmt | for (expr ; expr ; expr) stmt | foreach(vdecl : id)

expr → **lit** | **id** | **id** (actuals) | (expr) | expr + expr | expr - expr | expr * expr | expr / expr
| expr == expr | expr != expr | expr < expr | expr <= expr | expr > expr | expr >=
expr | expr = expr | expr .* expr | expr ./ expr | expr .^ expr

type → int | float | bool | string

matrix → type | type[**lit**] | matrix[**lit**]

actuals → expr | actuals, expr

else_if → else_if elif (expr) stmt | **ε**

4 Project Plan

4.1 Project Planning Process:

The MatriCs team spent the first two months of the project duration planning the features of the function. After the initial planning stage, the functionalities were defined and depending on these the scanner and the parser were updated. After the initial scanner and parser update stage, codegen and semant were updated accordingly. After the implementation of each feature a detailed set of test cases were written and tested for any bug or edge cases. The MatriCs team worked on each feature one by one; and while one half of the team was working on implementing the feature, the other team was working on developing relevant test code and coming up with relevant built in functions relative to the feature being implemented. After the development of the feature was done and tested, the feature was once again discussed by the team. The team would discuss the applications and the usability of the feature and would update the relevant configuration files accordingly.

4.2 Style Guide Used By The Team

4.2.1 Variable and Function Declarations

- Unless the variable being declared is a constant do not use capital letters to identify variables
- Always declare variables on top of the code block
- Do not start a variable or a function name with a number; always start with a lowercase letter

- Parameter names in the function definition or declaration should be different than the variable names in the function body itself
- One variable per declaration
- Do not declare unused variables

4.2.2 Braces and Spacing

- Braces are used even when optional in for, while and if/else statements
- For each block indentation use 2 spaces to indicate the scope of the statement being made
- Allow for maximum of 100 characters per line and if this limit is passed make sure that you do a line break

4.3 Project Timeline

January-February:
- Initial group meetings begin
- Brainstorming about the kind of language to be implemented
- Drafting the proposal
- Discussions on the proposal and about the TA comments
- Drafting the LRM
- Team meets at least once a week and discusses for at least an hour

March:
- Begin discussing the LRM and its applicability to code with our mentor TA
- Changing the syntax and LRM accordingly
- Download the MicroC compiler and begin studying the configuration files
- Implement Hello World
- Implement Scanner and Parser as well as other primitive data types
- Team meets at least twice a week and mostly does coding

April - May:
- Implement special data types
- Implement built in functions
- Discuss and implement function structure
- Start developing test suits on a regular basis
- Start brainstorming and developing the demo code for the presentation
- Start writing the project report and make the project presentation

4.4 Roles and Responsibilities of Each Team Member

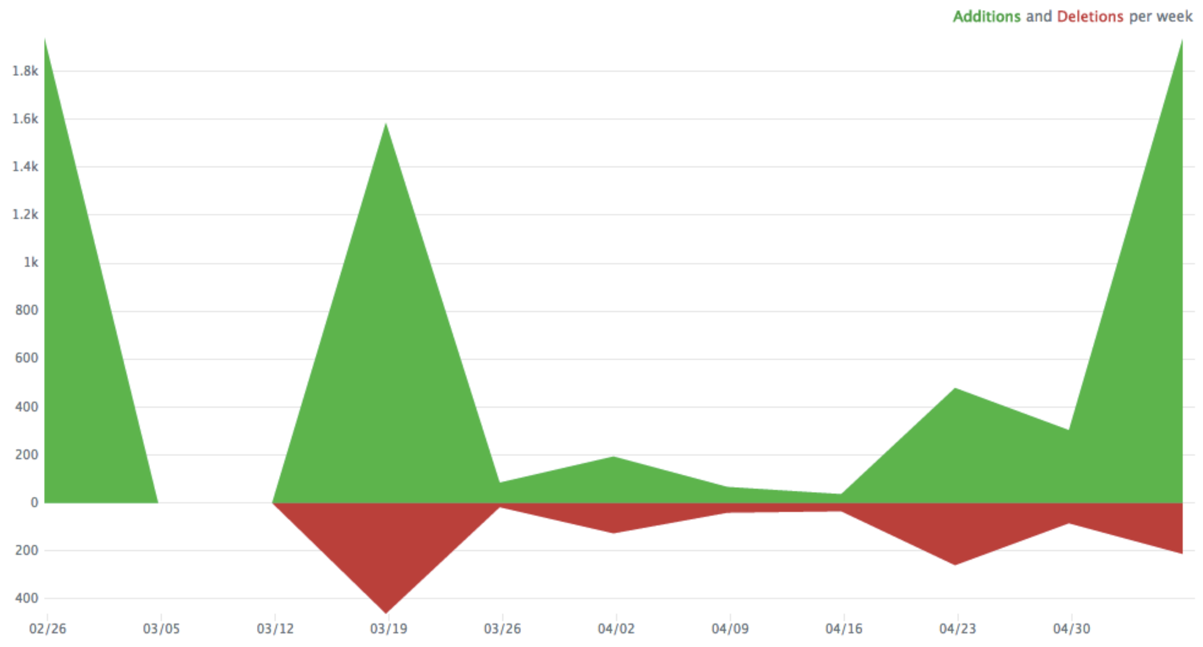
In addition to the roles defined at the beginning of the semester, each team member took active role in the implementation of features. The team tried to work together as much as possible to help each other overcome challenging implementations, debugging and effective testing.

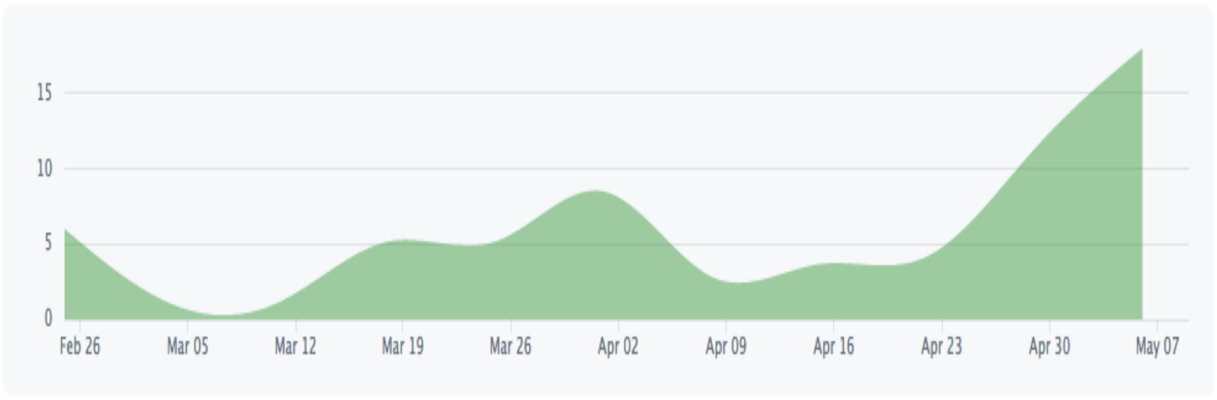
4.4 Software Development Environment

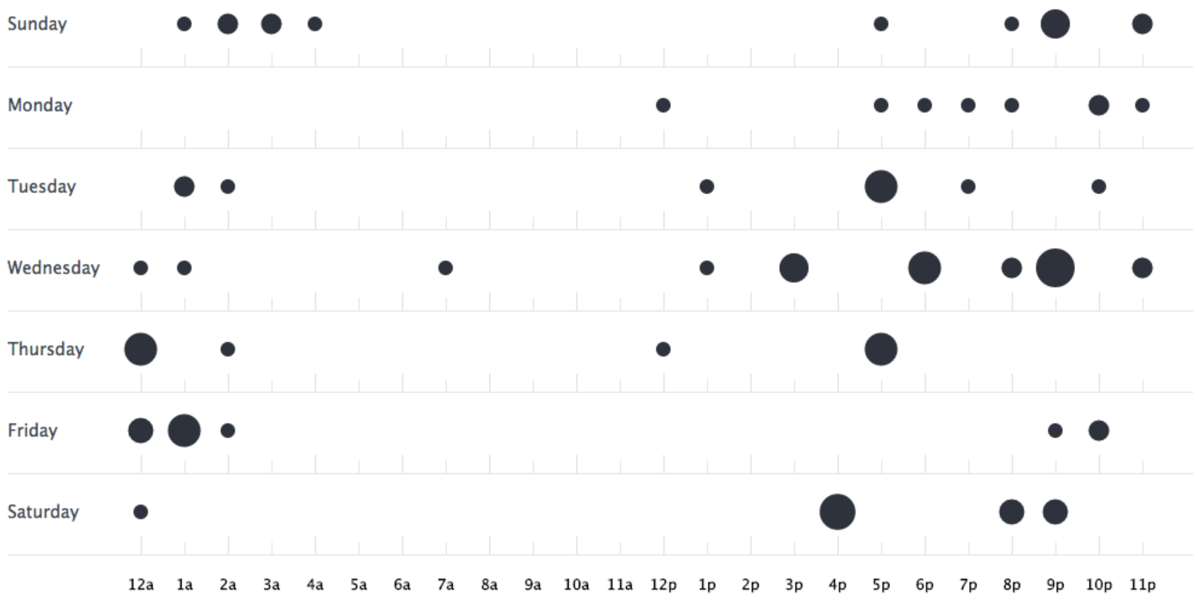
In order to develop the language LLVM 3.0.8 and its library functions were used. Additionally to make best use of version control and to ensure that each member of the team has instant access to the most recent version of the code, Github was used.

4.5 Project Log

The following graphs reflecting our progress throughout the project are extracted from our project repo:

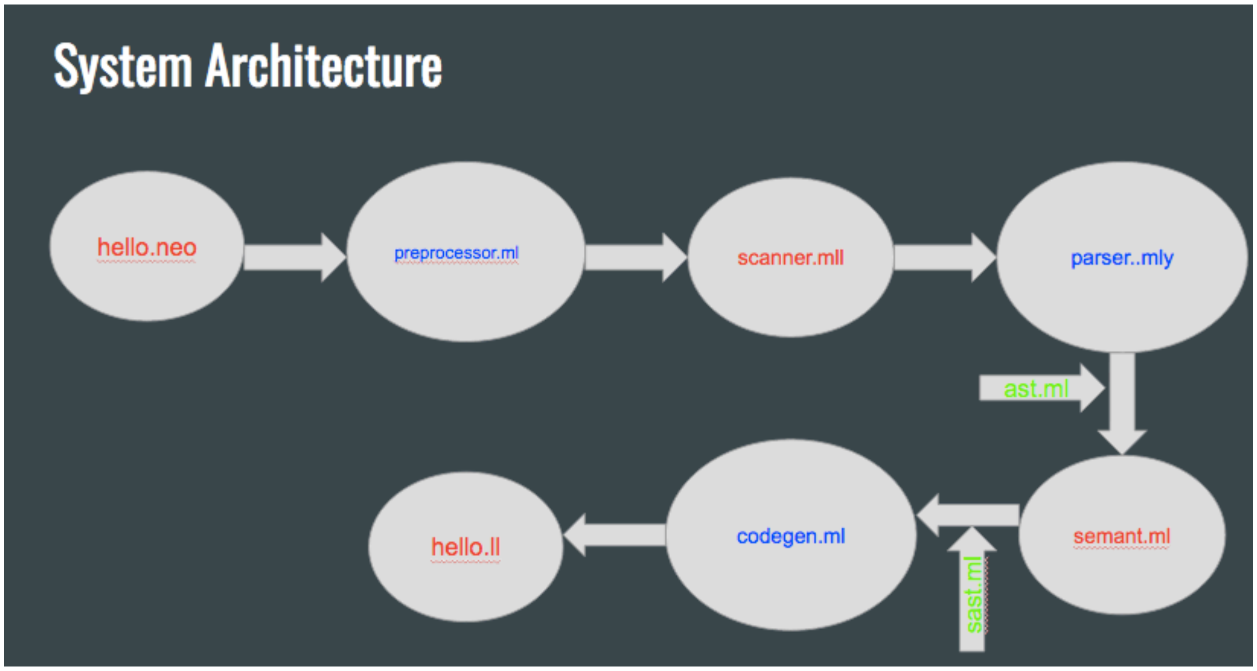



15
10
5
0
Feb 26
Mar 05
Mar 12
Mar 19
Mar 26
Apr 02
Apr 09
Apr 16
Apr 23
Apr 30
May 07


Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
12a
1a
2a
3a
4a
5a
6a
7a
8a
9a
10a
11a
12p
1p
2p
3p
4p
5p
6p
7p
8p
9p
10p
11p

5. Architectural Design

5.1 Block Diagram of the Major Components of Our Translator



5.2 Interfaces Between the Components

The following modules and interfaces are used in MatriCs:

- preprocessor.ml : Checks if the input file has any references to the standard library.
- scanner.mll: Takes in the scanned input file from preprocessor.ml and tokenizes the input file.

- parser.mly: Takes in the tokenized input and checks if its syntax is correct. If the syntax is completely correct, it generates an abstract syntax tree of the input code.
- semant.ml: Takes in the AST from parser and checks if its syntactically correct or not. If the AST passes all of the checks in the semant, semant.mly generates a semantically checked syntax tree (SAST).
- codegen.ml : Takes in the SAST generated and converts its leaves into LLVM IR.
- neo.ml : MatriCs compiler that calls all of the modules and operates. In terms of operation it gives the used a few options by giving three different compilation flags as outlined in the language tutorial section.
- ast.ml : Represents the abstract syntax tree of MatriCs's language representation.
- sast.ml: Representation of the semantically checked abstract syntax tree of MatriCs's language representation.
- stdlib.neo : Contains the standard library of a group of functions and it is called by the preprocessor when the program includes this library.

**Note that since the team worked on every feature as a whole, each component was implemented by everyone.

6 Test Plan

6.1 Example Program and Its LLVM output

Example programs and their outputs can be found in the tests directory of the source code.

6.2 Test Suites

The MicroC test script, namely, testall.sh was used to run all of the tests. This test script takes in a .neo file and the designated output of the input code in the form of a .out file. It compares the actual output of the code with the contents in the .out file and outputs the llvm output, the actual output and the differences between the output and the designated output file in case the tests fail. Note that these files are outputted only when the code passes all of the modules but outputs some result other than the designated result.

6.3 Choosing Tests

In order to cover as much of the code as possible in terms of testing, a test suite was written after each feature implementation. Therefore every feature including functions, variable declarations, definitions, and control flows were tested in a separate test suite. To check the compatibility of the test code for every case some of the test suites were designed to cover more than a single feature.

6.4 Test Automation

While the team didn’t use any automation tool externally, the testing suites were tested using testall.sh, which was a very automated process for the scope of this project.

7 Lessons Learned

Talal - always make the best use of OCaml - although it might seem to be a challenging language its pattern matching functions come in very handy especially when implementing complicated data types

Manos - never leave error checking to the last minute, always consider each fail case after or during the implementation of a language. The error that wasn't checked before might show up later in another language

Duru - Test each feature with more than one test suite and consider each and every case to make sure that everything works

Flo - START EARLY

Nikhil - Always work in a team and consult for help - you don't have much time in this project

TESTS:

```
int main()
{
  int i;
  bool b;

  i = 42;
  i = 10;
  b = true;
  b = false;
  i = false; /* Fail: assigning a bool to an integer */
}

int main() {
```

```
int[2,2] a;
int[2,2] b;
int[4] a_flat;
int[4] b_flat;
int[4] d_flat;
int[2,2] mat;

int i;
int j;
int k;
int l;
int m;
int z;

int c;
int c1;
int c2;

a = [[1,2], [3,4]];
b = [[5,6], [7,8]];
z = 6;
z++;
z--;
z++;

c = 0;
for(i = 0; i < 2; i = i + 1) {
        for (j = 0; j < 2; j = j + 1) {
                a_flat[c] = a[i, j];
                b_flat[c] = b[i, j];
                c = c + 1;
        }
}

c1 = 0;
for(k = 0; k < 4; k = k + 1) {
        d_flat[c1] = a_flat[c1] + b_flat[c1];
        c1 = c1 + 1;
}

// print_int(d_flat[0]);
// print_int(d_flat[1]);
// print_int(d_flat[2]);
// print_int(d_flat[3]);
```

```
        c2 = 0;
        for(l = 0; l < 2; l = l + 1) {
                for(m = 0; m < 2; m = m + 1) {
                        mat[l,m] = d_flat[c2];
                        c2 = c2 + 1;
                }
        }

        print_int(mat[0,0]);
        print_int(mat[0,1]);
        print_int(mat[1,0]);
        print_int(mat[1,1]);
        print_int(z);

        return 0;
}

int main() {
        // This is a comment
        /* This is *
         * another *
         * comment */
        return 0;
}

#include <stdlib.neo>

int main() {
   int[2,2,2] a;
   a = [[[1,2], [3,4]],
       [[5,6], [7,8]]];
   print3d(a);
}

int main (){

        int x;
        x = 5;
        return 0;

}

int main() {
    float a;
    float b;
    a = 1.4;
    b = 1.0;
    b = a + b;
                    print_float(b);
                    return 0;
}

int main() {
        float a;
        int b;
        float c;

        a = 5.0;
        b = 5;
        c = a + b;
        print_float(c);
        return 0;
}

int main (){

        string x;
        x = "hello\n";

        print(x);
        return 0;

}

int main (){

        string x;
        x = "hello\n";

        print(x);
        return 0;

}

int main() {
int i;
int j;
```

```
// int c;
// int x;
// int y;

int [2, 2] mat;
// c = 0;
for(i = 0; i < 2; i = i + 1) {
        for (j = 0; j < 2; j = j + 1) {
                if(i == j) {
                        // print_int(1);
                        // mat[i,j] = 1;
                        // print(mat[i,j]);
                        // x = 1;
                        mat[i, j] = 1;
                        print_int(mat[i,j]);
                        // c = c+1;
                }
                else {
                        // print_int(0);
                        // mat[i, j] = 0;
                        // print(mat[i, j]);
                        // y = 0;
                        mat[i, j] = 0;
                        print_int(mat[i,j]);
                        // c = c + 1;
                }
        }
}
return 0;
}

#include <stdlib.neo>

float[2,2] inverseMat2by2(int[2,2] a) {
   float[2,2] b;
   float inv_mult;

   inv_mult = 1.0/((a[0,0]*a[1,1]) - (a[0,1]*a[1,0]));

   b[0,0] = inv_mult * a[1,1];
   b[0,1] = (inv_mult * a[0,1]) * -1;
   b[1,0] = (inv_mult * a[1,0]) * -1;
   b[1,1] = inv_mult * a[0,0];
}
```

```
int main() {
   int[2,2] a;
   a = [[4,7],[2,6]];


   print2d_f(b);
}

int main() {
         int[2,2,2,2] a;
         int i;
         int j;
         int k;
         int l;

         a = [[[[1,2], [3,3]],
                  [[7,2], [9,1]]],
                  [[[1,2], [3,3]],
                  [[7,2], [9,1]]]];

         for (i = 0; i < 2; i = i+1) {
                  for (j = 0; j < 2; j = j+1) {
                           for (k = 0; k < 2; k = k+1) {
                                    for (l = 0; l < 2; l = l+1) {
                                             print_int(a[i,j,k,l]);
                                    }
                           }
                  }
         }
         return 0;
}

void print2d(int[2,2] c) {
int i;
int j;
   for(i = 0; i < 2; i++) {
      print("[");
      for(j = 0; j < 2; j++) {
         if(j != 1) {
            print_int(c[i,j]);
            print(",");
         } else {
            print_int(c[i,j]);
            }
        }
        print("]\n");
    }
}

int main() {
    int[2,2] a;
    a = [[1,2],[3,4]];
    print2d(a);
}

void print3d(int[2,2,2] c) {
int i;
int j;
int k;
    for(i = 0; i < 2; i++) {
        print("[");
        for(j = 0; j < 2; j++) {
            print("[");
            for(k = 0; k < 2; k++) {
                if(k != 1) {
                    print_int(c[i,j,k]);
                    print(",");
                } else {
                    print_int(c[i,j,k]);
                }
            }
            if(j != 1) {
                print("], ");
            } else {
                print("]");
            }
        }
        print("]\n");
    }
}

int main() {
    int[2,2,2] a;
    a = [[[1,2], [3,4]],
         [[5,6], [7,8]]];
    print3d(a);
}
```

```
int main (){

        bool x;

        x = true;

        printb(x);

        return 0;
}

int main() {

        int[3] x;
        int y;
        int z;
        int a;

        x = [10, 20, 30];
        y = x[0] + 10;
        z = x[1] + 0;
        a = x[2] - 10;

        print_int(y);
        print_int(z);
        print_int(a);
}

int main() {

        int[3] x;
        int y;
        int z;
        int a;

        x = [10, 20, 30];
        y = x[0] / 10;
        z = x[1] * 0;
        a = x[2] - 10;

        print_int(y);
        print_int(z);
        print_int(a);
```

```
}

int main() {
        bool x;
        x = false;
        printb(x);
        return 0;
}

int main (){

        int x;

        x = 5;

        print_int(x);

        return 0;

}

int main() {
        string x;
        x = "my string";
        print(x);
        return 0;
}

int main() {
        bool x;
        x = true;
        printb(x);
        return 0;
}

int main() {
        int[4] a;
        int i;
        int c;
        int counter;

        a = [1, 2, 3, 4];
        c = 4;
        counter = 0;
```

```
	print("[");
	while(c > 0) {
		if(counter == 0) {
			print_int(a[counter]);
			counter = counter + 1;
			c = c - 1;
		}
		else {
			print(",");
			print_int(a[counter]);
			counter = counter + 1;
			c = c - 1;
			// print(",");
		}
	}
	print("]");
}

int main() {
	int[5] v;
	v = [1, 2, 3, 4, 5];

	print_int(v[0]);
	print_int(v[1]);
	print_int(v[2]);
	print_int(v[3]);
	print_int(v[4]);
}

int main() {
	int[4] a;
	a = [1, 2, 3, 4];

	if (a[1] == 2) {
		printb(true);
	}
	else {
		printb(false);
	}
}

int main() {
	int[4] b;
```

```
        b = [1, 2, 3, 4];

        if (b[1] == 3) {
                printb(true);
        }
        else {
                printb(false);
        }
}

int main() {
        int i;
        i = 1;
        while (i < 5) {
                print_int(i);
                i = i + 1;
        }
        return 0;
}

int main() {

        int[2,2] a;
        int i;
        int j;
        int[4] b;
        int c;
        int[4] b2;
        int c2;
        int[2,2] mat;

        int k;
        int l;
        int m;
        int n;
        int c3;

        a = [[1,2], [3,4]];
        c = 0;

        for(i = 0; i < 2; i = i + 1) {
                for(j = 0; j < 2; j = j + 1) {
                        // print_int(a[i,j]);
                        b[c] = a[i,j];
                        c = c + 1;
                }
        }

        c2 = 0;
        for(k = 0; k < 2; k = k + 1) {
                for(l = 0; l < 2; l = l + 1) {
                b2[c2] = b[k + l*2];
                c2 = c2+1;
                }
        }

        // print_int(b2[0]);
        // print_int(b2[1]);
        // print_int(b2[2]);
        // print_int(b2[3]);

        c3 = 0;
        for(m = 0; m < 2; m = m + 1) {
                for(n = 0; n < 2; n = n + 1) {
                        mat[m,n] = b2[c3];
                        c3 = c3 + 1;
                }
        }

        print_int(mat[0,0]);
        print_int(mat[0,1]);
        print_int(mat[1,0]);
        print_int(mat[1,1]);
}

#include <stdlib.neo>

int main (){
        int[5] x;
        int a;
        int u;
        u = 9;
        x = [1,2,3,4,5];
        a = x[2] + 3;

        print_int(a);
   print_int(u);
        return 0;
```

}

Ast:

```
(* Abstract Syntax Tree and
functions for printing it *)
```

```
type op = Add | Sub | Mult | Div | Mod | Equal | Neq
| Less | Leq | Greater | Geq |
         And | Or


type uop = Neg | Not


type uopment = Increment | Decrement


(* HERE ADD NUM TYPE FOR FLOATS AND INTS*)
type typ = Int | Float | Bool | MyString | Void
         | Vector of typ * int list


type bind = typ * string


type expr =
   Literal of int
 | Fliteral of float
 | BoolLit of bool
 | MyStringLit of string
 | Vector_lit of expr list
 | Id of string
 | Vdecl of bind
 | Binop of expr * op * expr
 | Unop of uop * expr
 | Incrementer of expr * uopment
 | Assign of expr * expr
 | Call of string * expr list
 | Vector_access of string * expr list
 | Reference of string
 | Dimlist of string
 | Noexpr

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

type func_decl = {
   typ : typ;
   fname : string;
   formals : bind list;
   locals : bind list;
   body : stmt list;
 }

type program = bind list * func_decl list

(* Pretty-printing functions *)
```

```
let rec string_of_typ = function

   Int -> "int"

 | Float -> "float"

 | Bool -> "bool"

 | MyString -> "string"

 | Void -> "void"

 | Vector(t, l) -> (string_of_typ t)^"["^

   (List.fold_left (fun str n -> str ^",
"^string_of_int n) "" l)^"]"


let string_of_op = function

   Add -> "+"

 | Sub -> "-"

 | Mult -> "*"

 | Div -> "/"

 | Mod -> "%"

 | Equal -> "=="

 | Neq -> "!="

 | Less -> "<"

 | Leq -> "<="

 | Greater -> ">"

 | Geq -> ">="

 | And -> "&&"

 | Or -> "||"


let string_of_uop = function

   Neg -> "-"

 | Not -> "!"


let string_of_uopment = function
```

```
   Increment -> "++"
 | Decrement -> "--"


let rec string_of_expr = function
   Literal(l) -> string_of_int l
 | Fliteral(f) -> string_of_float f
 | BoolLit(true) -> "true"
 | BoolLit(false) -> "false"
 | MyStringLit(s) -> s
 | Vector_lit(el) -> "[" (* ^ String.concat ", "
(List.map string_of_expr el) ^ "]" *)
 | Id(s) -> s
 | Vdecl(t, s) -> string_of_typ t^" "^s
 | Binop(e1, o, e2) ->
     string_of_expr e1 ^ " " ^ string_of_op o ^ " " ^
string_of_expr e2
 | Unop(o, e) -> string_of_uop o ^ string_of_expr e
 | Incrementer(e, uop) -> string_of_expr e ^" "^
string_of_uopment uop
 | Assign(v, e) -> string_of_expr v ^ " = " ^
string_of_expr e
 | Call(f, el) ->
     f ^ "(" ^ String.concat ", " (List.map
string_of_expr el) ^ ")"
 | Vector_access(v, i) ->
     v ^ "[" ^
     (List.fold_left (fun str n -> str ^",
"^string_of_expr n) "" i) ^"]"
 | Dimlist(v) ->
     v ^ ".dims"
 | Noexpr -> ""
 (*ADD PATTERN FOR VECTOR_LIT AND VECTOR_ACCESS*)


let rec string_of_stmt = function
```

```
   Block(stmts) ->

     "{\n" ^ String.concat "" (List.map
string_of_stmt stmts) ^ "}\n"
  | Expr(expr) -> string_of_expr expr ^ ";\n";

  | Return(expr) -> "return " ^ string_of_expr expr ^
";\n";
  | If(e, s, Block([])) -> "if (" ^ string_of_expr e ^
")\n" ^ string_of_stmt s
  | If(e, s1, s2) ->  "if (" ^ string_of_expr e ^
")\n" ^
     string_of_stmt s1 ^ "else\n" ^ string_of_stmt s2

  | For(e1, e2, e3, s) ->

     "for (" ^ string_of_expr e1  ^ " ; " ^
string_of_expr e2 ^ " ; " ^
     string_of_expr e3  ^ ") " ^ string_of_stmt s

  | While(e, s) -> "while (" ^ string_of_expr e ^ ") "
^ string_of_stmt s



let string_of_vdecl (t, id) = string_of_typ t ^ " " ^
id ^ ";\n"



let string_of_fdecl fdecl =

 string_of_typ fdecl.typ ^ " " ^

 fdecl.fname ^ "(" ^ String.concat ", " (List.map snd
fdecl.formals) ^
 ")\n{\n" ^

 String.concat "" (List.map string_of_vdecl
fdecl.locals) ^
 String.concat "" (List.map string_of_stmt
fdecl.body) ^
 "}\n"



let string_of_program (vars, funcs) =

 String.concat "" (List.map string_of_vdecl vars) ^
"\n" ^
```

```
                    String.concat "\n" (List.map string_of_fdecl funcs)
```

Parser:

```
/* Ocamlyacc parser for
MicroC */

%{
open Ast
%}

%token SEMI COLON LPAREN RPAREN LBRACE RBRACE LBRACKET RBRACKET
COMMA DOT ROWS COLS
%token PLUS MINUS TIMES DIVIDE MOD ASSIGN NOT DIMS

%token PLUSPLUS MINMIN

%token PLUS MINUS TIMES DIVIDE ASSIGN NOT DIMS

%token EQ NEQ LT LEQ GT GEQ TRUE FALSE AND OR

%token RETURN IF ELSE FOR WHILE INT BOOL FLOAT STRTYPE VOID
VECTOR MATRIX
%token <string> STRING

%token <int> LITERAL

%token <float> FLITERAL

%token <string> ID

%token EOF


%nonassoc NOELSE

%nonassoc ELSE

%nonassoc PLUSPLUS MINMIN

%right ASSIGN

%left OR

%left AND

%left EQ NEQ
```

```
%left LT GT LEQ GEQ

%left PLUS MINUS

%left TIMES DIVIDE MOD

%right NOT NEG


%start program

%type <Ast.program> program


%%


program:

 decls EOF { $1 }


decls:

  /* nothing */ { [], [] }

| decls vdecl { ($2 :: fst $1), snd $1 }

| decls fdecl { fst $1, ($2 :: snd $1) }


fdecl:

  typ ID LPAREN formals_opt RPAREN LBRACE vdecl_list stmt_list
RBRACE
    { { typ = $1;

        fname = $2;

        formals = $4;

        locals = List.rev $7;

        body = List.rev $8 } }


formals_opt:

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


formal_list:
   typ ID                   { [($1,$2)] }
 | formal_list COMMA typ ID { ($3,$4) :: $1 }


typ:
   INT       { Int }
 | FLOAT      { Float }
 | BOOL             { Bool }
 | STRTYPE     { MyString }
 | VOID             { Void }
 | typ LBRACKET dim_list RBRACKET { Vector($1, $3) }


dim_list:
 /* nothing */ {[]}
| dim           { List.rev $1 }


dim:
   LITERAL                { [$1] }
 | dim COMMA LITERAL { $3 :: $1 }


vdecl_list:
   /* nothing */    { [] }
 | vdecl_list vdecl { $2 :: $1 }


vdecl:
  typ ID SEMI { ($1, $2) }
```

```
stmt_list:

   /* nothing */  { [] }

 | stmt_list stmt { $2 :: $1 }



stmt:

   expr SEMI { Expr $1 }

 | RETURN SEMI { Return Noexpr }

 | RETURN expr SEMI { Return $2 }

 | LBRACE stmt_list RBRACE { Block(List.rev $2) }

 | IF LPAREN expr RPAREN stmt %prec NOELSE { If($3, $5,
Block([])) }
 | IF LPAREN expr RPAREN stmt ELSE stmt    { If($3, $5, $7) }

 | FOR LPAREN expr_opt SEMI expr SEMI expr_opt RPAREN stmt

    { For($3, $5, $7, $9) }

 | WHILE LPAREN expr RPAREN stmt { While($3, $5) }



expr_opt:

   /* nothing */ { Noexpr }

 | expr          { $1 }



expr:

   literal          {$1}

 | expr PLUS   expr { Binop($1, Add,   $3) }

 | expr MINUS  expr { Binop($1, Sub,   $3) }

 | expr TIMES  expr { Binop($1, Mult,  $3) }

 | expr DIVIDE expr { Binop($1, Div,   $3) }

 | expr MOD    expr { Binop($1, Mod,   $3) }

 | expr EQ     expr { Binop($1, Equal, $3) }

 | expr NEQ    expr { Binop($1, Neq,   $3) }
```

```
  | expr LT     expr { Binop($1, Less,   $3) }
  | expr LEQ    expr { Binop($1, Leq,    $3) }
  | expr GT     expr { Binop($1, Greater, $3) }
  | expr GEQ    expr { Binop($1, Geq,    $3) }
  | expr AND    expr { Binop($1, And,    $3) }
  | expr OR     expr { Binop($1, Or,     $3) }
  | MINUS expr %prec NEG { Unop(Neg, $2) }
  | NOT expr             { Unop(Not, $2) }
  | expr PLUSPLUS        { Incrementer($1, Increment)}
  | expr MINMIN          { Incrementer($1, Decrement)}
  | expr ASSIGN expr     { Assign($1, $3) }


  | ID LPAREN actuals_opt RPAREN { Call($1, $3) }
  | LPAREN expr RPAREN           { $2 }


  | ID LBRACKET explst RBRACKET    { Vector_access($1, List.rev
$3) }
  | vector                         { Vector_lit($1) }


  | ID DOT DIMS                    { Dimlist($1) }

literal:
    LITERAL          { Literal($1) }
  | FLITERAL         { Fliteral($1)  }
  | TRUE             { BoolLit(true) }
  | FALSE            { BoolLit(false) }
  | ID               { Id($1) }
  | STRING           { MyStringLit($1) }


vector:
  LBRACKET RBRACKET                    {[]}
|  LBRACKET vect_list RBRACKET          {List.rev $2}


vect_list:
 vect_element                          { [$1] }
| vect_list COMMA vect_element          { $3 :: $1 }


vect_element:
 vector                                { Vector_lit($1) }
| literal                               { $1 }


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


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


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

Codegen:

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

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

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

Detailed documentation on the OCaml LLVM library:

http://llvm.moe/
http://llvm.moe/ocaml/

*)


module L = Llvm
module A = Ast
module S = Sast


module StringMap = Map.Make(String)

let translate (globals, functions) =
 let context = L.global_context () in
 let the_module = L.create_module context "MatriCs"
 and i32_t  = L.i32_type  context
 and f64_t  = L.double_type context (* prob with floats *)
 (* and i8_t   = L.i8_type   context *)
 and i1_t   = L.i1_type   context
 and str_t  = L.pointer_type (L.i8_type (context))
 and array_t = L.array_type
 and void_t = L.void_type context in


 let rec ltype_of_typ = function
```

```
      A.Int -> i32_t
    | A.Float -> f64_t
    | A.Bool -> i1_t
    | A.MyString -> str_t
    | A.Void -> void_t
    | A.Vector(typ, szl) -> match szl with
      [] -> ltype_of_typ typ
      | [x] ->  array_t (ltype_of_typ (A.Vector(typ, []))) x
      | hd::tl -> array_t (ltype_of_typ (A.Vector(typ, tl))) hd
    in

  (* Declare each global variable; remember its value in a map *)
  let global_vars =
    let global_var m (t, n) =
      let init = L.const_int (ltype_of_typ t) 0
      in StringMap.add n (L.define_global n init the_module) m in
    List.fold_left global_var StringMap.empty globals in


  (* Declare printf(), which the print built-in function will call
*)
  let printf_t = L.var_arg_function_type i32_t [| str_t |] in
  let printf_func = L.declare_function "printf" printf_t
the_module in


  (* Define each function (arguments and return type) so we can
call it *)
  let function_decls =
    let function_decl m fdecl =
      let name = fdecl.S.sfname
      and formal_types =
           Array.of_list (List.map (fun (t,_) -> ltype_of_typ t)
fdecl.S.sformals)
      in let ftype = L.function_type (ltype_of_typ fdecl.S.styp)
```

```
formal_types in
     StringMap.add name (L.define_function name ftype the_module,
fdecl) m in
   List.fold_left function_decl StringMap.empty functions in


 (* Fill in the body of the given function *)

 let build_function_body fdecl =

   let (the_function, _) = StringMap.find fdecl.S.sfname
function_decls in
   let builder = L.builder_at_end context (L.entry_block
the_function) in



   let int_format_str = L.build_global_stringptr "%d" "fmt"
builder in
   let float_format_str = L.build_global_stringptr "%f" "fmt"
builder in


   (* Construct the function's "locals": formal arguments and
locally
      declared variables.  Allocate each on the stack, initialize
their
      value, if appropriate, and remember their values in the
"locals" map *)
   let local_vars =

     let add_formal m (t, n) p = L.set_value_name n p;

       let local = L.build_alloca (ltype_of_typ t) n builder in

       ignore (L.build_store p local builder);

       StringMap.add n local m in



     let add_local m (t, n) =

       let local_var = L.build_alloca (ltype_of_typ t) n builder

     in StringMap.add n local_var m in



   let formals = List.fold_left2 add_formal StringMap.empty
fdecl.S.sformals
```

```
        (Array.to_list (L.params the_function)) in
        List.fold_left add_local formals fdecl.S.slocals in


    (* Return the value for a variable or formal argument *)
    let lookup n = try StringMap.find n local_vars
                   with Not_found -> StringMap.find n global_vars
    in


    (* Construct code for an expression; return its value *)
    let rec expr builder ex =
      let build_vect vname indices assign =
        if assign > 0 then
          L.build_gep (lookup vname) (Array.append [|L.const_int
i32_t 0|] (Array.of_list (List.map (fun e -> expr builder e)
indices))) vname builder
        else
          L.build_load (L.build_gep (lookup vname) (Array.append
[|L.const_int i32_t 0|] (Array.of_list (List.map (fun e -> expr
builder e) indices))) vname builder) vname builder
      in
      let build_vect_ref vname i =
        let rec make_empty_lst i1 l =
          if i1 > 0 then
            make_empty_lst (i1-1) (0::l)
          else
            l
        in
        let eml = make_empty_lst i [] in
        (L.build_in_bounds_gep (lookup vname) ( Array.append
[|L.const_int i32_t 0|] (Array.of_list (List.map (fun e -> expr
builder (S.SLit(e))) eml))) vname builder)
      in
    (match ex with
          S.SLit i -> L.const_int i32_t i
      | S.SFlit f -> L.const_float f64_t f
      | S.SBoolLit b -> L.const_int i1_t (if b then 1 else 0)
      | S.SMyStringLit str -> L.build_global_stringptr str "tmp"
builder
      | S.SNoexpr -> L.const_int i32_t 0
      | S.SId(s, _) -> L.build_load (lookup s) s builder
      | S.SVector_lit(el, ty, diml) -> (match diml with
        [x] -> L.const_array (ltype_of_typ ty) (Array.of_list
(List.map (expr builder) el))
        | hd::tl -> L.const_array (ltype_of_typ (A.Vector(ty,tl)))
(Array.of_list (List.map (expr builder) el)))


(*        match diml with
       [] -> L.const_array (ltype_of_typ ty)
       | [x] ->  L.const_array array_t ((A.Vector(ty, []))) x
       | hd::tl -> *)
(*
       let lst = List.map (expr builder) el in
       let arr = Array.of_list lst in
       let makevect vty = function
       | SVector_lit(el, _, _) -> L.const_array (A.Vector()) arr
       |
       array_t (ltype_of_typ (A.Vector(typ, []))) x
       in makevect List.hd lst
         L.const_array (ltype_of_typ ty) arr *)
      | S.SBinop (e1, op, e2, t1, t2, t) ->
          let e1' = expr builder e1
          and e2' = expr builder e2 in
          let b = (match op with
            A.Add when t = A.Int            -> L.build_add
                                 | A.Add when t = A.Float     ->
L.build_fadd
```

```
        | A.Mod when t = A.Int    -> L.build_srem
        | A.Mod when t = A.Float  -> L.build_frem
                              | A.Sub when t = A.Int
        -> L.build_sub
                              | A.Sub when t = A.Float     ->
L.build_fsub
                              | A.Mult when t = A.Int      ->
L.build_mul
                              | A.Mult when t = A.Float ->
L.build_fmul
                              | A.Div when t = A.Int
        -> L.build_sdiv
                              | A.Div when t = A.Float     ->
L.build_fdiv
          | A.And     -> L.build_and
          | A.Or      -> L.build_or
          | A.Equal   -> L.build_icmp L.Icmp.Eq
          | A.Neq     -> L.build_icmp L.Icmp.Ne
          | A.Less    -> L.build_icmp L.Icmp.Slt
          | A.Leq     -> L.build_icmp L.Icmp.Sle
          | A.Greater -> L.build_icmp L.Icmp.Sgt
          | A.Geq     -> L.build_icmp L.Icmp.Sge
          ) in
                              let (e1'', e2'') = match t with
                                     Float ->
                                            ((match t1 with
                                            Int -> L.build_sitofp
e1' (ltype_of_typ t) "tmp1" builder
                                            | _ -> e1'),
                                            (match t2 with
                                            Int -> L.build_sitofp
e2' (ltype_of_typ t) "tmp2" builder
                                            | _ -> e2'))
                                     | _ -> (e1', e2')
                              in b e1'' e2'' "tmp" builder
      | S.SUnop(op, e, t) ->
```

```
          let e' = expr builder e in
          (match op with
            A.Neg     -> L.build_neg
          | A.Not     -> L.build_not) e' "tmp" builder
      | S.SAssign (s, e, _) -> let e' = expr builder e in
        (match s with
          SId(var, _) -> ignore (L.build_store e' (lookup var)
builder); e'
      | SVector_access(vname, idx, ty) -> let gep = build_vect
vname idx 1 in
           ignore (L.build_store e' gep builder); e'
           | _ -> raise(Failure("should not reach here")))
      | S.SCall ("print_int", [e], _) | S.SCall ("printb", [e], _)
->
            L.build_call printf_func [| int_format_str ; (expr
builder e) |]
              "printf" builder
      | S.SCall ("print_float", [e], _) ->
         L.build_call printf_func [| float_format_str ; (expr
builder e) |]
           "printf" builder
      | S.SCall ("print", [e], _) ->
          L.build_call printf_func [| (expr builder e) |] "printf"
builder
      | S.SCall (f, act, _) ->
        let (fdef, fdecl) = StringMap.find f function_decls in
           let actuals = List.rev (List.map (expr builder)
(List.rev act)) in
           let result = (match fdecl.S.styp with A.Void -> ""
                                             | _ -> f ^
"_result") in
          L.build_call fdef (Array.of_list actuals) result
builder
      | S.SVector_access (vname, idx, typ) ->
           build_vect vname idx 0
```

```
     | S.SDimlist (v, dl) -> L.const_array i32_t (Array.of_list
(List.map (fun i -> L.const_int i32_t i) dl)))
     in



   (* Invoke "f builder" if the current block doesn't already

      have a terminal (e.g., a branch). *)

   let add_terminal builder f =

     match L.block_terminator (L.insertion_block builder) with

       Some _ -> ()

     | None -> ignore (f builder) in


   (* Build the code for the given statement; return the builder
for

      the statement's successor *)

   let rec stmt builder = function

       S.SBlock sl -> List.fold_left stmt builder sl

     | S.SExpr e -> ignore (expr builder e); builder

     | S.SReturn e -> ignore (match fdecl.S.styp with

         A.Void -> L.build_ret_void builder

       | _ -> L.build_ret (expr builder e) builder); builder

     | S.SIf (predicate, then_stmt, else_stmt) ->

        let bool_val = expr builder predicate in

        let merge_bb = L.append_block context "merge"
the_function in



        let then_bb = L.append_block context "then" the_function
in
        add_terminal (stmt (L.builder_at_end context then_bb)
then_stmt)
          (L.build_br merge_bb);



        let else_bb = L.append_block context "else" the_function
in
```

```
        add_terminal (stmt (L.builder_at_end context else_bb)
else_stmt)
          (L.build_br merge_bb);


        ignore (L.build_cond_br bool_val then_bb else_bb
builder);
        L.builder_at_end context merge_bb


     | S.SWhile (predicate, body) ->
         let pred_bb = L.append_block context "while"
the_function in
         ignore (L.build_br pred_bb builder);


         let body_bb = L.append_block context "while_body"
the_function in
         add_terminal (stmt (L.builder_at_end context body_bb)
body)
           (L.build_br pred_bb);


         let pred_builder = L.builder_at_end context pred_bb in
         let bool_val = expr pred_builder predicate in


         let merge_bb = L.append_block context "merge"
the_function in
         ignore (L.build_cond_br bool_val body_bb merge_bb
pred_builder);
         L.builder_at_end context merge_bb


     | S.SFor (e1, e2, e3, body) -> stmt builder
           ( S.SBlock [S.SExpr e1 ; S.SWhile (e2, S.SBlock [body
; S.SExpr e3]) ] )
   in
```

```
    (* Build the code for each statement in the function *)
    let builder = stmt builder (S.SBlock fdecl.S.sbody) in


    (* Add a return if the last block falls off the end *)
    add_terminal builder (match fdecl.S.styp with
        A.Void -> L.build_ret_void
      | t -> L.build_ret (L.const_int (ltype_of_typ t) 0))
  in


  List.iter build_function_body functions;
  the_module
```

Scanner:

```
open Ast

(* Expressions *)
type sexpr =
         SLit of int
       | SFlit of float
       | SBoolLit of bool
       | SMyStringLit of string
       | SVector_lit of sexpr list * typ * int list
       | SId of string * typ
       | SBinop of sexpr * op * sexpr * typ * typ * typ
       | SUnop of uop * sexpr * typ
       | SAssign of sexpr * sexpr * typ
       | SCall of string * sexpr list * typ
       | SVector_access of string * sexpr list * typ
       | SReference of string * typ
       | SDimlist of string * int list
       | SNoexpr

(* Statements *)
type sstmt =
         SBlock of sstmt list
       | SExpr of sexpr
       | SReturn of sexpr
```

```
        | SIf of sexpr * sstmt * sstmt
        | SFor of sexpr * sexpr * sexpr * sstmt
        | SWhile of sexpr * sstmt

(* Function Declarations *)
type sfunc_decl = {
        styp                    : typ;
        sfname                          : string;
        sformals                : bind list;
        slocals                 : bind list;
        sbody                   : sstmt list;
}

(* All method declarations | Main entry method *)
type sprogram = bind list * sfunc_decl list
```

Semant:

```
(*Semantic
checking for
MatriCs
compiler*)


                    open Ast

                    open Sast


                    module StringMap = Map.Make(String)


                    (* Semantic checking of a program. Returns void if successful,

                      throws an exception if something is wrong.


                      Check each global variable, then check each function *)


                    let check (globals, functions) =
(* Raise an exception if the given list has a duplicate *)
let report_duplicate exceptf list =
  let rec helper = function
            n1 :: n2 :: _ when n1 = n2 -> raise (Failure (exceptf
n1))
      | _ :: t -> helper t
      | [] -> ()
  in helper (List.sort compare list)
in


(* Raise an exception if a given binding is to a void type *)
let check_not_void exceptf = function
    (Void, n) -> raise (Failure (exceptf n))
  | _ -> ()
in

(* Raise an exception of the given rvalue type cannot be assigned to
   the given lvalue type *)
let check_assign lvaluet rvaluet err =
  (match lvaluet with
    Vector(ltyp, lsize) ->
      (match rvaluet with
        Vector(rtyp, rsize) -> if ltyp == rtyp then ltyp else raise
err
        | _ -> if ltyp == rvaluet then ltyp else raise err)
    | _ -> if lvaluet == rvaluet then lvaluet else raise err)
in


(**** Checking Global Variables ****)
```

```
 List.iter (check_not_void (fun n -> "illegal void global " ^ n))
globals;

 report_duplicate (fun n -> "duplicate global " ^ n) (List.map snd
globals);

 (**** Checking Functions ****)

 if List.mem "int_to_string" (List.map (fun fd -> fd.fname) functions)
 then raise (Failure ("function int_to_string may not be defined"))
else ();
 if List.mem "print" (List.map (fun fd -> fd.fname) functions)
 then raise (Failure ("function print may not be defined")) else ();

 report_duplicate (fun n -> "duplicate function " ^ n)
   (List.map (fun fd -> fd.fname) functions);

 if List.mem "print" (List.map (fun fd -> fd.fname) functions)
 then raise (Failure ("function print may not be defined")) else ();

 (* Function declaration for a named function *)
   let built_in_decls_funcs =  [
     { typ = Void; fname = "print_int"; formals = [(Int, "x")];
     locals = []; body = [] };

     { typ = Void; fname = "print_float"; formals = [(Float, "x")];
     locals = []; body = [] };
     { typ = Void; fname = "printb"; formals = [(Bool, "x")];
     locals = []; body = [] };
(*
     { typ = Void; fname = "dimlist"; formals = [(Vector(), "v")];
     locals = []; body = [] };
*)
     ]
  in


  let built_in_decls_names = [ "print_int"; "print_float"; "printb"(*;
"dimlist"*)]


in


 let built_in_decls = List.fold_right2 (StringMap.add)
                       built_in_decls_names
                       built_in_decls_funcs
                       (StringMap.singleton "print"
                               { typ = Void; fname = "print"; formals
= [(MyString, "x")];
                               locals = []; body = [] })


 in




 let function_decls = List.fold_left (fun m fd -> StringMap.add
fd.fname fd m)
                        built_in_decls functions
 in
 let function_decl s = try StringMap.find s function_decls

      with Not_found -> raise (Failure ("unrecognized function " ^ s))

 in



 let _ = function_decl "main" in (* Ensure "main" is defined *)




 (* -- Top-level function -- *)

 let check_function func =



   List.iter (check_not_void (fun n -> "illegal void formal " ^ n ^

     " in " ^ func.fname)) func.formals;



   report_duplicate (fun n -> "duplicate formal " ^ n ^ " in " ^
func.fname)
     (List.map snd func.formals);



   List.iter (check_not_void (fun n -> "illegal void local " ^ n ^

     " in " ^ func.fname)) func.locals;



   report_duplicate (fun n -> "duplicate local " ^ n ^ " in " ^
func.fname)
     (List.map snd func.locals);



   (* Type of each variable (global, formal, or local *)

   let symbols = List.fold_left (fun m (t, n) -> StringMap.add n t m)
```

```
            StringMap.empty (globals @ func.formals @ func.locals )
   in


   (* Function to print all symbols *)
   (* List.iter (fun (t, n) -> print_string ( string_of_typ t ^ " " ^
n)) func.formals; *)


   let type_of_identifier s =
     try StringMap.find s symbols
     with Not_found -> raise (Failure ("undeclared identifier " ^ s))
   in


   let match_binop t1 t2 op e =
     (match op with
     Add | Sub | Mult | Mod | Div ->
                             (match t1 with
               Int ->
                                             (match t2 with
                                                     Int -> Int
                                                     | Float -> Float
                                                     | _ -> raise
(Failure ("undefined operation " ^
                             string_of_op op ^ "on type " ^
string_of_typ t2)))
               | Float -> Float
                                     | _ -> raise (Failure ("undefined
operation " ^
                             string_of_op op ^ "on type " ^
string_of_typ t1)))
               | Equal | Neq when t1 = t2 -> Bool
               | Less | Leq | Greater | Geq
                             when t1 = Int && t2 = Int -> Bool
```

```
                  | Less | Leq | Greater | Geq
                             when t1 = Float && t2 = Float -> Bool
                  | And | Or when t1 = Bool && t2 = Bool -> Bool
                  | _ -> raise (Failure ("illegal binary operator " ^
             string_of_typ t1 ^ " " ^ string_of_op op ^ " " ^
             string_of_typ t2 ^ " in " ^ string_of_expr e)))
                  in


    (* Return the type of an expression or throw an exception *)
    let rec expr = function
              Literal _ -> Int
        | Fliteral _ -> Float
        | BoolLit _ -> Bool
        | Id s -> type_of_identifier s
        | MyStringLit _ -> MyString
        | Vector_lit elements ->
          let hdel = List.hd elements in
          (match hdel with
           Vector_lit(els) ->
             let rec check_vect_vects = function
              | [] -> raise(Failure("empty literal not allowed"))
              | [x] -> let Vector(typ, szl) = expr x in Vector(typ,
((List.length elements)::szl))
              | fst :: snd :: tail -> let Vector(t1, s1) = expr fst and
Vector(t2, s2) = expr snd in
                 if t1 == t2 then
                   let flag = List.iter2 (fun a b -> if a != b then
raise (Failure("nested vector literals are of different sizes " ))
else () ) s1 s2
                   in check_vect_vects (snd::tail)
                 else raise (Failure("nested vector literals are of
different types "^string_of_typ t1^" and "^string_of_typ t2))
             in  check_vect_vects elements
          | _ -> let rec check_vector_types i = function
                | [] -> raise( Failure ("empty literal not allowed"))
                | [el] -> Vector(expr el, [i+1]) (* HACKY FIX  *)
                | fst :: snd :: tail ->
                  if (expr fst) == (expr snd) then
                    check_vector_types (i+1) (snd::tail)
                  else raise (Failure ("unmatched element types in
vector literal " ^
                    string_of_typ (expr fst) ^ ", " ^ string_of_typ
(expr snd)))
               in check_vector_types 0 elements)

        | Binop(e1, op, e2) as e -> let t1 = expr e1 and t2 = expr e2
in
                    (match op with
                    Add | Sub | Mod | Mult | Div ->
                                            (match t1 with
                             Int ->
                                                           (match t2
with
                                                                  Int
-> Int
                                                                  |
Float -> Float
                                                                  | _
-> raise (Failure ("undefined operation " ^
                                            string_of_op op ^ "on type
" ^ string_of_typ t2)))
                             | Float -> Float
                                                  | _ -> raise
(Failure ("undefined operation " ^
                                            string_of_op op ^ "on type
" ^ string_of_typ t1)))
                             | Equal | Neq when t1 = t2 -> Bool
                             | Less | Leq | Greater | Geq
                                            when t1 = Int && t2 = Int
-> Bool
```

```
                              | Less | Leq | Greater | Geq
                                             when t1 = Float && t2 =
Float -> Bool
                              | And | Or when t1 = Bool && t2 = Bool ->
Bool
                              | _ -> raise (Failure ("illegal binary
operator " ^
                          string_of_typ t1 ^ " " ^ string_of_op op ^ "
" ^
                          string_of_typ t2 ^ " in " ^ string_of_expr
e)))
                              | Unop(op, e) as ex -> let t = expr e in
       (match op with
                 Neg when t = Int -> Int
                                                      |      Neg when t
= Float -> Float
                | Not when t = Bool -> Bool
                  | _ -> raise (Failure ("illegal unary operator " ^
string_of_uop op ^
                                  string_of_typ t ^ " in " ^
string_of_expr ex))
         )
       | Incrementer(e, uop) as ex -> let t = expr e in
         (match t with
           Int -> Int
           | _ -> raise (Failure("illegal type cannot be incremented "
^ string_of_typ t)))
       | Noexpr -> Void
       | Assign(var_ex, e) as ex ->
         (match var_ex with
           Id var -> let lt = type_of_identifier var
                     and rt = expr e in
             check_assign lt rt (Failure ("illegal assignment " ^
string_of_typ lt ^
                                   " = " ^ string_of_typ rt ^ " in " ^
                                   string_of_expr ex))
           | Vector_access(vnm, idx) -> let lt = expr var_ex
```

```
                                    and rt = expr e in
             check_assign lt rt (Failure ("illegal vector assignment "
^ string_of_typ lt ^
              " = " ^ string_of_typ rt ^ " in " ^
              string_of_expr ex))
           | _ -> raise (Failure ("illegal assignment " ^
           string_of_expr var_ex ^ " = " ^ string_of_expr e ^
           " in " ^ string_of_expr ex)))
       | Call(fname, actuals) as call -> let fd = function_decl fname
in
          if List.length actuals != List.length fd.formals then
            raise (Failure ("expecting " ^ string_of_int
              (List.length fd.formals) ^ " arguments in " ^
string_of_expr call))
          else
            List.iter2 (fun (ft, _) e -> let et = expr e in
               ignore (check_assign ft et
                 (Failure ("illegal actual argument found " ^
string_of_typ et ^
                 " expected " ^ string_of_typ ft ^ " in " ^
string_of_expr e))))
              fd.formals actuals;
            fd.typ
       | Vector_access(nm, ilst) -> let Vector(typ, sz) =
type_of_identifier nm in
           (let rec check_i = function
             [idx] -> let idxtyp = expr idx in
                   if idxtyp != Int then raise (Failure ("array " ^ nm
                     ^ " index not an integer"))
                   else typ
              | hd::tl -> let idxtyp = expr hd in
             if idxtyp != Int then raise (Failure ("array " ^ nm
                  ^ " index not an integer"))
           else check_i tl in check_i ilst)
       | Dimlist s -> let nm = type_of_identifier s in
```

```
           (match nm with
             Vector(typ, szl) -> Vector(Int, [(List.length szl)])
           | _ -> raise(Failure("dims cannot be called on non-vector
type "^s)))
         (* TODO: TRY IMPLEMENTING INDEX OUT OF BOUNDS
         else let Vector(typ, sz) = type_of_identifier nm in
           if (sz - 1) < idx then raise (Failure ("array " ^ nm
                ^ " index out of bounds")) *)
   in

   let check_bool_expr e = if expr e != Bool
     then raise (Failure ("expected Boolean expression in " ^
string_of_expr e))
     else ()
   in

   (* Verify a statement or throw an exception *)
   let rec stmt = function
          Block sl -> let rec check_block = function
          [Return _ as s] -> stmt s
        | Return _ :: _ -> raise (Failure "nothing may follow a
return")
        | Block sl :: ss -> check_block (sl @ ss)
        | s :: ss -> stmt s ; check_block ss
        | [] -> ()
       in check_block sl
     | Expr e -> ignore (expr e)
     | Return e -> let t = expr e in if t = func.typ then () else
        raise (Failure ("return gives " ^ string_of_typ t ^ " expected
" ^
                        string_of_typ func.typ ^ " in " ^
string_of_expr e))
```

```
      | If(p, b1, b2) -> check_bool_expr p; stmt b1; stmt b2
      | For(e1, e2, e3, st) -> ignore (expr e1); check_bool_expr e2;
                               ignore (expr e3); stmt st
      | While(p, s) -> check_bool_expr p; stmt s
    in
    stmt (Block func.body);
  in

  List.iter check_function functions;

  let ast_to_sast func =
    let symbols = List.fold_left (fun m (t, n) -> StringMap.add n t m)
      StringMap.empty (globals @ func.formals @ func.locals )
    in

    (* Function to print all symbols *)
    (* List.iter (fun (t, n) -> print_string ( string_of_typ t ^ " " ^
n)) func.formals; *)

    let type_of_identifier s =
      try StringMap.find s symbols
      with Not_found -> raise (Failure ("undeclared identifier " ^ s))
    in

    let sast_to_typ = function
      SId(_, t)                   -> t
      | SLit(_)                   -> Int
      | SFlit(_)                  -> Float
      | SBoolLit(_)               -> Bool
      | SMyStringLit(_)          -> MyString
      | SBinop(_, op, _, _, _, t) -> t
      | SAssign(_, _, t)         -> t
      | SCall(_, _, t)           -> t
      | SUnop(_, _, t)           -> t
      | SVector_access(_, _, t)   -> t
      | _ -> raise (Failure ("vector type not supported"))
    in


    (* Return the type of an expression or throw an exception *)
    let rec sexpr = function
       Literal i -> SLit(i)
      | Fliteral f -> SFlit(f)
      | BoolLit b -> SBoolLit(b)
      | Id s -> SId(s, type_of_identifier s)
      | MyStringLit st -> SMyStringLit(st)


      | Vector_lit elements ->
        let rec check_vect dimlist elm =
          let el = List.hd elm in
            match el with
              Vector_lit(ellist) -> check_vect (List.length elm ::
dimlist) ellist
              | x -> ((List.length elm :: dimlist), sexpr x)
        in let dml, xtyp = check_vect [] elements
        and selements = List.map sexpr elements in
        (* SVector_lit(selements, (sast_to_typ xtyp), dml) *)
        let head = List.hd selements in
          (match head with
           _ -> SVector_lit(selements, (sast_to_typ xtyp), dml)
          | SVector_lit(_, childtyp , childdml) ->
SVector_lit(selements, Vector(childtyp, childdml), dml))
```

```
     | Binop(e1, op, e2) as e -> let t1 = sexpr e1 and t2 = sexpr e2
in
             let typ1 = sast_to_typ t1 and typ2 = sast_to_typ t2 in
                         let typ_of_bop =
                                (match op with
                 Add | Sub | Mult | Mod | Div ->
                                       (match typ1 with
                            Int ->
                                                    (match typ2
with
                                                           Int
-> Int
                                                           |
Float -> Float
                                                           | _
-> raise (Failure ("undefined operation " ^
                                       string_of_op op ^ "on type
" ^ string_of_typ typ2)))
                            | Float -> Float
                                              | _ -> raise
(Failure ("undefined operation " ^
                                       string_of_op op ^ "on type
" ^ string_of_typ typ1)))
                            | Equal | Neq when typ1 = typ2 -> Bool
                            | Less | Leq | Greater | Geq
                                       when typ1 = Int && typ2 =
Int -> Bool
                            | Less | Leq | Greater | Geq
                                       when typ1 = Float && typ2
= Float -> Bool
                            | And | Or when typ1 = Bool && typ2 =
Bool -> Bool
                            | _ -> raise (Failure ("illegal binary
operator " ^
                         string_of_typ typ1 ^ " " ^ string_of_op op ^
" " ^
                         string_of_typ typ2))) in
       SBinop(t1, op, t2, typ1, typ2, typ_of_bop)
      | Unop(op, e) -> let t = sexpr e in
       SUnop(op, t, sast_to_typ(t))
      | Incrementer(e, uop) ->
        (match uop with
          Increment -> sexpr (Assign(e, Binop(e, Add, Literal(1))))
          | Decrement -> sexpr (Assign(e, Binop(e, Sub, Literal(1))))
)(* let t = sexpr e in
       let type_of_e = sast_to_typ t in
       let type_of_exp = (
         match type_of_e with
           Int -> Int
         | _ -> raise (Failure ("Illegal type " ^ string_of_typ
type_of_e ^ " " ^ "cannot be incremented"))
       ) in
       SIncremeneter(e, uop, type_of_exp)
*)
      | Noexpr -> SNoexpr


      | Assign(var_ex, e) as ex->
       (match var_ex with
         Id var -> let lt = sexpr var_ex
                   and rt = sexpr e
                   and ty = type_of_identifier var in
                   SAssign(lt, rt, ty)
         | Vector_access(vnm, idx) ->
           let lt = sexpr var_ex
           and rt = sexpr e
           and vty = type_of_identifier vnm in
           (match vty with
            Vector(ty, _) -> SAssign(lt, rt, ty)
           | _ -> raise(Failure("illegal assignment " ^
           string_of_expr var_ex ^ " = " ^ string_of_expr e ^
           " in " ^ string_of_expr ex)) (* should not reach here after
check *) )
          | _ -> raise(Failure("illegal assignment " ^
           string_of_expr var_ex ^ " = " ^ string_of_expr e ^
           " in " ^ string_of_expr ex))) (* should not reach here
after check *)
       (* let lt = sexpr var_ex in
       let rt = sexpr e in
       let ty = type_of_identifier s
         in SAssign(lt, rt, ty) *)
      | Call(fname, actuals) -> let fd = function_decl fname in
         let sactuals = List.map sexpr actuals in
         SCall(fname, sactuals, fd.typ) (* sast_to_typ(sexpr (List.hd
sactuals))) *)
      | Vector_access(vname, idx) -> let Vector(typ, _) =
type_of_identifier vname in
         let sidx = List.map sexpr idx in
         SVector_access(vname, sidx, typ)
      | Dimlist s -> let vect = type_of_identifier s in
       (match vect with
         Vector(t,dl) -> SDimlist(s, dl)
         | _ -> raise(Failure("dims cannot be called on non-vector
type "^s))
       )



   in


   let rec sstmt = function
```

```
    (*    SBlock of sstmt list   *)
      Return(e)       -> SReturn(sexpr e)
    | Block(stmt_l)     -> SBlock(List.map sstmt stmt_l)
    | Expr(e)         -> SExpr(sexpr e)
    | If(e, s1, s2)     -> SIf((sexpr e), (sstmt s1), (sstmt s2))
    | For(e1, e2, e3, s)  -> SFor((sexpr e1), (sexpr e2), (sexpr e3),
(sstmt s))
    | While(e, s)     -> SWhile((sexpr e), (sstmt s))
    in
 List.map sstmt func.body;
in



 let convert_fdecl_to_sfdecl fdecl =
   {
     sfname        = fdecl.fname;
     styp          = fdecl.typ;
     sformals      = fdecl.formals;
     slocals       = fdecl.locals;
     sbody         = ast_to_sast fdecl;
   }
 in

 let
   sfdecls = List.map convert_fdecl_to_sfdecl functions
 in
 (globals, sfdecls)
```

Std Lib:

```
//Transpose 2x2
                    int transpose2(int[2, 2] mat) {
                           int i;
                           int j;
int k;

int l;

int m;

int n;


int [4] vec1;

int [4] vec2;


int count1;

int count2;

int count3;


int [2, 2] tr;


count1 = 0;

for(i = 0; i < 2; i = i + 1) {

        for(j = 0; j < 2; j = j + 1) {

                vec1[count1] = mat[i, j];

                count1 = count1 + 1;

        }

}


count2 = 0;

for(k = 0; k < 2; k = k + 1) {

        for(l = 0; l < 2; l = l + 1) {

                vec2[count2] = vec1[k + l*2];

                count2 = count2 + 1;

        }

}
```

```
        count3 = 0;
        for(m = 0; m < 2; m = m + 1) {
                for(n = 0; n < 2; n = n + 1) {
                        tr[m, n] = vec2[count3];
                        count3 = count3 + 1;
                }
        }
        return 0;
}


//Tranpose 3x3
int transpose3(int [3, 3] mat) {
        int i;
        int j;
        int k;
        int l;
        int m;
        int n;


        int [9] vec1;
        int [9] vec2;


        int count1;
        int count2;
        int count3;


        int [3, 3] tr;
        count1 = 0;

        for(i = 0; i < 3; i = i + 1) {

                for(j = 0; j < 3; j = j + 1) {

                        vec1[count1] = mat[i, j];

                        count1 = count1 + 1;

                }

        }



        count2 = 0;

        for(k = 0; k < 3; k = k + 1) {

                for(l = 0; l < 3; l = l + 1) {

                        vec2[count2] = vec1[k + l*3];

                        count2 = count2 + 1;

                }

        }



        count3 = 0;

        for(m = 0; m < 3; m = m + 1) {

                for(n = 0; n < 3; n = n + 1) {

                        tr[m, n] = vec2[count3];

                        count3 = count3 + 1;

                }

        }

        return 0;

}



//Tranpose 4x4

int transpose4(int [4, 4] mat) {

        int i;
        int j;

        int k;

        int l;

        int m;

        int n;


        int [16] vec1;

        int [16] vec2;


        int count1;

        int count2;

        int count3;


        int [4, 4] tr;


        count1 = 0;

        for(i = 0; i < 4; i = i + 1) {

                for(j = 0; j < 4; j = j + 1) {

                        vec1[count1] = mat[i, j];

                        count1 = count1 + 1;

                }

        }


        count2 = 0;

        for(k = 0; k < 4; k = k + 1) {

                for(l = 0; l < 4; l = l + 1) {

                        vec2[count2] = vec1[k + l*4];

                        count2 = count2 + 1;

                }
```

```
        }

        count3 = 0;
        for(m = 0; m < 4; m = m + 1) {
                for(n = 0; n < 4; n = n + 1) {
                        tr[m, n] = vec2[count3];
                        count3 = count3 + 1;
                }
        }
        return 0;
}

// Transpose 5x5
int transpose5(int [5, 5] mat) {
        int i;
        int j;
        int k;
        int l;
        int m;
        int n;

        int [25] vec1;
        int [25] vec2;

        int count1;
        int count2;
        int count3;

        int [5, 5] tr;
        count1 = 0;

        for(i = 0; i < 5; i = i + 1) {

                for(j = 0; j < 5; j = j + 1) {

                        vec1[count1] = mat[i, j];

                        count1 = count1 + 1;

                }

        }



        count2 = 0;

        for(k = 0; k < 5; k = k + 1) {

                for(l = 0; l < 5; l = l + 1) {

                        vec2[count2] = vec1[k + l*5];

                        count2 = count2 + 1;

                }

        }



        count3 = 0;

        for(m = 0; m < 5; m = m + 1) {

                for(n = 0; n < 5; n = n + 1) {

                        tr[m, n] = vec2[count3];

                        count3 = count3 + 1;

                }

        }

        return 0;

}


// Add 2-D Matrices

int add2(int [2, 2] mat1, int [2, 2] mat2) {
```

```
int[4] a_flat;

int[4] b_flat;

int[4] d_flat;

int[2, 2] add_mat;



int i;

int j;

int k;

int l;

int m;



int count1;

int count2;

int count3;



count1 = 0;

for(i = 0; i < 2; i = i + 1) {

        for(j = 0; j < 2; j = j + 1) {

                a_flat[count1] = mat1[i, j];

                b_flat[count1] = mat2[i, j];

                count1 = count1 + 1;

        }

}



count2 = 0;

for(k = 0; k < 4; k = k + 1) {

        d_flat[count2] = a_flat[count2] + b_flat[count2];

        count2 = count2 + 1;

}
```

```
        count3 = 0;
        for(l = 0; l < 2; l = l + 1) {
                for(m = 0; m < 2; m = m + 1) {
                        add_mat[l, m] = d_flat[count3];
                        count3 = count3 + 1;
                }
        }


        return 0;
}


int add3(int [3, 3] mat1, int [3, 3] mat2) {
        int[9] a_flat;
        int[9] b_flat;
        int[9] d_flat;
        int[3, 3] add_mat;


        int i;
        int j;
        int k;
        int l;
        int m;


        int count1;
        int count2;
        int count3;
        count1 = 0;
        for(i = 0; i < 3; i = i + 1) {
                for(j = 0; j < 3; j = j + 1) {
                        a_flat[count1] = mat1[i, j];
                        b_flat[count1] = mat2[i, j];
                        count1 = count1 + 1;
                }
        }

        count2 = 0;
        for(k = 0; k < 9; k = k + 1) {
                d_flat[count2] = a_flat[count2] + b_flat[count2];
                count2 = count2 + 1;
        }

        count3 = 0;
        for(l = 0; l < 3; l = l + 1) {
                for(m = 0; m < 3; m = m + 1) {
                        add_mat[l, m] = d_flat[count3];
                        count3 = count3 + 1;
                }
        }

        return 0;
}

int add4(int [4, 4] mat1, int [4, 4] mat2) {
        int[16] a_flat;
        int[16] b_flat;
```

```
int[16] d_flat;
int[4, 4] add_mat;


int i;
int j;
int k;
int l;
int m;


int count1;
int count2;
int count3;


count1 = 0;
for(i = 0; i < 4; i = i + 1) {
       for(j = 0; j < 4; j = j + 1) {
              a_flat[count1] = mat1[i, j];
              b_flat[count1] = mat2[i, j];
              count1 = count1 + 1;
       }
}


count2 = 0;
for(k = 0; k < 16; k = k + 1) {
       d_flat[count2] = a_flat[count2] + b_flat[count2];
       count2 = count2 + 1;
}


count3 = 0;
```

```
        for(l = 0; l < 4; l = l + 1) {

                for(m = 0; m < 4; m = m + 1) {

                        add_mat[l, m] = d_flat[count3];

                        count3 = count3 + 1;

                }

        }



        return 0;

}



int add5(int [5, 5] mat1, int [5, 5] mat2) {

        int[25] a_flat;

        int[25] b_flat;

        int[25] d_flat;

        int[5, 5] add_mat;



        int i;

        int j;

        int k;

        int l;

        int m;



        int count1;

        int count2;

        int count3;



        count1 = 0;

        for(i = 0; i < 5; i = i + 1) {

                for(j = 0; j < 5; j = j + 1) {
```

```
                a_flat[count1] = mat1[i, j];

                b_flat[count1] = mat2[i, j];

                count1 = count1 + 1;

            }

        }



        count2 = 0;

        for(k = 0; k < 25; k = k + 1) {

            d_flat[count2] = a_flat[count2] + b_flat[count2];

            count2 = count2 + 1;

        }



        count3 = 0;

        for(l = 0; l < 5; l = l + 1) {

            for(m = 0; m < 5; m = m + 1) {

                add_mat[l, m] = d_flat[count3];

                count3 = count3 + 1;

            }

        }



        return 0;

    }



    // Subtract 2-D Matrices

    int subtract2(int [2, 2] mat1, int [2, 2] mat2) {

        int[4] a_flat;

        int[4] b_flat;

        int[4] d_flat;

        int[2, 2] sub_mat;
```

```
int i;
int j;
int k;
int l;
int m;


int count1;
int count2;
int count3;


count1 = 0;
for(i = 0; i < 2; i = i + 1) {
	for(j = 0; j < 2; j = j + 1) {
		a_flat[count1] = mat1[i, j];
		b_flat[count1] = mat2[i, j];
		count1 = count1 + 1;
	}
}


count2 = 0;
for(k = 0; k < 4; k = k + 1) {
	d_flat[count2] = a_flat[count2] - b_flat[count2];
	count2 = count2 + 1;
}


count3 = 0;
for(l = 0; l < 2; l = l + 1) {
	for(m = 0; m < 2; m = m + 1) {
```

```
                sub_mat[l, m] = d_flat[count3];
                count3 = count3 + 1;
            }
        }

        return 0;
}

int subtract3(int [3, 3] mat1, int [3, 3] mat2) {
        int[9] a_flat;
        int[9] b_flat;
        int[9] d_flat;
        int[3, 3] sub_mat;

        int i;
        int j;
        int k;
        int l;
        int m;

        int count1;
        int count2;
        int count3;

        count1 = 0;
        for(i = 0; i < 3; i = i + 1) {
            for(j = 0; j < 3; j = j + 1) {
                a_flat[count1] = mat1[i, j];
                b_flat[count1] = mat2[i, j];
                count1 = count1 + 1;
            }
        }

        count2 = 0;
        for(k = 0; k < 9; k = k + 1) {
            d_flat[count2] = a_flat[count2] - b_flat[count2];
            count2 = count2 + 1;
        }

        count3 = 0;
        for(l = 0; l < 3; l = l + 1) {
            for(m = 0; m < 3; m = m + 1) {
                sub_mat[l, m] = d_flat[count3];
                count3 = count3 + 1;
            }
        }

        return 0;
    }

    int subtract4(int [4, 4] mat1, int [4, 4] mat2) {
        int[16] a_flat;
        int[16] b_flat;
        int[16] d_flat;
        int[4, 4] sub_mat;

        int i;
        int j;
```

```
int k;
int l;
int m;


int count1;
int count2;
int count3;


count1 = 0;
for(i = 0; i < 4; i = i + 1) {
        for(j = 0; j < 4; j = j + 1) {
                a_flat[count1] = mat1[i, j];
                b_flat[count1] = mat2[i, j];
                count1 = count1 + 1;
        }
}


count2 = 0;
for(k = 0; k < 16; k = k + 1) {
        d_flat[count2] = a_flat[count2] - b_flat[count2];
        count2 = count2 + 1;
}


count3 = 0;
for(l = 0; l < 4; l = l + 1) {
        for(m = 0; m < 4; m = m + 1) {
                sub_mat[l, m] = d_flat[count3];
                count3 = count3 + 1;
        }
        }


        return 0;
}


int subtract5(int [5, 5] mat1, int [5, 5] mat2) {
        int[25] a_flat;
        int[25] b_flat;
        int[25] d_flat;
        int[5, 5] sub_mat;


        int i;
        int j;
        int k;
        int l;
        int m;


        int count1;
        int count2;
        int count3;


        count1 = 0;
        for(i = 0; i < 5; i = i + 1) {
                for(j = 0; j < 5; j = j + 1) {
                        a_flat[count1] = mat1[i, j];
                        b_flat[count1] = mat2[i, j];
                        count1 = count1 + 1;
                }
        }
        count2 = 0;
        for(k = 0; k < 25; k = k + 1) {
                d_flat[count2] = a_flat[count2] - b_flat[count2];
                count2 = count2 + 1;
        }

        count3 = 0;
        for(l = 0; l < 5; l = l + 1) {
                for(m = 0; m < 5; m = m + 1) {
                        sub_mat[l, m] = d_flat[count3];
                        count3 = count3 + 1;
                }
        }

        return 0;
}

//Identity 2x2
int id2() {
        int i;
        int j;

        int [2, 2] mat;
        print("[");
        for(i = 0; i < 2; i = i + 1) {
                for (j = 0; j < 2; j = j + 1) {
                        if(i == j) {
                                mat[i, j] = 1;
```

```
                            print_int(mat[i,j]);
                 }
                 else {
                    mat[i, j] = 0;
                    print_int(mat[i,j]);
                     }
             }
        }
        print("]");
        return 0;
        }


        // Identity 3x3
        int id3() {
                int i;
                int j;


                int [3, 3] mat;
                print("[");
                for(i = 0; i < 3; i = i + 1) {
                        for (j = 0; j < 3; j = j + 1) {
                                if(i == j) {
                                        mat[i, j] = 1;
                                        print_int(mat[i,j]);
                     }
                     else {
                        mat[i, j] = 0;
                        print_int(mat[i,j]);
                         }
                }
```

```
}
print("]");
return 0;
}


// Identity 4x4
int id4() {
       int i;
       int j;


       int [4, 4] mat;
       print("[");
       for(i = 0; i < 4; i = i + 1) {
              for (j = 0; j < 4; j = j + 1) {
                     if(i == j) {
                            mat[i, j] = 1;
                            print_int(mat[i,j]);
            }
            else {
              mat[i, j] = 0;
              print_int(mat[i,j]);
               }
       }
}
print("]");
return 0;
}


// Identity 5x5
int id5() {
        int i;

        int j;



        int [5, 5] mat;

        print("[");

        for(i = 0; i < 5; i = i + 1) {

                for (j = 0; j < 5; j = j + 1) {

                        if(i == j) {

                                mat[i, j] = 1;

                                print_int(mat[i,j]);

             }

             else {

                mat[i, j] = 0;

                print_int(mat[i,j]);

                 }

        }

}

print("]");

return 0;

}



// Identity 6x6

int id6() {

        int i;

        int j;



        int [6, 6] mat;

        print("[");

        for(i = 0; i < 6; i = i + 1) {

                for (j = 0; j < 6; j = j + 1) {
                        if(i == j) {
                                mat[i, j] = 1;
                                print_int(mat[i,j]);
             }
             else {
                mat[i, j] = 0;
                print_int(mat[i,j]);
                 }
        }
}
print("]");
return 0;
}


// Identity 7x7
int id7() {
        int i;
        int j;


        int [7, 7] mat;
        print("[");
        for(i = 0; i < 7; i = i + 1) {
                for (j = 0; j < 7; j = j + 1) {
                        if(i == j) {
                                mat[i, j] = 1;
                                print_int(mat[i,j]);
             }
             else {
                mat[i, j] = 0;
                print_int(mat[i,j]);
```

```
                }

        }

}

print("]");

return 0;

}



// Identity 8x8

int id8() {

        int i;

        int j;



        int [8, 8] mat;

        print("[");

        for(i = 0; i < 8; i = i + 1) {

                for (j = 0; j < 8; j = j + 1) {

                        if(i == j) {

                                mat[i, j] = 1;

                                print_int(mat[i,j]);

             }

             else {

                mat[i, j] = 0;

                print_int(mat[i,j]);

                }

        }

}

print("]");

return 0;

}
```

```
// Identity 9x9
int id9() {
        int i;
        int j;


        int [9, 9] mat;
        print("[");
        for(i = 0; i < 9; i = i + 1) {
                for (j = 0; j < 9; j = j + 1) {
                        if(i == j) {
                                mat[i, j] = 1;
                                print_int(mat[i,j]);
             }
             else {
                mat[i, j] = 0;
                print_int(mat[i,j]);
                 }
        }
}
print("]");
return 0;
}


// Identity 10x10
int id10() {
        int i;
        int j;


        int [10, 10] mat;
        print("[");
        for(i = 0; i < 10; i = i + 1) {
                for (j = 0; j < 10; j = j + 1) {
                        if(i == j) {
                                mat[i, j] = 1;
                                print_int(mat[i,j]);
                     }
                     else {
                        mat[i, j] = 0;
                        print_int(mat[i,j]);
                         }
        }
}
print("]");
return 0;
}


// Print Vector Size 2
void print_vec2(int[2] a) {
        int i;
        int c;
        int counter;


        c = 2;
        counter = 0;

        print("[");
        while(c > 0) {
                if(counter == 0) {
                        print_int(a[counter]);
                        counter = counter + 1;
                c = c - 1;
            }
            else {
                print(",");
                print_int(a[counter]);
                counter = counter + 1;
                c = c - 1;
            }
        }
        print("]");
}


void print_vec3(int[3] a) {
        int i;
        int c;
        int counter;


        c = 3;
        counter = 0;

        print("[");
        while(c > 0) {
            if(counter == 0) {
                print_int(a[counter]);
                counter = counter + 1;
                c = c - 1;
            }
            else {
                print(",");
                print_int(a[counter]);
                counter = counter + 1;
                c = c - 1;
            }
        }
        print("]");
}


void print_vec4(int[4] a) {
        int i;
        int c;
        int counter;


        c = 4;
        counter = 0;

        print("[");
        while(c > 0) {
            if(counter == 0) {
                print_int(a[counter]);
                counter = counter + 1;
                c = c - 1;
            }
            else {
                print(",");
                print_int(a[counter]);
                counter = counter + 1;
                c = c - 1;
            }
        }
        print("]");
```

```
}


void print_vec5(int[5] a) {
        int i;
        int c;
        int counter;


        c = 5;
        counter = 0;

        print("[");
        while(c > 0) {
                if(counter == 0) {
                        print_int(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
                else {
                        print(",");
                        print_int(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
        }
        print("]");
}


void print_vec6(int[6] a) {
        int i;
        int c;
        int counter;


        c = 6;
        counter = 0;

        print("[");
        while(c > 0) {
                if(counter == 0) {
                        print_int(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
                else {
                        print(",");
                        print_int(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
        }
        print("]");
}


void print_vec7(int[7] a) {
        int i;
        int c;
        int counter;


        c = 7;
        counter = 0;
        print("[");
        while(c > 0) {
                if(counter == 0) {
                        print_int(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
                else {
                        print(",");
                        print_int(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
        }
        print("]");
}


void print_vecf2(float[2] a) {
        int i;
        int c;
        int counter;


        c = 2;
        counter = 0;

        print("[");
        while(c > 0) {
                if(counter == 0) {
                        print_float(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
                else {
                        print(",");
                        print_float(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
        }
        print("]");
}


void print_vecf3(float[3] a) {
        int i;
        int c;
        int counter;


        c = 3;
        counter = 0;

        print("[");
        while(c > 0) {
                if(counter == 0) {
                        print_float(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
                else {
                        print(",");
                        print_float(a[counter]);
                counter = counter + 1;

                c = c - 1;

            }

        }

        print("]");

    }



    void print_vecf4(float[4] a) {

        int i;

        int c;

        int counter;



        c = 4;

        counter = 0;


        print("[");

        while(c > 0) {

            if(counter == 0) {

                print_float(a[counter]);

                counter = counter + 1;

                c = c - 1;

            }

            else {

                print(",");

                print_float(a[counter]);

                counter = counter + 1;

                c = c - 1;

            }

        }

        print("]");
```

```
}


void print_vecf5(float[5] a) {
        int i;
        int c;
        int counter;


        c = 5;
        counter = 0;

        print("[");
        while(c > 0) {
                if(counter == 0) {
                        print_float(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
                else {
                        print(",");
                        print_float(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
        }
        print("]");
}


void print_vecf6(float[6] a) {
        int i;
        int c;
        int counter;


        c = 6;
        counter = 0;

        print("[");
        while(c > 0) {
                if(counter == 0) {
                        print_float(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
                else {
                        print(",");
                        print_float(a[counter]);
                        counter = counter + 1;
                        c = c - 1;
                }
        }
        print("]");
}


// Print Vector Size 7 float
void print_vecf7(float[7] a) {
        int i;
        int c;
        int counter;


        c = 7;
        counter = 0;
        print("[");

        while(c > 0) {

                if(counter == 0) {

                        print_float(a[counter]);

                        counter = counter + 1;

                        c = c - 1;

                }

                else {

                        print(",");

                        print_float(a[counter]);

                        counter = counter + 1;

                        c = c - 1;

                }

        }

        print("]");

}


void print3d(int[2,2,2] c) {

int i;

int j;

int k;

   for(i = 0; i < 2; i++) {

       print("[");

       for(j = 0; j < 2; j++) {

           print("[");

           for(k = 0; k < 2; k++) {

               if(k != 1) {

                   print_int(c[i,j,k]);

                   print(",");

               } else {
                   print_int(c[i,j,k]);
               }
           }
           if(j != 1) {
               print("], ");
           } else {
               print("]");
           }
       }
       print("]\n");
   }
}
```