

Extend Language Final Report

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1. Introduction

Extend is a declarative programming language meant to support spreadsheet-like functionality. It contains features such as side-effect-free values, immutability, and automatic formula adjustments relative to rows and columns. Extend is compiled to the LLVM (Low Level Virtual Machine) intermediate representation, which in turn is reduced to machine assembly. Extend takes inspiration from software such as Microsoft Excel, which allows users to link several formulae on dependent groups of data together, but takes this technology a step further by allowing users to encapsulate such calculations as functions.

1.1 Inspiration & Use Cases

Inspiration

The design goal of our language was to be "a spreadsheet you can compile". Extend was conceptualized to address the limitations that prevented the spreadsheet environment from evolving into a compiled, flexible programming language. To create this, there were three main things that needed to be changed about the way interactive spreadsheets work:

- The language needs reusable functions as opposed to having to copy & paste a block of cells.
- Cell ranges need to be created with dynamic runtime-determined dimensions.
- Cells need to be able to contain composite values in addition to single numbers or strings.

With these changes in mind, we attempted to keep the semantics as similar as possible to traditional spreadsheet programs; this meant implementing a dynamically typed language that is tolerant of potential errors in its input data. Extend degrades gracefully in the presence of potential data errors.

Spreadsheet applications cannot be 'run' on different sets of input data. Extend was conceptualized as a language to create standalone executables that can be repeatedly run on multiple files, thereby removing the need to manually enter inputs. In building this language, our mission was to bring the best of spreadsheets and computation into one product.

Complex Calculations Across Many Inputs

Extend is spiritually closer in behavior to Microsoft Excel than traditional imperative programming languages. The order of computation is determined implicitly by the language rather than explicitly by the developer. In addition, in one line of code, a single formula can be assigned to all the cells in a variable. The feature acts similarly to Python's list comprehension, or OCaml's `List.map` functionality.

Flexibility

Extend allows the dimensions of ranges to be determined dynamically at runtime, and handles most type errors by degrading gracefully instead of crashing the program. The standard library that Extend delivers

includes a subset of the functions that are built into conventional spreadsheet applications. As many of these as possible were implemented in Extend itself.

2. Language Usage Tutorial

This will cover the configuration of the user's environment and the usage of Extend's features.

2.1 Setup

The Extend compiler requires that the OCaml Language and LLVM be installed on the host machine. Development was done in a virtual machine running the 64-bit Ubuntu operating system. In order to quickly get Extend up and running, please use [this virtual machine](#), which has been provided as part of the course.

After booting up the virtual machine, clone the Extend git repository:

```
1 git clone https://github.com/ExtendLang/Extend.git
```

2.2 Compiling and Running Extend Code

To build the Extend compiler, the first steps are the following.

```
1 cd Extend/  
2 make
```

If this does not successfully build, run `eval 'opam config env'`, which should configure the environment to use OPAM packages. Alternatively, add this command to your bash profile.

After running `make`, you should see a `main.byte` file. To compile and run an Extend program, we have provided a shell script to simplify the process for the user:

```
1 ./compile.sh samples/helloworld.xtnd
```

This should produce an `out` file. Running `./out` should successfully execute the program.

2.3 Illustrating the Benefits of Extend

Spreadsheet applications require the use of manual input in order to apply the same calculation to a different set of data. Extend aims to tackle this problem by offering portability. Below is an example of a spreadsheet user calculating the unit vector of a column vector:

	A	B	C	D	E
1	1	1			0.050965
2	2	4			0.101929
3	3	9			0.152894
4	4	16			0.203859
5	5	25			0.254824
6	6	36			0.305788
7	7	49			0.356753
8	8	64			0.407718
9	9	81			0.458682
10	10	100			0.509647
11	=A!*A!		385	19.62142	=A!/\$D\$11
12			=SUM(B1:B10)	=C11^0.5	

The Excel user must manually input the data, and additionally make space for the intermediate steps of the calculation. If the number of elements of the vector were changed, the formulas would need to be changed in the spreadsheet; similarly, if you needed to do this on a second vector, you would have to copy and paste the cells doing intermediate calculations. Below is the equivalent function in Extend, written to work on any column vector that is passed in:

```

1  normalize_column_vector([m,1] arg) {
2      [m,1] squared_lengths := #arg * #arg, normalized := #arg / vector_norm;
3      vector_norm := sqrt(sum(squared_lengths));
4      return normalized;
5  }
```

Another simple example is concatenating a row of strings of variable length with a common delimiter. This in an entirely manual operation for the spreadsheet user; a step-by-step attempt is shown below.

	A	B	C	D	E	F
1	hello	world	hello again	,	<- comma, space	
2						
3	hello,	<- This fails.				
4	=CONCATENATE(A1:C1, D1)					
5						
6	hello	hello, world	hello, world, hello again			
7	=A1	=CONCATENATE(A1,D1,B1)	=CONCATENATE(B6,D1,C1)			

Performing a delimiter 'join' like the above can be performed in a simple program in Extend without knowing the size of the row. The following function, which is included in the Extend standard library, performs this on arguments of any size and can be reused throughout the program.

```

1  main(args) {
2      bar := {"Hello", "Goodbye", "Hello Again"};
3      str := ", ";
4      return print_endline(concatRow(bar, str));\\ prints "Hello, Goodbye, Hello Again"
5  }
6
7  concatRow([1,n] cells, joiner) {
8      [1,n] accum;
9      accum[0,0] = #cells;
10     accum[0,1:] = accum[[-1]] + joiner + #cells;
11     return accum[-1];
12 }
```

As evidenced above by simple examples, Extend offers flexibility that is significantly harder to achieve with conventional spreadsheet applications. As the nature of the data grows in complexity and variety, Extend's value increases.

2.4 Writing Extend Code - The Basics

As is tradition, here is "Hello World" in Extend. The following program, `helloworld.xtnd`, illustrates a basic usage of the Extend language.

```
1  main(args) {
2      foo := printv(1, "Hello World\n") -> 0;
3      return foo;
4  }
```

Below is a short tour of the features of Extend. More detail can be found in the next chapter - the Language Reference Manual.

Adjusting to Extend's Declarative Nature

The biggest difference between Extend and most traditional programming languages is that the concept of an imperative statement does not exist. An Extend function consists solely of variable declarations, formula assignments, and a return expression. When a function is called, its **return** expression is evaluated, along with the values of any variables that the return expression depends on. In a traditional imperative language, the order of operations is determined explicitly by the developer; in Extend, the order is determined implicitly by the desired result.

The following file compiles and prints successfully.

```
1  main(args) {
2      foo := "Hello World!";    // Combined var declaration and formula assignment
3      return print_endline(foo); // Return expression is a call to print_endline().
4  }
```

However, the file below is not a legal Extend program:

```
1  main(args) {
2      foo := "Hello World!"; // OK
3      print_endline(foo);    // Not OK
4      return foo;
5  }
```

As illustrated, Extend only evaluates what is needed to produce the value required by **return**. Any non-essential declarations or formula assignments will not be evaluated by the program.

Functions

An Extend program is mostly composed of functions. They are declared with the syntax `function_name([optional_dimensions] function_arguments){...}`. Below is the syntax of the **main** function, which is needed to run Extend code, within a simple Extend program.

```
1  main(args) {
2      return 0;
3  }
```

The return type of a function is a value that can be of any type or dimensions. **Ranges** will be discussed in a later section of this chapter. A function is composed of variable declarations and formula assignments and concludes with the **return** statement. Note that the **return** statement is always the last statement in the function.

Function Parameters

Function parameters consist of zero or more ranges, signed with an optional dimension. If the arguments have been written with dimensions, those dimensions will be verified at runtime. this can either be used to initialize a variable with the dimensions of the argument, or verify that the dimensions are what the function expects.

```
1     foo([m,n] arg){
2         return m * n; \\ m and n initialized through arg
3     }
4
5     bar([1,1] arg){
6         return 0; \\ 1 by 1 ranges should be primitive data types. If arg is not a
           primitive, a runtime error will be thrown
7     }
```

Data Types

Extend has three primitive data types: Numbers, Strings, and `empty`; and one composite type, `Range`. An example of each is shown below.

```
1     myNumber    := 5;
2     myString    := "Hello World";
3     myEmpty     := empty;
4     my2x3Range  := {3, 4, "five"; "a", "b", "c"};
```

Variables

In Extend, **variables** are composed of cells to which formulas are assigned. The first time (and only the first time!) an individual cell is referenced by an expression, its value is calculated according to its assigned formula. A cell's value is not calculated if the cell is never referred to, and is never recalculated; all cell values are immutable. A cell's value can be any of Extend's types, and different cells of a single variable can have different types.

```
1     [1,2] foo; // Declares a variable with 1 row and 2 columns (2 cells total)
2     [1,3] bar := 4; // Declares a variable with 1 row and 3 columns and
3                   // assigns the literal value 4 as the formula for each cell
4     [1,2] baz;           // Declares a 1x2 variable baz
5     baz[0,0] = "first";   // Assigns literal "first" as the formula for the
6     baz[0,1] = 1 + 1;     // 1st cell and the expression 1+1 for the 2nd cell
7     life := 6, universe := 7; // Declares 1x1 variables life and universe
8     answer := life * universe; // Declares a 1x1 variable the_answer and assigns
9                                // the formula life * universe to its sole cell
10    [1,10] half_and_half; // Declares a 1x10 variable half_and_half
11    half_and_half[0,0:5] = "milk"; // Assigns "milk" to the first five cells
12    half_and_half[0,5:10] = "cream"; // and "cream" to the second five cells
```

Note that we declare a variable and assign a formula to all of its cells in a single line with `:=`. If the variable has already been declared, a formula must be assigned using `=` instead of `:=`. As illustrated in this example, a single formula can be assigned to multiple cells of a variable with the slice syntax. The converse is not true: multiple formulas applying to a single cell will cause a runtime error. The contents of the slice, as well as the dimensions of the variable, can be any expression that evaluates to a number, not just a literal number. For example, this code snippet assigns the dimensions based on the `howBig()` function and the "left" and "right" formulas based on the `breakpoint()` function:

```

1     breakpoint() {
2         return 7;
3     }
4     howBig() {
5         return 11;
6     }
7     foo_func() {
8         [1,howBig()] foo;
9         foo[0, :breakpoint()] = "left";
10        foo[0, breakpoint():-1] = "right";
11        foo[0, -1] = "last";
12        return foo;
13    }

```

This example also illustrates that the start (or end) index of a slice can be omitted if the developer wants the formula to apply from the beginning (or to the end) of the dimension, and that negative numbers can be used in a slice to count backwards from the end. As with all values in Extend, the dimensions of a variable, and the slices to which a formula applies, are immutable. The first time a variable is referred to (directly or indirectly) by the return expression, its dimensions and the formula assignment slices are computed; from that point on, they never change. In the example above, the `howBig()` function is invoked once, but the `breakpoint()` function is actually called twice: once for the "left" formula, and once for the "right" formula.

Variables vs. Ranges

A variable is not a data type; it is a collection of one or more cells with assigned formulas. A range is a value, which is internally implemented as a pointer to a subset of a variable's cells. A range is always composed of more than one value; a variable may have a single cell. The variable "backing" a range may not have been explicitly defined by the developer; for example, range literals are implemented using an anonymous variable.

Range Slicing & Selection

Python-style array-slicing syntax can be applied to ranges, which will return a subrange based on either absolute or relative indexing. All indices are zero-based.

```

1     foo[0,2] \\ The cell in the first row, third column
2     foo[0,:] \\ The range of cells in the first row
3     foo[0,[1]] \\ The range in the column that is 1 column right of the left-hand-
                side cell.
4     foo[,] \\ Cell in first row, first column if 1 by 1. If not, then relative first
                row and relative first column

```

More examples and detail can be found in the next chapter.

The Hash Operator

A common case for ranges in Excel is to perform calculations on specific cells. For example, `foo[,]` is commonly used to retrieve the cell that is being calculated on. Since this is a popular use case, the `#` operator will perform the same functionality.

Application on Ranges

Extend, in the vein of spreadsheets, allows the programmer to apply functions cell-wise on a range. Using the `#` operator, we can perform cell-wise multiplication across two ranges.

```

1     foo([m,n] arg1, [m,n] arg2){
2         [m,n] bar := #arg1 * #arg2; \\ Multiplies the cell in arg1 with the
           corresponding cell in arg2.
3         return bar;
4     }

```

This is an incredibly powerful aspect of Extend. Make sure to study it well!

Range Attribute Functions

Extend has the `row()` and `column()` functions, which respectively return the row and column of the cell that is being calculated at that point in time. There is also a `size(expr)` function, which returns a 1 by 2 range; the first cell contains the number of rows, and the second cell contains the number of columns.

Cell Evaluation, Side Effects, and Precedence Expressions

As mentioned before, a cell's value is calculated at most once. It is evaluated when it is the only cell selected from a variable, or when a selection containing the cell is assigned as a range to another cell. In general, the language is designed so you don't have to think about this! However, in the case of formulas that call functions with side effects, it's important to understand the behavior. When necessary, a precedence expression (using the `->` operator) can be used to force the evaluation of one expression before another. A precedence expression calculates the first expression, discards the result, and evaluates to the second expression. The following example should help clarify how cell evaluation is performed:

```

1     main(args) {
2         foo := print_endline("Once") -> 2;
3         bar := foo + foo;
4         return print_endline(bar);
5     }

```

This program prints "Once" and then prints 4. Before calling `print_endline`, Extend calculates the value of `bar`, which in turn requires the value of `foo` (twice). The first time `foo`'s value is calculated, `print_endline()` is called with the argument "Once", and then `foo` evaluates to the constant 2. The second time that `foo`'s value is required to calculate `bar`, it's already available: it is 2. Therefore, `print_endline("Once")` is not called a second time.

Operators

Extend includes a comprehensive set of operators. Each category is listed in order of precedence. A more detailed explanation of each operator can be found in the Language Reference Manual.

Arithmetic Operators

- Unary Operations: `-`
- Binary Operations: `**`, `*`, `/`, `%`, `+`, `-`

Bitwise Operators

- Unary Operations: `~`
- Binary Operations: `«`, `»`, `&`, `|`, `^`

Boolean Operators

- Unary Operations: `!`
- Binary Operations: `==`, `!=`, `<`, `>`, `<=`, `>=`, `&&`, `||`

String Concatenation

Note that the `+` symbol can be used to perform concatenation between two strings.

```
1 "Hello " + "World\n"
```

The size and typeof operators

Extend offers a `typeof(expr)` operator, which takes an expression and returns Number, String, Range, or Empty (as a string). It also has the `size(expr)` operator, which returns the dimensions of its argument as a 1 x 2 range.

Conditionals

There are two types of conditional expressions: the if-then-else (ternary) conditional and a `switch` expression.

If-Then-Else

The two equivalent ways to write the ternary expression are as follows:

C/Java style: `condition ? expr_if_true : expr_if_false`

Spreadsheet style: `if(condition, expr_if_true, expr_if_false)`

The Switch Expression

Below is an example of the switch expression used in a function:

```
1 odd_or_even(foo) {  
2   return switch(foo \% 2) {  
3     case 0: "Even";  
4     case 1: "Odd";  
5     default: "Not an integer";  
6   };  
7 }
```

In the example above, the `switch` expression used `foo % 2` as an argument; however, this is not required, so a switch expression can be used (as in Go) as a replacement for a sequence of if-then-else conditionals.

Import Statements

In Extend, you can import other Extend files at the top of your program via relative directory path. The use case is below:

```
1 import "../programs/stat_library.xtnd"
```

2.5 Standard Library Functions

Extend offers an assortment of standard library functions. Extend imports `stdlib.xtnd`, which has aggregated all the standard library functions for the user's disposal.

While their usage will be covered in more length in the Language Reference Manual, here are some of the more useful standard library functions to remember.

Basic Functions

The `toString()` Function

The `toString()` function takes an argument and renders its value as a string.

```
1 return "Hello " + toString(14); \\ "Hello 14"
```

The Print Function

As used throughout this tutorial, the `print_endline` function is used to print an expression with a newline.

Math Functions

Borrowing from C's standard library math functions, Extend offers: `sin`, `cos`, `tan`, `acos`, `asin`, `atan`, `sinh`, `cosh`, `tanh`, `exp`, `log`, `log10`, `sqrt`, `ceil`, `fabs` and `floor`.

```
1 main(args){
2     bar := sqrt(16);
3     return print_endline(bar) -> 0; \\ Prints 4 to stdout
4 }
```

File I/O

Extend has `open`, `close`, `read`, and `write` functions to interact with files. Usage is as follows:

```
1 main(args){
2     return write(STDOUT, read(open("test_file.txt", "r"),5)) -> 0; \\ Writes 5
3     characters from test_file.txt to stdout
4 }
```

Additional Standard Library Functions

Flatten

The `flatten` function turns a rectangular range into a long row vector.

```
1 flatten({1,2,3; 4,5,6}) // yields {1,2,3,4,5,6}
```

Match

The `match` function takes a row or column vector and a value, and locates the index of that value, if applicable

Binary Search

The `bsearch` function will search a sorted column vector for a value.

Statistics Functions

Extend additionally offers basic statistical functions such as `sum`, `max`, `avg`, and `stddev`.

Matrix Multiplication

The `mmult` function multiplies two compatible rectangular ranges together in matrix-fashion.

Concatenation

The `concatRow` function takes a column vector and a delimiter and returns a string of each element in the vector joined by the delimiter.

Repeat

The `repeat` function takes a string and number `x`, and returns a string where the argument string is repeated `x` times.

```
1 repeat("Hello", 3) \\ "HelloHelloHello"
```

Split & Split to Range

The `split` function takes a string and a splitter and returns a vector of the delimited characters. Expanding on this, the `splittoRange` function takes a string, row splitter, and column splitter and returns a rectangular range with the characters delimited by the splitters.

Parsing Strings

The `parseString` function leverages the above two functions to create an actual range with the characters parsed as numeric values.

Reverse

Reverse takes a string and reverses it.

Trim Functions

The `trim` function removes preceding and following whitespace from a string and returns the new string. Similarly, the `ltrim` function removes preceding whitespace, and `rtrim` the following whitespace.

Plotting Bar Charts

Providing a file handle, a row vector, and an equivalently sized vector of labels to `bar_chart` will allow the user to write a bar graph in GIF form to the file descriptor.

3. Language Reference Manual

3.1 Introduction to Extend

Extend is a domain-specific programming language used to designate ranges of cells as reusable functions. It is a dynamically-typed, statically-scoped, declarative language that uses lazy evaluation to carry out computations. Once computed, all values are immutable. In order to offer the best performance, Extend compiles down to LLVM.

Extend's syntax is meant to provide clear punctuation and easily understandable cell range access specifications, while borrowing elements from languages with C-style syntax for ease of development. Despite these syntactic similarities, the semantics of an Extend program have more in common with a spreadsheet such as Microsoft Excel than imperative languages such as C, Java or Python.

3.2 Structure of an Extend Program

An Extend program consists of one or more source files. A source file can contain any number of import directives, function definitions, global variable declarations, and external library declarations, in any order.

Import Statements

Import statements in Extend are written with `import`, followed by the name of a file in double quotes, and terminated with a semicolon. The syntax is as follows:

```
1 import "string.xtnd";
```

Extend imports act like `#include` in C, except that multiple imports of the same file are ignored. The imports are all aggregated into a single namespace.

Function Definitions

Function definitions comprise the bulk of an Extend program. In short, a function consists of a set of variable declarations, formula assignments, and a return expression. Each variable consists of cells; the values of each cell are, if necessary, calculated according to formulas which each apply to a specified subset of the cells. Each cell value, once calculated, is immutable. A couple examples follow for context; functions are described in detail in section 3.5.

```
1 isNumber(x) {
2     return typeof(x) == "Number";
3 }
4
5 sum_column([m,1] rng) {
6     /* Returns the sum of the values in the column, skipping any values that are non-
7        numeric */
7     [m,1] running_sum;
8     running_sum[0,0] = #rng;
```



```

9   running_sum[1:,0] = running_sum[[-1],] + (isNumber(#rng) ? #rng : 0);
10  return running_sum[-1];
11 }

```

Global Variables

In essence, global variable declarations function as constants in Extend. They are written with the keyword **global**, followed by a variable declaration in the combined variable declaration and assignment format described in section 3.5. As with local variables, the cell values of a global variable, once computed, are immutable. A few examples follow:

```

1  global pi := 3.14159265359;
2  global num_points := 24;
3  global [num_points,1]
4    circle_x_vals := cos(2 * pi * row() / num_points),
5    circle_y_vals := sin(2 * pi * row() / num_points);

```

External Library Declarations

An external library is declared with the **extern** keyword, followed by the name of an object file in double quotes, followed by a semicolon-delimited list of external function declarations enclosed by curly braces. A library declaration informs the compiler of the functions' names and signatures and instructs the compiler to link the object file when producing an executable. An external function declared as **foo** will call an appropriately written C function **extend_foo**. An example follows:

```

1  extern "mylib.o" {
2    foo(arg1, arg2);
3    bar();
4  }

```

This declaration would cause the compiler to link **mylib.o** and would make the C functions **extend_foo** and **extend_bar** available to Extend programs as **foo** and **bar** respectively. The required signature and format of the external functions is specified precisely in section 3.5.

main function

When a compiled Extend program is executed, the **main** function is evaluated. All computations necessary to calculate the return value of the function are performed, after which the program terminates. The **main** function must be a function of a single argument, conventionally denoted **args**, which is guaranteed to be a 1-by-n range containing the command line arguments.

Scoping and Namespace

For functions and for global variables, there is a single namespace that is shared between all files composing an Extend program, and they are visible throughout the entire program. Functions declared in external libraries share this namespace as well. For a local variable, the scope is the entire body of the function in which it is defined. Functions may declare local variables sharing a name with a global variable; inside that function, the name will refer to the local variable.

```

1  global x := "I'm a global";
2
3  foo() {
4    y := x; // Scope of x is entire function
5    x := "In here I'm a local";
6    return y; // Returns "In here I'm a local"

```

```

7 }
8
9 bar(x) {
10     return x; // Parameters mask globals; returns argument
11 }
12
13 baz() {
14     return x; // Returns "I'm a global"
15 }

```

3.3 Types and Literals

Extend has three primitive data types, **Number**, **String**, and **Empty**, and one composite type, **Range**.

Primitive Data Types

A **Number** is an immutable primitive value corresponding to a double-precision 64-bit binary format IEEE 754 value. Numbers can be written in an Extend source file as either integer or floating point constants; both are represented internally as floating-point values. There is no separate type representing an integer.

A **String** is an immutable primitive value that is internally represented as a C-style null-terminated byte array corresponding to ASCII values. A String can be written in an Extend source file as a sequence of characters enclosed in double quotes, with the usual escaping conventions. Extend does not allow for slicing of strings to access specific characters; access to the contents of a string will only be available through standard library functions.

The **Empty** type can be written as the keyword **empty**, and serves a similar function to NULL in SQL; it represents the absence of a value.

Primitive Data Types	Examples
Number	42 or -5 or 2.71828 or 314159e-5
String	"Hello, World!\n" or "foo" or ""
Empty	empty

Ranges

Extend has one composite type, **Range**. A range borrows conceptually from spreadsheets; it is a group of cells with two dimensions, described as rows and columns. Each cell is assigned a formula that either evaluates to a Number, a String, **empty**, or another Range. Cell formulas are described in detail in section 3.5. A range can either be declared as described in section 3.5 or with a range literal expression. Ranges can be nested arbitrarily deeply and can be used to represent (immutable) lists, matrices, or more complicated data structures.

Range Literals

A range literal is a semicolon-delimited list of rows, enclosed in curly brackets. Each row is a comma-delimited list of numbers, strings, or range literals. A few examples follow:

```

1 legal_ranges() {
2     r1 := {"Don't"; "Panic"}; // two rows, one column
3     r2 := {"Don't", "Think", "Twice"}; // one row, three columns
4     r3 := {1,2,3;4,5,6;7,8,9}; // three rows, three columns
5     r4 := {"Hello";0,1,2,3,4}; // two rows, five columns

```

```

6   r5 := {{{{{1}}}}}; // one row, one column
7   r7 := {-1.5,-2.5,{-2,"nested"},-3.5}; // one row, four columns
8   return
9       print_endline(r1) ->print_endline(r2) ->print_endline(r3) ->
10      print_endline(r4) -> print_endline(r5) -> print_endline(r7);
11 }
12
13 main(args) {
14     return legal_ranges();
15 }

```

3.4 Expressions

Expressions in Extend allow for arithmetic and boolean operations, function calls, conditional branching, extraction of contents of other variables, string concatenation, and determination of the location of the cell containing the expression. The sections for boolean and conditional operators refer to *truthy* and *falsey* values: the **Number** 0 is the only falsey value; all other values are *truthy*. As **empty** represents the absence of a value, it is neither *truthy* nor *falsey*.

Arithmetic Operators

The arithmetic operators listed below take one or two expressions and return a number, if both expressions are Numbers, or **empty** otherwise. Operators grouped within the same inner box have the same level of precedence, and are listed from highest precedence to lowest precedence. All of the binary operators are infix operators, and, with the exception of exponentiation, are left-associative. Exponentiation, bitwise negation, and unary negation are right-associative. All of the unary operators are prefix operators. The bitwise operators round their operands to the nearest signed 32-bit integer (rounding half to even) before performing the operation and evaluate to a Number.

Operator	Description	Definition
<code>~</code>	Bitwise NOT	Performs a bitwise negation on the binary representation of an expression.
<code>-</code>	Unary negation	A simple negative sign to negate expressions.
<code>**</code>	Power	Returns the first expression raised to the power of the second expression
<code>*</code>	Multiplication	Multiplies two expressions
<code>/</code>	Division	Divides first expression by second.
<code>%</code>	Modulo	Finds the remainder by dividing the expression on the left side of the modulo by the right side expression.
<code><<</code>	Left Shift	Performs a bitwise left shift on the binary representation of an expression.
<code>>></code>	Right Shift	Performs a sign-propagating bitwise right shift on the binary representation of an expression.
<code>&</code>	Bitwise AND	Performs a bitwise AND between two expressions.
<code>+</code>	Addition	Adds two expressions together.
<code>-</code>	Subtraction	Subtracts second expression from first.
<code> </code>	Bitwise OR	Performs a bitwise OR between two expressions.
<code>^</code>	Bitwise XOR	Performs a bitwise exclusive OR between two expressions.

```
1 easy() {
2   return 3 - -3 ** 2 %5; //-1
3 }
4 g_eazy() {
5   return (((1 << 2 | 1) << 2) | 1) << 1; //42
6 }
```

Boolean Operators

These operators take one or two expressions and evaluate to **empty**, 0 or 1. Operators grouped within the same inner box have the same level of precedence and are listed from highest precedence to lowest precedence. All of these operators besides logical negation are infix, left-associative operators. The logical AND and OR operators feature short-circuit evaluation. Logical NOT is a prefix, right-associative operator. Besides logical NOT, all boolean operators have lower precedence than all arithmetic operators. For Strings, the boolean operators `<`, `<=`, `>`, and `>=` implement case-sensitive lexicographic comparison.

Operator	Description	Definition
!	Logical NOT	Evaluates to 0 or 1 given a truthy or falsey value respectively. <code>!empty</code> evaluates to <code>empty</code> . It has equal precedence with <code>and</code> and unary minus.
==	Equals	Always evaluates to 0 if the two expressions have different types. If both expressions are primitive values, evaluates to 1 if they have the same type and the same value, or 0 otherwise. If both expressions are ranges, evaluates to 1 if the two ranges have the same dimensions and each cell of the first expression == the corresponding cell of the second expression. <code>empty == empty</code> evaluates to 1. Strings are compared by value.
!=	Not equals	<code>x != y</code> is equivalent to <code>!(x == y)</code> .
<	Less than	If the expressions are both Numbers or both Strings and the first expression is less than the second, evaluates to 1. If the expressions are both Numbers or both Strings and the first expression is greater than or equal to the second, evaluates to 0. Otherwise, evaluates to <code>empty</code> .
>	Greater than	Equivalent rules about typing as for <.
<=	Less than or equal to	Equivalent rules about typing as for <.
>=	Greater than or equal to	Equivalent rules about typing as for <.
&&	Short-circuit Logical AND	If the first expression is falsey or <code>empty</code> , evaluates to 0 or <code>empty</code> respectively. Otherwise, if the second expression is truthy, falsey, or <code>empty</code> , evaluates to 1, 0, or <code>empty</code> respectively.
	Short-circuit Logical OR	If the first expression is truthy or <code>empty</code> , evaluates to 1 or <code>empty</code> respectively. Otherwise, if the second expression is truthy, falsey, or <code>empty</code> , evaluates to 1, 0, or <code>empty</code> respectively.

```

1 somethings_false() {
2   return !1 != !1 || 4 <= 3;
3 }
4 somethings_empty() {
5   return empty || empty <= !3 || 5 > 3;
6 }
7 somethings_true() {
8   return 6 > 2 && !(1 == !1);
9 }

```

Conditional Expressions

There are two types of conditional expressions: a simple ternary if-then-else expression and a **switch** expression which can represent more complex logic.

Ternary Expressions

A ternary expression, written either as `cond-expr ? expr-if-true : expr-if-false` or, equivalently, `if(cond-expr, expr-if-true, expr-if-false)` evaluates to `expr-if-true` if `cond-expr` is truthy, or `expr-if-false` if `cond-expr` is falsey. If `cond-expr` is empty, the expression evaluates to `empty`. Both `expr-if-true` and `expr-if-false` are mandatory. `expr-if-true` is only evaluated if `cond-expr` is truthy, and `expr-if-false` is only evaluated if `cond-expr` is falsey. If `cond-expr` is empty, neither expression is evaluated. The ternary operator `? :` has the lowest precedence level of all operators.

Switch Expressions

A **switch** expression takes a optional condition, and a list of cases and expressions that the overall expression should evaluate to if the case applies. In the event that multiple cases are true, the expression of the first matching case encountered will be evaluated. An example is provided below:

```
1 switch_example(foo) {
2   return switch (foo) {
3     case 2: "foo is 2";
4     case 3,4: "foo is 3 or 4";
5     default: "none of the above";
6   };
7 }
8
9 alternate_format(foo) {
10  return switch {
11    case foo == 2:
12      "foo is 2";
13    case foo == 3, foo == 4:
14      "foo is 3 or 4";
15    default:
16      "none of the above";
17  };
18 }
```

The format for a **switch** statement is the keyword **switch**, optionally followed by pair of parentheses containing an expression **switch-expr**, followed by a list of case clauses enclosed in curly braces and delimited by semicolons. A case clause consists of the keyword **case** followed by a comma-separated list of expressions **case-expr1** [, **case-expr2**, [...]], a colon, and an expression **match-expr**, or the keyword **default**, a colon, and an expression **default-expr**. If **switch-expr** is omitted, the **switch** expression evaluates to the **match-expr** for the first case where one of the **case-exprs** is truthy, or **default-expr** if none of the **case-exprs** apply. If **switch-expr** is present, the **switch** expression evaluates to the **match-expr** for the first case where one of the **case-exprs** is equal (with equality defined as for the `==` operator) to **switch-expr**, or **default-expr** if none of the **case-exprs** apply.

The **switch** expression can be used to compactly represent what in most imperative languages would require a long string such as `if (cond1) {...} else if (cond2) {...}`. The **switch** operator is internally converted to an equivalent (possibly nested) ternary expression; as a result, it features short-circuit evaluation throughout.

Additional Operators

There are four additional operators available to determine the size and type of other expressions. In addition, the infix `+` operator is overloaded to perform string concatenation.

Operator	Description	Definition
<code>size(expr)</code>	Dimensions	Evaluates to a Range consisting of one row and two columns; the first cell contains the number of rows of <code>expr</code> and the second contains the number of columns. If <code>expr</code> is a Number, a String, or Empty, both cells will contain 1.
<code>typeof(expr)</code>	Value Type	Evaluates to "Number", "String", "Range", or "Empty".
<code>row()</code>	Row Location	No arguments; returns the row of the cell that is being calculated
<code>column()</code>	Column Location	No arguments; returns the column of the cell that is being calculated
<code>+</code>	String concatenation	"Hello, " + "World!\n" == "Hello, World!\n"

Given `[5,5]foo`, then `foo[1,4] = row() * 2 + col()` will evaluate to 6.

Function Calls

A function expression consists of an identifier and an optional list of expressions enclosed in parentheses and separated by commas. The value of the expression is the result of applying the function to the arguments passed in as expressions. The arguments are evaluated from left to right before the function is called. For more detail, see section 3.5.

Range Expressions

Range expressions are used to select part or all of a range. A range expression consists of a bare identifier, a bare range literal, or an expression and a selector. If a range expression has exactly 1 row and 1 column, the value of the expression is the value of the single cell of the range. If it has more than 1 row or more than 1 column, the value of the expression is the selected range. If the range has zero or fewer rows or zero or fewer columns, the value of the expression is `empty`. If a range expression with a selector would access a row index or column index greater than the number of rows or columns of the range, or a negative row or column index, the value of the expression is `empty`.

Slices

A slice consists of an optional integer literal or expression `start`, a colon, and an optional integer literal or expression `end`, or a single integer literal or expression `index`. If `start` is omitted, it defaults to 0. If `end` is omitted, it defaults to the length of the dimension. A single `index` with no colon is equivalent to `index:index+1`. Enclosing `start` or `end` in square brackets is equivalent to the expression `row() + start` or `row() + end`, for a row slice, or `column() + start` or `column() + end` for a column slice. The slice includes `start` and excludes `end`, so the length of a slice is `end - start`. A negative value is interpreted as the length of the dimension minus the value. As mentioned above, the value of a range that is not 1 by 1 is a range, but the value of a 1 by 1 range is essentially dereferenced to the result of the cell formula.

Selections

A selection expression consists of an expression and a pair of slices separated by a comma and enclosed in square brackets, i.e. `[row_slice, column_slice]`. If one of the dimensions of the range has length 1, the comma and the slice for that dimension can be omitted. If the comma is present but a slice is omitted, that slice defaults to `[0]` for a slice corresponding to a dimension of length greater than one, or `0` for a slice corresponding to a dimension of length one.

Corresponding Cell

A very common selection to make is the cell in the "corresponding location" of a different variable. Since this case is so common, `#var` is syntactic sugar for `var[,]`. As a result, if `var` has more than column and more than one row, `#var` is equivalent to `var[row()],column()]`. If `var` has multiple rows and one column, it is equivalent to `var[row(),0]`. If `var` has one row and multiple columns, it is equivalent to `var[0,column()]`; and if `var` has one row and one column, it is equal to `var[0,0]`.

Selection Examples

```
1 selection_examples() {
2   foo[0,2] /* This evaluates to the cell value in the first row and third column. */
3   foo[0,:] /* Evaluates to the range of cells in the first row of foo. */
4   foo[:,2] /* Evaluates to the range of cells in the third column of foo. */
5   foo[:,[1]] /* The internal brackets denote RELATIVE notation.
6   In this case, 1 column right of the column of the left-hand-side cell. */
7
8   foo[3,] /* Equivalent to foo[3,[0]] if foo has more than one column
9   or foo[3,0] if foo has one column */
10
11  foo[5:, 7:] /* All cells starting from the 6th row and 8th column to the bottom
12             right */
13  foo[[1]:[2], 0:[7]]
14  /* Selects the rows between the 1st and 2nd row after LHS row, and
15     all the columns up to the 7th column to the right of the LHS column */
16
17  /* In this example, each cell of bar would be equal to the cell
18     * in foo in the equivalent location plus 1. */
19  [5,5] foo;
20  [5,5] bar := #foo + 1; // #foo = foo[[0],[0]]
21
22  /* In this example, bar would be a 3x5 range where in each row,
23     * the value in bar is equal to the value in foo in the same column.
24     * In other words, each row of bar would be a copy of foo. */
25  [1,5] foo; // foo has 1 row, 5 columns
26  [3,5] bar := #foo; // #foo = foo[0,[0]]
27
28  /* In this example, the values of baz would be
29     * 11, 12, 13 in the first row;
30     * 21, 22, 23 in the second row;
31     * 31, 32, 33 in the third row. */
32  foo := {1,2,3}; // 1 row, 3 columns
33  bar := {10;20;30}; // 3 rows, 1 column
34  [3,3] baz := #foo + #bar; // Equivalent to foo[0,[0]] + bar[[0],0]
35 }
```


Precedence Expressions

A precedence expression is used to force the evaluation of one expression before another, when that order of operation is required for functions with side-effects. It consists of an expression `prec-expr`, the precedence operator `->`, and an expression `succ-expr`. The value of the expression is `succ-expr`, but the value of `prec-expr` will be calculated first and the result ignored. All functions written purely in Extend are free of side effects. However, some of the external functions provided by the standard library, such as for file I/O and plotting, do have side effects. The precedence operator has the second-lowest grammatical precedence of all operators, higher only than the ternary operator.

3.5 Functions

The bulk of an Extend program consists of functions. Although Extend has some features, such as immutability and lazy evaluation, that are inspired by functional languages, its functions are not *first class objects*. By default, the standard library is automatically compiled and linked with a program, but there are no functions built into the language itself.

Format

As in most programming languages, the header of the function declares the parameters it accepts. The body of the function consists of an optional set of variable declarations and formula assignments, which can occur in any order, and a return statement, which must be the last statement in the function body. All variable declarations and formula assignments, in addition to the return statement, must be terminated by a semicolon. This very simple function returns whatever value is passed into it:

```
1 foo(arg) {  
2     return arg;  
3 }
```

Variable Declarations

A variable declaration associates an identifier with a range of cells of the specified dimensions, which are listed in square brackets before the identifier. For convenience, if the square brackets and dimensions are omitted, the identifier will be associated with a single cell. In addition, multiple identifiers, separated by commas, can be listed after the dimensions; all of these identifiers will be separate ranges, but with equal dimension sizes. The dimensions can be specified as any valid expression that evaluates to a Number, which will be rounded to the nearest signed 32-bit integer. If either dimension is zero or negative, or if the expression does not evaluate to a Number, a runtime error causing the program to halt will occur.

```
1 [2, 5] foo; // Declares foo as a range with 2 rows and 5 columns  
2 [m, n] bar; // Declares bar as a range with m rows and n columns  
3 [3, 3] ham, eggs, spam; // Declares ham, eggs and spam as distinct 3x3 ranges  
4 baz; // Declares baz as a single cell
```

Formula Assignment

A formula assignment assigns an expression to a subset of the cells of a variable. Unlike most imperative languages, this expression is not immediately evaluated, but is instead only evaluated if and when it is needed to calculate the return value of the function. A formula assignment consists of an identifier, an optional pair of slices enclosed in square brackets specifying the subset of the cells that the assignment applies to, an `=`, and an expression, followed by a semicolon. As with the expressions specifying the dimensions of a range, these slices specifying the cell subset can contain arbitrary expressions, as long as the expression taken as a

whole evaluates to a Number, which will be rounded to the nearest signed 32-bit integer. Negative numbers are legal in these slices, and correspond to (dimension length + value).

```
1 [5, 2] foo, bar, baz; // Declares foo, bar, and baz as distinct 5x2 ranges
2 foo[0,0] = 42; // Assigns the expression 42 to the first cell of the first row of foo
3 foo[0,1] = foo[0,0] * 2; // Assigns (foo[0,0] * 2) to the 2nd cell of the 1st row of
   foo
4 bar = 3.14159; // Assigns pi to every cell of every row of bar
5 baz[1:-1,0:1] = 2.71828; // Assigns e to cells (1,0) through (3,1), inclusive, of baz
6
7 /* The next line assigns foo[[-1],0] + 2 to every cell in
8    both columns of foo, besides the first row */
9 foo[1:,: ] = foo[[-1],0] + 2;
```

The last line of the source snippet above demonstrates the idiomatic Extend way of simulating an imperative language's loop; `foo[4,0]` would evaluate to $42+2+2+2+2 = 50$ and `foo[4,1]` would evaluate to $(42*2)+2+2+2+2 = 92$.

Combined Variable Declaration and Formula Assignment

For convenience, a variable declaration and a formula assignment to all cells of that variable can be combined on a single line by inserting a `:=` and an expression after the identifier. Multiple variables and assignments, separated by commas, can be declared on a single line as well. All global variables must be defined using the combined declaration and formula assignment syntax.

```
1 /* Creates two 2x2 ranges; every cell of foo evaluates to 1 and every cell of
2    bar evaluates to 2. */
3 [2,2] foo := 1, bar := 2;
```

Formula Assignment Errors

If the developer writes code in such a way that more than one formula applies to a cell, a runtime error will occur if the cell's value is required to compute the return expression. If there is no formula assigned to a cell, the cell will evaluate to `empty`.

Parameter Declarations

Parameters can be declared with or without dimensions. If dimensions are declared, they can either be specified as integer literals or as identifiers. If a dimension is specified as an integer literal, the program will verify the dimension of the argument before beginning to evaluate the return expression; if it does not match, a runtime error will occur causing the program to halt. If it is specified as an identifier, that variable will contain the dimension size and will be available inside the function body. If the same identifier is repeated in the function declaration, the program will verify that every parameter dimension with that identifier has equal dimension size; if they differ, a runtime error will occur causing the program to halt. A few examples follow:

```
1 number_of_cells([m,n] arg) {
2   return m*n; // m and n are initialized with the dimensions of arg
3 }
4
5 die_unless_primitive([1,1] arg) {
6   return 0; // If arg is not a primitive value, a runtime error will occur
7 }
8
9 num_cells_if_column_vector([m,1] arg) {
10  // If arg has one column, return number of cells; otherwise runtime error
```

```

11     return m;
12 }
13
14 die_unless_square([m,m] arg) {
15     return 0; // Runtime error if number of rows != number of columns
16 }
17
18 num_cells_if_same_size([m,n] arg1, [m,n] arg2) {
19     // If arguments are the same size, return # of cells, otherwise runtime error
20     return m*n;
21 }
22
23 main(args) {
24     [3,4] foo;
25     [3,5] bar;
26     return print_endline(num_cells_if_same_size(foo,bar));
27 }

```

Application on Ranges

Extend gives the developer the power to easily apply operations in a functional style on ranges. For example, the following function performs cell wise addition:

```

1 foo([m,n] arg1, [m,n] arg2) {
2     [m,n] bar := #arg1 + #arg2;
3     return bar;
4 }

```

This function normalizes a column vector to have unit norm:

```

1 normalize_column_vector([m,1] arg) {
2     [m,1] squared_lengths := #arg * #arg, normalized := #arg / vector_norm;
3     vector_norm := sqrt(sum(squared_lengths));
4     return normalized;
5 }

```

Lazy Evaluation and Circular References

All cell values and variable dimensions are evaluated lazily if and when they are needed to calculate the return expression. Using lazy evaluation ensures that the cell values are calculated in a valid topological sort order and allows for detection of circular references; internally this is accomplished by constructing a function for each formula which is called the first time the cell's value is needed, and marking the cell as "in-progress" once it starts being evaluated and as "complete" once the value has been calculated. The only guarantees the language places on the order of cell evaluation are: (1) It will be a valid topological ordering; (2) In conditional expressions and in short-circuiting operator expressions, only the relevant conditional branches will be evaluated; and (3) In an expression using the precedence operator, the preceeding expression will be evaluated before the succeeding expression. A range selection consisting of multiple cells will not cause the constituent cells to be evaluated; however, selection of a single cell will cause that cell's value to be evaluated. If a program is written in such a way as to cause a circular dependency of one cell on another, and the return expression is dependent on that cell's value, a runtime error will occur. For example, in the following function:

```

1 maybeCircular(truth_value) {
2     x := x;
3     return truth_value ? x : 0;

```

```

4  }
5
6  main(args) {
7      foo :=
8          print_endline("To be or not to be?") ->
9          print_endline("Enter \"Not to be\" to attempt to evaluate a circular reference.")
10         ->
11         readline(STDIN);
12
13     return
14         maybeCircular(foo == "Not to be" || foo == "\"Not to be\"") ->
15         print_endline("Good thing I didn't look at the value of x.");
16 }

```

A runtime error will occur if `maybeCircular(1)` is called; but if `maybeCircular(0)` is called, the function will simply return 0.

External Libraries

Using the following library declaration:

```

1  extern "mylib.o" {
2      foo(arg1, arg2);
3      bar();
4  }

```

will make the functions `foo` (taking two arguments) and `bar` (taking zero arguments) available within `Extend`. In LLVM, the compiler will declare external functions `extend_foo` and `extend_bar` as functions of two and zero arguments respectively. All arguments must have the type `value_p`, and the function must have return type `value_p`, declared in the `Extend` standard library header file. In other words, the C file compiled to generate the library must have defined:

```

1  value_p extend_foo(value_p arg1, value_p arg2) {
2      /* function body here; */
3  }
4
5  value_p extend_bar() {
6      /* function body here; */
7  }

```

3.6 Standard Library Reference

3.7 Example Program

```

1  import "./samples/stdlib.xtnd";
2
3  main([1,n] args) {
4      /* Get a working copy */
5      return 0;
6  }

```

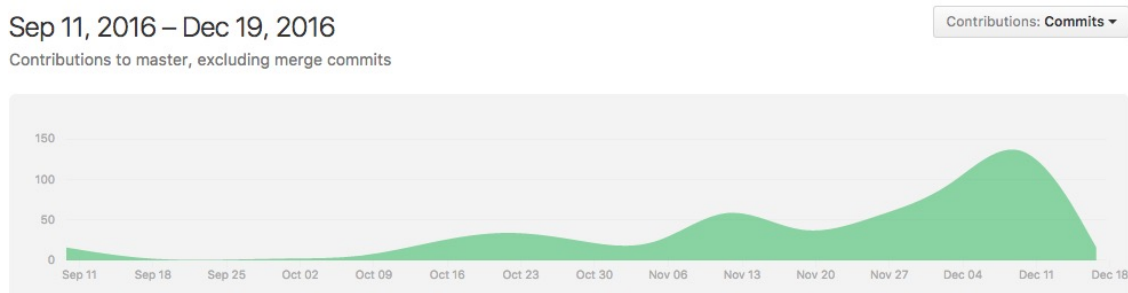
4. Project Plan

4.1 Meetings

Our goals were outlined by weekly meetings. We regularly met with Jacob Graff, our advisor throughout the development of Extend. Jacob served as a sounding board whenever Extend’s fundamental design philosophy was debated, and as a guide as we determined whether we were on track. We used any leftover time on those days to set goals for the upcoming week and pair program if time permitted.

Our team also met weekly on Fridays to further discuss the progression of Extend. In the first half of the semester, the discussions were primarily philosophical, as decisions had to be made about the language grammar and behavior of certain Extend artifacts prior to development. In the second half, time was devoted to ironing out the development timeline, discussing bugs, and making compiler implementation decisions.

4.2 Development Workflow



Github & Travis CI

Our development and documentation were all done entirely through version control to maximize independent productivity. New features were introduced to the master branch through pull requests, and the team used this as a platform to peer review code to maximize code quality before such features entered production.

An important aspect of development for us was continuous integration. Each pull request we made triggered a Travis build, which kept us informed regarding unexpected hiccups that sometimes arose during development. Travis CI ensured that new features were implemented with protecting the code base in mind, and provided quick visibility as to whether a new feature would break the existing build. Any changeset to the master branch must:

1. Pass Travis CI.
2. Be approved by another member of the team.

3. Be up to date with the master branch.

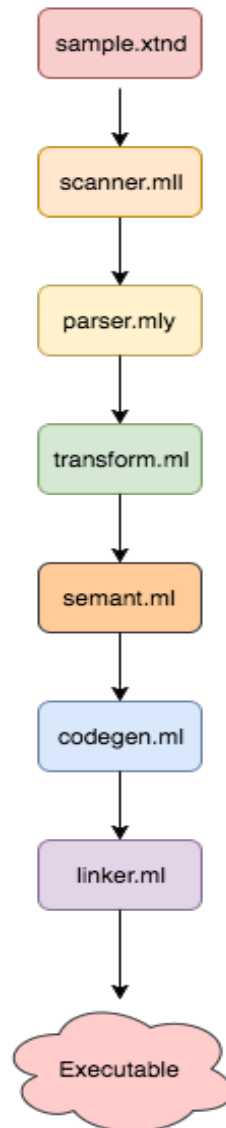
The Interpreter

In our efforts to maximize our effectiveness when building the compiler, we additionally built a working interpreter to test the language semantics and run example Extend programs. This helped us determine language decisions at an earlier stage in the process, and helped us benchmark the success of our compiler by comparing the number of testcases passed by both.

4.3 Team Member Responsibilities

Team Member	Responsibilities	GitHub Profile
Jared Samet	design philosophy, semantic transformations, code generation	oracleofnj
Nigel Schuster	development protocol, code generation, scripting	Neitsch
Ishaan Kolluri	initial LRM, Final Report, regression tests, stdlib functions, scripting	ishaankolluri
Kevin Ye	initial scanner, regression tests, stdlib functions	kevinye1

5. Extend's Internal Architecture



5.1 The Extend Compiler

The Extend compilation process consists of several source files, each of which performs a different function in the compilation pipeline.

- `scanner.mll`: OCamllex scanner - consumes tokens.
- `parser.mly`: OCaml yacc parser - represents the Extend grammar.
- `ast.ml`: Abstract Syntax Tree, created from the output of the parser and representing the structure of an Extend program.
- `transform.ml`: Performs syntactic desugaring for easier compilation.
- `semant.ml`: Analyzes the semantics of the program to ensure that the program adheres to the rules of the language.
- `codegen.ml`: The LLVM IR code generator.
- `linker.ml`: Calls intermediary compilation steps on the generated `.ll`, including external functions if needed.

The Scanner

The function of `scanner.mll` is to parse a text stream into various tokens to be used in an Extend program. Only the tokens that are valid in Extend are to be given to the parser; all others will return a syntax error marked by the line and character number.

The Parser and Abstract Syntax Tree

The parser converts the tokens read by the scanner into a syntax tree deemed acceptable grammar within the Extend Language. This is converted into an Abstract Syntax Tree, which has nodes that can be consumed by the back end of the Extend compiler.

The Transformer

The transformer is the first step in converting the AST into LLVM code. It takes the AST and reduces its breadth. This step is done to preserve the convenience for the user, but reduces the complexity for the actual compile step. It's important to note that the amount of transformation here is large; every expression on the left hand side, even if just a single number, gets turned into a variable.

This is how the user declares a variable.

```
1 [2,2] foo;
```

This is how the transformer desugars the same code.

```
1 rows_of_foo := 2;  
2 cols_of_foo := 2;  
3 [rows_of_foo, cols_of_foo] foo;
```

Every expression before or after a comma or colon will become an internal temporary variable in the desugaring process. The transformer also transforms `&&`, `||`, `and` and `switch` into ternary conditionals to enable short-circuiting. Lastly, the transformer performs some semantic analysis to ensure that there are no duplicate variables within a function, and no duplicate functions within a program.

The Semantic Analyzer

The semantic analyzer consumes the reduced AST. It ensures that Extend functions, variables, expressions, and more are being used properly at compile time, and throws flavorful exceptions to the user so that they may better understand why their program was illegal. In Extend, there are no real type errors, as we attempt to degrade many gracefully. However, the semantic analyzer ensures that functions exist and have the right number of arguments, and that identifiers refer to real variables within their scope.

The Code Generator

Once the Extend AST passes semantic analysis, the code generator turns the reduced AST into LLVM code. Since the variable evaluation approach of Extend is not imperative, this process is fairly elaborate. Specifically for each Extend function it creates a collection of variable blueprints. In its most basic form each blueprint has a reference to one or more formulas that calculate the value of the variable. The intricacies of this approach are beyond the scope of this overview.

The Linker

If successful LLVM IR is generated, the linker will adopt the role of building an executable object from the .ll file. This includes compiling it to an object file and linking the runtime environment along with other imported libraries.

5.2 Extend Runtime

Once a function is called, it recursively looks up what the return value depends on and calculates those values. For this process it is vital that the blueprints created by the Code Generator are correct. The algorithm uses those blueprints to instantiate relevant variables. Ultimately this allows very efficient calculation of the return value without understanding the underlying system.

Take three arguments - scope, row, and cell. This lets the function refer to other local variables in that function. The function `getVal` tells us whether we can actually run the function or not.

We generate code for every single variable in every single function.

6. Testing

Due to Extend being a large undertaking, we took steps to ensure that all features were working as the design of the language intended.

This was done through implementing test cases that isolated specific aspects of the Extend language to ensure that each feature worked correctly. For basic components, we wrote a plethora of tests to illustrate functionality. For undertakings that required more debate on the design of the language, other tests were created and modified throughout development.

6.1 Feature Integration & Testing

Development of new features naturally means that they must be deemed legal by the scanner, parser, semantic analyzer, and code generator. As we developed new features, the process was roughly as follows:

1. Write a simple test that illustrated the feature to test.
2. Write the expected output of the aforementioned test to a text file.
3. Confirm that the scanner consumes the tokens related to the feature.
4. Confirm that the parser grammar has been adjusted to accomodate the new feature.
5. Confirm that the semantic analyzer and transformer can properly identify and check the new feature code.
6. Confirm that code generation generates the appropriate LLVM IR for the new features - such as allocating memory, building calls, and more.
7. Ensure that the test written can write its output to `stdout`, to be compared with expected output.
8. Compile and test the code to ensure that the code has worked to the team's expectations.

Earlier in the development process, we tested the front end of our compiler by JSON-ifying the abstract syntax tree, printing it, and examinining it. As we settled into full-fledged development, we would test with a full-feature regression test suite. Later in the semester, JSON-ifying still proved to be useful, as it gave us the option to print debug statements if needed.

6.2 Regression Test Suite

Extend's test suite is executable through the `testscript.sh` script at the top level of the project. There are over 100 integration test files for various features of the Extend language, and a corresponding file with their expected output to `stdout`. This is to ensure that the successful implementation of one feature does not impact that of others.

Regression tests were placed in the `testcases/inputs_regression` directory. Tests that did not pass at the time were placed in the `testcases/inputs` directory. The test script compiles and executes each test, and compares it with the corresponding expected output file, living in the `testcases/expected` directory. Whenever a test passed in `inputs`, it was automatically moved over to `inputs_regression`.

Note: We have added a full test listing at the end of this document. Please refer to the chapter titled "Test Listing" for more detail.

Integration with Travis CI

The aforementioned test suite is run by Travis CI in the event that the Extend compiler is successfully built; otherwise, the build will fail and exit. In our development workflow, checking the logs during build failures sometimes revealed that tests in the regression test suite did not succeed as expected. This integration kept the far-reaching effects of newly introduced features entirely transparent throughout the process.

Using Travis CI allowed us to maintain the working ability of our compiler, as it ensured that every new feature pushed to the master branch would still result in a successful build. This proved to be invaluable when testing the compiler at a macro-level, or providing Jacob, our TA, with up-to-date demonstrations.

7. Extend Code Listing

7.1 scanner.mll

```
1 {
2   open Lexing
3   open Parser
4   open String
5
6   exception SyntaxError of string
7   let syntax_error lexbuf = raise (SyntaxError("Invalid character: " ^ Lexing.lexeme
8     lexbuf))
9 }
10
11 let digit = ['0'-'9']
12 let exp = 'e' ('+'|'-')? ['0'-'9']+
13 let flt = (digit)+ ('.' (digit)* exp?|exp)
14 let id = ['a'-'z' 'A'-'Z'] ['a'-'z' 'A'-'Z' '0'-'9' '_' ]*
15
16 rule token = parse
17   ['\n']           { new_line lexbuf; token lexbuf }
18 | [' ' '\t' '\r']   { token lexbuf } (* Whitespace *)
19 | "/*"             { multiline_comment lexbuf }
20 | "//"             { oneline_comment lexbuf }
21 | "\""             { read_string (Buffer.create 17) lexbuf }
22 | '['              { LSQBRACK }
23 | ']'              { RSQBRACK }
24 | '('              { LPAREN }
25 | ')'              { RPAREN }
26 | '{'              { LBRACE }
27 | '}'              { RBRACE }
28 | ":@"             { GETS }
29 | '='              { ASN }
30 | ':'              { COLON }
31 | ','              { COMMA }
32 | ">"              { PRECEDES }
33 | '?'              { QUESTION }
34 | "=="             { EQ }
35 | "!="             { NOTEQ }
36 | '<'              { LT }
37 | '>'              { GT }
38 | "<="             { LTEQ }
39 | ">="             { GTEQ }
40 | ';'              { SEMI }
```

```

41 | '!'          { LOGNOT }
42 | "&&"        { LOGAND }
43 | "||"        { LOGOR }
44 | '~'         { BITNOT }
45 | '&'         { BITAND }
46 | '|'         { BITOR }
47 | '^'         { BITXOR }
48 | '+'         { PLUS }
49 | '-'         { MINUS }
50 | '*'         { TIMES }
51 | '/'         { DIVIDE }
52 | '%'         { MOD }
53 | "**"         { POWER }
54 | "<<"         { LSHIFT }
55 | ">>"         { RSHIFT }
56 | '#'         { HASH }
57 | "if"        { IF }
58 | "empty"     { EMPTY }
59 | "size"      { SIZE }
60 | "typeof"    { TYPEOF }
61 | "row"       { ROW }
62 | "column"    { COLUMN }
63 | "switch"    { SWITCH }
64 | "case"      { CASE }
65 | "default"   { DEFAULT }
66 | "return"    { RETURN }
67 | "import"    { IMPORT }
68 | "global"    { GLOBAL }
69 | "extern"    { EXTERN }
70 | digit+ as lit { LIT_INT(int_of_string lit) }
71 | flt as lit   { LIT_FLOAT(float_of_string lit) }
72 | id as lit    { ID(lit) }
73 | eof         { EOF }
74 | _           { syntax_error lexbuf }
75
76 and multiline_comment = parse
77   "*/" { token lexbuf }
78 | '\n' { new_line lexbuf; multiline_comment lexbuf }
79 | _    { multiline_comment lexbuf }
80
81 and oneline_comment = parse
82   '\n' { new_line lexbuf; token lexbuf }
83 | _    { oneline_comment lexbuf }
84
85 (* read_string mostly taken from:
86 https://realworldocaml.org/v1/en/html/parsing-with-ocamllex-and-menhir.html *)
87 and read_string buf =
88   parse
89   | '"'        { LIT_STRING (Buffer.contents buf) }
90   | '\n'       { new_line lexbuf; Buffer.add_char buf '\n'; read_string buf lexbuf }
91   | '\\\n' 'n' { Buffer.add_char buf '\n'; read_string buf lexbuf }
92   | '\\\n' 'r' { Buffer.add_char buf '\r'; read_string buf lexbuf }
93   | '\\\n' 't' { Buffer.add_char buf '\t'; read_string buf lexbuf }
94   | '\\\n' ([^'\n\r\t'] as lxm)
95   | { Buffer.add_char buf lxm; read_string buf lexbuf }
96   | [^'"' '\\\n']+

```

```

97     { Buffer.add_string buf (Lexing.lexeme lexbuf);
98       read_string buf lexbuf
99     }
100   | _      { syntax_error lexbuf }
101   | eof    { raise (Failure("unterminated string")) }

```

7.2 parser.mly

```

1  /* Ocamlyacc parser for Extend */
2
3  %{
4  open Ast
5  %}
6
7  %token LSQBRACK RSQBRACK LPAREN RPAREN LBRACE RBRACE HASH
8  %token COLON COMMA QUESTION IF GETS ASN SEMI PRECEDES
9  %token SWITCH CASE DEFAULT SIZE TYPEOF ROW COLUMN
10 %token PLUS MINUS TIMES DIVIDE MOD POWER LSHIFT RSHIFT
11 %token EQ NOTEQ GT LT GTEQ LTEQ
12 %token LOGNOT LOGAND LOGOR
13 %token BITNOT BITXOR BITAND BITOR
14 %token EMPTY RETURN IMPORT GLOBAL EXTERN
15 %token <int> LIT_INT
16 %token <float> LIT_FLOAT
17 %token <string> LIT_STRING
18 %token <string> ID
19 %token EOF
20
21 %right QUESTION
22 %left PRECEDES
23 %left LOGOR
24 %left LOGAND
25 %left EQ NOTEQ LT GT LTEQ GTEQ
26 %left PLUS MINUS BITOR BITXOR
27 %left TIMES DIVIDE MOD LSHIFT RSHIFT BITAND
28 %right POWER
29 %right BITNOT LOGNOT NEG
30 %left LSQBRACK
31
32 %start program
33 %type <Ast.raw_program> program
34
35 %%
36
37 program:
38     program_piece EOF { let (imp, glob, fnc, ext) = $1 in (List.rev imp, List.rev
39       glob, List.rev fnc, List.rev ext) }
40
41 program_piece:
42     /* nothing */ {([],[],[],[])}
43   | program_piece import      { let (imp, glob, fnc, ext) = $1 in ($2 :: imp, glob,
44     fnc, ext) }
45   | program_piece global      { let (imp, glob, fnc, ext) = $1 in (imp, $2 :: glob,
46     fnc, ext) }
47   | program_piece func_decl   { let (imp, glob, fnc, ext) = $1 in (imp, glob, $2 ::

```

```

        fnc, ext) }
45 | program_piece extern      { let (imp, glob, fnc, ext) = $1 in (imp, glob, fnc, $2
    :: ext) }
46
47 import:
48     IMPORT LIT_STRING SEMI {$2}
49
50 global:
51     GLOBAL varinit {$2}
52
53 extern:
54     EXTERN LIT_STRING LBRACE opt_extern_list RBRACE {(Library($2, $4))}
55
56 opt_extern_list:
57     /* nothing */ { [] }
58 | extern_list { List.rev $1 }
59
60 extern_list:
61     extern_fn { [$1] }
62 | extern_list extern_fn { $2 :: $1 }
63
64 extern_fn:
65     ID LPAREN func_param_list RPAREN SEMI
66     { {
67         extern_fn_name = $1;
68         extern_fn_params = $3;
69         extern_fn_libname = "";
70         extern_ret_val = (None, None);
71     } }
72
73 func_decl:
74     ID LPAREN func_param_list RPAREN LBRACE opt_stmt_list ret_stmt RBRACE
75     { {
76         name = $1;
77         params = $3;
78         body = $6;
79         raw_asserts = [];
80         ret_val = ((None, None), $7)
81     } }
82
83 opt_stmt_list:
84     /* nothing */ { [] }
85 | stmt_list { List.rev $1 }
86
87 stmt_list:
88     stmt { [$1] }
89 | stmt_list stmt { $2 :: $1 }
90
91 stmt:
92     varinit { $1 } | assign { $1 }
93
94 ret_stmt:
95     RETURN expr SEMI {$2}
96
97 varinit:
98     var_list SEMI { Varinit((None, None), List.rev $1) }

```

```

99   | dim var_list SEMI { Varinit($1, List.rev $2) }
100
101 var_list:
102   ID varassign { [ ($1, $2)] }
103   | var_list COMMA ID varassign { ($3, $4) :: $1}
104
105 varassign:
106   /* nothing */ { None }
107   | GETS expr { Some $2 }
108
109 assign:
110   ID lhs_sel ASN expr SEMI { Assign($1, $2, Some $4) }
111
112 expr:
113   expr rhs_sel      { Selection($1, $2) }
114   | HASH ID          { Selection(Id($2), (None, None)) }
115   | op_expr           { $1 }
116   | ternary_expr      { $1 }
117   | switch_expr       { $1 }
118   | func_expr         { $1 }
119   | range_expr        { $1 }
120   | expr PRECEDES expr { Precedence($1, $3) }
121   | LPAREN expr RPAREN { $2 }
122   | ID                { Id($1) }
123   | LIT_INT            { LitInt($1) }
124   | LIT_FLOAT           { LitFlt($1) }
125   | LIT_STRING         { LitString($1) }
126   | EMPTY              { Empty }
127
128 op_expr:
129   expr PLUS expr      { BinOp($1, Plus, $3) }
130   | expr MINUS expr    { BinOp($1, Minus, $3) }
131   | expr TIMES expr    { BinOp($1, Times, $3) }
132   | expr DIVIDE expr   { BinOp($1, Divide, $3) }
133   | expr MOD expr      { BinOp($1, Mod, $3) }
134   | expr POWER expr    { BinOp($1, Pow, $3) }
135   | expr LSHIFT expr   { BinOp($1, LShift, $3) }
136   | expr RSHIFT expr   { BinOp($1, RShift, $3) }
137   | expr LOGAND expr   { BinOp($1, LogAnd, $3) }
138   | expr LOGOR expr    { BinOp($1, LogOr, $3) }
139   | expr BITXOR expr   { BinOp($1, BitXor, $3) }
140   | expr BITAND expr   { BinOp($1, BitAnd, $3) }
141   | expr BITOR expr    { BinOp($1, BitOr, $3) }
142   | expr EQ expr       { BinOp($1, Eq, $3) }
143   | expr NOTEQ expr    { UnOp(LogNot, (BinOp($1, Eq, $3))) }
144   | expr GT expr       { BinOp($1, Gt, $3) }
145   | expr LT expr       { BinOp($1, Lt, $3) }
146   | expr GTEQ expr     { BinOp($1, GtEq, $3) }
147   | expr LTEQ expr     { BinOp($1, LtEq, $3) }
148   | SIZE LPAREN expr RPAREN { UnOp(SizeOf, $3) }
149   | TYPEOF LPAREN expr RPAREN { UnOp(TypeOf, $3) }
150   | ROW LPAREN RPAREN     { UnOp(Row, Empty) }
151   | COLUMN LPAREN RPAREN { UnOp(Column, Empty) }
152   | MINUS expr %prec NEG  { UnOp(Neg, $2) }
153   | LOGNOT expr           { UnOp(LogNot, $2) }
154   | BITNOT expr           { UnOp(BitNot, $2) }

```



```

155
156 ternary_expr:
157     IF LPAREN expr COMMA expr COMMA expr RPAREN { Ternary($3, $5, $7) }
158     | expr QUESTION expr COLON expr %prec QUESTION { Ternary($1, $3, $5) }
159
160 switch_expr:
161     SWITCH LPAREN switch_cond RPAREN LBRACE default_case_list RBRACE { Switch($3, fst
162         $6, snd $6) }
163     | SWITCH LBRACE default_case_list RBRACE { Switch(None, fst $3, snd $3) }
164
165 switch_cond:
166     /* nothing */ { None }
167     | expr { Some $1 }
168
169 default_case_list:
170     case_list {(List.rev $1, Empty)}
171     | case_list default_expr {(List.rev $1, $2)}
172
173 case_list:
174     case_stmt { [$1] }
175     | case_list case_stmt { $2 :: $1 }
176
177 case_stmt:
178     CASE case_expr_list COLON expr SEMI { (List.rev $2, $4) }
179
180 default_expr:
181     DEFAULT COLON expr SEMI { $3 }
182
183 case_expr_list:
184     expr { [$1] }
185     | case_expr_list COMMA expr { $3 :: $1 }
186
187 func_expr:
188     ID LPAREN opt_arg_list RPAREN { Call($1, $3) }
189
190 range_expr:
191     LBRACE row_list RBRACE { allow_range_literal (LitRange(List.rev $2)) }
192
193 row_list:
194     col_list {[List.rev $1]}
195     | row_list SEMI col_list {List.rev $3 :: $1}
196
197 col_list:
198     expr {[ $1]}
199     | col_list COMMA expr {$3 :: $1}
200
201 opt_arg_list:
202     /* nothing */ {[]}
203     | arg_list { List.rev $1 }
204
205 arg_list:
206     expr {[ $1]}
207     | arg_list COMMA expr {$3 :: $1}
208
209 lhs_sel:
210     /* nothing */ { (None, None) }

```

```

210 /* commented out: LSQBRACK lslice RSQBRACK { (Some $2, None) } */
211 | LSQBRACK lslice COMMA lslice RSQBRACK { (Some $2, Some $4) }
212
213 rhs_sel:
214     LSQBRACK rslice RSQBRACK { (Some $2, None) }
215 | LSQBRACK rslice COMMA rslice RSQBRACK { (Some $2, Some $4) }
216
217 lslice:
218     /* commented out: nothing production { (None, None) } */
219     lslice_val { (Some $1, None) }
220 | lslice_val COLON lslice_val { (Some $1, Some $3) }
221 | lslice_val COLON { (Some $1, Some DimensionEnd) }
222 | COLON lslice_val { (Some DimensionStart, Some $2) }
223 | COLON { (Some DimensionStart, Some DimensionEnd) }
224
225 rslice:
226     /* nothing */ { (None, None) }
227 | rslice_val { (Some $1, None) }
228 | rslice_val COLON rslice_val { (Some $1, Some $3) }
229 | rslice_val COLON { (Some $1, Some DimensionEnd) }
230 | COLON rslice_val { (Some DimensionStart, Some $2) }
231 | COLON { (Some DimensionStart, Some DimensionEnd) }
232
233 lslice_val:
234     expr { Abs($1) }
235
236 rslice_val:
237     expr { Abs($1) }
238 | LSQBRACK expr RSQBRACK { Rel($2) }
239
240 func_param_list:
241     /* nothing */ { [] }
242 | func_param_int_list { List.rev $1 }
243
244 func_param_int_list:
245     func_sin_param { [$1] }
246 | func_param_int_list COMMA func_sin_param { $3 :: $1 }
247
248 func_sin_param:
249     ID { ((None, None), $1) }
250 | dim ID { ($1, $2) }
251
252 dim:
253     LSQBRACK expr RSQBRACK { (Some $2, None) }
254 | LSQBRACK expr COMMA expr RSQBRACK { (Some $2, Some $4) }

```

7.3 ast.ml

```

1 type op      = Plus | Minus | Times | Divide | Mod | Pow |
2              LShift | RShift | BitOr | BitAnd | BitXor |
3              Eq | Gt | GtEq | Lt | LtEq | LogAnd | LogOr
4 type unop    = Neg | LogNot | BitNot | SizeOf | TypeOf | Row | Column | Truthy
5
6 type expr    = LitInt of int |
7              LitFlt of float |

```

```

8         LitString of string |
9         LitRange of (expr list) list |
10        Id of string |
11        Empty |
12        BinOp of expr * op * expr |
13        UnOp of unop * expr |
14        Ternary of expr * expr * expr |
15        Switch of expr option * case list * expr |
16        Call of string * expr list |
17        Selection of expr * sel |
18        ReducedTernary of string * string * string |
19        Precedence of expr * expr
20 and index    = Abs of expr |
21              = Rel of expr |
22              = DimensionStart |
23              = DimensionEnd
24 and slice    = index option * index option
25 and sel      = slice option * slice option
26 and case     = expr list * expr
27
28 type dim      = expr option * expr option
29 type var      = dim * string
30 type assign   = string * sel * expr option
31 type init     = string * expr option
32 type stmt     = Assign of assign |
33               = Varinit of dim * init list
34
35 type raw_func = {
36     name: string;
37     params: var list;
38     body: stmt list;
39     raw_asserts: expr list;
40     ret_val: dim * expr;
41 }
42
43 type extern_func = {
44     extern_fn_name: string;
45     extern_fn_params: var list;
46     extern_fn_libname: string;
47     extern_ret_val: dim;
48 }
49
50 type library   = Library of string * extern_func list
51 type raw_program = string list * stmt list * raw_func list * library list
52
53 (* Desugared types below *)
54 module StringMap = Map.Make(String)
55 type formula   = {
56     formula_row_start: index;
57     formula_row_end: index option;
58     formula_col_start: index;
59     formula_col_end: index option;
60     formula_expr: expr;
61 }
62
63 type dim_expr = DimOneByOne

```

```

64         | DimId of string
65
66 type variable = {
67     var_rows: dim_expr;
68     var_cols: dim_expr;
69     var_formulas: formula list;
70 }
71
72 type func_decl = {
73     func_params: var list;
74     func_body: variable StringMap.t;
75     func_asserts: expr list;
76     func_ret_val: dim * expr;
77 }
78
79 type program = (variable StringMap.t) * (func_decl StringMap.t) * (extern_func
    StringMap.t)
80
81 type listable = Inits of init list |
82                 Vars of var list |
83                 Stmts of stmt list |
84                 RawFuncs of raw_func list |
85                 Externs of extern_func list |
86                 Libraries of library list |
87                 Exprs of expr list |
88                 Rows of (expr list) list |
89                 Strings of string list |
90                 Cases of case list |
91                 Formulas of formula list
92
93 exception IllegalRangeLiteral of string
94 exception TransformedAway of string
95
96 let quote_string str =
97     let escape_characters = Str.regexp "[\n \t \r \\ \"]" in
98     let replace_fn s = match Str.matched_string s with
99         "\n" -> "\\n" |
100         "\t" -> "\\t" |
101         "\r" -> "\\r" |
102         "\"" -> "\\\"" |
103         "\\" -> "\\\" |
104         _ -> Str.matched_string s in
105     "\"" ^ Str.global_substitute escape_characters replace_fn str ^ "\""
106
107 let string_of_op o = "\"" ^ (match o with
108     Plus -> "+" | Minus -> "-" | Times -> "*" | Divide -> "/" | Mod -> "%" | Pow ->
        "**" |
109     LShift -> "<<" | RShift -> ">>" | BitOr -> "|" | BitAnd -> "&" | BitXor -> "^" |
110     Eq -> "==" | Gt -> ">" | GtEq -> ">=" | Lt -> "<" | LtEq -> "<=" |
111     LogAnd -> "&&" | LogOr -> "||" ) ^ "\""
112
113 let string_of_unop = function
114     Neg -> "\"-\"" | LogNot -> "\"!\"" | BitNot -> "\"~\"" | Truthy -> "\"truthy\"" |
115     SizeOf -> "\"size\"" | TypeOf -> "\"type\"" | Row -> "\"row\"" | Column -> "\"
        column\""
116

```

```

117 let rec string_of_expr = function
118   LitInt(l) ->      "{ \"LitInt\": \" ^ string_of_int l ^ \"}"
119 | LitFlt(l) ->      "{ \"LitFlt\": \" ^ string_of_float l ^ \"}"
120 | LitString(s) ->    "{ \"LitString\": \" ^ quote_string s ^ \"}"
121 | LitRange(rowlist) -> "{ \"LitRange\": \" ^ string_of_list (Rows rowlist) ^ \"}"
122 | Id(s) ->          "{ \"Id\": \" ^ quote_string s ^ \"}"
123 | Empty ->          "\"Empty\""
124 | BinOp(e1, o, e2) -> "{ \"BinOp\": { \" ^
125   \"expr1\": \" ^ string_of_expr e1 ^ \", \" ^
126   \"operator\": \" ^ string_of_op o ^ \", \" ^
127   \"expr2\": \" ^ string_of_expr e2 ^ \"}}}"
128 | UnOp(o, e) ->      "{ \"UnOp\": { \" ^
129   \"operator\": \" ^ string_of_unop o ^ \", \" ^
130   \"expr\": \" ^ string_of_expr e ^ \"}}}"
131 | Ternary(c, e1, e2) -> "{ \"Ternary\": { \" ^
132   \"condition\": \" ^ string_of_expr c ^ \", \" ^
133   \"ifExpr\": \" ^ string_of_expr e1 ^ \", \" ^
134   \"elseExpr\": \" ^ string_of_expr e2 ^ \"}}}"
135 | ReducedTernary(s1, s2, s3) -> "{ \"ReducedTernary\": { \" ^
136   \"truthiness\": \" ^ quote_string s1 ^ \", \" ^
137   \"true_values\": \" ^ quote_string s2 ^ \", \" ^
138   \"false_values\": \" ^ quote_string s3 ^ \"}}}"
139 | Switch(eo, cases, dflt) -> "{ \"Switch\": { \" ^
140   \"condition\": \" ^
141   (match eo with None -> \"null\" | Some e ->
142     string_of_expr e) ^ \", \" ^
143   \"cases\": \" ^ string_of_list (Cases cases) ^ \", \" ^
144   \"defaultExpr\": \" ^ string_of_expr dflt ^ \"}}}"
145 | Call(f, arguments) -> "{ \"Call\": { \" ^
146   \"function\": \" ^ quote_string f ^ \", \" ^
147   \"arguments\": \" ^ string_of_list (Exprs arguments) ^
148   \"}}}"
149 | Selection(e, s) ->    "{ \"Selection\": { \" ^
150   \"expr\": \" ^ string_of_expr e ^ \", \" ^
151   \"slices\": \" ^ string_of_sel s ^ \"}}}"
152 | Precedence(e1, e2) -> "{ \"Precedence\": { \" ^
153   \"prior_expr\": \" ^ string_of_expr e1 ^ \", \" ^
154   \"dependent_expr\": \" ^ string_of_expr e2 ^ \"}}}"
155
156 and string_of_case (el, e) =
157   "{ \"Cases\": \" ^ string_of_list (Exprs el) ^ \", \" ^
158   \"expr\": \" ^ string_of_expr e ^ \"}"
159
160 and string_of_sel (s1, s2) =
161   "{ \"slice1\": \" ^ string_of_slice s1 ^ \", \"slice2\": \" ^ string_of_slice s2 ^ \"}"
162
163 and string_of_slice = function
164   None -> "null"
165 | Some (start_idx, end_idx) -> "{ \"start\": \" ^ string_of_index start_idx ^ \", \"end
166   \": \" ^ string_of_index end_idx ^ \"}"
167
168 and string_of_index = function
169   None -> "null"
170 | Some (Abs(e)) -> "{ \"Absolute\": \" ^ string_of_expr e ^ \"}"
171 | Some (Rel(e)) -> "{ \"Relative\": \" ^ string_of_expr e ^ \"}"
172 | Some (DimensionStart) -> "\"DimensionStart\""

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```

170 | Some(DimensionEnd) -> "\"DimensionEnd\""
171
172 and string_of_dim (d1,d2) = "{\"d1\": \" ^ (match d1 with None -> \"null\" | Some e ->
    string_of_expr e) ^ \", \" ^
173     \"d2\": \" ^ (match d2 with None -> \"null\" | Some e ->
        string_of_expr e) ^ \"}"
174
175 and string_of_var (d, s) = "{\"Dimensions\": \" ^ string_of_dim d ^ \", \" ^
    \"VarName\": \" ^ quote_string s ^ \"}"
176
177
178 and string_of_assign (s, selection, eo) =
179     \"{\"VarName\": \" ^ quote_string s ^ \", \" ^
180     \"{\"Selection\": \" ^ string_of_sel selection ^ \", \" ^
181     \"{\"expr\": \" ^ (match eo with None -> \"null\" | Some e -> string_of_expr e) ^ \"}"
182
183 and string_of_varinit (d, inits) =
184     \"{\"Dimensions\": \" ^ string_of_dim d ^
185     \",\"Initializations\": \" ^ string_of_list (Inits inits) ^ \"}"
186
187 and string_of_init (s, eo) =
188     \"{\"VarName\": \" ^ quote_string s ^ \", \" ^
189     \"{\"expr\": \" ^ (match eo with None -> \"null\" | Some e -> string_of_expr e) ^ \"}"
190
191 and string_of_stmt = function
192     Assign(a) -> \"{\"Assign\": \" ^ string_of_assign a ^ \"}"
193 | Varinit(d, inits) -> \"{\"Varinit\": \" ^ string_of_varinit (d, inits) ^ \"}"
194
195 and string_of_range (d, e) = \"{\"Dimensions\": \" ^ string_of_dim d ^ \", \" ^
    \"{\"expr\": \" ^ string_of_expr e ^ \"}"
196
197
198 and string_of_raw_func fd =
199     \"{\"Name\": \" ^ quote_string fd.name ^ \",\" ^
200     \"{\"Params\": \" ^ string_of_list (Vars fd.params) ^ \",\" ^
201     \"{\"Stmts\": \" ^ string_of_list (Stmts fd.body) ^ \",\" ^
202     \"{\"Assertions\": \" ^ string_of_list (Exprs fd.raw_asserts) ^ \",\" ^
203     \"{\"ReturnVal\": \" ^ string_of_range fd.ret_val ^ \"}"
204
205 and string_of_extern_func fd =
206     \"{\"Name\": \" ^ quote_string fd.extern_fn_name ^ \",\" ^
207     \"{\"Params\": \" ^ string_of_list (Vars fd.extern_fn_params) ^ \",\" ^
208     \"{\"Library\": \" ^ quote_string fd.extern_fn_libname ^ \",\" ^
209     \"{\"ReturnDim\": \" ^ string_of_dim fd.extern_ret_val ^ \"}"
210
211 and string_of_library (Library(lib_name, lib_fns)) =
212     \"{\"LibraryName\": \" ^ quote_string lib_name ^ \",\" ^
213     \"{\"ExternalFunctions\": \" ^ string_of_list (Externs lib_fns) ^ \"}"
214
215 and string_of_dimexpr = function
216     DimOneByOne -> "1"
217 | DimId(s) -> quote_string s
218
219 and string_of_formula f =
220     \"{\"RowStart\": \" ^ string_of_index (Some f.formula_row_start) ^ \",\" ^
221     \"{\"RowEnd\": \" ^ string_of_index (f.formula_row_end) ^ \",\" ^
222     \"{\"ColumnStart\": \" ^ string_of_index (Some f.formula_col_start) ^ \",\" ^
223     \"{\"ColumnEnd\": \" ^ string_of_index (f.formula_col_end) ^ \",\" ^

```

```

224   "\"Formula\": \" ^ string_of_expr f.formula_expr ^ \""
225
226 and string_of_list l =
227   let stringrep = (match l with
228     | Inits (il) -> List.map string_of_init il
229     | Vars (vl) -> List.map string_of_var vl
230     | Stmts (sl) -> List.map string_of_stmt sl
231     | RawFuncs (fl) -> List.map string_of_raw_func fl
232     | Externs (efl) -> List.map string_of_extern_func efl
233     | Libraries (libl) -> List.map string_of_library libl
234     | Exprs (el) -> List.map string_of_expr el
235     | Rows (rl) -> List.map (fun (el : expr list) -> string_of_list (Exprs el)) rl
236     | Strings (sl) -> List.map quote_string sl
237     | Cases (cl) -> List.map string_of_case cl
238     | Formulas (fl) -> List.map string_of_formula fl)
239   in "[" ^ String.concat ", " stringrep ^ "]"
240
241 let string_of_raw_program (imp, glb, fs, exts) =
242   "{" ^ "\"Program\": {" ^
243     "\"Imports\": \" ^ string_of_list (Strings imp) ^ \",\" ^
244     "\"Globals\": \" ^ string_of_list (Stmts glb) ^ \",\" ^
245     "\"ExternalLibraries\": \" ^ string_of_list (Libraries exts) ^ \",\" ^
246     "\"Functions\": \" ^ string_of_list (RawFuncs fs) ^ \"}"
247
248 let string_of_variable v =
249   "{" ^ "\"Rows\": \" ^ string_of_dimexpr v.var_rows ^ \",\" ^
250   "\"Columns\": \" ^ string_of_dimexpr v.var_cols ^ \",\" ^
251   "\"Formulas\": \" ^ string_of_list (Formulas v.var_formulas) ^ \""
252
253 let string_of_map value_desc val_printing_fn m =
254   let f_key_val_list k v l = (
255     "{" ^ "\" ^ value_desc ^ \"Name\": \" ^ quote_string k ^ \", \" ^
256     "\" ^ value_desc ^ \"Def\": \" ^ val_printing_fn v ^ \""
257   ) :: l in
258   "[" ^ String.concat ", " (List.rev (StringMap.fold f_key_val_list m [])) ^ "]"
259
260 let string_of_funcdecl f =
261   "{" ^ "\"Params\": \" ^ string_of_list (Vars f.func_params) ^ \",\" ^
262   "\"Variables\": \" ^ string_of_map "Variable" string_of_variable f.func_body ^ \",\" ^
263   "\"Assertions\": \" ^ string_of_list (Exprs f.func_asserts) ^ \",\" ^
264   "\"ReturnVal\": \" ^ string_of_range f.func_ret_val ^ \""
265
266 let string_of_program (glb, fs, exts) =
267   "{" ^ "\"Program\": {" ^
268     "\"Globals\": \" ^ string_of_map "Variable" string_of_variable glb ^ \",\" ^
269     "\"Functions\": \" ^ string_of_map "Function" string_of_funcdecl fs ^ \",\" ^
270     "\"ExternalFunctions\": \" ^ string_of_map "ExternalFunctions"
271       string_of_extern_func exts ^ \"}"
272
273 let allow_range_literal = function
274   LitRange(rowlist) ->
275     let rec check_range_literal rl =
276       List.for_all (fun exprs -> List.for_all check_basic_expr exprs) rl
277     and check_basic_expr = function
278       LitInt(_) | UnOp(Neg, LitInt(_)) | LitFlt(_) | UnOp(Neg, LitFlt(_)) |
279       LitString(_) | Empty -> true

```

```

278         | LitRange(rl) -> check_range_literal rl
279         | _ -> false in
280
281         if check_range_literal rowlist then LitRange(rowlist)
282         else raise(IllegalRangeLiteral(string_of_expr (LitRange(rowlist))))
283     | e -> raise(IllegalRangeLiteral(string_of_expr e))

```

7.4 transform.ml

```

1  open Ast
2  open Lexing
3  open Parsing
4  open Semant
5
6  module StringSet = Set.Make (String);;
7  let importSet = StringSet.empty;;
8
9  let idgen =
10     (* from http://stackoverflow.com/questions/10459363/side-effects-and-top-level-
       expressions-in-ocaml*)
11     let count = ref (-1) in
12     fun prefix -> incr count; "_tmp_" ^ prefix ^ string_of_int !count;;
13
14  let expand_file include_stdlib filename =
15     let print_error_location filename msg lexbuf =
16         let pos = lexbuf.lex_curr_p in
17         prerr_endline ("Syntax error in \"^ filename ^ "\": " ^ msg) ;
18         prerr_endline ("Line " ^ (string_of_int pos.pos_lnum) ^ " at character " ^ (
            string_of_int (pos.pos_cnum - pos.pos_bol))) in
19
20  let rec expand_imports processed_imports globals fns exts dir = function
21     [] -> ([], globals, fns, exts)
22     | (import, use_dir) :: imports ->
23     (* print_endline "-----";
24        print_endline ("Working on: " ^ import) ;
25        print_endline ("Already processed:"); *)
26     (* StringSet.iter (fun a -> print_endline a) processed_imports; *)
27     let in_chan = open_in import in
28     let lexbuf = (Lexing.from_channel (in_chan)) in
29     let (file_imports, file_globals, file_functions, file_extens) =
30         try Parser.program Scanner.token lexbuf
31         with
32             Parsing.Parse_error -> print_error_location import "" lexbuf ; exit(-1)
33             | Scanner.SyntaxError(s) -> print_error_location import s lexbuf ; exit(-1)
34     in
35     let file_imports = List.map (fun file -> (if use_dir then (dir ^ "/" ) else "") ^
        file) file_imports in
36     let new_proc = StringSet.add import processed_imports and _ = close_in in_chan
        in
37     (* print_endline ("Now I'm done with: ") ; *)
38     (* StringSet.iter (fun a -> print_endline a) new_proc; *)
39     let first_im_hearing_about imp = not (StringSet.mem imp new_proc || List.mem imp
        (List.map fst imports)) in
40     let new_imports = List.map (fun e -> (e, true)) (StringSet.elements (StringSet.
        of_list (List.filter first_im_hearing_about file_imports))) in

```



```

41      (* print_endline ("First I'm hearing about:") ; *)
42      (* List.iter print_endline new_imports; *)
43      expand_imports new_proc (globals @ file_globals) (fns @ file_functions) (exts @
        file_extens) (Filename.dirname import) (imports @ new_imports) in
44  expand_imports
45    StringSet.empty [] [] []
46    (Filename.dirname filename)
47    (if include_stdlib then [(filename, true); ("src/stdlib/stdlib.xtnd", false)] else
        [(filename, true)])
48
49  let expand_expressions (imports, globals, functions, externs) =
50    let lit_zero = LitInt(0) in let abs_zero = Abs(lit_zero) in
51    let lit_one = LitInt(1) in let abs_one = Abs(lit_one) in
52    let one_by_one = (Some lit_one, Some lit_one) in
53    let zero_comma_zero = (Some (Some abs_zero, Some abs_one),
54                          Some (Some abs_zero, Some abs_one)) in
55    let entire_dimension = (Some DimensionStart, Some DimensionEnd) in
56    let entire_range = (Some entire_dimension, Some entire_dimension) in
57
58    let expand_expr expr_loc = function
59      (* Create a new variable for all expressions on the LHS to hold the result;
60       return the new expression and whatever new statements are necessary to create
61       the new variable *)
62      Empty      -> raise (IllegalExpression("Empty not allowed in " ^ expr_loc))
63      | LitString(s) -> raise (IllegalExpression("String literal " ^ quote_string s ^ "
        not allowed in " ^ expr_loc))
64      | LitRange(rl) -> raise (IllegalExpression("Range literal " ^ string_of_list (Rows
        rl) ^ " not allowed in " ^ expr_loc))
65      | e          -> let new_id = idgen expr_loc in (
66        Id(new_id),
67        [Varinit (one_by_one, [(new_id, None)]);
68        Assign (new_id, zero_comma_zero, Some e)]) in
69
70    let expand_index index_loc = function
71      (* Expand one index of a slice if necessary. *)
72      Abs(e) -> let (new_e, new_stmts) = expand_expr index_loc e in
73      (Abs(new_e), new_stmts)
74      | DimensionStart -> (DimensionStart, [])
75      | DimensionEnd -> (DimensionEnd, [])
76      | Rel(_) -> raise (IllegalExpression("relative - this shouldn't be possible")) in
77
78    let expand_slice slice_loc = function
79      (* Expand one or both sides as necessary. *)
80      None -> (entire_dimension, [])
81      | Some (Some (Abs(e)), None) ->
82        let (start_e, start_stmts) = expand_expr (slice_loc ^ "_start") e in
83        ((Some (Abs(start_e)), None), start_stmts)
84      | Some (Some idx_start, Some idx_end) ->
85        let (new_start, new_start_exprs) = expand_index (slice_loc ^ "_start") idx_start
86        in
87        let (new_end, new_end_exprs) = expand_index (slice_loc ^ "_end") idx_end in
88        ((Some new_start, Some new_end), new_start_exprs @ new_end_exprs)
89      | Some (Some _, None) | Some (None, _) -> raise (IllegalExpression("Illegal slice
        - this shouldn't be possible")) in
90
91    let expand_assign asgn_loc (var_name, (row_slice, col_slice), formula) =

```

```

90     (* expand_assign: Take an Assign and return a list of more
91        atomic statements, with new variables replacing any
92        complex expressions in the selection slices and with single
93        index values desugared to expr:expr+1. *)
94     try
95         let (new_row_slice, row_exprs) = expand_slice (asgn_loc ^ "_" ^ var_name ^ "_row"
96             ^ row_slice) in
97         let (new_col_slice, col_exprs) = expand_slice (asgn_loc ^ "_" ^ var_name ^ "_col"
98             ^ col_slice) in
99         Assign(var_name, (Some new_row_slice, Some new_col_slice), formula) :: (
100             row_exprs @ col_exprs)
101     with IllegalExpression(s) =>
102         raise (IllegalExpression("Illegal expression (" ^ s ^ ") in " ^
103             string_of_assign (var_name, (row_slice, col_slice),
104                 formula))) in
105
106 let expand_init (r, c) (v, e) =
107     Varinit((Some r, Some c), [(v, None)]) ::
108     match e with
109     | None => []
110     | Some e => [Assign (v, entire_range, Some e)] in
111
112 let expand_dimension dim_loc = function
113     None -> expand_expr dim_loc (LitInt(1))
114     | Some e -> expand_expr dim_loc e in
115
116 let expand_varinit fname ((row_dim, col_dim), inits) =
117     (* expand_varinit: Take a Varinit and return a list of more atomic
118        statements. Each dimension will be given a temporary ID, which
119        will be declared as [1,1] _tmpXXX; the formula for tmpXXX will be
120        set as a separate assignment; the original variable will be
121        declared as [_tmpXXX, _tmpYYY] var; and the formula assignment
122        will be applied to [:::]. *)
123     try
124         let (row_e, row_stmts) = expand_dimension (fname ^ "_" ^ (String.concat "_" (
125             List.map fst inits)) ^ "_row_dim") row_dim in
126         let (col_e, col_stmts) = expand_dimension (fname ^ "_" ^ (String.concat "_" (
127             List.map fst inits)) ^ "_col_dim") col_dim in
128         row_stmts @ col_stmts @ List.concat (List.map (expand_init (row_e, col_e)) inits
129             )
130     with IllegalExpression(s) =>
131         raise (IllegalExpression("Illegal expression (" ^ s ^ ") in " ^
132             string_of_varinit ((row_dim, col_dim), inits))) in
133
134 let expand_stmt fname = function
135     Assign(a) -> expand_assign fname a
136     | Varinit(d, inits) -> expand_varinit fname (d, inits) in
137
138 let expand_stmt_list fname stmts = List.concat (List.map (expand_stmt fname) stmts)
139     in
140
141 let expand_params fname params =
142     let needs_sizevar = function
143         ((None, None), _) -> false
144         | _ -> true in
145     let params_with_sizevar = List.map (fun x -> (idgen (fname ^ "_" ^ (snd x) ^ "

```

```

    _size"), x)) (List.filter needs_sizevar params) in
138 let expanded_args = List.map (fun (sv, ((rv, cv), s)) -> ((sv, s), [(sv, abs_zero
    ), rv); ((sv, abs_one), cv)])) params_with_sizevar in
139 let (sizes, inits) = (List.map fst expanded_args, List.concat (List.map snd
    expanded_args)) in
140 let add_item (varset, (assertlist, initlist)) ((sizevar, pos), var) =
141   (match var with
142     Some Id(s) ->
143       if StringSet.mem s varset then
144         (* We've seen this variable before; don't initialize it, just assert it *)
145         (varset, (BinOp(Id(s), Eq, Selection(Id(sizevar), (Some(Some(pos), None),
            None))) :: assertlist, initlist))
146       else
147         (* We're seeing a string for the first time; don't assert it, just create
            it *)
148         (StringSet.add s varset, (assertlist,
149           Assign(s, zero_comma_zero, Some (Selection(Id(
            sizevar), (Some(Some(pos), None), None)))) ::
150           Varinit(one_by_one, [(s, None)]) ::
151           initlist))
152   | Some LitInt(i) -> (* Seeing a number; don't do anything besides create an
        assertion *)
153     (varset, (BinOp(LitInt(i), Eq, Selection(Id(sizevar), (Some(Some(pos), None),
        None))) :: assertlist, initlist))
154   | Some e -> raise (IllegalExpression("Illegal expression (" ^ string_of_expr e
        ^ ") in function signature"))
155   | _ -> raise (IllegalExpression("Cannot supply a single dimension in function
        signature"))) in
156 let (rev_assertions, rev_inits) = snd (List.fold_left add_item (StringSet.empty,
    ([], [])) inits) in
157 let create_sizevar (sizevar, arg) = [
158   Varinit(one_by_one, [(sizevar, None)]);
159   Assign(sizevar, entire_range, Some(UnOp(SizeOf, Id(arg))))] in
160 (List.concat (List.map create_sizevar sizes), List.rev rev_assertions, List.rev
    rev_inits) in
161
162 let expand_function f =
163   let (new_sizevars, assertions, size_inits) = expand_params f.name f.params in
164   let new_retval_id = idgen (f.name ^ "_retval") in
165   let new_retval = Id(new_retval_id) in
166   let retval_inits = [Varinit (one_by_one, [(new_retval_id, None)]];
167     Assign (new_retval_id, zero_comma_zero, Some (snd f.ret_val))]
    in
168   let new_assert_id = idgen (f.name ^ "_assert") in
169   let add_assert al a = BinOp(al, LogAnd, a) in
170   let new_assert_expr = List.fold_left add_assert (LitInt(1)) assertions in
171   let new_assert = Id(new_assert_id) in
172   let assert_inits = [Varinit (one_by_one, [(new_assert_id, None)]];
173     Assign (new_assert_id, zero_comma_zero, Some new_assert_expr)]
    in
174   {
175     name = f.name;
176     params = f.params;
177     raw_asserts = [new_assert];
178     body = new_sizevars @ size_inits @ retval_inits @ assert_inits @
        expand_stmt_list f.name f.body;

```

```

179     ret_val = (fst f.ret_val, new_retval)
180   } in
181   (imports, expand_stmt_list "global" globals, List.map expand_function functions,
    externs);;
182
183 let create_maps (imports, globals, functions, externs) =
184   let vd_of_vi = function
185     (* vd_of_vi— Take a bare Varinit from the previous transformations
186       and return a (string, variable) pair *)
187     Varinit((Some r, Some c), [(v, None)]) -> (v, {
188       var_rows = (match r with
189         LitInt(1) -> DimOneByOne
190         | Id(s) -> DimId(s)
191         | _ -> raise (LogicError("Unrecognized expression for rows of " ^ v)));
192       var_cols = (match c with
193         LitInt(1) -> DimOneByOne
194         | Id(s) -> DimId(s)
195         | _ -> raise (LogicError("Unrecognized expression for rows of " ^ v)));
196       var_formulas = [];
197     })
198   | _ -> raise (LogicError("Unrecognized format for post-desugaring Varinit")) in
199
200 let add_formula m = function
201   Varinit(_,_) -> m
202   | Assign(var_name, (Some (Some row_start, row_end), Some (Some col_start, col_end
203     )), Some e) ->
204     if StringMap.mem var_name m
205     then (let v = StringMap.find var_name m in
206       StringMap.add var_name {v with var_formulas = v.var_formulas @ [{
207         formula_row_start = row_start;
208         formula_row_end = row_end;
209         formula_col_start = col_start;
210         formula_col_end = col_end;
211         formula_expr = e;
212       }]} m)
213     else raise (UnknownVariable(string_of_stmt (Assign(var_name, (Some (Some
214       row_start, row_end), Some (Some col_start, col_end)), Some e))))
215   | Assign(a) -> raise (LogicError("Unrecognized format for post-desugaring Assign:
216     " ^ string_of_stmt (Assign(a)))) in
217
218 let vds_of_stmts stmts =
219   let is_varinit = function Varinit(_,_) -> true | _ -> false in
220   let varinits = List.filter is_varinit stmts in
221   let vars_just_the_names = map_of_list (List.map vd_of_vi varinits) in
222   List.fold_left add_formula vars_just_the_names stmts in
223
224 let fd_of_raw_func f = (f.name, {
225   func_params = f.params;
226   func_body = vds_of_stmts f.body;
227   func_ret_val = f.ret_val;
228   func_asserts = f.raw_asserts;
229 }) in
230
231 let tupleize_library (Library(lib_name, lib_fns)) =
232   List.map (fun ext_fn -> (ext_fn.extern_fn_name, {ext_fn with extern_fn_libname =
233     lib_name})) lib_fns in

```

```

230
231 (vds_of_stmts globals,
232   map_of_list (List.map fd_of_raw_func functions),
233   map_of_list (List.concat (List.map tupleize_library externs)))
234
235 let single_formula e = {
236   formula_row_start = DimensionStart;
237   formula_row_end = Some DimensionEnd;
238   formula_col_start = DimensionStart;
239   formula_col_end = Some DimensionEnd;
240   formula_expr = e;
241 }
242
243 let ternarize_exprs (globals, functions, externs) =
244   let rec ternarize_expr lhs_var = function
245     BinOp(e1, LogAnd, e2) ->
246       let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
247       let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
248       (Ternary(UnOp(Truthy, new_e1), UnOp(Truthy, new_e2), LitInt(0)), new_e1_vars @
         new_e2_vars)
249   | BinOp(e1, LogOr, e2) ->
250       let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
251       let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
252       (Ternary(UnOp(Truthy, new_e1), LitInt(1), UnOp(Truthy, new_e2)), new_e1_vars @
         new_e2_vars)
253   | BinOp(e1, op, e2) ->
254       let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
255       let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
256       (BinOp(new_e1, op, new_e2), new_e1_vars @ new_e2_vars)
257   | UnOp(op, e) ->
258       let (new_e, new_e_vars) = ternarize_expr lhs_var e in
259       (UnOp(op, new_e), new_e_vars)
260   | Ternary(cond, e1, e2) ->
261       let (new_cond, new_cond_vars) = ternarize_expr lhs_var cond in
262       let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
263       let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
264       (Ternary(new_cond, new_e1, new_e2), new_cond_vars @ new_e1_vars @ new_e2_vars)
265   | Call(fname, args) ->
266       let new_args_and_vars = List.map (ternarize_expr lhs_var) args in
267       (Call(fname, (List.map fst new_args_and_vars)), List.concat (List.map snd
         new_args_and_vars))
268   | Selection(e, (sl1, sl2)) ->
269       let (new_e, new_e_vars) = ternarize_expr lhs_var e in
270       let (new_sl1, new_sl1_vars) = ternarize_slice lhs_var sl1 in
271       let (new_sl2, new_sl2_vars) = ternarize_slice lhs_var sl2 in
272       (Selection(new_e, (new_sl1, new_sl2)), new_e_vars @ new_sl1_vars @ new_sl2_vars)
273   | Precedence(e1, e2) ->
274       let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
275       let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
276       (Precedence(new_e1, new_e2), new_e1_vars @ new_e2_vars)
277   | Switch(cond, cases, dflt) ->
278       ternarize_switch lhs_var cases dflt cond
279   (* | Debug(e) ->
280       let (new_e, new_e_vars) = ternarize_expr lhs_var e in
281       (Debug(new_e), new_e_vars) *)
282   | e -> (e, [])

```

```

283 and ternarize_switch lhs_var cases dflt cond =
284   let (new_cond_expr, new_cond_vars) = (match cond with
285     Some cond_expr ->
286       let (lhs_varname, lhs_vardef) = lhs_var in
287       let new_id = idgen (lhs_varname ^ "_switch_cond") in
288       let (new_e, new_e_vars) = ternarize_expr lhs_var cond_expr in
289       (Some (Selection (Id (new_id), (Some (Some (Rel (LitInt (0))), None), Some (Some (Rel (
290         LitInt (0))), None))),),
291       (new_id, {lhs_vardef with var_formulas = [single_formula new_e]})) ::
292       new_e_vars
293   | None ->
294     (None, [])
295   ) in
296   let new_cases_and_vars = List.map (ternarize_case lhs_var new_cond_expr) cases in
297   let new_cases = List.map fst new_cases_and_vars in
298   let new_case_vars = List.concat (List.map snd new_cases_and_vars) in
299   let (new_dflt, new_dflt_vars) = ternarize_expr lhs_var dflt in
300   let rec combine_everything = function
301     [] -> new_dflt
302     | (combined_cases, e) :: more_cases -> Ternary (combined_cases, e,
303       combine_everything more_cases) in
304   (combine_everything new_cases, new_cond_vars @ new_case_vars @ new_dflt_vars)
305 and ternarize_case lhs_var cond (conds, e) =
306   let new_conds_and_vars = List.map (ternarize_expr lhs_var) conds in
307   let new_conds = List.map fst new_conds_and_vars in
308   let new_cond_vars = List.concat (List.map snd new_conds_and_vars) in
309   let (new_e, new_e_vars) = ternarize_expr lhs_var e in
310   let unify_case_cond_and_switch_cond case_cond = function
311     None -> case_cond
312     | Some switch_cond -> BinOp (switch_cond, Eq, case_cond) in
313   let rec unify_switch_cond_and_case_conds switch_cond = function
314     [case_cond] -> unify_case_cond_and_switch_cond case_cond switch_cond
315     | case_cond :: case_conds ->
316       let (combined_expr, _) = ternarize_expr lhs_var
317         (BinOp (unify_case_cond_and_switch_cond case_cond switch_cond, LogOr,
318           unify_switch_cond_and_case_conds switch_cond case_conds)) in
319       combined_expr
320     | [] -> raise (LogicError ("Empty case condition list")) in
321   ((unify_switch_cond_and_case_conds cond new_conds, new_e), new_cond_vars @
322     new_e_vars)
323 and ternarize_slice lhs_var = function
324   None -> (None, [])
325   | Some (i1, i2) ->
326     let (new_i1, new_i1_vars) = ternarize_index lhs_var i1 in
327     let (new_i2, new_i2_vars) = ternarize_index lhs_var i2 in
328     (Some (new_i1, new_i2), new_i1_vars @ new_i2_vars)
329 and ternarize_index lhs_var = function
330   Some Abs (e) ->
331     let (new_e, new_e_vars) = ternarize_expr lhs_var e in
332     (Some (Abs (new_e)), new_e_vars)
333   | Some Rel (e) ->
334     let (new_e, new_e_vars) = ternarize_expr lhs_var e in
335     (Some (Rel (new_e)), new_e_vars)
336   | i -> (i, []) in
337 let ternarize_formula lhs_var f =
338   let (new_expr, new_vars) = ternarize_expr lhs_var f.formula_expr in

```

```

335     ({f with formula_expr = new_expr}, new_vars) in
336 let ternarize_variable varname vardef =
337     let new_formulas_and_vars = List.map (ternarize_formula (varname, vardef)) vardef.
        var_formulas in
338     ({vardef with var_formulas = List.map fst new_formulas_and_vars}, List.concat (
        List.map snd new_formulas_and_vars)) in
339 let ternarize_variables fn_name m =
340     let new_variables_and_maps = StringMap.mapi (fun varname vardef ->
        ternarize_variable (fn_name ^ "_" ^ varname) vardef) m in
341     let add_item var_name (orig_var, new_vars) l = ((var_name, orig_var) :: fst l,
        new_vars :: snd l) in
342     let combined_list = StringMap.fold add_item new_variables_and_maps ([], []) in
343     map_of_list (List.rev (fst combined_list) @ List.concat (snd combined_list)) in
344 let ternarize_function fn_name fn_def = {fn_def with func_body = ternarize_variables
        fn_name fn_def.func_body} in
345 (ternarize_variables "global" globals, StringMap.mapi ternarize_function functions,
        externs)
346
347 let reduce_ternaries (globals, functions, externs) =
348     let rec reduce_expr lhs_var = function
349         | BinOp(e1, op, e2) ->
350             let (new_e1, new_e1_vars) = reduce_expr lhs_var e1 in
351             let (new_e2, new_e2_vars) = reduce_expr lhs_var e2 in
352             (BinOp(new_e1, op, new_e2), new_e1_vars @ new_e2_vars)
353         | UnOp(op, e) ->
354             let (new_e, new_e_vars) = reduce_expr lhs_var e in
355             (UnOp(op, new_e), new_e_vars)
356         | Ternary(cond, e1, e2) -> reduce_ternary lhs_var cond e1 e2
357         | Call(fname, args) ->
358             let new_args_and_vars = List.map (reduce_expr lhs_var) args in
359             (Call(fname, (List.map fst new_args_and_vars)), List.concat (List.map snd
                new_args_and_vars))
360         | Selection(e, (sl1, sl2)) ->
361             let (new_e, new_e_vars) = reduce_expr lhs_var e in
362             let (new_sl1, new_sl1_vars) = reduce_slice lhs_var sl1 in
363             let (new_sl2, new_sl2_vars) = reduce_slice lhs_var sl2 in
364             (Selection(new_e, (new_sl1, new_sl2)), new_e_vars @ new_sl1_vars @ new_sl2_vars)
365         | Precedence(e1, e2) ->
366             let (new_e1, new_e1_vars) = reduce_expr lhs_var e1 in
367             let (new_e2, new_e2_vars) = reduce_expr lhs_var e2 in
368             (Precedence(new_e1, new_e2), new_e1_vars @ new_e2_vars)
369         (* | Debug(e) ->
370             let (new_e, new_e_vars) = reduce_expr lhs_var e in
371             (Debug(new_e), new_e_vars) *)
372         | e -> (e, [])
373 and reduce_ternary lhs_var cond e1 e2 =
374     let (new_cond, new_cond_vars) = reduce_expr lhs_var cond in
375     let (new_true_e, new_true_vars) = reduce_expr lhs_var e1 in
376     let (new_false_e, new_false_vars) = reduce_expr lhs_var e2 in
377     let (lhs_varname, lhs_vardef) = lhs_var in
378     let new_cond_id = idgen (lhs_varname ^ "_truthiness") in
379     let new_true_id = idgen (lhs_varname ^ "_values_if_true") in
380     let new_false_id = idgen (lhs_varname ^ "_values_if_false") in
381     (ReducedTernary(new_cond_id, new_true_id, new_false_id),
382     (new_cond_id, {lhs_vardef with var_formulas = [single_formula (UnOp(Truthy,
        new_cond))]})) ::

```

```

383     (new_true_id, {lhs_vardef with var_formulas = [single_formula new_true_e]}) ::
384     (new_false_id, {lhs_vardef with var_formulas = [single_formula new_false_e]}) ::
385     (new_cond_vars @ new_true_vars @ new_false_vars))
386 and reduce_slice lhs_var = function
387     None -> (None, [])
388   | Some (i1, i2) ->
389     let (new_i1, new_i1_vars) = reduce_index lhs_var i1 in
390     let (new_i2, new_i2_vars) = reduce_index lhs_var i2 in
391     (Some (new_i1, new_i2), new_i1_vars @ new_i2_vars)
392 and reduce_index lhs_var = function
393     Some Abs(e) ->
394       let (new_e, new_e_vars) = reduce_expr lhs_var e in
395       (Some (Abs(new_e)), new_e_vars)
396   | Some Rel(e) ->
397     let (new_e, new_e_vars) = reduce_expr lhs_var e in
398     (Some (Rel(new_e)), new_e_vars)
399   | i -> (i, []) in
400 let reduce_formula lhs_var f =
401   let (new_expr, new_vars) = reduce_expr lhs_var f.formula_expr in
402   ({f with formula_expr = new_expr}, new_vars) in
403 let reduce_variable varname vardef =
404   let new_formulas_and_vars = List.map (reduce_formula (varname, vardef)) vardef.
405     var_formulas in
406   ({vardef with var_formulas = List.map fst new_formulas_and_vars}, List.concat (
407     List.map snd new_formulas_and_vars)) in
408 let reduce_variables fn_name m =
409   let new_variables_and_maps = StringMap.mapi (fun varname vardef -> reduce_variable
410     (fn_name ^ "_" ^ varname) vardef) m in
411   let add_item var_name (orig_var, new_vars) l = ((var_name, orig_var) :: fst l,
412     new_vars :: snd l) in
413   let combined_list = StringMap.fold add_item new_variables_and_maps ([], []) in
414   map_of_list (List.rev (fst combined_list) @ List.concat (snd combined_list)) in
415 let reduce_function fn_name fn_def = {fn_def with func_body = reduce_variables
416   fn_name fn_def.func_body} in
417 (reduce_variables "global" globals, StringMap.mapi reduce_function functions,
418   externs)
419
420 let create_ast filename =
421   let ast_imp_res = expand_file true filename in
422   let ast_expanded = expand_expressions ast_imp_res in
423   let ast_mapped = create_maps ast_expanded in check_semantics ast_mapped ;
424   let ast_ternarized = ternarize_exprs ast_mapped in
425   let ast_reduced = reduce_ternaries ast_ternarized in check_semantics ast_reduced ;
426   ast_reduced

```

7.5 semant.ml

```

1 open Ast
2
3 exception IllegalExpression of string;;
4 exception DuplicateDefinition of string;;
5 exception UnknownVariable of string;;
6 exception UnknownFunction of string;;
7 exception WrongNumberArgs of string;;
8 exception LogicError of string;;

```



```

9
10 type symbol = LocalVariable of int | GlobalVariable of int | FunctionParameter of int
    | ExtendFunction of int
11 and symbolTable = symbol StringMap.t
12 and symbolTableType = Locals | Globals | ExtendFunctions
13
14 let map_of_list list_of_tuples =
15   (* map_of_list: Take a list of the form [("foo", 2); ("bar", 3)]
16     and create a StringMap using the first value of the tuple as
17     the key and the second value of the tuple as the value. Raises
18     an exception if the key appears more than once in the list. *)
19   let rec aux acc = function
20     [] -> acc
21     | t :: ts ->
22       if (StringMap.mem (fst t) acc) then raise(DuplicateDefinition(fst t))
23       else aux (StringMap.add (fst t) (snd t) acc) ts in
24   aux StringMap.empty list_of_tuples
25
26 let index_map table_type m =
27   let add_item key _ (accum_map, accum_idx) =
28     let index_val = match table_type with Locals -> LocalVariable(accum_idx) | Globals
29       -> GlobalVariable(accum_idx) | ExtendFunctions -> ExtendFunction(accum_idx) in
30     (StringMap.add key index_val accum_map, accum_idx + 1) in
31   StringMap.fold add_item m (StringMap.empty, 0)
32
33 let create_symbol_table global_symbols fn_def =
34   let (local_indices, _) = index_map Locals fn_def.func_body in
35   let add_param (st, idx) param_name =
36     let new_st = StringMap.add param_name (FunctionParameter(idx)) st in
37     (new_st, idx + 1) in
38   let (params_and_globals, _) = List.fold_left add_param (global_symbols, 0) (List.map
39     snd fn_def.func_params) in
40   StringMap.fold StringMap.add local_indices params_and_globals
41
42 let check_semantics (globals, functions, externs) =
43   let fn_signatures = map_of_list
44     ((StringMap.fold (fun s f l -> (s, List.length f.func_params) :: l) functions
45       []) @
46      (StringMap.fold (fun s f l -> (s, List.length f.extern_fn_params) :: l) externs
47        [])) in
48   let (global_symbols, _) = index_map Globals globals in
49
50   let check_call context called_fname num_args =
51     if (not (StringMap.mem called_fname fn_signatures)) then
52       (print_endline ("In " ^ context ^ "()", the undefined function " ^ called_fname ^
53         "()" was called") ;
54       raise(UnknownFunction(context ^ "," ^ called_fname)))
55     else let signature_args = StringMap.find called_fname fn_signatures in
56       if num_args != signature_args then
57         (print_endline ("In " ^ context ^ "()", the function " ^ called_fname ^ "()" was
58           called with " ^
59             string_of_int num_args ^ " arguments " ^ "but the signature
60             specifies "
61             ^ string_of_int signature_args) ;
62         raise(WrongNumberArgs(context ^ "," ^ called_fname)))
63       else () in

```

```

57
58 let rec check_expr fname symbols = function
59   BinOp(e1,_,e2) -> check_expr fname symbols e1 ; check_expr fname symbols e2
60   | UnOp(_, e) -> check_expr fname symbols e
61   | Ternary(cond, e1, e2) -> check_expr fname symbols cond ; check_expr fname
62     symbols e1 ; check_expr fname symbols e2
63   | ReducedTernary(s1, s2, s3) -> check_expr fname symbols (Id(s1)) ; check_expr
64     fname symbols (Id(s2)) ; check_expr fname symbols (Id(s3))
65   | Id(s) -> if StringMap.mem s symbols then () else raise(UnknownVariable(fname ^
66     "(): " ^ s))
67   | Switch(Some e, cases, dflt) -> check_expr fname symbols e ; List.iter (fun c ->
68     check_case fname symbols c) cases ; check_expr fname symbols dflt
69   | Switch(None, cases, dflt) -> List.iter (fun c -> check_case fname symbols c)
70     cases ; check_expr fname symbols dflt
71   | Call(called_fname, args) ->
72     check_call fname called_fname (List.length args) ;
73     List.iter (fun a -> check_expr fname symbols a) args
74   | Selection(e, (s11, s12)) -> check_expr fname symbols e ; check_slice fname
75     symbols s11 ; check_slice fname symbols s12
76   | Precedence(e1, e2) -> check_expr fname symbols e1 ; check_expr fname symbols e2
77   (* | Debug(e) -> check_expr fname symbols e ; *)
78   | LitInt(_) | LitFlt(_) | LitRange(_) | LitString(_) | Empty -> ()
79 and check_case fname symbols (conds, e) = List.iter (fun c -> check_expr fname
80   symbols c) conds ; check_expr fname symbols e
81 and check_slice fname symbols = function
82   None -> ()
83   | Some (i1, i2) -> check_index fname symbols i1 ; check_index fname symbols i2
84 and check_index fname symbols = function
85   Some Abs(e) -> check_expr fname symbols e
86   | Some Rel(e) -> check_expr fname symbols e
87   | _ -> () in
88 let check_formula fname symbols f =
89   check_index fname symbols (Some f.formula_row_start) ;
90   check_index fname symbols f.formula_row_end ;
91   check_index fname symbols (Some f.formula_col_start) ;
92   check_index fname symbols f.formula_col_end ;
93   check_expr fname symbols f.formula_expr in
94 let check_dim fname symbols = function
95   DimOneByOne -> ()
96   | DimId(s) -> check_expr fname symbols (Id(s)) in
97 let check_variable fname symbols v =
98   check_dim fname symbols v.var_rows ;
99   check_dim fname symbols v.var_cols ;
100   List.iter (fun f -> check_formula fname symbols f) v.var_formulas in
101 let check_variables context symbols vars =
102   StringMap.iter (fun _ v -> check_variable context symbols v) vars in
103 let check_function fname f =
104   if StringMap.mem fname externs then raise(DuplicateDefinition(fname ^ "() is
105     defined as both an external and local function")) else ();
106   let locals = f.func_body in
107   let params = List.map snd f.func_params in
108   List.iter
109     (fun param ->
110       if StringMap.mem param locals then raise(DuplicateDefinition(param ^ " is
111         defined multiple times in " ^ fname ^ "()))

```

```

104     else ()
105     params ;
106     let local_symbols = create_symbol_table global_symbols f in
107     check_variables fname local_symbols f.func_body ;
108     check_expr fname local_symbols (snd f.func_ret_val)
109
110     in check_variables "global_variables" global_symbols globals ; StringMap.iter
        check_function functions

```

7.6 codeGenTypes.ml

```

1 type something = {
2   var_instance_t : Llvm.lltype;
3   subrange_t : Llvm.lltype;
4   resolved_formula_t : Llvm.lltype;
5   value_t : Llvm.lltype;
6   dimensions_t : Llvm.lltype;
7   var_defn_t : Llvm.lltype;
8   var_defn_p : Llvm.lltype;
9   string_t : Llvm.lltype;
10  number_t : Llvm.lltype;
11  extend_scope_t : Llvm.lltype;
12  formula_t : Llvm.lltype;
13  formula_call_t : Llvm.lltype;
14  formula_p : Llvm.lltype;
15  formula_call_p : Llvm.lltype;
16  var_instance_p : Llvm.lltype;
17  subrange_p : Llvm.lltype;
18  resolved_formula_p : Llvm.lltype;
19  value_p : Llvm.lltype;
20  extend_scope_p : Llvm.lltype;
21  string_p : Llvm.lltype;
22  string_p_p : Llvm.lltype;
23  var_instance_p_p : Llvm.lltype;
24  int_t : Llvm.lltype;
25  long_t : Llvm.lltype;
26  flags_t : Llvm.lltype;
27  char_t : Llvm.lltype;
28  bool_t : Llvm.lltype;
29  void_t : Llvm.lltype;
30  char_p : Llvm.lltype;
31  char_p_p : Llvm.lltype;
32  (*void_p : Llvm.lltype;*)
33  float_t : Llvm.lltype;
34  rhs_index_t : Llvm.lltype;
35  rhs_slice_t : Llvm.lltype;
36  rhs_selection_t : Llvm.lltype;
37  rhs_index_p : Llvm.lltype;
38  rhs_slice_p : Llvm.lltype;
39  rhs_selection_p : Llvm.lltype;
40 };
41
42 type scope_field_type = VarDefn | VarInst | VarNum | ScopeRefCount | FunctionParams
43 let scope_field_type_index = function
44   VarDefn -> 0

```

```

45 | VarInst -> 1
46 | VarNum -> 2
47 | ScopeRefCount -> 3
48 | FunctionParams -> 4
49
50 type value_field_flags = Empty | Number | String | Range
51 let value_field_flags_index = function
52     Empty -> 0
53     | Number -> 1
54     | String -> 2
55     | Range -> 3
56 let int_to_type_array = [|"Empty"; "Number"; "String"; "Range"|]
57
58 type value_field = Flags | Number | String | Subrange
59 let value_field_index = function
60     Flags -> 0
61     | Number -> 1
62     | String -> 2
63     | Subrange -> 3
64
65 type var_defn_field = Rows | Cols | NumFormulas | Formulas | OneByOne | VarName
66 let var_defn_field_index = function
67     Rows -> 0
68     | Cols -> 1
69     | NumFormulas -> 2
70     | Formulas -> 3
71     | OneByOne -> 4
72     | VarName -> 5
73
74 type formula_field = FromFirstRow | RowStartNum | ToLastRow | RowEndNum |
    FromFirstCols | ColStartNum | ToLastCol | ColEndNum | IsSingleRow | IsSingleCol |
    FormulaCall
75 let formula_field_index = function
76     FromFirstRow -> 0
77     | RowStartNum -> 1
78     | ToLastRow -> 2
79     | RowEndNum -> 3
80     | FromFirstCols -> 4
81     | ColStartNum -> 5
82     | ToLastCol -> 6
83     | ColEndNum -> 7
84     | IsSingleRow -> 8
85     | IsSingleCol -> 9
86     | FormulaCall -> 10
87
88 type var_instance_field = Rows | Cols | NumFormulas | Formulas | Closure | Values |
    Status
89 let var_instance_field_index = function
90     Rows -> 0
91     | Cols -> 1
92     | NumFormulas -> 2
93     | Formulas -> 3
94     | Closure -> 4
95     | Values -> 5
96     | Status -> 6
97

```

```

98 type var_instance_status_flags = NeverExamined | Calculated | InProgress
99 let var_instance_status_flags_index = function
100     NeverExamined -> 0
101     | Calculated -> 2
102     | InProgress -> 4
103
104 type subrange_field = BaseRangePtr | BaseOffsetRow | BaseOffsetCol | SubrangeRows |
    SubrangeCols
105 let subrange_field_index = function
106     BaseRangePtr -> 0
107     | BaseOffsetRow -> 1
108     | BaseOffsetCol -> 2
109     | SubrangeRows -> 3
110     | SubrangeCols -> 4
111
112 type dimensions_field = DimensionRows | DimensionCols
113 let dimensions_field_index = function
114     DimensionRows -> 0
115     | DimensionCols -> 1
116
117 type string_field = StringCharPtr | StringLen | StringRefCount
118 let string_field_index = function
119     StringCharPtr -> 0
120     | StringLen -> 1
121     | StringRefCount -> 2
122
123 type rhs_index_field = RhsExprVal | RhsIndexType
124 let rhs_index_field_index = function
125     RhsExprVal -> 0
126     | RhsIndexType -> 1
127
128 type rhs_index_type_flags = RhsIdxAbs | RhsIdxRel | RhsIdxDimStart | RhsIdxDimEnd
129 let rhs_index_type_flags_const = function
130     RhsIdxAbs -> 0
131     | RhsIdxRel -> 1
132     | RhsIdxDimStart -> 2
133     | RhsIdxDimEnd -> 4 (* No 3 *)
134
135 type rhs_slice_field = RhsSliceStartIdx | RhsSliceEndIdx
136 let rhs_slice_field_index = function
137     RhsSliceStartIdx -> 0
138     | RhsSliceEndIdx -> 1
139
140 type rhs_selection_field = RhsSelSlice1 | RhsSelSlice2
141 let rhs_selection_field_index = function
142     RhsSelSlice1 -> 0
143     | RhsSelSlice2 -> 1
144
145 let setup_types ctx =
146     let var_instance_t = LlvM.named_struct_type ctx "var_instance" (*Range struct is a 2
        D Matrix of values*)
147     and subrange_t = LlvM.named_struct_type ctx "subrange" (*Subrange is a wrapper
        around a range to cut cells*)
148     and int_t = LlvM.i32_type ctx (*Integer*)
149     and long_t = LlvM.i64_type ctx
150     and float_t = LlvM.double_type ctx

```

```

151 and flags_t = LlvM.i8_type ctx (*Flags for statuses*)
152 and char_t = LlvM.i8_type ctx (*Simple ASCII character*)
153 and bool_t = LlvM.i1_type ctx (*boolean 0 = false, 1 = true*)
154 and void_t = LlvM.void_type ctx (**)
155 and value_t = LlvM.named_struct_type ctx "value" (*Value encapsulates the content of
    a cell*)
156 and dimensions_t = LlvM.named_struct_type ctx "dimensions" (**)
157 and resolved_formula_t = LlvM.named_struct_type ctx "resolved_formula"
158 and extend_scope_t = LlvM.named_struct_type ctx "extend_scope"
159 and var_defn_t = LlvM.named_struct_type ctx "var_defn"
160 and formula_t = LlvM.named_struct_type ctx "formula"
161 and string_t = LlvM.named_struct_type ctx "string" in
162 let var_instance_p = (LlvM.pointer_type var_instance_t)
163 and var_defn_p = LlvM.pointer_type var_defn_t
164 and resolved_formula_p = (LlvM.pointer_type resolved_formula_t)
165 and subrange_p = (LlvM.pointer_type subrange_t)
166 and value_p = (LlvM.pointer_type value_t)
167 and value_p_p = (LlvM.pointer_type (LlvM.pointer_type value_t))
168 and extend_scope_p = (LlvM.pointer_type extend_scope_t)
169 and char_p = (LlvM.pointer_type char_t)
170 and string_p = (LlvM.pointer_type string_t)
171 and char_p_p = (LlvM.pointer_type (LlvM.pointer_type char_t))
172 and string_p_p = (LlvM.pointer_type (LlvM.pointer_type string_t))
173 and number_t = float_t
174 and formula_p = (LlvM.pointer_type formula_t) in
175 let rhs_index_t = LlvM.named_struct_type ctx "rhs_index"
176 and rhs_slice_t = LlvM.named_struct_type ctx "rhs_slice"
177 and rhs_selection_t = LlvM.named_struct_type ctx "rhs_selection" in
178 let rhs_index_p = LlvM.pointer_type rhs_index_t
179 and rhs_slice_p = LlvM.pointer_type rhs_slice_t
180 and rhs_selection_p = LlvM.pointer_type rhs_selection_t
181 (*and void_p = (LlvM.pointer_type void_t)*) in
182 let var_instance_p_p = (LlvM.pointer_type var_instance_p)
183 and formula_call_t = (LlvM.function_type value_p [|extend_scope_p(*scope*); int_t(*
    row*); int_t(*col*)|]) in
184 let formula_call_p = LlvM.pointer_type formula_call_t in
185 let _ = LlvM.struct_set_body rhs_index_t (Array.of_list [
186     value_p (*val_of_expr*);
187     char_t (*rhs_index_type*);
188 ]) false in
189 let _ = LlvM.struct_set_body rhs_slice_t (Array.of_list [
190     rhs_index_p (*slice start index*);
191     rhs_index_p (*slice end index*);
192 ]) false in
193 let _ = LlvM.struct_set_body rhs_selection_t (Array.of_list [
194     rhs_slice_p (*first slice*);
195     rhs_slice_p (*second slice*);
196 ]) false in
197 let _ = LlvM.struct_set_body var_instance_t (Array.of_list [
198     int_t(*rows*);
199     int_t(*columns*);
200     int_t(*numFormulas*);
201     resolved_formula_p(*formula with resolved dimensions*);
202     extend_scope_p(*scope that contains all variables of a function*);
203     value_p_p(*2D array of cell values*);
204     char_p(*2D array of calculation status for each cell*);

```

```

205     char_p(*Name*);
206   }) false
207   and _ = LlvM.struct_set_body var_defn_t (Array.of_list [
208     int_t(*Rows*);
209     int_t(*Cols*);
210     int_t(*Number of formulas*);
211     formula_p;
212     char_t(*Is one by one range*);
213     char_p(*Name*);
214   }) false
215   and _ = LlvM.struct_set_body formula_t (Array.of_list [
216     char_t (*from First row*);
217     int_t (*row Start num*);
218     char_t (*to last row*);
219     int_t (*row end num*);
220     char_t (*from first col*);
221     int_t (*col start*);
222     char_t (*to last col*);
223     int_t (*col end num*);
224     char_t (* is single row *);
225     char_t (* is single col *);
226     formula_call_p (*formula to call*);
227   }) false
228   and _ = LlvM.struct_set_body extend_scope_t (Array.of_list [
229     var_defn_p(*variable definitions*);
230     var_instance_p_p(*variable instances*);
231     int_t(*number of variables*);
232     int_t(*reference count*);
233     LlvM.pointer_type value_p;
234   }) false
235   and _ = LlvM.struct_set_body subrange_t (Array.of_list [
236     var_instance_p(*The target range*);
237     int_t(*row offset*);
238     int_t(*column offset*);
239     int_t(*row count*);
240     int_t(*column count*)
241   }) false
242   and _ = LlvM.struct_set_body value_t (Array.of_list [
243     flags_t (*First bit indicates whether it is an int or a range*);
244     number_t (*Numeric value of the cell*);
245     string_p (*String value of the cell if applicable*);
246     subrange_p (*Range value of the cell if applicable*);
247     (*float_t (Double value of the cell*)
248   }) false
249   and _ = LlvM.struct_set_body string_t (Array.of_list [
250     char_p (*Pointer to null-terminated string*);
251     long_t (*Length of string*);
252     int_t (*Reference count*)
253   }) false
254   and _ = LlvM.struct_set_body dimensions_t (Array.of_list [int_t; int_t]) false in
255   {
256     var_instance_t = var_instance_t;
257     value_t = value_t;
258     subrange_t = subrange_t;
259     resolved_formula_t = resolved_formula_t;
260     dimensions_t = dimensions_t;

```

```

261     number_t = number_t;
262     string_t = string_t;
263     extend_scope_t = extend_scope_t;
264     formula_t = formula_t;
265     formula_call_t = formula_call_t;
266
267     var_defn_t = var_defn_t;
268     var_defn_p = var_defn_p;
269     var_instance_p = var_instance_p;
270     subrange_p = subrange_p;
271     value_p = value_p;
272     resolved_formula_p = resolved_formula_p;
273     string_p = string_p;
274     char_p = char_p;
275     extend_scope_p = extend_scope_p;
276     formula_p = formula_p;
277     formula_call_p = formula_call_p;
278
279     var_instance_p_p = var_instance_p_p;
280
281     int_t = int_t;
282     long_t = long_t;
283     float_t = float_t;
284     flags_t = flags_t;
285     bool_t = bool_t;
286     char_t = char_t;
287     void_t = void_t;
288     char_p_p = char_p_p;
289     string_p_p = string_p_p;
290
291     rhs_index_t = rhs_index_t;
292     rhs_slice_t = rhs_slice_t;
293     rhs_selection_t = rhs_selection_t;
294     rhs_index_p = rhs_index_p;
295     rhs_slice_p = rhs_slice_p;
296     rhs_selection_p = rhs_selection_p;
297 }

```

7.7 codegen.ml

```

1  (* Extend code generator *)
2
3  open Ast
4  open Semant
5  open CodeGenTypes
6  exception NotImplemented
7
8  let runtime_functions = Hashtbl.create 20
9
10 let (=>) struct_ptr elem = (fun val_name builder ->
11     let the_pointer = Llvml.build_struct_gep struct_ptr elem "the_pointer" builder in
12     Llvml.build_load the_pointer val_name builder);;
13
14 let ($>) val_to_store (struct_ptr, elem) = (fun builder ->
15     let the_pointer = Llvml.build_struct_gep struct_ptr elem "" builder in

```



```

16     Llvm.build_store val_to_store the_pointer builder);;
17
18 (* from http://stackoverflow.com/questions/243864/what-is-the-ocaml-idiom-equivalent-
   to-pythons-range-function without the infix *)
19 let zero_until i =
20   let rec aux n acc =
21     if n < 0 then acc else aux (n-1) (n :: acc)
22   in aux (i-1) []
23
24 let create_runtime_functions ctx bt the_module =
25   let add_runtime_func fname returntype arglist =
26     let the_func = Llvm.declare_function fname (Llvm.function_type returntype arglist)
27       the_module
28   in Hashtbl.add runtime_functions fname the_func in
29   add_runtime_func "strlen" bt.long_t [|bt.char_p|];
30   add_runtime_func "strcmp" bt.long_t [|bt.char_p; bt.char_p|];
31   add_runtime_func "pow" bt.float_t [|bt.float_t; bt.float_t|];
32   add_runtime_func "lrint" bt.int_t [|bt.float_t|];
33   add_runtime_func "llvm.memcpy.p0i8.p0i8.i64" bt.void_t [|bt.char_p; bt.char_p; bt.
34     long_t; bt.int_t; bt.bool_t|];
35   add_runtime_func "incStack" bt.void_t [|];
36   add_runtime_func "getVal" bt.value_p [|bt.var_instance_p; bt.int_t; bt.int_t|];
37   add_runtime_func "rg_eq" bt.int_t [|bt.value_p; bt.value_p|];
38   add_runtime_func "clone_value" bt.value_p [|bt.value_p|];
39   (* add_runtime_func "freeMe" (Llvm.void_type ctx) [|bt.extend_scope_p|]; *)
40   add_runtime_func "getSize" bt.value_p [|bt.var_instance_p|];
41   add_runtime_func "get_variable" bt.var_instance_p [|bt.extend_scope_p; bt.int_t|];
42   add_runtime_func "null_init" (Llvm.void_type ctx) [|bt.extend_scope_p|];
43   add_runtime_func "debug_print" (Llvm.void_type ctx) [|bt.value_p; bt.char_p|];
44   add_runtime_func "new_string" bt.value_p [|bt.char_p|];
45   add_runtime_func "deref_subrange_p" bt.value_p [|bt.subrange_p|];
46   add_runtime_func "debug_print_selection" (Llvm.void_type ctx) [|bt.rhs_selection_p
47     |];
48   add_runtime_func "extract_selection" bt.value_p [|bt.value_p; bt.rhs_selection_p; bt
49     .int_t; bt.int_t|];
50   add_runtime_func "box_command_line_args" bt.value_p [|bt.int_t; bt.char_p_p|];
51   add_runtime_func "verify_assert" (Llvm.void_type ctx) [|bt.value_p; bt.char_p_p|];
52   ()
53
54 let translate (globals, functions, externs) =
55
56   (* LLVM Boilerplate *)
57   let context = Llvm.global_context () in
58   let base_module = Llvm.create_module context "Extend" in
59   let base_types = setup_types context in
60
61   (* Declare the runtime functions that we need to call *)
62   create_runtime_functions context base_types base_module ;
63
64   (* Build function_llvalues, which is a StringMap from function name to llvalue.
65    * It includes both functions from external libraries, such as the standard library,
66    * and functions declared within Extend. *)
67   let declare_library_function fname func accum_map =
68     let llvm_ftype = Llvm.function_type base_types.value_p (Array.of_list (List.map (
69       fun a -> base_types.value_p) func.extern_fn_params)) in
70     let llvm_fname = "extend_" ^ fname in

```

```

66     let llvm_fn = LlvM.declare_function llvm_fname llvm_ftype base_module in
67     StringMap.add fname llvm_fn accum_map in
68 let library_functions = StringMap.fold declare_library_function externs StringMap.
    empty in
69 let define_user_function fname func =
70     let llvm_fname = "extend_" ^ fname in
71     let llvm_ftype = LlvM.function_type base_types.value_p (Array.of_list (List.map (
        fun a -> base_types.value_p) func.func_params)) in
72     let llvm_fn = LlvM.define_function llvm_fname llvm_ftype base_module in
73     (func, llvm_fn) in
74 let extend_functions = StringMap.map define_user_function functions in
75 let function_llvalues = StringMap.fold StringMap.add (StringMap.map snd
    extend_functions) library_functions in
76
77 (* Build the global symbol table *)
78 let (global_symbols, num_globals) = index_map Globals globals in
79 let (extend_fn_numbers, num_extend_fns) = index_map ExtendFunctions extend_functions
    in
80
81 (* Create the global array that will hold each function's array of var_defns. *)
82 let vardefn_ptr = LlvM.const_pointer_null base_types.var_defn_p in
83 let vardefn_array = Array.make (StringMap.cardinal extend_functions) vardefn_ptr in
84 let array_of_vardefn_ptrs = LlvM.define_global "array_of_vardefn_ptrs" (LlvM.
    const_array base_types.var_defn_p vardefn_array) base_module in
85
86 (* Create the pointer to the global scope object *)
87 let global_scope_loc = LlvM.define_global "global_scope_loc" (LlvM.
    const_pointer_null base_types.extend_scope_p) base_module in
88
89 let main_def = LlvM.define_function "main" (LlvM.function_type base_types.int_t [|
    base_types.int_t; base_types.char_p_p|]) base_module in
90 let main_bod = LlvM.builder_at_end context (LlvM.entry_block main_def) in
91
92 let init_def = LlvM.define_function "initialize_vardefns" (LlvM.function_type (LlvM.
    void_type context) [|]) base_module in
93 let init_bod = LlvM.builder_at_end context (LlvM.entry_block init_def) in
94
95 let literal_def = LlvM.define_function "initialize_literals" (LlvM.function_type (
    LlvM.void_type context) [|]) base_module in
96 let literal_bod = LlvM.builder_at_end context (LlvM.entry_block literal_def) in
97
98 (* Create the array of value_ps that will contain the responses to TypeOf(val) *)
99 let null_val_ptr = LlvM.const_pointer_null base_types.value_p in
100 let null_val_array = Array.make (Array.length int_to_type_array) null_val_ptr in
101 let array_of_typeof_val_ptrs = LlvM.define_global "array_of_val_ptrs" (LlvM.
    const_array base_types.value_p null_val_array) base_module in
102 let create_typeof_string i s =
103     let sp = LlvM.build_global_stringptr s "global_typeof_stringptr" literal_bod in
104     let vp = LlvM.build_call (Hashtbl.find runtime_functions "new_string") [|sp|] "
        global_typeof_string" literal_bod in
105     let vp_dst = LlvM.build_in_bounds_gep array_of_typeof_val_ptrs [|LlvM.const_int
        base_types.int_t 0; LlvM.const_int base_types.int_t i|] ("global_typeof_dst")
        literal_bod in
106     let _ = LlvM.build_store vp vp_dst literal_bod in
107     () in
108 Array.iteri create_typeof_string int_to_type_array ;

```

```

109
110 (* Look these two up once and for all *)
111 (* let deepCopy = Hashtbl.find runtime_functions "deepCopy" in *)
112 (* let freeMe = Hashtbl.find runtime_functions "freeMe" in *)
113 let getVal = Hashtbl.find runtime_functions "getVal" in (*getVal retrieves the value
    of a variable instance for a specific x and y*)
114 let getVar = Hashtbl.find runtime_functions "get_variable" in (*getVar retrieves a
    variable instance based on the offset. It instantiates the variable if it does
    not exist yet*)
115
116 (* build_formula_function takes a symbol table and an expression, builds the LLVM
    function, and returns the llvalue of the function *)
117 let build_formula_function (varname, formula_idx) symbols formula_expr =
118     let form_decl = LlvM.define_function ("formula_fn_" ^ varname ^ "_num_" ^ (
        string_of_int formula_idx)) base_types.formula_call_t base_module in
119     let builder_at_top = LlvM.builder_at_end context (LlvM.entry_block form_decl) in
120     let local_scope = LlvM.param form_decl 0 in
121     let cell_row = LlvM.param form_decl 1 in
122     let cell_col = LlvM.param form_decl 2 in
123     let global_scope = LlvM.build_load global_scope_loc "global_scope" builder_at_top
        in
124
125     (* Some repeated stuff to avoid cut & paste *)
126     let empty_type = (LlvM.const_int base_types.char_t (value_field_flags_index Empty)
        ) in
127     let number_type = (LlvM.const_int base_types.char_t (value_field_flags_index
        Number)) in
128     let string_type = (LlvM.const_int base_types.char_t (value_field_flags_index
        String)) in
129     let range_type = (LlvM.const_int base_types.char_t (value_field_flags_index Range)
        ) in
130     let make_block blockname =
131         let new_block = LlvM.append_block context blockname form_decl in
132         let new_builder = LlvM.builder_at_end context new_block in
133         (new_block, new_builder) in
134     let store_number value_ptr store_builder number_llvalue =
135         let sp = LlvM.build_struct_gep value_ptr (value_field_index Number) "num_pointer
        " store_builder in
136         let _ = LlvM.build_store number_type (LlvM.build_struct_gep value_ptr (
        value_field_index Flags) "" store_builder) store_builder in
137         ignore (LlvM.build_store number_llvalue sp store_builder) in
138     let store_empty value_ptr store_builder =
139         ignore (LlvM.build_store empty_type (LlvM.build_struct_gep value_ptr (
        value_field_index Flags) "" store_builder) store_builder) in
140
141     let make_truthiness_blocks blockprefix ret_val =
142         let (merge_bb, merge_builder) = make_block (blockprefix ^ "_merge") in
143
144         let (make_true_bb, make_true_builder) = make_block (blockprefix ^ "_true") in
145         let _ = store_number ret_val make_true_builder (LlvM.const_float base_types.
        float_t 1.0) in
146         let _ = LlvM.build_br merge_bb make_true_builder in
147
148         let (make_false_bb, make_false_builder) = make_block (blockprefix ^ "_false") in
149         let _ = store_number ret_val make_false_builder (LlvM.const_float base_types.
        float_t 0.0) in

```

```

150     let _ = LlvM.build_br merge_bb make_false_builder in
151
152     let (make_empty_bb, make_empty_builder) = make_block (blockprefix ^ "_empty") in
153     let _ = store_empty ret_val make_empty_builder in
154     let _ = LlvM.build_br merge_bb make_empty_builder in
155
156     (make_true_bb, make_false_bb, make_empty_bb, merge_builder) in
157
158 let rec build_expr old_builder exp = match exp with
159   LitInt(i) -> let vvv = LlvM.const_float base_types.float_t (float_of_int i) in
160     let ret_val = LlvM.build_malloc base_types.value_t "int_ret_val" old_builder
161       in
162     let _ = store_number ret_val old_builder vvv in
163     (ret_val, old_builder)
164 | LitFlt(f) -> let vvv = LlvM.const_float base_types.float_t f in
165     let ret_val = LlvM.build_malloc base_types.value_t "flt_ret_val" old_builder
166       in
167     let _ = store_number ret_val old_builder vvv in
168     (ret_val, old_builder)
169 | UnOp(Neg, LitInt(i)) -> build_expr old_builder (LitInt(-i))
170 | UnOp(Neg, LitFlt(f)) -> build_expr old_builder (LitFlt(-f))
171 | Empty ->
172   let ret_val = LlvM.build_malloc base_types.value_t "empty_ret_val" old_builder
173     in
174   let _ = store_empty ret_val old_builder in
175   (ret_val, old_builder)
176 (* | Debug(e) ->
177   let (ret_val, new_builder) = build_expr old_builder e in
178   let _ = LlvM.build_call (Hashtbl.find runtime_functions "debug_print") [|
179     ret_val; LlvM.const_pointer_null base_types.char_p|] "" new_builder in
180   (ret_val, new_builder) *)
181 | Id(name) ->
182   let create_and_deref_subrange appropriate_scope i =
183     let llvm_var = LlvM.build_call getVar [|appropriate_scope; LlvM.const_int
184       base_types.int_t i|] "llvm_var" old_builder in
185     let base_var_num_rows = (llvm_var => (var_instance_field_index Rows)) "
186       base_var_num_rows" old_builder in
187     let base_var_num_cols = (llvm_var => (var_instance_field_index Cols)) "
188       base_var_num_rows" old_builder in
189     let subrange_ptr = LlvM.build_alloca base_types.subrange_t "subrange_ptr"
190       old_builder in
191     let _ = (llvm_var $> (subrange_ptr, (subrange_field_index BaseRangePtr)))
192       old_builder in
193     let _ = ((LlvM.const_null base_types.int_t) $> (subrange_ptr, (
194       subrange_field_index BaseOffsetRow))) old_builder in
195     let _ = ((LlvM.const_null base_types.int_t) $> (subrange_ptr, (
196       subrange_field_index BaseOffsetCol))) old_builder in
197     let _ = (base_var_num_rows $> (subrange_ptr, (subrange_field_index
198       SubrangeRows))) old_builder in
199     let _ = (base_var_num_cols $> (subrange_ptr, (subrange_field_index
200       SubrangeCols))) old_builder in
201     (LlvM.build_call (Hashtbl.find runtime_functions "deref_subrange_p") [|
202       subrange_ptr|] "local_id_ret_val" old_builder, old_builder) in
203   (
204     match (try StringMap.find name symbols with Not_found -> raise(LogicError("
205       Something went wrong with your semantic analysis - " ^ name ^ " not found

```

```

    "))) with
191   LocalVariable(i) -> create_and_deref_subrange local_scope i
192 | GlobalVariable(i) -> create_and_deref_subrange global_scope i
193 | FunctionParameter(i) ->
194   let paramarray = (local_scope => (scope_field_type_index FunctionParams))
    "paramarray" old_builder in
195   let param_addr = LlvM.build_in_bounds_gep paramarray [|LlvM.const_int
    base_types.int_t i|] "param_addr" old_builder in
196   let param = LlvM.build_load param_addr "param" old_builder in
197   (LlvM.build_call (Hashtbl.find runtime_functions "clone_value") [|param|]
    "function_param_ret_val" old_builder, old_builder)
198 | ExtendFunction(i) -> raise(LogicError("Something went wrong with your
    semantic analysis - function " ^ name ^ " used as variable in RHS for " ^
    varname))
199 )
200 | ReducedTernary(cond_var, true_var, false_var) ->
201   let get_llvm_var name getvar_builder =
202     match (try StringMap.find name symbols with Not_found -> raise(LogicError("
    Something went wrong with your transformation - Reduced Ternary name " ^
    name ^ " not found")) with
203     LocalVariable(i) -> LlvM.build_call getVar [|local_scope; LlvM.const_int
    base_types.int_t i|] "llvm_var" getvar_builder
204 | GlobalVariable(i) -> LlvM.build_call getVar [|global_scope; LlvM.const_int
    base_types.int_t i|] "llvm_var" getvar_builder
205 | _ -> raise(LogicError("Something went wrong with your transformation -
    Reduced Ternary name " ^ name ^ " not a local or global variable")) in
206
207   let (empty_bb, empty_builder) = make_block "empty" in
208   let (not_empty_bb, not_empty_builder) = make_block "not_empty" in
209   let (truthy_bb, truthy_builder) = make_block "truthy" in
210   let (falsey_bb, falsey_builder) = make_block "falsey" in
211   let (merge_bb, merge_builder) = make_block "merge" in
212
213   let ret_val_addr = LlvM.build_alloca base_types.value_p "tern_ret_val_addr"
    old_builder in
214   let cond_llvm_var = get_llvm_var cond_var old_builder in
215   let cond_val = LlvM.build_call getVal [|cond_llvm_var; cell_row; cell_col|] "
    cond_val" old_builder in
216   let cond_val_type = (cond_val => (value_field_index Flags)) "cond_val_type"
    old_builder in
217   let is_empty = LlvM.build_icmp LlvM.Icmp.Eq empty_type cond_val_type "is_empty
    " old_builder in
218   let _ = LlvM.build_cond_br is_empty empty_bb not_empty_bb old_builder in
219
220   (* Empty basic block: *)
221   let ret_val_empty = LlvM.build_malloc base_types.value_t "tern_empty"
    empty_builder in
222   let _ = store_empty ret_val_empty empty_builder in
223   let _ = LlvM.build_store ret_val_empty ret_val_addr empty_builder in
224   let _ = LlvM.build_br merge_bb empty_builder in
225
226   (* Not empty basic block: *)
227   let the_number = (cond_val => (value_field_index Number)) "the_number"
    not_empty_builder in
228   let is_not_zero = LlvM.build_fcmp LlvM.Fcmp.One the_number (LlvM.const_float
    base_types.number_t 0.0) "is_not_zero" not_empty_builder in (* Fcmp.One =

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    Not equal *)
229 let _ = LlvM.build_cond_br is_not_zero truthy_bb falsey_bb not_empty_builder
    in
230
231 (* Truthy basic block: *)
232 let truthy_llvm_var = get_llvm_var true_var truthy_builder in
233 let truthy_val = LlvM.build_call getVal [|truthy_llvm_var; cell_row; cell_col
    |] "truthy_val" truthy_builder in
234 let _ = LlvM.build_store truthy_val ret_val_addr truthy_builder in
235 let _ = LlvM.build_br merge_bb truthy_builder in
236
237 (* Falsey basic block: *)
238 let falsey_llvm_var = get_llvm_var false_var falsey_builder in
239 let falsey_val = LlvM.build_call getVal [|falsey_llvm_var; cell_row; cell_col
    |] "falsey_val" falsey_builder in
240 let _ = LlvM.build_store falsey_val ret_val_addr falsey_builder in
241 let _ = LlvM.build_br merge_bb falsey_builder in
242
243 let ret_val = LlvM.build_load ret_val_addr "tern_ret_val" merge_builder in
244 (ret_val, merge_builder)
245 | Selection(expr, sel) ->
246 let (expr_val, expr_builder) = build_expr old_builder expr in
247 let build_rhs_index idx_builder = function
248   Abs(e) ->
249     let (idx_expr_val, next_builder) = build_expr idx_builder e in
250     let rhs_idx_ptr = LlvM.build_alloca base_types.rhs_index_t "idx_ptr"
251     next_builder in
252     let _ = (idx_expr_val $> (rhs_idx_ptr, (rhs_index_field_index RhsExprVal))
253     ) next_builder in
254     let _ = ((LlvM.const_int base_types.char_t (rhs_index_type_flags_const
255     RhsIdxAbs)) $> (rhs_idx_ptr, (rhs_index_field_index RhsIndexType)))
256     next_builder in
257     (rhs_idx_ptr, next_builder)
258 | Rel(e) ->
259 let (idx_expr_val, next_builder) = build_expr idx_builder e in
260 let rhs_idx_ptr = LlvM.build_alloca base_types.rhs_index_t "idx_ptr"
261 next_builder in
262 let _ = (idx_expr_val $> (rhs_idx_ptr, (rhs_index_field_index RhsExprVal))
263 ) next_builder in
264 let _ = ((LlvM.const_int base_types.char_t (rhs_index_type_flags_const
265 RhsIdxRel)) $> (rhs_idx_ptr, (rhs_index_field_index RhsIndexType)))
266 next_builder in
267 (rhs_idx_ptr, next_builder)
268 | DimensionStart ->
269 let rhs_idx_ptr = LlvM.build_alloca base_types.rhs_index_t "idx_ptr"
270 idx_builder in
271 let _ = ((LlvM.const_pointer_null base_types.value_p) $> (rhs_idx_ptr, (
272 rhs_index_field_index RhsExprVal))) idx_builder in
273 let _ = ((LlvM.const_int base_types.char_t (rhs_index_type_flags_const
274 RhsIdxDimStart)) $> (rhs_idx_ptr, (rhs_index_field_index RhsIndexType))
275 ) idx_builder in
276 (rhs_idx_ptr, idx_builder)
277 | DimensionEnd ->
278 let rhs_idx_ptr = LlvM.build_alloca base_types.rhs_index_t "idx_ptr"
279 idx_builder in
280 let _ = ((LlvM.const_pointer_null base_types.value_p) $> (rhs_idx_ptr, (

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    rhs_index_field_index RhsExprVal))) idx_builder in
268 let _ = ((Llvm.const_int base_types.char_t (rhs_index_type_flags_const
    RhsIdxDimEnd)) $> (rhs_idx_ptr, (rhs_index_field_index RhsIndexType)))
    idx_builder in
269 (rhs_idx_ptr, idx_builder) in
270 let build_rhs_slice slice_builder = function
271 (Some start_idx, Some end_idx) ->
272 let rhs_slice_ptr = Llvm.build_alloca base_types.rhs_slice_t "slice_ptr"
    slice_builder in
273 let (start_idx_ptr, next_builder) = build_rhs_index slice_builder
    start_idx in
274 let (end_idx_ptr, last_builder) = build_rhs_index next_builder end_idx in
275 let _ = (start_idx_ptr $> (rhs_slice_ptr, (rhs_slice_field_index
    RhsSliceStartIdx))) last_builder in
276 let _ = (end_idx_ptr $> (rhs_slice_ptr, (rhs_slice_field_index
    RhsSliceEndIdx))) last_builder in
277 (rhs_slice_ptr, last_builder)
278 | (Some single_idx, None) ->
279 let rhs_slice_ptr = Llvm.build_alloca base_types.rhs_slice_t "slice_ptr"
    slice_builder in
280 let (single_idx_ptr, last_builder) = build_rhs_index slice_builder
    single_idx in
281 let _ = (single_idx_ptr $> (rhs_slice_ptr, (rhs_slice_field_index
    RhsSliceStartIdx))) last_builder in
282 let _ = ((Llvm.const_pointer_null base_types.rhs_index_p) $> (
    rhs_slice_ptr, (rhs_slice_field_index RhsSliceEndIdx))) last_builder in
283 (rhs_slice_ptr, last_builder)
284 | (None, None) ->
285 let rhs_slice_ptr = Llvm.build_alloca base_types.rhs_slice_t "slice_ptr"
    slice_builder in
286 let _ = ((Llvm.const_pointer_null base_types.rhs_index_p) $> (
    rhs_slice_ptr, (rhs_slice_field_index RhsSliceStartIdx))) slice_builder
    in
287 let _ = ((Llvm.const_pointer_null base_types.rhs_index_p) $> (
    rhs_slice_ptr, (rhs_slice_field_index RhsSliceEndIdx))) slice_builder
    in
288 (rhs_slice_ptr, slice_builder)
289 | (None, Some illegal_idx) -> print_endline (string_of_expr exp) ; raise (
    LogicError("This slice should not be grammatically possible")) in
290 let build_rhs_sel sel_builder = function
291 (Some first_slice, Some second_slice) ->
292 let rhs_selection_ptr = Llvm.build_alloca base_types.rhs_selection_t "
    selection_ptr" sel_builder in
293 let (first_slice_ptr, next_builder) = build_rhs_slice sel_builder
    first_slice in
294 let (second_slice_ptr, last_builder) = build_rhs_slice next_builder
    second_slice in
295 let _ = (first_slice_ptr $> (rhs_selection_ptr, (rhs_selection_field_index
    RhsSelSlice1))) last_builder in
296 let _ = (second_slice_ptr $> (rhs_selection_ptr, (
    rhs_selection_field_index RhsSelSlice2))) last_builder in
297 (rhs_selection_ptr, last_builder)
298 | (Some single_slice, None) ->
299 let rhs_selection_ptr = Llvm.build_alloca base_types.rhs_selection_t "
    selection_ptr" sel_builder in
300 let (single_slice_ptr, last_builder) = build_rhs_slice sel_builder

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    single_slice in
301   let _ = (single_slice_ptr $> (rhs_selection_ptr, (
        rhs_selection_field_index RhsSelSlice1))) last_builder in
302   let _ = ((Llvm.const_pointer_null base_types.rhs_slice_p) $> (
        rhs_selection_ptr, (rhs_selection_field_index RhsSelSlice2)))
        last_builder in
303   (rhs_selection_ptr, last_builder)
304 | (None, None) ->
305   let rhs_selection_ptr = Llvm.build_alloca base_types.rhs_selection_t "
        selection_ptr" sel_builder in
306   let _ = ((Llvm.const_pointer_null base_types.rhs_slice_p) $> (
        rhs_selection_ptr, (rhs_selection_field_index RhsSelSlice1)))
        sel_builder in
307   let _ = ((Llvm.const_pointer_null base_types.rhs_slice_p) $> (
        rhs_selection_ptr, (rhs_selection_field_index RhsSelSlice2)))
        sel_builder in
308   (rhs_selection_ptr, sel_builder)
309 | (None, Some illegal_idx) -> print_endline (string_of_expr exp) ; raise (
        LogicError("This selection should not be grammatically possible")) in
310 let (selection_ptr, builder_to_end_all_builders) = build_rhs_sel expr_builder
    sel in
311 (* let _ = Llvm.build_call (Hashtbl.find runtime_functions "
        debug_print_selection") [|selection_ptr|] "" builder_to_end_all_builders in
    *)
312 let ret_val = Llvm.build_call (Hashtbl.find runtime_functions "
        extract_selection") [|expr_val; selection_ptr; cell_row; cell_col|] "
    ret_val" builder_to_end_all_builders in
313 (* let _ = Llvm.build_call (Hashtbl.find runtime_functions "debug_print") [|
    ret_val; Llvm.const_pointer_null base_types.char_p|] ""
    builder_to_end_all_builders in *)
314 (ret_val, builder_to_end_all_builders)
315 | Precedence(a,b) -> let (_, new_builder) = build_expr old_builder a in
    build_expr new_builder b
316 | LitString(str) ->
317   let initbod_charptr = Llvm.build_global_stringptr str "initbod_charptr"
        literal_bod in
318   let initbod_val_p = Llvm.build_call (Hashtbl.find runtime_functions "
        new_string") [|initbod_charptr|] "initbod_val_p" literal_bod in
319   let global_val_p_p = Llvm.define_global "global_litstring_p" (Llvm.
        const_pointer_null base_types.value_p) base_module in
320   let _ = Llvm.build_store initbod_val_p global_val_p_p literal_bod in
321
322   let local_val_p = Llvm.build_load global_val_p_p "local_value_p" old_builder
        in
323   let ret_val = Llvm.build_call (Hashtbl.find runtime_functions "clone_value")
        [|local_val_p|] "ret_val" old_builder in
324   (ret_val, old_builder)
325 | LitRange(rl) ->
326   let num_rows = List.length rl in
327   let num_cols = List.fold_left max 0 (List.map List.length rl) in
328   if num_rows = 1 && num_cols = 1 then build_expr old_builder (List.hd (List.hd
        rl))
329   else
330     let global_val_p_p = Llvm.define_global "global_litrangle_p" (Llvm.
        const_pointer_null base_types.value_p) base_module in
331     let initbod_val_p = Llvm.build_malloc base_types.value_t "initbod_val_p"

```



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    literal_bod in
332 let _ = LlvM.build_store initbod_val_p global_val_p_p literal_bod in
333 let _ = (range_type $> (initbod_val_p, (value_field_index Flags)))
    literal_bod in
334 let anonymous_subrange_p = LlvM.build_malloc base_types.subrange_t "
    anonymous_subrange" literal_bod in
335 let _ = (anonymous_subrange_p $> (initbod_val_p, (value_field_index Subrange
    ))) literal_bod in
336
337 let _ = ((LlvM.const_int base_types.int_t 0) $> (anonymous_subrange_p, (
    subrange_field_index BaseOffsetRow))) literal_bod in
338 let _ = ((LlvM.const_int base_types.int_t 0) $> (anonymous_subrange_p, (
    subrange_field_index BaseOffsetCol))) literal_bod in
339 let _ = ((LlvM.const_int base_types.int_t num_rows) $> (anonymous_subrange_p
    , (subrange_field_index SubrangeRows))) literal_bod in
340 let _ = ((LlvM.const_int base_types.int_t num_cols) $> (anonymous_subrange_p
    , (subrange_field_index SubrangeCols))) literal_bod in
341 let anonymous_var_inst_p = LlvM.build_malloc base_types.var_instance_t "
    anonymous_var_inst" literal_bod in
342 let _ = (anonymous_var_inst_p $> (anonymous_subrange_p, (
    subrange_field_index BaseRangePtr))) literal_bod in
343
344 let _ = ((LlvM.const_int base_types.int_t num_rows) $> (anonymous_var_inst_p
    , (var_instance_field_index Rows))) literal_bod in
345 let _ = ((LlvM.const_int base_types.int_t num_cols) $> (anonymous_var_inst_p
    , (var_instance_field_index Cols))) literal_bod in
346 let _ = ((LlvM.const_int base_types.int_t 0) $> (anonymous_var_inst_p, (
    var_instance_field_index NumFormulas))) literal_bod in
347 let _ = ((LlvM.const_pointer_null base_types.resolved_formula_p) $> (
    anonymous_var_inst_p, (var_instance_field_index Formulas))) literal_bod
    in
348 let _ = ((LlvM.const_pointer_null base_types.extend_scope_p) $> (
    anonymous_var_inst_p, (var_instance_field_index Closure))) literal_bod in
349 let vals_array = LlvM.build_array_malloc base_types.value_p (LlvM.const_int
    base_types.int_t (num_rows * num_cols)) "vals_array" literal_bod in
350 let _ = (vals_array $> (anonymous_var_inst_p, (var_instance_field_index
    Values))) literal_bod in
351 let status_array = LlvM.build_array_malloc base_types.char_t (LlvM.const_int
    base_types.int_t (num_rows * num_cols)) "status_array" literal_bod in
352 let _ = (status_array $> (anonymous_var_inst_p, (var_instance_field_index
    Status))) literal_bod in
353
354 let get_val_p e = let (vp, _) = build_expr literal_bod e in vp in
355 let val_p_list_list = List.map (fun x -> List.map get_val_p x) rl in
356 let cellnums = zero_until (num_rows * num_cols) in
357 let build_empty x =
358     let emptyval = LlvM.build_malloc base_types.value_t (" " ^ (string_of_int x
    )) literal_bod in
359     let _ = store_empty emptyval literal_bod in
360     let emptydst = LlvM.build_in_bounds_gep vals_array [|LlvM.const_int
    base_types.int_t x|] " " literal_bod in
361     let _ = LlvM.build_store emptyval emptydst literal_bod in
362     let statusdst = LlvM.build_in_bounds_gep status_array [|LlvM.const_int
    base_types.int_t x|] " " literal_bod in
363     let _ = LlvM.build_store (LlvM.const_int base_types.char_t (
    var_instance_status_flags_index Calculated)) statusdst literal_bod in

```

```

364     () in
365     List.iter build_empty cellnums ;
366     let store_val r c realval =
367         let realdst = LlvM.build_in_bounds_gep vals_array [|LlvM.const_int
            base_types.int_t (r * num_cols + c)|] ("litrangeelemdst" ^ (
            string_of_int r) ^ "_" ^ (string_of_int c)) literal_bod in
368         let _ = LlvM.build_store realval realdst literal_bod in
369     () in
370     let store_row r cols = List.iteri (fun c v -> store_val r c v) cols in
371     List.iteri store_row val_p_list_list ;
372     (* let _ = LlvM.build_call (Hashtbl.find runtime_functions "debug_print") [|
        initbod_val_p; LlvM.const_pointer_null base_types.char_p|] "" literal_bod
        in *)
373
374     let local_val_p = LlvM.build_load global_val_p_p "local_value_p" old_builder
        in
375     (* let _ = LlvM.build_call (Hashtbl.find runtime_functions "debug_print") [|
        local_val_p; LlvM.const_pointer_null base_types.char_p|] "" old_builder
        in *)
376     let ret_val = LlvM.build_call (Hashtbl.find runtime_functions "clone_value")
        [|local_val_p|] "ret_val" old_builder in
377     (* let _ = LlvM.build_call (Hashtbl.find runtime_functions "debug_print") [|
        ret_val; LlvM.const_pointer_null base_types.char_p|] "" old_builder in *)
378     (ret_val, old_builder)
379 | Call(fn,exl) -> (*TODO: Call needs to be reviewed. Possibly switch call
    arguments to value_p*)
380     let build_one_expr (arg_list, intermediate_builder) e =
381         let (arg_val, next_builder) = build_expr intermediate_builder e in
382         (arg_val :: arg_list, next_builder) in
383     let (reversed_arglist, call_builder) = List.fold_left build_one_expr ([],
        old_builder) exl in
384     let args = Array.of_list (List.rev reversed_arglist) in
385     let result = LlvM.build_call (
386         StringMap.find fn function_llvalues
387         ) args "call_ret_val" call_builder in
388     (result, call_builder)
389 | BinOp(expr1,op,expr2) -> (
390     let (val1, builder1) = build_expr old_builder expr1 in
391     let (val2, int_builder) = build_expr builder1 expr2 in
392     let bit_shift = (LlvM.const_int base_types.char_t 4) in
393     let expr1_type = (val1 => (value_field_index Flags)) "expr1_type"
        int_builder in
394     let expr2_type = (val2 => (value_field_index Flags)) "expr2_type"
        int_builder in
395     let expr1_type_shifted = LlvM.build_shl expr1_type bit_shift "
        expr_1_type_shifted" int_builder in
396     let combined_type = LlvM.build_add expr1_type_shifted expr2_type "
        combined_type" int_builder in
397     let number_number = LlvM.const_add (LlvM.const_shl number_type bit_shift)
        number_type in
398     let string_string = LlvM.const_add (LlvM.const_shl string_type bit_shift)
        string_type in
399     let empty_empty = LlvM.const_add (LlvM.const_shl empty_type bit_shift)
        empty_type in
400     let range_range = LlvM.const_add (LlvM.const_shl range_type bit_shift)
        range_type in

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401     let build_simple_binop oppp int_builder =
402         (let ret_val = LlvM.build_malloc base_types.value_t "binop_minus_ret_val"
403           int_builder in
404           let _ = LlvM.build_store
405             (
406               LlvM.const_int
407               base_types.char_t
408               (value_field_flags_index Empty)
409             ) (
410               LlvM.build_struct_gep
411               ret_val
412               (value_field_index Flags)
413               ""
414               int_builder
415             )
416           in
417           let bailout = (LlvM.append_block context "" form_decl) in
418           let bbailout = LlvM.builder_at_end context bailout in
419           let (numnum_bb, numnum_builder) = make_block "numnum" in
420           let numeric_val_1 = (val1 => (value_field_index Number)) "number_one"
421             numnum_builder in
422           let numeric_val_2 = (val2 => (value_field_index Number)) "number_two"
423             numnum_builder in
424           let numeric_res = oppp numeric_val_1 numeric_val_2 "numeric_res"
425             numnum_builder in
426           let _ = LlvM.build_store
427             numeric_res (
428               LlvM.build_struct_gep
429               ret_val
430               (value_field_index Number)
431               ""
432               numnum_builder
433             )
434           numnum_builder in
435           let _ = LlvM.build_store
436             (
437               LlvM.const_int
438               base_types.char_t
439               (value_field_flags_index Number)
440             ) (
441               LlvM.build_struct_gep
442               ret_val
443               (value_field_index Flags)
444               ""
445               numnum_builder
446             )
447           numnum_builder in
448           let _ = LlvM.build_br bailout numnum_builder in
449           let _ = LlvM.build_cond_br (LlvM.build_icmp LlvM.Icmp.Eq combined_type
450             number_number "" int_builder) numnum_bb bailout int_builder in
451           (ret_val, bbailout)
452         )
453     and build_simple_int_binop oppp int_builder =
454         (let ret_val = LlvM.build_malloc base_types.value_t "binop_minus_ret_val"
455           int_builder in

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```

451     let _ = LlvM.build_store
452     (
453         LlvM.const_int
454         base_types.char_t
455         (value_field_flags_index Empty)
456     ) (
457         LlvM.build_struct_gep
458         ret_val
459         (value_field_index Flags)
460         ""
461         int_builder
462     )
463     int_builder
464 in
465     let bailout = (LlvM.append_block context "" form_decl) in
466     let bbailout = LlvM.builder_at_end context bailout in
467     let (numnum_bb, numnum_builder) = make_block "numnum" in
468     let roundfl x = LlvM.build_call (Hashtbl.find runtime_functions "lrint
469 ") [|x|] "" numnum_builder in
470     let numeric_val_1 = roundfl ((val1 => (value_field_index Number)) "
471     number_one" numnum_builder) in
472     let numeric_val_2 = roundfl ((val2 => (value_field_index Number)) "
473     number_two" numnum_builder) in
474     let numeric_res = oppp numeric_val_1 numeric_val_2 "numeric_res"
475     numnum_builder in
476     let _ = LlvM.build_store
477     (LlvM.build_sitofp numeric_res base_types.float_t "" numnum_builder
478     )
479     (
480         LlvM.build_struct_gep
481         ret_val
482         (value_field_index Number)
483         ""
484         numnum_builder
485     )
486     numnum_builder in
487     let _ = LlvM.build_store
488     (
489         LlvM.const_int
490         base_types.char_t
491         (value_field_flags_index Number)
492     ) (
493         LlvM.build_struct_gep
494         ret_val
495         (value_field_index Flags)
496         ""
497         numnum_builder
498     )
499     numnum_builder in
500     let _ = LlvM.build_br bailout numnum_builder in
501     let _ = LlvM.build_cond_br (LlvM.build_icmp LlvM.Icmp.Eq combined_type
502     number_number "" int_builder) numnum_bb bailout int_builder in
503     (ret_val, bbailout)
504 ) in
505 let build_boolean_op numeric_comparator string_comparator int_builder =
506     let ret_val = LlvM.build_malloc base_types.value_t "binop_gt_ret_val"

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501         int_builder in
502     let (make_true_bb, make_false_bb, make_empty_bb, merge_builder) =
503         make_truthiness_blocks "binop_eq" ret_val in
504
505     let (numnum_bb, numnum_builder) = make_block "numnum" in
506     let numeric_val_1 = (val1 => (value_field_index Number)) "number_one"
507     numnum_builder in
508     let numeric_val_2 = (val2 => (value_field_index Number)) "number_two"
509     numnum_builder in
510     let numeric_greater = LlvM.build_fcmp numeric_comparator numeric_val_1
511     numeric_val_2 "numeric_greater" numnum_builder in
512     let _ = LlvM.build_cond_br numeric_greater make_true_bb make_false_bb
513     numnum_builder in
514
515     let (strsr_bb, strsr_builder) = make_block "strsr" in
516     let str_p_1 = (val1 => (value_field_index String)) "string_one"
517     strsr_builder in
518     let str_p_2 = (val2 => (value_field_index String)) "string_two"
519     strsr_builder in
520     let char_p_1 = (str_p_1 => (string_field_index StringCharPtr)) "char_p_one"
521     " strsr_builder in
522     let char_p_2 = (str_p_2 => (string_field_index StringCharPtr)) "char_p_two"
523     " strsr_builder in
524     let strcmp_result = LlvM.build_call (Hashtbl.find runtime_functions "
525     strcmp") [|char_p_1; char_p_2|] "strcmp_result" strsr_builder in
526     let string_greater = LlvM.build_icmp string_comparator strcmp_result (LlvM
527     .const_null base_types.long_t) "string_greater" strsr_builder in
528     let _ = LlvM.build_cond_br string_greater make_true_bb make_false_bb
529     strsr_builder in
530
531     let switch_inst = LlvM.build_switch combined_type make_empty_bb 2
532     int_builder in (* Incompatible ==> default to empty *)
533     LlvM.add_case switch_inst number_number numnum_bb;
534     LlvM.add_case switch_inst string_string strsr_bb;
535     (ret_val, merge_builder) in
536 match op with
537 | Minus -> build_simple_binop LlvM.build_fsub int_builder
538 | Plus ->
539     let result = LlvM.build_malloc base_types.value_t "" int_builder
540     and stradd = (LlvM.append_block context "" form_decl)
541     and numadd = (LlvM.append_block context "" form_decl)
542     and bailout = (LlvM.append_block context "" form_decl)
543     and numorstorother = (LlvM.append_block context "" form_decl)
544     and storother = (LlvM.append_block context "" form_decl)
545     in
546     let bstradd = LlvM.builder_at_end context stradd
547     and bnumadd = LlvM.builder_at_end context numadd
548     and bnumorstorother = LlvM.builder_at_end context numorstorother
549     and bstorother = LlvM.builder_at_end context storother
550     and bbailout = LlvM.builder_at_end context bailout
551     and _ = LlvM.build_store (LlvM.const_int base_types.char_t (
552     value_field_flags_index Empty)) (LlvM.build_struct_gep result (
553     value_field_index Flags) "" int_builder) int_builder
554     in
555     let isnumber = LlvM.build_icmp LlvM.Icmp.Eq (LlvM.build_load (LlvM.
556     build_struct_gep val1 (value_field_index Flags) "" bnumorstorother)

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```

    "" bnumorstrorother) (Llvm.const_int base_types.char_t (
    value_field_flags_index Number)) "" bnumorstrorother
540 and isstring = Llvm.build_icmp Llvm.Icmp.Eq (Llvm.build_load (Llvm.
    build_struct_gep val1 (value_field_index Flags) "" bstrorother) ""
    bstrorother) (Llvm.const_int base_types.char_t (
    value_field_flags_index String)) "" bstrorother
541 and isnumorstring = Llvm.build_icmp Llvm.Icmp.Eq (Llvm.build_load (Llvm.
    build_struct_gep val1 (value_field_index Flags) "" int_builder) ""
    int_builder) (Llvm.build_load (Llvm.build_struct_gep val2 (
    value_field_index Flags) "" int_builder) "" int_builder) ""
    int_builder
542 and _ = Llvm.build_store (Llvm.build_fadd (Llvm.build_load (Llvm.
    build_struct_gep val1 (value_field_index Number) "" bnumadd) ""
    bnumadd) (Llvm.build_load (Llvm.build_struct_gep val2 (
    value_field_index Number) "" bnumadd) "" bnumadd) "" bnumadd) (Llvm.
    build_struct_gep result (value_field_index Number) "" bnumadd)
    bnumadd
543 and _ = Llvm.build_store (Llvm.const_int base_types.char_t (
    value_field_flags_index Number)) (Llvm.build_struct_gep result (
    value_field_index Flags) "" bnumadd) bnumadd
544 and str1 = Llvm.build_load (Llvm.build_struct_gep val1 (
    value_field_index String) "" bstradd) "" bstradd
545 and str2 = Llvm.build_load (Llvm.build_struct_gep val2 (
    value_field_index String) "" bstradd) "" bstradd
546 and newstr = (Llvm.build_malloc base_types.string_t "" bstradd) in
547 let len1 = Llvm.build_load (Llvm.build_struct_gep str1 (
    string_field_index StringLen) "" bstradd) "" bstradd
548 and len2 = Llvm.build_load (Llvm.build_struct_gep str2 (
    string_field_index StringLen) "" bstradd) "" bstradd
549 and p1 = Llvm.build_load (Llvm.build_struct_gep str1 (string_field_index
    StringCharPtr) "" bstradd) "" bstradd
550 and p2 = Llvm.build_load (Llvm.build_struct_gep str2 (string_field_index
    StringCharPtr) "" bstradd) "" bstradd
551 and dst_char_ptr_ptr = (Llvm.build_struct_gep newstr (string_field_index
    StringCharPtr) "" bstradd)
552 and _ = Llvm.build_store (Llvm.const_int base_types.char_t (
    value_field_flags_index String)) (Llvm.build_struct_gep result (
    value_field_index Flags) "" bstradd) bstradd
553 and _ = Llvm.build_store newstr (Llvm.build_struct_gep result (
    value_field_index String) "" bstradd) bstradd in
554 let fullLen = Llvm.build_nsw_add (Llvm.build_nsw_add len1 len2 ""
    bstradd) (Llvm.const_int base_types.long_t 1) "" bstradd
555 and extra_byte2 = (Llvm.build_add len2 (Llvm.const_int base_types.long_t
    1) "" bstradd) in
556 let dst_char = Llvm.build_array_malloc base_types.char_t (Llvm.
    build_trunc fullLen base_types.int_t "" bstradd) "" bstradd in
557 let dst_char2 = Llvm.build_in_bounds_gep dst_char [|len1|] "" bstradd in
558 let _ = Llvm.build_call (Hashtbl.find runtime_functions "llvm.memcpy.
    p0i8.p0i8.i64") [|dst_char; p1; len1; (Llvm.const_int base_types.
    int_t 0); (Llvm.const_int base_types.bool_t 0)|] "" bstradd
559 and _ = Llvm.build_call (Hashtbl.find runtime_functions "llvm.memcpy.
    p0i8.p0i8.i64") [|dst_char2; p2; extra_byte2; (Llvm.const_int
    base_types.int_t 0); (Llvm.const_int base_types.bool_t 0)|] ""
    bstradd
560 and _ = Llvm.build_store dst_char dst_char_ptr_ptr bstradd
561 in

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```

562     let _ = LlvM.build_store (LlvM.build_nsw_add fullLen (LlvM.const_int
      base_types.long_t (-1)) "" bstradd) (LlvM.build_struct_gep newstr (
      string_field_index StringLen) "" bstradd) bstradd
563   in
564   let _ = LlvM.build_cond_br isnumorstring numorstorother bailout
      int_builder
565   and _ = LlvM.build_cond_br isnumber numadd storother bnumorstorother
566   and _ = LlvM.build_cond_br isstring stradd bailout bstorother
567   and _ = LlvM.build_br bailout bstradd
568   and _ = LlvM.build_br bailout bnumadd
569   in
570   (result, bbailout)
571 | Times -> build_simple_binop LlvM.build_fmul int_builder
572 | Eq ->
573   (* let _ = LlvM.build_call (Hashtbl.find runtime_functions "debug_print")
      [|val1; LlvM.build_global_stringptr "Eq operator - value 1" ""
      old_builder|] "" int_builder in
574   let _ = LlvM.build_call (Hashtbl.find runtime_functions "debug_print") [|
      val2; LlvM.build_global_stringptr "Eq operator - value 2" ""
      old_builder|] "" int_builder in *)
575   let ret_val = LlvM.build_malloc base_types.value_t "binop_eq_ret_val"
      int_builder in
576   let (make_true_bb, make_false_bb, _, merge_builder) =
      make_truthiness_blocks "binop_eq" ret_val in
577
578   let (numnum_bb, numnum_builder) = make_block "numnum" in
579   let numeric_val_1 = (val1 => (value_field_index Number)) "number_one"
      numnum_builder in
580   let numeric_val_2 = (val2 => (value_field_index Number)) "number_two"
      numnum_builder in
581   let numeric_equality = LlvM.build_fcmp LlvM.Fcmp.Oeq numeric_val_1
      numeric_val_2 "numeric_equality" numnum_builder in
582   let _ = LlvM.build_cond_br numeric_equality make_true_bb make_false_bb
      numnum_builder in
583
584   let (strsr_bb, strsr_builder) = make_block "strsr" in
585   let str_p_1 = (val1 => (value_field_index String)) "string_one"
      strsr_builder in
586   let str_p_2 = (val2 => (value_field_index String)) "string_two"
      strsr_builder in
587   let char_p_1 = (str_p_1 => (string_field_index StringCharPtr)) "char_p_one"
      " strsr_builder in
588   let char_p_2 = (str_p_2 => (string_field_index StringCharPtr)) "char_p_two"
      " strsr_builder in
589   let strcmp_result = LlvM.build_call (Hashtbl.find runtime_functions "
      strcmp") [|char_p_1; char_p_2|] "strcmp_result" strsr_builder in
590   let string_equality = LlvM.build_icmp LlvM.Icmp.Eq strcmp_result (LlvM.
      const_null base_types.long_t) "string_equality" strsr_builder in
591   let _ = LlvM.build_cond_br string_equality make_true_bb make_false_bb
      strsr_builder in
592
593   let (rngrng_bb, rngrng_builder) = make_block "rngrng" in
594   (* TODO: Make this case work *)
595   let eqt = LlvM.build_is_not_null (LlvM.build_call (Hashtbl.find
      runtime_functions "rg_eq") [|val1; val2|] "" rngrng_builder) ""
      rngrng_builder in

```

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596         let _ = LlvM.build_cond_br eqt make_true_bb make_false_bb rngrng_builder
597             in
598         let switch_inst = LlvM.build_switch combined_type make_false_bb 4
599             int_builder in (* Incompatible ==> default to false *)
600         LlvM.add_case switch_inst number_number numnum_bb;
601         LlvM.add_case switch_inst string_string strstr_bb;
602         LlvM.add_case switch_inst range_range rngrng_bb;
603         LlvM.add_case switch_inst empty_empty make_true_bb; (* Nothing to check in
604             this case, just return true *)
605         (ret_val, merge_builder)
606     | Gt -> build_boolean_op LlvM.Fcmp.Ogt LlvM.Icmp.Sgt int_builder
607     | GtEq -> build_boolean_op LlvM.Fcmp.Oge LlvM.Icmp.Sge int_builder
608     | Lt -> build_boolean_op LlvM.Fcmp.Olt LlvM.Icmp.Slt int_builder
609     | LtEq -> build_boolean_op LlvM.Fcmp.Ole LlvM.Icmp.Sle int_builder
610     | LogAnd | LogOr -> raise (TransformedAway("&& and || should have been
611         transformed into a short-circuit ternary expression! Error in the
612         following expression:\n" ^ string_of_expr exp))
613     | Divide -> build_simple_binop LlvM.build_fdiv int_builder
614     | Mod -> build_simple_binop LlvM.build_frem int_builder
615     | Pow -> (
616         let powcall numeric_val_1 numeric_val_2 valname b =
617             LlvM.build_call (Hashtbl.find runtime_functions "pow") [|numeric_val_1;
618                 numeric_val_2|] "" b in
619         build_simple_binop powcall int_builder)
620     | LShift -> build_simple_int_binop LlvM.build_shl int_builder
621     | RShift -> build_simple_int_binop LlvM.build_lshr int_builder
622     | BitOr -> build_simple_int_binop LlvM.build_or int_builder
623     | BitAnd -> build_simple_int_binop LlvM.build_and int_builder
624     | BitXor -> build_simple_int_binop LlvM.build_xor int_builder
625 )
626 | UnOp(SizeOf,expr) ->
627     let ret_val = LlvM.build_malloc base_types.value_t "unop_size_ret_val"
628         old_builder in
629     (* TODO: We actually have to keep track of these anonymous objects somewhere
630         so we can free them *)
631     let _ = (range_type $> (ret_val, (value_field_index Flags))) old_builder in
632     let anonymous_subrange_p = LlvM.build_malloc base_types.subrange_t "
633         anonymous_subrange" old_builder in
634     let _ = (anonymous_subrange_p $> (ret_val, (value_field_index Subrange)))
635         old_builder in
636     let _ = ((LlvM.const_int base_types.int_t 0) $> (anonymous_subrange_p, (
637         subrange_field_index BaseOffsetRow))) old_builder in
638     let _ = ((LlvM.const_int base_types.int_t 0) $> (anonymous_subrange_p, (
639         subrange_field_index BaseOffsetCol))) old_builder in
640     let _ = ((LlvM.const_int base_types.int_t 1) $> (anonymous_subrange_p, (
641         subrange_field_index SubrangeRows))) old_builder in
642     let _ = ((LlvM.const_int base_types.int_t 2) $> (anonymous_subrange_p, (
643         subrange_field_index SubrangeCols))) old_builder in
644     let anonymous_var_inst_p = LlvM.build_malloc base_types.var_instance_t "
645         anonymous_var_inst" old_builder in
646     let _ = (anonymous_var_inst_p $> (anonymous_subrange_p, (subrange_field_index
647         BaseRangePtr))) old_builder in

```



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636 let _ = ((Llvm.const_int base_types.int_t 1) $> (anonymous_var_inst_p, (
var_instance_field_index Rows))) old_builder in
637 let _ = ((Llvm.const_int base_types.int_t 2) $> (anonymous_var_inst_p, (
var_instance_field_index Cols))) old_builder in
638 let _ = ((Llvm.const_int base_types.int_t 0) $> (anonymous_var_inst_p, (
var_instance_field_index NumFormulas))) old_builder in
639 let _ = ((Llvm.const_pointer_null base_types.resolved_formula_p) $> (
anonymous_var_inst_p, (var_instance_field_index Formulas))) old_builder in
640 let _ = ((Llvm.const_pointer_null base_types.extend_scope_p) $> (
anonymous_var_inst_p, (var_instance_field_index Closure))) old_builder in
641 let num_rows_val = Llvm.build_malloc base_types.value_t "num_rows_val"
old_builder in
642 let num_cols_val = Llvm.build_malloc base_types.value_t "num_cols_val"
old_builder in
643 let vals_array = Llvm.build_array_malloc base_types.value_p (Llvm.const_int
base_types.int_t 2) "vals_array" old_builder in
644 let _ = (vals_array $> (anonymous_var_inst_p, (var_instance_field_index Values
))) old_builder in
645 let _ = Llvm.build_store num_rows_val (Llvm.build_in_bounds_gep vals_array [|
Llvm.const_int base_types.int_t 0|] "" old_builder) old_builder in
646 let _ = Llvm.build_store num_cols_val (Llvm.build_in_bounds_gep vals_array [|
Llvm.const_int base_types.int_t 1|] "" old_builder) old_builder in
647 let status_array = Llvm.build_array_malloc base_types.char_t (Llvm.const_int
base_types.int_t 2) "status_array" old_builder in
648 let _ = (status_array $> (anonymous_var_inst_p, (var_instance_field_index
Status))) old_builder in
649 let _ = Llvm.build_store (Llvm.const_int base_types.char_t (
var_instance_status_flags_index Calculated)) (Llvm.build_in_bounds_gep
status_array [|Llvm.const_int base_types.int_t 0|] "" old_builder)
old_builder in
650 let _ = Llvm.build_store (Llvm.const_int base_types.char_t (
var_instance_status_flags_index Calculated)) (Llvm.build_in_bounds_gep
status_array [|Llvm.const_int base_types.int_t 1|] "" old_builder)
old_builder in
651
652 let (expr_val, expr_builder) = build_expr old_builder expr in
653 let val_flags = (expr_val => (value_field_index Flags)) "val_flags"
expr_builder in
654 let is_subrange = Llvm.build_icmp Llvm.Icmp.Eq val_flags range_type "
is_subrange" expr_builder in
655
656 let (merge_bb, merge_builder) = make_block "merge" in
657
658 let (primitive_bb, primitive_builder) = make_block "primitive" in
659 let _ = store_number num_rows_val primitive_builder (Llvm.const_float
base_types.float_t 1.0) in
660 let _ = store_number num_cols_val primitive_builder (Llvm.const_float
base_types.float_t 1.0) in
661 let _ = Llvm.build_br merge_bb primitive_builder in
662
663 let (subrange_bb, subrange_builder) = make_block "subrange" in
664 let subrange_ptr = (expr_val => (value_field_index Subrange)) "subrange_ptr"
subrange_builder in
665 let rows_as_int = (subrange_ptr => (subrange_field_index SubrangeRows)) "
rows_as_int" subrange_builder in
666 let cols_as_int = (subrange_ptr => (subrange_field_index SubrangeCols)) "

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        cols_as_int" subrange_builder in
667   let rows_as_float = LlvM.build_sitofp rows_as_int base_types.float_t "
        rows_as_float" subrange_builder in
668   let cols_as_float = LlvM.build_sitofp cols_as_int base_types.float_t "
        cols_as_float" subrange_builder in
669   let _ = store_number num_rows_val subrange_builder rows_as_float in
670   let _ = store_number num_cols_val subrange_builder cols_as_float in
671   let _ = LlvM.build_br merge_bb subrange_builder in
672
673   let _ = LlvM.build_cond_br is_subrange subrange_bb primitive_bb expr_builder
        in
674   (ret_val, merge_builder)
675 | UnOp(Truthy, expr) ->
676   let ret_val = LlvM.build_malloc base_types.value_t "unop_truthy_ret_val"
        old_builder in
677   let (expr_val, expr_builder) = build_expr old_builder expr in
678
679   let (truthy_bb, falsey_bb, empty_bb, merge_builder) = make_truthiness_blocks "
        unop_truthy" ret_val in
680
681   let expr_flags = (expr_val => (value_field_index Flags)) "expr_flags"
        expr_builder in
682   let is_empty_bool = (LlvM.build_icmp LlvM.Icmp.Eq expr_flags (LlvM.const_int
        base_types.flags_t (value_field_flags_index Empty)) "is_empty_bool"
        expr_builder) in
683   let is_empty = LlvM.build_zext is_empty_bool base_types.char_t "is_empty"
        expr_builder in
684   let is_empty_two = LlvM.build_shl is_empty (LlvM.const_int base_types.char_t
        1) "is_empty_two" expr_builder in
685   let is_number = LlvM.build_icmp LlvM.Icmp.Eq expr_flags (LlvM.const_int
        base_types.flags_t (value_field_flags_index Number)) "is_number"
        expr_builder in
686   let the_number = (expr_val => (value_field_index Number)) "the_number"
        expr_builder in
687   let is_zero = LlvM.build_fcmp LlvM.Fcmp.Oeq the_number (LlvM.const_float
        base_types.number_t 0.0) "is_zero" expr_builder in
688   let is_numeric_zero_bool = LlvM.build_and is_zero is_number "
        is_numeric_zero_bool" expr_builder in
689   let is_numeric_zero = LlvM.build_zext is_numeric_zero_bool base_types.char_t "
        is_numeric_zero" expr_builder in
690   let switch_num = LlvM.build_add is_empty_two is_numeric_zero "switch_num"
        expr_builder in
691   let switch_inst = LlvM.build_switch switch_num empty_bb 2 expr_builder in
692   LlvM.add_case switch_inst (LlvM.const_int base_types.char_t 0) truthy_bb; (*
        empty << 1 + is_zero == 0 ==> truthy *)
693   LlvM.add_case switch_inst (LlvM.const_int base_types.char_t 1) falsey_bb; (*
        empty << 1 + is_zero == 1 ==> falsey *)
694   (ret_val, merge_builder)
695 | UnOp(LogNot, expr) ->
696   let (truth_val, truth_builder) = build_expr old_builder (UnOp(Truthy, expr))
        in
697   let the_number = (truth_val => (value_field_index Number)) "the_number"
        truth_builder in
698   let not_the_number = LlvM.build_fsub (LlvM.const_float base_types.float_t 1.0)
        the_number "not_the_number" truth_builder in
699   let sp = LlvM.build_struct_gep truth_val (value_field_index Number) "

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    num_pointer" truth_builder in
700   let _ = LlvM.build_store not_the_number sp truth_builder in
701   (truth_val, truth_builder)
702 | UnOp(Neg, expr) ->
703   let ret_val = LlvM.build_malloc base_types.value_t "unop_truthy_ret_val"
    old_builder in
704   let _ = store_empty ret_val old_builder in
705   let (expr_val, expr_builder) = build_expr old_builder expr in
706   let expr_type = (expr_val => (value_field_index Flags)) "expr_type"
    expr_builder in
707   let is_number = LlvM.build_icmp LlvM.Icmp.Eq expr_type number_type "is_number"
    expr_builder in
708   let (finish_bb, finish_builder) = make_block "finish" in
709
710   let (number_bb, number_builder) = make_block "number" in
711   let the_number = (expr_val => (value_field_index Number)) "the_number"
    number_builder in
712   let minus_the_number = LlvM.build_fneg the_number "minus_the_number"
    number_builder in
713   let _ = store_number ret_val number_builder minus_the_number in
714   let _ = LlvM.build_br finish_bb number_builder in
715
716   let _ = LlvM.build_cond_br is_number number_bb finish_bb expr_builder in
717   (ret_val, finish_builder)
718 | UnOp(BitNot, expr) ->
719   let ret_val = LlvM.build_malloc base_types.value_t "unop_truthy_ret_val"
    old_builder in
720   let (expr_val, expr_builder) = build_expr old_builder expr in
721
722   let (numnum_bb, numnum_builder) = make_block "numnum" in
723   let (make_empty_bb, make_empty_builder) = make_block (" " ^ "_empty") in
724   let (finish_bb, finish_builder) = make_block "finish" in
725
726   let _ = store_empty ret_val make_empty_builder in
727   let _ = LlvM.build_br finish_bb make_empty_builder in
728
729   let expr_type = (expr_val => (value_field_index Flags)) "expr_type"
    expr_builder in
730   let is_number = LlvM.build_icmp LlvM.Icmp.Eq expr_type number_type "is_number"
    expr_builder in
731   let _ = LlvM.build_cond_br is_number numnum_bb make_empty_bb expr_builder in
732
733   let expr_num = LlvM.build_call (Hashtbl.find runtime_functions "lrint") [|((
    expr_val => (value_field_index Number)) "expr_type" numnum_builder)|] " "
    numnum_builder in
734   let _ = store_number ret_val numnum_builder (LlvM.build_sitofp (LlvM.build_not
    expr_num " " numnum_builder) base_types.float_t " " numnum_builder) in
735   let _ = LlvM.build_br finish_bb numnum_builder in
736
737   (ret_val, finish_builder)
738 | UnOp(TypeOf, expr) ->
739   let (expr_val, expr_builder) = build_expr old_builder expr in
740   let expr_type = (expr_val => (value_field_index Flags)) "expr_type"
    expr_builder in
741   let vp_to_clone_loc = LlvM.build_in_bounds_gep array_of_typeof_val_ptrs [|LlvM
    .const_int base_types.int_t 0; expr_type|] ("vp_to_clone_log") expr_builder

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742         in
743         let vp_to_clone = LlvM.build_load vp_to_clone_loc "vp_to_clone" expr_builder
744         in
745         let ret_val = LlvM.build_call (Hashtbl.find runtime_functions "clone_value")
746         [|vp_to_clone|] "typeof_ret_val" expr_builder in
747         (ret_val, expr_builder)
748     | UnOp(Row, _) ->
749         let row_as_int = cell_row in
750         let row_as_float = LlvM.build_sitofp row_as_int base_types.float_t "
751         row_as_float" old_builder in
752         let ret_val = LlvM.build_malloc base_types.value_t "ret_val" old_builder in
753         let _ = store_number ret_val old_builder row_as_float in
754         (ret_val, old_builder)
755     | UnOp(Column, _) ->
756         let col_as_int = cell_col in
757         let col_as_float = LlvM.build_sitofp col_as_int base_types.float_t "
758         col_as_float" old_builder in
759         let ret_val = LlvM.build_malloc base_types.value_t "ret_val" old_builder in
760         let _ = store_number ret_val old_builder col_as_float in
761         (ret_val, old_builder)
762     | Switch(_,_,_) | Ternary(_,_,_) -> raise(TransformedAway("These expressions
763     should have been transformed away")) in
764     (* | unknown_expr -> print_endline (string_of_expr unknown_expr);raise
765     NotImplemented in *)
766     let (ret_value_p, final_builder) = build_expr builder_at_top formula_expr in
767     let _ = LlvM.build_ret ret_value_p final_builder in
768     form_decl in
769
770 (*build formula creates a formula declaration in a separate method from the function
771 it belongs to*)
772 let build_formula (varname, idx) formula_array element symbols =
773     let storage_addr = LlvM.build_in_bounds_gep formula_array [|LlvM.const_int
774     base_types.int_t idx|] "" init_bod in
775     let getStarts = function (* Not really just for starts *)
776     Abs(LitInt(1)) | Abs(LitInt(0)) | DimensionStart | DimensionEnd -> (1, -1)
777     | Abs(Id(s)) ->
778     (match StringMap.find s symbols with
779     LocalVariable(i) | GlobalVariable(i) -> (0, i)
780     | _ -> raise(TransformedAway("Error in " ^ varname ^ ": The LHS expressions
781     should always either have dimension length 1 or be the name of a variable
782     in their own scope.")))
783     | _ -> print_endline ("Error in " ^ varname ^ " formula number " ^ string_of_int
784     idx); raise(LogicError("Something wrong with the index of formula: " ^
785     string_of_formula element)) in
786     let getEnds = function
787     Some x -> let (b, c) = getStarts x in (b, c, 0)
788     | None -> (0, -1, 1) in
789     let (fromStartRow, rowStartVarnum) = getStarts element.formula_row_start in
790     let (fromStartCol, colStartVarnum) = getStarts element.formula_col_start in
791     let (toEndRow, rowEndVarnum, isSingleRow) = getEnds element.formula_row_end in
792     let (toEndCol, colEndVarnum, isSingleCol) = getEnds element.formula_col_end in
793
794     let _ = LlvM.build_store (LlvM.const_int base_types.char_t fromStartRow) (LlvM.
795     build_struct_gep storage_addr (formula_field_index FromFirstRow) "" init_bod)
796     in
797     let _ = LlvM.build_store (LlvM.const_int base_types.int_t rowStartVarnum) (LlvM.

```

```

    build_struct_gep storage_addr (formula_field_index RowStartNum) "" init_bod)
    init_bod in
783 let _ = LlvM.build_store (LlvM.const_int base_types.char_t toEndRow) (LlvM.
    build_struct_gep storage_addr (formula_field_index ToLastRow) "" init_bod)
    init_bod in
784 let _ = LlvM.build_store (LlvM.const_int base_types.int_t rowEndVarnum) (LlvM.
    build_struct_gep storage_addr (formula_field_index RowEndNum) "" init_bod)
    init_bod in
785 let _ = LlvM.build_store (LlvM.const_int base_types.char_t isSingleRow) (LlvM.
    build_struct_gep storage_addr (formula_field_index IsSingleRow) "" init_bod)
    init_bod in
786
787 let _ = LlvM.build_store (LlvM.const_int base_types.char_t fromStartCol) (LlvM.
    build_struct_gep storage_addr (formula_field_index FromFirstCols) "" init_bod)
    init_bod in
788 let _ = LlvM.build_store (LlvM.const_int base_types.int_t colStartVarnum) (LlvM.
    build_struct_gep storage_addr (formula_field_index ColStartNum) "" init_bod)
    init_bod in
789 let _ = LlvM.build_store (LlvM.const_int base_types.char_t toEndCol) (LlvM.
    build_struct_gep storage_addr (formula_field_index ToLastCol) "" init_bod)
    init_bod in
790 let _ = LlvM.build_store (LlvM.const_int base_types.int_t colEndVarnum) (LlvM.
    build_struct_gep storage_addr (formula_field_index ColEndNum) "" init_bod)
    init_bod in
791 let _ = LlvM.build_store (LlvM.const_int base_types.char_t isSingleCol) (LlvM.
    build_struct_gep storage_addr (formula_field_index IsSingleCol) "" init_bod)
    init_bod in
792
793 let form_decl = build_formula_function (varname, idx) symbols element.formula_expr
    in
794 let _ = LlvM.build_store form_decl (LlvM.build_struct_gep storage_addr (
    formula_field_index FormulaCall) "" init_bod) init_bod in
795 () in
796
797 (* Builds a var_defn struct for each variable *)
798 let build_var_defn defn varname va symbols =
799     let numForm = List.length va.var_formulas in
800     let formulas = LlvM.build_array_malloc base_types.formula_t (LlvM.const_int
        base_types.int_t numForm) "" init_bod in
801     (*getDefn simply looks up the correct definition for a dimension declaration of a
        variable. Note that currently it is ambiguous whether it is a variable or a
        literal. TOOD: consider negative numbers*)
802     let getDefn = function
803         DimId(a) -> (match StringMap.find a symbols with LocalVariable(i) -> i |
            GlobalVariable(i) -> i | _ -> raise(TransformedAway("Error in " ^ varname ^
                ": The LHS expressions should always either have dimension length 1 or be
                the name of a variable in their own scope.")))
804         | DimOneByOne -> 1 in
805     let _ = (match va.var_rows with
806         DimOneByOne -> LlvM.build_store (LlvM.const_int base_types.char_t 1) (LlvM.
            build_struct_gep defn (var_defn_field_index OneByOne) "" init_bod)
            init_bod
807         | DimId(a) -> (
808             let _ = LlvM.build_store (LlvM.const_int base_types.char_t 0) (LlvM.
                build_struct_gep defn (var_defn_field_index OneByOne) "" init_bod)
                init_bod in ());

```

```

809         let _ = Llvm.build_store (Llvm.const_int base_types.int_t (getDefn va.
            var_rows)) (Llvm.build_struct_gep defn (var_defn_field_index Rows) ""
            init_bod) init_bod in ();
810         Llvm.build_store (Llvm.const_int base_types.int_t (getDefn va.var_cols)) (
            Llvm.build_struct_gep defn (var_defn_field_index Cols) "" init_bod)
            init_bod
811     )
812 ) in
813 let _ = Llvm.build_store (Llvm.const_int base_types.int_t numForm) (Llvm.
    build_struct_gep defn (var_defn_field_index NumFormulas) "" init_bod) init_bod
814 and _ = Llvm.build_store formulas (Llvm.build_struct_gep defn (
    var_defn_field_index Formulas) "" init_bod) init_bod
815 and _ = Llvm.build_store (Llvm.build_global_stringptr varname "" init_bod) (Llvm.
    build_struct_gep defn (var_defn_field_index VarName) "" init_bod) init_bod in
816 List.iteri (fun idx elem -> build_formula (varname, idx) formulas elem symbols) va
    .var_formulas in
817
818 (* Creates a scope object and inserts the necessary instructions into main to
    populate the var_defns, and
819 * into the function specified by builder to populate the scope object. *)
820 let build_scope_obj
821     fname (* The function name, or "globals" *)
822     symbols (* The symbols to use when creating the functions *)
823     vars (* The variables to build definitions and formula-functions for *)
824     static_location_ptr (* The copy of the global pointer used in main *)
825     var_defns_loc (* The copy of the global pointer used in the local function *)
826     num_params (* How many parameters the function takes *)
827     builder (* The LLVM builder for the local function *)
828     =
829     let cardinal = Llvm.const_int base_types.int_t (StringMap.cardinal vars) in
830     let build_var_defns =
831         let static_var_defns = Llvm.build_array_malloc base_types.var_defn_t cardinal (
            fname ^ "_static_var_defns") init_bod in
832         let _ = Llvm.build_store static_var_defns static_location_ptr init_bod in
833         let add_variable varname va (sm, count) =
834             let fullname = fname ^ "_" ^ varname in
835             let defn = (Llvm.build_in_bounds_gep static_var_defns [|Llvm.const_int
                base_types.int_t count|] (fullname ^ "_defn") init_bod) in
836             let _ = build_var_defn defn fullname va symbols in
837             (StringMap.add varname count sm, count + 1) in
838         ignore (StringMap.fold add_variable vars (StringMap.empty, 0)) in
839
840     let var_defns = Llvm.build_load var_defns_loc (fname ^ "_global_defn_ptr_loc")
        builder in
841     let var_insts = Llvm.build_array_malloc base_types.var_instance_p cardinal "
        var_insts" builder in
842     let scope_obj = Llvm.build_malloc base_types.extend_scope_t "scope_obj" builder in
843
844     (*Store variable definition and instance*)
845     let _ = Llvm.build_store var_defns (Llvm.build_struct_gep scope_obj (
        scope_field_type_index VarDefn) "" builder) builder in
846     let _ = Llvm.build_store var_insts (Llvm.build_struct_gep scope_obj (
        scope_field_type_index VarInst) "" builder) builder in
847     let _ = Llvm.build_store cardinal (Llvm.build_struct_gep scope_obj (
        scope_field_type_index VarNum) "" builder) builder in
848     let _ = Llvm.build_store (Llvm.const_int base_types.int_t 0) (Llvm.

```

```

        build_struct_gep scope_obj (scope_field_type_index ScopeRefCount) "" builder)
        builder in
849   let paramarray = if num_params > 0 then LlvM.build_array_malloc base_types.value_p
        (LlvM.const_int base_types.int_t num_params) "paramarray" builder else LlvM.
        const_pointer_null (LlvM.pointer_type base_types.value_p) in
850   let _ = LlvM.build_store paramarray (LlvM.build_struct_gep scope_obj (
        scope_field_type_index FunctionParams) "" builder) builder in
851   let copy_fn_arg i =
852     let param_addr = LlvM.build_in_bounds_gep paramarray [|LlvM.const_int base_types
        .int_t i|] (fname ^ "_param_" ^ string_of_int i ^ "_loc") builder in
853     ignore (LlvM.build_store (LlvM.param (StringMap.find fname function_llvalues) i)
        param_addr builder) in
854   List.iter copy_fn_arg (zero_until num_params);
855   let _ = LlvM.build_call (Hashtbl.find runtime_functions "null_init") [|scope_obj|]
        "" builder in
856   build_var_defns ; scope_obj in
857 (* End of build_scope_obj *)
858
859 let build_function fname (fn_def, fn_llvalue) =
860   (* Build the symbol table for this function *)
861   let symbols = create_symbol_table global_symbols fn_def in
862   let fn_idx = match StringMap.find fname extend_fn_numbers with ExtendFunction(i)
        -> i | _ -> raise (LogicError(fname ^ " not in function table")) in
863   let builder = LlvM.builder_at_end context (LlvM.entry_block fn_llvalue) in
864   let static_location_ptr = LlvM.build_in_bounds_gep array_of_vardefn_ptrs [|LlvM.
        const_int base_types.int_t 0; LlvM.const_int base_types.int_t fn_idx|] (fname ^
        "_global_defn_ptr") init_bod in
865   let var_defns_loc = LlvM.build_in_bounds_gep array_of_vardefn_ptrs [|LlvM.
        const_int base_types.int_t 0; LlvM.const_int base_types.int_t fn_idx|] (fname ^
        "_local_defn_ptr") builder in
866   let scope_obj = build_scope_obj fname symbols fn_def.func_body static_location_ptr
        var_defns_loc (List.length fn_def.func_params) builder in
867   let get_special_val special_name = function
868     Id(s) -> (match (try StringMap.find s symbols with Not_found -> raise(
        LogicError("Something went wrong with your semantic analysis - " ^ s ^ "
        not found")))) with
869       LocalVariable(i) ->
870         let llvm_var = LlvM.build_call getVar [|scope_obj; LlvM.const_int
        base_types.int_t i|] (special_name ^ "_var") builder in
871         LlvM.build_call getVal [|llvm_var; LlvM.const_int base_types.int_t 0; LlvM
        .const_int base_types.int_t 0|] (special_name ^ "_val") builder
872       | _ -> raise (TransformedAway("Error in " ^ fname ^ ": The " ^ special_name ^
        " value should always have been transformed into a local variable"))
873       | _ -> raise (TransformedAway("Error in " ^ fname ^ ": The " ^ special_name ^
        " value should always have been transformed into a local variable")) in
874   let assert_val = get_special_val "assert" (List.hd fn_def.func_asserts) in
875   let _ = LlvM.build_call (Hashtbl.find runtime_functions "verify_assert") [|
        assert_val; LlvM.build_global_stringptr fname "" builder|] "" builder in
876   let ret_val = get_special_val "return" (snd fn_def.func_ret_val) in
877   let _ = LlvM.build_ret ret_val builder in () in
878 (* End of build_function *)
879
880 (* Build the global scope object *)
881 let vardefn_p_p = LlvM.build_alloca base_types.var_defn_p "v_p_p" init_bod in
882 let global_scope_obj = build_scope_obj "globals" global_symbols globals vardefn_p_p
        vardefn_p_p 0 init_bod in

```

```

883 let _ = LlvM.build_call (Hashtbl.find runtime_functions "incStack") [||] "" init_bod
      in
884 let _ = LlvM.build_store global_scope_obj global_scope_loc init_bod in
885
886 (*iterates over function definitions*)
887 StringMap.iter build_function extend_functions ;
888
889 (* Define the LLVM entry point for the program *)
890 let extend_entry_point = StringMap.find "main" function_llvalues in
891 let _ = LlvM.build_ret_void init_bod in
892 let _ = LlvM.build_ret_void literal_bod in
893 let _ = LlvM.build_call init_def [||] "" main_bod in
894 let _ = LlvM.build_call literal_def [||] "" main_bod in
895 let cmd_line_args = LlvM.build_call (Hashtbl.find runtime_functions "
      box_command_line_args") [|LlvM.param main_def 0; LlvM.param main_def 1|] "
      cmd_line_args" main_bod in
896 let _ = LlvM.build_call extend_entry_point [|cmd_line_args|] "" main_bod in
897 let _ = LlvM.build_ret (LlvM.const_int base_types.int_t 0) main_bod in
898
899 base_module
900
901 let build_this ast_mapped =
902   let modu = (translate ast_mapped) in
903   let _ = LlvM_analysis.assert_valid_module modu in
904   modu

```

7.8 linker.ml

```

1 module StringSet = Set.Make(String)
2 let link xtndOut ast compiler outputFile =
3   let tmpFilenameLL = Filename.temp_file "" ".ll"
4   and tmpFilenameC = Filename.temp_file "" ".o"
5   and getExterns (_,_,extern) =
6     StringSet.elements
7       (Ast.StringMap.fold
8         (fun key value store -> StringSet.add value.Ast.extern_fn_libname store)
9         extern
10        StringSet.empty) in
11   let tmpChan = open_out tmpFilenameLL in
12   output_string tmpChan xtndOut; close_out tmpChan;
13   let call1 = (String.concat " " ("llc-3.8" :: "-filetype=obj" :: tmpFilenameLL :: "-o
      " :: tmpFilenameC :: []))
14   and call2 = (String.concat " " (compiler :: "-o" :: outputFile :: tmpFilenameC :: (
      getExterns ast))) ^ " -lm" in
15   let rescl = Sys.command call1 in
16   if rescl == 0 then (
17     Sys.remove tmpFilenameLL;
18     let resc2 = Sys.command call2 in
19     Sys.remove tmpFilenameC;
20     if resc2 == 0 then () else raise Not_found
21   )
22   else (Sys.remove tmpFilenameC;raise Not_found)

```

7.9 main.ml


```

1  open Ast;;
2
3  let print_ast = ref false
4  let compile_ast = ref false
5  let link = ref false
6  let output = ref "./out"
7  let compiler = ref "gcc"
8  let working_dir = ref "."
9
10 let the_ast = ref (StringMap.empty, StringMap.empty, StringMap.empty)
11 let just_one_please = ref false
12
13 let speclist = [
14     ("-p", Arg.Set print_ast, "Print the AST");
15     ("-c", Arg.Set compile_ast, "Compile the program");
16     ("-l", Arg.Set link, "Link the program");
17     ("-cc", Arg.Set_string compiler, "Compiler to use");
18     ("-o", Arg.Set_string output, "Location to output to");
19     ("-w", Arg.Set_string working_dir, "Working directory");
20 ]
21
22 let usage_message = "Welcome to Extend!\n\nUsage: extend <options> <source-file>\n\
    nOptions are:"
23
24 let parse_ast filename =
25   if !just_one_please
26   then print_endline "Any files after the first one are ignored."
27   else just_one_please := true ; the_ast := (Transform.create_ast filename);;
28
29 Arg.parse speclist parse_ast usage_message;
30 Sys.chdir !working_dir;
31 if not !just_one_please then Arg.usage speclist usage_message else ();
32 if !print_ast then print_endline (string_of_program !the_ast) else ();
33 if !compile_ast then
34   let compiled = (Llvm.string_of_llmodule (Codegen.translate !the_ast))
35   in
36     if not (!link) then print_endline compiled
37     else Linker.link compiled !the_ast !compiler !output
38 else ();

```

7.10 lib.c

```

1  #include<stdio.h>
2  #include<stdlib.h>
3  #include<math.h>
4  #include<string.h>
5  #include<stdbool.h>
6  #include "../lib/gdchart0.94b/gdc.h"
7  #include "../lib/gdchart0.94b/gdchart.h"
8  /* #include <sys/time.h> */
9  #include <time.h>
10 #include "runtime.h"
11
12 /* Value type */
13 #define FLAG_EMPTY 0

```

```

14 #define FLAG_NUMBER 1
15 #define FLAG_STRING 2
16 #define FLAG_SUBRANGE 3
17
18 /* Status flag */
19 #define CALCULATED 2
20 #define IN_PROGRESS 4
21
22 #define MAX_FILES 255
23 FILE *open_files[1 + MAX_FILES] = {NULL};
24 int open_num_files = 0;
25
26 value_p extend_print(value_p whatever, value_p text) {
27     if(!assertSingleString(text)) return new_val();
28     if(!assertText(text)) return new_val();
29     printf("%s", text->str->text);
30     return new_val();
31 }
32
33 value_p extend_printv(value_p whatever, value_p text) {
34     printf("%s", text->str->text);
35     return new_val();
36 }
37
38 value_p extend_printd(value_p whatever, value_p text) {
39     printf("%f\n", text->numericVal);
40     value_p result = malloc(sizeof(struct value_t));
41     return result;
42 }
43
44 value_p extend_to_string(value_p val) {
45     if(assertSingleNumber(val)) {
46         double possible_num = val->numericVal;
47         int rounded_int = (int) lrint(possible_num);
48         char *converted_str;
49         if (fabs(possible_num - rounded_int) < FLOAT_CUTOFF) {
50             int size = snprintf(NULL, 0, "%d", rounded_int);
51             converted_str = malloc(size + 1);
52             sprintf(converted_str, "%d", rounded_int);
53         } else {
54             int size = snprintf(NULL, 0, "%f", possible_num);
55             converted_str = malloc(size + 1);
56             sprintf(converted_str, "%f", possible_num);
57         }
58         value_p result = new_string(converted_str);
59         free(converted_str);
60         return result;
61     }
62     else if(assertSingleString(val)) return val;
63     else if(val->flags == FLAG_EMPTY) {
64         return new_string("empty");
65     }
66     else if(val->flags == FLAG_SUBRANGE) {
67         int i,j,len;
68         value_p value;
69         char *result, *res;

```

```

70     len = 0;
71     subrange_p sr = val->subrange;
72     value_p *strs = malloc(sizeof(value_p) * sr->subrange_num_cols * sr->
73         subrange_num_rows);
74     for(i = 0; i < sr->subrange_num_rows; i++) {
75         for(j = 0; j < sr->subrange_num_cols; j++) {
76             value = extend_to_string(getValSR(sr, i, j));
77             //debug_print(value, "");
78             strs[i * sr->subrange_num_cols + j] = value;
79             len += value->str->length;
80         }
81     }
82     len += sr->subrange_num_rows * sr->subrange_num_cols + 1 /*closing paren*/;
83     res = result = malloc(len + 1/*terminal character*/);
84     *result = '{';
85     result++;
86     for(i = 0; i < sr->subrange_num_rows; i++) {
87         for(j = 0; j < sr->subrange_num_cols; j++) {
88             memcpy(result, strs[i * sr->subrange_num_cols + j]->str->text, strs[i * sr->
89                 subrange_num_cols + j]->str->length);
90             result += strs[i * sr->subrange_num_cols + j]->str->length;
91             if(j != sr->subrange_num_cols - 1) {
92                 *result = ',';
93                 result++;
94             }
95             if(i != sr->subrange_num_rows - 1) {
96                 *result = ';';
97                 result++;
98             }
99             *result = ' ';
100             value_p v = new_string(res);
101             free(res);
102             return v;
103         } else {
104             __builtin_unreachable();
105         }
106     } // If the struct does not hold a string or number, return empty?
107     return new_val();
108 }
109
110 #define EXPOSE_MATH_FUNC(name) value_p extend_##name(value_p a){if(!assertSingleNumber
111     (a)) return new_val();double val = name(a->numericVal);return new_number(val);}
112 EXPOSE_MATH_FUNC(sin)
113 EXPOSE_MATH_FUNC(cos)
114 EXPOSE_MATH_FUNC(tan)
115 EXPOSE_MATH_FUNC(acos)
116 EXPOSE_MATH_FUNC(asin)
117 EXPOSE_MATH_FUNC(atan)
118 EXPOSE_MATH_FUNC(sinh)
119 EXPOSE_MATH_FUNC(cosh)
120 EXPOSE_MATH_FUNC(tanh)
121 EXPOSE_MATH_FUNC(exp)
122 EXPOSE_MATH_FUNC(log)
123 EXPOSE_MATH_FUNC(log10)

```

```

123 EXPOSE_MATH_FUNC(sqrt)
124 EXPOSE_MATH_FUNC(ceil)
125 EXPOSE_MATH_FUNC(fabs)
126 EXPOSE_MATH_FUNC(floor)
127
128 value_p extend_round(value_p num, value_p number_of_digits) {
129     if (!assertSingleNumber(num) || !assertSingleNumber(number_of_digits)) return
        new_val();
130     double factor_of_10 = pow(10,number_of_digits->numericVal);
131     return new_number(rint(num->numericVal * factor_of_10) / factor_of_10);
132 }
133
134 value_p extend_len(value_p str_val) {
135     if (!assertSingleString(str_val)) return new_val();
136     return new_number((double) str_val->str->length);
137 }
138
139 value_p extend_get_stdin() {
140     if (open_num_files + 1 > MAX_FILES) {
141         return new_val();
142     } else {
143         open_num_files++;
144         open_files[open_num_files] = stdin;
145         return new_number((double) open_num_files);
146     }
147 }
148
149 value_p extend_get_stdout() {
150     if (open_num_files + 1 > MAX_FILES) {
151         return new_val();
152     } else {
153         open_num_files++;
154         open_files[open_num_files] = stdout;
155         return new_number((double) open_num_files);
156     }
157 }
158
159 value_p extend_get_stderr() {
160     if (open_num_files + 1 > MAX_FILES) {
161         return new_val();
162     } else {
163         open_num_files++;
164         open_files[open_num_files] = stderr;
165         return new_number((double) open_num_files);
166     }
167 }
168
169 value_p extend_open(value_p filename, value_p mode){
170     FILE *val;
171     if (    !assertSingleString(filename)
172         || !assertSingleString(mode)
173         || open_num_files + 1 > MAX_FILES) {
174         return new_val();
175     }
176     val = fopen(filename->str->text, mode->str->text);
177     if(val == NULL) return new_val();

```

```

178     open_num_files++;
179     open_files[open_num_files] = val;
180     return new_number((double) open_num_files);
181 }
182
183 value_p extend_close(value_p file_handle) {
184     if(!assertSingleNumber(file_handle)) {
185         // Per the LRM this is actually supposed to crash the program.
186         fprintf(stderr, "EXITING - Attempted to close something that was not a valid file
187             pointer\n");
188         exit(-1);
189     }
190     int fileNum = (int) file_handle->numericVal;
191
192     if (fileNum > open_num_files || open_files[fileNum] == NULL) {
193         // Per the LRM this is actually supposed to crash the program.
194         fprintf(stderr, "EXITING - Attempted to close something that was not a valid file
195             pointer\n");
196         exit(-1);
197     }
198     fclose(open_files[fileNum]);
199     open_files[fileNum] = NULL; // Empty the container for the pointer.
200     return new_val(); // assuming it was an open valid handle, close() is just supposed
201         to return empty
202 }
203
204 value_p extend_read(value_p file_handle, value_p num_bytes){
205     /* TODO: Make it accept empty */
206     if(!assertSingleNumber(file_handle) || !assertSingleNumber(num_bytes)) return
207         new_val();
208     int max_bytes = (int)num_bytes->numericVal;
209     int fileNum = (int)file_handle->numericVal;
210     if (fileNum > open_num_files || open_files[fileNum] == NULL) return new_val();
211     FILE *f = open_files[fileNum];
212     max_bytes = (int) num_bytes->numericVal;
213     if (max_bytes == 0) {
214         long cur_pos = ftell(f);
215         fseek(f, 0, SEEK_END);
216         long end_pos = ftell(f);
217         fseek(f, cur_pos, SEEK_SET);
218         max_bytes = end_pos - cur_pos;
219     }
220     char *buf = malloc(sizeof(char) * (max_bytes + 1));
221     int bytes_read = fread(buf, sizeof(char), max_bytes, f);
222     buf[bytes_read] = 0;
223     value_p result = new_string(buf);
224     free(buf);
225     return result;
226     //edge case: how to return the entire contents of the file if n == empty?
227 }
228
229 value_p extend_readline(value_p file_handle) {
230     int i=0, buf_size = 256;
231     char next_char;
232     if (!assertSingleNumber(file_handle)) return new_val();
233     int fileNum = (int) file_handle->numericVal;

```

```

230 FILE *f = open_files[fileNum];
231 if (fileNum > open_num_files || open_files[fileNum] == NULL) {
232     return new_val();
233 }
234 char *buf = (char *) malloc (buf_size * sizeof(char));
235 while ((next_char = fgetc(f)) != '\n') {
236     buf[i++] = next_char;
237     if (i == buf_size - 2) {
238         buf_size *= 2;
239         char *new_buf = (char *) malloc (buf_size * sizeof(char));
240         memcpy(new_buf, buf, i);
241         free(buf);
242         buf = new_buf;
243     }
244 }
245 buf[i] = '\0';
246 value_p result = new_string(buf);
247 free(buf);
248 return result;
249 }
250
251 value_p extend_write(value_p file_handle, value_p buffer){
252     if(!assertSingleNumber(file_handle) || !assertSingleString(buffer)) return new_val()
253     ;
254     int fileNum = (int) file_handle->numericVal;
255     if (fileNum > open_num_files || open_files[fileNum] == NULL) {
256         // Per the LRM this is actually supposed to crash the program.
257         fprintf(stderr, "EXITING - Attempted to write to something that was not a valid
258             file pointer\n");
259         exit(-1);
260     }
261     fwrite(buffer->str->text, 1, buffer->str->length, open_files[fileNum]);
262     // TODO: make this return empty once compiler handles Id(s)
263     // RN: Use the return value to close the file
264     return new_number((double) fileNum);
265 }
266
267 #ifdef PLOT
268 value_p extend_plot(value_p file_name){
269     // extract the numerical values from the first parameter - values
270     if(!assertSingle(file_name)) return new_val();
271     float a[6] = { 0.5, 0.09, 0.6, 0.85, 0.0, 0.90 },
272           b[6] = { 1.9, 1.3, 0.6, 0.75, 0.1, 2.0 };
273     char *t[6] = { "Chicago", "New York", "L.A.", "Atlanta", "Paris, MD\n(USA) ", "
274         London" };
275     unsigned long sc[2] = { 0xFF8080, 0x8080FF };
276     GDC_BGColor = 0xFFFFFFFFL;
277     GDC_LineColor = 0x000000L;
278     GDC_SetColor = &(sc[0]);
279     GDC_stack_type = GDC_STACK_BESIDE;
280     // Using the line below, can also spit to stdout and fwrite from Extend
281     // printf( "Content-Type: image/png\n\n" );
282     FILE *outpng = fopen("extend.png", "wb");
283     out_graph(250, 200, outpng, GDC_3DBAR, 6, t, 2, a, b);
284     fclose(outpng);
285     return new_val();

```

```

283 }
284
285 value_p extend_bar_chart(value_p file_handle, value_p labels, value_p values){
286     // Mandates 1 row, X columns
287     if(!assertSingleNumber(file_handle)) return new_val();
288     int fileNum = (int)file_handle->numericVal;
289     if (fileNum > open_num_files || open_files[fileNum] == NULL) return new_val();
290     FILE *f = open_files[fileNum];
291     int data_length = labels->subrange->subrange_num_cols;
292     if(data_length != values->subrange->subrange_num_cols) return new_val();
293
294     float *graph_values = malloc(sizeof(float) * data_length);
295     char **graph_labels = malloc(sizeof(char*) * data_length);
296     for(int i = 0; i < data_length; i++){
297         graph_labels[i] = getValSR(labels->subrange, 0, i)->str->text;
298         graph_values[i] = (float)getValSR(values->subrange, 0, i)->numericVal;
299     }
300     unsigned long sc[2] = {0xFF8080, 0x8080FF};
301     GDC_BGColor = 0xFFFFFFL;
302     GDC_LineColor = 0x000000L;
303     GDC_SetColor = &(sc[0]);
304     GDC_stack_type = GDC_STACK_BESIDE;
305     out_graph(250, 200, f, GDC_3DBAR, data_length, graph_labels, 1, graph_values);
306     // width, height, file handle, graph type, number of data points, labels, number of
        data sets, the data sets
307     free(graph_labels);
308     free(graph_values);
309     fclose(f);
310     return new_val();
311 }
312
313 value_p extend_line_chart(value_p file_handle, value_p labels, value_p x_values){
314     if(!assertSingleNumber(file_handle)) return new_val();
315     int fileNum = (int)file_handle->numericVal;
316     if (fileNum > open_num_files || open_files[fileNum] == NULL) return new_val();
317     FILE *f = open_files[fileNum];
318     int data_length = labels->subrange->subrange_num_cols;
319     if(data_length != x_values->subrange->subrange_num_cols) return new_val();
320     float *graph_x_values = malloc(sizeof(float) * data_length);
321     char **graph_labels = malloc(sizeof(char*) * data_length);
322     for(int i = 0; i < data_length; i++){
323         graph_labels[i] = getValSR(labels->subrange, 0, i)->str->text;
324         graph_x_values[i] = (float)getValSR(x_values->subrange, 0, i)->numericVal;
325     }
326     unsigned long sc[2] = {0xFF8080, 0x8080FF};
327     GDC_BGColor = 0xFFFFFFL;
328     GDC_LineColor = 0x000000L;
329     GDC_SetColor = &(sc[0]);
330     GDC_stack_type = GDC_STACK_BESIDE;
331     out_graph(250, 200, f, GDC_LINE, data_length, graph_labels, 1, graph_x_values);
332     free(graph_labels);
333     free(graph_x_values);
334     fclose(f);
335     return new_val();
336 }
337 #endif

```

```

338
339 value_p extend_current_hour() {
340     time_t ltime;
341     struct tm info;
342     ltime = time(&ltime);
343     localtime_r(&ltime, &info);
344     return new_number((double) info.tm_hour);
345 }
346
347 value_p extend_isNaN(value_p val) {
348     if (!assertSingleNumber(val)) return new_val();
349     double d = val->numericVal;
350     return isnan(d) ? new_number(1.0) : new_number(0.0);
351 }
352
353 value_p extend_isInfinite(value_p val) {
354     if (!assertSingleNumber(val)) return new_val();
355     double d = val->numericVal;
356     if (isinf(d)) {
357         return d < 0 ? new_number(-1.0) : new_number(1.0);
358     } else {
359         return new_number(0.0);
360     }
361 }
362
363 value_p extend_parseFloat(value_p val) {
364     if (!assertSingleString(val)) return new_val();
365     return new_number(atof(val->str->text));
366 }
367
368 value_p extend_toASCII(value_p val) {
369     if (!assertSingleString(val) || val->str->length == 0) return new_val();
370     value_p *val_arr = malloc(sizeof(value_p) * val->str->length);
371     int i;
372     for(i = 0; i < val->str->length; i++) {
373         value_p my_val = malloc(sizeof(struct value_t));
374         my_val->flags = FLAG_NUMBER;
375         my_val->numericVal = (double)val->str->text[i];
376         val_arr[i] = my_val;
377     }
378     value_p _new = new_subrange(1, val->str->length, val_arr);
379     return _new;
380 }
381
382 value_p extend_fromASCII(value_p val) {
383     if(val->flags == FLAG_NUMBER) {
384         char s[2];
385         s[0] = ((char)lrint(val->numericVal));
386         s[1] = '\0';
387         return new_string(s);
388     }
389     else if(val->flags == FLAG_SUBRANGE) {
390         int rows, cols, len;
391         rows = val->subrange->subrange_num_rows;
392         cols = val->subrange->subrange_num_cols;
393         if(rows > 1 && cols > 1) return new_val();

```



```

394     else len = (rows == 1 ? cols : rows);
395     char *text = malloc(1 + sizeof(char) * len);
396     for(rows = 0; rows < val->subrange->subrange_num_rows; rows++) {
397         for(cols = 0; cols < val->subrange->subrange_num_cols; cols++) {
398             value_p single = getValSR(val->subrange, rows, cols);
399             if(single->flags != FLAG_NUMBER) {
400                 free(text);
401                 return new_val();
402             }
403             text[rows + cols] = (char)lrint(single->numericVal);
404         }
405     }
406     text[len] = '\0';
407     value_p ret = new_string(text);
408     free(text);
409     return ret;
410 } else if (val->flags == FLAG_EMPTY) {
411     return new_string("");
412 } else {
413     return new_val();
414 }
415 }

```

7.11 runtime.c

```

1  #include<stdio.h>
2  #include<stdlib.h>
3  #include<math.h>
4  #include<sys/resource.h>
5  #include<string.h>
6  #include<stdbool.h>
7  #include "runtime.h"
8
9  struct value_t zero_val = {FLAG_NUMBER, 0.0, NULL, NULL};
10 struct value_t one_val = {FLAG_NUMBER, 1.0, NULL, NULL};
11 struct rhs_index absolute_zero = {&zero_val, RHS_IDX_ABSOLUTE};
12 struct rhs_index absolute_one = {&one_val, RHS_IDX_ABSOLUTE};
13 struct rhs_slice zero_to_one = {&absolute_zero, &absolute_one};
14 struct rhs_slice corresponding_cell = {NULL, NULL};
15
16 void debug_print_subrange(subrange_p subrng);
17
18 void debug_print(value_p val, char *which_value) {
19     char *flag_meanings[4] = {"Empty", "Number", "String", "Subrange"};
20     fprintf(stderr, "-----Everything you ever wanted to know about %s:-----\n",
21             which_value == NULL ? "some anonymous variable" : which_value);
22     fprintf(stderr, "Memory address: %p\n", val);
23     if (val == NULL) {
24         fprintf(stderr, "-----Nice try asking me to dereference a null pointer\n
25         -----");
26     }
27     return;
28 }
29
30 fprintf(stderr, "Flags: %d (%s)\n", val->flags, flag_meanings[val->flags]);
31 fprintf(stderr, "NumericVal: %f\n", val->numericVal);
32 fprintf(stderr, "String contents: Probably safer not to check that pointer (%p)

```

```

        blindly\n", val->str);
29 if (val->flags == FLAG_STRING && val->str != NULL) {
30     fprintf(stderr, "It says it's a string and it's not a NULL pointer though, so here
        you go:\n");
31     fprintf(stderr, "String refcount: %d\n", val->str->refs);
32     fprintf(stderr, "String length: %ld\n", val->str->length);
33     fprintf(stderr, "String char* memory address: %p\n", val->str->text);
34     if (val->str->text == NULL) {
35         fprintf(stderr, "Not going to print the contents of NULL!\n");
36     } else {
37         fprintf(stderr, "String char* contents:\n%s\n", val->str->text);
38     }
39 }
40 fprintf(stderr, "Subrange contents: Probably safer not to check that pointer (%p)
        blindly either\n", val->subrange);
41 if (val->flags == FLAG_SUBRANGE && val->subrange != NULL) {
42     fprintf(stderr, "It says it's a subrange and it's not a NULL pointer though, so
        here you go:\n");
43     debug_print_subrange(val->subrange);
44 }
45 fprintf(stderr, "————That's all I've got to say about %s:————\n", which_value ==
        NULL ? "some anonymous variable" : which_value);
46 }
47
48 void debug_print_formula(struct ExtendFormula *fdef) {
49     fprintf(stderr, "————Everything you ever wanted to know about your favorite
        formula:————\n");
50     fprintf(stderr, "RowStart varnum: %d %d\n", fdef->rowStart_varnum, fdef->
        fromFirstRow);
51     fprintf(stderr, "RowEnd varnum: %d %d\n", fdef->rowEnd_varnum, fdef->toLastRow);
52     fprintf(stderr, "ColStart varnum: %d %d\n", fdef->colStart_varnum, fdef->
        fromFirstCol);
53     fprintf(stderr, "ColEnd varnum: %d %d\n", fdef->colEnd_varnum, fdef->toLastCol);
54 }
55
56 void debug_print_res_formula(struct ResolvedFormula *rdef) {
57     fprintf(stderr, "Some formula with function pointer %p applies to: [%d:%d,%d:%d]\n",
        rdef->formula, rdef->rowStart, rdef->rowEnd, rdef->colStart, rdef->colEnd);
58 }
59
60 void debug_print_vardefn(struct var_defn *pdef) {
61     fprintf(stderr, "————Everything you ever wanted to know about var defn %s:————\n
        ", pdef->name);
62     fprintf(stderr, "Row varnum: %d\n", pdef->rows_varnum);
63     fprintf(stderr, "Col varnum: %d\n", pdef->cols_varnum);
64     fprintf(stderr, "Num formulas: %d\n", pdef->numFormulas);
65     fprintf(stderr, "Formula defs: \n");
66     int i;
67     for (i=0; i < pdef->numFormulas; i++) {
68         debug_print_formula(pdef->formulas + i);
69     }
70     fprintf(stderr, "Is 1x1: %d\n", pdef->isOneByOne);
71 }
72
73 void debug_print_varinst(struct var_instance *inst) {
74     fprintf(stderr, "————Everything you ever wanted to know about var %s:————\n",

```

```

    inst->name);
75 fprintf(stderr, "Rows: %d\n", inst->rows);
76 fprintf(stderr, "Cols: %d\n", inst->cols);
77 fprintf(stderr, "Num formulas: %d\n", inst->numFormulas);
78 fprintf(stderr, "*****Formulas:*****\n");
79 int i;
80 for (i = 0; i < inst->numFormulas; i++) {
81     debug_print_res_formula(inst->formulas + i);
82 }
83 fprintf(stderr, "**** End of Formulas *** \n");
84 fprintf(stderr, "~~~~~Cells:~~~~~\n");
85 fprintf(stderr, "Status memory address: %p\n", inst->status);
86 for (i = 0; i < inst->rows * inst->cols; i++) {
87     printf("%s[%d,%d]: Status=%d\n", inst->name, i / inst->cols, i % inst->cols, inst
        ->status[i]);
88     if (inst->status[i] == CALCULATED) {
89         printf("%s[%d,%d] Value:\n", inst->name, i / inst->cols, i % inst->cols);
90         debug_print(inst->values[i], inst->name);
91     }
92 }
93 fprintf(stderr, "~~~ End of Cells: ~~~\n");
94 }
95
96 void debug_print_subrange(subrange_p subrng) {
97     fprintf(stderr, "-----Everything you wanted to know about this subrange-----\n");
98     fprintf(stderr, "Offset: [%d,%d]\n", subrng->base_var_offset_row, subrng->
        base_var_offset_col);
99     fprintf(stderr, "Dimensions: [%d,%d]\n", subrng->subrange_num_rows, subrng->
        subrange_num_cols);
100    fprintf(stderr, "Subrange of: \n");
101    debug_print_varinst(subrng->range);
102 }
103
104 void debug_print_index(struct rhs_index *idx) {
105     if (idx == NULL) {
106         fprintf(stderr, "I'd rather not try to print out the contents of a NULL index.\n");
107         ;
108         exit(-1);
109     }
110     fprintf(stderr, "Index type: ");
111     switch(idx->rhs_index_type) {
112     case RHS_IDX_ABSOLUTE:
113         fprintf(stderr, "Absolute\n");
114         if (idx->val_of_expr == NULL) {
115             fprintf(stderr, "I wasn't expecting this, but the value pointer is NULL. Maybe
                there's a good reason for it, so I'll keep going...\n");
116         } else {
117             debug_print(idx->val_of_expr, "an absolute index");
118         }
119         break;
120     case RHS_IDX_RELATIVE:
121         fprintf(stderr, "Relative\n");
122         if (idx->val_of_expr == NULL) {
123             fprintf(stderr, "I wasn't expecting this, but the value pointer is NULL. Maybe
                there's a good reason for it, so I'll keep going...\n");
124         } else {

```

```

124     debug_print(idx->val_of_expr, "a relative index");
125 }
126 break;
127 case RHS_IDX_DIM_START:
128     fprintf(stderr, "DimensionStart\n");
129     if (idx->val_of_expr != NULL) {
130         fprintf(stderr, "This definitely isn't supposed to happen - the value pointer
131             isn't NULL. You should look into that.\n");
132         exit(-1);
133     }
134     break;
135 case RHS_IDX_DIM_END:
136     fprintf(stderr, "DimensionEnd\n");
137     if (idx->val_of_expr != NULL) {
138         fprintf(stderr, "This definitely isn't supposed to happen - the value pointer
139             isn't NULL. You should look into that.\n");
140         exit(-1);
141     }
142 }
143
144 void debug_print_slice(struct rhs_slice *sl) {
145     if (sl == NULL) {
146         fprintf(stderr, "I'd rather not try to print out the contents of a NULL slice.\n");
147         exit(-1);
148     }
149     fprintf(stderr, "-----Everything about this slice-----\n");
150     fprintf(stderr, "Start and end index memory addresses: %p and %p\n", sl->
151         slice_start_index, sl->slice_end_index);
152     if (sl->slice_start_index != NULL) {
153         fprintf(stderr, "Start index info:\n");
154         debug_print_index(sl->slice_start_index);
155         if (sl->slice_end_index != NULL) {
156             fprintf(stderr, "End index info:\n");
157             debug_print_index(sl->slice_end_index);
158         }
159     } else {
160         if (sl->slice_end_index != NULL) {
161             fprintf(stderr, "Start index is NULL but end index is not NULL. That should
162                 never happen.\n");
163             fprintf(stderr, "Attempting to print contents anyway:\n");
164             fflush(stderr);
165             debug_print_index(sl->slice_end_index);
166         }
167     }
168 }
169
170 void debug_print_selection(struct rhs_selection *sel) {
171     if (sel == NULL) {
172         fprintf(stderr, "I'd rather not try to print out the contents of a NULL selection
173             .\n");
174         exit(-1);
175     }
176     fprintf(stderr, "-----Everything about this selection-----\n");

```

```

174     fprintf(stderr, "Slice memory addresses: %p and %p\n", sel->slice1, sel->slice2);
175     if (sel->slice1 != NULL) {
176         fprintf(stderr, "Slice 1 info:\n");
177         debug_print_slice(sel->slice1);
178         if (sel->slice2 != NULL) {
179             fprintf(stderr, "Slice 2 info:\n");
180             debug_print_slice(sel->slice2);
181         }
182     } else {
183         if (sel->slice2 != NULL) {
184             fprintf(stderr, "Slice 1 is NULL but slice 2 is not NULL. That should never
185                 happen.\n");
186             fprintf(stderr, "Attempting to print contents anyway:\n");
187             fflush(stderr);
188             debug_print_slice(sel->slice2);
189         }
190     }
191     fprintf(stderr, "————That's all I've got about that selection————\n\n");
192 }
193 int rg_eq(value_p val1, value_p val2) {
194     int res = 1;
195     if (val1->flags != val2->flags) res = 0;
196     else if (val1->flags == FLAG_EMPTY) ;
197     else if (val1->flags == FLAG_NUMBER && val1->numericVal != val2->numericVal) res = 0;
198     else if (val1->flags == FLAG_STRING && strcmp(val1->str->text, val2->str->text)) res
199         = 0;
200     else if (val1->flags == FLAG_SUBRANGE) {
201         subrange_p sr1 = val1->subrange;
202         subrange_p sr2 = val2->subrange;
203         if (sr1->subrange_num_cols != sr2->subrange_num_cols || sr1->subrange_num_rows !=
204             sr2->subrange_num_rows) {
205             return 0;
206         } else {
207             int i, j;
208             value_p v1, v2;
209             for (i = 0; i < sr1->subrange_num_rows; i++) {
210                 for (j = 0; j < sr1->subrange_num_cols; j++) {
211                     v1 = getValSR(sr1, i, j);
212                     v2 = getValSR(sr2, i, j);
213                     if (rg_eq(v1, v2) == 0) {
214                         return 0;
215                     }
216                 }
217             }
218         }
219     }
220     return res;
221 }
222 void incStack() {
223     const rlim_t kStackSize = 64L * 1024L * 1024L;
224     struct rlimit rl;
225     int result;
226     result = getrlimit(RLIMIT_STACK, &rl);

```

```

227     rl.rlim_cur = rl.rlim_max;
228     result = setrlimit(RLIMIT_STACK, &rl);
229 }
230
231 double setNumeric(value_p result, double val) {
232     result->flags = FLAG_NUMBER;
233     return (result->numericVal = val);
234 }
235
236 double setFlag(value_p result, double flag_num) {
237     return (result->flags = flag_num);
238 }
239
240 int assertSingle(value_p value) {
241     /* TODO: dereference 1 by 1 subrange */
242     return !(value->flags == FLAG_SUBRANGE);
243 }
244
245 int assertSingleNumber(value_p p) {
246     if (!assertSingle(p)) {
247         return 0;
248     }
249     return (p->flags == FLAG_NUMBER);
250 }
251
252 int assertText(value_p my_val) {
253     return (my_val->flags == FLAG_STRING);
254 }
255
256 int assertSingleString(value_p p) {
257     if (!assertSingle(p)) {
258         return 0;
259     }
260     return (p->flags == FLAG_STRING);
261 }
262
263 int assertEmpty(value_p p) {
264     if (!assertSingle(p)) {
265         return 0;
266     }
267     return (p->flags == FLAG_EMPTY);
268 }
269
270 value_p new_val() {
271     value_p empty_val = malloc(sizeof(struct value_t));
272     setFlag(empty_val, FLAG_EMPTY);
273     return empty_val;
274 }
275
276 value_p new_number(double val) {
277     value_p new_v = malloc(sizeof(struct value_t));
278     setFlag(new_v, FLAG_NUMBER);
279     setNumeric(new_v, val);
280     return new_v;
281 }
282

```

```

283 value_p new_string(char *s) {
284     if (s == NULL) return new_val();
285     value_p new_v = malloc(sizeof(struct value_t));
286     setFlag(new_v, FLAG_STRING);
287     string_p new_str = malloc(sizeof(struct string_t));
288     long len = strlen(s);
289     new_str->text = malloc(len+1);
290     strcpy(new_str->text, s);
291     new_str->length = len;
292     new_str->refs = 1;
293     new_v->str = new_str;
294     return new_v;
295 }
296
297 struct ExtendScope *global_scope;
298
299 void null_init(struct ExtendScope *scope_ptr) {
300     int i;
301     for(i = 0; i < scope_ptr->numVars; i++)
302         scope_ptr->vars[i] = NULL;
303 }
304
305 char getIntFromOneByOne(struct ExtendScope *scope_ptr, int varnum, int *result) {
306     if (!scope_ptr->defns[varnum].isOneByOne) {
307         fprintf(stderr, "A variable (%s) that is supposedly one by one is not defined that
308             way.\n", scope_ptr->defns[varnum].name);
309         exit(-1);
310     }
311     struct var_instance *inst = get_variable(scope_ptr, varnum);
312     if (inst->rows != 1 || inst->cols != 1) {
313         fprintf(stderr, "A variable (%s) that is defined as one by one is somehow actually
314             %d by %d.\n", inst->name, inst->rows, inst->cols);
315         exit(-1);
316     }
317     value_p val = getVal(inst, 0, 0);
318     if (!assertSingleNumber(val) || !isfinite(val->numericVal)) {
319         return 0;
320     }
321     *result = (int) lrint(val->numericVal);
322     return 1;
323 }
324
325 struct var_instance *instantiate_variable(struct ExtendScope *scope_ptr, struct
326     var_defn def) {
327     struct var_instance *inst = malloc(sizeof(struct var_instance));
328     if(def.isOneByOne) {
329         inst->rows = 1;
330         inst->cols = 1;
331     } else {
332         if (!getIntFromOneByOne(scope_ptr, def.rows_varnum, &inst->rows)) {
333             fprintf(stderr, "EXITING - The expression for the number of rows of variable %s
334                 did not evaluate to a finite Number.\n", def.name);
335             exit(-1);
336         }
337         if (!getIntFromOneByOne(scope_ptr, def.cols_varnum, &inst->cols)) {
338             fprintf(stderr, "EXITING - The expression for the number of columns of variable

```

```

        %s did not evaluate to a finite Number.\n", def.name);
335     exit(-1);
336 }
337 if (inst->rows <= 0 || inst->cols <= 0) {
338     fprintf(stderr, "EXITING - The requested dimensions for variable %s were [%d, %d
        ]; they must both be greater than zero.\n", def.name, inst->rows, inst->cols)
        ;
339     exit(-1);
340 }
341 }
342 // TODO: do the same thing for each FormulaFP to turn an ExtendFormula into a
        ResolvedFormula
343 inst->numFormulas = def.numFormulas;
344 inst->closure = scope_ptr;
345 inst->name = def.name;
346 int size = inst->rows * inst->cols;
347 inst->values = malloc(sizeof(value_p) * size);
348 memset(inst->values, 0, sizeof(value_p) * size);
349 inst->status = malloc(sizeof(char) * size);
350 memset(inst->status, 0, sizeof(char) * size);
351 inst->formulas = malloc(sizeof(struct ResolvedFormula) * inst->numFormulas);
352 //debug_print_vardefn(&def);
353 //debug_print_varinst(inst);
354 int i, j;
355 for(i = 0; i < inst->numFormulas; i++) {
356
357     // Set the formula function pointer to the pointer from the definition
358     inst->formulas[i].formula = def.formulas[i].formula;
359
360     if (def.isOneByOne) {
361         inst->formulas[i].rowStart = 0;
362         inst->formulas[i].rowEnd = 1;
363         inst->formulas[i].colStart = 0;
364         inst->formulas[i].colEnd = 1;
365     } else {
366         if(def.formulas[i].fromFirstRow) {
367             inst->formulas[i].rowStart = 0;
368         } else {
369             if (!getIntFromOneByOne(scope_ptr, def.formulas[i].rowStart_varnum, &inst->
                formulas[i].rowStart)) {
370                 fprintf(stderr, "EXITING - The requested starting row for formula %d of %s
                    did not evaluate to a finite number.\n", i, inst->name);
371                 exit(-1);
372             }
373             if (inst->formulas[i].rowStart < 0) {
374                 inst->formulas[i].rowStart += inst->rows;
375             }
376             if (inst->formulas[i].rowStart < 0 || inst->formulas[i].rowStart >= inst->rows
                ) {
377                 //Doesn't matter, but will never get called
378             }
379         }
380         if (def.formulas[i].isSingleRow) {
381             inst->formulas[i].rowEnd = inst->formulas[i].rowStart + 1;
382         } else if (def.formulas[i].toLastRow) {
383             inst->formulas[i].rowEnd = inst->rows;

```



```

384     } else {
385         if (!getIntFromOneByOne(scope_ptr, def.formulas[i].rowEnd_varnum, &inst->
            formulas[i].rowEnd)) {
386             fprintf(stderr, "EXITING - The requested ending row for formula %d of %s did
                not evaluate to a finite number.\n", i, inst->name);
387             exit(-1);
388         }
389         if (inst->formulas[i].rowEnd < 0) {
390             inst->formulas[i].rowEnd += inst->rows;
391         }
392     }
393     if(def.formulas[i].fromFirstCol) {
394         inst->formulas[i].colStart = 0;
395     } else {
396         if (!getIntFromOneByOne(scope_ptr, def.formulas[i].colStart_varnum, &inst->
            formulas[i].colStart)) {
397             fprintf(stderr, "EXITING - The requested starting column for formula %d of %
                s did not evaluate to a finite number.\n", i, inst->name);
398             exit(-1);
399         }
400         if (inst->formulas[i].colStart < 0) {
401             inst->formulas[i].colStart += inst->cols;
402         }
403         if (inst->formulas[i].colStart < 0 || inst->formulas[i].colStart >= inst->cols
            ) {
404             //Doesn't matter, but will never get called
405         }
406     }
407     if (def.formulas[i].isSingleCol) {
408         inst->formulas[i].colEnd = inst->formulas[i].colStart + 1;
409     } else if (def.formulas[i].toLastCol) {
410         inst->formulas[i].colEnd = inst->cols;
411     } else {
412         if (!getIntFromOneByOne(scope_ptr, def.formulas[i].colEnd_varnum, &inst->
            formulas[i].colEnd)) {
413             fprintf(stderr, "EXITING - The requested starting column for formula %d of %
                s did not evaluate to a finite number.\n", i, inst->name);
414             exit(-1);
415         }
416         if (inst->formulas[i].colEnd < 0) {
417             inst->formulas[i].colEnd += inst->cols;
418         }
419     }
420 }
421 }
422
423 for (i = 1; i < inst->numFormulas; i++) {
424     for (j = 0; j < i; j++) {
425         int intersectRowStart = (inst->formulas[i].rowStart > inst->formulas[j].rowStart
            ) ? inst->formulas[i].rowStart : inst->formulas[j].rowStart;
426         int intersectColStart = (inst->formulas[i].colStart > inst->formulas[j].colStart
            ) ? inst->formulas[i].colStart : inst->formulas[j].colStart;
427         int intersectRowEnd = (inst->formulas[i].rowEnd < inst->formulas[j].rowEnd) ?
            inst->formulas[i].rowEnd : inst->formulas[j].rowEnd;
428         int intersectColEnd = (inst->formulas[i].colEnd < inst->formulas[j].colEnd) ?
            inst->formulas[i].colEnd : inst->formulas[j].colEnd;

```

```

429     if (intersectRowEnd > intersectRowStart && intersectColEnd > intersectColStart)
430     {
431         fprintf(stderr, "Runtime error: Multiple formulas were assigned to %s[%d:%d,%d
            :%d].\n", inst->name,
            intersectRowStart, intersectRowEnd, intersectColStart,
            intersectColEnd);
432         exit(-1);
433     }
434 }
435 }
436
437 scope_ptr->refcount++;
438 return inst;
439 }
440
441 struct var_instance *get_variable(struct ExtendScope *scope_ptr, int varnum) {
442     if (varnum >= scope_ptr->numVars) {
443         fprintf(stderr, "Runtime error: Asked for nonexistant variable number\n");
444         exit(-1);
445     }
446     if (scope_ptr->vars[varnum] == NULL) {
447         scope_ptr->vars[varnum] = instantiate_variable(scope_ptr, scope_ptr->defns[varnum
            ]);
448     }
449     return scope_ptr->vars[varnum];
450 }
451
452 char assertInBounds(struct var_instance *defn, int r, int c) {
453     return (
454         r >= 0 && r < defn->rows &&
455         c >= 0 && c < defn->cols
456     );
457 }
458
459 value_p calcVal(struct var_instance *inst, int r, int c) {
460     int i;
461     for (i = 0; i < inst->numFormulas; i++) {
462         if (
463             r >= inst->formulas[i].rowStart && r < inst->formulas[i].rowEnd &&
464             c >= inst->formulas[i].colStart && c < inst->formulas[i].colEnd
465         ) {
466             return (inst->formulas[i].formula)(inst->closure, r, c);
467         }
468     }
469     return new_val();
470 }
471
472 value_p clone_value(value_p old_value) {
473     value_p new_value = (value_p) malloc(sizeof(struct value_t));
474     new_value->flags = old_value->flags;
475     switch (new_value->flags) {
476         case FLAG_EMPTY:
477             break;
478         case FLAG_NUMBER:
479             new_value->numericVal = old_value->numericVal;
480             break;

```

```

481     case FLAG_STRING:
482         new_value->str = old_value->str;
483         new_value->str->refs++;
484         break;
485     case FLAG_SUBRANGE:
486         new_value->subrange = (subrange_p) malloc(sizeof(struct subrange_t));
487         memcpy(new_value->subrange, old_value->subrange, sizeof(struct subrange_t));
488         if (new_value->subrange->range->closure != NULL) {
489             new_value->subrange->range->closure->refcount++; /* Not sure about this one */
490         }
491         break;
492     default:
493         fprintf(stderr, "clone_value(%p): Illegal value of flags: %c\n", old_value,
494             new_value->flags);
495         exit(-1);
496         break;
497 }
498 return new_value;
499 }
500 void delete_string_p(string_p old_string) {
501     old_string->refs--;
502     if (old_string->refs == 0) {
503         /* free(old_string); */
504     }
505 }
506
507 void delete_subrange_p(subrange_p old_subrange) {
508     if (old_subrange->range->closure != NULL) {
509         old_subrange->range->closure->refcount--;
510     }
511     free(old_subrange);
512 }
513
514 void delete_value(value_p old_value) {
515     switch (old_value->flags) {
516         case FLAG_EMPTY:
517             break;
518         case FLAG_NUMBER:
519             break;
520         case FLAG_STRING:
521             delete_string_p(old_value->str); /* doesn't do anything besides decrement the
522                 ref count now */
523             break;
524         case FLAG_SUBRANGE:
525             delete_subrange_p(old_value->subrange);
526             break;
527         default:
528             fprintf(stderr, "delete_value(%p): Illegal value of flags: %c\n", old_value,
529                 old_value->flags);
530             exit(-1);
531             break;
532     }
533 }
534 value_p deref_subrange_p(subrange_p subrng) {

```

```

534     if (subrng == NULL) {
535         fprintf(stderr, "Exiting - asked to dereference a NULL pointer.\n");
536         exit(-1);
537     }
538     if (subrng->subrange_num_rows == 1 && subrng->subrange_num_cols == 1) {
539         return getVal(subrng->range, subrng->base_var_offset_row, subrng->
            base_var_offset_col);
540     } else {
541         value_p new_value = (value_p) malloc (sizeof(struct value_t));
542         new_value->flags = FLAG_SUBRANGE;
543         new_value->numericVal = 0.0;
544         new_value->str = NULL;
545         new_value->subrange = (subrange_p) malloc (sizeof(struct subrange_t));
546         memcpy(new_value->subrange, subrng, sizeof(struct subrange_t));
547         if (new_value->subrange->range->closure != NULL) {
548             new_value->subrange->range->closure->refcount++;
549         }
550         return new_value;
551     }
552 }
553
554 value_p new_subrange(int num_rows, int num_cols, value_p *vals) {
555     /* This function does not check its arguments; if you supply fewer
556      * than num_rows * num_cols elements in vals, it will crash.
557      * Only use this function if you know what you're doing. */
558     struct subrange_t sr;
559     sr.range = (struct var_instance *) malloc (sizeof(struct var_instance));
560     sr.base_var_offset_row = 0;
561     sr.base_var_offset_col = 0;
562     sr.subrange_num_rows = num_rows;
563     sr.subrange_num_cols = num_cols;
564     sr.range->rows = num_rows;
565     sr.range->cols = num_cols;
566     sr.range->numFormulas = 0;
567     sr.range->formulas = NULL;
568     sr.range->closure = NULL;
569     sr.range->values = (value_p *) malloc(num_rows * num_cols * sizeof(value_p));
570     sr.range->status = (char *) malloc (num_rows * num_cols * sizeof(char));
571     sr.range->name = NULL;
572     int i;
573     for (i = 0; i < num_rows * num_cols; i++) {
574         sr.range->values[i] = clone_value(vals[i]);
575         sr.range->status[i] = CALCULATED;
576     }
577     return deref_subrange_p(&sr);
578 }
579
580 value_p box_command_line_args(int argc, char **argv) {
581     value_p *vals = (value_p *) malloc (argc * sizeof(value_p));
582     int i;
583     for (i = 0; i < argc; i++) {
584         vals[i] = new_string(argv[i]);
585     }
586     value_p ret = new_subrange(1, argc, vals);
587     for (i = 0; i < argc; i++) {
588         free(vals[i]);

```

```

589     }
590     free(vals);
591     return ret;
592 }
593
594 char resolve_rhs_index(struct rhs_index *index, int dimension_len, int
    dimension_cell_num, int *result_ptr) {
595     if (index == NULL) {
596         fprintf(stderr, "Exiting - asked to dereference a NULL index\n");
597         exit(-1);
598     }
599     int i;
600     switch(index->rhs_index_type) {
601         case RHS_IDX_ABSOLUTE:
602             if (!assertSingleNumber(index->val_of_expr)) return false;
603             i = (int) lrint(index->val_of_expr->numericVal);
604             if (i >= 0) {
605                 *result_ptr = i;
606             } else {
607                 *result_ptr = i + dimension_len;
608             }
609             return true;
610             break;
611         case RHS_IDX_RELATIVE:
612             if (!assertSingleNumber(index->val_of_expr)) return false;
613             *result_ptr = dimension_cell_num + (int) lrint(index->val_of_expr->numericVal);
614             return true;
615             break;
616         case RHS_IDX_DIM_START:
617             *result_ptr = 0;
618             return true;
619             break;
620         case RHS_IDX_DIM_END:
621             *result_ptr = dimension_len;
622             return true;
623             break;
624         default:
625             fprintf(stderr, "Exiting - illegal index type\n");
626             exit(-1);
627             break;
628     }
629 }
630
631 char resolve_rhs_slice(struct rhs_slice *slice, int dimension_len, int
    dimension_cell_num, int *start_ptr, int *end_ptr) {
632     char start_success, end_success;
633     if (slice == NULL) {
634         fprintf(stderr, "Exiting - asked to dereference a NULL slice\n");
635         exit(-1);
636     }
637     if (slice->slice_start_index == NULL) {
638         if (slice->slice_end_index != NULL) {
639             fprintf(stderr, "Exiting - illegal slice\n");
640             exit(-1);
641         }
642         if (dimension_len == 1) {

```

```

643     *start_ptr = 0;
644     *end_ptr = 1;
645     return true;
646 } else {
647     *start_ptr = dimension_cell_num;
648     *end_ptr = dimension_cell_num + 1;
649     return true;
650 }
651 } else {
652     start_success = resolve_rhs_index(slice->slice_start_index, dimension_len,
        dimension_cell_num, start_ptr);
653     if (!start_success) return false;
654     if (slice->slice_end_index == NULL) {
655         *end_ptr = *start_ptr + 1;
656         return true;
657     } else {
658         end_success = resolve_rhs_index(slice->slice_end_index, dimension_len,
        dimension_cell_num, end_ptr);
659         return end_success;
660     }
661 }
662 }
663
664 value_p extract_selection(value_p expr, struct rhs_selection *sel, int r, int c) {
665     int expr_rows, expr_cols;
666     struct subrange_t subrange;
667     struct rhs_slice *row_slice_p, *col_slice_p;
668     int row_start, row_end, col_start, col_end;
669     char row_slice_success, col_slice_success;
670
671     if (expr == NULL || sel == NULL) {
672         fprintf(stderr, "Exiting - asked to extract a selection using a NULL pointer.\n");
673         exit(-1);
674     }
675     switch(expr->flags) {
676         case FLAG_EMPTY:
677             return new_val();
678             break;
679         case FLAG_NUMBER: case FLAG_STRING:
680             expr_rows = 1;
681             expr_cols = 1;
682             break;
683         case FLAG_SUBRANGE:
684             expr_rows = expr->subrange->subrange_num_rows;
685             expr_cols = expr->subrange->subrange_num_cols;
686             break;
687         default:
688             fprintf(stderr, "Exiting - invalid value type\n");
689             exit(-1);
690             break;
691     }
692     if (sel->slice1 == NULL) {
693         if (sel->slice2 != NULL) {
694             fprintf(stderr, "Exiting - illegal selection\n");
695             exit(-1);
696         }

```

```

697     row_slice_p = &corresponding_cell;
698     col_slice_p = &corresponding_cell;
699 } else {
700     if (sel->slice2 == NULL) {
701         if (expr_rows == 1) {
702             row_slice_p = &zero_to_one;
703             col_slice_p = sel->slicel;
704         } else if (expr_cols == 1) {
705             row_slice_p = sel->slicel;
706             col_slice_p = &zero_to_one;
707         } else {
708             return new_val();
709         }
710     }
711     /* Alternately:
712     fprintf(stderr, "Runtime error: Only given one slice for a value with multiple
713        rows and multiple columns\n");
714     debug_print(expr);
715     exit(-1); */
716     }
717     } else {
718         row_slice_p = sel->slicel;
719         col_slice_p = sel->slice2;
720     }
721 }
722 row_slice_success = resolve_rhs_slice(row_slice_p, expr_rows, r, &row_start, &
723     row_end);
724 col_slice_success = resolve_rhs_slice(col_slice_p, expr_cols, c, &col_start, &
725     col_end);
726 if (!row_slice_success || !col_slice_success) return new_val();
727 if (row_start < 0) row_start = 0;
728 if (col_start < 0) col_start = 0;
729 if (row_end > expr_rows) row_end = expr_rows;
730 if (col_end > expr_cols) col_end = expr_cols;
731 if (row_start <= row_end || col_start <= col_end) return new_val();
732 if (expr->flags == FLAG_NUMBER || expr->flags == FLAG_STRING) {
733     /* You would have thought we could figure this out a lot further up
734     * in the code, but had to be sure that (row_start, row_end, col_start, col_end)
735     * actually ended up as (0, 1, 0, 1) */
736     return clone_value(expr);
737 } else {
738     subrange.range = expr->subrange->range;
739     subrange.base_var_offset_row = expr->subrange->base_var_offset_row + row_start;
740     subrange.base_var_offset_col = expr->subrange->base_var_offset_col + col_start;
741     subrange.subrange_num_rows = row_end - row_start;
742     subrange.subrange_num_cols = col_end - col_start;
743     return deref_subrange_p(&subrange);
744 }
745 }
746
747 value_p getValSR(struct subrange_t *sr, int r, int c) {
748     if(sr->subrange_num_rows <= r || sr->subrange_num_cols <= c || r < 0 || c < 0)
749         return new_val();
750     return getVal(sr->range, r + sr->base_var_offset_row, c + sr->base_var_offset_col);
751 }
752
753 void verify_assert(value_p val, char *fname) {
754     if ((!assertSingleNumber(val)) || val->numericVal != 1.0) {

```

```

750     fprintf(stderr, "EXITING - The function %s was called with arguments of the wrong
751         dimensions.\n", fname);
752     exit(-1);
753 }
754
755 value_p getVal(struct var_instance *inst, int r, int c) {
756     /* If we're going to return new_val() then we have to
757      * do clone_value(). Otherwise the receiver won't know
758      * whether or not they can free the value_p they get back.
759      * I think this should return, dangerously, return NULL if it's
760      * invalid, and the callers will have to be careful to check the value.
761      * The alternative is to always clone_value - safer, but much slower
762      * and makes our memory issues even bigger.
763      * Right now there are only a few places that call this. */
764
765     if(!assertInBounds(inst, r, c)) return NULL;
766     int cell_number = r * inst->cols + c;
767     char cell_status = inst->status[cell_number];
768     switch(cell_status) {
769         case NEVER_EXAMINED:
770             inst->status[cell_number] = IN_PROGRESS;
771             inst->values[cell_number] = calcVal(inst, r, c);
772             if (inst->values[cell_number]->flags == FLAG_SUBRANGE) {
773                 int i, j;
774                 for (i = 0; i < inst->values[cell_number]->subrange->subrange_num_rows; i++) {
775                     for (j = 0; j < inst->values[cell_number]->subrange->subrange_num_cols; j++)
776                         {
777                             /* Prevent sneaky circular references */
778                             getVal(inst->values[cell_number]->subrange->range,
779                                     i + inst->values[cell_number]->subrange->base_var_offset_row,
780                                     j + inst->values[cell_number]->subrange->base_var_offset_col);
781                         }
782                 }
783             inst->status[cell_number] = CALCULATED;
784             break;
785         case IN_PROGRESS:
786             fprintf(stderr, "EXITING - Circular reference in %s[%d,%d]\n", inst->name, r, c)
787                 ;
788             exit(-1);
789             break;
790         case CALCULATED:
791             if (inst->values[cell_number] == NULL) {
792                 fprintf(stderr, "Supposedly, %s[%d,%d] was already calculated, but there is a
793                     null pointer there.\n", inst->name, r, c);
794                 fprintf(stderr, "Attempting to print contents of the variable instance where
795                     this occurred:\n");
796                 fflush(stderr);
797                 debug_print_varinst(inst);
798                 exit(-1);
799             }
800             break;
801         default:
802             fprintf(stderr, "Unrecognized cell status %d (row %d, col %d)!\n", cell_status,
803                 r, c);

```



```

800     fprintf(stderr, "Attempting to print contents of the variable instance where
      this occurred:\n");
801     fflush(stderr);
802     debug_print_varinst(inst);
803     exit(-1);
804     break;
805 }
806 return inst->values[cell_number];
807 }

```

7.12 stdlib.xtnd

```

1  extern "stdlib.a" {
2      current_hour();
3      print(whatever, text);
4      printv(whatever, text);
5      printf(whatever, text);
6      to_string(val);
7      sin(val);
8      cos(val);
9      tan(val);
10     acos(val);
11     asin(val);
12     atan(val);
13     sinh(val);
14     cosh(val);
15     tanh(val);
16     exp(val);
17     log(val);
18     log10(val);
19     sqrt(val);
20     ceil(val);
21     fabs(val);
22     floor(val);
23     isNaN(val);
24     len(str);
25     round(val, number_of_digits);
26     isInfinite(val);
27     get_stdin();
28     get_stdout();
29     get_stderr();
30     open(filename, mode);
31     close(file_handle);
32     read(file_handle, num_bytes);
33     readline(file_handle);
34     write(file_handle, buffer);
35     toASCII(val);
36     fromASCII(val);
37     plot(val);
38     bar_chart(file_handle, labels, vals);
39     line_chart(file_handle, labels, x_vals);
40     parseFloat(val);
41 }
42
43 global STDIN := get_stdin();

```

```
44 global STDOUT := get_stdout();
45 global STDERR := get_stderr();
46
47 print_endline(val) {
48     return write(STDOUT, to_string(val) + "\n");
49 }
```

8. Tests and Output

helloworld.xtnd

```
1 main(args) {  
2   foo := printf(1,"Hello World\n") -> 0;  
3   return foo;  
4 }
```

helloworld.xtnd - Expected Output

```
1 Hello World
```

test-access-cell.xtnd

```
1 main([1,n] args) {  
2   [2,2] foo := "string";  
3   bar := foo[1,1];  
4   return print(1,to_string(bar)) -> print(1, "\n") -> 0;  
5 }
```

test-access-cell.xtnd - Expected Output

```
1 string
```

test-access-column-cell.xtnd

```
1 main([1,n] args) {  
2   [4,1] foo := "string";  
3   return print(1,to_string( foo[1,0]))+"\n") -> 0;  
4 }
```

test-access-column-cell.xtnd - Expected Output

```
1 string
```

test-access-hashtag-multi-dim.xtnd

```
1 main([1,n] args) {  
2   [4,4] foo := "string";  
3   return print(1,to_string( #foo)+"\n") -> 0;  
4 }
```

test-access-hashtag-multi-dim.xtnd - Expected Output

```
1 string
```

test-access-hashtag-single-dim.xtnd

```

1 main([1,n] args) {
2   [1,1] foo := "string";
3   return print(1,to_string( #foo)+"\n") -> 0;
4 }

```

test-access-hashtag-single-dim.xtnd - Expected Output

```

1 string

```

test-access-relative-range.xtnd

```

1 main([1,n] args) {
2   [4,4] foo := "string";
3   return print(1,to_string( foo[, [1]])+"\n") -> 0;
4 }

```

test-access-relative-range.xtnd - Expected Output

```

1 string

```

test-acos.xtnd

```

1 main(args) {
2   return printd(1, acos(0.0)) -> 0;
3 }

```

test-acos.xtnd - Expected Output

```

1 1.570796

```

test-addition.xtnd

```

1 main(args){
2   return print(1,to_string( 5 + 7)+"\n") -> 0;
3 }

```

test-addition.xtnd - Expected Output

```

1 12

```

test-addition-empty.xtnd

```

1 main([1,1] args){
2   return print(1,to_string( empty + 5)+"\n") -> 0;
3 }

```

test-addition-empty.xtnd - Expected Output

```

1 empty

```

test-asin.xtnd

```

1 main([1,n] args) {
2   return printd(1, asin(0.5)) -> 0;
3 }

```

test-asin.xtnd - Expected Output

```

1 0.523599

```

test-atan.xtnd

```
1 main([1,n] args) {  
2     return printf(1, atan(45.0)) -> 0;  
3 }
```

test-atan.xtnd - Expected Output

```
1 1.548578
```

test-basic-func.xtnd

```
1 main([1,n] args) {  
2     foo := 2;  
3     bar := 3;  
4     foobar := foo + bar;  
5     return print(1,to_string( 0)+"\n") -> 0;  
6 }
```

test-basic-func.xtnd - Expected Output

```
1 0
```

test-bitnot.xtnd

```
1 main(args) {  
2     return print_endline(~{"a",1}) -> print_endline(~1) -> print_endline(~0) ->  
3     print_endline(~"a") -> print_endline(empty);  
4 }
```

test-bitnot.xtnd - Expected Output

```
1 empty  
2 -2  
3 -1  
4 empty  
5 empty
```

test-bitwise-and.xtnd

```
1 main([1,1] args){  
2     return print(1,to_string( 23 & 12)+"\n") -> 0;  
3 }
```

test-bitwise-and.xtnd - Expected Output

```
1 4
```

test-bitwise-and-empty.xtnd

```
1 main([1,1] args){  
2     return print(1,to_string( empty & 4)+"\n") -> 0;  
3 }
```

test-bitwise-and-empty.xtnd - Expected Output

```
1 empty
```

test-bitwise-left.xtnd

```

1 main([1,1] args){
2     return print(1,to_string( 14 << 2)+"\n") -> 0;
3 }

```

test-bitwise-left.xtnd - Expected Output

```

1 56

```

test-bitwise-left-empty.xtnd

```

1 main([1,1] args){
2     return print(1,to_string( empty >> 1)+"\n") -> 0;
3 }

```

test-bitwise-left-empty.xtnd - Expected Output

```

1 empty

```

test-bitwise-not.xtnd

```

1 main([1,1] args){
2     /* Should return -89 */
3     return print(1,to_string( ~88)+"\n") -> 0;
4 }

```

test-bitwise-not.xtnd - Expected Output

```

1 -89

```

test-bitwise-not-empty.xtnd

```

1 main([1,1] args){
2     /* Should return empty */
3     return print(1,to_string( ~empty)+"\n") -> 0;
4 }

```

test-bitwise-not-empty.xtnd - Expected Output

```

1 empty

```

test-bitwise-or.xtnd

```

1 main([1,1] args){
2     return print(1,to_string( 14 | 12)+"\n") -> 0;
3 }

```

test-bitwise-or.xtnd - Expected Output

```

1 14

```

test-bitwise-or-empty.xtnd

```

1 main([1,1] args){
2     return print(1,to_string( empty | 2)+"\n") -> 0;
3 }

```

test-bitwise-or-empty.xtnd - Expected Output

```

1 empty

```

test-bitwise-right.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( 12 >> 2)+"\n") -> 0;
3 }
```

test-bitwise-right.xtnd - Expected Output

```
1 3
```

test-bitwise-right-empty.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( empty >> 2)+"\n") -> 0;
3 }
```

test-bitwise-right-empty.xtnd - Expected Output

```
1 empty
```

test-bitwise-xor.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( 14 ^ 12)+"\n") -> 0;
3 }
```

test-bitwise-xor.xtnd - Expected Output

```
1 2
```

test-bitwise-xor-empty.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( empty ^ 2)+"\n") -> 0;
3 }
```

test-bitwise-xor-empty.xtnd - Expected Output

```
1 empty
```

test-boolean-equals.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( 5 == 6)+"\n") -> 0;
3 }
```

test-boolean-equals.xtnd - Expected Output

```
1 0
```

test-boolean-equals-both-empty.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( empty == empty)+"\n") -> 0;
3 }
```

test-boolean-equals-both-empty.xtnd - Expected Output

```
1 1
```

test-boolean-equals-harder.xtnd

```
1 main([1,1] args){
2     return
3     printv(1, "True cases for ==\n") ->
4     printd(1, (5 == 5)) ->
5     printd(1, (5 == 5.0)) ->
6     printd(1, (0.5 == 5e-1)) ->
7     printd(1, (50 == 5e1)) ->
8     printd(1, 2 + 2 == 4) ->
9     printd(1, "foo" == "foo") ->
10    printd(1, "" == "") ->
11    printd(1, empty == empty) ->
12    printd(1, empty == !empty) ->
13    printd(1, !"foo" == !"bar") ->
14    printd(1, (2 ? 3 : 4) == ("foo" ? 3 : "not 4") ) ->
15
16    printv(1, "\nFalse cases for ==\n") ->
17    printd(1, (5 == 6)) ->
18    printd(1, (5 == 5.01)) ->
19    printd(1, (0.5 == 5e-2)) ->
20    printd(1, (50 == 5e2)) ->
21    printd(1, 2 + 2 == 5) ->
22    printd(1, "foo" == "bar") ->
23    printd(1, "" == "foo") ->
24    printd(1, "" == empty) ->
25    printd(1, 2 == empty) ->
26    printd(1, empty == 2) ->
27    printd(1, (2 ? 3 : 4) == ("foo" ? "not 3" : 4) ) ->
28
29    printv(1, "\nTrue cases for !=\n") ->
30    printd(1, (5 != 6)) ->
31    printd(1, (5 != 5.01)) ->
32    printd(1, (0.5 != 5e-2)) ->
33    printd(1, (50 != 5e2)) ->
34    printd(1, 2 + 2 != 5) ->
35    printd(1, "foo" != "bar") ->
36    printd(1, "" != "foo") ->
37    printd(1, "" != empty) ->
38    printd(1, 2 != empty) ->
39    printd(1, empty != 2) ->
40    printd(1, (2 ? 3 : 4) != ("foo" ? "not 3" : 4) ) ->
41
42    printv(1, "\nFalse cases for !=\n") ->
43    printd(1, (5 != 5)) ->
44    printd(1, (5 != 5.0)) ->
45    printd(1, (0.5 != 5e-1)) ->
46    printd(1, (50 != 5e1)) ->
47    printd(1, 2 + 2 != 4) ->
48    printd(1, "foo" != "foo") ->
49    printd(1, "" != "") ->
50    printd(1, empty != empty) ->
51    printd(1, empty != !empty) ->
52    printd(1, !"foo" != !"bar") ->
53    printd(1, (2 ? 3 : 4) != ("foo" ? 3 : "not 4") ) ->
54
55    0;
```


56 }

test-boolean-equals-harder.xtnd - Expected Output

```
1 True cases for ==
2 1.000000
3 1.000000
4 1.000000
5 1.000000
6 1.000000
7 1.000000
8 1.000000
9 1.000000
10 1.000000
11 1.000000
12 1.000000
13
14 False cases for ==
15 0.000000
16 0.000000
17 0.000000
18 0.000000
19 0.000000
20 0.000000
21 0.000000
22 0.000000
23 0.000000
24 0.000000
25 0.000000
26
27 True cases for !=
28 1.000000
29 1.000000
30 1.000000
31 1.000000
32 1.000000
33 1.000000
34 1.000000
35 1.000000
36 1.000000
37 1.000000
38 1.000000
39
40 False cases for !=
41 0.000000
42 0.000000
43 0.000000
44 0.000000
45 0.000000
46 0.000000
47 0.000000
48 0.000000
49 0.000000
50 0.000000
51 0.000000
```

test-boolean-equals-one-empty.xtnd

```

1 main([1,1] args){
2     return print(1,to_string( empty == 5)+"\n") -> 0;
3 }

```

test-boolean-equals-one-empty.xtnd - Expected Output

```

1 0

```

test-boolean-logical-not-equals.xtnd

```

1 main([1,1] args){
2     return print(1,to_string( 6 != 7)+"\n") -> 0;
3 }

```

test-boolean-logical-not-equals.xtnd - Expected Output

```

1 1

```

test-boolean-logical-not-equals-both-empty.xtnd

```

1 main([1,1] args){
2     return print(1,to_string( empty != empty)+"\n") -> 0;
3 }

```

test-boolean-logical-not-equals-both-empty.xtnd - Expected Output

```

1 0

```

test-boolean-logical-not-equals-one-empty.xtnd

```

1 main([1,1] args){
2     return print(1,to_string( empty != 5)+"\n") -> 0;
3 }

```

test-boolean-logical-not-equals-one-empty.xtnd - Expected Output

```

1 1

```

test-calling-func-from-import.xtnd

```

1 import "../samples/gcd_func.xtnd";
2
3 main([1,n] args){
4     return print(1,to_string( gcd(70, 55)+"\n") -> 0;
5 }

```

test-calling-func-from-import.xtnd - Expected Output

```

1 5

```

test-ceil.xtnd

```

1 main([1,n] args) {
2     return printd(1, ceil(10.45)) -> 0;
3 }

```

test-ceil.xtnd - Expected Output

```

1 11.000000

```

test-cos.xtnd

```
1 main([1,n] args) {  
2     return printf(1, cos(45.0)) -> 0;  
3 }
```

test-cos.xtnd - Expected Output

```
1 0.525322
```

test-cosh.xtnd

```
1 main([1,n] args) {  
2     return printf(1, cosh(45.0)) -> 0;  
3 }
```

test-cosh.xtnd - Expected Output

```
1 17467135528742547456.000000
```

test-division.xtnd

```
1 main([1,1] args){  
2     /* Should evaluate to 4 */  
3     return printf(1,to_string( 20 / 5)+"\n") -> 0;  
4 }
```

test-division.xtnd - Expected Output

```
1 4
```

test-division-empty.xtnd

```
1 main([1,n] args){  
2     /* Should return empty */  
3     return printf(1,to_string( empty / 5)+"\n") -> 0;  
4 }
```

test-division-empty.xtnd - Expected Output

```
1 empty
```

test-exp.xtnd

```
1 main([1,n] args) {  
2     return printf(1, exp(2.0)) -> 0;  
3 }
```

test-exp.xtnd - Expected Output

```
1 7.389056
```

test-fabs.xtnd

```
1 main([1,n] args) {  
2     return printf(1, fabs(-45.0)) -> 0;  
3 }
```

test-fabs.xtnd - Expected Output

```
1 45.000000
```

test-file-close.xtnd

```
1 main(args){
2     return close(open("testcases/assets/test_file.txt", "r")) -> print(1,"Made it this
   far\n") -> 0;
3 }
```

test-file-close.xtnd - Expected Output

```
1 Made it this far
```

test-file-read.xtnd

```
1 main(args){
2     return print(1, read(open("testcases/assets/test_file.txt", "r"),5)) -> 0;
3 }
```

test-file-read.xtnd - Expected Output

```
1 This
```

test-file-slurp.xtnd

```
1 main(args){
2     return
3     print(1, read(open("testcases/assets/test_file.txt", "r"),0)) ->
4     0;
5 }
```

test-file-slurp.xtnd - Expected Output

```
1 This is a test file!
```

test-file-write.xtnd

```
1 main(args){
2     handle := open("testcases/assets/test_file_write.out", "w");
3     return
4     write(handle, "Hello") ->
5     close(handle) ->
6     print(1,"Made it this far\n") ->
7     0;
8 }
```

test-file-write.xtnd - Expected Output

```
1 Made it this far
```

test-floor.xtnd

```
1 main([1,n] args) {
2     return printf(1, floor(10.45)) -> 0;
3 }
```

test-floor.xtnd - Expected Output

```
1 10.000000
```

test-func-params.xtnd

```

1 main([1,n] args) {
2     return print(1,to_string( foo("string"))+"\n") -> 0;
3 }
4 foo([1,1] arg) {
5     return arg;
6 }

```

test-func-params.xtnd - Expected Output

```

1 string

```

test-func-params-omit-dim.xtnd

```

1 main([1,n] args) {
2     return print(1,to_string( foo("string"))+"\n") -> 0;
3 }
4 foo([1,1] arg) {
5     return arg;
6 }

```

test-func-params-omit-dim.xtnd - Expected Output

```

1 string

```

test-global-hello.xtnd

```

1 bar() {
2     foo := 5;
3     return 2;
4 }
5
6 global foo := printv(1,"Hello Globals!\n") -> 0;
7
8 main(args) {
9     return foo;
10 }

```

test-global-hello.xtnd - Expected Output

```

1 Hello Globals!

```

test-global-masking.xtnd

```

1 bar() {
2     foo := 5;
3     return 2;
4 }
5
6 global foo := printv(1,"Hello Globals!\n") -> 0;
7
8 main(args) {
9     foo := printv(1,"Hello Locals!\n") -> 0;
10    return foo;
11 }

```

test-global-masking.xtnd - Expected Output

```

1 Hello Locals!

```

test-globals-between-imports.xtnd

```
1 import "../testcases/assets/string.xtnd";
2 global foo;
3 global [2, 5] bar;
4 import "../testcases/assets/string.xtnd";
```

test-globals-between-imports.xtnd - Expected Output

```
1 Hello
```

test-greater-than.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( 6 > 5)+"\n") -> 0;
3 }
```

test-greater-than.xtnd - Expected Output

```
1 1
```

test-greater-than-empty.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( empty > 5)+"\n") -> 0;
3 }
```

test-greater-than-empty.xtnd - Expected Output

```
1 empty
```

test-greater-than-or-equal.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( 7 >= 7)+"\n") -> 0;
3 }
```

test-greater-than-or-equal.xtnd - Expected Output

```
1 1
```

test-greater-than-or-equal-empty.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( empty >= 7)+"\n") -> 0;
3 }
```

test-greater-than-or-equal-empty.xtnd - Expected Output

```
1 empty
```

test-less-than.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( 6 < 7)+"\n") -> 0;
3 }
```

test-less-than.xtnd - Expected Output

```
1 1
```

test-less-than-empty.xtnd

```
1 main([1,1] args){
2     return print(1,to_string( empty > 5)+"\n") -> 0;
3 }
```

test-less-than-empty.xtnd - Expected Output

```
1 empty
```

test-less-than-or-equal.xtnd

```
1 main([1,1] args){
2     return print(1,to_string( 7 <= 5)+"\n") -> 0;
3 }
```

test-less-than-or-equal.xtnd - Expected Output

```
1 0
```

test-less-than-or-equal-empty.xtnd

```
1 main([1,1] args){
2     return print(1,to_string( empty <= 8)+"\n") -> 0;
3 }
```

test-less-than-or-equal-empty.xtnd - Expected Output

```
1 empty
```

test-log.xtnd

```
1 main([1,n] args) {
2     return printf(1, log(10.0)) -> 0;
3 }
```

test-log.xtnd - Expected Output

```
1 2.302585
```

test-log10.xtnd

```
1 main([1,n] args) {
2     return printf(1, log10(100.0)) -> 0;
3 }
```

test-log10.xtnd - Expected Output

```
1 2.000000
```

test-logical-and.xtnd

```
1 main([1,1] args){
2     return print(1,to_string( 1 && 6)+"\n") -> 0;
3 }
```

test-logical-and.xtnd - Expected Output

```
1 1
```

test-logical-and-empty.xtnd

```
1 main([1,1] args){
2     return print(1,to_string( empty && 1)+"\n") -> 0;
3 }
```

test-logical-and-empty.xtnd - Expected Output

```
1 empty
```

test-logical-not.xtnd

```
1 main([1,1] args){
2     return print(1,to_string( !5)+"\n") -> 0;
3 }
```

test-logical-not.xtnd - Expected Output

```
1 0
```

test-logical-not-empty.xtnd

```
1 main([1,1] args){
2     return print(1,to_string( !empty)+"\n") -> 0;
3 }
```

test-logical-not-empty.xtnd - Expected Output

```
1 empty
```

test-logical-or.xtnd

```
1 main([1,1] args){
2     return print(1,to_string( 5 || 6)+"\n") -> 0;
3 }
```

test-logical-or.xtnd - Expected Output

```
1 1
```

test-logical-or-empty.xtnd

```
1 main([1,1] args){
2     return print(1,to_string( empty || 4)+"\n") -> 0;
3 }
```

test-logical-or-empty.xtnd - Expected Output

```
1 empty
```

test-modulo.xtnd

```
1 main([1,n] args){
2     /* Should return 1 */
3     return print(1,to_string( 5 % 4)+"\n") -> 0;
4 }
```

test-modulo.xtnd - Expected Output

```
1 1
```


test-modulo-empty.xtnd

```
1 main([1,n] args){
2     /* Should return empty */
3     return print(1,to_string( empty % 5)+"\n") -> 0;
4 }
```

test-modulo-empty.xtnd - Expected Output

```
1 empty
```

test-multiple-imports.xtnd

```
1 import "../..//testcases/assets/string.xtnd";
2 import "../..//testcases/assets/string.xtnd";
```

test-multiple-imports.xtnd - Expected Output

```
1 Hello
```

test-multiplication.xtnd

```
1 main([1,n] args){
2     /* Should evaluate to 35 */
3     return print(1,to_string( 7 * 5)+"\n") -> 0;
4 }
```

test-multiplication.xtnd - Expected Output

```
1 35
```

test-multiplication-empty.xtnd

```
1 main([1,n] args){
2     /* Should evaluate to empty */
3     return print(1,to_string( empty * 5)+"\n") -> 0;
4 }
```

test-multiplication-empty.xtnd - Expected Output

```
1 empty
```

test-nan-and-infinity.xtnd

```
1 main(args) {
2     should_be_nan := sqrt(-1);
3     should_also_be_nan := 0 / 0;
4     should_be_plus_inf := 2 / 0;
5     should_be_minus_inf := -3 / 0;
6     should_be_normal := 4;
7     foo := "Hello";
8     bar := empty;
9     [3,3] baz := row() * column();
10
11     return
12         print_endline(typeof(should_be_nan)) -> // "Number"
13         print_endline(typeof(should_also_be_nan)) -> // "Number"
14         print_endline(typeof(should_be_plus_inf)) -> // "Number"
15         print_endline(typeof(should_be_minus_inf)) -> // "Number"
```

```

16     print_endline(typeof(should_be_normal)) -> // "Number"
17     print_endline(typeof(foo)) -> // "String"
18     print_endline(typeof(bar)) -> // "Empty"
19     print_endline(typeof(baz)) -> // "Range"
20     print_endline("") ->
21
22     print_endline(isNaN(should_be_nan)) -> // 1
23     print_endline(isNaN(should_also_be_nan)) -> // 1
24     print_endline(isNaN(should_be_plus_inf)) -> // 0
25     print_endline(isNaN(should_be_minus_inf)) -> // 0
26     print_endline(isNaN(should_be_normal)) -> // 0
27     print_endline(isNaN(foo)) -> // 0
28     print_endline(isNaN(bar)) -> // 0
29     print_endline(isNaN(baz)) -> // 0
30     print_endline("") ->
31
32     print_endline(isInfinite(should_be_nan)) -> // 0
33     print_endline(isInfinite(should_also_be_nan)) -> // 0
34     print_endline(isInfinite(should_be_plus_inf)) -> // 1
35     print_endline(isInfinite(should_be_minus_inf)) -> // -1
36     print_endline(isInfinite(should_be_normal)) -> // 0
37     print_endline(isInfinite(foo)) -> // 0
38     print_endline(isInfinite(bar)) -> // 0
39     print_endline(isInfinite(baz)) -> // 0
40
41     0;
42 }

```

test-nan-and-infinity.xtnd - Expected Output

```

1  Number
2  Number
3  Number
4  Number
5  Number
6  String
7  Empty
8  Range
9
10 1
11 1
12 0
13 0
14 0
15 empty
16 empty
17 empty
18
19 0
20 0
21 1
22 -1
23 0
24 empty
25 empty
26 empty

```

test-parse-error.xtnd

```
1 main(args){
2     foo := 5$5;
3     return foo;
4 }
```

test-parse-error.xtnd - Expected Output

```
1 Syntax error in "./testcases/inputs_regression/test_parse_error.xtnd": Invalid
   character: $
2 Line 2 at character 11
```

test-parse-error-after-multiline-comment.xtnd

```
1 main(args){
2     /* This is a comment spanning multiple lines.
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21 20 of them, in fact. */
22     foo := 5/5;
23     bar := $$$$
24     return foo;
25 }
```

test-parse-error-after-multiline-comment.xtnd - Expected Output

```
1 Syntax error in "./testcases/inputs_regression/
   test_parse_error_after_multiline_comment.xtnd": Invalid character: $
2 Line 23 at character 10
```

test-parse-error-comment.xtnd

```
1 main(args){
2     foo := 5/5;
3     /* Test comment */ foo := 5$5;
4     return foo;
5 }
```

test-parse-error-comment.xtnd - Expected Output

```
1 Syntax error in "./testcases/inputs_regression/test_parse_error_comment.xtnd": Invalid
   character: $
2 Line 3 at character 30
```

test-parse-error-missing-semicolon.xtnd

```
1 main([1,1] args){
2   x := switch() {
3     case 1 > 2: 100;
4     case 3 > 0: 200
5   };
6   return printf(1,toString(x)+"\n") -> 0;
7 }
```

test-parse-error-missing-semicolon.xtnd - Expected Output

```
1 Syntax error in "./testcases/inputs_regression/test_parse_error_missing_semicolon.xtnd
   ":
2 Line 5 at character 2
```

test-parse-error-newlines.xtnd

[illegible]

test-parse-error-newlines.xtnd - Expected Output

```
1 Syntax error in "../testcases/inputs_regression/test_parse_error_newlines.xtnd":
    Invalid character: $
2 Line 3 at character 52
```

test-parse-error-string.xtnd

```
1  main(args){
2      foo := "Hello";$$$;
3      return foo;
4  }
```

test-parse-error-string.xtnd - Expected Output

```
1 Syntax error in "./testcases/inputs_regression/test_parse_error_string.xtnd": Invalid
  character: $
2 Line 2 at character 18
```

test-power.xtnd

```
1 main([1,n] args){
2     /* Should return 216 */
3     return print(1,to_string( 6**3)+"\n") -> 0;
4 }
```

test-power.xtnd - Expected Output

1 216

test-power-empty.xtnd

```
1 main([1,n] args){
2     /* Should return empty */
3     return print(1,to_string( empty**5)+"\n") -> 0;
4 }
```

test-power-empty.xtnd - Expected Output

```
1 empty
```

test-print-empty.xtnd

```
1 main([1,n] args) {  
2   foo := empty;  
3   return print(1,to_string( foo)+"\n") -> 0;  
4 }
```

test-print-empty.xtnd - Expected Output

```
1 empty
```

test-print-nums.xtnd

```
1 main([1,n] args) {  
2   foo := 1;  
3   return print(1,to_string( foo)+"\n") -> 0;  
4 }
```

test-print-nums.xtnd - Expected Output

```
1 1
```

test-print-str.xtnd

```
1 main([1,n] args) {  
2   foo := "string";  
3   return print(1,to_string( foo)+"\n") -> 0;  
4 }
```

test-print-str.xtnd - Expected Output

```
1 string
```

test-range-equality.xtnd

```
1 main(args) {  
2   my1 := {"Hello, world", "Goodbye, world"};  
3   my2 := {"Hello, world", "Goodbye, world"};  
4   my3 := {3,4,5,{"Hello, world", "Goodbye, world"},6,7,8};  
5   my4 := {3,empty,5,{"Hello, world", "Goodbye, world"},6,7,8};  
6   my5 := {3,4,5,{"Hello, world"; "Goodbye, world"},6,7,8};  
7   [2,2] foo := my1;  
8   [2,1] bar := my1;  
9   [3,3] ident := row() == column();  
10  ident_lit := {1,0,0;0,1,0;0,0,1};  
11  [3,3] all_ones := 1;  
12  baz := my2;  
13  return  
14    // True cases  
15    print_endline(my1 == my2) ->  
16    print_endline(baz == my1) ->  
17    print_endline(foo[0,0] == my2) ->  
18    print_endline(foo[0,1] == my2) ->  
19    print_endline(foo[0,0] == foo[1,1]) ->  
20    print_endline(foo[:,0] == bar) ->
```

```

21     print_endline(my3[3] == my1) ->
22     print_endline(ident == ident_lit) ->
23     print_endline("") ->
24
25     // False cases
26     print_endline(my3 == my5) ->
27     print_endline(my3 == my4) ->
28     print_endline(foo == bar) ->
29     print_endline(foo == foo[0,0]) ->
30     print_endline(ident == all_ones) ->
31     print_endline(ident == 1) ->
32     print_endline(all_ones == 1) ->
33     0
34     ;
35 }

```

test-range-equality.xtnd - Expected Output

```

1 1
2 1
3 1
4 1
5 1
6 1
7 1
8 1
9
10 0
11 0
12 0
13 0
14 0
15 0
16 0

```

test-ref-between-globals.xtnd

```

1 global [2,2] foo;
2 global [2,2] bar;
3 main([1,n] args) {
4     foo := 1;
5     bar := foo;
6     return print(1,to_string( bar)+"\n") -> 0;
7 }

```

test-ref-between-globals.xtnd - Expected Output

```

1 1

```

test-short-circuiting-and.xtnd

```

1 main([1,1] args){
2     return 0 && print(1,"FAIL\n") -> print(1,"PASS\n") -> 0;
3 }

```

test-short-circuiting-and.xtnd - Expected Output

```

1 PASS

```

test-short-circuiting-and2.xtnd

```
1 main([1,1] args){
2   return 1 && print(1,"PASS1\n") -> print(1,"PASS2\n") -> 0;
3 }
```

test-short-circuiting-and2.xtnd - Expected Output

```
1 PASS1
2 PASS2
```

test-short-circuiting-or.xtnd

```
1 main([1,1] args){
2   return 0 || print(1,"PASS1\n") -> print(1,"PASS2\n") -> 0;
3 }
```

test-short-circuiting-or.xtnd - Expected Output

```
1 PASS1
2 PASS2
```

test-short-circuiting-or2.xtnd

```
1 main([1,1] args){
2   return 1 || print(1,"FAIL\n") -> print(1,"PASS\n") -> 0;
3 }
```

test-short-circuiting-or2.xtnd - Expected Output

```
1 PASS
```

test-signature-vars.xtnd

```
1 foo([m,n] arg) {
2   return "I was called with an argument with " + to_string(m) + " rows and " +
      to_string(n) + " columns.";
3 }
4
5 main([1,1] args) {
6   [42,17] x;
7   return print(1,foo(x)+"\n") -> 0;
8 }
```

test-signature-vars.xtnd - Expected Output

```
1 I was called with an argument with 42 rows and 17 columns.
```

test-sin.xtnd

```
1 main([1,n] args) {
2   return printd(1, sin(45.0)) -> 0;
3 }
```

test-sin.xtnd - Expected Output

```
1 0.850904
```

test-sin-through-function.xtnd

```

1 internal_sin(x,y,z) {
2     return sin(z);
3 }
4
5 main([1,n] args) {
6     return printf(1, internal_sin(1,2,45.0)) -> 0;
7 }

```

test-sin-through-function.xtnd - Expected Output

```

1 0.850904

```

test-sin-through-function-and-global.xtnd

```

1 global theta := 45.0;
2
3 internal_sin(x,y,z) {
4     return sin(z);
5 }
6
7 main([1,n] args) {
8     return printf(1, internal_sin(1,2,theta)) -> 0;
9 }

```

test-sin-through-function-and-global.xtnd - Expected Output

```

1 0.850904

```

test-single-import.xtnd

```

1 import "../samples/gcd_func.xtnd";
2
3 main([1,n] args) {
4     return printf(1, to_string(gcd(70, 55)) + "\n") -> 0;
5 }

```

test-single-import.xtnd - Expected Output

```

1 5

```

test-sinh.xtnd

```

1 main([1,n] args) {
2     return printf(1, sinh(45.0)) -> 0;
3 }

```

test-sinh.xtnd - Expected Output

```

1 17467135528742547456.000000

```

test-sqrt.xtnd

```

1 main([1,n] args) {
2     return printf(1, sqrt(9.0)) -> 0;
3 }

```

test-sqrt.xtnd - Expected Output

```

1 3.000000

```


test-string-concatenation.xtnd

```
1 main(args) {
2   foo :=
3     printf(1,"Hello " + "World\n") ->
4     printf(1,"Hello " + "World" + "\n") ->
5     printf(1,("Hello " + "World") + (" " + "\n")) ->
6     0;
7   return foo;
8 }
```

test-string-concatenation.xtnd - Expected Output

```
1 Hello World
2 Hello World
3 Hello World
```

test-subtraction.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( 7 - 5)+"\n") -> 0;
3 }
```

test-subtraction.xtnd - Expected Output

```
1 2
```

test-subtraction-empty.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( empty - 2)+"\n") -> 0;
3 }
```

test-subtraction-empty.xtnd - Expected Output

```
1 empty
```

test-switch-v1.xtnd

```
1 main([1,1] args){
2   x := switch(1) {
3     case 1: 100;
4     case 2: 200;
5     default: 300;
6   };
7   return print(1,to_string(x)+"\n") -> 0;
8 }
```

test-switch-v1.xtnd - Expected Output

```
1 100
```

test-switch-v10.xtnd

```
1 main([1,1] args){
2   x := switch {
3     case 0: 100;
4     case "also true": 200;
5     default: 99;
6   };
7   return printd(1,x) -> 0;
8 }
```

test-switch-v10.xtnd - Expected Output

```
1 200.000000
```

test-switch-v11.xtnd

```
1 main([1,1] args){
2   x := switch {
3     case 0: 100;
4     default: 99;
5   };
6   return printf(1,x) -> 0;
7 }
```

test-switch-v11.xtnd - Expected Output

```
1 99.000000
```

test-switch-v2.xtnd

```
1 main([1,1] args){
2   x := switch(2) {
3     case 1: 100;
4     case 2: 200;
5     default: 300;
6   };
7   return print(1,to_string(x)+"\n") -> 0;
8 }
```

test-switch-v2.xtnd - Expected Output

```
1 200
```

test-switch-v3.xtnd

```
1 main([1,1] args){
2   x := switch(3) {
3     case 1: 100;
4     case 2: 200;
5     default: 300;
6   };
7   return print(1,to_string(x)+"\n") -> 0;
8 }
```

test-switch-v3.xtnd - Expected Output

```
1 300
```

test-switch-v4.xtnd

```
1 main([1,1] args){
2   x := switch(2) {
3     case 1, 2: 100;
4     default: 300;
5   };
6   return print(1,to_string(x)+"\n") -> 0;
7 }
```

test-switch-v4.xtnd - Expected Output

```
1 100
```

test-switch-v5.xtnd

```
1 main([1,1] args){
2   x := switch(3) {
3     case 1, 2: 100;
4     default: 300;
5   };
6   return print(1,to_string(x)+"\n") -> 0;
7 }
```

test-switch-v5.xtnd - Expected Output

```
1 300
```

test-switch-v6.xtnd

```
1 main([1,1] args){
2   x := switch(3) {
3     case 1, 2: 100;
4     case 0, 3: 200;
5     default: 300;
6   };
7   return print(1,to_string(x)+"\n") -> 0;
8 }
```

test-switch-v6.xtnd - Expected Output

```
1 200
```

test-switch-v7.xtnd

```
1 main([1,1] args){
2   x := switch(4) {
3     case 1, 2: 100;
4     case 0, 3: 200;
5   };
6   return print(1,to_string(x)+"\n") -> 0;
7 }
```

test-switch-v7.xtnd - Expected Output

```
1 empty
```

test-switch-v8.xtnd

```
1 main([1,1] args){
2   x := switch() {
3     case 1 > 2: 100;
4     case 3 > 0: 200;
5   };
6   return print(1,to_string(x)+"\n") -> 0;
7 }
```

test-switch-v8.xtnd - Expected Output

```
1 200
```

test-switch-v9.xtnd

```
1 main([1,1] args){
2   x := switch {
3     case "true": 100;
4     case "also true": 200;
5   };
6   return printf(1,x) -> 0;
7 }
```

test-switch-v9.xtnd - Expected Output

```
1 100.000000
```

test-tan.xtnd

```
1 main([1,n] args) {
2   return printf(1, tan(45.0)) -> 0;
3 }
```

test-tan.xtnd - Expected Output

```
1 1.619775
```

test-tanh.xtnd

```
1 main([1,n] args) {
2   return printf(1, tanh(45.0)) -> 0;
3 }
```

test-tanh.xtnd - Expected Output

```
1 1.000000
```

test-ternary-conditional.xtnd

```
1 main([1,1] args){
2   return print(1,to_string(5 ? 2 : 3) + "\n") -> 0;
3 }
```

test-ternary-conditional.xtnd - Expected Output

```
1 2
```

test-ternary-conditional-empty.xtnd

```
1 main([1,1] args){
2   return print(1,to_string( empty ? 5 : 6)+"\n") -> 0;
3 }
```

test-ternary-conditional-empty.xtnd - Expected Output

```
1 empty
```

test-unary-negation.xtnd

```
1 main([1,n] args){
2   /* Should return -33 */
3   return print(1,to_string( -33)+"\n") -> 0;
4 }
```

test-unary-negation.xtnd - Expected Output

```
1 -33
```

test-unary-negation-empty.xtnd

```
1 main([1,n] args){  
2   return print(1,to_string( -empty)+"\n") -> 0;  
3 }
```

test-unary-negation-empty.xtnd - Expected Output

```
1 empty
```

9. Git Logs

```
1 1bcb830 2016-12-18T19:48:02-05:00 GitHub: Merge pull request #41 from ExtendLang/
   plotting
2 1cd2360 2016-12-18T19:46:21-05:00 GitHub: Merge branch 'master' into plotting
3 0058659 2016-12-18T19:30:35-05:00 GitHub: Merge pull request #129 from ExtendLang/
   remove-debug-final
4 b54f4aa 2016-12-18T18:54:47-05:00 GitHub: Fix MAXFLOAT
5 9324fb8 2016-12-18T18:50:59-05:00 GitHub: Merge branch 'master' into plotting
6 f152bc9 2016-12-18T18:32:21-05:00 oracleofnj: Remove Debug()
7 c069630 2016-12-18T18:15:40-05:00 Nigel Schuster: Linking plotter is optional
8 e9dbd0f 2016-12-18T17:05:54-05:00 GitHub: Merge pull request #128 from ExtendLang/back
   -to-parsing
9 b602263 2016-12-18T14:12:48-05:00 oracleofnj: Merge in cool program
10 45d14cf 2016-12-18T14:12:28-05:00 GitHub: Merge pull request #127 from ExtendLang/
   strcat-bug
11 790bc51 2016-12-18T14:00:48-05:00 oracleofnj: Merge branch 'cool_program' into back-to
   -parsing
12 2eba5e5 2016-12-18T13:59:44-05:00 oracleofnj: Replace C extend_parseString with in-
   language parseString
13 1b664be 2016-12-18T09:14:51-05:00 Nigel Schuster: Corrected travis file
14 554b584 2016-12-18T09:13:54-05:00 Nigel Schuster: Cleand up Makefile mess
15 a222916 2016-12-18T08:19:54-05:00 GitHub: Merge branch 'master' into plotting
16 d064d8a 2016-12-18T01:49:39-05:00 Ishaan: Cleanup line function
17 47dace5 2016-12-18T01:48:28-05:00 Ishaan: Test single parameter line chart
18 8f5cf52 2016-12-18T01:43:49-05:00 Ishaan: Fix the testcase fail
19 84cd775 2016-12-18T01:41:50-05:00 Ishaan: update testcase
20 a425775 2016-12-18T01:39:43-05:00 Ishaan: Figure out 2 line issue
21 ba2c3c1 2016-12-18T01:34:34-05:00 Ishaan: Add y values and update testcase
22 7ad5986 2016-12-18T01:18:28-05:00 Ishaan: Trying another version of line
23 b8732dd 2016-12-18T00:42:25-05:00 Ishaan: Fix derp in linechart
24 20e2c43 2016-12-18T00:40:22-05:00 Ishaan: Added basic linechart function to examine
25 b404e12 2016-12-17T23:56:16-05:00 Ishaan: Cast to float
26 e866f68 2016-12-17T23:38:40-05:00 Ishaan: Reverse row and col
27 8419510 2016-12-17T23:27:13-05:00 oracleofnj: That's a wrap
28 6ec3e0e 2016-12-17T23:17:46-05:00 oracleofnj: Proof of concept
29 302af00 2016-12-17T23:09:14-05:00 Ishaan: Updating checks
30 7b09def 2016-12-17T23:03:14-05:00 Ishaan: Testing bar chart plotting, will clean up
   later
31 20adaca 2016-12-17T20:40:13-05:00 oracleofnj: Some bugfixes
32 ad69dcf 2016-12-17T20:12:33-05:00 oracleofnj: Fixed extend side
33 8f76e59 2016-12-17T20:10:06-05:00 Kevin: Fixed highest_tsp to take in any number of
   players
34 0707084 2016-12-17T19:53:58-05:00 oracleofnj: Isolating
35 4479213 2016-12-17T19:47:38-05:00 oracleofnj: much longer
36 4be857f 2016-12-17T19:41:59-05:00 oracleofnj: seg fault
```

```

37 74358c1 2016-12-17T19:34:18-05:00 Kevin: Interesting program in Extend
38 ab1e1d2 2016-12-17T16:12:00-05:00 oracleofnj: Add some more stdlib funcs
39 b53463d 2016-12-17T14:51:24-05:00 GitHub: Merge pull request #125 from ExtendLang/
    stdlib-string
40 39046bc 2016-12-17T14:39:54-05:00 oracleofnj: Merge branch 'master' into stdlib-string
41 a01cc84 2016-12-17T14:39:40-05:00 oracleofnj: Use toString in toLiteral
42 ec7f10d 2016-12-17T14:38:30-05:00 GitHub: Merge pull request #102 from ExtendLang/
    circular-hotfix
43 73c454b 2016-12-17T14:34:42-05:00 GitHub: Merge branch 'master' into circular-hotfix
44 8126e2e 2016-12-17T14:24:22-05:00 oracleofnj: native toString
45 037728d 2016-12-17T13:46:34-05:00 Nigel Schuster: A lot of wrong paths make it work
46 0a4fd9d 2016-12-17T13:26:34-05:00 Nigel Schuster: Next attempt
47 56905f8 2016-12-17T13:19:59-05:00 Nigel Schuster: Merge branch 'plotting' of https://
    github.com/ExtendLang/Extend into plotting
48 fbf3a1e 2016-12-17T13:19:52-05:00 Nigel Schuster: Manual install (maybe?)
49 1171b71 2016-12-17T13:10:19-05:00 GitHub: Merge branch 'master' into plotting
50 0dbf85d 2016-12-17T13:07:56-05:00 Nigel Schuster: Added libgd for travis
51 060ae45 2016-12-17T13:01:35-05:00 oracleofnj: Merge branch 'master' into stdlib-string
52 4402208 2016-12-17T13:01:24-05:00 oracleofnj: Add round
53 23c2ae6 2016-12-17T13:00:05-05:00 GitHub: Merge pull request #123 from ExtendLang/size
    -asserts
54 0ef936b 2016-12-17T12:33:31-05:00 oracleofnj: Fix merge conflicts
55 4c51203 2016-12-17T11:59:30-05:00 oracleofnj: Right confusion
56 c05cf61 2016-12-17T11:52:34-05:00 oracleofnj: Fix import dir bug
57 39edbb4 2016-12-17T11:46:06-05:00 oracleofnj: Merge branch 'master' into size-asserts
58 339cb1f 2016-12-17T11:45:54-05:00 oracleofnj: Fix merge conflict
59 7462381 2016-12-17T11:44:50-05:00 GitHub: Merge pull request #122 from ExtendLang/
    split-stdlib
60 61ac8f2 2016-12-17T11:38:19-05:00 oracleofnj: Size asserts
61 606af9f 2016-12-17T11:22:36-05:00 oracleofnj: Transform asserts into more useful form;
    add calc of assert value to codegen
62 8743e4c 2016-12-17T11:07:31-05:00 Nigel Schuster: Explicit maxfloat
63 0f96e70 2016-12-17T11:02:09-05:00 Nigel Schuster: merge master; Keep tc around for
    testing
64 1882524 2016-12-17T10:54:10-05:00 Nigel Schuster: Creating archive
65 ee4f369 2016-12-17T10:40:17-05:00 oracleofnj: Combine asserts into a single expression
66 0f0f1c8 2016-12-17T10:38:56-05:00 Nigel Schuster: Added right and left to stdlib
67 4dc1597 2016-12-17T10:35:11-05:00 Nigel Schuster: Made compiling workable
68 fa43425 2016-12-17T10:30:23-05:00 oracleofnj: Split stdlib
69 824c53c 2016-12-17T10:11:13-05:00 Nigel Schuster: Added toUpper and toLower
70 ec24177 2016-12-17T10:02:30-05:00 Nigel Schuster: Implemented to and from ASCII
71 ab2e8f8 2016-12-17T09:15:39-05:00 GitHub: Merge pull request #116 from ExtendLang/line
    -plus
72 5d1610b 2016-12-17T09:08:57-05:00 GitHub: Merge branch 'master' into line-plus
73 df3a827 2016-12-17T09:08:48-05:00 GitHub: Merge pull request #117 from ExtendLang/cmd-
    args
74 32a3487 2016-12-17T09:02:27-05:00 GitHub: Merge branch 'master' into cmd-args
75 a8f9d33 2016-12-17T09:00:23-05:00 Nigel Schuster: Args
76 bfccf0c 2016-12-17T08:58:08-05:00 Nigel Schuster: Cut down line count for plus
77 a6bc89a 2016-12-17T08:48:31-05:00 GitHub: Merge pull request #114 from ExtendLang/only
    -new-string
78 5c96b7f 2016-12-17T08:03:27-05:00 GitHub: Merge pull request #109 from ExtendLang/unop
    -bitnot
79 3834210 2016-12-17T00:33:37-05:00 oracleofnj: Get rid of box string in favor of
    new_string_all_the_way, renamed new_string
80 375bea7 2016-12-16T23:56:35-05:00 oracleofnj: Merge branch 'unop-bitnot' into remove-

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    interpreter
81  fb1bd77 2016-12-16T23:54:43-05:00 oracleofnj: Clean up; remove interpreter; change
    DimInt to DimOneByOne
82  539dd75 2016-12-16T23:46:35-05:00 GitHub: Merge branch 'master' into unop-bitnot
83  5668e53 2016-12-16T23:43:57-05:00 Nigel Schuster: Using lrint instead of fptosi
84  45691eb 2016-12-16T23:35:38-05:00 GitHub: Merge pull request #111 from ExtendLang/
    global-semant
85  2cdfb8b 2016-12-16T23:33:26-05:00 GitHub: Merge branch 'master' into global-semant
86  c9500d9 2016-12-16T23:33:14-05:00 GitHub: Merge pull request #112 from ExtendLang/
    remove-function-signatures
87  0c24f54 2016-12-16T23:25:23-05:00 oracleofnj: Remove return signature from grammar and
    all test cases
88  e7f2864 2016-12-16T23:03:53-05:00 oracleofnj: Merge branch 'cleanup-1' into global-
    semant
89  567507e 2016-12-16T22:53:20-05:00 oracleofnj: Check globals; use same symbol_table
    function for semant and codegen
90  33e3942 2016-12-16T22:11:13-05:00 GitHub: Merge branch 'master' into plotting
91  55d8185 2016-12-16T22:00:30-05:00 Nigel Schuster: Removed comments and unnecessary
    files
92  629042f 2016-12-16T21:37:07-05:00 GitHub: Merge branch 'master' into unop-bitnot
93  48b139a 2016-12-16T21:34:09-05:00 Nigel Schuster: Implemented unary bitnot
94  39b02cd 2016-12-16T21:27:22-05:00 oracleofnj: Merge branch 'master' into global-semant
95  28c0983 2016-12-16T21:27:05-05:00 oracleofnj: Remove leftover printf
96  dc182df 2016-12-16T21:09:00-05:00 GitHub: Merge pull request #105 from ExtendLang/rg-
    eq
97  8cdf5c4 2016-12-16T19:31:26-05:00 oracleofnj: Expand test cases for range equality
98  41a3ccc 2016-12-16T19:18:44-05:00 GitHub: Merge branch 'master' into rg-eq
99  8dbebc1 2016-12-16T19:18:15-05:00 GitHub: Merge pull request #104 from ExtendLang/
    prevent-overlapping-formulas
100 c1431b5 2016-12-16T18:55:07-05:00 Nigel Schuster: Implemented basic subrange
    comparison
101 546536e 2016-12-16T18:47:12-05:00 oracleofnj: Detect overlapping formulas and give
    runtime error if present
102 3562e1b 2016-12-16T18:45:12-05:00 oracleofnj: Merge branch 'sr-val-fix' into prevent-
    overlapping-formulas
103 8713fa0 2016-12-16T18:42:40-05:00 oracleofnj: Checking
104 77d80b9 2016-12-16T18:26:31-05:00 Nigel Schuster: Fixed check for subrange
105 69fb0d2 2016-12-16T17:46:48-05:00 oracleofnj: Circular hotfix
106 4a3ec8d 2016-12-16T17:21:18-05:00 oracleofnj: Add concat
107 962c744 2016-12-16T12:09:00-05:00 GitHub: Merge pull request #101 from ExtendLang/
    finishing-these-range-literals
108 f234e00 2016-12-16T00:21:06-05:00 oracleofnj: Merge branch 'more-stdlib-functions'
    into finishing-these-range-literals
109 c9246ce 2016-12-16T00:20:59-05:00 oracleofnj: testing testing
110 6914039 2016-12-16T00:14:09-05:00 oracleofnj: Third time's the charm
111 4617e44 2016-12-16T00:01:12-05:00 oracleofnj: It compiles now
112 1d8e290 2016-12-15T23:42:43-05:00 oracleofnj: Fingers crossed
113 c9d28d3 2016-12-15T21:50:01-05:00 oracleofnj: Move all initializations into their own
    function; only box strings once
114 1cfdd16 2016-12-15T18:47:30-05:00 oracleofnj: Merge branch 'master' into more-stdlib-
    functions
115 19c2beb 2016-12-15T18:40:12-05:00 oracleofnj: Try a couple more things out
116 845cb04 2016-12-15T18:33:07-05:00 GitHub: Merge pull request #96 from ExtendLang/
    ternary-fix
117 4bfb3bc 2016-12-15T18:23:00-05:00 oracleofnj: Merge branch 'ternary-fix' into more-
    stdlib-functions

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118 ae55ca4 2016-12-15T18:21:58-05:00 oracleofnj: Define cell_row, cell_col
119 30a5db6 2016-12-15T18:19:56-05:00 oracleofnj: Merge branch 'ternary-fix' into more-
      stdlib-functions
120 b9f1f10 2016-12-15T18:17:53-05:00 oracleofnj: What is truth?
121 ac84c2f 2016-12-15T18:15:37-05:00 oracleofnj: Fix ternary to work properly with ranges
122 1f57d91 2016-12-15T17:03:26-05:00 oracleofnj: Look at this one
123 437ba46 2016-12-15T16:56:04-05:00 oracleofnj: Try this one
124 f0edf5b 2016-12-15T16:46:52-05:00 oracleofnj: Fixing bug
125 5ba31e6 2016-12-15T14:17:52-05:00 GitHub: Merge pull request #94 from ExtendLang/nan-
      inf
126 67c5739 2016-12-15T14:17:46-05:00 GitHub: Merge pull request #93 from ExtendLang/type-
      typeof
127 48a3d5c 2016-12-15T14:05:37-05:00 oracleofnj: Improve test case
128 8f08227 2016-12-15T13:58:46-05:00 oracleofnj: Add isNaN and isInfinite to stdlib
129 cbeec74 2016-12-15T13:30:31-05:00 oracleofnj: Rename token
130 9582228 2016-12-15T13:18:09-05:00 oracleofnj: Rename type to typeof
131 d1422c7 2016-12-15T10:42:19-05:00 GitHub: Merge pull request #92 from ExtendLang/
      compiler
132 66689bb 2016-12-15T09:08:56-05:00 Nigel Schuster: added working directory option,
      doing testing completely in tmp
133 a13ae93 2016-12-15T09:08:31-05:00 GitHub: Merge pull request #91 from ExtendLang/
      sizeof
134 a31add9 2016-12-15T09:08:13-05:00 GitHub: Merge pull request #90 from ExtendLang/
      subselect-C-side
135 2e67e06 2016-12-15T09:01:06-05:00 Nigel Schuster: Added option to specify compiler,
      using clang
136 c171450 2016-12-15T02:33:48-05:00 oracleofnj: SizeOf
137 c168044 2016-12-15T00:48:35-05:00 oracleofnj: Add row(), column() to codegen, add
      print_endline() to stdlib.xtnd
138 bf9426d 2016-12-15T00:27:13-05:00 oracleofnj: Print subrange
139 407ce41 2016-12-14T23:02:02-05:00 oracleofnj: Merge in subrange_string
140 756ea8e 2016-12-14T22:51:00-05:00 oracleofnj: Ranges
141 27a8e79 2016-12-14T22:16:13-05:00 oracleofnj: Resolve RHS slice
142 876d056 2016-12-14T22:02:56-05:00 oracleofnj: Resolve RHS index
143 b59e022 2016-12-14T21:46:00-05:00 Nigel Schuster: Added method to print subrange as
      string
144 a7d53a8 2016-12-14T19:55:38-05:00 oracleofnj: Merge branch 'master' into subselect-C-
      side
145 362e85b 2016-12-14T19:55:23-05:00 GitHub: Merge pull request #88 from ExtendLang/
      subselect
146 4912fa3 2016-12-14T19:40:10-05:00 oracleofnj: Add debug print info for slice
      structures
147 c1b33f4 2016-12-14T18:58:45-05:00 oracleofnj: Builder to end all builders
148 5d400c2 2016-12-14T18:55:06-05:00 oracleofnj: Add selection builders
149 29f6e28 2016-12-14T18:20:51-05:00 oracleofnj: Make additional infix operator for
      populating structure element
150 046d096 2016-12-14T17:49:19-05:00 oracleofnj: Set up RHS slice types
151 0d20933 2016-12-14T17:28:38-05:00 GitHub: Merge branch 'master' into plotting
152 614d84f 2016-12-14T17:25:20-05:00 Nigel Schuster: Dummy commit for travis
153 0e78574 2016-12-14T17:24:04-05:00 Nigel Schuster: Merge branch 'plotting' of https://
      github.com/ExtendLang/Extend into plotting
154 2da0d7d 2016-12-14T17:23:56-05:00 Nigel Schuster: Spelling fix
155 b25c2f5 2016-12-14T16:49:17-05:00 GitHub: Merge pull request #87 from ExtendLang/make-
      a-selection
156 7a12082 2016-12-14T16:43:38-05:00 oracleofnj: Move selection test cases back into
      inputs

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157 e2c08d5 2016-12-14T16:31:00-05:00 oracleofnj: Make IDs work with deref_subrange
158 02f2f0c 2016-12-14T15:21:31-05:00 GitHub: Merge pull request #86 from ExtendLang/
    include-stdlib
159 8b0503f 2016-12-14T15:18:14-05:00 GitHub: Merge branch 'master' into include-stdlib
160 1f034a0 2016-12-14T15:17:52-05:00 GitHub: Merge pull request #84 from ExtendLang/math-
    linker
161 1e6dd91 2016-12-14T14:58:44-05:00 oracleofnj: Add expected output for slurp
162 ff1a5e3 2016-12-14T14:53:38-05:00 oracleofnj: Remove extend_ prefix from all sample
    code
163 81a2828 2016-12-14T14:48:38-05:00 oracleofnj: Automatically add extend_ prefix to
    external functions
164 dccled3 2016-12-14T14:30:52-05:00 oracleofnj: Fix samples
165 9b2c28f 2016-12-14T12:39:45-05:00 oracleofnj: Include stdlib automatically
166 13650ce 2016-12-14T12:35:21-05:00 Nigel Schuster: Merge branch 'math-linker' of https
    ://github.com/ExtendLang/Extend into math-linker
167 2e0d90d 2016-12-14T12:35:06-05:00 Nigel Schuster: Merge branch 'math-linker' of https
    ://github.com/ExtendLang/Extend into math-linker
168 83c689e 2016-12-14T12:34:14-05:00 Nigel Schuster: Merge branch 'math-linker' of https
    ://github.com/ExtendLang/Extend into math-linker
169 127f600 2016-12-14T12:34:07-05:00 Nigel Schuster: Include sys/resources
170 b34d97a 2016-12-14T12:03:44-05:00 GitHub: Merge branch 'master' into math-linker
171 8297f33 2016-12-14T12:01:47-05:00 GitHub: Merge pull request #85 from ExtendLang/put-
    lt-back
172 6b0c74f 2016-12-14T11:33:45-05:00 Nigel Schuster: Include sys/resources
173 37470e9 2016-12-14T11:14:06-05:00 oracleofnj: Put back LT, comment out sys/time.h
174 6bde590 2016-12-14T11:12:16-05:00 Nigel Schuster: Increasing stack size
175 6acc621 2016-12-14T11:03:31-05:00 Nigel Schuster: Disabled linking math when creating
    an intermediate
176 d87b73c 2016-12-14T10:51:58-05:00 GitHub: Merge pull request #82 from ExtendLang/hard-
    to-repro-bug
177 d126e3c 2016-12-14T00:51:00-05:00 oracleofnj: Try with time.h instead of sys/time.h
178 a535612 2016-12-14T00:48:35-05:00 oracleofnj: Remove lrints
179 e844853 2016-12-14T00:34:37-05:00 oracleofnj: Initialize all variables and remove
    pointer math; bug appears fixed
180 4c1a421 2016-12-13T22:55:07-05:00 oracleofnj: Some formula is weird
181 5dbd409 2016-12-13T22:43:19-05:00 oracleofnj: Merge branch 'hard-to-repro-bug' of
    https://github.com/ExtendLang/Extend into hard-to-repro-bug
182 879eaf3 2016-12-13T22:43:17-05:00 oracleofnj: Testing
183 37f5ce2 2016-12-13T22:42:40-05:00 GitHub: Merge pull request #83 from ExtendLang/
    rounding-for-read
184 a1cfc5a 2016-12-13T22:34:21-05:00 Nigel Schuster: Added rounding at several places
185 e20f7e4 2016-12-13T21:36:13-05:00 oracleofnj: Half the time it works
186 9f97b1a 2016-12-13T20:38:08-05:00 GitHub: Merge branch 'master' into plotting
187 61bc9b6 2016-12-13T20:33:27-05:00 GitHub: Merge pull request #81 from ExtendLang/fix-
    em-all
188 4a810df 2016-12-13T19:34:29-05:00 Nigel Schuster: Corrected testcase outputs
189 ae5b8a8 2016-12-13T19:08:43-05:00 GitHub: Merge pull request #80 from ExtendLang/
    select
190 70b2704 2016-12-13T19:02:32-05:00 oracleofnj: No C99
191 15fd762 2016-12-13T18:42:21-05:00 oracleofnj: Merge branch 'master' into select
192 8e6e9ba 2016-12-13T18:42:05-05:00 GitHub: Merge pull request #78 from ExtendLang/unop-
    unary-minus
193 7a93885 2016-12-13T18:41:49-05:00 oracleofnj: Calculate all formula indices
194 07e63dc 2016-12-13T18:19:58-05:00 oracleofnj: Properly build instantiate var
195 1a29129 2016-12-13T17:24:16-05:00 oracleofnj: Replace bools with chars for
    compatibility between C and LLVM

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196 12e78a3 2016-12-13T17:17:54-05:00 oracleofnj: Added debug output
197 a483282 2016-12-13T16:13:30-05:00 oracleofnj: Merge branch 'master' into unop-unary-
    minus
198 f8c9b43 2016-12-13T16:13:09-05:00 oracleofnj: Make TypeOf work
199 8146d04 2016-12-13T16:12:17-05:00 GitHub: Merge pull request #75 from ExtendLang/fix-
    more-tc
200 94afc93 2016-12-13T16:02:35-05:00 Nigel Schuster: Corrected expected TC
201 f6f8276 2016-12-13T16:00:59-05:00 Nigel Schuster: Fixed string.xtnd file
202 dcd5766 2016-12-13T15:44:38-05:00 GitHub: Merge pull request #74 from ExtendLang/fix-
    tc
203 bfe1c07 2016-12-13T15:39:45-05:00 oracleofnj: Merge branch 'master' into unop-unary-
    minus
204 d9abfc0 2016-12-13T15:38:38-05:00 GitHub: Merge branch 'master' into fix-tc
205 50ed49c 2016-12-13T15:38:04-05:00 oracleofnj: Merging in main
206 23328f1 2016-12-13T15:37:18-05:00 GitHub: Merge pull request #73 from ExtendLang/and-
    or-xor
207 324779a 2016-12-13T15:32:26-05:00 Nigel Schuster: Corrected expected value
208 fafe2e6 2016-12-13T15:29:21-05:00 Nigel Schuster: Fixed string tc
209 022f05c 2016-12-13T15:23:59-05:00 Nigel Schuster: Fixed testcase
210 b12fe37 2016-12-13T15:18:57-05:00 Nigel Schuster: Implemented and, or and xor
211 90cbaa0 2016-12-13T15:16:31-05:00 Nigel Schuster: Added left and right shift
212 571ee7e 2016-12-13T14:56:05-05:00 Nigel Schuster: Merge branch 'power' of https://
    github.com/ExtendLang/Extend into power
213 aeab40d 2016-12-13T14:55:57-05:00 Nigel Schuster: Removed unnecessary level of
    indirection
214 e377567 2016-12-13T14:53:28-05:00 GitHub: Merge branch 'master' into power
215 6ad8512 2016-12-13T14:53:11-05:00 GitHub: Merge pull request #69 from ExtendLang/unop-
    unary-minus
216 71f395d 2016-12-13T14:46:27-05:00 Nigel Schuster: Power to the people of Extend
217 6a04209 2016-12-13T14:45:46-05:00 oracleofnj: Fix merge conflict
218 edb0ecc 2016-12-13T14:43:32-05:00 oracleofnj: Add unary minus
219 668a0eb 2016-12-13T14:37:19-05:00 GitHub: Merge pull request #68 from ExtendLang/mod-
    div
220 866b68f 2016-12-13T14:32:18-05:00 Nigel Schuster: Added modulo and division operation
221 46d5aa6 2016-12-13T14:26:35-05:00 oracleofnj: Merge branch 'master' into unop-typeof
222 84dfc33 2016-12-13T14:26:25-05:00 Nigel Schuster: Crunched some code
223 76210eb 2016-12-13T14:26:18-05:00 oracleofnj: Start on it
224 f4d5a81 2016-12-13T14:22:12-05:00 Nigel Schuster: Merge branch 'master' into
    simplification
225 f873242 2016-12-13T14:21:26-05:00 GitHub: Merge pull request #65 from ExtendLang/
    subtraction
226 fc94112 2016-12-13T14:20:35-05:00 Nigel Schuster: Added multiplication
227 6c26c2c 2016-12-13T14:19:07-05:00 GitHub: Merge branch 'master' into subtraction
228 4afd78e 2016-12-13T14:18:55-05:00 GitHub: Merge pull request #64 from ExtendLang/
    refactor-boolean-binops
229 d4d4388 2016-12-13T14:15:58-05:00 GitHub: Merge branch 'master' into refactor-boolean-
    binops
230 bd90241 2016-12-13T14:14:17-05:00 GitHub: Merge branch 'master' into subtraction
231 4042259 2016-12-13T14:13:09-05:00 Nigel Schuster: Added subtraction
232 663f399 2016-12-13T14:12:57-05:00 oracleofnj: Remove wildcard from BinOp pattern match
233 82a3db2 2016-12-13T14:11:31-05:00 Nigel Schuster: Merge branch 'master' into
    subtraction
234 1bf6bed 2016-12-13T14:09:47-05:00 oracleofnj: Add TransformedAway exception for LogAnd
    and LogOr
235 c7d4162 2016-12-13T14:02:13-05:00 GitHub: Merge pull request #63 from ExtendLang/more-
    binops

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236 952778e 2016-12-13T14:01:54-05:00 oracleofnj: Change Lt, Lte in grammar; implement GTE
 237 97821c8 2016-12-13T13:47:52-05:00 oracleofnj: GT
 238 1e1f973 2016-12-13T13:44:36-05:00 Nigel Schuster: Subtraction
 239 e0a883a 2016-12-13T13:37:57-05:00 oracleofnj: Remove NotEq from AST since != is parsed
 to UnOp(LogNot, BinOp(Eq, ...))
 240 cc40008 2016-12-13T12:49:33-05:00 GitHub: Merge pull request #60 from ExtendLang/
 addition2
 241 7123ebc 2016-12-13T12:41:09-05:00 GitHub: Merge branch 'master' into addition2
 242 a656f57 2016-12-13T12:38:12-05:00 GitHub: Merge pull request #61 from ExtendLang/debug
 -unop
 243 c3a96a9 2016-12-13T12:37:31-05:00 Nigel Schuster: Merge branch 'master' into plotting
 244 f59d962 2016-12-13T12:34:49-05:00 Nigel Schuster: Moved make of lib to travis script
 245 eb134b3 2016-12-13T12:29:53-05:00 Nigel Schuster: Moved testcases
 246 044c6bd 2016-12-13T12:29:07-05:00 Nigel Schuster: Fixed off by one error
 247 a64cc15 2016-12-13T12:14:45-05:00 oracleofnj: Add Debug expr
 248 59858a0 2016-12-13T11:33:12-05:00 oracleofnj: Whoops no space
 249 0426f34 2016-12-13T11:30:26-05:00 oracleofnj: Add test case
 250 49ffa86 2016-12-13T11:19:14-05:00 GitHub: Merge branch 'master' into addition2
 251 81533f4 2016-12-13T11:13:44-05:00 GitHub: Merge pull request #59 from ExtendLang/equal
 -rights
 252 3cdaa5a 2016-12-13T11:12:41-05:00 Nigel Schuster: String addition
 253 64d1760 2016-12-13T11:04:55-05:00 oracleofnj: Wake up please, GitHub
 254 840aeaf 2016-12-13T10:48:03-05:00 oracleofnj: Remove usage demonstration
 255 61ff439 2016-12-13T03:26:35-05:00 oracleofnj: Add string equality and test cases
 256 f3112e9 2016-12-13T01:57:10-05:00 oracleofnj: Reduce cut & paste
 257 08ce677 2016-12-13T01:35:46-05:00 oracleofnj: Remove obsolete testing file
 258 ae8a07e 2016-12-13T01:23:26-05:00 oracleofnj: Merge branch 'print_value_p' into equal-
 rights
 259 6090713 2016-12-13T01:22:47-05:00 oracleofnj: Use correct printf specifier
 260 862b38c 2016-12-13T01:19:14-05:00 oracleofnj: Merge branch 'print_value_p' into equal-
 rights
 261 5e913ad 2016-12-13T01:16:07-05:00 oracleofnj: Add debug_print; remove print statement
 that was causing us to falsely pass test cases from to_string; show usage in UnOp(
 Neg)
 262 50281b1 2016-12-13T00:47:28-05:00 oracleofnj: Numeric equality
 263 0f76aa4 2016-12-12T22:30:15-05:00 oracleofnj: Remove print flags
 264 200b8b6 2016-12-12T22:16:15-05:00 GitHub: Merge pull request #57 from ExtendLang/
 addition2
 265 da7c543 2016-12-12T12:43:31-05:00 Nigel Schuster: Setting flag for addition
 266 7e7276b 2016-12-12T12:37:35-05:00 Nigel Schuster: Merge branch 'master' into addition2
 267 8834635 2016-12-12T10:18:51-05:00 GitHub: Merge pull request #55 from ExtendLang/
 runtime
 268 53ae9e0 2016-12-12T10:06:24-05:00 GitHub: Merge branch 'master' into runtime
 269 6ed303e 2016-12-12T09:43:57-05:00 GitHub: Merge pull request #56 from ExtendLang/
 truthy-fix
 270 ae49ce6 2016-12-12T01:15:29-05:00 oracleofnj: Remove extra file
 271 7fe6a22 2016-12-12T01:11:53-05:00 oracleofnj: Falsey fix
 272 d1e196d 2016-12-12T00:23:13-05:00 Nigel Schuster: Extracted runtime into seperate file
 273 ecc620e 2016-12-12T00:17:06-05:00 GitHub: Merge pull request #54 from ExtendLang/final
 -draft-for-real
 274 4c8caa5 2016-12-12T00:09:16-05:00 GitHub: Merge branch 'master' into final-draft-for-
 real
 275 04d3b57 2016-12-12T00:00:29-05:00 GitHub: Merge pull request #39 from ExtendLang/more-
 lrm-ed
 276 39025b0 2016-12-11T23:59:18-05:00 Nigel Schuster: Fixed examples, made small
 corrections

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277 a875b41 2016-12-11T23:51:30-05:00 GitHub: Merge pull request #53 from ExtendLang/
    truthy
278 616dd34 2016-12-11T23:15:54-05:00 oracleofnj: Merge branch 'master' into truthy
279 0fa8255 2016-12-11T23:14:42-05:00 oracleofnj: Apparently still needs some work
280 78584d7 2016-12-11T23:09:07-05:00 oracleofnj: Thanks a lot Travis
281 b5673d2 2016-12-11T22:51:52-05:00 oracleofnj: TERRRRRRRRR NARRRRRRR
    EEEEEEEEEEEEEEEEEEE
282 b81bc1b 2016-12-11T22:04:25-05:00 oracleofnj: Maybe Truthy
283 b95d14f 2016-12-11T21:02:28-05:00 GitHub: Merge pull request #50 from ExtendLang/
    builder-hotfix
284 6dea96f 2016-12-11T20:40:47-05:00 oracleofnj: So many builders
285 8aa125f 2016-12-11T20:15:52-05:00 Nigel Schuster: Made som rpgroess
286 2a905c7 2016-12-11T19:15:47-05:00 GitHub: Merge pull request #47 from ExtendLang/
    function-parameter
287 2bc6c85 2016-12-11T19:11:33-05:00 oracleofnj: Add combined test case
288 860a11b 2016-12-11T19:04:35-05:00 oracleofnj: Merge branch 'master' into function-
    parameter
289 8c3499e 2016-12-11T19:03:39-05:00 oracleofnj: Remove extraneous printlines
290 99418c0 2016-12-11T19:02:31-05:00 oracleofnj: Make function parameters work
291 6c00a72 2016-12-11T18:45:46-05:00 Nigel Schuster: Some progress
292 387559b 2016-12-11T18:39:00-05:00 oracleofnj: First attempt
293 18fc1be 2016-12-11T18:08:11-05:00 GitHub: Merge pull request #45 from ExtendLang/empty
294 d7590da 2016-12-11T17:42:46-05:00 GitHub: Merge branch 'master' into plotting
295 f7e9be8 2016-12-11T16:30:05-05:00 GitHub: Merge branch 'master' into empty
296 f1dd8a5 2016-12-11T16:18:44-05:00 GitHub: Merge pull request #46 from ExtendLang/
    actually-make-global-scope
297 50366f4 2016-12-11T15:38:05-05:00 oracleofnj: Make sure locals are properly masking
    globals
298 046c7cc 2016-12-11T15:30:53-05:00 oracleofnj: Make globals work, fix bug
299 a844a46 2016-12-11T15:14:09-05:00 oracleofnj: So close
300 18db166 2016-12-11T15:05:42-05:00 GitHub: Merge branch 'master' into empty
301 67849f0 2016-12-11T15:01:52-05:00 oracleofnj: Make the global scope object
302 393d02c 2016-12-11T14:25:02-05:00 Nigel Schuster: Implemented empty, small flag
    setting fix
303 3c4681d 2016-12-11T13:31:12-05:00 GitHub: Merge pull request #44 from ExtendLang/float
    -display-hotfix
304 7be1001 2016-12-11T13:26:55-05:00 GitHub: Merge branch 'master' into float-display-
    hotfix
305 b192a23 2016-12-11T13:26:48-05:00 Nigel Schuster: Added gdchart compile step
306 abcffd0 2016-12-11T13:19:05-05:00 GitHub: Merge pull request #42 from ExtendLang/
    encapsulate-build-scope
307 556da44 2016-12-11T13:18:15-05:00 oracleofnj: Floating point math hotfix
308 0ad195e 2016-12-11T12:42:42-05:00 oracleofnj: Merge branch 'master' into encapsulate-
    build-scope
309 9caf464 2016-12-11T12:41:40-05:00 oracleofnj: Encapsulate a little more of building
    the scope
310 1ae8d43 2016-12-11T12:23:04-05:00 Ishaan: Add new gitignore
311 6278c7b 2016-12-11T12:18:49-05:00 Ishaan: Rebase and add gdchart in lib/
312 5594687 2016-12-11T12:13:20-05:00 Ishaan: Remove images from version control
313 294a6db 2016-12-11T12:13:20-05:00 Ishaan: Write to file instead of stdout
314 08e9f75 2016-12-11T12:11:13-05:00 Ishaan: Add hardcoded graph functionality
315 d65aad4 2016-12-11T12:09:28-05:00 GitHub: Merge pull request #40 from ExtendLang/make-
    global-scope
316 b5b33f1 2016-12-11T12:09:12-05:00 Ishaan: Update gitignore to avoid the gdchart
    package
317 6746e8a 2016-12-11T12:09:12-05:00 Ishaan: Checking gif

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318 83c2e09 2016-12-11T12:09:12-05:00 Ishaan: Add hardcoded plot function without params
    or installation
319 0f5a6ba 2016-12-11T12:04:05-05:00 oracleofnj: Merge branch 'master' into make-global-
    scope
320 56b58d9 2016-12-11T12:01:28-05:00 oracleofnj: Encapsulate build_var_defns
321 f25e5b3 2016-12-11T11:43:19-05:00 oracleofnj: Only construct var_defns once
322 9cee2fc 2016-12-11T10:07:36-05:00 Nigel Schuster: Testcases (#38)
323 f3f4bef 2016-12-11T00:45:44-05:00 oracleofnj: Make global variable to hold vardefns
324 a0ed757 2016-12-10T23:31:38-05:00 Nigel Schuster: Edited explanation for row() and
    column()
325 7c50ef2 2016-12-10T23:27:07-05:00 Nigel Schuster: Added info for strings
326 738e41b 2016-12-10T23:24:20-05:00 Nigel Schuster: Added boolean example
327 5377fdf 2016-12-10T23:19:26-05:00 Nigel Schuster: Added arithmetic example
328 a8f4ad9 2016-12-10T21:28:18-05:00 oracleofnj: Isolate the part of building a scope for
    reuse with global variables
329 58f7a4d 2016-12-10T18:05:01-05:00 Nigel Schuster: Performing copy before returning, so
    that memory can be freed with alloca
330 c0e56aa 2016-12-10T17:07:00-05:00 GitHub: Merge pull request #37 from ExtendLang/
    dereference
331 a4b35df 2016-12-10T16:42:17-05:00 Nigel Schuster: Removed obsolete methods
332 cf08a8c 2016-12-10T16:36:20-05:00 GitHub: Merge branch 'master' into dereference
333 ef0e5e7 2016-12-10T16:36:03-05:00 GitHub: Merge pull request #36 from ExtendLang/comp-
    warn
334 0177dc2 2016-12-10T16:35:50-05:00 GitHub: Merge pull request #35 from ExtendLang/
    linker
335 127f99d 2016-12-10T16:35:41-05:00 GitHub: Merge pull request #34 from ExtendLang/rel-
    import
336 b2e881d 2016-12-10T16:35:31-05:00 GitHub: Merge pull request #33 from ExtendLang/ts-
    fix
337 ce833d4 2016-12-10T16:14:34-05:00 Nigel Schuster: Dereferencing 1x1 subrange
338 e259556 2016-12-10T13:53:12-05:00 Nigel Schuster: Removed nodefaultlibs directive
339 09c3961 2016-12-10T13:50:19-05:00 Nigel Schuster: Modified linker to work for travis
340 36d662a 2016-12-10T13:37:27-05:00 Nigel Schuster: Attempt to link math
341 2d4564a 2016-12-10T13:22:14-05:00 Nigel Schuster: Linking math library
342 38ba6e6 2016-12-10T13:18:39-05:00 Nigel Schuster: Suppressing compiler warnings
343 9deac9b 2016-12-10T13:06:39-05:00 Nigel Schuster: Modified compile script. Removed
    debug output
344 d35607b 2016-12-10T13:04:30-05:00 Nigel Schuster: Simpler testscript
345 d37dac2 2016-12-10T12:36:45-05:00 Nigel Schuster: Fixed duplicate import issue
346 31c26bc 2016-12-10T12:30:29-05:00 Nigel Schuster: Added cmd args to link file
347 a350720 2016-12-10T11:40:50-05:00 Nigel Schuster: Switched import style from root
    directory to relative path
348 90e39b0 2016-12-10T11:24:19-05:00 Nigel Schuster: Fixed issue in testscript that might
    report false results when it fails early
349 718ecd3 2016-12-10T03:09:18-05:00 oracleofnj: Some changes to LRM; add if(a,b,c)
350 6a8f836 2016-12-09T18:29:22-05:00 GitHub: Merge pull request #24 from ExtendLang/final
    -draft-lrm
351 fc886a9 2016-12-09T18:23:52-05:00 oracleofnj: Merge branch 'final-draft-lrm'
352 cda63cb 2016-12-09T18:23:24-05:00 oracleofnj: Fix merge conflict
353 eac9e77 2016-12-09T18:04:08-05:00 GitHub: Merge pull request #29 from ExtendLang/
    refactor
354 fe825f4 2016-12-09T17:55:39-05:00 oracleofnj: Compact last bit
355 b02dbbe 2016-12-09T17:49:00-05:00 oracleofnj: Give formula functions names
356 edd7aa4 2016-12-09T17:40:57-05:00 Nigel Schuster: Removed artificats
357 9b49e20 2016-12-09T17:37:59-05:00 Nigel Schuster: Fixed I/O testcases
358 a4ad4b1 2016-12-09T17:18:13-05:00 Nigel Schuster: Merge

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359 b07398b 2016-12-09T17:17:19-05:00 Nigel Schuster: Added macro for function definition
360 ed01567 2016-12-09T17:17:06-05:00 oracleofnj: Make sizeof not break tests
361 a0a7054 2016-12-09T17:01:20-05:00 oracleofnj: Use symbol table
362 56fd61b 2016-12-09T16:11:10-05:00 oracleofnj: Merge branch 'refactor' of https://
    github.com/ExtendLang/Extend into refactor
363 38aedba 2016-12-09T16:10:35-05:00 oracleofnj: Create symbol table
364 dfb702e 2016-12-09T16:01:08-05:00 Nigel Schuster: Converted more to value_p from
    subrange_p
365 e963186 2016-12-09T15:42:35-05:00 Nigel Schuster: Made example TC work
366 eb76234 2016-12-09T11:14:58-05:00 Nigel Schuster: Made Hello World work again
367 08aeb70 2016-12-09T02:13:09-05:00 oracleofnj: Done for the night
368 cb39114 2016-12-09T01:35:36-05:00 oracleofnj: More refactoring
369 7974bbd 2016-12-08T23:53:31-05:00 oracleofnj: Banish the term extern
370 49af972 2016-12-08T23:45:30-05:00 oracleofnj: Add a couple comments
371 0fbf461 2016-12-08T21:52:24-05:00 oracleofnj: Get my bearings
372 5ecb599 2016-12-08T19:47:51-05:00 Nigel Schuster: Added some documentation
373 65066fc 2016-12-08T12:18:57-05:00 Nigel Schuster: Added name display for variable
374 fb18949 2016-12-07T23:44:17-05:00 oracleofnj: Merge branch 'master' into final-draft-
    lrm
375 4aab3dc 2016-12-07T23:43:25-05:00 oracleofnj: Update PDF
376 ed44d27 2016-12-07T23:43:01-05:00 oracleofnj: Fix failing test cases
377 9354fa7 2016-12-07T23:06:36-05:00 oracleofnj: Final draft candidate
378 78649f4 2016-12-07T18:09:46-05:00 oracleofnj: Almost done
379 05ded19 2016-12-07T15:47:52-05:00 oracleofnj: More work
380 f985cc8 2016-12-07T12:14:59-05:00 Nigel Schuster: Merge branch 'finish-transformations
    ' into get-val-rev
381 4b58ce9 2016-12-07T12:13:23-05:00 Nigel Schuster: Tried to add more instructions
382 0722412 2016-12-07T11:32:11-05:00 oracleofnj: Working
383 099efe7 2016-12-07T10:48:35-05:00 Nigel Schuster: Making progress on evaluating
    dimensions
384 fa09df7 2016-12-07T09:51:23-05:00 Nigel Schuster: Finally it works
385 cbb0577 2016-12-07T02:35:06-05:00 oracleofnj: Still WIP
386 e3c9436 2016-12-07T00:44:22-05:00 oracleofnj: WIP
387 b265e74 2016-12-07T00:41:23-05:00 Nigel Schuster: test commit to look at
388 18bb182 2016-12-07T00:35:06-05:00 oracleofnj: Still work in progress
389 a4554c0 2016-12-06T23:14:32-05:00 Nigel Schuster: At least it compiles
390 3432484 2016-12-06T22:42:22-05:00 Nigel Schuster: Getting closer. Need to add var_defn
    wrapper in build_formula
391 05145ca 2016-12-06T21:10:11-05:00 Nigel Schuster: Minor fix
392 af69b92 2016-12-06T17:23:45-05:00 oracleofnj: More updates
393 a65c24e 2016-12-06T16:14:10-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
394 85a4ccb 2016-12-06T16:12:31-05:00 oracleofnj: LRM update part 1
395 174a7b8 2016-12-06T11:09:31-05:00 Nigel Schuster: Made partial progress on
    implementing variable instantiation and such
396 90fc58e 2016-12-05T22:14:41-05:00 GitHub: Merge pull request #23 from ExtendLang/read-
    empty
397 767851d 2016-12-05T16:18:17-05:00 Nigel Schuster: Finished C side implementation of
    getVal
398 6b837d4 2016-12-05T16:06:34-05:00 Nigel Schuster: Merge branch 'master' into get-val
399 04c2c65 2016-12-05T15:53:35-05:00 oracleofnj: Add slurp by passing 0 max bytes
400 d8cf316 2016-12-05T14:46:46-05:00 oracleofnj: Start handling empty
401 910bd01 2016-12-05T14:27:07-05:00 GitHub: Merge pull request #21 from ExtendLang/
    fileio
402 1ce7f83 2016-12-05T14:18:41-05:00 oracleofnj: Create patch file
403 88480fb 2016-12-05T13:36:28-05:00 GitHub: Merge branch 'master' into fileio

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404 29d02d9 2016-12-05T13:34:27-05:00 oracleofnj: Fix merge conflict - keep expr_loc
405 52e7a8a 2016-12-05T13:32:54-05:00 GitHub: Merge pull request #22 from ExtendLang/rm-
    micro
406 bfa906b 2016-12-05T13:28:03-05:00 oracleofnj: Fix off-by-one bug
407 eb8dd71 2016-12-05T13:20:03-05:00 oracleofnj: Address issues
408 f1b11ee 2016-12-05T12:46:35-05:00 Nigel Schuster: Skeleton for get_val
409 e4e5e26 2016-12-05T09:25:17-05:00 Nigel Schuster: Removed microc reference
    implementation
410 270da2b 2016-12-05T02:40:59-05:00 GitHub: Merge branch 'master' into fileio
411 b928e98 2016-12-05T02:40:10-05:00 Ishaan: Remove bloat
412 894b511 2016-12-05T02:32:49-05:00 Ishaan: Added testcase
413 62b8e83 2016-12-05T02:30:16-05:00 Ishaan: Added fwrite implementation
414 77a23ae 2016-12-05T01:39:30-05:00 Ishaan: Added read
415 46e9b58 2016-12-05T00:07:16-05:00 Ishaan: Make refactoring changes and new helpers
416 a5b9066 2016-12-04T14:00:30-05:00 GitHub: Merge pull request #20 from ExtendLang/lhs-
    all-ids
417 35e9471 2016-12-04T13:38:44-05:00 oracleofnj: Put back Id(s) as it was
418 641d454 2016-12-04T13:36:36-05:00 oracleofnj: Always transform to ID on LHS, even for
    LitInts
419 0e8398f 2016-12-04T13:23:27-05:00 oracleofnj: Transform all LHS expressions including
    integers to IDs; check for strings or range literals and disallow
420 f47f2ba 2016-12-04T10:30:44-05:00 oracleofnj: Add error handling to close() and add a
    couple test cases
421 e95a95a 2016-12-04T10:07:01-05:00 oracleofnj: Add assertSingleNumber and get_number to
    eliminate more copy & paste
422 543e720 2016-12-04T09:47:03-05:00 oracleofnj: Add new_number() to eliminate some copy
    and paste
423 d7f10c9 2016-12-04T02:31:03-05:00 Ishaan: Tentative drafts of fileio functions
424 7d81e43 2016-12-04T00:15:20-05:00 oracleofnj: add diagnostic printf
425 868d9a4 2016-12-03T23:46:01-05:00 Ishaan: Cleanup
426 aa1e014 2016-12-03T23:42:46-05:00 Ishaan: Add file pointer array
427 88d05de 2016-12-03T18:38:34-05:00 Ishaan: Working on fopen
428 36f5848 2016-12-03T14:07:39-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
429 2ae2b83 2016-12-03T14:06:40-05:00 GitHub: Merge pull request #15 from ExtendLang/
    stdlib-fun
430 7c78a23 2016-12-03T14:02:51-05:00 oracleofnj: Move test_fabs out of regression test
    suite
431 0a8055b 2016-12-03T13:48:19-05:00 oracleofnj: make test | grep REGRESSION
432 a24742b 2016-12-02T22:50:43-05:00 Kevin: Merged stdlib with master
433 5243c5a 2016-12-02T18:16:36-05:00 Kevin: Removed magic numbers and add fabs test
434 330bec3 2016-12-02T13:49:34-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
435 8a60995 2016-12-01T23:38:54-05:00 GitHub: Merge pull request #18 from ExtendLang/
    parser-error
436 f0d33e2 2016-12-01T23:18:39-05:00 oracleofnj: Move error handling
437 3b24c3a 2016-12-01T23:16:53-05:00 oracleofnj: Adjust test script
438 60a732f 2016-12-01T22:55:28-05:00 oracleofnj: Merge branch 'master' into parser-error
439 5dec6a2 2016-12-01T22:55:05-05:00 oracleofnj: Thank you Nigel!!!
440 96a3028 2016-12-01T22:19:21-05:00 GitHub: Merge pull request #16 from ExtendLang/fail-
    silent
441 6c3696c 2016-12-01T21:59:40-05:00 oracleofnj: Figure out why test is failing
442 7912d5a 2016-12-01T21:26:03-05:00 GitHub: Merge branch 'master' into fail-silent
443 9702e5b 2016-12-01T21:14:35-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
444 5bdd52c 2016-12-01T21:13:45-05:00 GitHub: Merge pull request #17 from ExtendLang/

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lexbuf-pos
445 8893255 2016-12-01T20:35:04-05:00 oracleofnj: Add a couple test cases
446 2868653 2016-12-01T20:23:01-05:00 oracleofnj: Use lexbuf.lex_curr_p to calculate
    position
447 8c7b6ce 2016-12-01T18:59:49-05:00 GitHub: Merge pull request #11 from ExtendLang/
    parse_error
448 2885ac7 2016-12-01T18:56:15-05:00 Ishaan: Added test case for string
449 047cfec 2016-12-01T18:42:04-05:00 oracleofnj: Add short circuiting test cases
450 6acd7f6 2016-12-01T18:31:33-05:00 oracleofnj: Merge remote-tracking branch 'origin/
    fail-silent' into finish-transformations
451 72360f4 2016-12-01T17:09:08-05:00 Nigel Schuster: Minified error output for outputs
    that have not passed yet
452 5762112 2016-12-01T16:04:06-05:00 oracleofnj: Get rid of wildcard pattern match in
    interpreter
453 a90a343 2016-12-01T15:59:40-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
454 85bc21d 2016-12-01T15:59:05-05:00 oracleofnj: Remove unnecessary file
455 81fe565 2016-12-01T15:58:40-05:00 oracleofnj: Finish range literals
456 e9fb1c2 2016-12-01T15:04:03-05:00 Ishaan: Added increment to string buffer and tests
457 eb7c1e8 2016-12-01T15:04:03-05:00 Ishaan: Add partial character indexing
458 df09aea 2016-12-01T15:04:03-05:00 Ishaan: Add expected parse testcase intermediate
459 712a710 2016-12-01T15:04:03-05:00 Ishaan: Added tentative scanner-level line number
460 bf4ee6c 2016-12-01T15:04:03-05:00 Ishaan: Added SyntaxError Exception at scan level
461 da41520 2016-12-01T14:54:21-05:00 oracleofnj: So close
462 7abb394 2016-12-01T14:07:58-05:00 GitHub: Merge pull request #14 from ExtendLang/
    sinner
463 e0b7fdb 2016-12-01T14:05:38-05:00 Nigel Schuster: Rename empty to new_val
464 2cabadc 2016-12-01T11:58:03-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
465 6ea8cff 2016-12-01T10:10:26-05:00 Nigel Schuster: Using define instead of magic
    numbers
466 cd7d261 2016-12-01T10:07:10-05:00 Nigel Schuster: Merge branch 'master' into sinner
467 13cd317 2016-12-01T10:06:25-05:00 GitHub: Merge pull request #13 from ExtendLang/
    value_p
468 cf36f70 2016-12-01T09:47:38-05:00 oracleofnj: Sample digits function
469 4eed07 2016-12-01T01:02:56-05:00 Ishaan: Change print return type to empty
470 fa42f27 2016-12-01T00:41:47-05:00 Kevin: Fixed acos function
471 53d34ad 2016-12-01T00:29:32-05:00 Nigel Schuster: Moved double values type to numeric
472 f769c61 2016-12-01T00:18:07-05:00 Nigel Schuster: Merge branch 'sinner' into stdlib-
    fun
473 3986f38 2016-12-01T00:17:21-05:00 Nigel Schuster: Merge branch 'value_p' into sinner
474 5bd87f9 2016-12-01T00:14:45-05:00 Nigel Schuster: Explicitly declaring to link math
    library
475 4604545 2016-12-01T00:12:08-05:00 Nigel Schuster: Consistently using floats
476 38b9824 2016-11-30T23:46:14-05:00 Nigel Schuster: Merge branch 'value_p' into sinner
477 3303575 2016-11-30T23:45:25-05:00 Nigel Schuster: Explicitly declaring to link math
    library
478 31a74ec 2016-11-30T23:35:34-05:00 Nigel Schuster: Merge branch 'master' into value_p
479 7f0bc86 2016-11-30T23:04:34-05:00 Kevin: Finished remainder of stdlib
480 cd160df 2016-11-30T22:50:18-05:00 Kevin: Added more c functions to stdlib
481 e085977 2016-11-30T19:59:57-05:00 Nigel Schuster: Made sin function work
482 206ee5a 2016-11-30T19:07:28-05:00 Nigel Schuster: Moved all function signatures to
    value_p return value
483 effc20b 2016-11-30T18:45:52-05:00 GitHub: Merge pull request #12 from ExtendLang/easy-
    compile
484 3b6d7b7 2016-11-30T17:51:19-05:00 Nigel Schuster: Added script to compile and link

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485 febcff8 2016-11-30T15:54:45-05:00 oracleofnj: Add oddball formula test case and try
    out theory for range literal
486 4a1ff4f 2016-11-30T14:54:05-05:00 oracleofnj: Finish reducing Ternary to
    ReducedTernary
487 8f0a981 2016-11-30T12:35:43-05:00 oracleofnj: Working on reducing ternaries
488 d3c5812 2016-11-30T02:39:58-05:00 oracleofnj: Finish desugaring switch
489 0a22713 2016-11-30T00:09:10-05:00 oracleofnj: Getting ready to ternarize switch
490 84f016a 2016-11-29T21:54:15-05:00 oracleofnj: Fix bug in switch() with default case
491 d331b7a 2016-11-29T17:33:41-05:00 oracleofnj: Give desugaring variables easier-to-read
    names for debugging purposes
492 36f8de5 2016-11-29T16:14:46-05:00 oracleofnj: Missed one
493 d96da34 2016-11-29T16:13:21-05:00 oracleofnj: Transform &&, || into ternary
    expressions to support proper short-circuit evaluation
494 3a8efbc 2016-11-28T23:05:28-05:00 GitHub: Merge pull request #9 from ExtendLang/func-
    calls
495 7a2af49 2016-11-28T20:33:53-05:00 Nigel Schuster: Removed another ocaml 4.3 dep
496 468e79f 2016-11-28T19:50:53-05:00 Nigel Schuster: Added ocaml 4.3 as dep for travis (
    hopefully this works)
497 a408761 2016-11-28T19:35:49-05:00 Nigel Schuster: Fixed String.equal
498 90c3caf 2016-11-27T22:52:14-05:00 Nigel Schuster: Fixed interpreter for now
499 a18da78 2016-11-27T22:42:27-05:00 Nigel Schuster: Added accidentally created file
500 5647312 2016-11-27T22:41:22-05:00 Nigel Schuster: Made extern function calls work
501 872aa8c 2016-11-27T13:52:44-05:00 Nigel Schuster: Merge branch 'func-calls' of https
    ://github.com/ExtendLang/Extend into func-calls
502 26ef1cc 2016-11-27T13:51:06-05:00 Nigel Schuster: Merging list of functions
503 877336f 2016-11-27T12:15:11-05:00 GitHub: Merge branch 'master' into func-calls
504 5b3edb0 2016-11-27T12:14:43-05:00 GitHub: Merge pull request #8 from ExtendLang/stdlib
    -template
505 374273f 2016-11-27T12:13:52-05:00 Nigel Schuster: Function calls work now
506 952aab8 2016-11-27T09:54:12-05:00 Nigel Schuster: Merge extern
507 ac6268f 2016-11-26T23:06:00-05:00 Nigel Schuster: Boxing ints, added unop sizeof,
    actually returning subrange not dummy object
508 ca07be3 2016-11-26T21:27:19-05:00 Nigel Schuster: Unboxing hello world to and from
    subrange
509 aef6c19 2016-11-26T16:55:48-05:00 Nigel Schuster: Made Hello World somewhat workable
510 cfb637e 2016-11-25T18:27:37-05:00 Nigel Schuster: Fixed faulty setup on call
511 ebf926a 2016-11-25T17:48:57-05:00 Nigel Schuster: Added template in C
512 554fbb2 2016-11-23T22:28:29-05:00 oracleofnj: Better error message for WrongNumberArgs
513 f09e40e 2016-11-23T12:47:39-05:00 oracleofnj: Make sequence work
514 053980b 2016-11-22T16:02:27-05:00 oracleofnj: Actually commit all the extern stuff
515 0e0fa23 2016-11-22T14:36:54-05:00 Nigel Schuster: Added extern in Ast
516 aac63be 2016-11-21T23:52:25-05:00 oracleofnj: Better duplicate definition checking
517 08e2d07 2016-11-21T23:29:28-05:00 oracleofnj: Check assertions before evaluating fn
    return expression
518 69fa332 2016-11-21T18:01:23-05:00 oracleofnj: Add size assertions
519 22541c4 2016-11-21T12:48:34-05:00 oracleofnj: Fix bug in Call()
520 9a1d24b 2016-11-21T12:39:41-05:00 oracleofnj: Working on crazy bug
521 a485cee 2016-11-20T22:13:46-05:00 oracleofnj: Add test case for foo([m, n] arg)
522 10afe9a 2016-11-20T22:07:17-05:00 oracleofnj: Expand function signature
523 325e9ba 2016-11-20T18:53:52-05:00 oracleofnj: Well, this is awkward
524 0a76dc9 2016-11-20T18:41:12-05:00 oracleofnj: Add check of return value
525 488e34e 2016-11-20T18:31:39-05:00 oracleofnj: Add sample #1
526 93eebc5 2016-11-20T18:27:23-05:00 oracleofnj: Add semantic checking to make sure
    functions and variables on RHS exist
527 881f164 2016-11-20T17:22:40-05:00 oracleofnj: Check RHS slice to ensure end > start,
    otherwise evaluate to empty

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528 442ae91 2016-11-20T11:42:54-05:00 GitHub: Merge pull request #73 from Neitsch/
    interpreter-global
529 f7f701d 2016-11-20T11:30:06-05:00 Nigel Schuster: Added use of global variables to
    interpreter, fixed specs for logical or and and testcases with empty
530 367bc2b 2016-11-20T00:33:17-05:00 GitHub: Merge pull request #72 from Neitsch/codegen-
    part-app-fix
531 bdca834 2016-11-20T00:31:04-05:00 GitHub: Merge branch 'master' into codegen-part-app-
    fix
532 e956238 2016-11-20T00:28:49-05:00 GitHub: Merge pull request #71 from Neitsch/tc-fixes
533 9b742d1 2016-11-20T00:24:39-05:00 Nigel Schuster: Fixed partial function application
    warning
534 32f2989 2016-11-20T00:20:51-05:00 GitHub: Merge branch 'master' into tc-fixes
535 f87cb94 2016-11-20T00:20:35-05:00 GitHub: Merge pull request #69 from Neitsch/
    regression-tests
536 842ee5a 2016-11-20T00:18:56-05:00 GitHub: Merge branch 'master' into regression-tests
537 6d73717 2016-11-19T23:55:35-05:00 GitHub: Merge pull request #66 from Neitsch/fix-test
    -cases
538 05f317a 2016-11-19T22:37:36-05:00 Nigel Schuster: Fixed output on TCs
539 aa1d974 2016-11-19T22:33:40-05:00 Nigel Schuster: Fixed expected value for ternary
540 ab7653a 2016-11-19T22:32:27-05:00 Nigel Schuster: Fixed import testcases
541 848066c 2016-11-19T22:24:55-05:00 Nigel Schuster: Moved testcase asset to asset folder
542 53c9206 2016-11-19T22:21:48-05:00 Nigel Schuster: Corrected use of global variable in
    test_globals
543 5fe74a8 2016-11-19T22:21:00-05:00 Nigel Schuster: Fixed expected output for
    test_access_column_cells
544 214ab9d 2016-11-19T22:10:33-05:00 Nigel Schuster: Merge
545 fb31505 2016-11-19T22:08:42-05:00 Nigel Schuster: Passing testcases are in separate
    directory. Output of stats
546 5e39ba7 2016-11-19T21:55:03-05:00 Nigel Schuster: Merge
547 25263fe 2016-11-19T21:51:31-05:00 Nigel Schuster: Removed travis from build, removed
    super verbose output
548 0554ad9 2016-11-19T21:42:28-05:00 Nigel Schuster: Using precise lli version
549 04e5c4a 2016-11-19T18:30:32-05:00 oracleofnj: Add more operators to interpreter
550 e4a190c 2016-11-19T17:14:04-05:00 oracleofnj: Add argument to main and remove
    _expected from filenames
551 7cd2b3a 2016-11-19T16:53:12-05:00 oracleofnj: Merge branch 'master' into fix-test-
    cases
552 d1fddfd 2016-11-19T16:52:48-05:00 oracleofnj: Merge branch 'fix-test-cases' of https
    ://github.com/Neitsch/plt into fix-test-cases
553 36f72a1 2016-11-19T16:49:34-05:00 GitHub: Merge pull request #67 from Neitsch/
    test_cases
554 c46c87b 2016-11-19T16:47:26-05:00 GitHub: Merge branch 'master' into test_cases
555 642ce76 2016-11-19T16:39:50-05:00 Kevin: Fixed helloworld bug
556 ac3d7fa 2016-11-19T16:10:53-05:00 Kevin: Added corresponding AST result for gcd
    function
557 7b6b79e 2016-11-19T14:31:39-05:00 GitHub: Merge branch 'master' into fix-test-cases
558 a9320f3 2016-11-19T14:29:51-05:00 oracleofnj: Merge branch 'master' into fix-test-
    cases
559 24a3625 2016-11-19T14:27:48-05:00 oracleofnj: Add switch tests
560 de262b4 2016-11-19T14:24:39-05:00 GitHub: Merge pull request #60 from Neitsch/box-args
561 75e3f71 2016-11-18T20:39:23-05:00 oracleofnj: Fix parsing errors in test cases
562 4e38757 2016-11-18T16:00:10-05:00 GitHub: Merge branch 'master' into box-args
563 7146dce 2016-11-18T15:59:54-05:00 GitHub: Merge pull request #64 from Neitsch/reorg-
    test
564 f483ac7 2016-11-18T14:10:32-05:00 Kevin: Updated print statement for each test
565 09cb42f 2016-11-18T14:07:39-05:00 oracleofnj: Fix parse difference

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566 39634bb 2016-11-18T14:01:21-05:00 oracleofnj: Remove unnecessary files
567 d772725 2016-11-18T14:01:02-05:00 oracleofnj: Make inputs work with interpreter
568 f4456f8 2016-11-18T13:17:25-05:00 GitHub: Merge branch 'master' into test_cases
569 00aafb7 2016-11-18T13:16:08-05:00 Kevin: Renamed inputs folder
570 99db652 2016-11-18T12:51:40-05:00 Kevin: Renamed expected output extension and created
    input folder for test cases
571 2825ada 2016-11-18T12:51:33-05:00 Nigel Schuster: Added branch to build
572 aafabb2 2016-11-18T12:50:56-05:00 Nigel Schuster: Verbose output for travis debug
573 124d61e 2016-11-18T12:44:50-05:00 GitHub: Merge pull request #61 from Neitsch/reorg-
    test
574 82cf599 2016-11-18T12:34:57-05:00 oracleofnj: Modify test script to compare
    interpreter and compiler with expected
575 faecfa1 2016-11-18T01:48:44-05:00 oracleofnj: Fix merge conflict in box_args
576 41a81ce 2016-11-18T01:40:11-05:00 oracleofnj: Move argument boxing into a function
577 6f63e89 2016-11-18T00:48:07-05:00 GitHub: Merge pull request #59 from Neitsch/hello-
    hello
578 088dc45 2016-11-18T00:29:45-05:00 Nigel Schuster: Merge
579 012caaa 2016-11-18T00:12:40-05:00 GitHub: Merge pull request #58 from Neitsch/copy-
    argv
580 f84757b 2016-11-18T00:02:34-05:00 Nigel Schuster: Removed unnecessary files
581 18fbff1 2016-11-18T00:01:49-05:00 Nigel Schuster: Removed dummy arg reading, added
    printing to interpreter - helloworld TC passes
582 b866da3 2016-11-17T23:31:42-05:00 Nigel Schuster: Made hello world work
583 9463afa 2016-11-17T23:12:41-05:00 oracleofnj: Merge branch 'copy-argv' of https://
    github.com/Neitsch/plt into copy-argv
584 54858ab 2016-11-17T23:11:29-05:00 oracleofnj: Add => infix operator to cut down on all
    the build_struct_gep calls
585 bb11d6d 2016-11-17T23:10:24-05:00 GitHub: Merge branch 'master' into copy-argv
586 e123652 2016-11-17T22:28:12-05:00 oracleofnj: Add byte for zero
587 26a03b7 2016-11-17T22:24:17-05:00 oracleofnj: Add new_string function
588 b8028f9 2016-11-17T20:27:37-05:00 Kevin: Removed files from test folder
589 c85d9b7 2016-11-17T20:25:21-05:00 Kevin: Move testcases to testcases directory
590 f17c6b6 2016-11-17T20:21:38-05:00 Kevin Ye: Complete testcases for List/Range/Function
    /Expression with expected outputs
591 5e63cee 2016-11-17T17:40:31-05:00 GitHub: Merge pull request #54 from Neitsch/
    operation_tests
592 4a4a806 2016-11-17T17:19:13-05:00 GitHub: Merge branch 'master' into operation_tests
593 cafe20e 2016-11-17T17:19:11-05:00 GitHub: Merge pull request #52 from Neitsch/one-main-
    -arg
594 4b28df2 2016-11-17T17:17:44-05:00 GitHub: Merge branch 'master' into operation_tests
595 b728e2e 2016-11-17T17:16:20-05:00 GitHub: Merge branch 'master' into one-main-arg
596 d43a87b 2016-11-17T17:15:28-05:00 GitHub: Merge pull request #55 from Neitsch/shell-
    fix
597 b1238a0 2016-11-17T17:08:56-05:00 Nigel Schuster: Shell is not my strength
598 a6cc0ea 2016-11-17T17:05:09-05:00 Nigel Schuster: Screw you bourne shell
599 51fbe67 2016-11-17T16:59:50-05:00 Nigel Schuster: Using bourne shell style redirection
    :
600 3255e1b 2016-11-17T16:38:53-05:00 Ishaan: Modify test suite specs
601 f0ab4d8 2016-11-17T16:38:53-05:00 Ishaan: Moved expected output text files to
    directory
602 06d330c 2016-11-17T16:38:53-05:00 Ishaan: 75% through operator cases
603 e490548 2016-11-17T15:50:35-05:00 GitHub: Merge branch 'master' into one-main-arg
604 a4cf367 2016-11-17T15:50:29-05:00 GitHub: Merge pull request #51 from Neitsch/test-
    script
605 79ee3de 2016-11-17T15:18:58-05:00 oracleofnj: Call main() with first argument <empty>
    in interpreter

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606 c4f7437 2016-11-17T14:39:38-05:00 Nigel Schuster: Removed version specific lli
607 7b2236b 2016-11-17T14:35:55-05:00 Nigel Schuster: Fixed if no flag is given
608 e10f656 2016-11-17T14:24:20-05:00 Nigel Schuster: Outputting diff only if -p flag is
given
609 2d29597 2016-11-17T14:19:30-05:00 Nigel Schuster: Added it as build target
610 7af929a 2016-11-17T14:12:19-05:00 GitHub: Merge pull request #50 from Neitsch/test-
script
611 6ea43f6 2016-11-17T13:54:55-05:00 Nigel Schuster: Added more env variables to avoid
copy paste
612 05f27a2 2016-11-17T12:45:11-05:00 Nigel Schuster: Made simple testscript
613 aca43c1 2016-11-17T11:08:11-05:00 Nigel Schuster: Removed accidentally added files
614 9228eac 2016-11-17T04:52:31-05:00 Kevin Ye: Test cases for List of Tests and Range/
Function/Expression Tests
615 7feb392 2016-11-17T00:28:53-05:00 GitHub: Merge pull request #48 from Neitsch/
testing_list
616 6e42afa 2016-11-17T00:27:13-05:00 GitHub: Merge branch 'master' into testing_list
617 e40734b 2016-11-16T23:25:01-05:00 Ishaan: Added more test scenarios
618 41ef578 2016-11-16T17:50:03-05:00 GitHub: Merge pull request #49 from Neitsch/consume-
command-line-args
619 3cbf089 2016-11-16T17:45:58-05:00 oracleofnj: Fix merge conflict
620 1570836 2016-11-16T16:51:05-05:00 GitHub: Merge pull request #45 from Neitsch/doc
621 a8fbced 2016-11-16T16:38:49-05:00 Nigel Schuster: Fixed minor syntax error
622 c2f37c8 2016-11-16T16:30:43-05:00 Nigel Schuster: Merge
623 2fa73be 2016-11-16T16:05:37-05:00 oracleofnj: Set return code to length of argv[1]
624 bc21af6 2016-11-16T15:54:12-05:00 Ishaan: Added initial testing list
625 cd0d156 2016-11-16T15:50:39-05:00 oracleofnj: Start processing command line args
626 4a1fcac 2016-11-16T13:55:46-05:00 GitHub: Merge pull request #46 from Neitsch/number-
type
627 f1b481e 2016-11-16T11:04:44-05:00 Nigel Schuster: Added number type that defaults to
int
628 8944b9a 2016-11-16T00:19:33-05:00 GitHub: Merge pull request #44 from Neitsch/fix-arg
629 92fb7a3 2016-11-15T23:57:37-05:00 Nigel Schuster: Added a little documentation
630 bcbde36 2016-11-15T23:49:07-05:00 GitHub: Merge branch 'master' into fix-arg
631 fa1741a 2016-11-15T23:03:23-05:00 GitHub: Merge pull request #43 from Neitsch/more-
llvm-gen-js
632 57b2162 2016-11-15T22:39:38-05:00 Nigel Schuster: Using subranges instead of ranges
everywhere
633 9407677 2016-11-15T22:31:03-05:00 oracleofnj: Add hash table for common functions and
add dereference-the-range
634 46elfd5 2016-11-15T21:38:51-05:00 oracleofnj: Eliminate some copy & paste
635 660c049 2016-11-15T20:54:33-05:00 GitHub: Merge pull request #42 from Neitsch/llvm-gen
636 25b23cd 2016-11-15T17:23:54-05:00 Nigel Schuster: Fixed column retrieval for 1x1
637 3f02203 2016-11-15T17:17:02-05:00 Nigel Schuster: Fixed tests
638 26b8fcf 2016-11-15T17:15:08-05:00 Nigel Schuster: Merge
639 e347a87 2016-11-15T17:12:26-05:00 Nigel Schuster: Using more generic flag for values
640 aed28b3 2016-11-15T17:08:07-05:00 oracleofnj: Add is_subrange_1x1
641 cf5cbf0 2016-11-15T14:51:40-05:00 oracleofnj: Merge branch 'llvm-gen' of https://
github.com/Neitsch/plt into llvm-gen
642 c71d469 2016-11-15T14:51:19-05:00 oracleofnj: Replace String.equal with =
643 4b34abd 2016-11-15T14:41:37-05:00 GitHub: Merge branch 'master' into llvm-gen
644 a80a6d0 2016-11-15T14:41:07-05:00 oracleofnj: Add compile option to main
645 8ad5a19 2016-11-15T14:33:40-05:00 GitHub: Merge pull request #40 from Neitsch/
interpreter
646 3f0362a 2016-11-15T14:28:44-05:00 GitHub: Merge branch 'master' into interpreter
647 c0c95a2 2016-11-15T14:16:13-05:00 Nigel Schuster: Merge
648 d5f4024 2016-11-15T13:44:44-05:00 Nigel Schuster: Moved failing TCs

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649 42fd9ef 2016-11-15T12:21:57-05:00 oracleofnj: Fix bug in import
650 9c567c9 2016-11-15T11:11:30-05:00 Nigel Schuster: Working on imports, fixed most
    testcases
651 aa61ac9 2016-11-15T09:31:42-05:00 Nigel Schuster: Allocating scope object
652 cf1ebf9 2016-11-13T23:09:30-05:00 oracleofnj: Rewrite main to take options; fix bug
    where import didn't know about first filename
653 5749538 2016-11-13T21:59:28-05:00 Nigel Schuster: Added main function
654 d6daff3 2016-11-13T20:26:14-05:00 GitHub: Merge pull request #41 from Neitsch/
    LRM_String_Update
655 0a5d484 2016-11-13T18:45:29-05:00 oracleofnj: Revert "Generating function header"
656 6afe599 2016-11-13T18:44:58-05:00 Ishaan Kolluri: Added changes relating to strings.
657 137d7e2 2016-11-13T18:39:33-05:00 oracleofnj: Merge branch 'interpreter' of https://
    github.com/Neitsch/plt into interpreter
658 118bfc5 2016-11-13T18:38:34-05:00 oracleofnj: Allow single slice on RHS; make hashtag
    work
659 e376270 2016-11-13T17:55:41-05:00 Nigel Schuster: Added type arguments for functions
660 5cfb519 2016-11-13T17:26:23-05:00 Nigel Schuster: Set more types up
661 bf1d8bb 2016-11-13T15:30:35-05:00 Nigel Schuster: Merge branch 'interpreter' of https
    ://github.com/Neitsch/plt into interpreter
662 f83a0bc 2016-11-13T15:30:28-05:00 Nigel Schuster: Generating function header
663 3addcc8 2016-11-13T14:38:11-05:00 oracleofnj: Make size(expr) an operator instead of
    built-in function
664 9a74e14 2016-11-13T14:22:44-05:00 oracleofnj: Changing size() to be an operator
665 d6d2eaa 2016-11-13T00:08:41-05:00 oracleofnj: Add closure to interpreter_variable
666 64fba82 2016-11-12T22:38:39-05:00 oracleofnj: Added bsearch to show logic bug
667 66ffdb1 2016-11-12T19:21:07-05:00 oracleofnj: Add alpha version of function calls
668 376b29a 2016-11-12T17:17:23-05:00 oracleofnj: Add string as value type
669 08c61ee 2016-11-12T17:14:47-05:00 oracleofnj: Clean up discrepancies
670 a18d5fc 2016-11-08T11:38:22-05:00 oracleofnj: Fix bug with x[-1]
671 962f812 2016-11-07T23:27:08-05:00 oracleofnj: Refactor scope for interpreter; resolve
    variables on demand; make selections work properly
672 47bbef1 2016-11-06T22:05:55-05:00 oracleofnj: Minor adjustments to interpreter to work
    with mapped AST
673 fddc6bc 2016-11-06T18:32:17-05:00 oracleofnj: Eliminate extraneous nulls in JSON
674 ffddb17 2016-11-06T18:15:40-05:00 oracleofnj: Turn statement and function lists into
    StringMaps
675 6810003 2016-11-05T19:47:57-04:00 oracleofnj: Fix pattern matching warning
676 7107a46 2016-11-05T18:01:34-04:00 oracleofnj: Add function to check range literals for
    legality at parse time
677 80b13d1 2016-11-05T15:13:10-04:00 oracleofnj: Handle selections better
678 6cbb009 2016-11-04T15:48:58-04:00 oracleofnj: Count to 1,000,000 using tail-recursive
    versions of List.map and cartesian product
679 9b2252d 2016-11-04T15:25:13-04:00 oracleofnj: Show enter and exit
680 3585e43 2016-11-04T02:21:38-04:00 oracleofnj: See how high it can count recursively
681 38cf541 2016-11-04T02:15:50-04:00 oracleofnj: Get the easy parts of the interpreter
    working
682 5d81d6e 2016-11-03T17:17:51-04:00 oracleofnj: Start working on interpreter
683 0078cee 2016-11-01T23:40:57-04:00 oracleofnj: Got a non-tail-recursive version of
    topological sort working
684 85df175 2016-11-01T15:39:10-04:00 oracleofnj: Irrelevant highlighting thing
685 84c719a 2016-11-01T14:39:49-04:00 oracleofnj: Rearrange nested functions
686 557dc4e 2016-11-01T13:50:52-04:00 oracleofnj: Add circular import test case
687 c476798 2016-11-01T13:35:46-04:00 oracleofnj: Fix syntax errors
688 af5a31d 2016-11-01T13:31:49-04:00 GitHub: Merge pull request #37 from Neitsch/import-
    rec
689 d451cc4 2016-11-01T13:31:33-04:00 GitHub: Merge pull request #38 from Neitsch/import-

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load
690 02ca24f 2016-11-01T13:30:47-04:00 GitHub: Merge pull request #39 from Neitsch/wild-exc
691 6fa0e39 2016-10-31T16:43:17-04:00 Neitsch: Raising exceptions on certain values
692 e673dca 2016-10-31T15:56:43-04:00 Neitsch: Loading data from all imports
693 6a28c05 2016-10-31T15:40:41-04:00 Neitsch: Recursively looking up dependencies
694 3f28289 2016-10-31T11:53:10-04:00 GitHub: Merge pull request #36 from Neitsch/import-
    arrange
695 4eae3b 2016-10-31T11:01:00-04:00 Neitsch: Removed obsolete parts
696 7d7ble5 2016-10-31T10:59:12-04:00 Neitsch: Added unsorted function, globals and
    imports
697 7d70af2 2016-10-30T15:23:04-04:00 oracleofnj: Add some explanatory comments
698 40d6b16 2016-10-30T15:03:32-04:00 oracleofnj: More expansion samples
699 af9b01c 2016-10-30T14:48:44-04:00 oracleofnj: Refactor expansion code
700 903bc3f 2016-10-30T00:19:10-04:00 oracleofnj: Add test output
701 68b7b03 2016-10-30T00:17:02-04:00 oracleofnj: Add test case
702 a8bdf33 2016-10-30T00:04:05-04:00 oracleofnj: Add LHS slice expansion
703 4ee6fdf 2016-10-29T17:36:17-04:00 oracleofnj: Add output
704 2b8bcd 2016-10-29T17:27:22-04:00 oracleofnj: Expand dimension expressions
705 443a818 2016-10-26T16:31:51-04:00 GitHub: Merge pull request #35 from ishaankolluri/
    master
706 9ba3c65 2016-10-26T16:31:00-04:00 Ishaan Kolluri: Add UNIs
707 022e8cd 2016-10-26T16:25:57-04:00 GitHub: Merge pull request #34 from ishaankolluri/
    master
708 808aae5 2016-10-26T16:22:10-04:00 Ishaan Kolluri: Added change to precedence operators
709 0bd9c4a 2016-10-26T15:59:53-04:00 GitHub: Merge pull request #33 from Neitsch/final-
    slicing-comments
710 fb2b382 2016-10-26T15:54:11-04:00 oracleofnj: Thats all for now folks
711 e7020ec 2016-10-26T15:00:11-04:00 GitHub: Merge pull request #32 from Neitsch/final-
    lrm-edits
712 4683f14 2016-10-26T14:48:41-04:00 oracleofnj: Flesh out switch expressions, add
    precedence
713 4b7984a 2016-10-26T11:15:03-04:00 GitHub: Merge pull request #31 from Neitsch/more-lrm
    -edits
714 3d587c5 2016-10-26T11:10:15-04:00 oracleofnj: Incorporate requested edits and a few
    more clarifications
715 0c42b9c 2016-10-26T09:22:08-04:00 GitHub: Merge pull request #30 from ishaankolluri/
    LRM_update
716 cd81040 2016-10-26T03:30:20-04:00 ishaankolluri: Added changes to first half of LRM
717 63fb02b 2016-10-26T02:13:17-04:00 GitHub: Merge pull request #29 from Neitsch/lrm-
    edits
718 0941e96 2016-10-26T02:04:47-04:00 oracleofnj: Rebuild PDF
719 cb04069 2016-10-26T02:04:01-04:00 oracleofnj: Add built in functions
720 4abf638 2016-10-26T01:56:38-04:00 oracleofnj: Add built in functions
721 7661925 2016-10-26T00:04:22-04:00 oracleofnj: Initial comments
722 5932551 2016-10-25T21:30:40-04:00 GitHub: Merge pull request #28 from Neitsch/func-doc
    -fix
723 cc66297 2016-10-25T20:14:27-04:00 Nigel Schuster: Fixed mistakes in functions part of
    the doc
724 b978f00 2016-10-25T13:04:05-04:00 GitHub: Merge pull request #27 from ishaankolluri/
    master
725 125a5bb 2016-10-25T12:49:38-04:00 Ishaan Kolluri: Removed AUX file
726 2e1ea60 2016-10-25T11:30:35-04:00 GitHub: Merge pull request #26 from Neitsch/better-
    regexp
727 84b03ee 2016-10-25T01:22:31-04:00 oracleofnj: Fix let order
728 91b40c5 2016-10-25T01:14:43-04:00 oracleofnj: Improve regexp
729 eb24036 2016-10-24T23:55:38-04:00 GitHub: Merge pull request #23 from Neitsch/file-io

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730 991c918 2016-10-24T23:20:12-04:00 oracleofnj: Replace fopen, fclose etc. with open,
close etc.
731 338faa0 2016-10-24T23:14:30-04:00 oracleofnj: Fix file inclusion and rebuild PDF
732 b24edd3 2016-10-24T23:11:50-04:00 oracleofnj: Merge in expressions section
733 44a1cc5 2016-10-24T23:06:07-04:00 oracleofnj: Merge scanner changes and add regexp to
properly escape strings
734 2f09a64 2016-10-24T15:52:10-04:00 Kevin: Added the Expression Section 4 to LRM
735 1ea3c28 2016-10-24T15:26:16-04:00 oracleofnj: Merge branch 'master' into file-io
736 ec7cc9c 2016-10-24T15:21:23-04:00 Jared Samet: Replace repetitive code with more
idiomatic OCaml
737 8cd39ac 2016-10-24T11:05:33-04:00 Kevin: Added string literals to scanner
738 e5d2478 2016-10-24T11:00:39-04:00 Kevin: Added string literals to scanner
739 a692466 2016-10-24T01:09:21-04:00 oracleofnj: Fix tests until strings ready
740 8553a50 2016-10-24T01:08:29-04:00 oracleofnj: Fix tests until string ready
741 0ed4ad7 2016-10-24T00:55:08-04:00 oracleofnj: Add File IO, Entry point and Example to
LRM
742 71e0b1c 2016-10-23T22:58:21-04:00 oracleofnj: Fix section reference
743 92ac506 2016-10-23T22:39:06-04:00 Ishaan Kolluri: Make small change to data type
section
744 6abb290 2016-10-23T22:34:42-04:00 oracleofnj: Initial commit for File I/O section
745 67b4b65 2016-10-23T19:30:03-04:00 Nigel Schuster: Reduce eye pain
746 2824ee9 2016-10-23T19:03:24-04:00 GitHub: Merge pull request #20 from Neitsch/samples
747 f8ae543 2016-10-23T18:23:11-04:00 GitHub: Merge branch 'master' into samples
748 13d0896 2016-10-23T18:20:03-04:00 GitHub: Merge pull request #19 from Neitsch/sequence
-operator
749 e0c702d 2016-10-23T18:17:58-04:00 Neitsch: Fixed .gitignore
750 3a2cd60 2016-10-23T18:16:35-04:00 GitHub: Merge branch 'master' into sequence-operator
751 e42fe94 2016-10-23T18:05:48-04:00 Neitsch: Added code in LRM to test code samples
752 9d2cd17 2016-10-23T17:24:15-04:00 Neitsch: Merge branch 'master' into samples
753 167ddd2 2016-10-23T17:18:35-04:00 Neitsch: Removed test output
754 57319c4 2016-10-23T17:11:13-04:00 oracleofnj: Remove intermediate files
755 53824ea 2016-10-23T17:10:39-04:00 oracleofnj: Flip precedence of -> and ?: (?: is now
lowest)
756 7dedf93 2016-10-23T17:05:23-04:00 oracleofnj: Add sequence operator to scanner/parser/
AST
757 9805753 2016-10-23T17:01:31-04:00 GitHub: Merge pull request #17 from Neitsch/make-
correction
758 e0c7aed 2016-10-23T16:59:33-04:00 Neitsch: Fixed test
759 ec3d682 2016-10-23T16:41:00-04:00 GitHub: Merge branch 'master' into make-correction
760 ea05658 2016-10-23T16:40:24-04:00 Neitsch: Moved sequence file
761 0ca56a0 2016-10-23T16:10:14-04:00 Neitsch: Merge
762 9d1094e 2016-10-23T16:08:59-04:00 Neitsch: Added simple TCs, Moved Makefile to oasis
config
763 0a28413 2016-10-23T16:08:59-04:00 Neitsch: Completed initial functions section doc
764 0797f32 2016-10-23T16:08:12-04:00 Neitsch: Changed subsection header
765 9df31f7 2016-10-23T16:08:12-04:00 Neitsch: Added dimension section
766 8939903 2016-10-23T16:07:26-04:00 Neitsch: Started working on Functions
767 cae3b37 2016-10-23T16:06:27-04:00 Neitsch: Added dimension section
768 049c95d 2016-10-23T16:06:08-04:00 Neitsch: Started working on Functions
769 84d20b5 2016-10-23T16:01:00-04:00 Neitsch: Comparing sample code with correctly parsed
code in samples_comp
770 3f015ee 2016-10-23T15:52:01-04:00 GitHub: Merge pull request #18 from Neitsch/grammar-
bug-fixes
771 7e558c1 2016-10-23T15:44:20-04:00 GitHub: Merge branch 'master' into make-correction
772 edf3dea 2016-10-23T15:44:20-04:00 GitHub: Merge branch 'master' into grammar-bug-fixes
773 d4961eb 2016-10-23T15:43:16-04:00 GitHub: Merge pull request #15 from Neitsch/


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functions-doc
774 0e0bda5 2016-10-23T15:05:42-04:00 GitHub: Merge branch 'master' into functions-doc
775 4652c67 2016-10-23T15:00:35-04:00 Neitsch: Added simple TCs, Moved Makefile to oasis
    config
776 b45718d 2016-10-23T02:27:36-04:00 oracleofnj: Modify grammar to allow [m,n] foo, bar,
    baz;
777 143fcba 2016-10-22T23:23:10-04:00 GitHub: Merge pull request #16 from Neitsch/more-AST
778 a726236 2016-10-22T20:51:27-04:00 oracleofnj: Add comments and sample program
779 8db4098 2016-10-22T19:44:48-04:00 oracleofnj: Fix minor grammar bug
780 80754c3 2016-10-22T18:19:27-04:00 oracleofnj: Hook up scanner and parser
781 660de8c 2016-10-22T13:54:32-04:00 GitHub: Add stuff to the grammar, minor corrections
    (#14)
782 cfe827d 2016-10-21T20:50:51-04:00 Nigel Schuster: Completed initial functions section
    doc
783 3609366 2016-10-20T21:14:00-04:00 GitHub: Update scanner.mll
784 0d57652 2016-10-20T21:10:27-04:00 Kevin: Fixed bug in scanner
785 1848813 2016-10-20T20:21:49-04:00 Kevin: Made scanner
786 1b610ac 2016-10-20T13:50:22-04:00 Nigel Schuster: Merge
787 acb9b93 2016-10-20T13:44:06-04:00 Nigel Schuster: Changed subsection header
788 b95d039 2016-10-20T13:43:51-04:00 Nigel Schuster: Added dimension section
789 71b93bb 2016-10-20T13:43:09-04:00 Nigel Schuster: Started working on Functions
790 a15772c 2016-10-20T13:38:08-04:00 GitHub: Merge pull request #10 from ishaankolluri/
    LRM
791 dee63c7 2016-10-20T13:26:28-04:00 GitHub: Merge pull request #1 from Neitsch/grammar-
    doc
792 dc93dbf 2016-10-20T13:18:29-04:00 Nigel Schuster: Grammar import
793 4d763cb 2016-10-20T12:44:52-04:00 Ishaan Kolluri: Made refactor and edits to intro
    section of LRM
794 e7443cc 2016-10-20T11:46:54-04:00 Ishaan Kolluri: Merging
795 7542b5d 2016-10-20T11:16:35-04:00 Nigel Schuster: Added dimension section
796 995cf83 2016-10-19T12:28:09-04:00 Nigel Schuster: Started working on Functions
797 40c2a5a 2016-10-19T03:43:06-04:00 ishaankolluri: Initial LRM Commit part 1
798 02a5c17 2016-10-18T18:38:21-04:00 Ishaan Kolluri: Added LRM initial info
799 d8794e9 2016-10-17T19:47:42-04:00 GitHub: Merge pull request #9 from Neitsch/
    documentation
800 70aalb9 2016-10-16T13:36:23-04:00 Nigel Schuster: Added PDF Latex template
801 5111202 2016-10-14T19:59:45-04:00 GitHub: Added a bunch of stuff to the grammar: (#8)
802 da967e4 2016-10-12T13:24:50-04:00 Jared Samet: CFG Grammar (#6)
803 fea4e4b 2016-10-08T11:42:39-04:00 GitHub: There is no need to constantly build all
    branches. (#2)
804 7a5ccfc 2016-10-08T11:31:31-04:00 Nigel Schuster: Added greeting and newlines (#4)
805 10b17f7 2016-10-08T11:31:08-04:00 GitHub: Imported microc (#5)
806 726456f 2016-09-20T09:45:07-04:00 Nigel Schuster: [test] Add sample greeting to repo
    (#3)
807 9a2183d 2016-09-15T18:44:00-04:00 Nigel Schuster: Added merlin config
808 163e176 2016-09-14T18:51:53-04:00 Nigel Schuster: Moved whole build to script
809 d401eea 2016-09-14T18:43:58-04:00 Nigel Schuster: Added oasis opam package
810 ba7fd9c 2016-09-14T18:38:58-04:00 Nigel Schuster: Added ocaml configure (maybe this
    helps travis)
811 a461eae 2016-09-14T18:26:10-04:00 Nigel Schuster: Configuring opam environment for
    travis
812 ba2df2f 2016-09-14T18:19:26-04:00 Nigel Schuster: Added ocaml native compiler to apt
    package list
813 a8e5958 2016-09-14T17:24:36-04:00 Nigel Schuster: Added some more (possibly necessary
    opam packages
814 c54f5e3 2016-09-14T17:18:32-04:00 Nigel Schuster: Missed opam option

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815 b10adf0 2016-09-14T17:13:57-04:00 Nigel Schuster: Fixed opam install
816 124f7f3 2016-09-14T17:08:09-04:00 Nigel Schuster: Fixed YML error
817 4909fa8 2016-09-14T17:03:54-04:00 Nigel Schuster: Using avsm source
818 4b24046 2016-09-14T16:58:33-04:00 Nigel Schuster: Allow sudo
819 e7b50db 2016-09-14T16:56:57-04:00 Nigel Schuster: Fixed setup order
820 f6d7ac4 2016-09-14T16:50:02-04:00 Nigel Schuster: Manually installing apt packages
821 f4084ab 2016-09-14T16:40:55-04:00 Nigel Schuster: Test commit
822 d7c5e9a 2016-09-14T13:15:43-04:00 Nigel Schuster: Initial commit
```

10. Special Thanks

We'd like to thank Bruce Verderaime for the [gdchart](#) library, which we modified and shipped to provide Extend with graph plotting functionality. Additionally, we'd like to credit Thomas Boutell for the `gd` library, on which `gdchart` relies. The copyright notice is in the repository.