

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 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     return print_endline("Hello, World!");  
3 }
```

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  }
```

The next file compiles, but might surprise you by not printing anything.

```
1  main(args) {
2      foo := "Hello World!";    // Formula assigned, never evaluated
3      bar := print_endline(foo); // Formula assigned, never evaluated
4      return 0;                 // Return expression is just 0
5  }
```

And this file isn't a grammatical Extend program:

```
1  main(args) {
2      foo := "Hello World!"; // OK
3      print_endline(foo);    // Syntax error – not a declaration or assignment
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, declared with the usual syntax **f(x, y, ...)**. Each Extend program must have a **main()** function taking one argument, as shown above in "Hello World". Inside the function, this parameter will contain the command-line arguments. A function is composed of variable declarations and formula assignments and concludes with the **return** statement. It can return a value of any of the types discussed below, and it doesn't always need to return the same type. Note that the **return** statement is always the last statement in the function.

Data Types

Extend has three primitive data types: Number, String, 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() { return 7; }
2
3      howBig() { return 11; }
4
5      foo_func() {
6          [1,howBig()] foo;
7          foo[0, :breakpoint()] = "left";
8          foo[0, breakpoint():-1] = "right";
9          foo[0, -1] = "last";
10         return foo;
11     }
```

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. 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. A subtle point 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 - Similar, but not the same

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.

Function Parameters - Using Dimensions

Function arguments can be signed with dimensions. You can use these in two different ways, depending on what your function is doing. As a convenient way to find out the size of a range argument, just give the dimensions names:

```
1     foo([m,n] arg){
2         return m * n; // m and n initialized through arg
3     }
```

You can hardcode dimensions; if your function is called with a range whose dimensions don't match, a runtime error will occur:

```
1     determinant([2,2] arg){
2         return arg[0,0] * arg[1,1] - arg[0,1] * arg[1,0];
3     }
```

You can also combine these two mechanisms, by repeating a variable name:

```
1     betterBeSameSize([m,n] arg1, [m,n] arg2) {
2         return "I guess they were the same size."; // Error if they were different
3     }
```

Enough theory. Show me a function that does something!

This function adds its two arguments.

```
1     add(x, y) {
2         return x + y;
3     }
```

Come on, a real function.

```
1     euclideanDistance([1,2] ptA, [1,2] ptB) {
2         return sqrt((ptA[0] - ptB[0]) ** 2 + (ptA[1] - ptB[1]) ** 2);
3     }
```

Tell me about that bit where you wrote ptA[0]!

Range Slicing & Selection

The euclideanDistance() function above used a selection to extract the individual values from a range. ptA[0] is the first value of ptA and ptA[1] is the second value. Although ranges have rows and columns, you only need to give one index if a range is a vector—Extend will figure out what you mean. You can also get a slice, with essentially the same syntax as Python:

```
1     addTheFirstThreeElements([1,n] some_vector) {
2         return sum(some_vector[:3]);
3     }
```

If you're dealing with a 2-D range, you can get a rectangle by slicing both the rows and the columns.

```
1     topLeftCorner(m) {
2         return m[:2,:2] // Returns a 2x2 range with m[0,0], m[0,1], m[1,0], m[1,1]
3     }
```


How is this like a spreadsheet?

Here's the Extend equivalent of this spreadsheet:

	A	B	C	D	E
1		Revenue	Cost	Profit	
2	Q1	\$82,500	\$80,000	\$2,500 =B2-C2	
3	Q2	\$97,800	\$105,000	-\$7,200 =B3-C3	
4	Q3	\$560,000	\$130,000	\$430,000 =B4-C4	

```
1  calcProfit([n,1] revenue, [n,1] cost) {
2    [n,1] profit := revenue[[0]] - cost[[0]];
3    return profit;
4  }
5  main(args) {
6    revenue := {82500; 97800; 560000};
7    cost := {80000; 105000; 130000};
8    profit := calcProfit(revenue, cost);
9    return print_endline(profit);
10 }
```

Writing `revenue[[0]]` and `cost[[0]]` instead of `revenue[0]` and `cost[0]` means that the *n*th cell of profit is calculated by subtracting the *n*th cells of cost from the *n*th cell of revenue; the number inside the brackets gets added to the row index of the left-hand-side cell. Here's how to calculate the change in profits from one quarter to the next:

A	B	C	D
	Profit	Profit Growth	
Q1	\$2,500		
Q2	-\$7,200	-\$9,700 =B3-B2	
Q3	\$430,000	\$437,200 =B4-B3	

```
1  calcProfitGrowth([n,1] profits) {
2    [n,1] profitGrowth := profits[[0]] - profits[[-1]];
3    return profitGrowth;
4  }
5  main(args) {
6    profits := {2500; -7200; 430000};
7    return print_endline(calcProfitGrowth(profits));
8  }
```

Don't worry about the first cell - it'll be **empty**, not a program-ending `ArrayIndexOutOfBoundsException`. The selection syntax is very flexible; you can mix and match absolute and relative indexes and slices and omit the ones you don't need. There's a lot more examples in the language reference manual, but hopefully that should get you started! There's just one more special way you should know about to make a selection, since it's probably the most common selection you'll need.

The Hash Operator

The hash operator gets the cell that's in "the equivalent place" of the cell whose formula is being calculated. Here's the quick way to add two matrices:

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

And here's one more example to show its flexibility, with the spreadsheet equivalent:

	A	B	C	D
1		1	2	3
2	10	11	12	13
3	20	21	22	23
4	30	31	32	33

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

If you call `hashAdd` with `{1,2,3}` as the first argument and `{10;20;30}` as the second argument, your result will be the matrix in the image. Enjoy making selections!

Cell Evaluation, Side Effects, and Precedence Expressions

It's time for a little more theory. 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, if a cell formula calls a function with side effects, it's important to keep in mind that it will only be evaluated once for each cell with that formula.

Another feature related to side effects is the precedence expression. If you want to call a function such as `print_endline()` for its side effects, but don't want it to be your return statement, you can use a precedence expression (written with the `->` operator) to force the evaluation of one expression before another. For example, to display a prompt before asking the user for input, you could write:

```
1 speed := print_endline("What is the air-speed velocity of an unladen swallow?")  
2       -> readline(STDIN);
```

A precedence expression calculates the first expression, discards the result, and evaluates to the second expression. Putting it all together, 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 "Where am I?" operators

Extend has the `row()` and `column()` functions, which respectively return the row and column of the left-hand-side cell whose formula is being calculated.

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 predicate is always evaluated; only one of `expr_if_true` or `expr_if_false` will be evaluated—or neither, if the predicate is `empty`.

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"
```

2.4 Illustrating the Benefits of Extend

Excel and Google Sheets are pretty easy to use. Why go to all this trouble? 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.

2.5 Standard Library Functions

Extend offers an assortment of standard library functions. The standard library is automatically imported into each Extend program.

A complete listing can be found in the Language Reference Manual; 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
        characters from test_file.txt to stdout
3   }
```

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 a immutable primitive value that is internally represented 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
14  foo[[1]:[2], 0:[7]]
15  /* Selects the rows between the 1st and 2nd row after LHS row, and
16     all the columns up to the 7th column to the right of the LHS column */
17
18  /* In this example, each cell of bar would be equal to the cell
19     * in foo in the equivalent location plus 1. */
20  [5,5] foo;
21  [5,5] bar := #foo + 1; // #foo = foo[[0],[0]]
22
23  /* In this example, bar would be a 3x5 range where in each row,
24     * the value in bar is equal to the value in foo in the same column.
25     * In other words, each row of bar would be a copy of foo. */
26  [1,5] foo; // foo has 1 row, 5 columns
27  [3,5] bar := #foo; // #foo = foo[0,[0]]
28
29  /* In this example, the values of baz would be
30     * 11, 12, 13 in the first row;
31     * 21, 22, 23 in the second row;
32     * 31, 32, 33 in the third row. */
33  foo := {1,2,3}; // 1 row, 3 columns
34  bar := {10;20;30}; // 3 rows, 1 column
35  [3,3] baz := #foo + #bar; // Equivalent to foo[0,[0]] + bar[[0],0]
36 }
```


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  }

```

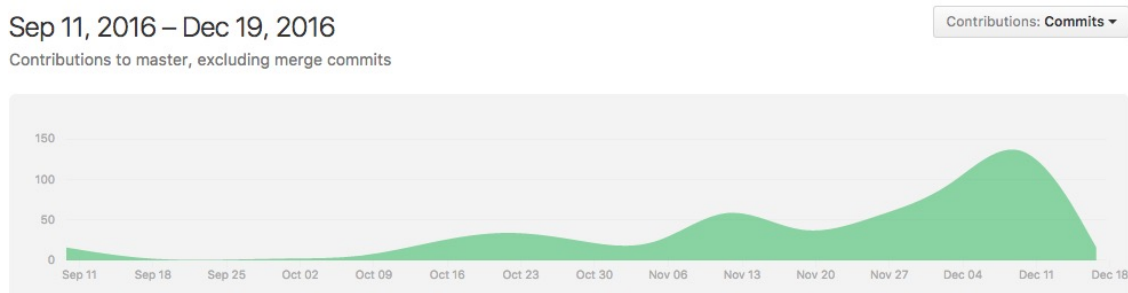
4. Project Plan

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.

Style Guide

None of the team members had any prior experience with Ocaml. Fundamentally we were developing a certain style in the process of creating the project. A few style choices were clear soon after starting to develop in Ocaml:

- Avoid deep nesting of functions
- Instead build better abstraction and reuse functions
- Use **let ... in** instead of **and**. While this creates a lot of closures, it helped us to develop quicker by not needing to restructure code for changes
- Use underscore for values you won't use any further. Llvm code generation inherently creates a lot of values where the return value is of no use. Therefore mark those return values with an underscore, since it hides the warning.
- Indent with spaces, not tabs. Indent by 2 for each level of nesting.
- Make intentions clear by naming return values, not by naming LLVM intermediate values.

These few rules helped us to control our code very well.

Further we were developing our runtime in C. We applied the following style rules:

- Indent with tabs.
- Stick to C99.
- Use **value_p** for user facing functions.
- Make sure to exit gracefully.

4.3 Language Evolution

Looking back at our original proposal, the language we delivered ended up surprisingly close. The biggest change was to allow strings and ranges as value types, which made the language immeasurably better. Initially, we wanted to only have Numbers; but allowing cells to contain ranges (composite values) and not just primitive values makes it a much more useful language. Otherwise, the syntax and semantics are very close to what was in our original proposal.

Our initial plan was to precalculate the dependencies among cells as best as possible at compile time and generate code accordingly. However, it quickly became clear that the language was better with runtime-determined cell dependencies and we therefore had to give up on a precomputed graph. We didn't have time in this class to implement an explicit stack as opposed to using recursion, but this could be overcome if it had to be.

Another fairly minor change was to eliminate the dimension signature for functions. As we played around with the language in the interpreter, it became clear that we weren't using them and it wasn't obvious why we would; they were dropped as a result.

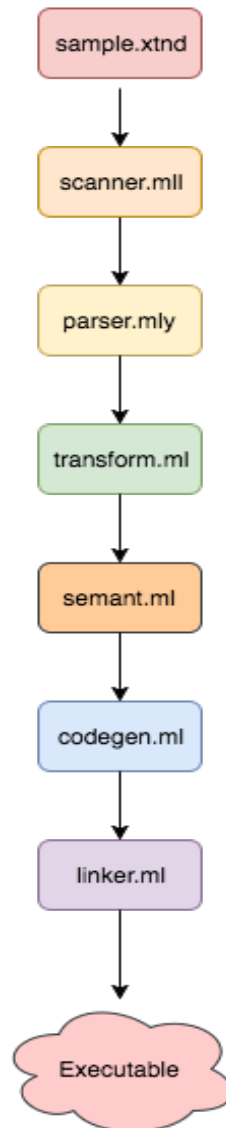
The Interpreter

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.

4.4 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 `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 | "debug"     { DEBUG }
71 | digit+ as lit { LIT_INT(int_of_string lit) }
72 | flt as lit   { LIT_FLOAT(float_of_string lit) }
73 | id as lit    { ID(lit) }
74 | eof          { EOF }
75 | _           { syntax_error lexbuf }
76
77 and multiline_comment = parse
78   "*/" { token lexbuf }
79 | '\n' { new_line lexbuf; multiline_comment lexbuf }
80 | _    { multiline_comment lexbuf }
81
82 and oneline_comment = parse
83   '\n' { new_line lexbuf; token lexbuf }
84 | _    { oneline_comment lexbuf }
85
86 (* read_string mostly taken from:
87 https://realworldocaml.org/v1/en/html/parsing-with-ocamllex-and-menhir.html *)
88 and read_string buf =
89   parse
90   | '"'       { LIT_STRING (Buffer.contents buf) }
91   | '\n'      { new_line lexbuf; Buffer.add_char buf '\n'; read_string buf lexbuf }
92   | '\\\' 'n' { Buffer.add_char buf '\n'; read_string buf lexbuf }
93   | '\\\' 'r' { Buffer.add_char buf '\r'; read_string buf lexbuf }
94   | '\\\' 't' { Buffer.add_char buf '\t'; read_string buf lexbuf }
95   | '\\\' ([^'\\\' 'n' 'r' 't'] as lxm)
96   | { Buffer.add_char buf lxm; read_string buf lexbuf }

```

```

97 | [^ ' " ' \ \ ' ]+
98 | { Buffer.add_string buf (Lexing.lexeme lexbuf);
99 |   read_string buf lexbuf
100 | }
101 | _ { syntax_error lexbuf }
102 | 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 DEBUG
16 %token <int> LIT_INT
17 %token <float> LIT_FLOAT
18 %token <string> LIT_STRING
19 %token <string> ID
20 %token EOF
21
22 %right QUESTION
23 %left PRECEDES
24 %left LOGOR
25 %left LOGAND
26 %left EQ NOTEQ LT GT LTEQ GTEQ
27 %left PLUS MINUS BITOR BITXOR
28 %left TIMES DIVIDE MOD LSHIFT RSHIFT BITAND
29 %right POWER
30 %right BITNOT LOGNOT NEG
31 %left LSQBRACK
32
33 %start program
34 %type <Ast.raw_program> program
35
36 %%
37
38 program:
39     program_piece EOF { let (imp, glob, fnc, ext) = $1 in (List.rev imp, List.rev
40         glob, List.rev fnc, List.rev ext) }
41
42 program_piece:
43     /* nothing */ { ([], [], [], []) }
44     | program_piece import { let (imp, glob, fnc, ext) = $1 in ($2 :: imp, glob,
45         fnc, ext) }
46     | program_piece global { let (imp, glob, fnc, ext) = $1 in (imp, $2 :: glob,

```

```

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

```



```

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

```

```

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

```

```

209
210 lhs_sel:
211     /* nothing */ { (None, None) }
212 /* commented out: LSQBRACK lslice RSQBRACK { (Some $2, None) } */
213 | LSQBRACK lslice COMMA lslice RSQBRACK { (Some $2, Some $4) }
214
215 rhs_sel:
216     LSQBRACK rslice RSQBRACK { (Some $2, None) }
217 | LSQBRACK rslice COMMA rslice RSQBRACK { (Some $2, Some $4) }
218
219 lslice:
220 /* commented out: nothing production { (None, None) } */
221     lslice_val { (Some $1, None) }
222 | lslice_val COLON lslice_val { (Some $1, Some $3) }
223 | lslice_val COLON { (Some $1, Some DimensionEnd) }
224 | COLON lslice_val { (Some DimensionStart, Some $2) }
225 | COLON { (Some DimensionStart, Some DimensionEnd) }
226
227 rslice:
228     /* nothing */ { (None, None) }
229 | rslice_val { (Some $1, None) }
230 | rslice_val COLON rslice_val { (Some $1, Some $3) }
231 | rslice_val COLON { (Some $1, Some DimensionEnd) }
232 | COLON rslice_val { (Some DimensionStart, Some $2) }
233 | COLON { (Some DimensionStart, Some DimensionEnd) }
234
235 lslice_val:
236     expr { Abs($1) }
237
238 rslice_val:
239     expr { Abs($1) }
240 | LSQBRACK expr RSQBRACK { Rel($2) }
241
242 func_param_list:
243     /* nothing */ { [] }
244 | func_param_int_list { List.rev $1 }
245
246 func_param_int_list:
247     func_sin_param { [$1] }
248 | func_param_int_list COMMA func_sin_param { $3 :: $1 }
249
250 func_sin_param:
251     ID { ((None, None), $1) }
252 | dim ID { ($1, $2) }
253
254 dim:
255     LSQBRACK expr RSQBRACK { (Some $2, None) }
256 | 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                Debug of expr
21 and index      = Abs of expr |
22                Rel of expr |
23                DimensionStart |
24                DimensionEnd
25 and slice      = index option * index option
26 and sel        = slice option * slice option
27 and case       = expr list * expr
28
29 type dim       = expr option * expr option
30 type var       = dim * string
31 type assign    = string * sel * expr option
32 type init      = string * expr option
33 type stmt      = Assign of assign |
34                Varinit of dim * init list
35
36 type raw_func = {
37   name: string;
38   params: var list;
39   body: stmt list;
40   raw_asserts: expr list;
41   ret_val: dim * expr;
42 }
43
44 type extern_func = {
45   extern_fn_name: string;
46   extern_fn_params: var list;
47   extern_fn_libname: string;
48   extern_ret_val: dim;
49 }
50
51 type library    = Library of string * extern_func list
52 type raw_program = string list * stmt list * raw_func list * library list
53
54 (* Desugared types below *)
55 module StringMap = Map.Make(String)
56 type formula    = {
57   formula_row_start: index;
58   formula_row_end: index option;
59   formula_col_start: index;
60   formula_col_end: index option;

```

```

61   formula_expr: expr;
62 }
63
64 type dim_expr = DimOneByOne
65   | DimId of string
66
67 type variable = {
68   var_rows: dim_expr;
69   var_cols: dim_expr;
70   var_formulas: formula list;
71 }
72
73 type func_decl = {
74   func_params: var list;
75   func_body: variable StringMap.t;
76   func_asserts: expr list;
77   func_ret_val: dim * expr;
78 }
79
80 type program = (variable StringMap.t) * (func_decl StringMap.t) * (extern_func
  StringMap.t)
81
82 type listable = Inits of init list |
83   Vars of var list |
84   Stmts of stmt list |
85   RawFuncs of raw_func list |
86   Externs of extern_func list |
87   Libraries of library list |
88   Exprs of expr list |
89   Rows of (expr list) list |
90   Strings of string list |
91   Cases of case list |
92   Formulas of formula list
93
94 exception IllegalRangeLiteral of string
95 exception TransformedAway of string
96
97 let quote_string str =
98   let escape_characters = Str.regexp "[\n \t \r \\ \"]" in
99   let replace_fn s = match Str.matched_string s with
100     "\n" -> "\\n"   |
101     "\t" -> "\\t"   |
102     "\r" -> "\\r"   |
103     "\\\" -> "\\\\"  |
104     "\"" -> "\\\""  |
105     _      -> Str.matched_string s in
106   "\"" ^ Str.global_substitute escape_characters replace_fn str ^ "\""
107
108 let string_of_op o = "\"" ^ (match o with
109   Plus -> "+" | Minus -> "-" | Times -> "*" | Divide -> "/" | Mod -> "%" | Pow ->
    "**" |
110   LShift -> "<<" | RShift -> ">>" | BitOr -> "|" | BitAnd -> "&" | BitXor -> "^" |
111   Eq -> "==" | Gt -> ">" | GtEq -> ">=" | Lt -> "<" | LtEq -> "<=" |
112   LogAnd -> "&&" | LogOr -> "||" ) ^ "\""
113
114 let string_of_unop = function

```

```

115     Neg -> "\"-\"" | LogNot -> "\"!\\"" | BitNot -> "\"~\"" | Truthy -> "\"truthy\"" |
116     SizeOf -> "\"size\"" | TypeOf -> "\"type\"" | Row -> "\"row\"" | Column -> "\"
        column\""
117
118 let rec string_of_expr = function
119     LitInt(l) ->         "{\\"LitInt\\": " ^ string_of_int l ^ "}"
120   | LitFlt(l) ->         "{\\"LitFlt\\": " ^ string_of_float l ^ "}"
121   | LitString(s) ->      "{\\"LitString\\": " ^ quote_string s ^ "}"
122   | LitRange(rowlist) -> "{\\"LitRange\\": " ^ string_of_list (Rows rowlist) ^ "}"
123   | Id(s) ->             "{\\"Id\\": " ^ quote_string s ^ "}"
124   | Empty ->             "\\Empty\\"
125   | BinOp(e1, o, e2) ->  "{\\"BinOp\\": { " ^
126                           "\\expr1\\": " ^ string_of_expr e1 ^ ", " ^
127                           "\\operator\\": " ^ string_of_op o ^ ", " ^
128                           "\\expr2\\": " ^ string_of_expr e2 ^ " } }"
129   | UnOp(o, e) ->        "{\\"UnOp\\": { " ^
130                           "\\operator\\": " ^ string_of_unop o ^ ", " ^
131                           "\\expr\\": " ^ string_of_expr e ^ " } }"
132   | Ternary(c, e1, e2) -> "{\\"Ternary\\": { " ^
133                           "\\condition\\": " ^ string_of_expr c ^ ", " ^
134                           "\\ifExpr\\": " ^ string_of_expr e1 ^ ", " ^
135                           "\\elseExpr\\": " ^ string_of_expr e2 ^ " } }"
136   | ReducedTernary(s1, s2, s3) -> "{\\"ReducedTernary\\": { " ^
137                                   "\\truthiness\\": " ^ quote_string s1 ^ ", " ^
138                                   "\\true_values\\": " ^ quote_string s2 ^ ", " ^
139                                   "\\false_values\\": " ^ quote_string s3 ^ " } }"
140   | Switch(eo, cases, dflt) -> "{\\"Switch\\": { " ^
141                                   "\\condition\\": " ^
142                                   (match eo with None -> "null" | Some e ->
                                    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   | Debug(e) -> string_of_expr e
156
157 and string_of_case (el, e) =
158     "{\\"Cases\\": " ^ string_of_list (Exprs el) ^ ", " ^
159     "\\expr\\": " ^ string_of_expr e ^ "}"
160
161 and string_of_sel (s1, s2) =
162     "{\\"slice1\\": " ^ string_of_slice s1 ^ ", \\"slice2\\": " ^ string_of_slice s2 ^ "}"
163
164 and string_of_slice = function
165     None -> "null"
166     | Some (start_idx, end_idx) -> "{\\"start\\": " ^ string_of_index start_idx ^ ", \\"end
        \": " ^ string_of_index end_idx ^ "}"

```

```

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

```

```

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

```



```

276 let rec check_range_literal rl =
277   List.for_all (fun exprs -> List.for_all check_basic_expr exprs) rl
278 and check_basic_expr = function
279   LitInt(_) | UnOp(Neg, LitInt(_)) | LitFlt(_) | UnOp(Neg, LitFlt(_)) |
     LitString(_) | Empty -> true
280   | LitRange(rl) -> check_range_literal rl
281   | _ -> false in
282
283   if check_range_literal rowlist then LitRange(rowlist)
284   else raise(IllegalRangeLiteral(string_of_expr (LitRange(rowlist))))
285 | 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
37     in
38     (* 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_extns) (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 ^ "
64       not allowed in " ^ expr_loc))
65     | LitRange(rl) -> raise (IllegalExpression("Range literal " ^ string_of_list (Rows
66       rl) ^ " not allowed in " ^ expr_loc))
67     | e -> let new_id = idgen expr_loc in (
68       Id(new_id),
69       [Varinit (one_by_one, [(new_id, None)]];
70       Assign (new_id, zero_comma_zero, Some e)]) in
71
72   let expand_index index_loc = function
73     (* Expand one index of a slice if necessary. *)
74     | Abs(e) -> let (new_e, new_stmts) = expand_expr index_loc e in
75     (Abs(new_e), new_stmts)
76     | DimensionStart -> (DimensionStart, [])
77     | DimensionEnd -> (DimensionEnd, [])
78     | Rel(_) -> raise (IllegalExpression("relative - this shouldn't be possible")) in
79
80   let expand_slice slice_loc = function
81     (* Expand one or both sides as necessary. *)
82     | None -> (entire_dimension, [])
83     | Some (Some (Abs(e)), None) ->
84       let (start_e, start_stmts) = expand_expr (slice_loc ^ "_start") e in
85       ((Some (Abs(start_e)), None), start_stmts)
86     | Some (Some idx_start, Some idx_end) ->
87       let (new_start, new_start_exprs) = expand_index (slice_loc ^ "_start") idx_start
88       in
89       let (new_end, new_end_exprs) = expand_index (slice_loc ^ "_end") idx_end in

```

```

86      ((Some new_start, Some new_end), new_start_exprs @ new_end_exprs)
87      | Some (Some _, None) | Some (None, _) -> raise (IllegalExpression("Illegal slice
      - this shouldn't be possible")) in
88
89  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
              ") row_slice in
96          let (new_col_slice, col_exprs) = expand_slice (asgn_loc ^ "_" ^ var_name ^ "_col
              ") col_slice in
97          Assign(var_name, (Some new_row_slice, Some new_col_slice), formula) :: (
              row_exprs @ col_exprs)
98      with IllegalExpression(s) ->
99          raise (IllegalExpression("Illegal expression (" ^ s ^ ") in " ^
100              string_of_assign (var_name, (row_slice, col_slice),
              formula))) in
101
102  let expand_init (r, c) (v, e) =
103      Varinit((Some r, Some c), [(v, None)]) ::
104      match e with
105      None -> []
106      | Some e -> [Assign (v, entire_range, Some e)] in
107
108  let expand_dimension dim_loc = function
109      None -> expand_expr dim_loc (LitInt(1))
110      | Some e -> expand_expr dim_loc e in
111
112  let expand_varinit fname ((row_dim, col_dim), inits) =
113      (* expand_varinit: Take a Varinit and return a list of more atomic
114         statements. Each dimension will be given a temporary ID, which
115         will be declared as [1,1] _tmpXXX; the formula for tmpXXX will be
116         set as a separate assignment; the original variable will be
117         declared as [_tmpXXX, _tmpYYY] var; and the formula assignment
118         will be applied to [(:, :)]. *)
119      try
120          let (row_e, row_stmts) = expand_dimension (fname ^ "_" ^ (String.concat "_" (
              List.map fst inits)) ^ "_row_dim") row_dim in
121          let (col_e, col_stmts) = expand_dimension (fname ^ "_" ^ (String.concat "_" (
              List.map fst inits)) ^ "_col_dim") col_dim in
122          row_stmts @ col_stmts @ List.concat (List.map (expand_init (row_e, col_e)) inits
              )
123      with IllegalExpression(s) ->
124          raise (IllegalExpression("Illegal expression (" ^ s ^ ") in " ^
125              string_of_varinit ((row_dim, col_dim), inits))) in
126
127  let expand_stmt fname = function
128      Assign(a) -> expand_assign fname a
129      | Varinit(d, inits) -> expand_varinit fname (d, inits) in
130
131  let expand_stmt_list fname stmts = List.concat (List.map (expand_stmt fname) stmts)
132      in

```

```

133 let expand_params fname params =
134   let needs_sizevar = function
135     ((None, None), _) -> false
136     | _ -> true in
137   let params_with_sizevar = List.map (fun x -> (idgen (fname ^ "_" ^ (snd x) ^ "
138     _size"), x)) (List.filter needs_sizevar params) in
139   let expanded_args = List.map (fun (sv, ((rv, cv), s)) -> ((sv, s), [((sv, abs_zero
140     ), rv); ((sv, abs_one), cv)])) params_with_sizevar in
141   let (sizes, inits) = (List.map fst expanded_args, List.concat (List.map snd
142     expanded_args)) in
143   let add_item (varset, (assertlist, initlist)) ((sizevar, pos), var) =
144     (match var with
145     Some Id(s) ->
146       if StringSet.mem s varset then
147         (* We've seen this variable before; don't initialize it, just assert it *)
148         (varset, (BinOp(Id(s), Eq, Selection(Id(sizevar), (Some(Some(pos), None),
149           None))) :: assertlist, initlist))
150       else
151         (* We're seeing a string for the first time; don't assert it, just create
152           it *)
153         (StringSet.add s varset, (assertlist,
154           Assign(s, zero_comma_zero, Some (Selection(Id(
155             sizevar), (Some(Some(pos), None), None)))) ::
156           Varinit(one_by_one, [(s, None)]) ::
157           initlist))
158     | Some LitInt(i) -> (* Seeing a number; don't do anything besides create an
159       assertion *)
160       (varset, (BinOp(LitInt(i), Eq, Selection(Id(sizevar), (Some(Some(pos), None),
161         None))) :: assertlist, initlist))
162     | Some e -> raise (IllegalExpression("Illegal expression (" ^ string_of_expr e
163       ^ ") in function signature"))
164     | _ -> raise (IllegalExpression("Cannot supply a single dimension in function
165       signature"))) in
166   let (rev_assertions, rev_inits) = snd (List.fold_left add_item (StringSet.empty,
167     ([], [])) inits) in
168   let create_sizevar (sizevar, arg) = [
169     Varinit(one_by_one, [(sizevar, None)]);
170     Assign(sizevar, entire_range, Some(UnOp(SizeOf, Id(arg))))] in
171   (List.concat (List.map create_sizevar sizes), List.rev rev_assertions, List.rev
172     rev_inits) in
173
174 let expand_function f =
175   let (new_sizevars, assertions, size_inits) = expand_params f.name f.params in
176   let new_retval_id = idgen (f.name ^ "_retval") in
177   let new_retval = Id(new_retval_id) in
178   let retval_inits = [Varinit (one_by_one, [(new_retval_id, None)]);
179     Assign (new_retval_id, zero_comma_zero, Some (snd f.ret_val))]
180     in
181   let new_assert_id = idgen (f.name ^ "_assert") in
182   let add_assert al a = BinOp(al, LogAnd, a) in
183   let new_assert_expr = List.fold_left add_assert (LitInt(1)) assertions in
184   let new_assert = Id(new_assert_id) in
185   let assert_inits = [Varinit (one_by_one, [(new_assert_id, None)]);
186     Assign (new_assert_id, zero_comma_zero, Some new_assert_expr)]
187     in
188   {

```

```

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;

```

```

226     }) in
227
228     let tupleize_library (Library(lib_name, lib_fns)) =
229         List.map (fun ext_fn -> (ext_fn.extern_fn_name, {ext_fn with extern_fn_libname =
230             lib_name})) lib_fns in
231
232     (vds_of_stmts globals,
233      map_of_list (List.map fd_of_raw_func functions),
234      map_of_list (List.concat (List.map tupleize_library externs)))
235
236 let single_formula e = {
237     formula_row_start = DimensionStart;
238     formula_row_end = Some DimensionEnd;
239     formula_col_start = DimensionStart;
240     formula_col_end = Some DimensionEnd;
241     formula_expr = e;
242 }
243
244 let ternarize_exprs (globals, functions, externs) =
245     let rec ternarize_expr lhs_var = function
246         BinOp(e1, LogAnd, e2) ->
247             let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
248             let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
249             (Ternary(UnOp(Truthy, new_e1), UnOp(Truthy, new_e2), LitInt(0)), new_e1_vars @
250                 new_e2_vars)
251         | BinOp(e1, LogOr, e2) ->
252             let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
253             let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
254             (Ternary(UnOp(Truthy, new_e1), LitInt(1), UnOp(Truthy, new_e2)), new_e1_vars @
255                 new_e2_vars)
256         | BinOp(e1, op, e2) ->
257             let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
258             let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
259             (BinOp(new_e1, op, new_e2), new_e1_vars @ new_e2_vars)
260         | UnOp(op, e) ->
261             let (new_e, new_e_vars) = ternarize_expr lhs_var e in
262             (UnOp(op, new_e), new_e_vars)
263         | Ternary(cond, e1, e2) ->
264             let (new_cond, new_cond_vars) = ternarize_expr lhs_var cond in
265             let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
266             let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
267             (Ternary(new_cond, new_e1, new_e2), new_cond_vars @ new_e1_vars @ new_e2_vars)
268         | Call(fname, args) ->
269             let new_args_and_vars = List.map (ternarize_expr lhs_var) args in
270             (Call(fname, (List.map fst new_args_and_vars)), List.concat (List.map snd
271                 new_args_and_vars))
272         | Selection(e, (s11, s12)) ->
273             let (new_e, new_e_vars) = ternarize_expr lhs_var e in
274             let (new_s11, new_s11_vars) = ternarize_slice lhs_var s11 in
275             let (new_s12, new_s12_vars) = ternarize_slice lhs_var s12 in
276             (Selection(new_e, (new_s11, new_s12)), new_e_vars @ new_s11_vars @ new_s12_vars)
277         | Precedence(e1, e2) ->
278             let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
279             let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
280             (Precedence(new_e1, new_e2), new_e1_vars @ new_e2_vars)
281         | 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)
292 | None ->
293   (None, [])
294 ) in
295 let new_cases_and_vars = List.map (ternarize_case lhs_var new_cond_expr) cases in
296 let new_cases = List.map fst new_cases_and_vars in
297 let new_case_vars = List.concat (List.map snd new_cases_and_vars) in
298 let (new_dflt, new_dflt_vars) = ternarize_expr lhs_var dflt in
299 let rec combine_everything = function
300   [] -> new_dflt
301   | (combined_cases, e) :: more_cases -> Ternary(combined_cases, e,
302     combine_everything more_cases) in
303 and ternarize_case lhs_var cond (conds, e) =
304   let new_conds_and_vars = List.map (ternarize_expr lhs_var) conds in
305   let new_conds = List.map fst new_conds_and_vars in
306   let new_cond_vars = List.concat (List.map snd new_conds_and_vars) in
307   let (new_e, new_e_vars) = ternarize_expr lhs_var e in
308   let unify_case_cond_and_switch_cond case_cond = function
309     None -> case_cond
310     | Some switch_cond -> BinOp(switch_cond, Eq, case_cond) in
311   let rec unify_switch_cond_and_case_conds switch_cond = function
312     [case_cond] -> unify_case_cond_and_switch_cond case_cond switch_cond
313     | case_cond :: case_conds ->
314       let (combined_expr, _) = ternarize_expr lhs_var
315         (BinOp(unify_case_cond_and_switch_cond case_cond switch_cond, LogOr,
316           unify_switch_cond_and_case_conds switch_cond case_conds)) in
317       combined_expr
317   | [] -> raise(LogicError("Empty case condition list")) in
318   ((unify_switch_cond_and_case_conds cond new_conds, new_e), new_cond_vars @
319     new_e_vars)
319 and ternarize_slice lhs_var = function
320   None -> (None, [])
321   | Some (i1, i2) ->
322     let (new_i1, new_i1_vars) = ternarize_index lhs_var i1 in
323     let (new_i2, new_i2_vars) = ternarize_index lhs_var i2 in
324     (Some (new_i1, new_i2), new_i1_vars @ new_i2_vars)
325 and ternarize_index lhs_var = function
326   Some Abs(e) ->
327     let (new_e, new_e_vars) = ternarize_expr lhs_var e in
328     (Some(Abs(new_e)), new_e_vars)
329   | Some Rel(e) ->

```

```

330     let (new_e, new_e_vars) = ternarize_expr lhs_var e in
331     (Some(Rel(new_e)), new_e_vars)
332 | i -> (i, []) in
333 let ternarize_formula lhs_var f =
334     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, (s11, s12)) ->
361         let (new_e, new_e_vars) = reduce_expr lhs_var e in
362         let (new_s11, new_s11_vars) = reduce_slice lhs_var s11 in
363         let (new_s12, new_s12_vars) = reduce_slice lhs_var s12 in
364         (Selection(new_e, (new_s11, new_s12)), new_e_vars @ new_s11_vars @ new_s12_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,
383      new_cond))]})) ::
384   (new_true_id, {lhs_vardef with var_formulas = [single_formula new_true_e]}) ::
385   (new_false_id, {lhs_vardef with var_formulas = [single_formula new_false_e]}) ::
386   (new_cond_vars @ new_true_vars @ new_false_vars))
387 and reduce_slice lhs_var = function
388   None -> (None, [])
389   | Some (i1, i2) ->
390     let (new_i1, new_i1_vars) = reduce_index lhs_var i1 in
391     let (new_i2, new_i2_vars) = reduce_index lhs_var i2 in
392     (Some (new_i1, new_i2), new_i1_vars @ new_i2_vars)
393 and reduce_index lhs_var = function
394   Some Abs(e) ->
395     let (new_e, new_e_vars) = reduce_expr lhs_var e in
396     (Some (Abs(new_e)), new_e_vars)
397   | Some Rel(e) ->
398     let (new_e, new_e_vars) = reduce_expr lhs_var e in
399     (Some (Rel(new_e)), new_e_vars)
400   | i -> (i, []) in
401 let reduce_formula lhs_var f =
402   let (new_expr, new_vars) = reduce_expr lhs_var f.formula_expr in
403   ({f with formula_expr = new_expr}, new_vars) in
404 let reduce_variable varname vardef =
405   let new_formulas_and_vars = List.map (reduce_formula (varname, vardef)) vardef.
406   var_formulas in
407   ({vardef with var_formulas = List.map fst new_formulas_and_vars}, List.concat (
408     List.map snd new_formulas_and_vars)) in
409 let reduce_variables fn_name m =
410   let new_variables_and_maps = StringMap.mapi (fun varname vardef -> reduce_variable
411     (fn_name ^ "_" ^ varname) vardef) m in
412   let add_item var_name (orig_var, new_vars) l = ((var_name, orig_var) :: fst l,
413     new_vars :: snd l) in
414   let combined_list = StringMap.fold add_item new_variables_and_maps ([],[]) in
415   map_of_list (List.rev (fst combined_list) @ List.concat (snd combined_list)) in
416 let reduce_function fn_name fn_def = {fn_def with func_body = reduce_variables
417   fn_name fn_def.func_body} in
418 (reduce_variables "global" globals, StringMap.mapi reduce_function functions,
419   externs)
420
421 let create_ast filename =
422   let ast_imp_res = expand_file true filename in
423   let ast_expanded = expand_expressions ast_imp_res in
424   let ast_mapped = create_maps ast_expanded in check_semantics ast_mapped ;
425   let ast_ternarized = ternarize_exprs ast_mapped in
426   let ast_reduced = reduce_ternaries ast_ternarized in check_semantics ast_reduced ;
427   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 " ^

```

```

53         string_of_int num_args ^ " arguments " ^ "but the signature
           specifies "
54         ^ string_of_int signature_args) ;
55     raise(WrongNumberArgs(context ^ "," ^ called_fname)))
56 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
   symbols e1 ; check_expr fname symbols e2
62 | ReducedTernary(s1, s2, s3) -> check_expr fname symbols (Id(s1)) ; check_expr
   fname symbols (Id(s2)) ; check_expr fname symbols (Id(s3))
63 | Id(s) -> if StringMap.mem s symbols then () else raise(UnknownVariable(fname ^
   "(): " ^ s))
64 | Switch(Some e, cases, dflt) -> check_expr fname symbols e ; List.iter (fun c ->
   check_case fname symbols c) cases ; check_expr fname symbols dflt
65 | Switch(None, cases, dflt) -> List.iter (fun c -> check_case fname symbols c)
   cases ; check_expr fname symbols dflt
66 | Call(called_fname, args) ->
67   check_call called_fname (List.length args) ;
68   List.iter (fun a -> check_expr fname symbols a) args
69 | Selection(e, (s11, s12)) -> check_expr fname symbols e ; check_slice fname
   symbols s11 ; check_slice fname symbols s12
70 | Precedence(e1, e2) -> check_expr fname symbols e1 ; check_expr fname symbols e2
71 | Debug(e) -> check_expr fname symbols e;
72 | LitInt(_) | LitFlt(_) | LitRange(_) | LitString(_) | Empty -> ()
73 and check_case fname symbols (conds, e) = List.iter (fun c -> check_expr fname
   symbols c) conds ; check_expr fname symbols e
74 and check_slice fname symbols = function
75   None -> ()
76 | Some (i1, i2) -> check_index fname symbols i1 ; check_index fname symbols i2
77 and check_index fname symbols = function
78   Some Abs(e) -> check_expr fname symbols e
79 | Some Rel(e) -> check_expr fname symbols e
80 | _ -> () in
81 let check_formula fname symbols f =
82   check_index fname symbols (Some f.formula_row_start) ;
83   check_index fname symbols f.formula_row_end ;
84   check_index fname symbols (Some f.formula_col_start) ;
85   check_index fname symbols f.formula_col_end ;
86   check_expr fname symbols f.formula_expr in
87 let check_dim fname symbols = function
88   DimOneByOne -> ()
89 | DimId(s) -> check_expr fname symbols (Id(s)) in
90 let check_variable fname symbols v =
91   check_dim fname symbols v.var_rows ;
92   check_dim fname symbols v.var_cols ;
93   List.iter (fun f -> check_formula fname symbols f) v.var_formulas in
94 let check_variables context symbols vars =
95   StringMap.iter (fun _ v -> check_variable context symbols v) vars in
96
97 let check_function fname f =
98   if StringMap.mem fname externs then raise(DuplicateDefinition(fname ^ "() is
   defined as both an external and local function")) else ();
99   let locals = f.func_body in

```

```

100   let params = List.map snd f.func_params in
101   List.iter
102     (fun param ->
103       if StringMap.mem param locals then raise(DuplicateDefinition(param ^ " is
104         defined multiple times in " ^ fname ^ "()"))
105       else ())
106     params ;
107   let local_symbols = create_symbol_table global_symbols f in
108   check_variables fname local_symbols f.func_body ;
109   check_expr fname local_symbols (snd f.func_ret_val)
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_def"
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 }
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 ])
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 ])
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 ])
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 ])
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 ])
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 ])
254 and _ = LlvM.struct_set_body dimensions_t (Array.of_list [int_t; int_t])
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 = LlvM.build_struct_gep struct_ptr elem "the_pointer" builder in
12     LlvM.build_load the_pointer val_name builder);;
13
14 let ($>) val_to_store (struct_ptr, elem) = (fun builder ->
15     let the_pointer = LlvM.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|];
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,

```

```

62  * and functions declared within Extend. *)
63  let declare_library_function fname func accum_map =
64    let llvm_ftype = LlvM.function_type base_types.value_p (Array.of_list (List.map (
        fun a -> base_types.value_p) func.extern_fn_params)) in
65    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.mapi 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.
150         float_t 0.0) in
151     let _ = LlvM.build_br merge_bb make_false_builder in
152
153     let (make_empty_bb, make_empty_builder) = make_block (blockprefix ^ "_empty") in
154     let _ = store_empty ret_val make_empty_builder in
155     let _ = LlvM.build_br merge_bb make_empty_builder in
156
157     (make_true_bb, make_false_bb, make_empty_bb, merge_builder) in
158
159 let rec build_expr old_builder exp = match exp with
160     LitInt(i) -> let vvv = LlvM.const_float base_types.float_t (float_of_int i) in
161     let ret_val = LlvM.build_malloc base_types.value_t "int_ret_val" old_builder
162         in
163     let _ = store_number ret_val old_builder vvv in
164     (ret_val, old_builder)
165 | LitFlt(f) -> let vvv = LlvM.const_float base_types.float_t f in
166     let ret_val = LlvM.build_malloc base_types.value_t "flt_ret_val" old_builder
167         in
168     let _ = store_number ret_val old_builder vvv in
169     (ret_val, old_builder)
170 | UnOp(Neg, LitInt(i)) -> build_expr old_builder (LitInt(-i))
171 | UnOp(Neg, LitFlt(f)) -> build_expr old_builder (LitFlt(-f))
172 | Empty ->
173     let ret_val = LlvM.build_malloc base_types.value_t "empty_ret_val" old_builder
174         in
175     let _ = store_empty ret_val old_builder in
176     (ret_val, old_builder)
177 | Debug(e) ->
178     let (ret_val, new_builder) = build_expr old_builder e in
179     let _ = LlvM.build_call (Hashtbl.find runtime_functions "debug_print") [|
180         ret_val; LlvM.const_pointer_null base_types.char_p|] "" new_builder in
181     (ret_val, new_builder)
182 | Id(name) ->
183     let create_and_deref_subrange appropriate_scope i =
184         let llvm_var = LlvM.build_call getVar [|appropriate_scope; LlvM.const_int
185             base_types.int_t i|] "llvm_var" old_builder in
186         let base_var_num_rows = (llvm_var => (var_instance_field_index Rows)) "
187             base_var_num_rows" old_builder in
188         let base_var_num_cols = (llvm_var => (var_instance_field_index Cols)) "
189             base_var_num_cols" old_builder in
190         let subrange_ptr = LlvM.build_alloca base_types.subrange_t "subrange_ptr"
191             old_builder in
192         let _ = (llvm_var $> (subrange_ptr, (subrange_field_index BaseRangePtr)))
193             old_builder in
194         let _ = ((LlvM.const_null base_types.int_t) $> (subrange_ptr, (
195             subrange_field_index BaseOffsetRow))) old_builder in
196         let _ = ((LlvM.const_null base_types.int_t) $> (subrange_ptr, (
197             subrange_field_index BaseOffsetCol))) old_builder in
198         let _ = (base_var_num_rows $> (subrange_ptr, (subrange_field_index
199             SubrangeRows))) old_builder in
200         let _ = (base_var_num_cols $> (subrange_ptr, (subrange_field_index
201             SubrangeCols))) old_builder in

```

```

188     (Llvm.build_call (Hashtbl.find runtime_functions "deref_subrange_p") [|
189         subrange_ptr|] "local_id_ret_val" old_builder, old_builder) in
190     (
191     match (try StringMap.find name symbols with Not_found -> raise(LogicError("
192         Something went wrong with your semantic analysis - " ^ name ^ " not found
193         "))) with
194     | LocalVariable(i) -> create_and_deref_subrange local_scope i
195     | GlobalVariable(i) -> create_and_deref_subrange global_scope i
196     | FunctionParameter(i) ->
197         let paramarray = (local_scope => (scope_field_type_index FunctionParams))
198             "paramarray" old_builder in
199         let param_addr = Llvm.build_in_bounds_gep paramarray [|Llvm.const_int
200             base_types.int_t i|] "param_addr" old_builder in
201         let param = Llvm.build_load param_addr "param" old_builder in
202         (Llvm.build_call (Hashtbl.find runtime_functions "clone_value") [|param|]
203             "function_param_ret_val" old_builder, old_builder)
204     | ExtendFunction(i) -> raise(LogicError("Something went wrong with your
205         semantic analysis - function " ^ name ^ " used as variable in RHS for " ^
206         varname))
207     )
208 | ReducedTernary(cond_var, true_var, false_var) ->
209     let get_llvm_var name getvar_builder =
210     match (try StringMap.find name symbols with Not_found -> raise(LogicError("
211         Something went wrong with your transformation - Reduced Ternary name " ^
212         name ^ " not found"))) with
213     | LocalVariable(i) -> Llvm.build_call getVar [|local_scope; Llvm.const_int
214         base_types.int_t i|] "llvm_var" getvar_builder
215     | GlobalVariable(i) -> Llvm.build_call getVar [|global_scope; Llvm.const_int
216         base_types.int_t i|] "llvm_var" getvar_builder
217     | _ -> raise(LogicError("Something went wrong with your transformation -
218         Reduced Ternary name " ^ name ^ " not a local or global variable")) in
219
220     let (empty_bb, empty_builder) = make_block "empty" in
221     let (not_empty_bb, not_empty_builder) = make_block "not_empty" in
222     let (truthy_bb, truthy_builder) = make_block "truthy" in
223     let (falsey_bb, falsey_builder) = make_block "falsey" in
224     let (merge_bb, merge_builder) = make_block "merge" in
225
226     let ret_val_addr = Llvm.build_alloca base_types.value_p "tern_ret_val_addr"
227         old_builder in
228     let cond_llvm_var = get_llvm_var cond_var old_builder in
229     let cond_val = Llvm.build_call getVal [|cond_llvm_var; cell_row; cell_col|] "
230         cond_val" old_builder in
231     let cond_val_type = (cond_val => (value_field_index Flags)) "cond_val_type"
232         old_builder in
233     let is_empty = Llvm.build_icmp Llvm.Icmp.Eq empty_type cond_val_type "is_empty
234         " old_builder in
235     let _ = Llvm.build_cond_br is_empty empty_bb not_empty_bb old_builder in
236
237     (* Empty basic block: *)
238     let ret_val_empty = Llvm.build_malloc base_types.value_t "tern_empty"
239         empty_builder in
240     let _ = store_empty ret_val_empty empty_builder in
241     let _ = Llvm.build_store ret_val_empty ret_val_addr empty_builder in
242     let _ = Llvm.build_br merge_bb empty_builder in

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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 =
        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"
            next_builder in
251          let _ = (idx_expr_val $> (rhs_idx_ptr, (rhs_index_field_index RhsExprVal))
            ) next_builder in
252          let _ = ((LlvM.const_int base_types.char_t (rhs_index_type_flags_const
            RhsIdxAbs)) $> (rhs_idx_ptr, (rhs_index_field_index RhsIndexType)))
            next_builder in
            (rhs_idx_ptr, next_builder)
253      | Rel(e) ->
254          let (idx_expr_val, next_builder) = build_expr idx_builder e in
255          let rhs_idx_ptr = LlvM.build_alloca base_types.rhs_index_t "idx_ptr"
            next_builder in
256          let _ = (idx_expr_val $> (rhs_idx_ptr, (rhs_index_field_index RhsExprVal))
            ) next_builder in
257          let _ = ((LlvM.const_int base_types.char_t (rhs_index_type_flags_const
            RhsIdxRel)) $> (rhs_idx_ptr, (rhs_index_field_index RhsIndexType)))
            next_builder in
            (rhs_idx_ptr, next_builder)
258      | DimensionStart ->
259          let rhs_idx_ptr = LlvM.build_alloca base_types.rhs_index_t "idx_ptr"
            idx_builder in
260          let _ = ((LlvM.const_pointer_null base_types.value_p) $> (rhs_idx_ptr, (
            rhs_index_field_index RhsExprVal))) idx_builder in
261          let _ = ((LlvM.const_int base_types.char_t (rhs_index_type_flags_const
            RhsIdxDimStart)) $> (rhs_idx_ptr, (rhs_index_field_index RhsIndexType))
            ) idx_builder in

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264         (rhs_idx_ptr, idx_builder)
265     | DimensionEnd ->
266         let rhs_idx_ptr = LlvM.build_alloca base_types.rhs_index_t "idx_ptr"
           idx_builder in
267         let _ = ((LlvM.const_pointer_null base_types.value_p) $> (rhs_idx_ptr, (
           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

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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
        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

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    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"
      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

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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)

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

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447         (ret_val, bbailout)
448     )
449     and build_simple_int_binop oppp int_builder =
450         (let ret_val = LlvM.build_malloc base_types.value_t "binop_minus_ret_val"
451           int_builder in
452         let _ = LlvM.build_store
453             (
454                 LlvM.const_int
455                 base_types.char_t
456                 (value_field_flags_index Empty)
457             ) (
458                 LlvM.build_struct_gep
459                 ret_val
460                 (value_field_index Flags)
461                 ""
462                 int_builder
463             )
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

```

```

        number_number "" int_builder) numnum_bb bailout int_builder in
497     (ret_val, bbailout)
498   ) in
499   let build_boolean_op numeric_comparator string_comparator int_builder =
500     let ret_val = LlvM.build_malloc base_types.value_t "binop_gt_ret_val"
        int_builder in
501     let (make_true_bb, make_false_bb, make_empty_bb, merge_builder) =
        make_truthiness_blocks "binop_eq" ret_val in
502
503     let (numnum_bb, numnum_builder) = make_block "numnum" in
504     let numeric_val_1 = (val1 => (value_field_index Number)) "number_one"
        numnum_builder in
505     let numeric_val_2 = (val2 => (value_field_index Number)) "number_two"
        numnum_builder in
506     let numeric_greater = LlvM.build_fcmp numeric_comparator numeric_val_1
        numeric_val_2 "numeric_greater" numnum_builder in
507     let _ = LlvM.build_cond_br numeric_greater make_true_bb make_false_bb
        numnum_builder in
508
509     let (strstr_bb, strstr_builder) = make_block "strstr" in
510     let str_p_1 = (val1 => (value_field_index String)) "string_one"
        strstr_builder in
511     let str_p_2 = (val2 => (value_field_index String)) "string_two"
        strstr_builder in
512     let char_p_1 = (str_p_1 => (string_field_index StringCharPtr)) "char_p_one"
        strstr_builder in
513     let char_p_2 = (str_p_2 => (string_field_index StringCharPtr)) "char_p_two"
        strstr_builder in
514     let strcmp_result = LlvM.build_call (Hashtbl.find runtime_functions "
        strcmp") [|char_p_1; char_p_2|] "strcmp_result" strstr_builder in
515     let string_greater = LlvM.build_icmp string_comparator strcmp_result (LlvM
        .const_null base_types.long_t) "string_greater" strstr_builder in
516     let _ = LlvM.build_cond_br string_greater make_true_bb make_false_bb
        strstr_builder in
517
518     let switch_inst = LlvM.build_switch combined_type make_empty_bb 2
        int_builder in (* Incompatible ==> default to empty *)
519     LlvM.add_case switch_inst number_number numnum_bb;
520     LlvM.add_case switch_inst string_string strstr_bb;
521     (ret_val, merge_builder) in
522   match op with
523   | Minus -> build_simple_binop LlvM.build_fsub int_builder
524   | Plus ->
525     let result = LlvM.build_malloc base_types.value_t "" int_builder
526     and stradd = (LlvM.append_block context "" form_decl)
527     and numadd = (LlvM.append_block context "" form_decl)
528     and bailout = (LlvM.append_block context "" form_decl)
529     and numorstrother = (LlvM.append_block context "" form_decl)
530     and strorother = (LlvM.append_block context "" form_decl)
531     in
532     let bstradd = LlvM.builder_at_end context stradd
533     and bnumadd = LlvM.builder_at_end context numadd
534     and bnumorstrother = LlvM.builder_at_end context numorstrother
535     and bstrother = LlvM.builder_at_end context strorother
536     and bbailout = LlvM.builder_at_end context bailout
537     and _ = LlvM.build_store (LlvM.const_int base_types.char_t (

```

```

        value_field_flags_index Empty)) (Llvm.build_struct_gep result (
        value_field_index Flags) "" int_builder) int_builder
538 in
539 let isnumber = Llvm.build_icmp Llvm.Icmp.Eq (Llvm.build_load (Llvm.
        build_struct_gep val1 (value_field_index Flags) "" bnumorstrother)
        "" bnumorstrother) (Llvm.const_int base_types.char_t (
        value_field_flags_index Number)) "" bnumorstrother
540 and isstring = Llvm.build_icmp Llvm.Icmp.Eq (Llvm.build_load (Llvm.
        build_struct_gep val1 (value_field_index Flags) "" bstrother) ""
        bstrother) (Llvm.const_int base_types.char_t (
        value_field_flags_index String)) "" bstrother
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) (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
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 numorstrorother bailout
        int_builder
565    and _ = Llvm.build_cond_br isnumber numadd strorother bnumorstrorother
566    and _ = Llvm.build_cond_br isstring stradd bailout bstrorother
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

```



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

```

```

633     let anonymous_var_inst_p = LlvM.build_malloc base_types.var_instance_t "
        anonymous_var_inst" old_builder in
634     let _ = (anonymous_var_inst_p $> (anonymous_subrange_p, (subrange_field_index
        BaseRangePtr))) old_builder in
635
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)) "
        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

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```

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

```

```

780
781     let _ = LlvM.build_store (LlvM.const_int base_types.char_t fromStartRow) (LlvM.
        build_struct_gep storage_addr (formula_field_index FromFirstRow) "" init_bod)
        init_bod in
782     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
      LocalVariable(i) ->
869       let llvm_var = LlvM.build_call getVar [|scope_obj; LlvM.const_int
      base_types.int_t i|] (special_name ^ "_var") builder in
870       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
871     | _ -> raise (TransformedAway("Error in " ^ fname ^ ": The " ^ special_name ^
      " value should always have been transformed into a local variable"))
872     | _ -> raise (TransformedAway("Error in " ^ fname ^ ": The " ^ special_name ^
      " value should always have been transformed into a local variable")) in
873   let assert_val = get_special_val "assert" (List.hd fn_def.func_asserts) in
874   let _ = LlvM.build_call (Hashtbl.find runtime_functions "verify_assert") [|
      assert_val; LlvM.build_global_stringptr fname "" builder|] "" builder in
875   let ret_val = get_special_val "return" (snd fn_def.func_ret_val) in
876   let _ = LlvM.build_ret ret_val builder in () in
877   (* 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) @ ["runtime.o"]))) ^ " -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 <sys/time.h> */
7  #include <time.h>
8  #include "runtime.h"

```

```

9
10 #define MAX_FILES 255
11 FILE *open_files[1 + MAX_FILES] = {NULL};
12 int open_num_files = 0;
13
14 value_p extend_print(value_p whatever, value_p text) {
15     if(!assertSingleString(text)) return new_val();
16     if(!assertText(text)) return new_val();
17     printf("%s", text->str->text);
18     return new_val();
19 }
20
21 value_p extend_printv(value_p whatever, value_p text) {
22     printf("%s", text->str->text);
23     return new_val();
24 }
25
26 value_p extend_printd(value_p whatever, value_p text) {
27     printf("%f\n", text->numericVal);
28     value_p result = malloc(sizeof(struct value_t));
29     return result;
30 }
31
32 value_p extend_to_string(value_p val) {
33     if(assertSingleNumber(val)) {
34         double possible_num = val->numericVal;
35         int rounded_int = (int) lrint(possible_num);
36         char *converted_str;
37         if (fabs(possible_num - rounded_int) < FLOAT_CUTOFF) {
38             int size = snprintf(NULL, 0, "%d", rounded_int);
39             converted_str = malloc(size + 1);
40             sprintf(converted_str, "%d", rounded_int);
41         } else {
42             int size = snprintf(NULL, 0, "%f", possible_num);
43             converted_str = malloc(size + 1);
44             sprintf(converted_str, "%f", possible_num);
45         }
46         value_p result = new_string(converted_str);
47         return result;
48     }
49     else if(assertSingleString(val)) return val;
50     else if(val->flags == FLAG_EMPTY) {
51         value_p _new = new_val();
52         setString(_new, "empty", 5);
53         return _new;
54     }
55     else if(val->flags == FLAG_SUBRANGE) {
56         int i,j,len;
57         value_p value;
58         char *result, *res;
59         len = 0;
60         subrange_p sr = val->subrange;
61         value_p *strs = malloc(sizeof(value_p) * sr->subrange_num_cols * sr->
            subrange_num_rows);
62         for(i = 0; i < sr->subrange_num_rows; i++) {
63             for(j = 0; j < sr->subrange_num_cols; j++) {

```

```

64     value = extend_to_string(getValSR(sr, i, j));
65     //debug_print(value, "");
66     strs[i * sr->subrange_num_cols + j] = value;
67     len += value->str->length;
68 }
69 }
70 len += sr->subrange_num_rows * sr->subrange_num_cols + 1 /*closing paren*/;
71 res = result = malloc(len + 1/*terminal character*/);
72 *result = '{';
73 result++;
74 for(i = 0; i < sr->subrange_num_rows; i++) {
75     for(j = 0; j < sr->subrange_num_cols; j++) {
76         memcpy(result, strs[i * sr->subrange_num_cols + j]->str->text, strs[i * sr->
77             subrange_num_cols + j]->str->length);
78         result += strs[i * sr->subrange_num_cols + j]->str->length;
79         if(j != sr->subrange_num_cols - 1) {
80             *result = ',';
81             result++;
82         }
83     }
84     if(i != sr->subrange_num_rows - 1) {
85         *result = ';';
86         result++;
87     }
88     *result = ' ';
89     value_p ret_val = new_val();
90     setString(ret_val, res, len);
91     return ret_val;
92 } else {
93     __builtin_unreachable();
94 }
95 // If the struct does not hold a string or number, return empty?
96 return new_val();
97 }
98
99 #define EXPOSE_MATH_FUNC(name) value_p extend_##name(value_p a){if(!assertSingleNumber
    (a)) return new_val();double val = name(a->numericVal);return new_number(val);}
100 EXPOSE_MATH_FUNC(sin)
101 EXPOSE_MATH_FUNC(cos)
102 EXPOSE_MATH_FUNC(tan)
103 EXPOSE_MATH_FUNC(acos)
104 EXPOSE_MATH_FUNC(asin)
105 EXPOSE_MATH_FUNC(atan)
106 EXPOSE_MATH_FUNC(sinh)
107 EXPOSE_MATH_FUNC(cosh)
108 EXPOSE_MATH_FUNC(tanh)
109 EXPOSE_MATH_FUNC(exp)
110 EXPOSE_MATH_FUNC(log)
111 EXPOSE_MATH_FUNC(log10)
112 EXPOSE_MATH_FUNC(sqrt)
113 EXPOSE_MATH_FUNC(ceil)
114 EXPOSE_MATH_FUNC(fabs)
115 EXPOSE_MATH_FUNC(floor)
116
117 value_p extend_get_stdin() {

```

```

118     if (open_num_files + 1 > MAX_FILES) {
119         return new_val();
120     } else {
121         open_num_files++;
122         open_files[open_num_files] = stdin;
123         return new_number((double) open_num_files);
124     }
125 }
126
127 value_p extend_get_stdout() {
128     if (open_num_files + 1 > MAX_FILES) {
129         return new_val();
130     } else {
131         open_num_files++;
132         open_files[open_num_files] = stdout;
133         return new_number((double) open_num_files);
134     }
135 }
136
137 value_p extend_get_stderr() {
138     if (open_num_files + 1 > MAX_FILES) {
139         return new_val();
140     } else {
141         open_num_files++;
142         open_files[open_num_files] = stderr;
143         return new_number((double) open_num_files);
144     }
145 }
146
147 value_p extend_open(value_p filename, value_p mode){
148     FILE *val;
149     if ( !assertSingleString(filename)
150         || !assertSingleString(mode)
151         || open_num_files + 1 > MAX_FILES) {
152         return new_val();
153     }
154     val = fopen(filename->str->text, mode->str->text);
155     if(val == NULL) return new_val();
156     open_num_files++;
157     open_files[open_num_files] = val;
158     return new_number((double) open_num_files);
159 }
160
161 value_p extend_close(value_p file_handle) {
162     if(!assertSingleNumber(file_handle)) {
163         // Per the LRM this is actually supposed to crash the program.
164         fprintf(stderr, "EXITING - Attempted to close something that was not a valid file
165             pointer\n");
166         exit(-1);
167     }
168     int fileNum = (int) file_handle->numericVal;
169
170     if (fileNum > open_num_files || open_files[fileNum] == NULL) {
171         // Per the LRM this is actually supposed to crash the program.
172         fprintf(stderr, "EXITING - Attempted to close something that was not a valid file
173             pointer\n");

```

```

172     exit(-1);
173 }
174 fclose(open_files[fileNum]);
175 open_files[fileNum] = NULL; // Empty the container for the pointer.
176 return new_val(); // assuming it was an open valid handle, close() is just supposed
    to return empty
177 }
178
179 value_p extend_read(value_p file_handle, value_p num_bytes){
180     if(!assertSingleNumber(file_handle) || !assertSingleNumber(num_bytes)) return
        new_val();
181     int max_bytes;
182     int fileNum = (int) file_handle->numericVal;
183     if (fileNum > open_num_files || open_files[fileNum] == NULL) return new_val();
184     FILE *f = open_files[fileNum];
185     max_bytes = (int) num_bytes->numericVal;
186     if (max_bytes == 0) {
187         long cur_pos = ftell(f);
188         fseek(f, 0, SEEK_END);
189         long end_pos = ftell(f);
190         fseek(f, cur_pos, SEEK_SET);
191         max_bytes = end_pos - cur_pos;
192     }
193     char *buf = malloc(sizeof(char) * (max_bytes + 1));
194     int bytes_read = fread(buf, sizeof(char), max_bytes, f);
195     buf[bytes_read] = 0;
196     value_p result = new_string(buf);
197     free(buf);
198     return result;
199     //edge case: how to return the entire contents of the file if n == empty?
200 }
201
202 value_p extend_readline(value_p file_handle) {
203     int i=0, buf_size = 256;
204     char next_char;
205     if (!assertSingleNumber(file_handle)) return new_val();
206     int fileNum = (int) file_handle->numericVal;
207     FILE *f = open_files[fileNum];
208     if (fileNum > open_num_files || open_files[fileNum] == NULL) {
209         return new_val();
210     }
211     char *buf = (char *) malloc (buf_size * sizeof(char));
212     while ((next_char = fgetc(f)) != '\n') {
213         buf[i++] = next_char;
214         if (i == buf_size - 2) {
215             buf_size *= 2;
216             char *new_buf = (char *) malloc (buf_size * sizeof(char));
217             memcpy(new_buf, buf, i);
218             free(buf);
219             buf = new_buf;
220         }
221     }
222     buf[i] = '\0';
223     value_p result = new_string(buf);
224     free(buf);
225     return result;

```

```

226 }
227
228 value_p extend_write(value_p file_handle, value_p buffer){
229     if(!assertSingleNumber(file_handle) || !assertSingleString(buffer)) return new_val()
230     ;
231     int fileNum = (int) file_handle->numericVal;
232     if (fileNum > open_num_files || open_files[fileNum] == NULL) {
233         // Per the LRM this is actually supposed to crash the program.
234         fprintf(stderr, "EXITING - Attempted to write to something that was not a valid
235             file pointer\n");
236         exit(-1);
237     }
238     fwrite(buffer->str->text, 1, buffer->str->length, open_files[fileNum]);
239     // TODO: make this return empty once compiler handles Id(s)
240     // RN: Use the return value to close the file
241     return new_number((double) fileNum);
242 }
243
244 value_p extend_current_hour() {
245     time_t ltime;
246     struct tm info;
247     ltime = time(&ltime);
248     localtime_r(&ltime, &info);
249     return new_number((double) info.tm_hour);
250 }
251
252 value_p extend_isNaN(value_p val) {
253     if (!assertSingleNumber(val)) return new_val();
254     double d = val->numericVal;
255     return isnan(d) ? new_number(1.0) : new_number(0.0);
256 }
257
258 value_p extend_isInfinite(value_p val) {
259     if (!assertSingleNumber(val)) return new_val();
260     double d = val->numericVal;
261     if (isinf(d)) {
262         return d < 0 ? new_number(-1.0) : new_number(1.0);
263     } else {
264         return new_number(0.0);
265     }
266 }
267
268 value_p extend_toASCII(value_p val) {
269     if (!assertSingleString(val)) return new_val();
270     value_p *val_arr = malloc(sizeof(value_p) * val->str->length);
271     int i;
272     for(i = 0; i < val->str->length; i++) {
273         value_p my_val = malloc(sizeof(struct value_t));
274         my_val->flags = FLAG_NUMBER;
275         my_val->numericVal = (double)val->str->text[i];
276         val_arr[i] = my_val;
277     }
278     value_p _new = new_subrange(1, val->str->length, val_arr);
279     return _new;
280 }

```

```

280 value_p extend_fromASCII(value_p val) {
281     value_p result = new_val();
282     if(val->flags == FLAG_NUMBER) {
283         char xxx = ((char)lrint(val->numericVal));
284         setString(result, &xxx, 1);
285     }
286     else if(val->flags == FLAG_SUBRANGE) {
287         int rows, cols, len;
288         rows = val->subrange->subrange_num_rows;
289         cols = val->subrange->subrange_num_cols;
290         if(rows > 1 && cols > 1) return result;
291         else len = rows == 1 ? cols : rows;
292         char *text = malloc(sizeof(char) * len);
293         for(rows = 0; rows < val->subrange->subrange_num_rows; rows++) {
294             for(cols = 0; cols < val->subrange->subrange_num_cols; cols++) {
295                 value_p single = getValSR(val->subrange, rows, cols);
296                 if(single->flags != FLAG_NUMBER) {
297                     free(text);
298                     return result;
299                 }
300                 text[rows + cols] = (char)lrint(single->numericVal);
301             }
302         }
303         setString(result, text, len);
304     }
305     return result;
306 }

```

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             -----");

```



```

24     return;
25 }
26 fprintf(stderr, "Flags: %d (%s)\n", val->flags, flag_meanings[val->flags]);
27 fprintf(stderr, "NumericVal: %f\n", val->numericVal);
28 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",
75         inst->name);
76     fprintf(stderr, "Rows: %d\n", inst->rows);
77     fprintf(stderr, "Cols: %d\n", inst->cols);
78     fprintf(stderr, "Num formulas: %d\n", inst->numFormulas);
79     fprintf(stderr, "*****Formulas:*****\n");
80     int i;
81     for (i = 0; i < inst->numFormulas; i++) {
82         debug_print_res_formula(inst->formulas + i);
83     }
84     fprintf(stderr, "**** End of Formulas *** \n");
85     fprintf(stderr, "~~~~~Cells:~~~~~\n");
86     fprintf(stderr, "Status memory address: %p\n", inst->status);
87     for (i = 0; i < inst->rows * inst->cols; i++) {
88         printf("%s[%d,%d]: Status=%d\n", inst->name, i / inst->cols, i % inst->cols, inst
89             ->status[i]);
90         if (inst->status[i] == CALCULATED) {
91             printf("%s[%d,%d] Value:\n", inst->name, i / inst->cols, i % inst->cols);
92             debug_print(inst->values[i], inst->name);
93         }
94     }
95     fprintf(stderr, "~~~ End of Cells: ~~~\n");
96 }
97
98 void debug_print_subrange(subrange_p subrng) {
99     fprintf(stderr, "————Everything you wanted to know about this subrange————\n");
100     fprintf(stderr, "Offset: [%d,%d]\n", subrng->base_var_offset_row, subrng->
101         base_var_offset_col);
102     fprintf(stderr, "Dimensions: [%d,%d]\n", subrng->subrange_num_rows, subrng->
103         subrange_num_cols);
104     fprintf(stderr, "Subrange of: \n");
105     debug_print_varinst(subrng->range);
106 }
107
108 void debug_print_index(struct rhs_index *idx) {
109     if (idx == NULL) {
110         fprintf(stderr, "I'd rather not try to print out the contents of a NULL index.\n");
111         ;
112         exit(-1);
113     }
114     fprintf(stderr, "Index type: ");
115     switch(idx->rhs_index_type) {
116     case RHS_IDX_ABSOLUTE:
117         fprintf(stderr, "Absolute\n");
118         if (idx->val_of_expr == NULL) {
119             fprintf(stderr, "I wasn't expecting this, but the value pointer is NULL. Maybe
120                 there's a good reason for it, so I'll keep going...\n");
121         } else {
122             debug_print(idx->val_of_expr, "an absolute index");
123         }
124         break;
125     case RHS_IDX_RELATIVE:

```

```

120     fprintf(stderr, "Relative\n");
121     if (idx->val_of_expr == NULL) {
122         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");
123     } 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
            isn't NULL. You should look into that.\n");
131         exit(-1);
132     }
133     break;
134 case RHS_IDX_DIM_END:
135     fprintf(stderr, "DimensionEnd\n");
136     if (idx->val_of_expr != NULL) {
137         fprintf(stderr, "This definitely isn't supposed to happen - the value pointer
            isn't NULL. You should look into that.\n");
138         exit(-1);
139     }
140     break;
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->
        slice_start_index, sl->slice_end_index);
151     if (sl->slice_start_index != NULL) {
152         fprintf(stderr, "Start index info:\n");
153         debug_print_index(sl->slice_start_index);
154         if (sl->slice_end_index != NULL) {
155             fprintf(stderr, "End index info:\n");
156             debug_print_index(sl->slice_end_index);
157         }
158     } else {
159         if (sl->slice_end_index != NULL) {
160             fprintf(stderr, "Start index is NULL but end index is not NULL. That should
                never happen.\n");
161             fprintf(stderr, "Attempting to print contents anyway:\n");
162             fflush(stderr);
163             debug_print_index(sl->slice_end_index);
164         }
165     }
166 }
167
168 void debug_print_selection(struct rhs_selection *sel) {
169     if (sel == NULL) {

```

```

170     fprintf(stderr, "I'd rather not try to print out the contents of a NULL selection
171         .\n");
172     exit(-1);
173 }
174 fprintf(stderr, "————Everything about this selection————\n");
175 fprintf(stderr, "Slice memory addresses: %p and %p\n", sel->slice1, sel->slice2);
176 if (sel->slice1 != NULL) {
177     fprintf(stderr, "Slice 1 info:\n");
178     debug_print_slice(sel->slice1);
179     if (sel->slice2 != NULL) {
180         fprintf(stderr, "Slice 2 info:\n");
181         debug_print_slice(sel->slice2);
182     }
183 } else {
184     if (sel->slice2 != NULL) {
185         fprintf(stderr, "Slice 1 is NULL but slice 2 is not NULL. That should never
186             happen.\n");
187         fprintf(stderr, "Attempting to print contents anyway:\n");
188         fflush(stderr);
189         debug_print_slice(sel->slice2);
190     }
191 }
192 fprintf(stderr, "————That's all I've got about that selection————\n\n");
193 }
194
195 int rg_eq(value_p val1, value_p val2) {
196     int res = 1;
197     if(val1->flags != val2->flags) res = 0;
198     else if(val1->flags == FLAG_EMPTY) ;
199     else if(val1->flags == FLAG_NUMBER && val1->numericVal != val2->numericVal) res = 0;
200     else if(val1->flags == FLAG_STRING && strcmp(val1->str->text, val2->str->text)) res
201         = 0;
202     else if(val1->flags == FLAG_SUBRANGE) {
203         subrange_p sr1 = val1->subrange;
204         subrange_p sr2 = val2->subrange;
205         if(sr1->subrange_num_cols != sr2->subrange_num_cols || sr1->subrange_num_rows !=
206             sr2->subrange_num_rows) {
207             return 0;
208         } else {
209             int i, j;
210             value_p v1, v2;
211             for(i = 0; i < sr1->subrange_num_rows; i++) {
212                 for(j = 0; j < sr1->subrange_num_cols; j++) {
213                     v1 = getValSR(sr1, i, j);
214                     v2 = getValSR(sr2, i, j);
215                     if(rg_eq(v1, v2) == 0) {
216                         return 0;
217                     }
218                 }
219             }
220         }
221     }
222     return res;
223 }
224
225 void incStack() {

```

```

222     const rlim_t kStackSize = 64L * 1024L * 1024L;
223     struct rlimit rl;
224     int result;
225
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 char* setString(value_p result, char *str, int length) {
237     result->flags = FLAG_STRING;
238     result->str = malloc(sizeof(struct string_t));
239     result->str->length = length;
240     return (result->str->text = str);
241 }
242
243 double setFlag(value_p result, double flag_num) {
244     return (result->flags = flag_num);
245 }
246
247 int assertSingle(value_p value) {
248     /* TODO: dereference 1 by 1 subrange */
249     return !(value->flags == FLAG_SUBRANGE);
250 }
251
252 int assertSingleNumber(value_p p) {
253     if (!assertSingle(p)) {
254         return 0;
255     }
256     return (p->flags == FLAG_NUMBER);
257 }
258
259 int assertText(value_p my_val) {
260     return (my_val->flags == FLAG_STRING);
261 }
262
263 int assertSingleString(value_p p) {
264     if (!assertSingle(p)) {
265         return 0;
266     }
267     return (p->flags == FLAG_STRING);
268 }
269
270 int assertEmpty(value_p p) {
271     if (!assertSingle(p)) {
272         return 0;
273     }
274     return (p->flags == FLAG_EMPTY);
275 }
276
277 value_p new_val() {

```

```

278     value_p empty_val = malloc(sizeof(struct value_t));
279     setFlag(empty_val, FLAG_EMPTY);
280     return empty_val;
281 }
282
283 value_p new_number(double val) {
284     value_p new_v = malloc(sizeof(struct value_t));
285     setFlag(new_v, FLAG_NUMBER);
286     setNumeric(new_v, val);
287     return new_v;
288 }
289
290 value_p new_string(char *s) {
291     if (s == NULL) return new_val();
292     value_p new_v = malloc(sizeof(struct value_t));
293     setFlag(new_v, FLAG_STRING);
294     string_p new_str = malloc(sizeof(struct string_t));
295     long len = strlen(s);
296     new_str->text = malloc(len+1);
297     strcpy(new_str->text, s);
298     new_str->length = len;
299     new_str->refs = 1;
300     new_v->str = new_str;
301     return new_v;
302 }
303
304 struct ExtendScope *global_scope;
305
306 void null_init(struct ExtendScope *scope_ptr) {
307     int i;
308     for(i = 0; i < scope_ptr->numVars; i++)
309         scope_ptr->vars[i] = NULL;
310 }
311
312 int getIntFromOneByOne(struct ExtendScope *scope_ptr, int varnum) {
313     if (!scope_ptr->defns[varnum].isOneByOne) {
314         fprintf(stderr, "The variable you claimed (%s) was one by one is not defined that
315             way.\n", scope_ptr->defns[varnum].name);
316     }
317     struct var_instance *inst = get_variable(scope_ptr, varnum);
318     if (inst->rows != 1 || inst->cols != 1) {
319         fprintf(stderr, "The variable you claimed (%s) was one by one is actually %d by %d
320             .\n", inst->name, inst->rows, inst->cols);
321         debug_print_varinst(inst);
322         exit(-1);
323     }
324     value_p val = getVal(inst, 0, 0);
325     if (!assertSingleNumber(val)) {
326         fprintf(stderr, "The variable you claimed (%s) was a number isn't.\n", inst->name);
327     }
328     debug_print(val, inst->name);
329     exit(-1);
330 }
331
332 return (int) lrint(val->numericVal);
333 }
334

```

```

331 struct var_instance *instantiate_variable(struct ExtendScope *scope_ptr, struct
    var_defn def) {
332     struct var_instance *inst = malloc(sizeof(struct var_instance));
333     if(def.isOneByOne) {
334         inst->rows = 1;
335         inst->cols = 1;
336     } else {
337         inst->rows = getIntFromOneByOne(scope_ptr, def.rows_varnum);
338         inst->cols = getIntFromOneByOne(scope_ptr, def.cols_varnum);
339     }
340     // TODO: do the same thing for each FormulaFP to turn an ExtendFormula into a
    ResolvedFormula
341     inst->numFormulas = def.numFormulas;
342     inst->closure = scope_ptr;
343     inst->name = def.name;
344     int size = inst->rows * inst->cols;
345     inst->values = malloc(sizeof(value_p) * size);
346     memset(inst->values, 0, sizeof(value_p) * size);
347     inst->status = malloc(sizeof(char) * size);
348     memset(inst->status, 0, sizeof(char) * size);
349     inst->formulas = malloc(sizeof(struct ResolvedFormula) * inst->numFormulas);
350     //debug_print_vardefn(&def);
351     //debug_print_varinst(inst);
352     int i, j;
353     for(i = 0; i < inst->numFormulas; i++) {
354
355         // Set the formula function pointer to the pointer from the definition
356         inst->formulas[i].formula = def.formulas[i].formula;
357
358         if (def.isOneByOne) {
359             inst->formulas[i].rowStart = 0;
360             inst->formulas[i].rowEnd = 1;
361             inst->formulas[i].colStart = 0;
362             inst->formulas[i].colEnd = 1;
363         } else {
364             if(def.formulas[i].fromFirstRow) {
365                 inst->formulas[i].rowStart = 0;
366             } else {
367                 inst->formulas[i].rowStart = getIntFromOneByOne(scope_ptr, def.formulas[i].
                    rowStart_varnum);
368                 if (inst->formulas[i].rowStart < 0) {
369                     inst->formulas[i].rowStart += inst->rows;
370                 }
371                 if (inst->formulas[i].rowStart < 0 || inst->formulas[i].rowStart >= inst->rows
                    ) {
372                     //Doesn't matter, but will never get called
373                 }
374             }
375             if (def.formulas[i].isSingleRow) {
376                 inst->formulas[i].rowEnd = inst->formulas[i].rowStart + 1;
377             } else if (def.formulas[i].toLastRow) {
378                 inst->formulas[i].rowEnd = inst->rows;
379             } else {
380                 inst->formulas[i].rowEnd = getIntFromOneByOne(scope_ptr, def.formulas[i].
                    rowEnd_varnum);
381                 if (inst->formulas[i].rowEnd < 0) {

```

```

382     inst->formulas[i].rowEnd += inst->rows;
383 }
384 }
385 if(def.formulas[i].fromFirstCol) {
386     inst->formulas[i].colStart = 0;
387 } else {
388     inst->formulas[i].colStart = getIntFromOneByOne(scope_ptr, def.formulas[i].
        colStart_varnum);
389     if (inst->formulas[i].colStart < 0) {
390         inst->formulas[i].colStart += inst->cols;
391     }
392     if (inst->formulas[i].colStart < 0 || inst->formulas[i].colStart >= inst->cols
        ) {
393         //Doesn't matter, but will never get called
394     }
395 }
396 if (def.formulas[i].isSingleCol) {
397     inst->formulas[i].colEnd = inst->formulas[i].colStart + 1;
398 } else if (def.formulas[i].toLastCol) {
399     inst->formulas[i].colEnd = inst->cols;
400 } else {
401     inst->formulas[i].colEnd = getIntFromOneByOne(scope_ptr, def.formulas[i].
        colEnd_varnum);
402     if (inst->formulas[i].colEnd < 0) {
403         inst->formulas[i].colEnd += inst->cols;
404     }
405 }
406 }
407 }
408
409 for (i = 1; i < inst->numFormulas; i++) {
410     for (j = 0; j < i; j++) {
411         int intersectRowStart = (inst->formulas[i].rowStart > inst->formulas[j].rowStart
            ) ? inst->formulas[i].rowStart : inst->formulas[j].rowStart;
412         int intersectColStart = (inst->formulas[i].colStart > inst->formulas[j].colStart
            ) ? inst->formulas[i].colStart : inst->formulas[j].colStart;
413         int intersectRowEnd = (inst->formulas[i].rowEnd < inst->formulas[j].rowEnd) ?
            inst->formulas[i].rowEnd : inst->formulas[j].rowEnd;
414         int intersectColEnd = (inst->formulas[i].colEnd < inst->formulas[j].colEnd) ?
            inst->formulas[i].colEnd : inst->formulas[j].colEnd;
415         if (intersectRowEnd > intersectRowStart && intersectColEnd > intersectColStart)
            {
416             fprintf(stderr, "Runtime error: Multiple formulas were assigned to %s[%d:%d,%d
                :%d].\n", inst->name,
417                 intersectRowStart, intersectRowEnd, intersectColStart,
                intersectColEnd);
418             exit(-1);
419         }
420     }
421 }
422
423 scope_ptr->refcount++;
424 return inst;
425 }
426
427 struct var_instance *get_variable(struct ExtendScope *scope_ptr, int varnum) {

```



```

428     if (varnum >= scope_ptr->numVars) {
429         fprintf(stderr, "Runtime error: Asked for nonexistent variable number\n");
430         exit(-1);
431     }
432     if (scope_ptr->vars[varnum] == NULL) {
433         scope_ptr->vars[varnum] = instantiate_variable(scope_ptr, scope_ptr->defns[varnum]
434             );
435     }
436     return scope_ptr->vars[varnum];
437 }
438 char assertInBounds(struct var_instance *defn, int r, int c) {
439     return (
440         r >= 0 && r < defn->rows &&
441         c >= 0 && c < defn->cols
442     );
443 }
444
445 value_p calcVal(struct var_instance *inst, int r, int c) {
446     int i;
447     for (i = 0; i < inst->numFormulas; i++) {
448         if (
449             r >= inst->formulas[i].rowStart && r < inst->formulas[i].rowEnd &&
450             c >= inst->formulas[i].colStart && c < inst->formulas[i].colEnd
451         ) {
452             return (inst->formulas[i].formula)(inst->closure, r, c);
453         }
454     }
455     return new_val();
456 }
457
458 value_p clone_value(value_p old_value) {
459     value_p new_value = (value_p) malloc(sizeof(struct value_t));
460     new_value->flags = old_value->flags;
461     switch (new_value->flags) {
462         case FLAG_EMPTY:
463             break;
464         case FLAG_NUMBER:
465             new_value->numericVal = old_value->numericVal;
466             break;
467         case FLAG_STRING:
468             new_value->str = old_value->str;
469             new_value->str->refs++;
470             break;
471         case FLAG_SUBRANGE:
472             new_value->subrange = (subrange_p) malloc(sizeof(struct subrange_t));
473             memcpy(new_value->subrange, old_value->subrange, sizeof(struct subrange_t));
474             if (new_value->subrange->range->closure != NULL) {
475                 new_value->subrange->range->closure->refcount++; /* Not sure about this one */
476             }
477             break;
478         default:
479             fprintf(stderr, "clone_value(%p): Illegal value of flags: %c\n", old_value,
480                 new_value->flags);
481             exit(-1);
482             break;

```

```

482     }
483     return new_value;
484 }
485
486 void delete_string_p(string_p old_string) {
487     old_string->refs--;
488     if (old_string->refs == 0) {
489         /* free(old_string); */
490     }
491 }
492
493 void delete_subrange_p(subrange_p old_subrange) {
494     if (old_subrange->range->closure != NULL) {
495         old_subrange->range->closure->refcount--;
496     }
497     free(old_subrange);
498 }
499
500 void delete_value(value_p old_value) {
501     switch (old_value->flags) {
502         case FLAG_EMPTY:
503             break;
504         case FLAG_NUMBER:
505             break;
506         case FLAG_STRING:
507             delete_string_p(old_value->str); /* doesn't do anything besides decrement the
508                                                ref count now */
509             break;
510         case FLAG_SUBRANGE:
511             delete_subrange_p(old_value->subrange);
512             break;
513         default:
514             fprintf(stderr, "delete_value(%p): Illegal value of flags: %c\n", old_value,
515                     old_value->flags);
516             exit(-1);
517             break;
518     }
519 }
520
521 value_p deref_subrange_p(subrange_p subrng) {
522     if (subrng == NULL) {
523         fprintf(stderr, "Exiting - asked to dereference a NULL pointer.\n");
524         exit(-1);
525     }
526     if (subrng->subrange_num_rows == 1 && subrng->subrange_num_cols == 1) {
527         return getVal(subrng->range, subrng->base_var_offset_row, subrng->
528                     base_var_offset_col);
529     } else {
530         value_p new_value = (value_p) malloc (sizeof(struct value_t));
531         new_value->flags = FLAG_SUBRANGE;
532         new_value->numericVal = 0.0;
533         new_value->str = NULL;
534         new_value->subrange = (subrange_p) malloc (sizeof(struct subrange_t));
535         memcpy(new_value->subrange, subrng, sizeof(struct subrange_t));
536         if (new_value->subrange->range->closure != NULL) {
537             new_value->subrange->range->closure->refcount++;
538         }
539     }
540 }

```

```

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

```

```

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

```

```

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

```

```

698     exit(-1); */
699     }
700     } else {
701         row_slice_p = sel->slice1;
702         col_slice_p = sel->slice2;
703     }
704 }
705 row_slice_success = resolve_rhs_slice(row_slice_p, expr_rows, r, &row_start, &
    row_end);
706 col_slice_success = resolve_rhs_slice(col_slice_p, expr_cols, c, &col_start, &
    col_end);
707 if (!row_slice_success || !col_slice_success) return new_val();
708 if (row_start < 0) row_start = 0;
709 if (col_start < 0) col_start = 0;
710 if (row_end > expr_rows) row_end = expr_rows;
711 if (col_end > expr_cols) col_end = expr_cols;
712 if (row_end <= row_start || col_end <= col_start) return new_val();
713 if (expr->flags == FLAG_NUMBER || expr->flags == FLAG_STRING) {
714     /* You would have thought we could figure this out a lot further up
715      * in the code, but had to be sure that (row_start, row_end, col_start, col_end)
716      * actually ended up as (0, 1, 0, 1) */
717     return clone_value(expr);
718 } else {
719     subrange.range = expr->subrange->range;
720     subrange.base_var_offset_row = expr->subrange->base_var_offset_row + row_start;
721     subrange.base_var_offset_col = expr->subrange->base_var_offset_col + col_start;
722     subrange.subrange_num_rows = row_end - row_start;
723     subrange.subrange_num_cols = col_end - col_start;
724     return deref_subrange_p(&subrange);
725 }
726 }
727
728 value_p getValSR(struct subrange_t *sr, int r, int c) {
729     if(sr->subrange_num_rows <= r || sr->subrange_num_cols <= c || r < 0 || c < 0)
730         return new_val();
731     return getVal(sr->range, r + sr->base_var_offset_row, c + sr->base_var_offset_col);
732 }
733
734 void verify_assert(value_p val, char *fname) {
735     if ((!assertSingleNumber(val)) || val->numericVal != 1.0) {
736         fprintf(stderr, "EXITING - The function %s was called with arguments of the wrong
            dimensions.\n", fname);
737         exit(-1);
738     }
739 }
740
741 value_p getVal(struct var_instance *inst, int r, int c) {
742     /* If we're going to return new_val() then we have to
743      * do clone_value(). Otherwise the receiver won't know
744      * whether or not they can free the value_p they get back.
745      * I think this should return, dangerously, return NULL if it's
746      * invalid, and the callers will have to be careful to check the value.
747      * The alternative is to always clone_value - safer, but much slower
748      * and makes our memory issues even bigger.
749      * Right now there are only a few places that call this. */
750

```

```

751 if(!assertInBounds(inst, r, c)) return NULL;
752 int cell_number = r * inst->cols + c;
753 char cell_status = inst->status[cell_number];
754 switch(cell_status) {
755     case NEVER_EXAMINED:
756         inst->status[cell_number] = IN_PROGRESS;
757         inst->values[cell_number] = calcVal(inst, r, c);
758         inst->status[cell_number] = CALCULATED;
759         break;
760     case IN_PROGRESS:
761         fprintf(stderr, "EXITING - Circular reference in %s[%d,%d]\n", inst->name, r, c)
762             ;
763         exit(-1);
764         break;
765     case CALCULATED:
766         if (inst->values[cell_number] == NULL) {
767             fprintf(stderr, "Supposedly, %s[%d,%d] was already calculated, but there is a
768                 null pointer there.\n", inst->name, r, c);
769             fprintf(stderr, "Attempting to print contents of the variable instance where
770                 this occurred:\n");
771             fflush(stderr);
772             debug_print_varinst(inst);
773             exit(-1);
774         }
775         break;
776     default:
777         fprintf(stderr, "Unrecognized cell status %d (row %d, col %d)!\n", cell_status,
778             r, c);
779         fprintf(stderr, "Attempting to print contents of the variable instance where
780             this occurred:\n");
781         fflush(stderr);
782         debug_print_varinst(inst);
783         exit(-1);
784         break;
785 }
786 return inst->values[cell_number];
787 }

```

7.12 stdlib.xtnd

```

1 extern "stdlib.o" {
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  isInfinite(val);
25  get_stdin();
26  get_stdout();
27  get_stderr();
28  open(filename, mode);
29  close(file_handle);
30  read(file_handle, num_bytes);
31  readline(file_handle);
32  write(file_handle, buffer);
33  toASCII(val);
34  fromASCII(val);
35  }
36
37  global STDIN := get_stdin();
38  global STDOUT := get_stdout();
39  global STDERR := get_stderr();
40
41  print_endline(val) {
42    return write(STDOUT, to_string(val) + "\n");
43  }

```


8. Tests and Output

helloworld.xtnd

```
1 main(args) {  
2   foo := print_endline("Hello World") -> 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_endline(bar) -> 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_endline(foo[1,0]) -> 0;  
4 }
```

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

```
1 string
```

test-access-column-cells.xtnd

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

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

```
1 {"string", "string", "string", "string"}
```

test-access-hashtag-multi-dim.xtnd

```

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

```

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

```

1 string

```

test-access-selected-range-1.xtnd

```

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

```

test-access-selected-range-1.xtnd - Expected Output

```

1 {"string", "string";
2 "string", "string"}

```

test-access-selected-range-2.xtnd

```

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

```

test-access-selected-range-2.xtnd - Expected Output

```

1 {"string", "string"}

```

test-access-x-range-of-cells.xtnd

```

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

```

test-access-x-range-of-cells.xtnd - Expected Output

```
1 {"string", "string", "string", "string"}
```

test-access-y-range-of-cells.xtnd

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

test-access-y-range-of-cells.xtnd - Expected Output

```
1 {"string";  
2 "string";  
3 "string";  
4 "string"}
```

test-acos.xtnd

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

test-acos.xtnd - Expected Output

```
1 1.570796
```

test-addition.xtnd

```
1 main(args){  
2   return print_endline(5 + 7) -> 0;  
3 }
```

test-addition.xtnd - Expected Output

```
1 12
```

test-addition-empty.xtnd

```
1 main([1,1] args){  
2   return print_endline( empty + 5) -> 0;  
3 }
```

test-addition-empty.xtnd - Expected Output

```
1 empty
```

test-asin.xtnd

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

test-asin.xtnd - Expected Output

```
1 0.523599
```

test-atan.xtnd

```

1 main([1,n] args) {
2     return print_endline( 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_endline( 0) -> 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) ->
        print_endline(~"a") -> print_endline(empty);
3 }

```

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_endline(23 & 12) -> 0;
3 }

```

test-bitwise-and.xtnd - Expected Output

```

1 4

```

test-bitwise-and-empty.xtnd

```

1 main([1,1] args){
2     return print_endline(empty & 4) -> 0;
3 }

```

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

```

1 empty

```

test-bitwise-left.xtnd

```

1 main([1,1] args){
2     return print_endline( 14 << 2) -> 0;
3 }

```

test-bitwise-left.xtnd - Expected Output

```

1 56

```

test-bitwise-left-empty.xtnd

```

1 main([1,1] args){
2     return print_endline( empty >> 1) -> 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_endline(~88) -> 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_endline( ~empty) -> 0;
4 }

```

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

```

1 empty

```

test-bitwise-or.xtnd

```

1 main([1,1] args){
2     return print_endline(14 | 12) -> 0;
3 }

```

test-bitwise-or.xtnd - Expected Output

```

1 14

```

test-bitwise-or-empty.xtnd

```

1 main([1,1] args){
2     return print_endline(empty | 2) -> 0;
3 }

```

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

```

1 empty

```

test-bitwise-right.xtnd

```
1 main([1,1] args){
2   return print_endline(12 >> 2) -> 0;
3 }
```

test-bitwise-right.xtnd - Expected Output

```
1 3
```

test-bitwise-right-empty.xtnd

```
1 main([1,1] args){
2   return print_endline( empty >> 2) -> 0;
3 }
```

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

```
1 empty
```

test-bitwise-xor.xtnd

```
1 main([1,1] args){
2   return print_endline(14 ^ 12) -> 0;
3 }
```

test-bitwise-xor.xtnd - Expected Output

```
1 2
```

test-bitwise-xor-empty.xtnd

```
1 main([1,1] args){
2   return print_endline(empty ^ 2) -> 0;
3 }
```

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

```
1 empty
```

test-boolean-equals.xtnd

```
1 main([1,1] args){
2   return print_endline( 5 == 6) -> 0;
3 }
```

test-boolean-equals.xtnd - Expected Output

```
1 0
```

test-boolean-equals-both-empty.xtnd

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

```
56 }
```

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

```
1 True cases for ==
2 1
3 1
4 1
5 1
6 1
7 1
8 1
9 1
10 1
11 1
12 1
13
14 False cases for ==
15 0
16 0
17 0
18 0
19 0
20 0
21 0
22 0
23 0
24 0
25 0
26
27 True cases for !=
28 1
29 1
30 1
31 1
32 1
33 1
34 1
35 1
36 1
37 1
38 1
39
40 False cases for !=
41 0
42 0
43 0
44 0
45 0
46 0
47 0
48 0
49 0
50 0
51 0
```

test-boolean-equals-one-empty.xtnd


```

1 main([1,1] args){
2     return print_endline( empty == 5) -> 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_endline( 6 != 7) -> 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_endline( empty != empty) -> 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_endline(empty != 5) -> 0;
3 }

```

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

```

1 1

```

test-calling-func-from-import.xtnd

```

1 main([1,n] args){
2     return print_endline( gcd(70, 55)) -> 0;
3 }

```

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

```

1 5

```

test-ceil.xtnd

```

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

```

test-ceil.xtnd - Expected Output

```

1 11

```

test-cos.xtnd

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

test-cos.xtnd - Expected Output

```
1 0.525322
```

test-cosh.xtnd

```
1 main([1,n] args) {
2     return print_endline( cosh(2.5)) -> 0;
3 }
```

test-cosh.xtnd - Expected Output

```
1 6.132289
```

test-division.xtnd

```
1 main([1,1] args){
2     /* Should evaluate to 4 */
3     return print_endline( 20 / 5) -> 0;
4 }
```

test-division.xtnd - Expected Output

```
1 4
```

test-division-empty.xtnd

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

test-division-empty.xtnd - Expected Output

```
1 empty
```

test-exp.xtnd

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

test-exp.xtnd - Expected Output

```
1 7.389056
```

test-fabs.xtnd

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

test-fabs.xtnd - Expected Output

```
1 45
```

test-file-close.xtnd

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

test-file-close.xtnd - Expected Output

```
1 Made it this far
```

test-file-read.xtnd

```
1 main(args){
2     return print_endline(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     write(STDOUT, (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_endline("Made it this far") ->
7     0;
8 }
```

test-file-write.xtnd - Expected Output

```
1 Made it this far
```

test-floor.xtnd

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

test-floor.xtnd - Expected Output

```
1 10
```

test-func-params.xtnd

```

1 main([1,n] args) {
2     return print_endline( foo("string")) -> 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_endline(foo("string")) -> 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 := print_endline("Hello Globals!") -> 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 := print_endline("Hello Globals!") -> 0;
7
8 main(args) {
9     foo := print_endline("Hello Locals!") -> 0;
10    return foo;
11 }

```

test-global-masking.xtnd - Expected Output

```

1 Hello Locals!

```

test-globals.xtnd

```
1 global [2,2] foo := 1;
2 main([1,n] args) {
3     return print_endline(foo) -> 0;
4 }
```

test-globals.xtnd - Expected Output

```
1 {1, 1;
2 1, 1}
```

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_endline( 6 > 5) -> 0;
3 }
```

test-greater-than.xtnd - Expected Output

```
1 1
```

test-greater-than-empty.xtnd

```
1 main([1,1] args){
2     return print_endline( empty > 5) -> 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_endline( 7 >= 7) -> 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_endline(empty >= 7) -> 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_endline( 6 < 7) -> 0;  
3 }
```

test-less-than.xtnd - Expected Output

```
1 1
```

test-less-than-empty.xtnd

```
1 main([1,1] args){  
2     return print_endline( empty > 5) -> 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_endline( 7 <= 5) -> 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_endline(empty <= 8) -> 0;  
3 }
```

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

```
1 empty
```

test-log.xtnd

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

test-log.xtnd - Expected Output

```
1 2.302585
```

test-log10.xtnd

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

test-log10.xtnd - Expected Output

```
1 2
```

`test-logical-and.xtnd`

```
1 main([1,1] args){
2     return print_endline( 1 && 6) -> 0;
3 }
```

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

```
1 1
```

`test-logical-and-empty.xtnd`

```
1 main([1,1] args){
2     return print_endline( empty && 1) -> 0;
3 }
```

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

```
1 empty
```

`test-logical-not.xtnd`

```
1 main([1,1] args){
2     return print_endline( !5) -> 0;
3 }
```

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

```
1 0
```

`test-logical-not-empty.xtnd`

```
1 main([1,1] args){
2     return print_endline( !empty) -> 0;
3 }
```

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

```
1 empty
```

`test-logical-or.xtnd`

```
1 main([1,1] args){
2     return print_endline( 5 || 6) -> 0;
3 }
```

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

```
1 1
```

`test-logical-or-empty.xtnd`

```
1 main([1,1] args){
2     return print_endline( empty || 4) -> 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_endline(5 % 4) -> 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_endline( empty % 5) -> 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_endline(7 * 5) -> 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_endline(empty * 5) -> 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
```

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

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

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

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

[illegible]

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

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

test-power.xtnd

```
1 main([1,n] args){
2     /* Should return 216 */
3     return print_endline(6**3) -> 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_endline(empty**5) -> 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_endline( foo) -> 0;
4 }
```

test-print-empty.xtnd - Expected Output

```
1 empty
```

test-print-multi-range.xtnd

```
1 main([1,n] args) {
2     [5,5] foo := 1;
3     return print_endline( foo) -> 0;
4 }
```

test-print-multi-range.xtnd - Expected Output

```
1 {1, 1, 1, 1, 1;
2 1, 1, 1, 1, 1;
3 1, 1, 1, 1, 1;
4 1, 1, 1, 1, 1;
5 1, 1, 1, 1, 1}
```

test-print-multi-str-range.xtnd

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

test-print-multi-str-range.xtnd - Expected Output

```
1 {"string", "string", "string", "string", "string"}
```

test-print-nums.xtnd

```

1 main([1,n] args) {
2   foo := 1;
3   return print_endline(foo) -> 0;
4 }

```

test-print-nums.xtnd - Expected Output

```

1 1

```

test-print-oned-range.xtnd

```

1 main([1,n] args) {
2   [1,10] foo := 1;
3   return print_endline( foo) -> 0;
4 }

```

test-print-oned-range.xtnd - Expected Output

```

1 {1, 1, 1, 1, 1, 1, 1, 1, 1, 1}

```

test-print-str.xtnd

```

1 main([1,n] args) {
2   foo := "string";
3   return print_endline(foo) -> 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_endline(bar) -> 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_endline("FAIL") -> print_endline("PASS") -> 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_endline("PASS1") -> print_endline("PASS2") -> 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_endline("PASS1") -> print_endline("PASS2") -> 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_endline("FAIL") -> print_endline("PASS") -> 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 " + toString(m) + " rows and " + toString
      (n) + " columns.";
3 }
4
5 main([1,1] args) {
6   [42,17] x;
7   return print_endline(foo(x)) -> 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 print_endline(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 print_endline(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 print_endline(internal_sin(1,2,theta)) -> 0;
9 }
```

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

```
1 0.850904
```

test-single-import.xtnd

```
1 main([1,n] args) {
2     return print_endline(gcd(70, 55)) -> 0;
3 }
```

test-single-import.xtnd - Expected Output

```
1 5
```

test-sinh.xtnd

```
1 main([1,n] args) {
2     return print_endline(sinh(3.0)) -> 0;
3 }
```

test-sinh.xtnd - Expected Output

```
1 10.017875
```

test-sqrt.xtnd

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

test-sqrt.xtnd - Expected Output

```
1 3
```

test-string-concatenation.xtnd

```
1 main(args) {
2     foo :=
3     print_endline("Hello " + "World") ->
4     print_endline("Hello " + "World") ->
5     print_endline("Hello " + ("World" + "")) ->
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_endline( 7 - 5) -> 0;
3 }
```

test-subtraction.xtnd - Expected Output

```
1 2
```

test-subtraction-empty.xtnd

```
1 main([1,1] args){
2   return print_endline( empty - 2) -> 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_endline(x) -> 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 print_endline(x) -> 0;
8 }
```

test-switch-v10.xtnd - Expected Output

```
1 200
```

test-switch-v11.xtnd

```

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

```

test-switch-v11.xtnd - Expected Output

```

1 99

```

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_endline(x) -> 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_endline(x) -> 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_endline(x) -> 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_endline(x) -> 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_endline(x) -> 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_endline(x) -> 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_endline(x) -> 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 print_endline(x) -> 0;
7 }

```

test-switch-v9.xtnd - Expected Output

```

1 100

```

test-tan.xtnd

```

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

```

test-tan.xtnd - Expected Output

```

1 1.619775

```

test-tanh.xtnd

```

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

```

test-tanh.xtnd - Expected Output

```

1 1

```

test-ternary-conditional.xtnd

```

1 main([1,1] args){
2   return print_endline(5 ? 2 : 3) -> 0;
3 }

```

test-ternary-conditional.xtnd - Expected Output

```

1 2

```

test-ternary-conditional-empty.xtnd

```

1 main([1,1] args){
2   return print_endline( empty ? 5 : 6) -> 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_endline( -33) -> 0;
4 }

```

test-unary-negation.xtnd - Expected Output

```
1 -33
```

test-unary-negation-empty.xtnd

```
1 main([1,n] args){  
2     return print_endline(-empty) -> 0;  
3 }
```

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

```
1 empty
```

9. Git Logs

```
1 2569ea5 2016-12-19T12:43:20-05:00 GitHub: Merge pull request #134 from ExtendLang/  
  stdlib-additions  
2 47f1167 2016-12-19T12:09:58-05:00 GitHub: Merge branch 'master' into stdlib-additions  
3 2e18028 2016-12-19T12:09:50-05:00 GitHub: Merge pull request #133 from ExtendLang/  
  mergesort  
4 142938e 2016-12-19T11:51:25-05:00 oracleofnj: Couple stdlib additions  
5 3fc2843 2016-12-19T10:17:09-05:00 Nigel Schuster: Mergesort example  
6 0b23496 2016-12-19T09:07:15-05:00 GitHub: Merge pull request #132 from ExtendLang/  
  fixing-tcs  
7 b86d992 2016-12-19T00:38:27-05:00 oracleofnj: Verify samples, compact TSP  
8 e859c75 2016-12-19T00:17:57-05:00 oracleofnj: Final test run with complete stdlib  
9 f02f2da 2016-12-19T00:13:20-05:00 oracleofnj: Remove obsolete print flavors  
10 dd65154 2016-12-19T00:08:17-05:00 oracleofnj: Merge branch 'master' into fixing-tcs  
11 82f4ad5 2016-12-19T00:07:45-05:00 oracleofnj: Merge branch 'master' of https://github.  
  com/ExtendLang/Extend  
12 d2cd19e 2016-12-19T00:07:30-05:00 oracleofnj: 125 / 125  
13 8d02537 2016-12-19T00:07:11-05:00 GitHub: Merge pull request #131 from ExtendLang/  
  webgif  
14 453b7f6 2016-12-18T23:33:06-05:00 oracleofnj: Back to passing all previously passing  
  TCs; on to stragglers  
15 6487840 2016-12-18T23:00:01-05:00 Nigel Schuster: Removed webgif from Makefile  
16 84dca34 2016-12-18T22:29:59-05:00 oracleofnj: Ignore webgif  
17 ed204c2 2016-12-18T22:29:32-05:00 oracleofnj: Ignore webgif  
18 1bcb830 2016-12-18T19:48:02-05:00 GitHub: Merge pull request #41 from ExtendLang/  
  plotting  
19 1cd2360 2016-12-18T19:46:21-05:00 GitHub: Merge branch 'master' into plotting  
20 0058659 2016-12-18T19:30:35-05:00 GitHub: Merge pull request #129 from ExtendLang/  
  remove-debug-final  
21 b54f4aa 2016-12-18T18:54:47-05:00 GitHub: Fix MAXFLOAT  
22 9324fb8 2016-12-18T18:50:59-05:00 GitHub: Merge branch 'master' into plotting  
23 f152bc9 2016-12-18T18:32:21-05:00 oracleofnj: Remove Debug()  
24 c069630 2016-12-18T18:15:40-05:00 Nigel Schuster: Linking plotter is optional  
25 e9dbd0f 2016-12-18T17:05:54-05:00 GitHub: Merge pull request #128 from ExtendLang/back  
  -to-parsing  
26 b602263 2016-12-18T14:12:48-05:00 oracleofnj: Merge in cool program  
27 45d14cf 2016-12-18T14:12:28-05:00 GitHub: Merge pull request #127 from ExtendLang/  
  strcat-bug  
28 790bc51 2016-12-18T14:00:48-05:00 oracleofnj: Merge branch 'cool_program' into back-to  
  -parsing  
29 2eba5e5 2016-12-18T13:59:44-05:00 oracleofnj: Replace C extend_parseString with in-  
  language parseString  
30 1b664be 2016-12-18T09:14:51-05:00 Nigel Schuster: Corrected travis file  
31 554b584 2016-12-18T09:13:54-05:00 Nigel Schuster: Cleand up Makefile mess  
32 a222916 2016-12-18T08:19:54-05:00 GitHub: Merge branch 'master' into plotting
```

```

33 d064d8a 2016-12-18T01:49:39-05:00 Ishaan: Cleanup line function
34 47dace5 2016-12-18T01:48:28-05:00 Ishaan: Test single parameter line chart
35 8f5cf52 2016-12-18T01:43:49-05:00 Ishaan: Fix the testcase fail
36 84cd775 2016-12-18T01:41:50-05:00 Ishaan: update testcase
37 a425775 2016-12-18T01:39:43-05:00 Ishaan: Figure out 2 line issue
38 ba2c3c1 2016-12-18T01:34:34-05:00 Ishaan: Add y values and update testcase
39 7ad5986 2016-12-18T01:18:28-05:00 Ishaan: Trying another version of line
40 b8732dd 2016-12-18T00:42:25-05:00 Ishaan: Fix derp in linechart
41 20e2c43 2016-12-18T00:40:22-05:00 Ishaan: Added basic linechart function to examine
42 b404e12 2016-12-17T23:56:16-05:00 Ishaan: Cast to float
43 e866f68 2016-12-17T23:38:40-05:00 Ishaan: Reverse row and col
44 8419510 2016-12-17T23:27:13-05:00 oracleofnj: That's a wrap
45 6ec3e0e 2016-12-17T23:17:46-05:00 oracleofnj: Proof of concept
46 302af00 2016-12-17T23:09:14-05:00 Ishaan: Updating checks
47 7b09def 2016-12-17T23:03:14-05:00 Ishaan: Testing bar chart plotting, will clean up
    later
48 20adaca 2016-12-17T20:40:13-05:00 oracleofnj: Some bugfixes
49 ad69dcf 2016-12-17T20:12:33-05:00 oracleofnj: Fixed extend side
50 8f76e59 2016-12-17T20:10:06-05:00 Kevin: Fixed highest_tsp to take in any number of
    players
51 0707084 2016-12-17T19:53:58-05:00 oracleofnj: Isolating
52 4479213 2016-12-17T19:47:38-05:00 oracleofnj: much longer
53 4be857f 2016-12-17T19:41:59-05:00 oracleofnj: seg fault
54 74358c1 2016-12-17T19:34:18-05:00 Kevin: Interesting program in Extend
55 ab1eld2 2016-12-17T16:12:00-05:00 oracleofnj: Add some more stdlib funcs
56 b53463d 2016-12-17T14:51:24-05:00 GitHub: Merge pull request #125 from ExtendLang/
    stdlib-string
57 39046bc 2016-12-17T14:39:54-05:00 oracleofnj: Merge branch 'master' into stdlib-string
58 a01cc84 2016-12-17T14:39:40-05:00 oracleofnj: Use toString in toLiteral
59 ec7f10d 2016-12-17T14:38:30-05:00 GitHub: Merge pull request #102 from ExtendLang/
    circular-hotfix
60 73c454b 2016-12-17T14:34:42-05:00 GitHub: Merge branch 'master' into circular-hotfix
61 8126e2e 2016-12-17T14:24:22-05:00 oracleofnj: native toString
62 037728d 2016-12-17T13:46:34-05:00 Nigel Schuster: A lot of wrong paths make it work
63 0a4fd9d 2016-12-17T13:26:34-05:00 Nigel Schuster: Next attempt
64 56905f8 2016-12-17T13:19:59-05:00 Nigel Schuster: Merge branch 'plotting' of https://
    github.com/ExtendLang/Extend into plotting
65 fbf3a1e 2016-12-17T13:19:52-05:00 Nigel Schuster: Manual install (maybe?)
66 1171b71 2016-12-17T13:10:19-05:00 GitHub: Merge branch 'master' into plotting
67 0dbf85d 2016-12-17T13:07:56-05:00 Nigel Schuster: Added libgd for travis
68 060ae45 2016-12-17T13:01:35-05:00 oracleofnj: Merge branch 'master' into stdlib-string
69 4402208 2016-12-17T13:01:24-05:00 oracleofnj: Add round
70 23c2ae6 2016-12-17T13:00:05-05:00 GitHub: Merge pull request #123 from ExtendLang/size
    -asserts
71 0ef936b 2016-12-17T12:33:31-05:00 oracleofnj: Fix merge conflicts
72 4c51203 2016-12-17T11:59:30-05:00 oracleofnj: Right confusion
73 c05cf61 2016-12-17T11:52:34-05:00 oracleofnj: Fix import dir bug
74 39edbb4 2016-12-17T11:46:06-05:00 oracleofnj: Merge branch 'master' into size-asserts
75 339cblf 2016-12-17T11:45:54-05:00 oracleofnj: Fix merge conflict
76 7462381 2016-12-17T11:44:50-05:00 GitHub: Merge pull request #122 from ExtendLang/
    split-stdlib
77 61ac8f2 2016-12-17T11:38:19-05:00 oracleofnj: Size asserts
78 606af9f 2016-12-17T11:22:36-05:00 oracleofnj: Transform asserts into more useful form;
    add calc of assert value to codegen
79 8743e4c 2016-12-17T11:07:31-05:00 Nigel Schuster: Explicit maxfloat
80 0f96e70 2016-12-17T11:02:09-05:00 Nigel Schuster: merge master; Keep tc around for

```

```

testing
81 1882524 2016-12-17T10:54:10-05:00 Nigel Schuster: Creating archive
82 ee4f369 2016-12-17T10:40:17-05:00 oracleofnj: Combine asserts into a single expression
83 0f0f1c8 2016-12-17T10:38:56-05:00 Nigel Schuster: Added right and left to stdlib
84 4dc1597 2016-12-17T10:35:11-05:00 Nigel Schuster: Made compiling workable
85 fa43425 2016-12-17T10:30:23-05:00 oracleofnj: Split stdlib
86 824c53c 2016-12-17T10:11:13-05:00 Nigel Schuster: Added toUpper and toLower
87 ec24177 2016-12-17T10:02:30-05:00 Nigel Schuster: Implemented to and from ASCII
88 ab2e8f8 2016-12-17T09:15:39-05:00 GitHub: Merge pull request #116 from ExtendLang/line
    -plus
89 5d1610b 2016-12-17T09:08:57-05:00 GitHub: Merge branch 'master' into line-plus
90 df3a827 2016-12-17T09:08:48-05:00 GitHub: Merge pull request #117 from ExtendLang/cmd-
    args
91 32a3487 2016-12-17T09:02:27-05:00 GitHub: Merge branch 'master' into cmd-args
92 a8f9d33 2016-12-17T09:00:23-05:00 Nigel Schuster: Args
93 bfccf0c 2016-12-17T08:58:08-05:00 Nigel Schuster: Cut down line count for plus
94 a6bc89a 2016-12-17T08:48:31-05:00 GitHub: Merge pull request #114 from ExtendLang/only
    -new-string
95 5c96b7f 2016-12-17T08:03:27-05:00 GitHub: Merge pull request #109 from ExtendLang/unop
    -bitnot
96 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
97 375bea7 2016-12-16T23:56:35-05:00 oracleofnj: Merge branch 'unop-bitnot' into remove-
    interpreter
98 fb1bd77 2016-12-16T23:54:43-05:00 oracleofnj: Clean up; remove interpreter; change
    DimInt to DimOneByOne
99 539dd75 2016-12-16T23:46:35-05:00 GitHub: Merge branch 'master' into unop-bitnot
100 5668e53 2016-12-16T23:43:57-05:00 Nigel Schuster: Using lrint instead of fptosi
101 45691eb 2016-12-16T23:35:38-05:00 GitHub: Merge pull request #111 from ExtendLang/
    global-semant
102 2cdfb8b 2016-12-16T23:33:26-05:00 GitHub: Merge branch 'master' into global-semant
103 c9500d9 2016-12-16T23:33:14-05:00 GitHub: Merge pull request #112 from ExtendLang/
    remove-function-signatures
104 0c24f54 2016-12-16T23:25:23-05:00 oracleofnj: Remove return signature from grammar and
    all test cases
105 e7f2864 2016-12-16T23:03:53-05:00 oracleofnj: Merge branch 'cleanup-1' into global-
    semant
106 567507e 2016-12-16T22:53:20-05:00 oracleofnj: Check globals; use same symbol_table
    function for semant and codegen
107 33e3942 2016-12-16T22:11:13-05:00 GitHub: Merge branch 'master' into plotting
108 55d8185 2016-12-16T22:00:30-05:00 Nigel Schuster: Removed comments and unnecessary
    files
109 629042f 2016-12-16T21:37:07-05:00 GitHub: Merge branch 'master' into unop-bitnot
110 48b139a 2016-12-16T21:34:09-05:00 Nigel Schuster: Implemented unary bitnot
111 39b02cd 2016-12-16T21:27:22-05:00 oracleofnj: Merge branch 'master' into global-semant
112 28c0983 2016-12-16T21:27:05-05:00 oracleofnj: Remove leftover printf
113 dc182df 2016-12-16T21:09:00-05:00 GitHub: Merge pull request #105 from ExtendLang/rg-
    eq
114 8cdf5c4 2016-12-16T19:31:26-05:00 oracleofnj: Expand test cases for range equality
115 41a3ccc 2016-12-16T19:18:44-05:00 GitHub: Merge branch 'master' into rg-eq
116 8dbebc1 2016-12-16T19:18:15-05:00 GitHub: Merge pull request #104 from ExtendLang/
    prevent-overlapping-formulas
117 c1431b5 2016-12-16T18:55:07-05:00 Nigel Schuster: Implemented basic subrange
    comparison
118 546536e 2016-12-16T18:47:12-05:00 oracleofnj: Detect overlapping formulas and give
    runtime error if present

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119 3562e1b 2016-12-16T18:45:12-05:00 oracleofnj: Merge branch 'sr-val-fix' into prevent-
    overlapping-formulas
120 8713fa0 2016-12-16T18:42:40-05:00 oracleofnj: Checking
121 77d80b9 2016-12-16T18:26:31-05:00 Nigel Schuster: Fixed check for subrange
122 69fb0d2 2016-12-16T17:46:48-05:00 oracleofnj: Circular hotfix
123 4a3ec8d 2016-12-16T17:21:18-05:00 oracleofnj: Add concat
124 962c744 2016-12-16T12:09:00-05:00 GitHub: Merge pull request #101 from ExtendLang/
    finishing-these-range-literals
125 f234e00 2016-12-16T00:21:06-05:00 oracleofnj: Merge branch 'more-stdlib-functions'
    into finishing-these-range-literals
126 c9246ce 2016-12-16T00:20:59-05:00 oracleofnj: testing testing
127 6914039 2016-12-16T00:14:09-05:00 oracleofnj: Third time's the charm
128 4617e44 2016-12-16T00:01:12-05:00 oracleofnj: It compiles now
129 1d8e290 2016-12-15T23:42:43-05:00 oracleofnj: Fingers crossed
130 c9d28d3 2016-12-15T21:50:01-05:00 oracleofnj: Move all initializations into their own
    function; only box strings once
131 1cfdd16 2016-12-15T18:47:30-05:00 oracleofnj: Merge branch 'master' into more-stdlib-
    functions
132 19c2beb 2016-12-15T18:40:12-05:00 oracleofnj: Try a couple more things out
133 845cb04 2016-12-15T18:33:07-05:00 GitHub: Merge pull request #96 from ExtendLang/
    ternary-fix
134 4bfb3bc 2016-12-15T18:23:00-05:00 oracleofnj: Merge branch 'ternary-fix' into more-
    stdlib-functions
135 ae55ca4 2016-12-15T18:21:58-05:00 oracleofnj: Define cell_row, cell_col
136 30a5db6 2016-12-15T18:19:56-05:00 oracleofnj: Merge branch 'ternary-fix' into more-
    stdlib-functions
137 b9f1f10 2016-12-15T18:17:53-05:00 oracleofnj: What is truth?
138 ac84c2f 2016-12-15T18:15:37-05:00 oracleofnj: Fix ternary to work properly with ranges
139 1f57d91 2016-12-15T17:03:26-05:00 oracleofnj: Look at this one
140 437ba46 2016-12-15T16:56:04-05:00 oracleofnj: Try this one
141 f0edf5b 2016-12-15T16:46:52-05:00 oracleofnj: Fixing bug
142 5ba31e6 2016-12-15T14:17:52-05:00 GitHub: Merge pull request #94 from ExtendLang/nan-
    inf
143 67c5739 2016-12-15T14:17:46-05:00 GitHub: Merge pull request #93 from ExtendLang/type-
    typeof
144 48a3d5c 2016-12-15T14:05:37-05:00 oracleofnj: Improve test case
145 8f08227 2016-12-15T13:58:46-05:00 oracleofnj: Add isNaN and isInfinite to stdlib
146 cbeec74 2016-12-15T13:30:31-05:00 oracleofnj: Rename token
147 9582228 2016-12-15T13:18:09-05:00 oracleofnj: Rename type to typeof
148 d1422c7 2016-12-15T10:42:19-05:00 GitHub: Merge pull request #92 from ExtendLang/
    compiler
149 66689bb 2016-12-15T09:08:56-05:00 Nigel Schuster: added working directory option,
    doing testing completely in tmp
150 a13ae93 2016-12-15T09:08:31-05:00 GitHub: Merge pull request #91 from ExtendLang/
    sizeof
151 a31add9 2016-12-15T09:08:13-05:00 GitHub: Merge pull request #90 from ExtendLang/
    subselect-C-side
152 2e67e06 2016-12-15T09:01:06-05:00 Nigel Schuster: Added option to specify compiler,
    using clang
153 c171450 2016-12-15T02:33:48-05:00 oracleofnj: SizeOf
154 c168044 2016-12-15T00:48:35-05:00 oracleofnj: Add row(), column() to codegen, add
    print_endline() to stdlib.xtnd
155 bf9426d 2016-12-15T00:27:13-05:00 oracleofnj: Print subrange
156 407ce41 2016-12-14T23:02:02-05:00 oracleofnj: Merge in subrange_string
157 756ea8e 2016-12-14T22:51:00-05:00 oracleofnj: Ranges
158 27a8e79 2016-12-14T22:16:13-05:00 oracleofnj: Resolve RHS slice

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159 876d056 2016-12-14T22:02:56-05:00 oracleofnj: Resolve RHS index
160 b59e022 2016-12-14T21:46:00-05:00 Nigel Schuster: Added method to print subragne as
    string
161 a7d53a8 2016-12-14T19:55:38-05:00 oracleofnj: Merge branch 'master' into subselect-C-
    side
162 362e85b 2016-12-14T19:55:23-05:00 GitHub: Merge pull request #88 from ExtendLang/
    subselect
163 4912fa3 2016-12-14T19:40:10-05:00 oracleofnj: Add debug print info for slice
    structures
164 c1b33f4 2016-12-14T18:58:45-05:00 oracleofnj: Builder to end all builders
165 5d400c2 2016-12-14T18:55:06-05:00 oracleofnj: Add selection builders
166 29f6e28 2016-12-14T18:20:51-05:00 oracleofnj: Make additional infix operator for
    populating structure element
167 046d096 2016-12-14T17:49:19-05:00 oracleofnj: Set up RHS slice types
168 0d20933 2016-12-14T17:28:38-05:00 GitHub: Merge branch 'master' into plotting
169 614d84f 2016-12-14T17:25:20-05:00 Nigel Schuster: Dummy commit for travis
170 0e78574 2016-12-14T17:24:04-05:00 Nigel Schuster: Merge branch 'plotting' of https://
    github.com/ExtendLang/Extend into plotting
171 2da0d7d 2016-12-14T17:23:56-05:00 Nigel Schuster: Spelling fix
172 b25c2f5 2016-12-14T16:49:17-05:00 GitHub: Merge pull request #87 from ExtendLang/make-
    a-selection
173 7a12082 2016-12-14T16:43:38-05:00 oracleofnj: Move selection test cases back into
    inputs
174 e2c08d5 2016-12-14T16:31:00-05:00 oracleofnj: Make IDs work with deref_subrange
175 02f2f0c 2016-12-14T15:21:31-05:00 GitHub: Merge pull request #86 from ExtendLang/
    include-stdlib
176 8b0503f 2016-12-14T15:18:14-05:00 GitHub: Merge branch 'master' into include-stdlib
177 1f034a0 2016-12-14T15:17:52-05:00 GitHub: Merge pull request #84 from ExtendLang/math-
    linker
178 1e6dd91 2016-12-14T14:58:44-05:00 oracleofnj: Add expected output for slurp
179 ff1a5e3 2016-12-14T14:53:38-05:00 oracleofnj: Remove extend_ prefix from all sample
    code
180 81a2828 2016-12-14T14:48:38-05:00 oracleofnj: Automatically add extend_ prefix to
    external functions
181 dccled3 2016-12-14T14:30:52-05:00 oracleofnj: Fix samples
182 9b2c28f 2016-12-14T12:39:45-05:00 oracleofnj: Include stdlib automatically
183 13650ce 2016-12-14T12:35:21-05:00 Nigel Schuster: Merge branch 'math-linker' of https
    ://github.com/ExtendLang/Extend into math-linker
184 2e0d90d 2016-12-14T12:35:06-05:00 Nigel Schuster: Merge branch 'math-linker' of https
    ://github.com/ExtendLang/Extend into math-linker
185 83c689e 2016-12-14T12:34:14-05:00 Nigel Schuster: Merge branch 'math-linker' of https
    ://github.com/ExtendLang/Extend into math-linker
186 127f600 2016-12-14T12:34:07-05:00 Nigel Schuster: Include sys/resources
187 b34d97a 2016-12-14T12:03:44-05:00 GitHub: Merge branch 'master' into math-linker
188 8297f33 2016-12-14T12:01:47-05:00 GitHub: Merge pull request #85 from ExtendLang/put-
    lt-back
189 6b0c74f 2016-12-14T11:33:45-05:00 Nigel Schuster: Include sys/resources
190 37470e9 2016-12-14T11:14:06-05:00 oracleofnj: Put back LT, comment out sys/time.h
191 6bde590 2016-12-14T11:12:16-05:00 Nigel Schuster: Increasing stack size
192 6acc621 2016-12-14T11:03:31-05:00 Nigel Schuster: Disabled linking math when creating
    an intermediate
193 d87b73c 2016-12-14T10:51:58-05:00 GitHub: Merge pull request #82 from ExtendLang/hard-
    to-repro-bug
194 d126e3c 2016-12-14T00:51:00-05:00 oracleofnj: Try with time.h instead of sys/time.h
195 a535612 2016-12-14T00:48:35-05:00 oracleofnj: Remove lrints
196 e844853 2016-12-14T00:34:37-05:00 oracleofnj: Initialize all variables and remove

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    pointer math; bug appears fixed
197 4c1a421 2016-12-13T22:55:07-05:00 oracleofnj: Some formula is weird
198 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
199 879eaf3 2016-12-13T22:43:17-05:00 oracleofnj: Testing
200 37f5ce2 2016-12-13T22:42:40-05:00 GitHub: Merge pull request #83 from ExtendLang/
    rounding-for-read
201 a1cfc5a 2016-12-13T22:34:21-05:00 Nigel Schuster: Added rounding at several places
202 e20f7e4 2016-12-13T21:36:13-05:00 oracleofnj: Half the time it works
203 9f97b1a 2016-12-13T20:38:08-05:00 GitHub: Merge branch 'master' into plotting
204 61bc9b6 2016-12-13T20:33:27-05:00 GitHub: Merge pull request #81 from ExtendLang/fix-
    em-all
205 4a810df 2016-12-13T19:34:29-05:00 Nigel Schuster: Corrected testcase outputs
206 ae5b8a8 2016-12-13T19:08:43-05:00 GitHub: Merge pull request #80 from ExtendLang/
    select
207 70b2704 2016-12-13T19:02:32-05:00 oracleofnj: No C99
208 15fd762 2016-12-13T18:42:21-05:00 oracleofnj: Merge branch 'master' into select
209 8e6e9ba 2016-12-13T18:42:05-05:00 GitHub: Merge pull request #78 from ExtendLang/unop-
    unary-minus
210 7a93885 2016-12-13T18:41:49-05:00 oracleofnj: Calculate all formula indices
211 07e63dc 2016-12-13T18:19:58-05:00 oracleofnj: Properly build instantiate var
212 1a29129 2016-12-13T17:24:16-05:00 oracleofnj: Replace bools with chars for
    compatibility between C and LLVM
213 12e78a3 2016-12-13T17:17:54-05:00 oracleofnj: Added debug output
214 a483282 2016-12-13T16:13:30-05:00 oracleofnj: Merge branch 'master' into unop-unary-
    minus
215 f8c9b43 2016-12-13T16:13:09-05:00 oracleofnj: Make TypeOf work
216 8146d04 2016-12-13T16:12:17-05:00 GitHub: Merge pull request #75 from ExtendLang/fix-
    more-tc
217 94afc93 2016-12-13T16:02:35-05:00 Nigel Schuster: Corrected expected TC
218 f6f8276 2016-12-13T16:00:59-05:00 Nigel Schuster: Fixed string.xtnd file
219 dcd5766 2016-12-13T15:44:38-05:00 GitHub: Merge pull request #74 from ExtendLang/fix-
    tc
220 bfe1c07 2016-12-13T15:39:45-05:00 oracleofnj: Merge branch 'master' into unop-unary-
    minus
221 d9abfc0 2016-12-13T15:38:38-05:00 GitHub: Merge branch 'master' into fix-tc
222 50ed49c 2016-12-13T15:38:04-05:00 oracleofnj: Merging in main
223 23328f1 2016-12-13T15:37:18-05:00 GitHub: Merge pull request #73 from ExtendLang/and-
    or-xor
224 324779a 2016-12-13T15:32:26-05:00 Nigel Schuster: Corrected expected value
225 fafe2e6 2016-12-13T15:29:21-05:00 Nigel Schuster: Fixed string tc
226 022f05c 2016-12-13T15:23:59-05:00 Nigel Schuster: Fixed testcase
227 b12fe37 2016-12-13T15:18:57-05:00 Nigel Schuster: Implemented and, or and xor
228 90cbaa0 2016-12-13T15:16:31-05:00 Nigel Schuster: Added left and right shift
229 571ee7e 2016-12-13T14:56:05-05:00 Nigel Schuster: Merge branch 'power' of https://
    github.com/ExtendLang/Extend into power
230 aeab40d 2016-12-13T14:55:57-05:00 Nigel Schuster: Removed unnecessary level of
    indirection
231 e377567 2016-12-13T14:53:28-05:00 GitHub: Merge branch 'master' into power
232 6ad8512 2016-12-13T14:53:11-05:00 GitHub: Merge pull request #69 from ExtendLang/unop-
    unary-minus
233 71f395d 2016-12-13T14:46:27-05:00 Nigel Schuster: Power to the people of Extend
234 6a04209 2016-12-13T14:45:46-05:00 oracleofnj: Fix merge conflict
235 edb0ecc 2016-12-13T14:43:32-05:00 oracleofnj: Add unary minus
236 668a0eb 2016-12-13T14:37:19-05:00 GitHub: Merge pull request #68 from ExtendLang/mod-
    div

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237 866b68f 2016-12-13T14:32:18-05:00 Nigel Schuster: Added modulo and division operation
 238 46d5aa6 2016-12-13T14:26:35-05:00 oracleofnj: Merge branch 'master' into unop-typeof
 239 84dfc33 2016-12-13T14:26:25-05:00 Nigel Schuster: Crunched some code
 240 76210eb 2016-12-13T14:26:18-05:00 oracleofnj: Start on it
 241 f4d5a81 2016-12-13T14:22:12-05:00 Nigel Schuster: Merge branch 'master' into
 simplification
 242 f873242 2016-12-13T14:21:26-05:00 GitHub: Merge pull request #65 from ExtendLang/
 subtraction
 243 fc94112 2016-12-13T14:20:35-05:00 Nigel Schuster: Added multiplication
 244 6c26c2c 2016-12-13T14:19:07-05:00 GitHub: Merge branch 'master' into subtraction
 245 4afd78e 2016-12-13T14:18:55-05:00 GitHub: Merge pull request #64 from ExtendLang/
 refactor-boolean-binops
 246 d4d4388 2016-12-13T14:15:58-05:00 GitHub: Merge branch 'master' into refactor-boolean-
 binops
 247 bd90241 2016-12-13T14:14:17-05:00 GitHub: Merge branch 'master' into subtraction
 248 4042259 2016-12-13T14:13:09-05:00 Nigel Schuster: Added subtraction
 249 663f399 2016-12-13T14:12:57-05:00 oracleofnj: Remove wildcard from BinOp pattern match
 250 82a3db2 2016-12-13T14:11:31-05:00 Nigel Schuster: Merge branch 'master' into
 subtraction
 251 1bf6bed 2016-12-13T14:09:47-05:00 oracleofnj: Add TransformedAway exception for LogAnd
 and LogOr
 252 c7d4162 2016-12-13T14:02:13-05:00 GitHub: Merge pull request #63 from ExtendLang/more-
 binops
 253 952778e 2016-12-13T14:01:54-05:00 oracleofnj: Change Lt, Lte in grammar; implement GTE
 254 97821c8 2016-12-13T13:47:52-05:00 oracleofnj: GT
 255 1e1f973 2016-12-13T13:44:36-05:00 Nigel Schuster: Subtraction
 256 e0a883a 2016-12-13T13:37:57-05:00 oracleofnj: Remove NotEq from AST since != is parsed
 to UnOp(LogNot, BinOp(Eq, ...))
 257 cc40008 2016-12-13T12:49:33-05:00 GitHub: Merge pull request #60 from ExtendLang/
 addition2
 258 7123ebc 2016-12-13T12:41:09-05:00 GitHub: Merge branch 'master' into addition2
 259 a656f57 2016-12-13T12:38:12-05:00 GitHub: Merge pull request #61 from ExtendLang/debug
 -unop
 260 c3a96a9 2016-12-13T12:37:31-05:00 Nigel Schuster: Merge branch 'master' into plotting
 261 f59d962 2016-12-13T12:34:49-05:00 Nigel Schuster: Moved make of lib to travis script
 262 eb134b3 2016-12-13T12:29:53-05:00 Nigel Schuster: Moved testcases
 263 044c6bd 2016-12-13T12:29:07-05:00 Nigel Schuster: Fixed off by one error
 264 a64cc15 2016-12-13T12:14:45-05:00 oracleofnj: Add Debug expr
 265 59858a0 2016-12-13T11:33:12-05:00 oracleofnj: Whoops no space
 266 0426f34 2016-12-13T11:30:26-05:00 oracleofnj: Add test case
 267 49ffa86 2016-12-13T11:19:14-05:00 GitHub: Merge branch 'master' into addition2
 268 81533f4 2016-12-13T11:13:44-05:00 GitHub: Merge pull request #59 from ExtendLang/equal-
 -rights
 269 3cdaa5a 2016-12-13T11:12:41-05:00 Nigel Schuster: String addition
 270 64d1760 2016-12-13T11:04:55-05:00 oracleofnj: Wake up please, GitHub
 271 840aeaf 2016-12-13T10:48:03-05:00 oracleofnj: Remove usage demonstration
 272 61ff439 2016-12-13T03:26:35-05:00 oracleofnj: Add string equality and test cases
 273 f3112e9 2016-12-13T01:57:10-05:00 oracleofnj: Reduce cut & paste
 274 08ce677 2016-12-13T01:35:46-05:00 oracleofnj: Remove obsolete testing file
 275 ae8a07e 2016-12-13T01:23:26-05:00 oracleofnj: Merge branch 'print_value_p' into equal-
 rights
 276 6090713 2016-12-13T01:22:47-05:00 oracleofnj: Use correct printf specifier
 277 862b38c 2016-12-13T01:19:14-05:00 oracleofnj: Merge branch 'print_value_p' into equal-
 rights
 278 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(

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Neg)
279 50281b1 2016-12-13T00:47:28-05:00 oracleofnj: Numeric equality
280 0f76aa4 2016-12-12T22:30:15-05:00 oracleofnj: Remove print flags
281 200b8b6 2016-12-12T22:16:15-05:00 GitHub: Merge pull request #57 from ExtendLang/
    addition2
282 da7c543 2016-12-12T12:43:31-05:00 Nigel Schuster: Setting flag for addition
283 7e7276b 2016-12-12T12:37:35-05:00 Nigel Schuster: Merge branch 'master' into addition2
284 8834635 2016-12-12T10:18:51-05:00 GitHub: Merge pull request #55 from ExtendLang/
    runtime
285 53ae9e0 2016-12-12T10:06:24-05:00 GitHub: Merge branch 'master' into runtime
286 6ed303e 2016-12-12T09:43:57-05:00 GitHub: Merge pull request #56 from ExtendLang/
    truthy-fix
287 ae49ce6 2016-12-12T01:15:29-05:00 oracleofnj: Remove extra file
288 7fe6a22 2016-12-12T01:11:53-05:00 oracleofnj: Falsey fix
289 d1e196d 2016-12-12T00:23:13-05:00 Nigel Schuster: Extracted runtime into seperate file
290 ecc620e 2016-12-12T00:17:06-05:00 GitHub: Merge pull request #54 from ExtendLang/final
    -draft-for-real
291 4c8caa5 2016-12-12T00:09:16-05:00 GitHub: Merge branch 'master' into final-draft-for-
    real
292 04d3b57 2016-12-12T00:00:29-05:00 GitHub: Merge pull request #39 from ExtendLang/more-
    lrm-ed
293 39025b0 2016-12-11T23:59:18-05:00 Nigel Schuster: Fixed examples, made small
    corrections
294 a875b41 2016-12-11T23:51:30-05:00 GitHub: Merge pull request #53 from ExtendLang/
    truthy
295 616dd34 2016-12-11T23:15:54-05:00 oracleofnj: Merge branch 'master' into truthy
296 0fa8255 2016-12-11T23:14:42-05:00 oracleofnj: Apparently still needs some work
297 78584d7 2016-12-11T23:09:07-05:00 oracleofnj: Thanks a lot Travis
298 b5673d2 2016-12-11T22:51:52-05:00 oracleofnj: TERRRRRRRRR NARRRRRRR
    EEEEEEEEEEEEEEEEEEE
299 b81bc1b 2016-12-11T22:04:25-05:00 oracleofnj: Maybe Truthy
300 b95d14f 2016-12-11T21:02:28-05:00 GitHub: Merge pull request #50 from ExtendLang/
    builder-hotfix
301 6dea96f 2016-12-11T20:40:47-05:00 oracleofnj: So many builders
302 8aa125f 2016-12-11T20:15:52-05:00 Nigel Schuster: Made som rpgroess
303 2a905c7 2016-12-11T19:15:47-05:00 GitHub: Merge pull request #47 from ExtendLang/
    function-parameter
304 2bc6c85 2016-12-11T19:11:33-05:00 oracleofnj: Add combined test case
305 860a11b 2016-12-11T19:04:35-05:00 oracleofnj: Merge branch 'master' into function-
    parameter
306 8c3499e 2016-12-11T19:03:39-05:00 oracleofnj: Remove extraneous printlines
307 99418c0 2016-12-11T19:02:31-05:00 oracleofnj: Make function parameters work
308 6c00a72 2016-12-11T18:45:46-05:00 Nigel Schuster: Some progress
309 387559b 2016-12-11T18:39:00-05:00 oracleofnj: First attempt
310 18fc1be 2016-12-11T18:08:11-05:00 GitHub: Merge pull request #45 from ExtendLang/empty
311 d7590da 2016-12-11T17:42:46-05:00 GitHub: Merge branch 'master' into plotting
312 f7e9be8 2016-12-11T16:30:05-05:00 GitHub: Merge branch 'master' into empty
313 f1dd8a5 2016-12-11T16:18:44-05:00 GitHub: Merge pull request #46 from ExtendLang/
    actually-make-global-scope
314 50366f4 2016-12-11T15:38:05-05:00 oracleofnj: Make sure locals are properly masking
    globals
315 046c7cc 2016-12-11T15:30:53-05:00 oracleofnj: Make globals work, fix bug
316 a844a46 2016-12-11T15:14:09-05:00 oracleofnj: So close
317 18db166 2016-12-11T15:05:42-05:00 GitHub: Merge branch 'master' into empty
318 67849f0 2016-12-11T15:01:52-05:00 oracleofnj: Make the global scope object
319 393d02c 2016-12-11T14:25:02-05:00 Nigel Schuster: Implemented empty, small flag

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    setting fix
320 3c4681d 2016-12-11T13:31:12-05:00 GitHub: Merge pull request #44 from ExtendLang/float
    -display-hotfix
321 7be1001 2016-12-11T13:26:55-05:00 GitHub: Merge branch 'master' into float-display-
    hotfix
322 b192a23 2016-12-11T13:26:48-05:00 Nigel Schuster: Added gdchart compile step
323 abcffd0 2016-12-11T13:19:05-05:00 GitHub: Merge pull request #42 from ExtendLang/
    encapsulate-build-scope
324 556da44 2016-12-11T13:18:15-05:00 oracleofnj: Floating point math hotfix
325 0ad195e 2016-12-11T12:42:42-05:00 oracleofnj: Merge branch 'master' into encapsulate-
    build-scope
326 9caf464 2016-12-11T12:41:40-05:00 oracleofnj: Encapsulate a little more of building
    the scope
327 1ae8d43 2016-12-11T12:23:04-05:00 Ishaan: Add new gitignore
328 6278c7b 2016-12-11T12:18:49-05:00 Ishaan: Rebase and add gdchart in lib/
329 5594687 2016-12-11T12:13:20-05:00 Ishaan: Remove images from version control
330 294a6db 2016-12-11T12:13:20-05:00 Ishaan: Write to file instead of stdout
331 08e9f75 2016-12-11T12:11:13-05:00 Ishaan: Add hardcoded graph functionality
332 d65aad4 2016-12-11T12:09:28-05:00 GitHub: Merge pull request #40 from ExtendLang/make-
    global-scope
333 b5b33f1 2016-12-11T12:09:12-05:00 Ishaan: Update gitignore to avoid the gdchart
    package
334 6746e8a 2016-12-11T12:09:12-05:00 Ishaan: Checking gif
335 83c2e09 2016-12-11T12:09:12-05:00 Ishaan: Add hardcoded plot function without params
    or installation
336 0f5a6ba 2016-12-11T12:04:05-05:00 oracleofnj: Merge branch 'master' into make-global-
    scope
337 56b58d9 2016-12-11T12:01:28-05:00 oracleofnj: Encapsulate build_var_defns
338 f25e5b3 2016-12-11T11:43:19-05:00 oracleofnj: Only construct var_defns once
339 9cee2fc 2016-12-11T10:07:36-05:00 Nigel Schuster: Testcases (#38)
340 f3f4bef 2016-12-11T00:45:44-05:00 oracleofnj: Make global variable to hold vardefns
341 a0ed757 2016-12-10T23:31:38-05:00 Nigel Schuster: Edited explanation for row() and
    column()
342 7c50ef2 2016-12-10T23:27:07-05:00 Nigel Schuster: Added info for strings
343 738e41b 2016-12-10T23:24:20-05:00 Nigel Schuster: Added boolean example
344 5377fdf 2016-12-10T23:19:26-05:00 Nigel Schuster: Added arithmetic example
345 a8f4ad9 2016-12-10T21:28:18-05:00 oracleofnj: Isolate the part of building a scope for
    reuse with global variables
346 58f7a4d 2016-12-10T18:05:01-05:00 Nigel Schuster: Performing copy before returning, so
    that memory can be freed with alloca
347 c0e56aa 2016-12-10T17:07:00-05:00 GitHub: Merge pull request #37 from ExtendLang/
    dereference
348 a4b35df 2016-12-10T16:42:17-05:00 Nigel Schuster: Removed obsolete methods
349 cf08a8c 2016-12-10T16:36:20-05:00 GitHub: Merge branch 'master' into dereference
350 ef0e5e7 2016-12-10T16:36:03-05:00 GitHub: Merge pull request #36 from ExtendLang/comp-
    warn
351 0177dc2 2016-12-10T16:35:50-05:00 GitHub: Merge pull request #35 from ExtendLang/
    linker
352 127f99d 2016-12-10T16:35:41-05:00 GitHub: Merge pull request #34 from ExtendLang/rel-
    import
353 b2e881d 2016-12-10T16:35:31-05:00 GitHub: Merge pull request #33 from ExtendLang/ts-
    fix
354 ce833d4 2016-12-10T16:14:34-05:00 Nigel Schuster: Dereferencing 1x1 subrange
355 e259556 2016-12-10T13:53:12-05:00 Nigel Schuster: Removed nodefaultlibs directive
356 09c3961 2016-12-10T13:50:19-05:00 Nigel Schuster: Modified linker to work for travis
357 36d662a 2016-12-10T13:37:27-05:00 Nigel Schuster: Attempt to link math

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358 2d4564a 2016-12-10T13:22:14-05:00 Nigel Schuster: Linking math library
359 38ba6e6 2016-12-10T13:18:39-05:00 Nigel Schuster: Suppressing compiler warnings
360 9deac9b 2016-12-10T13:06:39-05:00 Nigel Schuster: Modified compile script. Removed
    debug output
361 d35607b 2016-12-10T13:04:30-05:00 Nigel Schuster: Simpler testscript
362 d37dac2 2016-12-10T12:36:45-05:00 Nigel Schuster: Fixed duplicate import issue
363 31c26bc 2016-12-10T12:30:29-05:00 Nigel Schuster: Added cmd args to link file
364 a350720 2016-12-10T11:40:50-05:00 Nigel Schuster: Switched import style from root
    directory to relative path
365 90e39b0 2016-12-10T11:24:19-05:00 Nigel Schuster: Fixed issue in testscript that might
    report false results when it fails early
366 718ecd3 2016-12-10T03:09:18-05:00 oracleofnj: Some changes to LRM; add if(a,b,c)
367 6a8f836 2016-12-09T18:29:22-05:00 GitHub: Merge pull request #24 from ExtendLang/final
    -draft-lrm
368 fc886a9 2016-12-09T18:23:52-05:00 oracleofnj: Merge branch 'final-draft-lrm'
369 cda63cb 2016-12-09T18:23:24-05:00 oracleofnj: Fix merge conflict
370 eac9e77 2016-12-09T18:04:08-05:00 GitHub: Merge pull request #29 from ExtendLang/
    refactor
371 fe825f4 2016-12-09T17:55:39-05:00 oracleofnj: Compact last bit
372 b02dbbe 2016-12-09T17:49:00-05:00 oracleofnj: Give formula functions names
373 edd7aa4 2016-12-09T17:40:57-05:00 Nigel Schuster: Removed artifcats
374 9b49e20 2016-12-09T17:37:59-05:00 Nigel Schuster: Fixed I/O testcases
375 a4ad4b1 2016-12-09T17:18:13-05:00 Nigel Schuster: Merge
376 b07398b 2016-12-09T17:17:19-05:00 Nigel Schuster: Added macro for function definition
377 ed01567 2016-12-09T17:17:06-05:00 oracleofnj: Make sizeof not break tests
378 a0a7054 2016-12-09T17:01:20-05:00 oracleofnj: Use symbol table
379 56fd61b 2016-12-09T16:11:10-05:00 oracleofnj: Merge branch 'refactor' of https://
    github.com/ExtendLang/Extend into refactor
380 38aedba 2016-12-09T16:10:35-05:00 oracleofnj: Create symbol table
381 dfb702e 2016-12-09T16:01:08-05:00 Nigel Schuster: Converted more to value_p from
    subrange_p
382 e963186 2016-12-09T15:42:35-05:00 Nigel Schuster: Made example TC work
383 eb76234 2016-12-09T11:14:58-05:00 Nigel Schuster: Made Hello World work again
384 08aeb70 2016-12-09T02:13:09-05:00 oracleofnj: Done for the night
385 cb39114 2016-12-09T01:35:36-05:00 oracleofnj: More refactoring
386 7974bbd 2016-12-08T23:53:31-05:00 oracleofnj: Banish the term extern
387 49af972 2016-12-08T23:45:30-05:00 oracleofnj: Add a couple comments
388 0fbf461 2016-12-08T21:52:24-05:00 oracleofnj: Get my bearings
389 5ecb599 2016-12-08T19:47:51-05:00 Nigel Schuster: Added some documentation
390 65066fc 2016-12-08T12:18:57-05:00 Nigel Schuster: Added name display for variable
391 fb18949 2016-12-07T23:44:17-05:00 oracleofnj: Merge branch 'master' into final-draft-
    lrm
392 4aab3dc 2016-12-07T23:43:25-05:00 oracleofnj: Update PDF
393 ed44d27 2016-12-07T23:43:01-05:00 oracleofnj: Fix failing test cases
394 9354fa7 2016-12-07T23:06:36-05:00 oracleofnj: Final draft candidate
395 78649f4 2016-12-07T18:09:46-05:00 oracleofnj: Almost done
396 05ded19 2016-12-07T15:47:52-05:00 oracleofnj: More work
397 f985cc8 2016-12-07T12:14:59-05:00 Nigel Schuster: Merge branch 'finish-transformations
    ' into get-val-rev
398 4b58ce9 2016-12-07T12:13:23-05:00 Nigel Schuster: Tried to add more instructions
399 0722412 2016-12-07T11:32:11-05:00 oracleofnj: Working
400 099efe7 2016-12-07T10:48:35-05:00 Nigel Schuster: Making progress on evaluating
    dimensions
401 fa09df7 2016-12-07T09:51:23-05:00 Nigel Schuster: Finally it works
402 cbb0577 2016-12-07T02:35:06-05:00 oracleofnj: Still WIP
403 e3c9436 2016-12-07T00:44:22-05:00 oracleofnj: WIP

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404 b265e74 2016-12-07T00:41:23-05:00 Nigel Schuster: test commit to look at
405 18bb182 2016-12-07T00:35:06-05:00 oracleofnj: Still work in progress
406 a4554c0 2016-12-06T23:14:32-05:00 Nigel Schuster: At least it compiles
407 3432484 2016-12-06T22:42:22-05:00 Nigel Schuster: Getting closer. Need to add var_defn
    wrapper in build_formula
408 05145ca 2016-12-06T21:10:11-05:00 Nigel Schuster: Minor fix
409 af69b92 2016-12-06T17:23:45-05:00 oracleofnj: More updates
410 a65c24e 2016-12-06T16:14:10-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
411 85a4ccb 2016-12-06T16:12:31-05:00 oracleofnj: LRM update part 1
412 174a7b8 2016-12-06T11:09:31-05:00 Nigel Schuster: Made partial progress on
    implementing variable instantiation and such
413 90fc58e 2016-12-05T22:14:41-05:00 GitHub: Merge pull request #23 from ExtendLang/read-
    empty
414 767851d 2016-12-05T16:18:17-05:00 Nigel Schuster: Finished C side implementation of
    getVal
415 6b837d4 2016-12-05T16:06:34-05:00 Nigel Schuster: Merge branch 'master' into get-val
416 04c2c65 2016-12-05T15:53:35-05:00 oracleofnj: Add slurp by passing 0 max bytes
417 d8cf316 2016-12-05T14:46:46-05:00 oracleofnj: Start handling empty
418 910bd01 2016-12-05T14:27:07-05:00 GitHub: Merge pull request #21 from ExtendLang/
    fileio
419 1ce7f83 2016-12-05T14:18:41-05:00 oracleofnj: Create patch file
420 88480fb 2016-12-05T13:36:28-05:00 GitHub: Merge branch 'master' into fileio
421 29d02d9 2016-12-05T13:34:27-05:00 oracleofnj: Fix merge conflict - keep expr_loc
422 52e7a8a 2016-12-05T13:32:54-05:00 GitHub: Merge pull request #22 from ExtendLang/rm-
    micro
423 bfa906b 2016-12-05T13:28:03-05:00 oracleofnj: Fix off-by-one bug
424 eb8dd71 2016-12-05T13:20:03-05:00 oracleofnj: Address issues
425 f1b11ee 2016-12-05T12:46:35-05:00 Nigel Schuster: Skeleton for get_val
426 e4e5e26 2016-12-05T09:25:17-05:00 Nigel Schuster: Removed microc reference
    implementation
427 270da2b 2016-12-05T02:40:59-05:00 GitHub: Merge branch 'master' into fileio
428 b928e98 2016-12-05T02:40:10-05:00 Ishaan: Remove bloat
429 894b511 2016-12-05T02:32:49-05:00 Ishaan: Added testcase
430 62b8e83 2016-12-05T02:30:16-05:00 Ishaan: Added fwrite implementation
431 77a23ae 2016-12-05T01:39:30-05:00 Ishaan: Added read
432 46e9b58 2016-12-05T00:07:16-05:00 Ishaan: Make refactoring changes and new helpers
433 a5b9066 2016-12-04T14:00:30-05:00 GitHub: Merge pull request #20 from ExtendLang/lhs-
    all-ids
434 35e9471 2016-12-04T13:38:44-05:00 oracleofnj: Put back Id(s) as it was
435 641d454 2016-12-04T13:36:36-05:00 oracleofnj: Always transform to ID on LHS, even for
    LitInts
436 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
437 f47f2ba 2016-12-04T10:30:44-05:00 oracleofnj: Add error handling to close() and add a
    couple test cases
438 e95a95a 2016-12-04T10:07:01-05:00 oracleofnj: Add assertSingleNumber and get_number to
    eliminate more copy & paste
439 543e720 2016-12-04T09:47:03-05:00 oracleofnj: Add new_number() to eliminate some copy
    and paste
440 d7f10c9 2016-12-04T02:31:03-05:00 Ishaan: Tentative drafts of fileio functions
441 7d81e43 2016-12-04T00:15:20-05:00 oracleofnj: add diagnostic printf
442 868d9a4 2016-12-03T23:46:01-05:00 Ishaan: Cleanup
443 aa1e014 2016-12-03T23:42:46-05:00 Ishaan: Add file pointer array
444 88d05de 2016-12-03T18:38:34-05:00 Ishaan: Working on fopen
445 36f5848 2016-12-03T14:07:39-05:00 oracleofnj: Merge branch 'master' into finish-

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transformations
446 2ae2b83 2016-12-03T14:06:40-05:00 GitHub: Merge pull request #15 from ExtendLang/
    stdlib-fun
447 7c78a23 2016-12-03T14:02:51-05:00 oracleofnj: Move test_fabs out of regression test
    suite
448 0a8055b 2016-12-03T13:48:19-05:00 oracleofnj: make test | grep REGRESSION
449 a24742b 2016-12-02T22:50:43-05:00 Kevin: Merged stdlib with master
450 5243c5a 2016-12-02T18:16:36-05:00 Kevin: Removed magic numbers and add fabs test
451 330bec3 2016-12-02T13:49:34-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
452 8a60995 2016-12-01T23:38:54-05:00 GitHub: Merge pull request #18 from ExtendLang/
    parser-error
453 f0d33e2 2016-12-01T23:18:39-05:00 oracleofnj: Move error handling
454 3b24c3a 2016-12-01T23:16:53-05:00 oracleofnj: Adjust test script
455 60a732f 2016-12-01T22:55:28-05:00 oracleofnj: Merge branch 'master' into parser-error
456 5dec6a2 2016-12-01T22:55:05-05:00 oracleofnj: Thank you Nigel!!!
457 96a3028 2016-12-01T22:19:21-05:00 GitHub: Merge pull request #16 from ExtendLang/fail-
    silent
458 6c3696c 2016-12-01T21:59:40-05:00 oracleofnj: Figure out why test is failing
459 7912d5a 2016-12-01T21:26:03-05:00 GitHub: Merge branch 'master' into fail-silent
460 9702e5b 2016-12-01T21:14:35-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
461 5bdd52c 2016-12-01T21:13:45-05:00 GitHub: Merge pull request #17 from ExtendLang/
    lexbuf-pos
462 8893255 2016-12-01T20:35:04-05:00 oracleofnj: Add a couple test cases
463 2868653 2016-12-01T20:23:01-05:00 oracleofnj: Use lexbuf.lex_curr_p to calculate
    position
464 8c7b6ce 2016-12-01T18:59:49-05:00 GitHub: Merge pull request #11 from ExtendLang/
    parse_error
465 2885ac7 2016-12-01T18:56:15-05:00 Ishaan: Added test case for string
466 047cfec 2016-12-01T18:42:04-05:00 oracleofnj: Add short circuiting test cases
467 6acd7f6 2016-12-01T18:31:33-05:00 oracleofnj: Merge remote-tracking branch 'origin/
    fail-silent' into finish-transformations
468 72360f4 2016-12-01T17:09:08-05:00 Nigel Schuster: Minified error output for outputs
    that have not passed yet
469 5762112 2016-12-01T16:04:06-05:00 oracleofnj: Get rid of wildcard pattern match in
    interpreter
470 a90a343 2016-12-01T15:59:40-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
471 85bc21d 2016-12-01T15:59:05-05:00 oracleofnj: Remove unnecessary file
472 81fe565 2016-12-01T15:58:40-05:00 oracleofnj: Finish range literals
473 e9fblc2 2016-12-01T15:04:03-05:00 Ishaan: Added increment to string buffer and tests
474 eb7cle8 2016-12-01T15:04:03-05:00 Ishaan: Add partial character indexing
475 df09aea 2016-12-01T15:04:03-05:00 Ishaan: Add expected parse testcase intermediate
476 712a710 2016-12-01T15:04:03-05:00 Ishaan: Added tentative scanner-level line number
477 bf4ee6c 2016-12-01T15:04:03-05:00 Ishaan: Added SyntaxError Exception at scan level
478 da41520 2016-12-01T14:54:21-05:00 oracleofnj: So close
479 7abb394 2016-12-01T14:07:58-05:00 GitHub: Merge pull request #14 from ExtendLang/
    sinner
480 e0b7fdb 2016-12-01T14:05:38-05:00 Nigel Schuster: Rename empty to new_val
481 2cabadc 2016-12-01T11:58:03-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
482 6ea8cff 2016-12-01T10:10:26-05:00 Nigel Schuster: Using define instead of magic
    numbers
483 cd7d261 2016-12-01T10:07:10-05:00 Nigel Schuster: Merge branch 'master' into sinner
484 13cd317 2016-12-01T10:06:25-05:00 GitHub: Merge pull request #13 from ExtendLang/

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value_p
485 cf36f70 2016-12-01T09:47:38-05:00 oracleofnj: Sample digits function
486 4eed07 2016-12-01T01:02:56-05:00 Ishaan: Change print return type to empty
487 fa42f27 2016-12-01T00:41:47-05:00 Kevin: Fixed acos function
488 53d34ad 2016-12-01T00:29:32-05:00 Nigel Schuster: Moved double values type to numeric
489 f769c61 2016-12-01T00:18:07-05:00 Nigel Schuster: Merge branch 'sinner' into stdlib-
fun
490 3986f38 2016-12-01T00:17:21-05:00 Nigel Schuster: Merge branch 'value_p' into sinner
491 5bd87f9 2016-12-01T00:14:45-05:00 Nigel Schuster: Explicitly declaring to link math
library
492 4604545 2016-12-01T00:12:08-05:00 Nigel Schuster: Consistently using floats
493 38b9824 2016-11-30T23:46:14-05:00 Nigel Schuster: Merge branch 'value_p' into sinner
494 3303575 2016-11-30T23:45:25-05:00 Nigel Schuster: Explicitly declaring to link math
library
495 31a74ec 2016-11-30T23:35:34-05:00 Nigel Schuster: Merge branch 'master' into value_p
496 7f0bc86 2016-11-30T23:04:34-05:00 Kevin: Finished remainder of stdlib
497 cd160df 2016-11-30T22:50:18-05:00 Kevin: Added more c functions to stdlib
498 e085977 2016-11-30T19:59:57-05:00 Nigel Schuster: Made sin function work
499 206ee5a 2016-11-30T19:07:28-05:00 Nigel Schuster: Moved all function signatures to
value_p return value
500 effc20b 2016-11-30T18:45:52-05:00 GitHub: Merge pull request #12 from ExtendLang/easy-
compile
501 3b6d7b7 2016-11-30T17:51:19-05:00 Nigel Schuster: Added script to compile and link
502 febcff8 2016-11-30T15:54:45-05:00 oracleofnj: Add oddball formula test case and try
out theory for range literal
503 4a1ff4f 2016-11-30T14:54:05-05:00 oracleofnj: Finish reducing Ternary to
ReducedTernary
504 8f0a981 2016-11-30T12:35:43-05:00 oracleofnj: Working on reducing ternaries
505 d3c5812 2016-11-30T02:39:58-05:00 oracleofnj: Finish desugaring switch
506 0a22713 2016-11-30T00:09:10-05:00 oracleofnj: Getting ready to ternarize switch
507 84f016a 2016-11-29T21:54:15-05:00 oracleofnj: Fix bug in switch() with default case
508 d331b7a 2016-11-29T17:33:41-05:00 oracleofnj: Give desugaring variables easier-to-read
names for debugging purposes
509 36f8de5 2016-11-29T16:14:46-05:00 oracleofnj: Missed one
510 d96da34 2016-11-29T16:13:21-05:00 oracleofnj: Transform &&, || into ternary
expressions to support proper short-circuit evaluation
511 3a8efbc 2016-11-28T23:05:28-05:00 GitHub: Merge pull request #9 from ExtendLang/func-
calls
512 7a2af49 2016-11-28T20:33:53-05:00 Nigel Schuster: Removed another ocaml 4.3 dep
513 468e79f 2016-11-28T19:50:53-05:00 Nigel Schuster: Added ocaml 4.3 as dep for travis (
hopefully this works)
514 a408761 2016-11-28T19:35:49-05:00 Nigel Schuster: Fixed String.equal
515 90c3caf 2016-11-27T22:52:14-05:00 Nigel Schuster: Fixed interpreter for now
516 a18da78 2016-11-27T22:42:27-05:00 Nigel Schuster: Added accidentally created file
517 5647312 2016-11-27T22:41:22-05:00 Nigel Schuster: Made extern function calls work
518 872aa8c 2016-11-27T13:52:44-05:00 Nigel Schuster: Merge branch 'func-calls' of https
://github.com/ExtendLang/Extend into func-calls
519 26ef1cc 2016-11-27T13:51:06-05:00 Nigel Schuster: Merging list of functions
520 877336f 2016-11-27T12:15:11-05:00 GitHub: Merge branch 'master' into func-calls
521 5b3edb0 2016-11-27T12:14:43-05:00 GitHub: Merge pull request #8 from ExtendLang/stdlib
-template
522 374273f 2016-11-27T12:13:52-05:00 Nigel Schuster: Function calls work now
523 952aab8 2016-11-27T09:54:12-05:00 Nigel Schuster: Merge extern
524 ac6268f 2016-11-26T23:06:00-05:00 Nigel Schuster: Boxing ints, added unop sizeof,
actually returning subrange not dummy object
525 ca07be3 2016-11-26T21:27:19-05:00 Nigel Schuster: Unboxing hello world to and from

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    subrange
526 aef6c19 2016-11-26T16:55:48-05:00 Nigel Schuster: Made Hello World somewhat workable
527 cfb637e 2016-11-25T18:27:37-05:00 Nigel Schuster: Fixed faulty setup on call
528 ebf926a 2016-11-25T17:48:57-05:00 Nigel Schuster: Added template in C
529 554fbb2 2016-11-23T22:28:29-05:00 oracleofnj: Better error message for WrongNumberArgs
530 f09e40e 2016-11-23T12:47:39-05:00 oracleofnj: Make sequence work
531 053980b 2016-11-22T16:02:27-05:00 oracleofnj: Actually commit all the extern stuff
532 0e0fa23 2016-11-22T14:36:54-05:00 Nigel Schuster: Added extern in Ast
533 aac63be 2016-11-21T23:52:25-05:00 oracleofnj: Better duplicate definition checking
534 08e2d07 2016-11-21T23:29:28-05:00 oracleofnj: Check assertions before evaluating fn
    return expression
535 69fa332 2016-11-21T18:01:23-05:00 oracleofnj: Add size assertions
536 22541c4 2016-11-21T12:48:34-05:00 oracleofnj: Fix bug in Call()
537 9a1d24b 2016-11-21T12:39:41-05:00 oracleofnj: Working on crazy bug
538 a485cee 2016-11-20T22:13:46-05:00 oracleofnj: Add test case for foo([m, n] arg)
539 10afe9a 2016-11-20T22:07:17-05:00 oracleofnj: Expand function signature
540 325e9ba 2016-11-20T18:53:52-05:00 oracleofnj: Well, this is awkward
541 0a76dc9 2016-11-20T18:41:12-05:00 oracleofnj: Add check of return value
542 488e34e 2016-11-20T18:31:39-05:00 oracleofnj: Add sample #1
543 93eebc5 2016-11-20T18:27:23-05:00 oracleofnj: Add semantic checking to make sure
    functions and variables on RHS exist
544 881f164 2016-11-20T17:22:40-05:00 oracleofnj: Check RHS slice to ensure end > start,
    otherwise evaluate to empty
545 442ae91 2016-11-20T11:42:54-05:00 GitHub: Merge pull request #73 from Neitsch/
    interpreter-global
546 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
547 367bc2b 2016-11-20T00:33:17-05:00 GitHub: Merge pull request #72 from Neitsch/codegen-
    part-app-fix
548 bdca834 2016-11-20T00:31:04-05:00 GitHub: Merge branch 'master' into codegen-part-app-
    fix
549 e956238 2016-11-20T00:28:49-05:00 GitHub: Merge pull request #71 from Neitsch/tc-fixes
550 9b742d1 2016-11-20T00:24:39-05:00 Nigel Schuster: Fixed partial function application
    warning
551 32f2989 2016-11-20T00:20:51-05:00 GitHub: Merge branch 'master' into tc-fixes
552 f87cb94 2016-11-20T00:20:35-05:00 GitHub: Merge pull request #69 from Neitsch/
    regression-tests
553 842ee5a 2016-11-20T00:18:56-05:00 GitHub: Merge branch 'master' into regression-tests
554 6d73717 2016-11-19T23:55:35-05:00 GitHub: Merge pull request #66 from Neitsch/fix-test
    -cases
555 05f317a 2016-11-19T22:37:36-05:00 Nigel Schuster: Fixed output on TCs
556 aa1d974 2016-11-19T22:33:40-05:00 Nigel Schuster: Fixed expected value for ternary
557 ab7653a 2016-11-19T22:32:27-05:00 Nigel Schuster: Fixed import testcases
558 848066c 2016-11-19T22:24:55-05:00 Nigel Schuster: Moved testcase asset to asset folder
559 53c9206 2016-11-19T22:21:48-05:00 Nigel Schuster: Corrected use of global variable in
    test_globals
560 5fe74a8 2016-11-19T22:21:00-05:00 Nigel Schuster: Fixed expected output for
    test_access_column_cells
561 214ab9d 2016-11-19T22:10:33-05:00 Nigel Schuster: Merge
562 fb31505 2016-11-19T22:08:42-05:00 Nigel Schuster: Passing testcases are in separate
    directory. Output of stats
563 5e39ba7 2016-11-19T21:55:03-05:00 Nigel Schuster: Merge
564 25263fe 2016-11-19T21:51:31-05:00 Nigel Schuster: Removed travis from build, removed
    super verbose output
565 0554ad9 2016-11-19T21:42:28-05:00 Nigel Schuster: Using precise lli version
566 04e5c4a 2016-11-19T18:30:32-05:00 oracleofnj: Add more operators to interpreter

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567 e4a190c 2016-11-19T17:14:04-05:00 oracleofnj: Add argument to main and remove
    _expected from filenames
568 7cd2b3a 2016-11-19T16:53:12-05:00 oracleofnj: Merge branch 'master' into fix-test-
    cases
569 d1fddfd 2016-11-19T16:52:48-05:00 oracleofnj: Merge branch 'fix-test-cases' of https
    ://github.com/Neitsch/plt into fix-test-cases
570 36f72a1 2016-11-19T16:49:34-05:00 GitHub: Merge pull request #67 from Neitsch/
    test_cases
571 c46c87b 2016-11-19T16:47:26-05:00 GitHub: Merge branch 'master' into test_cases
572 642ce76 2016-11-19T16:39:50-05:00 Kevin: Fixed helloworld bug
573 ac3d7fa 2016-11-19T16:10:53-05:00 Kevin: Added corresponding AST result for gcd
    function
574 7b6b79e 2016-11-19T14:31:39-05:00 GitHub: Merge branch 'master' into fix-test-cases
575 a9320f3 2016-11-19T14:29:51-05:00 oracleofnj: Merge branch 'master' into fix-test-
    cases
576 24a3625 2016-11-19T14:27:48-05:00 oracleofnj: Add switch tests
577 de262b4 2016-11-19T14:24:39-05:00 GitHub: Merge pull request #60 from Neitsch/box-args
578 75e3f71 2016-11-18T20:39:23-05:00 oracleofnj: Fix parsing errors in test cases
579 4e38757 2016-11-18T16:00:10-05:00 GitHub: Merge branch 'master' into box-args
580 7146dce 2016-11-18T15:59:54-05:00 GitHub: Merge pull request #64 from Neitsch/reorg-
    test
581 f483ac7 2016-11-18T14:10:32-05:00 Kevin: Updated print statement for each test
582 09cb42f 2016-11-18T14:07:39-05:00 oracleofnj: Fix parse difference
583 39634bb 2016-11-18T14:01:21-05:00 oracleofnj: Remove unnecessary files
584 d772725 2016-11-18T14:01:02-05:00 oracleofnj: Make inputs work with interpreter
585 f4456f8 2016-11-18T13:17:25-05:00 GitHub: Merge branch 'master' into test_cases
586 00aafb7 2016-11-18T13:16:08-05:00 Kevin: Renamed inputs folder
587 99db652 2016-11-18T12:51:40-05:00 Kevin: Renamed expected output extension and created
    input folder for test cases
588 2825ada 2016-11-18T12:51:33-05:00 Nigel Schuster: Added branch to build
589 aafabb2 2016-11-18T12:50:56-05:00 Nigel Schuster: Verbose output for travis debug
590 124d61e 2016-11-18T12:44:50-05:00 GitHub: Merge pull request #61 from Neitsch/reorg-
    test
591 82cf599 2016-11-18T12:34:57-05:00 oracleofnj: Modify test script to compare
    interpreter and compiler with expected
592 faecfa1 2016-11-18T01:48:44-05:00 oracleofnj: Fix merge conflict in box_args
593 41a81ce 2016-11-18T01:40:11-05:00 oracleofnj: Move argument boxing into a function
594 6f63e89 2016-11-18T00:48:07-05:00 GitHub: Merge pull request #59 from Neitsch/hello-
    hello
595 088dc45 2016-11-18T00:29:45-05:00 Nigel Schuster: Merge
596 012caaa 2016-11-18T00:12:40-05:00 GitHub: Merge pull request #58 from Neitsch/copy-
    argv
597 f84757b 2016-11-18T00:02:34-05:00 Nigel Schuster: Removed unnecessary files
598 18fbff1 2016-11-18T00:01:49-05:00 Nigel Schuster: Removed dummy arg reading, added
    printing to interpreter - helloworld TC passes
599 b866da3 2016-11-17T23:31:42-05:00 Nigel Schuster: Made hello world work
600 9463afa 2016-11-17T23:12:41-05:00 oracleofnj: Merge branch 'copy-argv' of https://
    github.com/Neitsch/plt into copy-argv
601 54858ab 2016-11-17T23:11:29-05:00 oracleofnj: Add => infix operator to cut down on all
    the build_struct_gep calls
602 bb11d6d 2016-11-17T23:10:24-05:00 GitHub: Merge branch 'master' into copy-argv
603 e123652 2016-11-17T22:28:12-05:00 oracleofnj: Add byte for zero
604 26a03b7 2016-11-17T22:24:17-05:00 oracleofnj: Add new_string function
605 b8028f9 2016-11-17T20:27:37-05:00 Kevin: Removed files from test folder
606 c85d9b7 2016-11-17T20:25:21-05:00 Kevin: Move testcases to testcases directory
607 f17c6b6 2016-11-17T20:21:38-05:00 Kevin Ye: Complete testcases for List/Range/Function

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/Expression with expected outputs
608 5e63cee 2016-11-17T17:40:31-05:00 GitHub: Merge pull request #54 from Neitsch/
operation_tests
609 4a4a806 2016-11-17T17:19:13-05:00 GitHub: Merge branch 'master' into operation_tests
610 cafe20e 2016-11-17T17:19:11-05:00 GitHub: Merge pull request #52 from Neitsch/one-main
-arg
611 4b28df2 2016-11-17T17:17:44-05:00 GitHub: Merge branch 'master' into operation_tests
612 b728e2e 2016-11-17T17:16:20-05:00 GitHub: Merge branch 'master' into one-main-arg
613 d43a87b 2016-11-17T17:15:28-05:00 GitHub: Merge pull request #55 from Neitsch/shell-
fix
614 b1238a0 2016-11-17T17:08:56-05:00 Nigel Schuster: Shell is not my strength
615 a6cc0ea 2016-11-17T17:05:09-05:00 Nigel Schuster: Screw you bourne shell
616 51fbeb67 2016-11-17T16:59:50-05:00 Nigel Schuster: Using bourne shell style redirection
:
617 3255e1b 2016-11-17T16:38:53-05:00 Ishaan: Modify test suite specs
618 f0ab4d8 2016-11-17T16:38:53-05:00 Ishaan: Moved expected output text files to
directory
619 06d330c 2016-11-17T16:38:53-05:00 Ishaan: 75% through operator cases
620 e490548 2016-11-17T15:50:35-05:00 GitHub: Merge branch 'master' into one-main-arg
621 a4cf367 2016-11-17T15:50:29-05:00 GitHub: Merge pull request #51 from Neitsch/test-
script
622 79ee3de 2016-11-17T15:18:58-05:00 oracleofnj: Call main() with first argument <empty>
in interpreter
623 c4f7437 2016-11-17T14:39:38-05:00 Nigel Schuster: Removed version specific lli
624 7b2236b 2016-11-17T14:35:55-05:00 Nigel Schuster: Fixed if no flag is given
625 e10f656 2016-11-17T14:24:20-05:00 Nigel Schuster: Outputting diff only if -p flag is
given
626 2d29597 2016-11-17T14:19:30-05:00 Nigel Schuster: Added it as build target
627 7af929a 2016-11-17T14:12:19-05:00 GitHub: Merge pull request #50 from Neitsch/test-
script
628 6ea43f6 2016-11-17T13:54:55-05:00 Nigel Schuster: Added more env variables to avoid
copy paste
629 05f27a2 2016-11-17T12:45:11-05:00 Nigel Schuster: Made simple testscript
630 aca43c1 2016-11-17T11:08:11-05:00 Nigel Schuster: Removed accidentally added files
631 9228eac 2016-11-17T04:52:31-05:00 Kevin Ye: Test cases for List of Tests and Range/
Function/Expression Tests
632 7feb392 2016-11-17T00:28:53-05:00 GitHub: Merge pull request #48 from Neitsch/
testing_list
633 6e42afa 2016-11-17T00:27:13-05:00 GitHub: Merge branch 'master' into testing_list
634 e40734b 2016-11-16T23:25:01-05:00 Ishaan: Added more test scenarios
635 41ef578 2016-11-16T17:50:03-05:00 GitHub: Merge pull request #49 from Neitsch/consume-
command-line-args
636 3cbf089 2016-11-16T17:45:58-05:00 oracleofnj: Fix merge conflict
637 1570836 2016-11-16T16:51:05-05:00 GitHub: Merge pull request #45 from Neitsch/doc
638 a8fbced 2016-11-16T16:38:49-05:00 Nigel Schuster: Fixed minor syntax error
639 c2f37c8 2016-11-16T16:30:43-05:00 Nigel Schuster: Merge
640 2fa73be 2016-11-16T16:05:37-05:00 oracleofnj: Set return code to length of argv[1]
641 bc21af6 2016-11-16T15:54:12-05:00 Ishaan: Added initial testing list
642 cd0d156 2016-11-16T15:50:39-05:00 oracleofnj: Start processing command line args
643 4a1fcac 2016-11-16T13:55:46-05:00 GitHub: Merge pull request #46 from Neitsch/number-
type
644 flb481e 2016-11-16T11:04:44-05:00 Nigel Schuster: Added number type that defaults to
int
645 8944b9a 2016-11-16T00:19:33-05:00 GitHub: Merge pull request #44 from Neitsch/fix-arg
646 92fb7a3 2016-11-15T23:57:37-05:00 Nigel Schuster: Added a little documentation
647 bcbde36 2016-11-15T23:49:07-05:00 GitHub: Merge branch 'master' into fix-arg

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648 fa1741a 2016-11-15T23:03:23-05:00 GitHub: Merge pull request #43 from Neitsch/more-
    llvm-gen-js
649 57b2162 2016-11-15T22:39:38-05:00 Nigel Schuster: Using subranges instead of ranges
    everywhere
650 9407677 2016-11-15T22:31:03-05:00 oracleofnj: Add hash table for common functions and
    add dereference-the-range
651 46elfd5 2016-11-15T21:38:51-05:00 oracleofnj: Eliminate some copy & paste
652 660c049 2016-11-15T20:54:33-05:00 GitHub: Merge pull request #42 from Neitsch/llvm-gen
653 25b23cd 2016-11-15T17:23:54-05:00 Nigel Schuster: Fixed column retrieval for 1x1
654 3f02203 2016-11-15T17:17:02-05:00 Nigel Schuster: Fixed tests
655 26b8fcf 2016-11-15T17:15:08-05:00 Nigel Schuster: Merge
656 e347a87 2016-11-15T17:12:26-05:00 Nigel Schuster: Using more generic flag for values
657 aed28b3 2016-11-15T17:08:07-05:00 oracleofnj: Add is_subrange_1x1
658 cf5cbf0 2016-11-15T14:51:40-05:00 oracleofnj: Merge branch 'llvm-gen' of https://
    github.com/Neitsch/plt into llvm-gen
659 c71d469 2016-11-15T14:51:19-05:00 oracleofnj: Replace String.equal with =
660 4b34abd 2016-11-15T14:41:37-05:00 GitHub: Merge branch 'master' into llvm-gen
661 a80a6d0 2016-11-15T14:41:07-05:00 oracleofnj: Add compile option to main
662 8ad5a19 2016-11-15T14:33:40-05:00 GitHub: Merge pull request #40 from Neitsch/
    interpreter
663 3f0362a 2016-11-15T14:28:44-05:00 GitHub: Merge branch 'master' into interpreter
664 c0c95a2 2016-11-15T14:16:13-05:00 Nigel Schuster: Merge
665 d5f4024 2016-11-15T13:44:44-05:00 Nigel Schuster: Moved failing TCs
666 42fd9ef 2016-11-15T12:21:57-05:00 oracleofnj: Fix bug in import
667 9c567c9 2016-11-15T11:11:30-05:00 Nigel Schuster: Working on imports, fixed most
    testcases
668 aa61ac9 2016-11-15T09:31:42-05:00 Nigel Schuster: Allocating scope object
669 cf1ebf9 2016-11-13T23:09:30-05:00 oracleofnj: Rewrite main to take options; fix bug
    where import didn't know about first filename
670 5749538 2016-11-13T21:59:28-05:00 Nigel Schuster: Added main function
671 d6daff3 2016-11-13T20:26:14-05:00 GitHub: Merge pull request #41 from Neitsch/
    LRM_String_Update
672 0a5d484 2016-11-13T18:45:29-05:00 oracleofnj: Revert "Generating function header"
673 6afe599 2016-11-13T18:44:58-05:00 Ishaan Kolluri: Added changes relating to strings.
674 137d7e2 2016-11-13T18:39:33-05:00 oracleofnj: Merge branch 'interpreter' of https://
    github.com/Neitsch/plt into interpreter
675 118bfc5 2016-11-13T18:38:34-05:00 oracleofnj: Allow single slice on RHS; make hashtag
    work
676 e376270 2016-11-13T17:55:41-05:00 Nigel Schuster: Added type arguments for functions
677 5cfeb519 2016-11-13T17:26:23-05:00 Nigel Schuster: Set more types up
678 bf1d8bb 2016-11-13T15:30:35-05:00 Nigel Schuster: Merge branch 'interpreter' of https
    ://github.com/Neitsch/plt into interpreter
679 f83a0bc 2016-11-13T15:30:28-05:00 Nigel Schuster: Generating function header
680 3addcc8 2016-11-13T14:38:11-05:00 oracleofnj: Make size(expr) an operator instead of
    built-in function
681 9a74e14 2016-11-13T14:22:44-05:00 oracleofnj: Changing size() to be an operator
682 d6d2eaa 2016-11-13T00:08:41-05:00 oracleofnj: Add closure to interpreter_variable
683 64fba82 2016-11-12T22:38:39-05:00 oracleofnj: Added bsearch to show logic bug
684 66ffdb1 2016-11-12T19:21:07-05:00 oracleofnj: Add alpha version of function calls
685 376b29a 2016-11-12T17:17:23-05:00 oracleofnj: Add string as value type
686 08c61ee 2016-11-12T17:14:47-05:00 oracleofnj: Clean up discrepancies
687 a18d5fc 2016-11-08T11:38:22-05:00 oracleofnj: Fix bug with x[-1]
688 962f812 2016-11-07T23:27:08-05:00 oracleofnj: Refactor scope for interpreter; resolve
    variables on demand; make selections work properly
689 47bbef1 2016-11-06T22:05:55-05:00 oracleofnj: Minor adjustments to interpreter to work
    with mapped AST

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690 fddc6bc 2016-11-06T18:32:17-05:00 oracleofnj: Eliminate extraneous nulls in JSON
691 ffddb17 2016-11-06T18:15:40-05:00 oracleofnj: Turn statement and function lists into
StringMaps
692 6810003 2016-11-05T19:47:57-04:00 oracleofnj: Fix pattern matching warning
693 7107a46 2016-11-05T18:01:34-04:00 oracleofnj: Add function to check range literals for
legality at parse time
694 80b13d1 2016-11-05T15:13:10-04:00 oracleofnj: Handle selections better
695 6cbb009 2016-11-04T15:48:58-04:00 oracleofnj: Count to 1,000,000 using tail-recursive
versions of List.map and cartesian product
696 9b2252d 2016-11-04T15:25:13-04:00 oracleofnj: Show enter and exit
697 3585e43 2016-11-04T02:21:38-04:00 oracleofnj: See how high it can count recursively
698 38cf541 2016-11-04T02:15:50-04:00 oracleofnj: Get the easy parts of the interpreter
working
699 5d81d6e 2016-11-03T17:17:51-04:00 oracleofnj: Start working on interpreter
700 0078cee 2016-11-01T23:40:57-04:00 oracleofnj: Got a non-tail-recursive version of
topological sort working
701 85df175 2016-11-01T15:39:10-04:00 oracleofnj: Irrelevant highlighting thing
702 84c719a 2016-11-01T14:39:49-04:00 oracleofnj: Rearrange nested functions
703 557dc4e 2016-11-01T13:50:52-04:00 oracleofnj: Add circular import test case
704 c476798 2016-11-01T13:35:46-04:00 oracleofnj: Fix syntax errors
705 af5a31d 2016-11-01T13:31:49-04:00 GitHub: Merge pull request #37 from Neitsch/import-
rec
706 d451cc4 2016-11-01T13:31:33-04:00 GitHub: Merge pull request #38 from Neitsch/import-
load
707 02ca24f 2016-11-01T13:30:47-04:00 GitHub: Merge pull request #39 from Neitsch/wild-exc
708 6fa0e39 2016-10-31T16:43:17-04:00 Neitsch: Raising exceptions on certain values
709 e673dca 2016-10-31T15:56:43-04:00 Neitsch: Loading data from all imports
710 6a28c05 2016-10-31T15:40:41-04:00 Neitsch: Recursively looking up dependencies
711 3f28289 2016-10-31T11:53:10-04:00 GitHub: Merge pull request #36 from Neitsch/import-
arrange
712 4eae3b 2016-10-31T11:01:00-04:00 Neitsch: Removed obsolete parts
713 7d7ble5 2016-10-31T10:59:12-04:00 Neitsch: Added unsorted function, globals and
imports
714 7d70af2 2016-10-30T15:23:04-04:00 oracleofnj: Add some explanatory comments
715 40d6b16 2016-10-30T15:03:32-04:00 oracleofnj: More expansion samples
716 af9b01c 2016-10-30T14:48:44-04:00 oracleofnj: Refactor expansion code
717 903bc3f 2016-10-30T00:19:10-04:00 oracleofnj: Add test output
718 68b7b03 2016-10-30T00:17:02-04:00 oracleofnj: Add test case
719 a8bdf33 2016-10-30T00:04:05-04:00 oracleofnj: Add LHS slice expansion
720 4ee6fdf 2016-10-29T17:36:17-04:00 oracleofnj: Add output
721 2b8bced 2016-10-29T17:27:22-04:00 oracleofnj: Expand dimension expressions
722 443a818 2016-10-26T16:31:51-04:00 GitHub: Merge pull request #35 from ishaankolluri/
master
723 9ba3c65 2016-10-26T16:31:00-04:00 Ishaan Kolluri: Add UNIs
724 022e8cd 2016-10-26T16:25:57-04:00 GitHub: Merge pull request #34 from ishaankolluri/
master
725 808aae5 2016-10-26T16:22:10-04:00 Ishaan Kolluri: Added change to precedence operators
726 0bd9c4a 2016-10-26T15:59:53-04:00 GitHub: Merge pull request #33 from Neitsch/final-
slicing-comments
727 fb2b382 2016-10-26T15:54:11-04:00 oracleofnj: Thats all for now folks
728 e7020ec 2016-10-26T15:00:11-04:00 GitHub: Merge pull request #32 from Neitsch/final-
lrn-edits
729 4683f14 2016-10-26T14:48:41-04:00 oracleofnj: Flesh out switch expressions, add
precedence
730 4b7984a 2016-10-26T11:15:03-04:00 GitHub: Merge pull request #31 from Neitsch/more-lrn-
-edits

731 3d587c5 2016-10-26T11:10:15-04:00 oracleofnj: Incorporate requested edits and a few more clarifications

732 0c42b9c 2016-10-26T09:22:08-04:00 GitHub: Merge pull request #30 from ishaankolluri/LRM_update

733 cd81040 2016-10-26T03:30:20-04:00 ishaankolluri: Added changes to first half of LRM

734 63fb02b 2016-10-26T02:13:17-04:00 GitHub: Merge pull request #29 from Neitsch/lrm-edits

735 0941e96 2016-10-26T02:04:47-04:00 oracleofnj: Rebuild PDF

736 cb04069 2016-10-26T02:04:01-04:00 oracleofnj: Add built in functions

737 4abf638 2016-10-26T01:56:38-04:00 oracleofnj: Add built in functions

738 7661925 2016-10-26T00:04:22-04:00 oracleofnj: Initial comments

739 5932551 2016-10-25T21:30:40-04:00 GitHub: Merge pull request #28 from Neitsch/func-doc-fix

740 cc66297 2016-10-25T20:14:27-04:00 Nigel Schuster: Fixed mistakes in functions part of the doc

741 b978f00 2016-10-25T13:04:05-04:00 GitHub: Merge pull request #27 from ishaankolluri/master

742 125a5bb 2016-10-25T12:49:38-04:00 Ishaan Kolluri: Removed AUX file

743 2e1ea60 2016-10-25T11:30:35-04:00 GitHub: Merge pull request #26 from Neitsch/better-regexp

744 84b03ee 2016-10-25T01:22:31-04:00 oracleofnj: Fix let order

745 91b40c5 2016-10-25T01:14:43-04:00 oracleofnj: Improve regexp

746 eb24036 2016-10-24T23:55:38-04:00 GitHub: Merge pull request #23 from Neitsch/file-io

747 991c918 2016-10-24T23:20:12-04:00 oracleofnj: Replace fopen, fclose etc. with open, close etc.

748 338faa0 2016-10-24T23:14:30-04:00 oracleofnj: Fix file inclusion and rebuild PDF

749 b24edd3 2016-10-24T23:11:50-04:00 oracleofnj: Merge in expressions section

750 44a1cc5 2016-10-24T23:06:07-04:00 oracleofnj: Merge scanner changes and add regexp to properly escape strings

751 2f09a64 2016-10-24T15:52:10-04:00 Kevin: Added the Expression Section 4 to LRM

752 1ea3c28 2016-10-24T15:26:16-04:00 oracleofnj: Merge branch 'master' into file-io

753 ec7cc9c 2016-10-24T15:21:23-04:00 Jared Samet: Replace repetitive code with more idiomatic OCaml

754 8cd39ac 2016-10-24T11:05:33-04:00 Kevin: Added string literals to scanner

755 e5d2478 2016-10-24T11:00:39-04:00 Kevin: Added string literals to scanner

756 a692466 2016-10-24T01:09:21-04:00 oracleofnj: Fix tests until strings ready

757 8553a50 2016-10-24T01:08:29-04:00 oracleofnj: Fix tests until string ready

758 0ed4ad7 2016-10-24T00:55:08-04:00 oracleofnj: Add File IO, Entry point and Example to LRM

759 71e0b1c 2016-10-23T22:58:21-04:00 oracleofnj: Fix section reference

760 92ac506 2016-10-23T22:39:06-04:00 Ishaan Kolluri: Make small change to data type section

761 6abb290 2016-10-23T22:34:42-04:00 oracleofnj: Initial commit for File I/O section

762 67b4b65 2016-10-23T19:30:03-04:00 Nigel Schuster: Reduce eye pain

763 2824ee9 2016-10-23T19:03:24-04:00 GitHub: Merge pull request #20 from Neitsch/samples

764 f8ae543 2016-10-23T18:23:11-04:00 GitHub: Merge branch 'master' into samples

765 13d0896 2016-10-23T18:20:03-04:00 GitHub: Merge pull request #19 from Neitsch/sequence-operator

766 e0c702d 2016-10-23T18:17:58-04:00 Neitsch: Fixed .gitignore

767 3a2cd60 2016-10-23T18:16:35-04:00 GitHub: Merge branch 'master' into sequence-operator

768 e42fe94 2016-10-23T18:05:48-04:00 Neitsch: Added code in LRM to test code samples

769 9d2cd17 2016-10-23T17:24:15-04:00 Neitsch: Merge branch 'master' into samples

770 167ddd2 2016-10-23T17:18:35-04:00 Neitsch: Removed test output

771 57319c4 2016-10-23T17:11:13-04:00 oracleofnj: Remove intermediate files

772 53824ea 2016-10-23T17:10:39-04:00 oracleofnj: Flip precedence of -> and ?: (?: is now lowest)


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773 7dedf93 2016-10-23T17:05:23-04:00 oracleofnj: Add sequence operator to scanner/parser/
    AST
774 9805753 2016-10-23T17:01:31-04:00 GitHub: Merge pull request #17 from Neitsch/make-
    correction
775 e0c7aed 2016-10-23T16:59:33-04:00 Neitsch: Fixed test
776 ec3d682 2016-10-23T16:41:00-04:00 GitHub: Merge branch 'master' into make-correction
777 ea05658 2016-10-23T16:40:24-04:00 Neitsch: Moved sequence file
778 0ca56a0 2016-10-23T16:10:14-04:00 Neitsch: Merge
779 9d1094e 2016-10-23T16:08:59-04:00 Neitsch: Added simple TCs, Moved Makefile to oasis
    config
780 0a28413 2016-10-23T16:08:59-04:00 Neitsch: Completed initial functions section doc
781 0797f32 2016-10-23T16:08:12-04:00 Neitsch: Changed subsection header
782 9df31f7 2016-10-23T16:08:12-04:00 Neitsch: Added dimension section
783 8939903 2016-10-23T16:07:26-04:00 Neitsch: Started working on Functions
784 cae3b37 2016-10-23T16:06:27-04:00 Neitsch: Added dimension section
785 049c95d 2016-10-23T16:06:08-04:00 Neitsch: Started working on Functions
786 84d20b5 2016-10-23T16:01:00-04:00 Neitsch: Comparing sample code with correctly parsed
    code in samples_comp
787 3f015ee 2016-10-23T15:52:01-04:00 GitHub: Merge pull request #18 from Neitsch/grammar-
    bug-fixes
788 7e558c1 2016-10-23T15:44:20-04:00 GitHub: Merge branch 'master' into make-correction
789 edf3dea 2016-10-23T15:44:20-04:00 GitHub: Merge branch 'master' into grammar-bug-fixes
790 d4961eb 2016-10-23T15:43:16-04:00 GitHub: Merge pull request #15 from Neitsch/
    functions-doc
791 0e0bda5 2016-10-23T15:05:42-04:00 GitHub: Merge branch 'master' into functions-doc
792 4652c67 2016-10-23T15:00:35-04:00 Neitsch: Added simple TCs, Moved Makefile to oasis
    config
793 b45718d 2016-10-23T02:27:36-04:00 oracleofnj: Modify grammar to allow [m,n] foo, bar,
    baz;
794 143fcb8 2016-10-22T23:23:10-04:00 GitHub: Merge pull request #16 from Neitsch/more-AST
795 a726236 2016-10-22T20:51:27-04:00 oracleofnj: Add comments and sample program
796 8db4098 2016-10-22T19:44:48-04:00 oracleofnj: Fix minor grammar bug
797 80754c3 2016-10-22T18:19:27-04:00 oracleofnj: Hook up scanner and parser
798 660de8c 2016-10-22T13:54:32-04:00 GitHub: Add stuff to the grammar, minor corrections
    (#14)
799 cfe827d 2016-10-21T20:50:51-04:00 Nigel Schuster: Completed initial functions section
    doc
800 3609366 2016-10-20T21:14:00-04:00 GitHub: Update scanner.mll
801 0d57652 2016-10-20T21:10:27-04:00 Kevin: Fixed bug in scanner
802 1848813 2016-10-20T20:21:49-04:00 Kevin: Made scanner
803 1b610ac 2016-10-20T13:50:22-04:00 Nigel Schuster: Merge
804 acb9b93 2016-10-20T13:44:06-04:00 Nigel Schuster: Changed subsection header
805 b95d039 2016-10-20T13:43:51-04:00 Nigel Schuster: Added dimension section
806 71b93bb 2016-10-20T13:43:09-04:00 Nigel Schuster: Started working on Functions
807 a15772c 2016-10-20T13:38:08-04:00 GitHub: Merge pull request #10 from ishaankolluri/
    LRM
808 dee63c7 2016-10-20T13:26:28-04:00 GitHub: Merge pull request #1 from Neitsch/grammar-
    doc
809 dc93dbf 2016-10-20T13:18:29-04:00 Nigel Schuster: Grammar import
810 4d763cb 2016-10-20T12:44:52-04:00 Ishaan Kolluri: Made refactor and edits to intro
    section of LRM
811 e7443cc 2016-10-20T11:46:54-04:00 Ishaan Kolluri: Merging
812 7542b5d 2016-10-20T11:16:35-04:00 Nigel Schuster: Added dimension section
813 995cf83 2016-10-19T12:28:09-04:00 Nigel Schuster: Started working on Functions
814 40c2a5a 2016-10-19T03:43:06-04:00 ishaankolluri: Initial LRM Commit part 1
815 02a5c17 2016-10-18T18:38:21-04:00 Ishaan Kolluri: Added LRM initial info

```

```

816 d8794e9 2016-10-17T19:47:42-04:00 GitHub: Merge pull request #9 from Neitsch/
    documentation
817 70aalb9 2016-10-16T13:36:23-04:00 Nigel Schuster: Added PDF Latex template
818 5111202 2016-10-14T19:59:45-04:00 GitHub: Added a bunch of stuff to the grammar: (#8)
819 da967e4 2016-10-12T13:24:50-04:00 Jared Samet: CFG Grammar (#6)
820 fea4e4b 2016-10-08T11:42:39-04:00 GitHub: There is no need to constantly build all
    branches. (#2)
821 7a5ccfc 2016-10-08T11:31:31-04:00 Nigel Schuster: Added greeting and newlines (#4)
822 10b17f7 2016-10-08T11:31:08-04:00 GitHub: Imported microc (#5)
823 726456f 2016-09-20T09:45:07-04:00 Nigel Schuster: [test] Add sample greeting to repo
    (#3)
824 9a2183d 2016-09-15T18:44:00-04:00 Nigel Schuster: Added merlin config
825 163e176 2016-09-14T18:51:53-04:00 Nigel Schuster: Moved whole build to script
826 d401eea 2016-09-14T18:43:58-04:00 Nigel Schuster: Added oasis opam package
827 ba7fd9c 2016-09-14T18:38:58-04:00 Nigel Schuster: Added ocaml configure (maybe this
    helps travis)
828 a461eae 2016-09-14T18:26:10-04:00 Nigel Schuster: Configuring opam environment for
    travis
829 ba2df2f 2016-09-14T18:19:26-04:00 Nigel Schuster: Added ocaml native compiler to apt
    package list
830 a8e5958 2016-09-14T17:24:36-04:00 Nigel Schuster: Added some more (possibly necessary
    opam packages
831 c54f5e3 2016-09-14T17:18:32-04:00 Nigel Schuster: Missed opam option
832 b10adf0 2016-09-14T17:13:57-04:00 Nigel Schuster: Fixed opam install
833 124f7f3 2016-09-14T17:08:09-04:00 Nigel Schuster: Fixed YML error
834 4909fa8 2016-09-14T17:03:54-04:00 Nigel Schuster: Using avsm source
835 4b24046 2016-09-14T16:58:33-04:00 Nigel Schuster: Allow sudo
836 e7b50db 2016-09-14T16:56:57-04:00 Nigel Schuster: Fixed setup order
837 f6d7ac4 2016-09-14T16:50:02-04:00 Nigel Schuster: Manually installing apt packages
838 f4084ab 2016-09-14T16:40:55-04:00 Nigel Schuster: Test commit
839 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.