# Extend Language Final Report


| Ishaan Kolluri | Jared Samet | Nigel Schuster | Kevin Ye |
|---|---|---|---|
| isk2108 | jss2272 | ns3158 | ky2294 |
| Project Manager | Language Guru | System Architect | Tester |


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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, theremby 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:

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

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

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

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

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

### Enough theory. Show me a function that does something!

This function adds its two arguments.

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

Come on, a real function.

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

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:

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

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

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

### 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 |

```
calcProfit([n,1] revenue, [n,1] cost) {
  [n,1] profit := revenue[[0]] - cost[[0]];
  return profit;
}
main(args) {
  revenue := {82500; 97800; 560000};
  cost := {80000; 105000; 130000};
  profit := calcProfit(revenue, cost);
  return print_endline(profit);
}
```

Writing revenue[[0]] and cost[[0]] instead of revenue[0] and cost[0] means that the nth cell of profit is calculated by subtracting the nth cells of cost from the nth 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 |

```
calcProfitGrowth([n,1] profits) {
  [n,1] profitGrowth := profits[[0]] - profits[[-1]];
  return profitGrowth;
}
main(args) {
  profits := {2500;-7200;430000};
  return print_endline(calcProfitGrowth(profits));
}
```

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:

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

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.

```
    "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(conditional, 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:

```
    odd_or_even(foo){
      return switch(foo % 2) {
        case 0: "Even";
        case 1: "Odd";
        default: "Not an integer";
      };
    }
```

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.

```
main(args){
  bar := {"Hello", "Goodbye", "Hello Again"};
  str := ", ";
  return print_endline(concatRow(bar, str)); // prints "Hello, Goodbye, Hello Again"
}

concatRow([1,n] cells, joiner) {
  [1,n] accum;
  accum[0,0] = #cells;
  accum[0,1:] = accum[[-1]] + joiner + #cells;
  return accum[-1];
}
```

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 of the functions in the standard library can be found in the Language Reference Manual; some of the more popular ones are listed below.

### Basic Functions

#### The toString() Function

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

```
    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`.

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

## 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 multiples 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-
        numeric */
7   [m,1] running_sum;
8   running_sum[0,0] = #rng;
```

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

## 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:

```
global pi := 3.14159265359;
global num_points := 24;
global [num_points,1]
  circle_x_vals := cos(2 * pi * row() / num_points),
  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:

```
extern "mylib.o" {
  foo(arg1, arg2);
  bar();
}
```

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.

```
global x := "I'm a global";

foo() {
  y := x; // Scope of x is entire function
  x := "In here I'm a local";
  return y; // Returns "In here I'm a local"
```

```
}

bar(x) {
  return x; // Parameters mask globals; returns argument
}

baz() {
  return x; // Returns "I'm a global"
}
```

## 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:

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

```
  r5 := {{{{{1}}}}}; // one row, one column
  r7 := {-1.5,-2.5,{-2,"nested"},-3.5}; // one row, four columns
  return
    print_endline(r1) ->print_endline(r2) ->print_endline(r3) ->
    print_endline(r4) -> print_endline(r5) -> print_endline(r7);
}

main(args) {
  return legal_ranges();
}
```

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

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

## 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. `!empty` evaluates to `empty`. It has equal precedence with  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. `empty` == `empty` evaluates to 1. Strings are compared by value. |
| `!=` | `Not equals` | `x != y` is equivalent to `!(x == y)`. |
| `<` | `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 `empty`. |
| `>` | `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 `empty`, evaluates to 0 or `empty` respectively. Otherwise, if the second expression is truthy, falsey, or `empty`, evaluates to 1, 0, or `empty` respectively. |
| `\|\|` | `Short-circuit Logical OR` | If the first expression is truthy or `empty`, evaluates to 1 or `empty` respectively. Otherwise, if the second expression is truthy, falsey, or `empty`, evaluates to 1, 0, or `empty` 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:

```
switch_example(foo) {
  return switch (foo) {
    case 2: "foo is 2";
    case 3,4: "foo is 3 or 4";
    default: "none of the above";
  };
}

alternate_format(foo) {
  return switch {
    case foo == 2:
      "foo is 2";
    case foo == 3, foo == 4:
      "foo is 3 or 4";
    default:
      "none of the above";
  };
}
```

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-expr`s is truthy, or `default-expr` if none of the `case-expr`s apply. If `switch-expr` is present, the `switch` expression evaluates to the `match-expr` for the first case where one of the `case-expr`s is equal (with equality defined as for the `==` operator) to `switch-expr`, or `default-expr` if none of the `case-expr`s 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 |
|---|---|---|
| `size(expr)` | `Dimensions` | Evaluates to a Range consisting of one row and two columns; the first cell contains the number of rows of `expr` and the second contains the number of columns. If `expr` is a Number, a String, or Empty, both cells will contain 1. |
| `typeof(expr)` | `Value Type` | Evaluates to "Number", "String", "Range", or "Empty". |
| `row()` | `Row Location` | No arguments; returns the row of the cell that is being calculated |
| `column()` | `Column Location` | No arguments; returns the column of the cell that is being calculated |
| `+` | `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

```
selection_examples() {
  foo[0,2] /* This evaluates to the cell value in the first row and third column. */
  foo[0,:] /* Evaluates to the range of cells in the first row of foo. */
  foo[:,2] /* Evaluates to the range of cells in the third column of foo. */
  foo[:,[1]] /* The internal brackets denote RELATIVE notation.
  In this case, 1 column right of the column of the left-hand-side cell. */

  foo[3,] /* Equivalent to foo[3,[0]] if foo has more than one column
  or foo[3,0] if foo has one column */

  foo[5:, 7:] /* All cells starting from the 6th row and 8th column to the bottom
      right */

  foo[[1]:[2], 0:[7]]
  /* Selects the rows between the 1st and 2nd row after LHS row, and
     all the columns up to the 7th column to the right of the LHS column */

  /* In this example, each cell of bar would be equal to the cell
   * in foo in the equivalent location plus 1. */
  [5,5] foo;
  [5,5] bar := #foo + 1; // #foo = foo[[0],[0]]

  /* In this example, bar would be a 3x5 range where in each row,
   * the value in bar is equal to the value in foo in the same column.
   * In other words, each row of bar would be a copy of foo. */
  [1,5] foo; // foo has 1 row, 5 columns
  [3,5] bar := #foo; // #foo = foo[0,[0]]

  /* In this example, the values of baz would be
   * 11, 12, 13 in the first row;
   * 21, 22, 23 in the second row;
   * 31, 32, 33 in the third row. */
  foo := {1,2,3}; // 1 row, 3 columns
  bar := {10;20;30}; // 3 rows, 1 column
  [3,3] baz := #foo + #bar; // Equivalent to foo[0,[0]] + bar[[0],0]
}
```

### 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).

```
[5, 2] foo, bar, baz; // Declares foo, bar, and baz as distinct 5x2 ranges
foo[0,0] = 42; // Assigns the expression 42 to the first cell of the first row of foo
foo[0,1] = foo[0,0] * 2; // Assigns (foo[0,0] * 2) to the 2nd cell of the 1st row of
    foo
bar = 3.14159; // Assigns pi to every cell of every row of bar
baz[1:-1,0:1] = 2.71828; // Assigns e to cells (1,0) through (3,1), inclusive, of baz

/* The next line assigns foo[[-1],0] + 2 to every cell in
   both columns of foo, besides the first row */
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.

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

```
number_of_cells([m,n] arg) {
  return m*n; // m and n are initialized with the dimensions of arg
}

die_unless_primitive([1,1] arg) {
  return 0; // If arg is not a primitive value, a runtime error will occur
}

num_cells_if_column_vector([m,1] arg) {
  // If arg has one column, return number of cells; otherwise runtime error
```

```
  return m;
}

die_unless_square([m,m] arg) {
  return 0; // Runtime error if number of rows != number of columns
}

num_cells_if_same_size([m,n] arg1, [m,n] arg2) {
  // If arguments are the same size, return # of cells, otherwise runtime error
  return m*n;
}

main(args) {
  [3,4] foo;
  [3,5] bar;
  return print_endline(num_cells_if_same_size(foo,bar));
}
```

### 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:

```
foo([m,n] arg1, [m,n] arg2) {
  [m,n] bar := #arg1 + #arg2;
  return bar;
}
```

This function normalizes a column vector to have unit norm:

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

### 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:

```
maybeCircular(truth_value) {
  x := x;
  return truth_value ? x : 0;
```

```
}

main(args) {
  foo :=
    print_endline("To be or not to be?") ->
    print_endline("Enter \"Not to be\" to attempt to evaluate a circular reference.")
        ->
    readline(STDIN);

  return
    maybeCircular(foo == "Not to be" || foo == "\"Not to be\"") ->
    print_endline("Good thing I didn't look at the value of x.");
}
```

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:

```
extern "mylib.o" {
  foo(arg1, arg2);
  bar();
}
```

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:

```
value_p extend_foo(value_p arg1, value_p arg2) {
  /* function body here; */
}

value_p extend_bar() {
  /* function body here; */
}
```

## 3.6 Standard Library Reference

## 3.7 Example Program

```
import "./samples/stdlib.xtnd";

main([1,n] args) {
  /* Get a working copy */
  return 0;
}
```

# 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.

## 4.3 Project Feature Completion Timeline

Over the semester, we implemented our compiler from front end to back end, incorporating test cases throughout the way. Below are timestamps of our project progress throughout the semester.

1. Scanner (Early October)
2. Parser and JSON output (Mid October)
3. Finalize Language Semantics (Late October)
4. Implement interpreter (Mostly feature complete by early November)
5. Most transformations done, compile Hello World (Mid November)
6. Finalize test suite (End November)
7. Compile function calls, finish transformations (Early December)
8. Reference variables (Early December)
9. Feature complete compiler (December 15)
10. Presentation to Professor Edwards (December 19)

### 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 indermediate 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.

## 4.4 Language Evolution

The language we delivered ended up surprisingly close to our initial proposal. 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.

One 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.

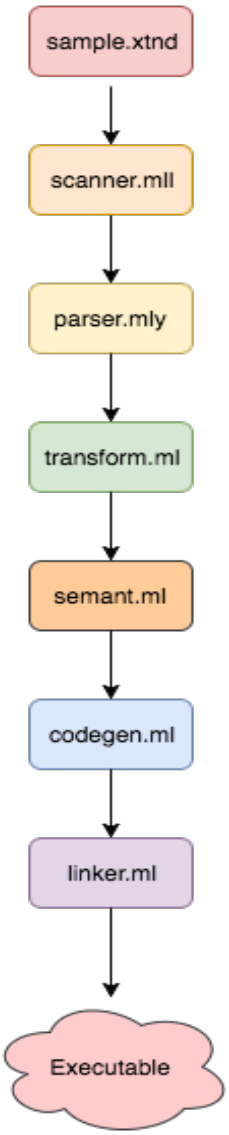
### The Interpreter

Mainly because we implemented a declarative language, we built a working interpreter fairly early in the process to make sure we understood how to actually compile our language. Having it allowed us to test the language semantics, run example Extend programs, and make language decisions at an earlier stage. It also helped us benchmark the success of our compiler by comparing the number of testcases passed by both. A lot of the expressive power of Extend comes from the selection / slicing operator and a surprisingly high percentage of code in the compiler (20

## 4.5 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`: OCamlyacc 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;
```

A similar transformation is performed on formula assignments:

```
1     foo[g(x):4,3+3] = "Couldn't you have stuck to integers?";
```

is transformed into:

```
1     start_row := g(x);
2     end_row   := 4;
3     start_col := 3+3;
4     foo[start_row:end_row,start_col] = "Couldn't you have stuck to integers?";
```

Every expression before or after a comma or colon will become an internal temporary variable in the desugaring process. In addition to generating temporary variables, Extend also transforms `&&, ||, and switch` into ternary conditionals to enable short-circuiting. Finally, 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 involving expressions on the right-hand-side of a formula, as we attempt to degrade many gracefully. There are type errors possible on the left-hand side, but since they are assigned dynamically, very few can be determined at compile time. For function calls, the semantic analyzer ensures that the function exists and is called with the right number of arguments; and for variables, the analysis checks that the identifier refers to a real variables within the appropriate 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. There is one function created per formula, which is available to be called if the value of a cell with that formula is needed; and there is one function created per Extend function, which initializes a scope object with a collection of blueprints for all the local variables of that function. In its most basic form, each blueprint has a reference to one or more formulas that calculate the value of the variable. The section on the runtime goes into more detail on how this architecture is used.

### 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

Extend's cell values are lazily evaluated, which means they need to be implemented using function pointers. For each function that the Extend developer writes, the corresponding LLVM function that is generated is essentially identical: allocate a scope object for that function call, initialize that object with the appropriate set of variable definitions and the function arguments to that scope object, and then evaluate the variables corresponding to the size assertion and the return expression for that function. All of the "individualized" code lives in what we refer to as the formula-functions; for each distinct formula, the compiler generates a corresponding function that can be called when the corresponding cell's value is needed. Each formula-function shares the same signature: the arguments are a pointer to a scope and the row and column number of the cell being evaluated, and the return value is a pointer to a value struct (which holds the type and contents of the value.)

The two main functions of our C runtime, therefore, are instantiate_variable(), which looks at the variable definition "blueprint" and calculates the actual dimensions of the variable for that particular function call,

and calculates the actual range of cells to which each formula applies; and getVal(), which determines if a particular cell value has already been calculated or not, and calls the appropriate formula-function if not.

Before actually calling the main Extend entry point, our executable initializes a global array with the appropriate variable definitions for each function. When an Extend function is called, it simply copies the appropriate pointer into that array into its scope object.

Leaving aside the variables introduced by the transformation step, this Extend function:

```
1    foo() {
2      x := 1;
3      return x;
4    }
```

would result in the LLVM equivalent of the following pseudocode (not written in any actual language) being generated:

```
1    value_p foo() {
2      scope = new ExtendScope;
3
4      // Load the apropriate set of definitions for foo
5      scope->defns = global_definitions[42];
6
7      // Create an array of pointers to variable instances; one
8      // pointer per variable. Only one variable in this function
9      scope->insts = new var_instance* [1];
10
11     // getVar calls instantiate_var if that instance pointer is still NULL,
12     // or just returns the pointer if it's already been instantiated.
13     // The instantiated variable keeps a copy of the pointer to its scope
14     var_instance *return_variable = getVar(scope, 0);
15
16     // Get the value of cell [0,0] of return_variable
17     return getVal(return_variable, 0, 0);
18   }
```

Since the newly initialized scope object will hold all NULL pointers for the instances, getVar() will end up calling instantiate_variable, which will determine that x has 1 row and 1 column; there is only a single formula for x, applying to all cells of x; and that that formula corresponds to the function pointer indicated in the variable definition. When getVal is called, the value pointer for the [0,0]th cell will similarly be NULL. As a result, getVal() will determine the function pointer for the appropriate formula and then call it, supplying as arguments a pointer to the scope and (0,0) for the row and column.

The actual C structures used are listed below:

```
1
2  // Each formula-function has the following signature:
3  typedef value_p (*FormulaFP) (struct ExtendScope *scope, int row, int col);
4
5  // This structure tells the runtime how to actually calculate the range of
6  // cells to which each formula applies.
7  struct ExtendFormula {
8    /* These 10 variables correspond to formula_row_start through formula_col_end,
9     * where char singleRow/Col are true if formula_row_end is None */
10   char fromFirstRow;
11   int rowStart_varnum;
12   char toLastRow;
13   int rowEnd_varnum;
14   char fromFirstCol;
```

```
    int colStart_varnum;
    char toLastCol;
    int colEnd_varnum;

    char isSingleRow;
    char isSingleCol;

    FormulaFP formula;
  };

  // For a particular variable instance, this structure holds the results
  // of the calculations for each formula.
  struct ResolvedFormula {
    int rowStart, rowEnd, colStart, colEnd;
    FormulaFP formula;
  };

  struct var_defn {
    /* This is like a class definition — for every declared variable in the
     * Extend source, there should be one instance of these per compiled program.
     * They should just live in the global program storage.
     * It corresponds to Ast.variable */
     int rows_varnum;
     int cols_varnum;
     int numFormulas;
     struct ExtendFormula *formulas;
     char isOneByOne;
     char *name;
  };

  struct var_instance {
    /* This is an actual instance of a variable — we get one of these
     * per variable per time a function is called (assuming the contents
     * of the variable get examined.  */
    int rows, cols;
    int numFormulas;
    struct ResolvedFormula *formulas;
    struct ExtendScope *closure;
    value_p *values;
    char *status;
    char *name;
  };

  // One scope object gets created per Extend function call
  struct ExtendScope {
    struct var_defn *defns;
    struct var_instance **vars;
    int numVars;
    int refcount;
    value_p *functionParams;
  };
```

# 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 Travic 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. Example Source Programs

Below are two example programs we've implemented in Extend to illustrate some of our language's features and use cases.

## 7.1 maybeCircular

This program illustrates how Extend lazily evaluates. Since we shortcircuit the ternary conditional below, based on what the user inputs, this program will either complete or throw a runtime error.

```
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     readline(STDIN);
11
12   return
13     maybeCircular(foo == "Not to be" || foo == "\"Not to be\"") ->
14     print_endline("Good thing I didn't look at the value of x.");
15 }
```

## 7.2 True Shooting Percentage

This program parses calculates the true shooting efficiency NBA players. It reads in a string from a file, parses it into a variable, and prints and calculates the true shooting percentage for each player based on values in the vector. It additionally prints the player with the highest percentage, and writes the results to a GIF bar chart.

```
1  main(args) {
2    welcome := "NBA True Shooting Percentage\n————————————————————————————————";
3    data := parseString(read(open("tsp_data","r"),0));
4
5    // Calculates TSP for each player
6    [10,2] players;
7    players[:,0:1] = data[[0],[0]];
8    players[:,1:] = calculate_tsp(data[[0],1],data[[0],2],data[[0],3]);
9
10   // Calculates which player has the highest TSP
```

```
  player := highest_tsp(players);
  [10,1] playerSummary := players[[0],0] + ": " + toString(players[[0],1]);

  return
    print_endline(welcome) ->
    print_endline(concatRow(transpose(playerSummary),"\n")) ->
    print_endline("————————————————————————————") ->
    print_endline("The player with the highest True Shooting Percentage is " + player
        [0,0] + " with a TSP of " + toString(player[0,1]) + "!") ->
    bar_chart(open("barchart.png","wb"), transpose(players[:,0]), transpose(players
        [:,1]));
}

calculate_tsp(pts,fga,fta) {
  tsp := pts / (2.0 * (fga + (0.44 * fta)));
  return tsp;
}

highest_tsp([m,n] players) {
  [m,1] tsp_ranking;
  tsp_ranking[0,0] = players[0,:];
  tsp_ranking[1:,:] = (players[[0],1] > tsp_ranking[[-1],0][1]) ?  players[[0],:] :
      tsp_ranking[[-1],0];
  return tsp_ranking[m-1,0];
}
```

# 8. Reflection

## 8.1 Ishaan

When working on a long-term project, communication is paramount. Throughout this project, I realized that maximum productivity occurred when the team kept a constant line of communication open regarding language and code design. Additionally, it's important to identify where people can be most productive. If one person is more efficient at a certain task, more progress will be made if they work on similar material. Lastly, as the design of the language evolves over time, it's important to build a system that allows for flexibility, as you never know what may change later in the development process.

## 8.2 Jared

I really enjoyed this project from start to finish. In my former life, I worked in finance and was intimately familiar with Excel's strengths and weaknesses as a result, and as the language guru I tried to incorporate what I thought were the best points of spreadsheets into our language. It was a lot of work, but of the good kind - the appeal of being able to build something and see it in action is what brought me back from finance in the first place. Over a two-day span, our compiler went from not being able to handle "==" to being nearly feature complete; it was an incredible feeling to see its expressive power explode as we successively implemented each additional basic building block of the language.

Things I think we did well: To my eyes, the syntax is concise without being incomprehensibly terse and it is easy to write programs in the language; I'm still impressed by how few lines of code it took to implement the splitToRange() function; and I think we essentially delivered what we had in mind when the project began. After being a thorn in my side for weeks, I think we finally implemented literals correctly (initialize once and then do shallow copies when they're actually referenced.) Having a working interpreter very early in the process made it easy to test out the syntax of the language, come up with some test cases, and have a concrete game plan for the actual implementation of the compiler.

Things where we could have done better: We followed the MicroC template a little too closely and it would have been better to implement a separate SAST as opposed to just an AST. Although I am fairly sure we don't allow any semantic errors past, it would have been nice to have the "extra confidence" that a SAST would have given us that all of the symbols would indeed be where they were supposed to be, enforced by the typing. We whiffed on memory management. I was disappointed that we didn't have time to implement an explicit stack instead of using recursion but came to terms with that.

All in all, this was a fantastic experience and I had a great time working with the team!

## 8.3 Nigel

Team projects by its nature are a very unique challenge for a student. Nevertheless these projects are incredibly valuable by providing a more applied experience. Thus, I am glad that I was able to put a lot of effort into this project. Communication proved to be a key element in the project: We had weekly team meetings, meetings with the TA, a chatroom and ad hoc in person discussions. All this helped to bounce

ideas off one another, prioritize well and avoid a mismatch in expectations. Of course some problems are inevitable. Therefore I think one of our key assets was our test suite. At any point in time it allowed us to see the next step ahead - the next thing we want to make work. In the same vein our code review process proved very effective (PR required approval plus passing CI). I admit that at some points in the development process I was slacking off, especially when facing LLVM codegen for the first time. However I am glad, that my team mates motivated me and helped me to get back on track. Summarizing, every project has its issues, but by planning ahead and hard work, we built a surprisingly good and feature complete language that is close to our initial goal.

## 8.4 Kevin

Working on this group project this semester has been a rewarding experience and posed quite the challenge. It was something very new to me and I had trouble at first balancing all my work. But I slowly adapted and got used to it. My takeaway from this experience would have to be learning the importance of communication and having a set structure. One of my biggest problems in life is that I have a hard time asking for help. Mainly because I'm afraid of getting judged for asking a dumb question. But communication is key in any team project I've learned. I could've easily asked my teammates, who were always willing to help, for help on a problem I'm having than spent hours trying to figure it out on my own. And oftentimes, in doing so, I would learn something new, which is great. I had several other classes this semester that also had me doing group projects and I felt like the overall workflow for those group projects weren't as organized as our PLT project. This was simply due to the fact that we set a structure right from the start. We had weekly meetings with our advisor along with weekly meetings with each other and a group chat, which when all combined together kept us on track on everything that needed to be done.

# 9. Extend Code Listing

## 9.1 scanner.mll

```
(* jss2272 isk2108 ky2294 *)

{
  open Lexing
  open Parser
  open String

  exception SyntaxError of string
  let syntax_error lexbuf = raise (SyntaxError("Invalid character: " ^ Lexing.lexeme
      lexbuf))
}

let digit = ['0'-'9']
let exp = 'e'('+'|'-')?['0'-'9']+
let flt = (digit)+ ('.' (digit)* exp?|exp)
let id = ['a'-'z' 'A'-'Z']['a'-'z' 'A'-'Z' '0'-'9' '_']*


rule token = parse
  ['\n']               { new_line lexbuf; token lexbuf }
| [' ' '\t' '\r']      { token lexbuf }   (* Whitespace *)
| "/*"                 { multiline_comment lexbuf }
| "//"                 { oneline_comment lexbuf }
| '"'                  { read_string (Buffer.create 17) lexbuf }
| '['             { LSQBRACK }
| ']'             { RSQBRACK }
| '('             { LPAREN }
| ')'             { RPAREN }
| '{'             { LBRACE }
| '}'             { RBRACE }
| ":="            { GETS }
| '='             { ASN }
| ':'             { COLON }
| ','             { COMMA }
| "->"            { PRECEDES }
| '?'             { QUESTION }
| "=="            { EQ }
| "!="            { NOTEQ }
| '<'             { LT }
| '>'             { GT }
| "<="            { LTEQ }
```

```
| ">="            { GTEQ }
| ';'             { SEMI }
| '!'             { LOGNOT }
| "&&"            { LOGAND }
| "||"            { LOGOR }
| '~'             { BITNOT }
| '&'             { BITAND }
| '|'             { BITOR }
| '^'             { BITXOR }
| '+'             { PLUS }
| '-'             { MINUS }
| '*'             { TIMES }
| '/'             { DIVIDE }
| '%'             { MOD }
| "**"            { POWER }
| "<<"            { LSHIFT }
| ">>"            { RSHIFT }
| '#'             { HASH }
| "if"            { IF }
| "empty"         { EMPTY }
| "size"          { SIZE }
| "typeof"        { TYPEOF }
| "row"           { ROW }
| "column"        { COLUMN }
| "switch"        { SWITCH }
| "case"          { CASE }
| "default"       { DEFAULT }
| "return"        { RETURN }
| "import"        { IMPORT }
| "global"        { GLOBAL }
| "extern"        { EXTERN }
| digit+ as lit   { LIT_INT(int_of_string lit) }
| flt as lit      { LIT_FLOAT(float_of_string lit) }
| id as lit       { ID(lit) }
| eof             { EOF }
| _               { syntax_error lexbuf }

and multiline_comment = parse
  "*/" { token lexbuf }
| '\n' { new_line lexbuf; multiline_comment lexbuf }
| _    { multiline_comment lexbuf }

and oneline_comment = parse
  '\n' { new_line lexbuf; token lexbuf }
| _    { oneline_comment lexbuf }

(* read_string mostly taken from:
https://realworldocaml.org/v1/en/html/parsing-with-ocamllex-and-menhir.html *)
and read_string buf =
  parse
  | '"'       { LIT_STRING (Buffer.contents buf) }
  | '\n'      { new_line lexbuf; Buffer.add_char buf '\n'; read_string buf lexbuf }
  | '\\' 'n'  { Buffer.add_char buf '\n'; read_string buf lexbuf }
  | '\\' 'r'  { Buffer.add_char buf '\r'; read_string buf lexbuf }
  | '\\' 't'  { Buffer.add_char buf '\t'; read_string buf lexbuf }
  | '\\' ([^'\\' 'n' 'r' 't'] as lxm)
```

```
    { Buffer.add_char buf lxm; read_string buf lexbuf }
  | [^ '"' '\\']+
    { Buffer.add_string buf (Lexing.lexeme lexbuf);
      read_string buf lexbuf
    }
  | _          { syntax_error lexbuf }
  | eof        { raise (Failure("unterminated string")) }
```

## 9.2 parser.mly

```
/* Ocamlyacc parser for Extend */
/* jss2272 ns3158 */

%{
open Ast
%}

%token LSQBRACK RSQBRACK LPAREN RPAREN LBRACE RBRACE HASH
%token COLON COMMA QUESTION IF GETS ASN SEMI PRECEDES
%token SWITCH CASE DEFAULT SIZE TYPEOF ROW COLUMN
%token PLUS MINUS TIMES DIVIDE MOD POWER LSHIFT RSHIFT
%token EQ NOTEQ GT LT GTEQ LTEQ
%token LOGNOT LOGAND LOGOR
%token BITNOT BITXOR BITAND BITOR
%token EMPTY RETURN IMPORT GLOBAL EXTERN
%token <int> LIT_INT
%token <float> LIT_FLOAT
%token <string> LIT_STRING
%token <string> ID
%token EOF

%right QUESTION
%left PRECEDES
%left LOGOR
%left LOGAND
%left EQ NOTEQ LT GT LTEQ GTEQ
%left PLUS MINUS BITOR BITXOR
%left TIMES DIVIDE MOD LSHIFT RSHIFT BITAND
%right POWER
%right BITNOT LOGNOT NEG
%left LSQBRACK

%start program
%type <Ast.raw_program> program

%%

program:
    program_piece EOF {  let (imp, glob, fnc, ext) = $1 in (List.rev imp, List.rev
        glob, List.rev fnc, List.rev ext) }

program_piece:
    /* nothing */ {([],[],[],[])}
  | program_piece import      { let (imp, glob, fnc, ext) = $1 in ($2 :: imp, glob,
      fnc, ext) }
```

```
44    | 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   | expr PRECEDES expr  { Precedence($1, $3) }
122   | LPAREN expr RPAREN  { $2 }
123   | ID                  { Id($1) }
124   | LIT_INT             { LitInt($1) }
125   | LIT_FLOAT           { LitFlt($1) }
126   | LIT_STRING          { LitString($1) }
127   | EMPTY               { Empty }
128
129 op_expr:
130     expr PLUS expr      { BinOp($1, Plus, $3) }
131   | expr MINUS expr     { BinOp($1, Minus, $3) }
132   | expr TIMES expr     { BinOp($1, Times, $3) }
133   | expr DIVIDE expr    { BinOp($1, Divide, $3) }
134   | expr MOD expr       { BinOp($1, Mod, $3) }
135   | expr POWER expr     { BinOp($1, Pow, $3) }
136   | expr LSHIFT expr    { BinOp($1, LShift, $3) }
137   | expr RSHIFT expr    { BinOp($1, RShift, $3) }
138   | expr LOGAND expr    { BinOp($1, LogAnd, $3) }
139   | expr LOGOR expr     { BinOp($1, LogOr, $3) }
140   | expr BITXOR expr    { BinOp($1, BitXor, $3) }
141   | expr BITAND expr    { BinOp($1, BitAnd, $3) }
142   | expr BITOR expr     { BinOp($1, BitOr, $3) }
143   | expr EQ expr        { BinOp($1, Eq, $3) }
144   | expr NOTEQ expr     { UnOp(LogNot,(BinOp($1, Eq, $3))) }
145   | expr GT expr        { BinOp($1, Gt, $3) }
146   | expr LT expr        { BinOp($1, Lt, $3) }
147   | expr GTEQ expr      { BinOp($1, GtEq, $3) }
148   | expr LTEQ expr      { BinOp($1, LtEq, $3) }
149   | SIZE LPAREN expr RPAREN { UnOp(SizeOf, $3) }
150   | TYPEOF LPAREN expr RPAREN { UnOp(TypeOf, $3) }
151   | ROW LPAREN RPAREN       { UnOp(Row, Empty)}
152   | COLUMN LPAREN RPAREN    { UnOp(Column, Empty)}
```

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

```
208
209 lhs_sel:
210     /* nothing */                          { (None, None) }
211 /* commented out: LSQBRACK lslice RSQBRACK { (Some $2, None) } */
212   | LSQBRACK lslice COMMA lslice RSQBRACK { (Some $2, Some $4) }
213
214 rhs_sel:
215     LSQBRACK rslice RSQBRACK               { (Some $2, None) }
216   | LSQBRACK rslice COMMA rslice RSQBRACK { (Some $2, Some $4) }
217
218 lslice:
219   /* commented out: nothing production { (None, None) } */
220     lslice_val                             { (Some $1, None) }
221   | lslice_val COLON lslice_val            { (Some $1, Some $3) }
222   | lslice_val COLON                       { (Some $1, Some DimensionEnd) }
223   | COLON lslice_val                       { (Some DimensionStart, Some $2) }
224   | COLON                                  { (Some DimensionStart, Some DimensionEnd) }
225
226 rslice:
227     /* nothing */                          { (None, None) }
228   | rslice_val                             { (Some $1, None) }
229   | rslice_val COLON rslice_val            { (Some $1, Some $3) }
230   | rslice_val COLON                       { (Some $1, Some DimensionEnd) }
231   | COLON rslice_val                       { (Some DimensionStart, Some $2) }
232   | COLON                                  { (Some DimensionStart, Some DimensionEnd) }
233
234 lslice_val:
235     expr { Abs($1) }
236
237 rslice_val:
238     expr { Abs($1) }
239   | LSQBRACK expr RSQBRACK { Rel($2) }
240
241 func_param_list:
242     /* nothing */ { [] }
243   | func_param_int_list { List.rev $1 }
244
245 func_param_int_list:
246     func_sin_param { [$1] }
247   | func_param_int_list COMMA func_sin_param { $3 :: $1 }
248
249 func_sin_param:
250     ID { ((None, None), $1) }
251   | dim ID { ($1, $2) }
252
253 dim:
254     LSQBRACK expr RSQBRACK { (Some $2, None) }
255   | LSQBRACK expr COMMA expr RSQBRACK { (Some $2, Some $4) }
```

## 9.3 ast.ml

```
1 (* jss2272 *)
2 type op       = Plus | Minus | Times | Divide | Mod | Pow |
3                 LShift | RShift | BitOr | BitAnd | BitXor |
4                 Eq | Gt | GtEq | Lt | LtEq | LogAnd | LogOr
```

```
type unop     = Neg | LogNot | BitNot | SizeOf | TypeOf | Row | Column | Truthy

type expr     = LitInt of int |
                LitFlt of float |
                LitString of string |
                LitRange of (expr list) list |
                Id of string |
                Empty |
                BinOp of expr * op * expr |
                UnOp of unop * expr |
                Ternary of expr * expr * expr |
                Switch of expr option * case list * expr |
                Call of string * expr list |
                Selection of expr * sel |
                ReducedTernary of string * string * string |
                Precedence of expr * expr
and  index    = Abs of expr |
                Rel of expr |
                DimensionStart |
                DimensionEnd
and  slice    = index option * index option
and  sel      = slice option * slice option
and  case     = expr list * expr

type dim      = expr option * expr option
type var      = dim * string
type assign   = string * sel * expr option
type init     = string * expr option
type stmt     = Assign of assign |
                Varinit of dim * init list

type raw_func = {
    name: string;
    params: var list;
    body: stmt list;
    raw_asserts: expr list;
    ret_val: dim * expr;
}

type extern_func = {
    extern_fn_name: string;
    extern_fn_params: var list;
    extern_fn_libname: string;
    extern_ret_val: dim;
}

type library  = Library of string * extern_func list
type raw_program = string list * stmt list * raw_func list * library list

(* Desugared types below *)
module StringMap = Map.Make(String)
type formula  = {
  formula_row_start: index;
  formula_row_end: index option;
  formula_col_start: index;
  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
```

```
    Neg -> "\"-\"" | LogNot -> "\"!\"" | BitNot -> "\"~\"" | Truthy -> "\"truthy\"" |
    SizeOf -> "\"size\"" | TypeOf -> "\"type\"" | Row -> "\"row\"" | Column -> "\"
        column\""

let rec string_of_expr = function
    LitInt(l) ->          "{\"LitInt\":" ^ string_of_int l ^ "}"
  | LitFlt(l) ->          "{\"LitFlt\":" ^ string_of_float l ^ "}"
  | LitString(s) ->       "{\"LitString\":" ^ quote_string s ^ "}"
  | LitRange(rowlist) ->  "{\"LitRange\": " ^ string_of_list (Rows rowlist) ^ "}"
  | Id(s) ->              "{\"Id\": " ^ quote_string s ^ "}"
  | Empty ->              "\"Empty\""
  | BinOp(e1, o, e2) ->   "{\"BinOp\": {" ^
                            "\"expr1\": " ^ string_of_expr e1 ^ ", " ^
                            "\"operator\": " ^ string_of_op o ^ ", " ^
                            "\"expr2\": " ^ string_of_expr e2 ^ "}}"
  | UnOp(o, e) ->         "{\"UnOp\": {" ^
                            "\"operator\": " ^ string_of_unop o ^ ", " ^
                            "\"expr\": " ^ string_of_expr e ^ "}}"
  | Ternary(c, e1, e2) -> "{\"Ternary\": {" ^
                            "\"condition\": " ^ string_of_expr c ^ ", " ^
                            "\"ifExpr\": " ^ string_of_expr e1 ^ ", " ^
                          "\"elseExpr\": " ^ string_of_expr e2 ^ "}}"
  | ReducedTernary(s1, s2, s3) -> "{\"ReducedTernary\": {" ^
                            "\"truthiness\": " ^ quote_string s1 ^ ", " ^
                            "\"true_values\": " ^ quote_string s2 ^ ", " ^
                            "\"false_values\": " ^ quote_string s3 ^ "}}"
  | Switch(eo, cases, dflt) ->  "{\"Switch\": {" ^
                                  "\"condition\": " ^
                                    (match eo with None -> "null" | Some e ->
                                        string_of_expr e) ^ ", " ^
                                  "\"cases\": " ^ string_of_list (Cases cases) ^ ", " ^
                                  "\"defaultExpr\": " ^ string_of_expr dflt ^ "}}"
  | Call(f, arguments) -> "{\"Call\": {" ^
                            "\"function\": " ^ quote_string f ^ ", " ^
                            "\"arguments\": " ^ string_of_list (Exprs arguments) ^
                                "}}"
  | Selection(e, s) ->    "{\"Selection\": {" ^
                            "\"expr\": " ^ string_of_expr e ^ ", " ^
                            "\"slices\": " ^ string_of_sel s ^ "}}"
  | Precedence(e1, e2) -> "{\"Precedence\": { " ^
                            "\"prior_expr\": " ^ string_of_expr e1 ^ ", " ^
                          "\"dependent_expr\": " ^ string_of_expr e2 ^ "}}"

and string_of_case (el, e) =
    "{\"Cases\": " ^ string_of_list (Exprs el) ^ ", " ^
     "\"expr\": " ^ string_of_expr e ^ "}"

and string_of_sel (s1, s2) =
    "{\"slice1\": " ^ string_of_slice s1 ^ ", \"slice2\": " ^ string_of_slice s2 ^ "}"

and string_of_slice = function
    None -> "null"
  | Some (start_idx, end_idx) -> "{\"start\": " ^ string_of_index start_idx ^ ", \"end
      \": " ^ string_of_index end_idx ^ "}"

and string_of_index = function
```

```
    None -> "null"
  | Some(Abs(e)) -> "{\"Absolute\": " ^ string_of_expr e ^ "}"
  | Some(Rel(e)) -> "{\"Relative\": " ^ string_of_expr e ^ "}"
  | Some(DimensionStart) -> "\"DimensionStart\""
  | Some(DimensionEnd) -> "\"DimensionEnd\""

and string_of_dim (d1,d2) = "{\"d1\": " ^ (match d1 with None -> "null" | Some e ->
    string_of_expr e) ^ ", " ^
                              "\"d2\": " ^ (match d2 with None -> "null" | Some e ->
                                  string_of_expr e) ^ "}"

and string_of_var (d, s) = "{\"Dimensions\": " ^ string_of_dim d ^ ", " ^
                             "\"VarName\": " ^ quote_string s ^ "}"

and string_of_assign (s, selection, eo) =
    "{\"VarName\": " ^ quote_string s ^ ", " ^
     "\"Selection\": " ^ string_of_sel selection ^ ", " ^
    "\"expr\": " ^ (match eo with None -> "null" | Some e -> string_of_expr e) ^ "}"

and string_of_varinit (d, inits) =
  "{\"Dimensions\": " ^ string_of_dim d ^
    ",\"Initializations\": " ^ string_of_list (Inits inits) ^ "}"

and string_of_init (s, eo) =
    "{\"VarName\": " ^ quote_string s ^ ", " ^
     "\"expr\": " ^ (match eo with None -> "null" | Some e -> string_of_expr e) ^ "}"

and string_of_stmt = function
    Assign(a) -> "{\"Assign\": " ^ string_of_assign a ^ "}"
  | Varinit(d, inits) -> "{\"Varinit\": " ^ string_of_varinit (d, inits) ^ "}"

and string_of_range (d, e) = "{\"Dimensions\": " ^ string_of_dim d ^ ", " ^
                              "\"expr\": " ^ string_of_expr e ^ "}"

and string_of_raw_func fd =
    "{\"Name\": " ^ quote_string fd.name ^ "," ^
     "\"Params\": " ^ string_of_list (Vars fd.params) ^ "," ^
     "\"Stmts\": " ^ string_of_list (Stmts fd.body) ^ "," ^
     "\"Assertions\": " ^ string_of_list (Exprs fd.raw_asserts) ^ "," ^
     "\"ReturnVal\": " ^ string_of_range fd.ret_val ^ "}"

and string_of_extern_func fd =
  "{\"Name\": " ^ quote_string fd.extern_fn_name ^ "," ^
  "\"Params\": " ^ string_of_list (Vars fd.extern_fn_params) ^ "," ^
  "\"Library\": " ^ quote_string fd.extern_fn_libname ^ "," ^
  "\"ReturnDim\": " ^ string_of_dim fd.extern_ret_val ^ "}"

and string_of_library (Library(lib_name, lib_fns)) =
  "{\"LibraryName\": " ^ quote_string lib_name ^ "," ^
  "\"ExternalFunctions\": " ^ string_of_list (Externs lib_fns) ^ "}"

and string_of_dimexpr = function
    DimOneByOne -> "1"
  | DimId(s) -> quote_string s

and string_of_formula f =
```

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

```
276         List.for_all (fun exprs -> List.for_all check_basic_expr exprs) rl
277       and check_basic_expr = function
278           LitInt(_) | UnOp(Neg, LitInt(_)) | LitFlt(_) | UnOp(Neg, LitFlt(_)) |
                LitString(_) | Empty -> true
279         | LitRange(rl) -> check_range_literal rl
280         | _ -> false in
281
282       if check_range_literal rowlist then LitRange(rowlist)
283       else raise(IllegalRangeLiteral(string_of_expr (LitRange(rowlist))))
284   | e -> raise(IllegalRangeLiteral(string_of_expr e))
```

## 9.4 transform.ml

```
1  (* jss2272 *)
2
3  open Ast
4  open Lexing
5  open Parsing
6  open Semant
7
8  module StringSet = Set.Make (String);;
9  let importSet = StringSet.empty;;
10
11 let idgen =
12   (* from http://stackoverflow.com/questions/10459363/side-effects-and-top-level-
       expressions-in-ocaml*)
13   let count = ref (-1) in
14   fun prefix -> incr count; "_tmp_" ^ prefix ^ string_of_int !count;;
15
16 let expand_file include_stdlib filename =
17   let print_error_location filename msg lexbuf =
18     let pos = lexbuf.lex_curr_p in
19     prerr_endline ("Syntax error in \"" ^ filename ^ "\": " ^ msg) ;
20     prerr_endline ("Line " ^ (string_of_int pos.pos_lnum) ^ " at character " ^ (
           string_of_int (pos.pos_cnum - pos.pos_bol))) in
21
22   let rec expand_imports processed_imports globals fns exts dir = function
23       [] -> ([], globals, fns, exts)
24     | (import, use_dir) :: imports ->
25       (* print_endline "---------";
26       print_endline ("Working on: " ^ import) ;
27       print_endline ("Already processed:"); *)
28       (* StringSet.iter (fun a -> print_endline a) processed_imports; *)
29       let in_chan = open_in import in
30       let lexbuf = (Lexing.from_channel (in_chan)) in
31       let (file_imports, file_globals, file_functions, file_externs) =
32         try Parser.program Scanner.token lexbuf
33         with
34           Parsing.Parse_error -> print_error_location import "" lexbuf ; exit(-1)
35         | Scanner.SyntaxError(s) -> print_error_location import s lexbuf ; exit(-1)
36       in
37       let file_imports = List.map (fun file -> (if use_dir then (dir ^ "/") else "") ^
             file) file_imports in
38       let new_proc = StringSet.add import processed_imports and _ = close_in in_chan
           in
```

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

```
87        let (new_end, new_end_exprs) = expand_index (slice_loc ^ "_end") idx_end in
88        ((Some new_start, Some new_end), new_start_exprs @ new_end_exprs)
89      | Some (Some _, None) | Some (None, _) -> raise (IllegalExpression("Illegal slice
            - this shouldn't be possible")) in
90
91    let expand_assign asgn_loc (var_name, (row_slice, col_slice), formula) =
92      (* expand_assign: Take an Assign and return a list of more
93         atomic statements, with new variables replacing any
94         complex expressions in the selection slices and with single
95         index values desugared to expr:expr+1. *)
96      try
97        let (new_row_slice, row_exprs) = expand_slice (asgn_loc ^ "_" ^ var_name ^ "_row
              ") row_slice in
98        let (new_col_slice, col_exprs) = expand_slice (asgn_loc ^ "_" ^ var_name ^ "_col
              ") col_slice in
99        Assign(var_name, (Some new_row_slice, Some new_col_slice), formula) :: (
              row_exprs @ col_exprs)
100     with IllegalExpression(s) ->
101       raise (IllegalExpression("Illegal expression (" ^ s ^ ") in " ^
102                                string_of_assign (var_name, (row_slice, col_slice),
                                     formula))) in
103
104   let expand_init (r, c) (v, e) =
105     Varinit((Some r, Some c), [(v, None)]) ::
106     match e with
107       None -> []
108     | Some e -> [Assign (v, entire_range, Some e)] in
109
110   let expand_dimension dim_loc = function
111       None -> expand_expr dim_loc (LitInt(1))
112     | Some e -> expand_expr dim_loc e in
113
114   let expand_varinit fname ((row_dim, col_dim), inits) =
115     (* expand_varinit: Take a Varinit and return a list of more atomic
116        statements. Each dimension will be given a temporary ID, which
117        will be declared as [1,1] _tmpXXX; the formula for tmpXXX will be
118        set as a separate assignment; the original variable will be
119        declared as [_tmpXXX, _tmpYYY] var; and the formula assignment
120        will be applied to [:,:]. *)
121     try
122       let (row_e, row_stmts) = expand_dimension (fname ^ "_" ^ (String.concat "_" (
              List.map fst inits)) ^ "_row_dim") row_dim in
123       let (col_e, col_stmts) = expand_dimension (fname ^ "_" ^ (String.concat "_" (
              List.map fst inits)) ^ "_col_dim") col_dim in
124       row_stmts @ col_stmts @ List.concat (List.map (expand_init (row_e, col_e)) inits
              )
125     with IllegalExpression(s) ->
126       raise (IllegalExpression("Illegal expression (" ^ s ^ ") in " ^
127                                string_of_varinit ((row_dim, col_dim), inits))) in
128
129   let expand_stmt fname = function
130     Assign(a) -> expand_assign fname a
131   | Varinit(d, inits) -> expand_varinit fname (d, inits) in
132
133   let expand_stmt_list fname stmts = List.concat (List.map (expand_stmt fname) stmts)
        in
```

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

```
176     {
177       name = f.name;
178       params = f.params;
179       raw_asserts = [new_assert];
180       body = new_sizevars @ size_inits @ retval_inits @ assert_inits @
              expand_stmt_list f.name f.body;
181       ret_val = (fst f.ret_val, new_retval)
182     } in
183   (imports, expand_stmt_list "global" globals, List.map expand_function functions,
        externs);;
184
185 let create_maps (imports, globals, functions, externs) =
186   let vd_of_vi = function
187     (*  vd_of_vi--- Take a bare Varinit from the previous transformations
188         and return a (string, variable) pair    *)
189       Varinit((Some r, Some c), [(v, None)]) -> (v, {
190         var_rows = (match r with
191               LitInt(1) -> DimOneByOne
192             | Id(s) -> DimId(s)
193             | _ -> raise (LogicError("Unrecognized expression for rows of " ^ v)));
194         var_cols = (match c with
195               LitInt(1) -> DimOneByOne
196             | Id(s) -> DimId(s)
197             | _ -> raise (LogicError("Unrecognized expression for rows of " ^ v)));
198         var_formulas = [];
199       })
200     | _ -> raise (LogicError("Unrecognized format for post-desugaring Varinit")) in
201
202   let add_formula m = function
203        Varinit(_,_) -> m
204      | Assign(var_name, (Some (Some row_start, row_end), Some (Some col_start, col_end
           )), Some e) ->
205        if StringMap.mem var_name m
206        then (let v = StringMap.find var_name m in
207              StringMap.add var_name {v with var_formulas = v.var_formulas @ [{
208                  formula_row_start = row_start;
209                  formula_row_end = row_end;
210                  formula_col_start = col_start;
211                  formula_col_end = col_end;
212                  formula_expr = e;
213                }]} m)
214        else raise (UnknownVariable(string_of_stmt (Assign(var_name, (Some (Some
               row_start, row_end), Some (Some col_start, col_end)), Some e))))
215      | Assign(a) -> raise (LogicError("Unrecognized format for post-desugaring Assign:
           " ^ string_of_stmt (Assign(a)))) in
216
217   let vds_of_stmts stmts =
218     let is_varinit = function Varinit(_,_) -> true | _ -> false in
219     let varinits = List.filter is_varinit stmts in
220     let vars_just_the_names = map_of_list (List.map vd_of_vi varinits) in
221     List.fold_left add_formula vars_just_the_names stmts in
222
223   let fd_of_raw_func f = (f.name, {
224       func_params = f.params;
225       func_body = vds_of_stmts f.body;
226       func_ret_val = f.ret_val;
```

```
227       func_asserts = f.raw_asserts;
228     }) in
229
230   let tupleize_library (Library(lib_name, lib_fns)) =
231     List.map (fun ext_fn -> (ext_fn.extern_fn_name, {ext_fn with extern_fn_libname =
          lib_name})) lib_fns in
232
233   (vds_of_stmts globals,
234    map_of_list (List.map fd_of_raw_func functions),
235    map_of_list (List.concat (List.map tupleize_library externs)))
236
237 let single_formula e = {
238   formula_row_start = DimensionStart;
239   formula_row_end = Some DimensionEnd;
240   formula_col_start = DimensionStart;
241   formula_col_end = Some DimensionEnd;
242   formula_expr = e;
243 }
244
245 let ternarize_exprs (globals, functions, externs) =
246   let rec ternarize_expr lhs_var = function
247       BinOp(e1, LogAnd, e2) ->
248       let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
249       let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
250       (Ternary(UnOp(Truthy,new_e1), UnOp(Truthy,new_e2), LitInt(0)), new_e1_vars @
            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 @
            new_e2_vars)
255     | BinOp(e1, op, e2) ->
256       let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
257       let (new_e2, new_e2_vars) = ternarize_expr lhs_var  e2 in
258       (BinOp(new_e1, op, new_e2), new_e1_vars @ new_e2_vars)
259     | UnOp(op, e) ->
260       let (new_e, new_e_vars) = ternarize_expr lhs_var e in
261       (UnOp(op, new_e), new_e_vars)
262     | Ternary(cond, e1, e2) ->
263       let (new_cond, new_cond_vars) = ternarize_expr lhs_var cond in
264       let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
265       let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
266       (Ternary(new_cond, new_e1, new_e2), new_cond_vars @ new_e1_vars @ new_e2_vars)
267     | Call(fname, args) ->
268       let new_args_and_vars = List.map (ternarize_expr lhs_var) args in
269       (Call(fname, (List.map fst new_args_and_vars)), List.concat (List.map snd
            new_args_and_vars))
270     | Selection(e, (sl1, sl2)) ->
271       let (new_e, new_e_vars) = ternarize_expr lhs_var e in
272       let (new_sl1, new_sl1_vars) = ternarize_slice lhs_var sl1 in
273       let (new_sl2, new_sl2_vars) = ternarize_slice lhs_var sl2 in
274       (Selection(new_e, (new_sl1, new_sl2)), new_e_vars @ new_sl1_vars @ new_sl2_vars)
275     | Precedence(e1, e2) ->
276       let (new_e1, new_e1_vars) = ternarize_expr lhs_var e1 in
277       let (new_e2, new_e2_vars) = ternarize_expr lhs_var e2 in
278       (Precedence(new_e1, new_e2), new_e1_vars @ new_e2_vars)
```

```
    | Switch(cond, cases, dflt) ->
      ternarize_switch lhs_var cases dflt cond
    (* | Debug(e) ->
      let (new_e, new_e_vars) = ternarize_expr lhs_var e in
      (Debug(new_e), new_e_vars) *)
    | e -> (e, [])
  and ternarize_switch lhs_var cases dflt cond =
    let (new_cond_expr, new_cond_vars) = (match cond with
          Some cond_expr ->
          let (lhs_varname, lhs_vardef) = lhs_var in
          let new_id = idgen (lhs_varname ^ "_switch_cond") in
          let (new_e, new_e_vars) = ternarize_expr lhs_var cond_expr in
          (Some (Selection(Id(new_id),(Some(Some(Rel(LitInt(0))),None),Some(Some(Rel(
              LitInt(0))),None)))),
           (new_id, {lhs_vardef with var_formulas = [single_formula new_e]}) ::
           new_e_vars)
        | None ->
          (None,[])
    ) in
    let new_cases_and_vars = List.map (ternarize_case lhs_var new_cond_expr) cases in
    let new_cases = List.map fst new_cases_and_vars in
    let new_case_vars = List.concat (List.map snd new_cases_and_vars) in
    let (new_dflt, new_dflt_vars) = ternarize_expr lhs_var dflt in
    let rec combine_everything = function
        [] -> new_dflt
      | (combined_cases, e) :: more_cases -> Ternary(combined_cases, e,
          combine_everything more_cases) in
    (combine_everything new_cases, new_cond_vars @ new_case_vars @ new_dflt_vars)
  and ternarize_case lhs_var cond (conds, e) =
    let new_conds_and_vars = List.map (ternarize_expr lhs_var) conds in
    let new_conds = List.map fst new_conds_and_vars in
    let new_cond_vars = List.concat (List.map snd new_conds_and_vars) in
    let (new_e, new_e_vars) = ternarize_expr lhs_var e in
    let unify_case_cond_and_switch_cond case_cond = function
        None -> case_cond
      | Some switch_cond -> BinOp(switch_cond,Eq,case_cond) in
    let rec unify_switch_cond_and_case_conds switch_cond = function
        [case_cond] -> unify_case_cond_and_switch_cond case_cond switch_cond
      | case_cond :: case_conds ->
        let (combined_expr, _) = ternarize_expr lhs_var
            (BinOp(unify_case_cond_and_switch_cond case_cond switch_cond, LogOr,
               unify_switch_cond_and_case_conds switch_cond case_conds)) in
        combined_expr
      | [] -> raise(LogicError("Empty case condition list")) in
    ((unify_switch_cond_and_case_conds cond new_conds, new_e),new_cond_vars @
       new_e_vars)
  and ternarize_slice lhs_var = function
      None -> (None, [])
    | Some (i1, i2) ->
      let (new_i1, new_i1_vars) = ternarize_index lhs_var i1 in
      let (new_i2, new_i2_vars) = ternarize_index lhs_var i2 in
      (Some (new_i1, new_i2), new_i1_vars @ new_i2_vars)
  and ternarize_index lhs_var = function
      Some Abs(e) ->
      let (new_e, new_e_vars) = ternarize_expr lhs_var e in
      (Some(Abs(new_e)), new_e_vars)
```

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

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

## 9.5 semant.ml

```
1 (* jss2272 *)
2
```

```
3  open Ast
4
5  exception IllegalExpression of string;;
6  exception DuplicateDefinition of string;;
7  exception UnknownVariable of string;;
8  exception UnknownFunction of string;;
9  exception WrongNumberArgs of string;;
10 exception LogicError of string;;
11
12 type symbol = LocalVariable of int | GlobalVariable of int | FunctionParameter of int
       | ExtendFunction of int
13 and  symbolTable = symbol StringMap.t
14 and  symbolTableType = Locals | Globals | ExtendFunctions
15
16 let map_of_list list_of_tuples =
17   (*  map_of_list: Take a list of the form [("foo", 2); ("bar", 3)]
18       and create a StringMap using the first value of the tuple as
19       the key and the second value of the tuple as the value. Raises
20       an exception if the key appears more than once in the list. *)
21   let rec aux acc = function
22       [] -> acc
23     | t :: ts ->
24       if (StringMap.mem (fst t) acc) then raise(DuplicateDefinition(fst t))
25       else aux (StringMap.add (fst t) (snd t) acc) ts in
26   aux StringMap.empty list_of_tuples
27
28 let index_map table_type m =
29   let add_item key _ (accum_map, accum_idx) =
30     let index_val = match table_type with Locals -> LocalVariable(accum_idx) | Globals
          -> GlobalVariable(accum_idx) | ExtendFunctions -> ExtendFunction(accum_idx) in
31     (StringMap.add key index_val accum_map, accum_idx + 1) in
32   StringMap.fold add_item m (StringMap.empty, 0)
33
34 let create_symbol_table global_symbols fn_def =
35   let (local_indices, _) = index_map Locals fn_def.func_body in
36   let add_param (st, idx) param_name =
37     let new_st = StringMap.add param_name (FunctionParameter(idx)) st in
38     (new_st, idx + 1) in
39   let (params_and_globals, _) = List.fold_left add_param (global_symbols, 0) (List.map
       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        (StringMap.fold (fun s f l -> (s, List.length f.extern_fn_params) :: l) externs
            [])) in
46   let (global_symbols, _) = index_map Globals globals in
47
48   let check_call context called_fname num_args =
49     if (not (StringMap.mem called_fname fn_signatures)) then
50       (print_endline ("In " ^ context ^ "(), the undefined function " ^ called_fname ^
           "() was called") ;
51        raise(UnknownFunction(context ^ "," ^ called_fname)))
52     else let signature_args = StringMap.find called_fname fn_signatures in
```

```
53      if num_args != signature_args then
54        (print_endline ("In " ^ context ^ "(), the function " ^ called_fname ^ "() was
              called with " ^
55                        string_of_int num_args ^ " arguments " ^ "but the signature
                              specifies "
56                        ^ string_of_int signature_args) ;
57         raise(WrongNumberArgs(context ^ "," ^ called_fname)))
58      else () in
59
60    let rec check_expr fname symbols = function
61        BinOp(e1,_,e2) -> check_expr fname symbols e1 ; check_expr fname symbols e2
62      | UnOp(_, e) -> check_expr fname symbols e
63      | Ternary(cond, e1, e2) -> check_expr fname symbols cond ; check_expr fname
            symbols e1 ; check_expr fname symbols e2
64      | ReducedTernary(s1, s2, s3) -> check_expr fname symbols (Id(s1)) ; check_expr
            fname symbols (Id(s2)) ; check_expr fname symbols (Id(s3))
65      | Id(s) -> if StringMap.mem s symbols then () else raise(UnknownVariable(fname ^
            "(): " ^ s))
66      | 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
67      | Switch(None, cases, dflt) -> List.iter (fun c -> check_case fname symbols c)
            cases ; check_expr fname symbols dflt
68      | Call(called_fname, args) ->
69        check_call fname called_fname (List.length args) ;
70        List.iter (fun a -> check_expr fname symbols a) args
71      | Selection(e, (sl1, sl2)) -> check_expr fname symbols e ; check_slice fname
            symbols sl1 ; check_slice fname symbols sl2
72      | Precedence(e1, e2) -> check_expr fname symbols e1 ; check_expr fname symbols e2
73      (* | Debug(e) -> check_expr fname symbols e; *)
74      | LitInt(_) | LitFlt(_) | LitRange(_) | LitString(_) | Empty -> ()
75    and check_case fname symbols (conds, e) = List.iter (fun c -> check_expr fname
          symbols c) conds ; check_expr fname symbols e
76    and check_slice fname symbols = function
77        None -> ()
78      | Some (i1, i2) -> check_index fname symbols i1 ; check_index fname symbols i2
79    and check_index fname symbols = function
80        Some Abs(e) -> check_expr fname symbols e
81      | Some Rel(e) -> check_expr fname symbols e
82      | _ -> () in
83    let check_formula fname symbols f =
84      check_index fname symbols (Some f.formula_row_start) ;
85      check_index fname symbols f.formula_row_end ;
86      check_index fname symbols (Some f.formula_col_start) ;
87      check_index fname symbols f.formula_col_end ;
88      check_expr fname symbols f.formula_expr in
89    let check_dim fname symbols = function
90        DimOneByOne -> ()
91      | DimId(s) -> check_expr fname symbols (Id(s)) in
92    let check_variable fname symbols v =
93      check_dim fname symbols v.var_rows ;
94      check_dim fname symbols v.var_cols ;
95      List.iter (fun f -> check_formula fname symbols f) v.var_formulas in
96    let check_variables context symbols vars =
97      StringMap.iter (fun _ v -> check_variable context symbols v) vars in
98
99    let check_function fname f =
```

```
100     if StringMap.mem fname externs then raise(DuplicateDefinition(fname ^ "() is
            defined as both an external and local function")) else ();
101     let locals = f.func_body in
102     let params = List.map snd f.func_params in
103     List.iter
104       (fun param ->
105          if StringMap.mem param locals then raise(DuplicateDefinition(param ^ " is
                defined multiple times in " ^ fname ^ "()"))
106          else ())
107       params ;
108     let local_symbols = create_symbol_table global_symbols f in
109     check_variables fname local_symbols f.func_body ;
110     check_expr fname local_symbols (snd f.func_ret_val)
111
112   in check_variables "global_variables" global_symbols globals ; StringMap.iter
        check_function functions
```

## 9.6 codeGenTypes.ml

```
1  (*
2  jss2272
3  ns3158
4  *)
5
6  type something = {
7    var_instance_t : Llvm.lltype;
8    subrange_t : Llvm.lltype;
9    resolved_formula_t : Llvm.lltype;
10   value_t : Llvm.lltype;
11   dimensions_t : Llvm.lltype;
12   var_defn_t : Llvm.lltype;
13   var_defn_p : Llvm.lltype;
14   string_t : Llvm.lltype;
15   number_t : Llvm.lltype;
16   extend_scope_t : Llvm.lltype;
17   formula_t : Llvm.lltype;
18   formula_call_t : Llvm.lltype;
19   formula_p : Llvm.lltype;
20   formula_call_p : Llvm.lltype;
21   var_instance_p : Llvm.lltype;
22   subrange_p : Llvm.lltype;
23   resolved_formula_p : Llvm.lltype;
24   value_p : Llvm.lltype;
25   extend_scope_p : Llvm.lltype;
26   string_p : Llvm.lltype;
27   string_p_p : Llvm.lltype;
28   var_instance_p_p : Llvm.lltype;
29   int_t : Llvm.lltype;
30   long_t : Llvm.lltype;
31   flags_t : Llvm.lltype;
32   char_t : Llvm.lltype;
33   bool_t : Llvm.lltype;
34   void_t : Llvm.lltype;
35   char_p : Llvm.lltype;
36   char_p_p : Llvm.lltype;
```

```
  (*void_p : Llvm.lltype;*)
  float_t : Llvm.lltype;
  rhs_index_t : Llvm.lltype;
  rhs_slice_t : Llvm.lltype;
  rhs_selection_t : Llvm.lltype;
  rhs_index_p : Llvm.lltype;
  rhs_slice_p : Llvm.lltype;
  rhs_selection_p : Llvm.lltype;
};;

type scope_field_type = VarDefn | VarInst | VarNum | ScopeRefCount | FunctionParams
let scope_field_type_index = function
    VarDefn -> 0
  | VarInst -> 1
  | VarNum -> 2
  | ScopeRefCount -> 3
  | FunctionParams -> 4

type value_field_flags = Empty | Number | String | Range
let value_field_flags_index = function
    Empty -> 0
  | Number -> 1
  | String -> 2
  | Range -> 3
let int_to_type_array = [|"Empty"; "Number"; "String"; "Range"|]

type value_field = Flags | Number | String | Subrange
let value_field_index = function
    Flags -> 0
  | Number -> 1
  | String -> 2
  | Subrange -> 3

type var_defn_field = Rows | Cols | NumFormulas | Formulas | OneByOne | VarName
let var_defn_field_index = function
    Rows -> 0
  | Cols -> 1
  | NumFormulas -> 2
  | Formulas -> 3
  | OneByOne -> 4
  | VarName -> 5

type formula_field  = FromFirstRow | RowStartNum | ToLastRow | RowEndNum |
    FromFirstCols | ColStartNum | ToLastCol | ColEndNum | IsSingleRow | IsSingleCol |
    FormulaCall
let formula_field_index = function
    FromFirstRow -> 0
  | RowStartNum -> 1
  | ToLastRow -> 2
  | RowEndNum -> 3
  | FromFirstCols -> 4
  | ColStartNum -> 5
  | ToLastCol -> 6
  | ColEndNum -> 7
  | IsSingleRow -> 8
  | IsSingleCol -> 9
```

```
  | FormulaCall -> 10

type var_instance_field = Rows | Cols | NumFormulas | Formulas | Closure | Values |
    Status
let var_instance_field_index = function
    Rows -> 0
  | Cols -> 1
  | NumFormulas -> 2
  | Formulas -> 3
  | Closure -> 4
  | Values -> 5
  | Status -> 6

type var_instance_status_flags = NeverExamined | Calculated | InProgress
let var_instance_status_flags_index = function
    NeverExamined -> 0
  | Calculated -> 2
  | InProgress -> 4

type subrange_field = BaseRangePtr | BaseOffsetRow | BaseOffsetCol | SubrangeRows |
    SubrangeCols
let subrange_field_index = function
    BaseRangePtr -> 0
  | BaseOffsetRow -> 1
  | BaseOffsetCol -> 2
  | SubrangeRows -> 3
  | SubrangeCols -> 4

type dimensions_field = DimensionRows | DimensionCols
let dimensions_field_index = function
    DimensionRows -> 0
  | DimensionCols -> 1

type string_field = StringCharPtr | StringLen | StringRefCount
let string_field_index = function
    StringCharPtr -> 0
  | StringLen -> 1
  | StringRefCount -> 2

type rhs_index_field = RhsExprVal | RhsIndexType
let rhs_index_field_index = function
    RhsExprVal -> 0
  | RhsIndexType -> 1

type rhs_index_type_flags = RhsIdxAbs | RhsIdxRel | RhsIdxDimStart | RhsIdxDimEnd
let rhs_index_type_flags_const = function
    RhsIdxAbs -> 0
  | RhsIdxRel -> 1
  | RhsIdxDimStart -> 2
  | RhsIdxDimEnd -> 4 (* No 3 *)

type rhs_slice_field = RhsSliceStartIdx | RhsSliceEndIdx
let rhs_slice_field_index = function
    RhsSliceStartIdx -> 0
  | RhsSliceEndIdx -> 1

```

```
145 type rhs_selection_field = RhsSelSlice1 | RhsSelSlice2
146 let rhs_selection_field_index = function
147     RhsSelSlice1 -> 0
148   | RhsSelSlice2 -> 1
149
150 let setup_types ctx =
151   let var_instance_t = Llvm.named_struct_type ctx "var_instance" (*Range struct is a 2
          D Matrix of values*)
152   and subrange_t = Llvm.named_struct_type ctx "subrange" (*Subrange is a wrapper
          around a range to cut cells*)
153   and int_t = Llvm.i32_type ctx (*Integer*)
154   and long_t = Llvm.i64_type ctx
155   and float_t = Llvm.double_type ctx
156   and flags_t = Llvm.i8_type ctx (*Flags for statuses*)
157   and char_t = Llvm.i8_type ctx (*Simple ASCII character*)
158   and bool_t = Llvm.i1_type ctx (*boolean 0 = false, 1 = true*)
159   and void_t = Llvm.void_type ctx (**)
160   and value_t = Llvm.named_struct_type ctx "value" (*Value encapsulates the content of
           a cell*)
161   and dimensions_t = Llvm.named_struct_type ctx "dimensions" (**)
162   and resolved_formula_t = Llvm.named_struct_type ctx "resolved_formula"
163   and extend_scope_t = Llvm.named_struct_type ctx "extend_scope"
164   and var_defn_t = Llvm.named_struct_type ctx "var_def"
165   and formula_t = Llvm.named_struct_type ctx "formula"
166   and string_t = Llvm.named_struct_type ctx "string" in
167   let var_instance_p = (Llvm.pointer_type var_instance_t)
168   and var_defn_p = Llvm.pointer_type var_defn_t
169   and resolved_formula_p = (Llvm.pointer_type resolved_formula_t)
170   and subrange_p = (Llvm.pointer_type subrange_t)
171   and value_p = (Llvm.pointer_type value_t)
172   and value_p_p = (Llvm.pointer_type (Llvm.pointer_type value_t))
173   and extend_scope_p = (Llvm.pointer_type extend_scope_t)
174   and char_p = (Llvm.pointer_type char_t)
175   and string_p = (Llvm.pointer_type string_t)
176   and char_p_p = (Llvm.pointer_type (Llvm.pointer_type char_t))
177   and string_p_p = (Llvm.pointer_type (Llvm.pointer_type string_t))
178   and number_t = float_t
179   and formula_p = (Llvm.pointer_type formula_t) in
180   let rhs_index_t = Llvm.named_struct_type ctx "rhs_index"
181   and rhs_slice_t = Llvm.named_struct_type ctx "rhs_slice"
182   and rhs_selection_t = Llvm.named_struct_type ctx "rhs_selection" in
183   let rhs_index_p = Llvm.pointer_type rhs_index_t
184   and rhs_slice_p = Llvm.pointer_type rhs_slice_t
185   and rhs_selection_p = Llvm.pointer_type rhs_selection_t
186   (*and void_p = (Llvm.pointer_type void_t)*) in
187   let var_instance_p_p = (Llvm.pointer_type var_instance_p)
188   and formula_call_t = (Llvm.function_type value_p [|extend_scope_p(*scope*); int_t(*
          row*); int_t(*col*)|]) in
189   let formula_call_p = Llvm.pointer_type formula_call_t in
190   let _ = Llvm.struct_set_body rhs_index_t (Array.of_list [
191       value_p (*val_of_expr*);
192       char_t (*rhs_index_type*);
193     ]) false in
194   let _ = Llvm.struct_set_body rhs_slice_t (Array.of_list [
195       rhs_index_p (*slice start index*);
196       rhs_index_p (*slice end index*);
```

```
    ]) false in
  let _ = Llvm.struct_set_body rhs_selection_t (Array.of_list [
      rhs_slice_p (*first slice*);
      rhs_slice_p (*second slice*);
    ]) false in
  let _ = Llvm.struct_set_body var_instance_t (Array.of_list [
      int_t(*rows*);
      int_t(*columns*);
      int_t(*numFormulas*);
      resolved_formula_p(*formula with resolved dimensions*);
      extend_scope_p(*scope that contains all variables of a function*);
      value_p_p(*2D array of cell values*);
      char_p(*2D array of calculation status for each cell*);
      char_p(*Name*);
    ]) false
  and _ = Llvm.struct_set_body var_defn_t (Array.of_list [
      int_t(*Rows*);
      int_t(*Cols*);
      int_t(*Number of formulas*);
      formula_p;
      char_t(*Is one by one range*);
      char_p(*Name*);
    ]) false
  and _ = Llvm.struct_set_body formula_t (Array.of_list [
      char_t (*from First row*);
      int_t (*row Start num*);
      char_t (*to last row*);
      int_t (*row end num*);
      char_t (*from first col*);
      int_t (*col start*);
      char_t (*to last col*);
      int_t (*col end num*);
      char_t (* is single row *);
      char_t (* is single col *);
      formula_call_p (*formula to call*);
    ]) false
  and _ = Llvm.struct_set_body extend_scope_t (Array.of_list [
      var_defn_p(*variable definitions*);
      var_instance_p_p(*variable instances*);
      int_t(*number of variables*);
      int_t(*reference count*);
      Llvm.pointer_type value_p;
    ]) false
  and _ = Llvm.struct_set_body subrange_t (Array.of_list [
      var_instance_p(*The target range*);
      int_t(*row offset*);
      int_t(*column offset*);
      int_t(*row count*);
      int_t(*column count*)
    ]) false
  and _ = Llvm.struct_set_body value_t (Array.of_list [
      flags_t (*First bit indicates whether it is an int or a range*);
      number_t (*Numeric value of the cell*);
      string_p (*String value of the cell if applicable*);
      subrange_p (*Range value of the cell if applicable*);
      (*float_t (Double value of the cell*)
```

```
    ]) false
  and _ = Llvm.struct_set_body string_t (Array.of_list [
      char_p (*Pointer to null-terminated string*);
      long_t (*Length of string*);
      int_t (*Reference count*)
    ]) false
  and _ = Llvm.struct_set_body dimensions_t (Array.of_list [int_t; int_t]) false in
  {
    var_instance_t = var_instance_t;
    value_t = value_t;
    subrange_t = subrange_t;
    resolved_formula_t = resolved_formula_t;
    dimensions_t = dimensions_t;
    number_t = number_t;
    string_t = string_t;
    extend_scope_t = extend_scope_t;
    formula_t = formula_t;
    formula_call_t = formula_call_t;

    var_defn_t = var_defn_t;
    var_defn_p = var_defn_p;
    var_instance_p = var_instance_p;
    subrange_p = subrange_p;
    value_p = value_p;
    resolved_formula_p = resolved_formula_p;
    string_p = string_p;
    char_p = char_p;
    extend_scope_p = extend_scope_p;
    formula_p = formula_p;
    formula_call_p = formula_call_p;

    var_instance_p_p = var_instance_p_p;

    int_t = int_t;
    long_t = long_t;
    float_t = float_t;
    flags_t = flags_t;
    bool_t = bool_t;
    char_t = char_t;
    void_t = void_t;
    char_p_p = char_p_p;
    string_p_p = string_p_p;

    rhs_index_t = rhs_index_t;
    rhs_slice_t = rhs_slice_t;
    rhs_selection_t = rhs_selection_t;
    rhs_index_p = rhs_index_p;
    rhs_slice_p = rhs_slice_p;
    rhs_selection_p = rhs_selection_p;
  }
```

## 9.7 codegen.ml

```
(*
  Extend code generator
```

```
3    jss2272
4    ns3158
5   *)
6
7   open Ast
8   open Semant
9   open CodeGenTypes
10  exception NotImplemented
11
12  let runtime_functions = Hashtbl.create 20
13
14  let (=>) struct_ptr elem = (fun val_name builder ->
15      let the_pointer = Llvm.build_struct_gep struct_ptr elem "the_pointer" builder in
16      Llvm.build_load the_pointer val_name builder);;
17
18  let ($>) val_to_store (struct_ptr, elem)  = (fun builder ->
19      let the_pointer = Llvm.build_struct_gep struct_ptr elem "" builder in
20      Llvm.build_store val_to_store the_pointer builder);;
21
22  (* from http://stackoverflow.com/questions/243864/what-is-the-ocaml-idiom-equivalent-
       to-pythons-range-function without the infix *)
23  let zero_until i =
24    let rec aux n acc =
25      if n < 0 then acc else aux (n-1) (n :: acc)
26    in aux (i-1) []
27
28  let create_runtime_functions ctx bt the_module =
29    let add_runtime_func fname returntype arglist =
30      let the_func = Llvm.declare_function fname (Llvm.function_type returntype arglist)
           the_module
31      in Hashtbl.add runtime_functions fname the_func in
32    add_runtime_func "strlen" bt.long_t [|bt.char_p|];
33    add_runtime_func "strcmp" bt.long_t [|bt.char_p; bt.char_p|];
34    add_runtime_func "pow" bt.float_t [|bt.float_t; bt.float_t|] ;
35    add_runtime_func "lrint" bt.int_t [|bt.float_t|] ;
36    add_runtime_func "llvm.memcpy.p0i8.p0i8.i64" bt.void_t [|bt.char_p; bt.char_p; bt.
        long_t; bt.int_t; bt.bool_t|] ;
37    add_runtime_func "incStack" bt.void_t [||] ;
38    add_runtime_func "getVal" bt.value_p [|bt.var_instance_p; bt.int_t; bt.int_t|] ;
39    add_runtime_func "rg_eq" bt.int_t [|bt.value_p; bt.value_p|] ;
40    add_runtime_func "clone_value" bt.value_p [|bt.value_p;|] ;
41    (* add_runtime_func "freeMe" (Llvm.void_type ctx) [|bt.extend_scope_p;|] ; *)
42    add_runtime_func "getSize" bt.value_p [|bt.var_instance_p;|] ;
43    add_runtime_func "get_variable" bt.var_instance_p [|bt.extend_scope_p; bt.int_t|] ;
44    add_runtime_func "null_init" (Llvm.void_type ctx) [|bt.extend_scope_p|] ;
45    add_runtime_func "debug_print" (Llvm.void_type ctx) [|bt.value_p ; bt.char_p|] ;
46    add_runtime_func "new_string" bt.value_p [|bt.char_p|] ;
47    add_runtime_func "deref_subrange_p" bt.value_p [|bt.subrange_p|];
48    add_runtime_func "debug_print_selection" (Llvm.void_type ctx) [|bt.rhs_selection_p
        |];
49    add_runtime_func "extract_selection" bt.value_p [|bt.value_p; bt.rhs_selection_p; bt
        .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,
66    * and functions declared within Extend. *)
67   let declare_library_function fname func accum_map =
68     let llvm_ftype = Llvm.function_type base_types.value_p (Array.of_list (List.map (
          fun a -> base_types.value_p) func.extern_fn_params)) in
69     let llvm_fname = "extend_" ^ fname in
70     let llvm_fn = Llvm.declare_function llvm_fname llvm_ftype base_module in
71     StringMap.add fname llvm_fn accum_map in
72   let library_functions = StringMap.fold declare_library_function externs StringMap.
       empty in
73   let define_user_function fname func =
74     let llvm_fname = "extend_" ^ fname in
75     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
76     let llvm_fn = Llvm.define_function llvm_fname llvm_ftype base_module in
77     (func, llvm_fn) in
78   let extend_functions = StringMap.mapi define_user_function functions in
79   let function_llvalues = StringMap.fold StringMap.add (StringMap.map snd
       extend_functions) library_functions in
80
81   (* Build the global symbol table *)
82   let (global_symbols, num_globals) = index_map Globals globals in
83   let (extend_fn_numbers, num_extend_fns) = index_map ExtendFunctions extend_functions
        in
84
85   (* Create the global array that will hold each function's array of var_defns. *)
86   let vardefn_ptr = Llvm.const_pointer_null base_types.var_defn_p in
87   let vardefn_array = Array.make (StringMap.cardinal extend_functions) vardefn_ptr in
88   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
89
90   (* Create the pointer to the global scope object *)
91   let global_scope_loc = Llvm.define_global "global_scope_loc" (Llvm.
       const_pointer_null base_types.extend_scope_p) base_module in
92
93   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
94   let main_bod = Llvm.builder_at_end context (Llvm.entry_block main_def) in
95
96   let init_def = Llvm.define_function "initialize_vardefns" (Llvm.function_type (Llvm.
       void_type context) [||]) base_module in
97   let init_bod = Llvm.builder_at_end context (Llvm.entry_block init_def) in
98
99   let literal_def = Llvm.define_function "initialize_literals" (Llvm.function_type (
       Llvm.void_type context) [||]) base_module in
```

```
100   let literal_bod = Llvm.builder_at_end context (Llvm.entry_block literal_def) in
101
102   (* Create the array of value_ps that will contain the responses to TypeOf(val) *)
103   let null_val_ptr = Llvm.const_pointer_null base_types.value_p in
104   let null_val_array = Array.make (Array.length int_to_type_array) null_val_ptr in
105   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
106   let create_typeof_string i s =
107     let sp = Llvm.build_global_stringptr s "global_typeof_stringptr" literal_bod in
108     let vp = Llvm.build_call (Hashtbl.find runtime_functions "new_string") [|sp|] "
          global_typeof_string" literal_bod in
109     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
110     let _ = Llvm.build_store vp vp_dst literal_bod in
111     () in
112   Array.iteri create_typeof_string int_to_type_array ;
113
114   (* Look these two up once and for all *)
115   (* let deepCopy = Hashtbl.find runtime_functions "deepCopy" in *)
116   (* let freeMe = Hashtbl.find runtime_functions "freeMe" in *)
117   let getVal = Hashtbl.find runtime_functions "getVal" in (*getVal retrieves the value
          of a variable instance for a specific x and y*)
118   let getVar = Hashtbl.find runtime_functions "get_variable" in (*getVar retrieves a
          variable instance based on the offset. It instanciates the variable if it does
          not exist yet*)
119
120   (* build_formula_function takes a symbol table and an expression, builds the LLVM
          function, and returns the llvalue of the function *)
121   let build_formula_function (varname, formula_idx) symbols formula_expr =
122     let form_decl = Llvm.define_function ("formula_fn_" ^ varname ^ "_num_" ^ (
          string_of_int formula_idx)) base_types.formula_call_t base_module in
123     let builder_at_top = Llvm.builder_at_end context (Llvm.entry_block form_decl) in
124     let local_scope = Llvm.param form_decl 0 in
125     let cell_row = Llvm.param form_decl 1 in
126     let cell_col = Llvm.param form_decl 2 in
127     let global_scope = Llvm.build_load global_scope_loc "global_scope" builder_at_top
          in
128
129     (* Some repeated stuff to avoid cut & paste *)
130     let empty_type = (Llvm.const_int base_types.char_t (value_field_flags_index Empty)
          ) in
131     let number_type = (Llvm.const_int base_types.char_t (value_field_flags_index
          Number)) in
132     let string_type = (Llvm.const_int base_types.char_t (value_field_flags_index
          String)) in
133     let range_type = (Llvm.const_int base_types.char_t (value_field_flags_index Range)
          ) in
134     let make_block blockname =
135       let new_block = Llvm.append_block context blockname form_decl in
136       let new_builder = Llvm.builder_at_end context new_block in
137       (new_block, new_builder) in
138     let store_number value_ptr store_builder number_llvalue =
139       let sp = Llvm.build_struct_gep value_ptr (value_field_index Number) "num_pointer
             " store_builder in
140       let _ = Llvm.build_store number_type (Llvm.build_struct_gep value_ptr (
```

```
          value_field_index Flags) "" store_builder) store_builder in
141       ignore (Llvm.build_store number_llvalue sp store_builder) in
142     let store_empty value_ptr store_builder =
143       ignore (Llvm.build_store empty_type (Llvm.build_struct_gep value_ptr (
              value_field_index Flags) "" store_builder) store_builder) in
144
145     let make_truthiness_blocks blockprefix ret_val =
146       let (merge_bb, merge_builder) = make_block (blockprefix ^ "_merge") in
147
148       let (make_true_bb, make_true_builder) = make_block (blockprefix ^ "_true") in
149       let _ = store_number ret_val make_true_builder (Llvm.const_float base_types.
              float_t 1.0) in
150       let _ = Llvm.build_br merge_bb make_true_builder in
151
152       let (make_false_bb, make_false_builder) = make_block (blockprefix ^ "_false") in
153       let _ = store_number ret_val make_false_builder (Llvm.const_float base_types.
              float_t 0.0) in
154       let _ = Llvm.build_br merge_bb make_false_builder in
155
156       let (make_empty_bb, make_empty_builder) = make_block (blockprefix ^ "_empty") in
157       let _ = store_empty ret_val make_empty_builder  in
158       let _ = Llvm.build_br merge_bb make_empty_builder in
159
160       (make_true_bb, make_false_bb, make_empty_bb, merge_builder) in
161
162     let rec build_expr old_builder exp = match exp with
163         LitInt(i) -> let vvv = Llvm.const_float base_types.float_t (float_of_int i) in
164         let ret_val = Llvm.build_malloc base_types.value_t "int_ret_val" old_builder
                in
165         let _ = store_number ret_val old_builder vvv in
166         (ret_val, old_builder)
167       | LitFlt(f) -> let vvv = Llvm.const_float base_types.float_t f in
168         let ret_val = Llvm.build_malloc base_types.value_t "flt_ret_val" old_builder
                in
169         let _ = store_number ret_val old_builder vvv in
170         (ret_val, old_builder)
171       | UnOp(Neg, LitInt(i)) -> build_expr old_builder (LitInt(-i))
172       | UnOp(Neg, LitFlt(f)) -> build_expr old_builder (LitFlt(-.f))
173       | Empty ->
174         let ret_val = Llvm.build_malloc base_types.value_t "empty_ret_val" old_builder
                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") [|
                ret_val; Llvm.const_pointer_null base_types.char_p|] "" new_builder in
180         (ret_val, new_builder) *)
181       | Id(name) ->
182         let create_and_deref_subrange appropriate_scope i =
183           let llvm_var = Llvm.build_call getVar [|appropriate_scope; Llvm.const_int
                  base_types.int_t i|] "llvm_var" old_builder in
184           let base_var_num_rows = (llvm_var => (var_instance_field_index Rows)) "
                  base_var_num_rows" old_builder in
185           let base_var_num_cols = (llvm_var => (var_instance_field_index Cols)) "
                  base_var_num_rows" old_builder in
```

```
186           let subrange_ptr = Llvm.build_alloca base_types.subrange_t "subrange_ptr"
                  old_builder in
187           let _ = (llvm_var $> (subrange_ptr, (subrange_field_index BaseRangePtr)))
                  old_builder in
188           let _ = ((Llvm.const_null base_types.int_t) $> (subrange_ptr, (
                  subrange_field_index BaseOffsetRow))) old_builder in
189           let _ = ((Llvm.const_null base_types.int_t) $> (subrange_ptr, (
                  subrange_field_index BaseOffsetCol))) old_builder in
190           let _ = (base_var_num_rows $> (subrange_ptr, (subrange_field_index
                  SubrangeRows))) old_builder in
191           let _ = (base_var_num_cols $> (subrange_ptr, (subrange_field_index
                  SubrangeCols))) old_builder in
192           (Llvm.build_call (Hashtbl.find runtime_functions "deref_subrange_p") [|
                  subrange_ptr|] "local_id_ret_val" old_builder, old_builder) in
193         (
194           match (try StringMap.find name symbols with Not_found -> raise(LogicError("
                  Something went wrong with your semantic analysis - " ^ name ^ " not found
                  "))) with
195             LocalVariable(i) -> create_and_deref_subrange local_scope i
196           | GlobalVariable(i) -> create_and_deref_subrange global_scope i
197           | FunctionParameter(i) ->
198             let paramarray = (local_scope => (scope_field_type_index FunctionParams))
                    "paramarray" old_builder in
199             let param_addr = Llvm.build_in_bounds_gep paramarray [|Llvm.const_int
                    base_types.int_t i|] "param_addr" old_builder in
200             let param = Llvm.build_load param_addr "param" old_builder in
201             (Llvm.build_call (Hashtbl.find runtime_functions "clone_value") [|param|]
                    "function_param_ret_val" old_builder, old_builder)
202           | ExtendFunction(i) -> raise(LogicError("Something went wrong with your
                  semantic analyis - function " ^ name ^ " used as variable in RHS for " ^
                  varname))
203         )
204       | ReducedTernary(cond_var, true_var, false_var) ->
205         let get_llvm_var name getvar_builder =
206           match (try StringMap.find name symbols with Not_found -> raise(LogicError("
                  Something went wront with your transformation - Reduced Ternary name " ^
                  name ^ " not found"))) with
207             LocalVariable(i) -> Llvm.build_call getVar [|local_scope; Llvm.const_int
                    base_types.int_t i|] "llvm_var" getvar_builder
208           | GlobalVariable(i) -> Llvm.build_call getVar [|global_scope; Llvm.const_int
                    base_types.int_t i|] "llvm_var" getvar_builder
209           | _ -> raise(LogicError("Something went wront with your transformation -
                  Reduced Ternary name " ^ name ^ " not a local or global variable")) in
210
211         let (empty_bb, empty_builder) = make_block "empty" in
212         let (not_empty_bb, not_empty_builder) = make_block "not_empty" in
213         let (truthy_bb, truthy_builder) = make_block "truthy" in
214         let (falsey_bb, falsey_builder) = make_block "falsey" in
215         let (merge_bb, merge_builder) = make_block "merge" in
216
217         let ret_val_addr = Llvm.build_alloca base_types.value_p "tern_ret_val_addr"
                old_builder in
218         let cond_llvm_var = get_llvm_var cond_var old_builder in
219         let cond_val = Llvm.build_call getVal [|cond_llvm_var; cell_row; cell_col|] "
                cond_val" old_builder in
220         let cond_val_type = (cond_val => (value_field_index Flags)) "cond_val_type"
```

```
            old_builder in
221         let is_empty = Llvm.build_icmp Llvm.Icmp.Eq empty_type cond_val_type "is_empty
                " old_builder in
222         let _ = Llvm.build_cond_br is_empty empty_bb not_empty_bb old_builder in
223
224         (* Empty basic block: *)
225         let ret_val_empty = Llvm.build_malloc base_types.value_t "tern_empty"
                empty_builder in
226         let _ = store_empty ret_val_empty empty_builder in
227         let _ = Llvm.build_store ret_val_empty ret_val_addr empty_builder in
228         let _ = Llvm.build_br merge_bb empty_builder in
229
230         (* Not empty basic block: *)
231         let the_number = (cond_val => (value_field_index Number)) "the_number"
                not_empty_builder in
232         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 *)
233         let _ = Llvm.build_cond_br is_not_zero truthy_bb falsey_bb not_empty_builder
                in
234
235         (* Truthy basic block: *)
236         let truthy_llvm_var = get_llvm_var true_var truthy_builder in
237         let truthy_val = Llvm.build_call getVal [|truthy_llvm_var; cell_row; cell_col
                |] "truthy_val" truthy_builder in
238         let _ = Llvm.build_store truthy_val ret_val_addr truthy_builder in
239         let _ = Llvm.build_br merge_bb truthy_builder in
240
241         (* Falsey basic block: *)
242         let falsey_llvm_var = get_llvm_var false_var falsey_builder in
243         let falsey_val = Llvm.build_call getVal [|falsey_llvm_var; cell_row; cell_col
                |] "falsey_val" falsey_builder in
244         let _ = Llvm.build_store falsey_val ret_val_addr falsey_builder in
245         let _ = Llvm.build_br merge_bb falsey_builder in
246
247         let ret_val = Llvm.build_load ret_val_addr "tern_ret_val" merge_builder in
248         (ret_val, merge_builder)
249       | Selection(expr, sel) ->
250         let (expr_val, expr_builder) = build_expr old_builder expr in
251         let build_rhs_index idx_builder = function
252             Abs(e) ->
253             let (idx_expr_val, next_builder) = build_expr idx_builder e in
254             let rhs_idx_ptr = Llvm.build_alloca base_types.rhs_index_t "idx_ptr"
                    next_builder in
255             let _ = (idx_expr_val $> (rhs_idx_ptr, (rhs_index_field_index RhsExprVal))
                    ) next_builder in
256             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
257             (rhs_idx_ptr, next_builder)
258           | Rel(e) ->
259             let (idx_expr_val, next_builder) = build_expr idx_builder e in
260             let rhs_idx_ptr = Llvm.build_alloca base_types.rhs_index_t "idx_ptr"
                    next_builder in
261             let _ = (idx_expr_val $> (rhs_idx_ptr, (rhs_index_field_index RhsExprVal))
                    ) next_builder in
```

```
262             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
263             (rhs_idx_ptr, next_builder)
264           | DimensionStart ->
265             let rhs_idx_ptr = Llvm.build_alloca base_types.rhs_index_t "idx_ptr"
                    idx_builder in
266             let _ = ((Llvm.const_pointer_null base_types.value_p) $> (rhs_idx_ptr, (
                    rhs_index_field_index RhsExprVal))) idx_builder in
267             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
268             (rhs_idx_ptr, idx_builder)
269           | DimensionEnd ->
270             let rhs_idx_ptr = Llvm.build_alloca base_types.rhs_index_t "idx_ptr"
                    idx_builder in
271             let _ = ((Llvm.const_pointer_null base_types.value_p) $> (rhs_idx_ptr, (
                    rhs_index_field_index RhsExprVal))) idx_builder in
272             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
273             (rhs_idx_ptr, idx_builder) in
274         let build_rhs_slice slice_builder = function
275             (Some start_idx, Some end_idx) ->
276             let rhs_slice_ptr = Llvm.build_alloca base_types.rhs_slice_t "slice_ptr"
                    slice_builder in
277             let (start_idx_ptr, next_builder) = build_rhs_index slice_builder
                    start_idx in
278             let (end_idx_ptr, last_builder) = build_rhs_index next_builder end_idx in
279             let _ = (start_idx_ptr $> (rhs_slice_ptr, (rhs_slice_field_index
                    RhsSliceStartIdx))) last_builder in
280             let _ = (end_idx_ptr $> (rhs_slice_ptr, (rhs_slice_field_index
                    RhsSliceEndIdx))) last_builder in
281             (rhs_slice_ptr,last_builder)
282           | (Some single_idx, None) ->
283             let rhs_slice_ptr = Llvm.build_alloca base_types.rhs_slice_t "slice_ptr"
                    slice_builder in
284             let (single_idx_ptr, last_builder) = build_rhs_index slice_builder
                    single_idx in
285             let _ = (single_idx_ptr $> (rhs_slice_ptr, (rhs_slice_field_index
                    RhsSliceStartIdx))) last_builder in
286             let _ = ((Llvm.const_pointer_null base_types.rhs_index_p) $> (
                    rhs_slice_ptr, (rhs_slice_field_index RhsSliceEndIdx))) last_builder in
287             (rhs_slice_ptr,last_builder)
288           | (None, None) ->
289             let rhs_slice_ptr = Llvm.build_alloca base_types.rhs_slice_t "slice_ptr"
                    slice_builder in
290             let _ = ((Llvm.const_pointer_null base_types.rhs_index_p) $> (
                    rhs_slice_ptr, (rhs_slice_field_index RhsSliceStartIdx))) slice_builder
                     in
291             let _ = ((Llvm.const_pointer_null base_types.rhs_index_p) $> (
                    rhs_slice_ptr, (rhs_slice_field_index RhsSliceEndIdx))) slice_builder
                    in
292             (rhs_slice_ptr,slice_builder)
293           | (None, Some illegal_idx) -> print_endline (string_of_expr exp) ; raise (
                  LogicError("This slice should not be grammatically possible")) in
```

```
294         let build_rhs_sel sel_builder = function
295             (Some first_slice, Some second_slice) ->
296             let rhs_selection_ptr = Llvm.build_alloca base_types.rhs_selection_t "
                    selection_ptr" sel_builder in
297             let (first_slice_ptr, next_builder) = build_rhs_slice sel_builder
                    first_slice in
298             let (second_slice_ptr, last_builder) = build_rhs_slice next_builder
                    second_slice in
299             let _ = (first_slice_ptr $> (rhs_selection_ptr, (rhs_selection_field_index
                     RhsSelSlice1))) last_builder in
300             let _ = (second_slice_ptr $> (rhs_selection_ptr, (
                    rhs_selection_field_index RhsSelSlice2))) last_builder in
301             (rhs_selection_ptr,last_builder)
302           | (Some single_slice, None) ->
303             let rhs_selection_ptr = Llvm.build_alloca base_types.rhs_selection_t "
                    selection_ptr" sel_builder in
304             let (single_slice_ptr, last_builder) = build_rhs_slice sel_builder
                    single_slice in
305             let _ = (single_slice_ptr $> (rhs_selection_ptr, (
                    rhs_selection_field_index RhsSelSlice1))) last_builder in
306             let _ = ((Llvm.const_pointer_null base_types.rhs_slice_p) $> (
                    rhs_selection_ptr, (rhs_selection_field_index RhsSelSlice2)))
                    last_builder in
307             (rhs_selection_ptr,last_builder)
308           | (None, None) ->
309             let rhs_selection_ptr = Llvm.build_alloca base_types.rhs_selection_t "
                    selection_ptr" sel_builder in
310             let _ = ((Llvm.const_pointer_null base_types.rhs_slice_p) $> (
                    rhs_selection_ptr, (rhs_selection_field_index RhsSelSlice1)))
                    sel_builder in
311             let _ = ((Llvm.const_pointer_null base_types.rhs_slice_p) $> (
                    rhs_selection_ptr, (rhs_selection_field_index RhsSelSlice2)))
                    sel_builder in
312             (rhs_selection_ptr,sel_builder)
313           | (None, Some illegal_idx) -> print_endline (string_of_expr exp) ; raise (
                 LogicError("This selection should not be grammatically possible")) in
314         let (selection_ptr, builder_to_end_all_builders) = build_rhs_sel expr_builder
                sel in
315         (* let _ = Llvm.build_call (Hashtbl.find runtime_functions "
                debug_print_selection") [|selection_ptr|] "" builder_to_end_all_builders in
                 *)
316         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
317         (* 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 *)
318         (ret_val, builder_to_end_all_builders)
319       | Precedence(a,b) -> let (_, new_builder) = build_expr old_builder a in
             build_expr new_builder b
320       | LitString(str) ->
321         let initbod_charptr = Llvm.build_global_stringptr str "initbod_charptr"
                literal_bod in
322         let initbod_val_p = Llvm.build_call (Hashtbl.find runtime_functions "
                new_string") [|initbod_charptr|] "initbod_val_p" literal_bod in
323         let global_val_p_p = Llvm.define_global "global_litstring_p" (Llvm.
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            const_pointer_null base_types.value_p) base_module in
324         let _ = Llvm.build_store initbod_val_p global_val_p_p literal_bod in
325
326         let local_val_p = Llvm.build_load global_val_p_p "local_value_p" old_builder
                in
327         let ret_val = Llvm.build_call (Hashtbl.find runtime_functions "clone_value")
                [|local_val_p|] "ret_val" old_builder in
328         (ret_val, old_builder)
329       | LitRange(rl) ->
330         let num_rows = List.length rl in
331         let num_cols = List.fold_left max 0 (List.map List.length rl) in
332         if num_rows = 1 && num_cols = 1 then build_expr old_builder (List.hd (List.hd
                rl))
333         else
334           let global_val_p_p = Llvm.define_global "global_litrange_p" (Llvm.
                const_pointer_null base_types.value_p) base_module in
335           let initbod_val_p = Llvm.build_malloc base_types.value_t "initbod_val_p"
                literal_bod in
336           let _ = Llvm.build_store initbod_val_p global_val_p_p literal_bod in
337           let _ = (range_type $> (initbod_val_p, (value_field_index Flags)))
                literal_bod in
338           let anonymous_subrange_p = Llvm.build_malloc base_types.subrange_t "
                anonymous_subrange" literal_bod in
339           let _ = (anonymous_subrange_p $> (initbod_val_p, (value_field_index Subrange
                ))) literal_bod in
340
341           let _ = ((Llvm.const_int base_types.int_t 0) $> (anonymous_subrange_p, (
                subrange_field_index BaseOffsetRow))) literal_bod in
342           let _ = ((Llvm.const_int base_types.int_t 0) $> (anonymous_subrange_p, (
                subrange_field_index BaseOffsetCol))) literal_bod in
343           let _ = ((Llvm.const_int base_types.int_t num_rows) $> (anonymous_subrange_p
                , (subrange_field_index SubrangeRows))) literal_bod in
344           let _ = ((Llvm.const_int base_types.int_t num_cols) $> (anonymous_subrange_p
                , (subrange_field_index SubrangeCols))) literal_bod in
345           let anonymous_var_inst_p = Llvm.build_malloc base_types.var_instance_t "
                anonymous_var_inst" literal_bod in
346           let _ = (anonymous_var_inst_p $> (anonymous_subrange_p, (
                subrange_field_index BaseRangePtr))) literal_bod in
347
348           let _ = ((Llvm.const_int base_types.int_t num_rows) $> (anonymous_var_inst_p
                , (var_instance_field_index Rows))) literal_bod in
349           let _ = ((Llvm.const_int base_types.int_t num_cols) $> (anonymous_var_inst_p
                , (var_instance_field_index Cols))) literal_bod in
350           let _ = ((Llvm.const_int base_types.int_t 0) $> (anonymous_var_inst_p, (
                var_instance_field_index NumFormulas))) literal_bod in
351           let _ = ((Llvm.const_pointer_null base_types.resolved_formula_p) $> (
                anonymous_var_inst_p, (var_instance_field_index Formulas))) literal_bod
                in
352           let _ = ((Llvm.const_pointer_null base_types.extend_scope_p) $> (
                anonymous_var_inst_p, (var_instance_field_index Closure))) literal_bod in
353           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
354           let _ = (vals_array $> (anonymous_var_inst_p, (var_instance_field_index
                Values))) literal_bod in
355           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
```

```
356           let _ = (status_array $> (anonymous_var_inst_p, (var_instance_field_index
                  Status))) literal_bod in
357
358           let get_val_p e = let (vp, _) = build_expr literal_bod e in vp in
359           let val_p_list_list = List.map (fun x -> List.map get_val_p x) rl in
360           let cellnums = zero_until (num_rows * num_cols) in
361           let build_empty x =
362             let emptyval = Llvm.build_malloc base_types.value_t ("" ^ (string_of_int x
                  )) literal_bod in
363             let _ = store_empty emptyval literal_bod in
364             let emptydst = Llvm.build_in_bounds_gep vals_array [|Llvm.const_int
                  base_types.int_t x|] "" literal_bod in
365             let _ = Llvm.build_store emptyval emptydst literal_bod in
366             let statusdst = Llvm.build_in_bounds_gep status_array [|Llvm.const_int
                  base_types.int_t x|] "" literal_bod in
367             let _ = Llvm.build_store (Llvm.const_int base_types.char_t (
                  var_instance_status_flags_index Calculated)) statusdst literal_bod in
368             () in
369           List.iter build_empty cellnums ;
370           let store_val r c realval =
371             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
372             let _ = Llvm.build_store realval realdst literal_bod in
373             () in
374           let store_row r cols = List.iteri (fun c v -> store_val r c v) cols in
375           List.iteri store_row val_p_list_list ;
376           (* let _ = Llvm.build_call (Hashtbl.find runtime_functions "debug_print") [|
                  initbod_val_p; Llvm.const_pointer_null base_types.char_p|] "" literal_bod
                   in *)
377
378           let local_val_p = Llvm.build_load global_val_p_p "local_value_p" old_builder
                   in
379           (* let _ = Llvm.build_call (Hashtbl.find runtime_functions "debug_print") [|
                  local_val_p; Llvm.const_pointer_null base_types.char_p|] "" old_builder
                  in *)
380           let ret_val = Llvm.build_call (Hashtbl.find runtime_functions "clone_value")
                   [|local_val_p|] "ret_val" old_builder in
381           (* let _ = Llvm.build_call (Hashtbl.find runtime_functions "debug_print") [|
                  ret_val; Llvm.const_pointer_null base_types.char_p|] "" old_builder in *)
382           (ret_val, old_builder)
383       | Call(fn,exl) -> (*TODO: Call needs to be reviewed. Possibly switch call
              arguments to value_p*)
384           let build_one_expr (arg_list, intermediate_builder) e =
385             let (arg_val, next_builder) = build_expr intermediate_builder e in
386             (arg_val :: arg_list, next_builder) in
387           let (reversed_arglist, call_builder) = List.fold_left build_one_expr ([],
                  old_builder) exl in
388           let args = Array.of_list (List.rev reversed_arglist) in
389           let result = Llvm.build_call (
390             StringMap.find fn function_llvalues
391             ) args "call_ret_val" call_builder in
392           (result, call_builder)
393       | BinOp(expr1,op,expr2) -> (
394           let (val1, builder1) = build_expr old_builder expr1 in
395           let (val2, int_builder) = build_expr builder1 expr2 in
```

```
396           let bit_shift = (Llvm.const_int base_types.char_t 4) in
397           let expr1_type = (val1 => (value_field_index Flags)) "expr1_type"
                  int_builder in
398           let expr2_type = (val2 => (value_field_index Flags)) "expr2_type"
                  int_builder in
399           let expr1_type_shifted = Llvm.build_shl expr1_type bit_shift "
                  expr_1_type_shifted" int_builder in
400           let combined_type = Llvm.build_add expr1_type_shifted expr2_type "
                  combined_type" int_builder in
401           let number_number = Llvm.const_add (Llvm.const_shl number_type bit_shift)
                  number_type in
402           let string_string = Llvm.const_add (Llvm.const_shl string_type bit_shift)
                  string_type in
403           let empty_empty = Llvm.const_add (Llvm.const_shl empty_type bit_shift)
                  empty_type in
404           let range_range = Llvm.const_add (Llvm.const_shl range_type bit_shift)
                  range_type in
405           let build_simple_binop oppp int_builder =
406             (let ret_val = Llvm.build_malloc base_types.value_t "binop_minus_ret_val"
                    int_builder in
407              let _ = Llvm.build_store
408                  (
409                    Llvm.const_int
410                    base_types.char_t
411                    (value_field_flags_index Empty)
412                  ) (
413                    Llvm.build_struct_gep
414                    ret_val
415                    (value_field_index Flags)
416                    ""
417                    int_builder
418                  )
419                  int_builder
420              in
421              let bailout = (Llvm.append_block context "" form_decl) in
422              let bbailout = Llvm.builder_at_end context bailout in
423              let (numnum_bb, numnum_builder) = make_block "numnum" in
424              let numeric_val_1 = (val1 => (value_field_index Number)) "number_one"
                     numnum_builder in
425              let numeric_val_2 = (val2 => (value_field_index Number)) "number_two"
                     numnum_builder in
426              let numeric_res = oppp numeric_val_1 numeric_val_2 "numeric_res"
                     numnum_builder in
427              let _ = Llvm.build_store
428                  numeric_res (
429                    Llvm.build_struct_gep
430                    ret_val
431                    (value_field_index Number)
432                    ""
433                    numnum_builder
434                  )
435                  numnum_builder in
436              let _ = Llvm.build_store
437                  (
438                    Llvm.const_int
439                    base_types.char_t
```

```
                    (value_field_flags_index Number)
                  ) (
                    Llvm.build_struct_gep
                    ret_val
                    (value_field_index Flags)
                    ""
                    numnum_builder
                  )
                  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
               (ret_val, bbailout)
            )
            and build_simple_int_binop oppp int_builder =
              (let ret_val = Llvm.build_malloc base_types.value_t "binop_minus_ret_val"
                  int_builder in
               let _ = Llvm.build_store
                   (
                     Llvm.const_int
                     base_types.char_t
                     (value_field_flags_index Empty)
                   ) (
                     Llvm.build_struct_gep
                     ret_val
                     (value_field_index Flags)
                     ""
                     int_builder
                   )
                   int_builder
               in
               let bailout = (Llvm.append_block context "" form_decl) in
               let bbailout = Llvm.builder_at_end context bailout in
               let (numnum_bb, numnum_builder) = make_block "numnum" in
               let roundfl x = Llvm.build_call (Hashtbl.find runtime_functions "lrint
                   ") [|x|] "" numnum_builder in
               let numeric_val_1 = roundfl ((val1 => (value_field_index Number)) "
                   number_one" numnum_builder) in
               let numeric_val_2 = roundfl ((val2 => (value_field_index Number)) "
                   number_two" numnum_builder) in
               let numeric_res = oppp numeric_val_1 numeric_val_2 "numeric_res"
                   numnum_builder in
               let _ = Llvm.build_store
                   (Llvm.build_sitofp numeric_res base_types.float_t "" numnum_builder
                       )
                   (
                     Llvm.build_struct_gep
                     ret_val
                     (value_field_index Number)
                     ""
                     numnum_builder
                   )
                   numnum_builder in
               let _ = Llvm.build_store
                   (
                     Llvm.const_int
```

```
                    base_types.char_t
                    (value_field_flags_index Number)
                  ) (
                    Llvm.build_struct_gep
                    ret_val
                    (value_field_index Flags)
                    ""
                    numnum_builder
                  )
                  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
               (ret_val, bbailout)
           ) in
         let build_boolean_op numeric_comparator string_comparator int_builder =
           let ret_val = Llvm.build_malloc base_types.value_t "binop_gt_ret_val"
               int_builder in
           let (make_true_bb, make_false_bb, make_empty_bb, merge_builder) =
               make_truthiness_blocks "binop_eq" ret_val in

           let (numnum_bb, numnum_builder) = make_block "numnum" in
           let numeric_val_1 = (val1 => (value_field_index Number)) "number_one"
               numnum_builder in
           let numeric_val_2 = (val2 => (value_field_index Number)) "number_two"
               numnum_builder in
           let numeric_greater = Llvm.build_fcmp numeric_comparator numeric_val_1
               numeric_val_2 "numeric_greater" numnum_builder in
           let _ = Llvm.build_cond_br numeric_greater make_true_bb make_false_bb
               numnum_builder in

           let (strstr_bb, strstr_builder) = make_block "strstr" in
           let str_p_1 = (val1 => (value_field_index String)) "string_one"
               strstr_builder in
           let str_p_2 = (val2 => (value_field_index String)) "string_two"
               strstr_builder in
           let char_p_1 = (str_p_1 => (string_field_index StringCharPtr)) "char_p_one
               " strstr_builder in
           let char_p_2 = (str_p_2 => (string_field_index StringCharPtr)) "char_p_two
               " strstr_builder in
           let strcmp_result = Llvm.build_call (Hashtbl.find runtime_functions "
               strcmp") [|char_p_1; char_p_2|] "strcmp_result" strstr_builder in
           let string_greater = Llvm.build_icmp string_comparator strcmp_result (Llvm
               .const_null base_types.long_t) "string_greater" strstr_builder in
           let _ = Llvm.build_cond_br string_greater make_true_bb make_false_bb
               strstr_builder in

           let switch_inst = Llvm.build_switch combined_type make_empty_bb 2
               int_builder in (* Incompatible ===> default to empty *)
           Llvm.add_case switch_inst number_number numnum_bb;
           Llvm.add_case switch_inst string_string strstr_bb;
           (ret_val, merge_builder) in
         match op with
           Minus -> build_simple_binop Llvm.build_fsub int_builder
         | Plus ->
             let result = Llvm.build_malloc base_types.value_t "" int_builder
```

```
530             and stradd = (Llvm.append_block context "" form_decl)
531             and numadd = (Llvm.append_block context "" form_decl)
532             and bailout = (Llvm.append_block context "" form_decl)
533             and numorstrorother = (Llvm.append_block context "" form_decl)
534             and strorother = (Llvm.append_block context "" form_decl)
535             in
536             let bstradd = Llvm.builder_at_end context stradd
537             and bnumadd = Llvm.builder_at_end context numadd
538             and bnumorstrorother = Llvm.builder_at_end context numorstrorother
539             and bstrorother = Llvm.builder_at_end context strorother
540             and bbailout = Llvm.builder_at_end context bailout
541             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
542             in
543             let isnumber = Llvm.build_icmp Llvm.Icmp.Eq (Llvm.build_load (Llvm.
                    build_struct_gep val1 (value_field_index Flags) "" bnumorstrorother)
                    "" bnumorstrorother) (Llvm.const_int base_types.char_t (
                    value_field_flags_index Number)) "" bnumorstrorother
544             and isstring = Llvm.build_icmp Llvm.Icmp.Eq (Llvm.build_load (Llvm.
                    build_struct_gep val1 (value_field_index Flags) "" bstrorother) ""
                    bstrorother) (Llvm.const_int base_types.char_t (
                    value_field_flags_index String)) "" bstrorother
545             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
546             and _ = Llvm.build_store (Llvm.build_fadd (Llvm.build_load (Llvm.
                    build_struct_gep val1 (value_field_index Number) "" bnumadd) ""
                    bnumadd) (Llvm.build_load (Llvm.build_struct_gep val2 (
                    value_field_index Number) "" bnumadd) "" bnumadd) "" bnumadd) (Llvm.
                    build_struct_gep result (value_field_index Number) "" bnumadd)
                    bnumadd
547             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
548             and str1 = Llvm.build_load (Llvm.build_struct_gep val1 (
                    value_field_index String) "" bstradd) "" bstradd
549             and str2 = Llvm.build_load (Llvm.build_struct_gep val2 (
                    value_field_index String) "" bstradd) "" bstradd
550             and newstr = (Llvm.build_malloc base_types.string_t "" bstradd) in
551             let len1 = Llvm.build_load (Llvm.build_struct_gep str1 (
                    string_field_index StringLen) "" bstradd) "" bstradd
552             and len2 = Llvm.build_load (Llvm.build_struct_gep str2 (
                    string_field_index StringLen) "" bstradd) "" bstradd
553             and p1 = Llvm.build_load (Llvm.build_struct_gep str1 (string_field_index
                     StringCharPtr) "" bstradd) "" bstradd
554             and p2 = Llvm.build_load (Llvm.build_struct_gep str2 (string_field_index
                     StringCharPtr) "" bstradd) "" bstradd
555             and dst_char_ptr_ptr = (Llvm.build_struct_gep newstr (string_field_index
                     StringCharPtr) "" bstradd)
556             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
557             and _ = Llvm.build_store newstr (Llvm.build_struct_gep result (
```

```
                value_field_index String) "" bstradd) bstradd in
558             let fullLen = Llvm.build_nsw_add (Llvm.build_nsw_add len1 len2 ""
                    bstradd) (Llvm.const_int base_types.long_t 1) "" bstradd
559             and extra_byte2 = (Llvm.build_add len2 (Llvm.const_int base_types.long_t
                     1) "" bstradd) in
560             let dst_char = Llvm.build_array_malloc base_types.char_t (Llvm.
                    build_trunc fullLen base_types.int_t "" bstradd) "" bstradd in
561             let dst_char2 = Llvm.build_in_bounds_gep dst_char [|len1|] "" bstradd in
562             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
563             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
564             and _ = Llvm.build_store dst_char dst_char_ptr_ptr bstradd
565             in
566             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
567             in
568             let _ = Llvm.build_cond_br isnumorstring numorstrorother bailout
                    int_builder
569             and _ = Llvm.build_cond_br isnumber numadd strorother bnumorstrorother
570             and _ = Llvm.build_cond_br isstring stradd bailout bstrorother
571             and _ = Llvm.build_br bailout bstradd
572             and _ = Llvm.build_br bailout bnumadd
573             in
574             (result, bbailout)
575         | Times -> build_simple_binop Llvm.build_fmul int_builder
576         | Eq ->
577           (* let _ = Llvm.build_call (Hashtbl.find runtime_functions "debug_print")
                    [|val1; Llvm.build_global_stringptr "Eq operator - value 1" ""
                    old_builder|] "" int_builder in
578           let _ = Llvm.build_call (Hashtbl.find runtime_functions "debug_print") [|
                    val2; Llvm.build_global_stringptr "Eq operator - value 2" ""
                    old_builder|] "" int_builder in *)
579           let ret_val = Llvm.build_malloc base_types.value_t "binop_eq_ret_val"
                    int_builder in
580           let (make_true_bb, make_false_bb, _, merge_builder) =
                    make_truthiness_blocks "binop_eq" ret_val in
581
582           let (numnum_bb, numnum_builder) = make_block "numnum" in
583           let numeric_val_1 = (val1 => (value_field_index Number)) "number_one"
                    numnum_builder in
584           let numeric_val_2 = (val2 => (value_field_index Number)) "number_two"
                    numnum_builder in
585           let numeric_equality = Llvm.build_fcmp Llvm.Fcmp.Oeq numeric_val_1
                    numeric_val_2 "numeric_equality" numnum_builder in
586           let _ = Llvm.build_cond_br numeric_equality make_true_bb make_false_bb
                    numnum_builder in
587
588           let (strstr_bb, strstr_builder) = make_block "strstr" in
589           let str_p_1 = (val1 => (value_field_index String)) "string_one"
                    strstr_builder in
590           let str_p_2 = (val2 => (value_field_index String)) "string_two"
```

```
                strstr_builder in
591             let char_p_1 = (str_p_1 => (string_field_index StringCharPtr)) "char_p_one
                    " strstr_builder in
592             let char_p_2 = (str_p_2 => (string_field_index StringCharPtr)) "char_p_two
                    " strstr_builder in
593             let strcmp_result = Llvm.build_call (Hashtbl.find runtime_functions "
                    strcmp") [|char_p_1; char_p_2|] "strcmp_result" strstr_builder in
594             let string_equality = Llvm.build_icmp Llvm.Icmp.Eq strcmp_result (Llvm.
                    const_null base_types.long_t) "string_equality" strstr_builder in
595             let _ = Llvm.build_cond_br string_equality make_true_bb make_false_bb
                    strstr_builder in
596
597             let (rngrng_bb, rngrng_builder) = make_block "rngrng" in
598             (* TODO: Make this case work *)
599             let eqt = Llvm.build_is_not_null (Llvm.build_call (Hashtbl.find
                    runtime_functions "rg_eq") [|val1; val2|] "" rngrng_builder) ""
                    rngrng_builder in
600             let _ = Llvm.build_cond_br eqt make_true_bb make_false_bb rngrng_builder
                    in
601
602             let switch_inst = Llvm.build_switch combined_type make_false_bb 4
                    int_builder in (* Incompatible ===> default to false *)
603             Llvm.add_case switch_inst number_number numnum_bb;
604             Llvm.add_case switch_inst string_string strstr_bb;
605             Llvm.add_case switch_inst range_range rngrng_bb;
606             Llvm.add_case switch_inst empty_empty make_true_bb; (* Nothing to check in
                     this case, just return true *)
607             (ret_val, merge_builder)
608           | Gt -> build_boolean_op Llvm.Fcmp.Ogt Llvm.Icmp.Sgt int_builder
609           | GtEq -> build_boolean_op Llvm.Fcmp.Oge Llvm.Icmp.Sge int_builder
610           | Lt -> build_boolean_op Llvm.Fcmp.Olt Llvm.Icmp.Slt int_builder
611           | LtEq -> build_boolean_op Llvm.Fcmp.Ole Llvm.Icmp.Sle int_builder
612           | 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))
613           | Divide-> build_simple_binop Llvm.build_fdiv int_builder
614           | Mod-> build_simple_binop Llvm.build_frem int_builder
615           | Pow-> (
616             let powcall numeric_val_1 numeric_val_2 valname b =
617               Llvm.build_call (Hashtbl.find runtime_functions "pow") [|numeric_val_1;
                      numeric_val_2|] "" b in
618             build_simple_binop powcall int_builder)
619           | LShift-> build_simple_int_binop Llvm.build_shl int_builder
620           | RShift-> build_simple_int_binop Llvm.build_lshr int_builder
621           | BitOr-> build_simple_int_binop Llvm.build_or int_builder
622           | BitAnd-> build_simple_int_binop Llvm.build_and int_builder
623           | BitXor-> build_simple_int_binop Llvm.build_xor int_builder
624         )
625       | UnOp(SizeOf,expr) ->
626         let ret_val = Llvm.build_malloc base_types.value_t "unop_size_ret_val"
                old_builder in
627
628         (* TODO: We actually have to keep track of these anonymous objects somewhere
                so we can free them *)
629         let _ = (range_type $> (ret_val, (value_field_index Flags))) old_builder in
630         let anonymous_subrange_p = Llvm.build_malloc base_types.subrange_t "
```

```
            anonymous_subrange" old_builder in
631         let _ = (anonymous_subrange_p $> (ret_val, (value_field_index Subrange)))
                old_builder in
632
633         let _ = ((Llvm.const_int base_types.int_t 0) $> (anonymous_subrange_p, (
                subrange_field_index BaseOffsetRow))) old_builder in
634         let _ = ((Llvm.const_int base_types.int_t 0) $> (anonymous_subrange_p, (
                subrange_field_index BaseOffsetCol))) old_builder in
635         let _ = ((Llvm.const_int base_types.int_t 1) $> (anonymous_subrange_p, (
                subrange_field_index SubrangeRows))) old_builder in
636         let _ = ((Llvm.const_int base_types.int_t 2) $> (anonymous_subrange_p, (
                subrange_field_index SubrangeCols))) old_builder in
637         let anonymous_var_inst_p = Llvm.build_malloc base_types.var_instance_t "
                anonymous_var_inst" old_builder in
638         let _ = (anonymous_var_inst_p $> (anonymous_subrange_p, (subrange_field_index
                BaseRangePtr))) old_builder in
639
640         let _ = ((Llvm.const_int base_types.int_t 1) $> (anonymous_var_inst_p, (
                var_instance_field_index Rows))) old_builder in
641         let _ = ((Llvm.const_int base_types.int_t 2) $> (anonymous_var_inst_p, (
                var_instance_field_index Cols))) old_builder in
642         let _ = ((Llvm.const_int base_types.int_t 0) $> (anonymous_var_inst_p, (
                var_instance_field_index NumFormulas))) old_builder in
643         let _ = ((Llvm.const_pointer_null base_types.resolved_formula_p) $> (
                anonymous_var_inst_p, (var_instance_field_index Formulas))) old_builder in
644         let _ = ((Llvm.const_pointer_null base_types.extend_scope_p) $> (
                anonymous_var_inst_p, (var_instance_field_index Closure))) old_builder in
645         let num_rows_val = Llvm.build_malloc base_types.value_t "num_rows_val"
                old_builder in
646         let num_cols_val = Llvm.build_malloc base_types.value_t "num_cols_val"
                old_builder in
647         let vals_array = Llvm.build_array_malloc base_types.value_p (Llvm.const_int
                base_types.int_t 2) "vals_array" old_builder in
648         let _ = (vals_array $> (anonymous_var_inst_p, (var_instance_field_index Values
                ))) old_builder in
649         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
650         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
651         let status_array = Llvm.build_array_malloc base_types.char_t (Llvm.const_int
                base_types.int_t 2) "status_array" old_builder in
652         let _ = (status_array $> (anonymous_var_inst_p, (var_instance_field_index
                Status))) old_builder in
653         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
654         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
655
656         let (expr_val, expr_builder) = build_expr old_builder expr in
657         let val_flags = (expr_val => (value_field_index Flags)) "val_flags"
                expr_builder in
658         let is_subrange = Llvm.build_icmp Llvm.Icmp.Eq val_flags range_type "
```

```
            is_subrange" expr_builder in
659
660         let (merge_bb, merge_builder) = make_block "merge" in
661
662         let (primitive_bb, primitive_builder) = make_block "primitive" in
663         let _ = store_number num_rows_val primitive_builder (Llvm.const_float
                base_types.float_t 1.0) in
664         let _ = store_number num_cols_val primitive_builder (Llvm.const_float
                base_types.float_t 1.0) in
665         let _ = Llvm.build_br merge_bb primitive_builder in
666
667         let (subrange_bb, subrange_builder) = make_block "subrange" in
668         let subrange_ptr = (expr_val => (value_field_index Subrange)) "subrange_ptr"
                subrange_builder in
669         let rows_as_int = (subrange_ptr => (subrange_field_index SubrangeRows)) "
                rows_as_int" subrange_builder in
670         let cols_as_int = (subrange_ptr => (subrange_field_index SubrangeCols)) "
                cols_as_int" subrange_builder in
671         let rows_as_float = Llvm.build_sitofp rows_as_int base_types.float_t "
                rows_as_float" subrange_builder in
672         let cols_as_float = Llvm.build_sitofp cols_as_int base_types.float_t "
                cols_as_float" subrange_builder in
673         let _ = store_number num_rows_val subrange_builder rows_as_float in
674         let _ = store_number num_cols_val subrange_builder cols_as_float in
675         let _ = Llvm.build_br merge_bb subrange_builder in
676
677         let _ = Llvm.build_cond_br is_subrange subrange_bb primitive_bb expr_builder
                in
678         (ret_val, merge_builder)
679       | UnOp(Truthy, expr) ->
680         let ret_val = Llvm.build_malloc base_types.value_t "unop_truthy_ret_val"
                old_builder in
681         let (expr_val, expr_builder) = build_expr old_builder expr in
682
683         let (truthy_bb, falsey_bb, empty_bb, merge_builder) = make_truthiness_blocks "
                unop_truthy" ret_val in
684
685         let expr_flags = (expr_val => (value_field_index Flags)) "expr_flags"
                expr_builder in
686         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
687         let is_empty = Llvm.build_zext is_empty_bool base_types.char_t "is_empty"
                expr_builder in
688         let is_empty_two = Llvm.build_shl is_empty (Llvm.const_int base_types.char_t
                1) "is_empty_two" expr_builder in
689         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
690         let the_number = (expr_val => (value_field_index Number)) "the_number"
                expr_builder in
691         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
692         let is_numeric_zero_bool = Llvm.build_and is_zero is_number "
                is_numeric_zero_bool" expr_builder in
693         let is_numeric_zero = Llvm.build_zext is_numeric_zero_bool base_types.char_t "
```

```
            is_numeric_zero" expr_builder in
694         let switch_num = Llvm.build_add is_empty_two is_numeric_zero "switch_num"
                expr_builder in
695         let switch_inst = Llvm.build_switch switch_num empty_bb 2 expr_builder in
696         Llvm.add_case switch_inst (Llvm.const_int base_types.char_t 0) truthy_bb; (*
                empty << 1 + is_zero == 0 ===> truthy *)
697         Llvm.add_case switch_inst (Llvm.const_int base_types.char_t 1) falsey_bb; (*
                empty << 1 + is_zero == 1 ===> falsey *)
698         (ret_val, merge_builder)
699       | UnOp(LogNot, expr) ->
700         let (truth_val, truth_builder) = build_expr old_builder (UnOp(Truthy, expr))
                in
701         let the_number = (truth_val => (value_field_index Number)) "the_number"
                truth_builder in
702         let not_the_number = Llvm.build_fsub (Llvm.const_float base_types.float_t 1.0)
                 the_number "not_the_number" truth_builder in
703         let sp = Llvm.build_struct_gep truth_val (value_field_index Number) "
                num_pointer" truth_builder in
704         let _ = Llvm.build_store not_the_number sp truth_builder in
705         (truth_val, truth_builder)
706       | UnOp(Neg, expr) ->
707         let ret_val = Llvm.build_malloc base_types.value_t "unop_truthy_ret_val"
                old_builder in
708         let _ = store_empty ret_val old_builder in
709         let (expr_val, expr_builder) = build_expr old_builder expr in
710         let expr_type = (expr_val => (value_field_index Flags)) "expr_type"
                expr_builder in
711         let is_number = Llvm.build_icmp Llvm.Icmp.Eq expr_type number_type "is_number"
                 expr_builder in
712         let (finish_bb, finish_builder) = make_block "finish" in
713
714         let (number_bb, number_builder) = make_block "number" in
715         let the_number = (expr_val => (value_field_index Number)) "the_number"
                number_builder in
716         let minus_the_number = Llvm.build_fneg the_number "minus_the_number"
                number_builder in
717         let _ = store_number ret_val number_builder minus_the_number in
718         let _ = Llvm.build_br finish_bb number_builder in
719
720         let _ = Llvm.build_cond_br is_number number_bb finish_bb expr_builder in
721         (ret_val, finish_builder)
722       | UnOp(BitNot, expr) ->
723         let ret_val = Llvm.build_malloc base_types.value_t "unop_truthy_ret_val"
                old_builder in
724         let (expr_val, expr_builder) = build_expr old_builder expr in
725
726         let (numnum_bb, numnum_builder) = make_block "numnum" in
727         let (make_empty_bb, make_empty_builder) = make_block ("" ^ "_empty") in
728         let (finish_bb, finish_builder) = make_block "finish" in
729
730         let _ = store_empty ret_val make_empty_builder  in
731         let _ = Llvm.build_br finish_bb make_empty_builder in
732
733         let expr_type = (expr_val => (value_field_index Flags)) "expr_type"
                expr_builder in
734         let is_number = Llvm.build_icmp Llvm.Icmp.Eq expr_type number_type "is_number"
```

```
            expr_builder in
735       let _ = Llvm.build_cond_br is_number numnum_bb make_empty_bb expr_builder in
736
737       let expr_num = Llvm.build_call (Hashtbl.find runtime_functions "lrint") [|((
              expr_val => (value_field_index Number)) "expr_type" numnum_builder)|] ""
              numnum_builder in
738       let _ = store_number ret_val numnum_builder (Llvm.build_sitofp (Llvm.build_not
              expr_num "" numnum_builder) base_types.float_t "" numnum_builder) in
739       let _ = Llvm.build_br finish_bb numnum_builder in
740
741       (ret_val, finish_builder)
742     | UnOp(TypeOf, expr) ->
743       let (expr_val, expr_builder) = build_expr old_builder expr in
744       let expr_type = (expr_val => (value_field_index Flags)) "expr_type"
              expr_builder in
745       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
746       let vp_to_clone = Llvm.build_load vp_to_clone_loc "vp_to_clone" expr_builder
              in
747       let ret_val = Llvm.build_call (Hashtbl.find runtime_functions "clone_value")
              [|vp_to_clone|] "typeof_ret_val" expr_builder in
748       (ret_val, expr_builder)
749     | UnOp(Row, _) ->
750       let row_as_int = cell_row in
751       let row_as_float = Llvm.build_sitofp row_as_int base_types.float_t "
              row_as_float" old_builder in
752       let ret_val = Llvm.build_malloc base_types.value_t "ret_val" old_builder in
753       let _ = store_number ret_val old_builder row_as_float in
754       (ret_val, old_builder)
755     | UnOp(Column, _) ->
756       let col_as_int = cell_col in
757       let col_as_float = Llvm.build_sitofp col_as_int base_types.float_t "
              col_as_float" old_builder in
758       let ret_val = Llvm.build_malloc base_types.value_t "ret_val" old_builder in
759       let _ = store_number ret_val old_builder col_as_float in
760       (ret_val, old_builder)
761     | Switch(_,_,_) | Ternary(_,_,_) -> raise(TransformedAway("These expressions
            should have been transformed away")) in
762     (* | unknown_expr -> print_endline (string_of_expr unknown_expr);raise
            NotImplemented in *)
763   let (ret_value_p, final_builder) = build_expr builder_at_top formula_expr in
764   let _ = Llvm.build_ret ret_value_p final_builder in
765   form_decl in
766
767 (*build formula creates a formula declaration in a separate method from the function
        it belongs to*)
768 let build_formula (varname, idx) formula_array element symbols =
769   let storage_addr = Llvm.build_in_bounds_gep formula_array [|Llvm.const_int
        base_types.int_t idx|] "" init_bod in
770   let getStarts = function (* Not really just for starts *)
771       Abs(LitInt(1)) | Abs(LitInt(0)) | DimensionStart | DimensionEnd -> (1, -1)
772     | Abs(Id(s)) ->
773       (match StringMap.find s symbols with
774          LocalVariable(i) | GlobalVariable(i) -> (0, i)
775        | _ -> 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.")))
776       | _ -> 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
777     let getEnds = function
778         Some x -> let (b, c) = getStarts x in (b, c, 0)
779       | None -> (0, -1, 1) in
780     let (fromStartRow, rowStartVarnum) = getStarts element.formula_row_start in
781     let (fromStartCol, colStartVarnum) = getStarts element.formula_col_start in
782     let (toEndRow, rowEndVarnum, isSingleRow) = getEnds element.formula_row_end in
783     let (toEndCol, colEndVarnum, isSingleCol) = getEnds element.formula_col_end in
784
785     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
786     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
787     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
788     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
789     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
790
791     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
792     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
793     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
794     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
795     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
796
797     let form_decl = build_formula_function (varname, idx) symbols element.formula_expr
             in
798     let _ = Llvm.build_store form_decl (Llvm.build_struct_gep storage_addr (
            formula_field_index FormulaCall) "" init_bod) init_bod in
799     () in
800
801   (* Builds a var_defn struct for each variable *)
802   let build_var_defn defn varname va symbols =
803     let numForm = List.length va.var_formulas in
804     let formulas = Llvm.build_array_malloc base_types.formula_t (Llvm.const_int
            base_types.int_t numForm) "" init_bod in
```

```
805     (*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*)
806     let getDefn = function
807         DimId(a) -> (match StringMap.find a symbols with LocalVariable(i) -> i |
                GlobalVariable(i) -> i | _ -> 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.")))
808       | DimOneByOne -> 1 in
809     let _ = (match va.var_rows with
810           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
811         | DimId(a) -> (
812             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 ();
813             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 ();
814             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
815           )
816       ) in
817     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
818     and _ = Llvm.build_store formulas (Llvm.build_struct_gep defn (
            var_defn_field_index Formulas) "" init_bod) init_bod
819     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
820     List.iteri (fun idx elem -> build_formula (varname, idx) formulas elem symbols) va
            .var_formulas in
821
822   (* Creates a scope object and inserts the necessary instructions into main to
          populate the var_defns, and
823    * into the function specified by builder to populate the scope object. *)
824   let build_scope_obj
825       fname (* The function name, or "globals" *)
826       symbols (* The symbols to use when creating the functions *)
827       vars (* The variables to build definitions and formula-functions for *)
828       static_location_ptr (* The copy of the global pointer used in main *)
829       var_defns_loc (* The copy of the global pointer used in the local function *)
830       num_params (* How many parameters the function takes *)
831       builder (* The LLVM builder for the local function *)
832     =
833     let cardinal = Llvm.const_int base_types.int_t (StringMap.cardinal vars) in
834     let build_var_defns =
835       let static_var_defns = Llvm.build_array_malloc base_types.var_defn_t cardinal (
              fname ^ "_static_var_defns") init_bod in
836       let _ = Llvm.build_store static_var_defns static_location_ptr init_bod in
837       let add_variable varname va (sm, count) =
838         let fullname = fname ^ "_" ^ varname in
839         let defn = (Llvm.build_in_bounds_gep static_var_defns [|Llvm.const_int
                base_types.int_t count|] (fullname ^ "_defn") init_bod) in
840         let _ = build_var_defn defn fullname va symbols in
```

```
841         (StringMap.add varname count sm, count + 1) in
842       ignore (StringMap.fold add_variable vars (StringMap.empty, 0)) in
843
844     let var_defns = Llvm.build_load var_defns_loc (fname ^ "_global_defn_ptr_loc")
            builder in
845     let var_insts = Llvm.build_array_malloc base_types.var_instance_p cardinal "
            var_insts" builder in
846     let scope_obj = Llvm.build_malloc base_types.extend_scope_t "scope_obj" builder in
847
848     (*Store variable definition and instance*)
849     let _ = Llvm.build_store var_defns (Llvm.build_struct_gep scope_obj (
            scope_field_type_index VarDefn) "" builder) builder in
850     let _ = Llvm.build_store var_insts (Llvm.build_struct_gep scope_obj (
            scope_field_type_index VarInst) "" builder) builder in
851     let _ = Llvm.build_store cardinal (Llvm.build_struct_gep scope_obj (
            scope_field_type_index VarNum) "" builder) builder in
852     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
853     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
854     let _ = Llvm.build_store paramarray (Llvm.build_struct_gep scope_obj (
            scope_field_type_index FunctionParams) "" builder) builder in
855     let copy_fn_arg i =
856       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
857       ignore (Llvm.build_store (Llvm.param (StringMap.find fname function_llvalues) i)
              param_addr builder) in
858     List.iter copy_fn_arg (zero_until num_params);
859     let _ = Llvm.build_call (Hashtbl.find runtime_functions "null_init") [|scope_obj|]
             "" builder in
860     build_var_defns ; scope_obj in
861   (* End of build_scope_obj *)
862
863   let build_function fname (fn_def, fn_llvalue) =
864     (* Build the symbol table for this function *)
865     let symbols = create_symbol_table global_symbols fn_def in
866     let fn_idx = match StringMap.find fname extend_fn_numbers with ExtendFunction(i)
            -> i | _ -> raise(LogicError(fname ^ " not in function table")) in
867     let builder = Llvm.builder_at_end context (Llvm.entry_block fn_llvalue) in
868     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
869     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
870     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
871     let get_special_val special_name = function
872         Id(s) -> (match (try StringMap.find s symbols with Not_found -> raise(
                LogicError("Something went wrong with your semantic analysis — " ^ s ^ "
                not found"))) with
873             LocalVariable(i) ->
874             let llvm_var = Llvm.build_call getVar [|scope_obj; Llvm.const_int
                    base_types.int_t i|] (special_name ^ "_var") builder in
```

```
875             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
876           | _ -> raise(TransformedAway("Error in " ^ fname ^ ": The " ^ special_name ^
                  " value should always have been transformed into a local variable")))
877       | _ -> raise(TransformedAway("Error in " ^ fname ^ ": The " ^ special_name ^ "
            value should always have been transformed into a local variable")) in
878     let assert_val = get_special_val "assert" (List.hd fn_def.func_asserts) in
879     let _ = Llvm.build_call (Hashtbl.find runtime_functions "verify_assert") [|
          assert_val; Llvm.build_global_stringptr fname "" builder|] "" builder in
880     let ret_val = get_special_val "return" (snd fn_def.func_ret_val) in
881     let _ = Llvm.build_ret ret_val builder in () in
882   (* End of build_function *)
883
884   (* Build the global scope object *)
885   let vardefn_p_p = Llvm.build_alloca base_types.var_defn_p "v_p_p" init_bod in
886   let global_scope_obj = build_scope_obj "globals" global_symbols globals vardefn_p_p
        vardefn_p_p 0 init_bod in
887   let _ = Llvm.build_call (Hashtbl.find runtime_functions "incStack") [||] "" init_bod
        in
888   let _ = Llvm.build_store global_scope_obj global_scope_loc init_bod in
889
890   (*iterates over function definitions*)
891   StringMap.iter build_function extend_functions ;
892
893   (* Define the LLVM entry point for the program *)
894   let extend_entry_point = StringMap.find "main" function_llvalues in
895   let _ = Llvm.build_ret_void init_bod in
896   let _ = Llvm.build_ret_void literal_bod in
897   let _ = Llvm.build_call init_def [||] "" main_bod in
898   let _ = Llvm.build_call literal_def [||] "" main_bod in
899   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
900   let _ = Llvm.build_call extend_entry_point [|cmd_line_args|] "" main_bod in
901   let _ = Llvm.build_ret (Llvm.const_int base_types.int_t 0) main_bod in
902
903   base_module
904
905 let build_this ast_mapped =
906   let modu = (translate ast_mapped) in
907   let _ = Llvm_analysis.assert_valid_module modu in
908   modu
```

## 9.8 linker.ml

```
1  (* ns3158 *)
2  module StringSet = Set.Make(String)
3  let link xtndOut ast compiler outputFile =
4    let tmpFilenameLL = Filename.temp_file "" ".ll"
5    and tmpFilenameC = Filename.temp_file "" ".o"
6    and getExterns (_,_,extern) =
7      StringSet.elements
8        (Ast.StringMap.fold
9          (fun key value store -> StringSet.add value.Ast.extern_fn_libname store)
10         extern
```

```
        StringSet.empty) in
  let tmpChan = open_out tmpFilenameLL in
  output_string tmpChan xtndOut; close_out tmpChan;
  let call1 = (String.concat " " ("llc-3.8" :: "-filetype=obj" :: tmpFilenameLL :: "-o
      " :: tmpFilenameC :: []))
  and call2 = (String.concat " " (compiler :: "-o" :: outputFile :: tmpFilenameC :: (
      getExterns ast))) ^ " -lm" in
  let resc1 = Sys.command call1 in
  if resc1 == 0 then (
    Sys.remove tmpFilenameLL;
    let resc2 = Sys.command call2 in
      Sys.remove tmpFilenameC;
      if resc2 == 0 then () else raise Not_found
    )
  else (Sys.remove tmpFilenameC;raise Not_found)
```

## 9.9 main.ml

```
(* jss2272 *)

open Ast;;

let print_ast = ref false
let compile_ast = ref false
let link = ref false
let output = ref "./out"
let compiler = ref "gcc"
let working_dir = ref "."

let the_ast = ref (StringMap.empty, StringMap.empty, StringMap.empty)
let just_one_please = ref false

let speclist = [
                ("-p", Arg.Set print_ast, "Print the AST");
                ("-c", Arg.Set compile_ast, "Compile the program");
                ("-l", Arg.Set link, "Link the program");
                ("-cc", Arg.Set_string compiler, "Compiler to use");
                ("-o", Arg.Set_string output, "Location to output to");
                ("-w", Arg.Set_string working_dir, "Working directory");
]

let usage_message = "Welcome to Extend!\n\nUsage: extend <options> <source-file>\n\
    nOptions are:"

let parse_ast filename =
  if !just_one_please
  then print_endline "Any files after the first one are ignored."
  else just_one_please := true ; the_ast := (Transform.create_ast filename);;

Arg.parse speclist parse_ast usage_message;
Sys.chdir !working_dir;
if not !just_one_please then Arg.usage speclist usage_message else ();
if !print_ast then print_endline (string_of_program !the_ast) else ();
if !compile_ast then
  let compiled = (Llvm.string_of_llmodule (Codegen.translate !the_ast))
```

```
  in
    if not (!link) then print_endline compiled
    else Linker.link compiled !the_ast !compiler !output
else ();
```

## 9.10 lib.c

```
/* jss2272 ns3158 isk2108 */

#include<stdio.h>
#include<stdlib.h>
#include<math.h>
#include<string.h>
#include<stdbool.h>
#include "../../lib/gdchart0.94b/gdc.h"
#include "../../lib/gdchart0.94b/gdchart.h"
/* #include <sys/time.h> */
#include <time.h>
#include "runtime.h"

/* Value type */
#define FLAG_EMPTY 0
#define FLAG_NUMBER 1
#define FLAG_STRING 2
#define FLAG_SUBRANGE 3

/* Status flag */
#define CALCULATED 2
#define IN_PROGRESS 4

#define MAX_FILES 255
FILE *open_files[1 + MAX_FILES] = {NULL};
int open_num_files = 0;

#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);}
EXPOSE_MATH_FUNC(sin)
EXPOSE_MATH_FUNC(cos)
EXPOSE_MATH_FUNC(tan)
EXPOSE_MATH_FUNC(acos)
EXPOSE_MATH_FUNC(asin)
EXPOSE_MATH_FUNC(atan)
EXPOSE_MATH_FUNC(sinh)
EXPOSE_MATH_FUNC(cosh)
EXPOSE_MATH_FUNC(tanh)
EXPOSE_MATH_FUNC(exp)
EXPOSE_MATH_FUNC(log)
EXPOSE_MATH_FUNC(log10)
EXPOSE_MATH_FUNC(sqrt)
EXPOSE_MATH_FUNC(ceil)
EXPOSE_MATH_FUNC(fabs)
EXPOSE_MATH_FUNC(floor)

value_p extend_round(value_p num, value_p number_of_digits) {
  if (!assertSingleNumber(num) || !assertSingleNumber(number_of_digits)) return
```

```
      new_val();
  double factor_of_10 = pow(10,number_of_digits->numericVal);
  return new_number(rint(num->numericVal * factor_of_10) / factor_of_10);
}

value_p extend_len(value_p str_val) {
  if (!assertSingleString(str_val)) return new_val();
  return new_number((double) str_val->str->length);
}

value_p extend_get_stdin() {
  if (open_num_files + 1 > MAX_FILES) {
    return new_val();
  } else {
    open_num_files++;
    open_files[open_num_files] = stdin;
    return new_number((double) open_num_files);
  }
}

value_p extend_get_stdout() {
  if (open_num_files + 1 > MAX_FILES) {
    return new_val();
  } else {
    open_num_files++;
    open_files[open_num_files] = stdout;
    return new_number((double) open_num_files);
  }
}

value_p extend_get_stderr() {
  if (open_num_files + 1 > MAX_FILES) {
    return new_val();
  } else {
    open_num_files++;
    open_files[open_num_files] = stderr;
    return new_number((double) open_num_files);
  }
}

value_p extend_open(value_p filename, value_p mode){
  FILE *val;
  if (   !assertSingleString(filename)
      || !assertSingleString(mode)
      || open_num_files + 1 > MAX_FILES) {
        return new_val();
  }
  val = fopen(filename->str->text, mode->str->text);
  if(val == NULL) return new_val();
  open_num_files++;
  open_files[open_num_files] = val;
  return new_number((double) open_num_files);
}

value_p extend_close(value_p file_handle) {
  if(!assertSingleNumber(file_handle)) {
```

```
103     // Per the LRM this is actually supposed to crash the program.
104     fprintf(stderr, "EXITING - Attempted to close something that was not a valid file
            pointer\n");
105     exit(-1);
106   }
107   int fileNum = (int) file_handle->numericVal;
108
109   if (fileNum > open_num_files || open_files[fileNum] == NULL) {
110     // Per the LRM this is actually supposed to crash the program.
111     fprintf(stderr, "EXITING - Attempted to close something that was not a valid file
            pointer\n");
112     exit(-1);
113   }
114   fclose(open_files[fileNum]);
115   open_files[fileNum] = NULL; // Empty the container for the pointer.
116   return new_val(); // asssuming it was an open valid handle, close() is just supposed
          to return empty
117 }
118
119 value_p extend_read(value_p file_handle, value_p num_bytes){
120   /* TODO: Make it accept empty */
121   if(!assertSingleNumber(file_handle) || !assertSingleNumber(num_bytes)) return
          new_val();
122   int max_bytes = (int)num_bytes->numericVal;
123   int fileNum = (int)file_handle->numericVal;
124   if (fileNum > open_num_files || open_files[fileNum] == NULL)  return new_val();
125   FILE *f = open_files[fileNum];
126   max_bytes = (int) num_bytes->numericVal;
127   if (max_bytes == 0) {
128     long cur_pos = ftell(f);
129     fseek(f, 0, SEEK_END);
130     long end_pos = ftell(f);
131     fseek(f, cur_pos, SEEK_SET);
132     max_bytes = end_pos - cur_pos;
133   }
134   char *buf = malloc(sizeof(char) * (max_bytes + 1));
135   int bytes_read = fread(buf, sizeof(char), max_bytes, f);
136   buf[bytes_read] = 0;
137   value_p result = new_string(buf);
138   free(buf);
139   return result;
140   //edge case: how to return the entire contents of the file if n == empty?
141 }
142
143 value_p extend_readline(value_p file_handle) {
144   int i=0, buf_size = 256;
145   char next_char;
146   if (!assertSingleNumber(file_handle)) return new_val();
147   int fileNum = (int) file_handle->numericVal;
148   FILE *f = open_files[fileNum];
149   if (fileNum > open_num_files || open_files[fileNum] == NULL) {
150     return new_val();
151   }
152   char *buf = (char *) malloc (buf_size * sizeof(char));
153   while ((next_char = fgetc(f)) != '\n') {
154     buf[i++] = next_char;
```

```
155     if (i == buf_size - 2) {
156       buf_size *= 2;
157       char *new_buf = (char *) malloc (buf_size * sizeof(char));
158       memcpy(new_buf, buf, i);
159       free(buf);
160       buf = new_buf;
161     }
162   }
163   buf[i] = '\0';
164   value_p result = new_string(buf);
165   free(buf);
166   return result;
167 }
168
169 value_p extend_write(value_p file_handle, value_p buffer){
170   if(!assertSingleNumber(file_handle) || !assertSingleString(buffer)) return new_val()
        ;
171   int fileNum = (int) file_handle->numericVal;
172   if (fileNum > open_num_files || open_files[fileNum] == NULL) {
173     // Per the LRM this is actually supposed to crash the program.
174     fprintf(stderr, "EXITING - Attempted to write to something that was not a valid
          file pointer\n");
175     exit(-1);
176   }
177   fwrite(buffer->str->text, 1, buffer->str->length, open_files[fileNum]);
178   // TODO: make this return empty once compiler handles Id(s)
179   // RN: Use the return value to close the file
180   return new_number((double) fileNum);
181 }
182
183 #ifdef PLOT
184 value_p extend_plot(value_p file_name){
185   // extract the numerical values from the first parameter - values
186   if(!assertSingle(file_name)) return new_val();
187   float a[6]  = { 0.5, 0.09, 0.6, 0.85, 0.0, 0.90 },
188         b[6]  = { 1.9, 1.3,  0.6, 0.75, 0.1, 2.0 };
189   char *t[6] = { "Chicago", "New York", "L.A.", "Atlanta", "Paris, MD\n(USA) ", "
        London" };
190   unsigned long sc[2]    = { 0xFF8080, 0x8080FF };
191   GDC_BGColor   = 0xFFFFFFL;
192   GDC_LineColor = 0x000000L;
193   GDC_SetColor  = &(sc[0]);
194   GDC_stack_type = GDC_STACK_BESIDE;
195   // Using the line below, can also spit to stdout and fwrite from Extend
196   // printf( "Content-Type: image/png\n\n" );
197   FILE *outpng = fopen("extend.png", "wb");
198   out_graph(250, 200, outpng, GDC_3DBAR, 6, t, 2, a, b);
199   fclose(outpng);
200   return new_val();
201 }
202
203 value_p extend_bar_chart(value_p file_handle, value_p labels, value_p values){
204   // Mandates 1 row, X columns
205   if(!assertSingleNumber(file_handle)) return new_val();
206   int fileNum = (int)file_handle->numericVal;
207   if (fileNum > open_num_files || open_files[fileNum] == NULL)  return new_val();
```

```
208   FILE *f = open_files[fileNum];
209   int data_length = labels->subrange->subrange_num_cols;
210   if(data_length != values->subrange->subrange_num_cols) return new_val();
211
212   float *graph_values = malloc(sizeof(float) * data_length);
213   char **graph_labels = malloc(sizeof(char*) * data_length);
214   for(int i = 0; i < data_length; i++){
215     graph_labels[i] = getValSR(labels->subrange, 0, i)->str->text;
216     graph_values[i] = (float)getValSR(values->subrange, 0, i)->numericVal;
217   }
218   unsigned long sc[2] = {0xFF8080, 0x8080FF};
219   GDC_BGColor   = 0xFFFFFFL;
220   GDC_LineColor = 0x000000L;
221   GDC_SetColor  = &(sc[0]);
222   GDC_stack_type = GDC_STACK_BESIDE;
223   out_graph(250, 200, f, GDC_3DBAR, data_length, graph_labels, 1, graph_values);
224   // width, height, file handle, graph type, number of data points, labels, number of
          data sets, the data sets
225   free(graph_labels);
226   free(graph_values);
227   fclose(f);
228   return new_val();
229 }
230
231 value_p extend_line_chart(value_p file_handle, value_p labels, value_p x_values){
232   if(!assertSingleNumber(file_handle)) return new_val();
233   int fileNum = (int)file_handle->numericVal;
234   if (fileNum > open_num_files || open_files[fileNum] == NULL)  return new_val();
235   FILE *f = open_files[fileNum];
236   int data_length = labels->subrange->subrange_num_cols;
237   if(data_length != x_values->subrange->subrange_num_cols) return new_val();
238   float *graph_x_values = malloc(sizeof(float) * data_length);
239   char **graph_labels = malloc(sizeof(char*) * data_length);
240   for(int i = 0; i < data_length; i++){
241     graph_labels[i] = getValSR(labels->subrange, 0, i)->str->text;
242     graph_x_values[i] = (float)getValSR(x_values->subrange, 0, i)->numericVal;
243   }
244   unsigned long sc[2] = {0xFF8080, 0x8080FF};
245   GDC_BGColor   = 0xFFFFFFL;
246   GDC_LineColor = 0x000000L;
247   GDC_SetColor  = &(sc[0]);
248   GDC_stack_type = GDC_STACK_BESIDE;
249   out_graph(250, 200, f, GDC_LINE, data_length, graph_labels, 1, graph_x_values);
250   free(graph_labels);
251   free(graph_x_values);
252   fclose(f);
253   return new_val();
254 }
255 #endif
256
257 value_p extend_isNaN(value_p val) {
258   if (!assertSingleNumber(val)) return new_val();
259   double d = val->numericVal;
260   return isnan(d) ? new_number(1.0) : new_number(0.0);
261 }
262
```

```
value_p extend_isInfinite(value_p val) {
  if (!assertSingleNumber(val)) return new_val();
  double d = val->numericVal;
  if (isinf(d)) {
      return d < 0 ? new_number(-1.0) : new_number(1.0);
  } else {
    return new_number(0.0);
  }
}

value_p extend_parseFloat(value_p val) {
  if (!assertSingleString(val)) return new_val();
  return new_number(atof(val->str->text));
}

value_p extend_toASCII(value_p val) {
  if (!assertSingleString(val) || val->str->length == 0) return new_val();
  value_p *val_arr = malloc(sizeof(value_p) * val->str->length);
  int i;
  for(i = 0; i < val->str->length; i++) {
    value_p my_val = malloc(sizeof(struct value_t));
    my_val->flags = FLAG_NUMBER;
    my_val->numericVal = (double)val->str->text[i];
    val_arr[i] = my_val;
  }
  value_p _new = new_subrange(1,val->str->length, val_arr);
  return _new;
}

value_p extend_fromASCII(value_p val) {
  if(val->flags == FLAG_NUMBER) {
    char s[2];
    s[0] = ((char)lrint(val->numericVal));
    s[1] = '\0';
    return new_string(s);
  }
  else if(val->flags == FLAG_SUBRANGE) {
    int rows, cols, len;
    rows = val->subrange->subrange_num_rows;
    cols = val->subrange->subrange_num_cols;
    if(rows > 1 && cols > 1) return new_val();
    else len = (rows == 1 ? cols : rows);
    char *text = malloc(1 + sizeof(char) * len);
    for(rows = 0; rows < val->subrange->subrange_num_rows; rows++) {
      for(cols = 0; cols < val->subrange->subrange_num_cols; cols++) {
        value_p single = getValSR(val->subrange, rows, cols);
        if(single->flags != FLAG_NUMBER) {
          free(text);
          return new_val();
        }
        text[rows + cols] = (char)lrint(single->numericVal);
      }
    }
    text[len] = '\0';
    value_p ret = new_string(text);
    free(text);
```

```
319     return ret;
320   } else if (val->flags == FLAG_EMPTY) {
321     return new_string("");
322   } else {
323     return new_val();
324   }
325 }
```

## 9.11 runtime.c

```
1  /* jss2272 ns3158 */
2
3  #include<stdio.h>
4  #include<stdlib.h>
5  #include<math.h>
6  #include<sys/resource.h>
7  #include<string.h>
8  #include<stdbool.h>
9  #include "runtime.h"
10
11 struct value_t zero_val = {FLAG_NUMBER, 0.0, NULL, NULL};
12 struct value_t one_val = {FLAG_NUMBER, 1.0, NULL, NULL};
13 struct rhs_index absolute_zero = {&zero_val, RHS_IDX_ABSOLUTE};
14 struct rhs_index absolute_one = {&one_val, RHS_IDX_ABSOLUTE};
15 struct rhs_slice zero_to_one = {&absolute_zero, &absolute_one};
16 struct rhs_slice corresponding_cell = {NULL, NULL};
17
18 void debug_print_subrange(subrange_p subrng);
19
20 void debug_print(value_p val, char *which_value) {
21   char *flag_meanings[4] = {"Empty", "Number", "String", "Subrange"};
22   fprintf(stderr, "———————Everything you ever wanted to know about %s:———————\n",
         which_value == NULL ? "some anonymous variable" : which_value);
23   fprintf(stderr, "Memory address: %p\n", val);
24   if (val == NULL) {
25     fprintf(stderr, "———————————————Nice try asking me to dereference a null pointer\n
         ———————————————");
26     return;
27   }
28   fprintf(stderr, "Flags: %d (%s)\n", val->flags, flag_meanings[val->flags]);
29   fprintf(stderr, "NumericVal: %f\n", val->numericVal);
30   fprintf(stderr, "String contents: Probably safer not to check that pointer (%p)
         blindly\n", val->str);
31   if (val->flags == FLAG_STRING && val->str != NULL) {
32     fprintf(stderr, "It says it's a string and it's not a NULL pointer though, so here
           you go:\n");
33     fprintf(stderr, "String refcount: %d\n", val->str->refs);
34     fprintf(stderr, "String length: %ld\n", val->str->length);
35     fprintf(stderr, "String char* memory address: %p\n", val->str->text);
36     if (val->str->text == NULL) {
37       fprintf(stderr, "Not going to print the contents of NULL!\n");
38     } else {
39       fprintf(stderr, "String char* contents:\n%s\n", val->str->text);
40     }
41   }
```

```
42    fprintf(stderr, "Subrange contents: Probably safer not to check that pointer (%p)
          blindly either\n", val->subrange);
43    if (val->flags == FLAG_SUBRANGE && val->subrange != NULL) {
44      fprintf(stderr, "It says it's a subrange and it's not a NULL pointer though, so
            here you go:\n");
45      debug_print_subrange(val->subrange);
46    }
47    fprintf(stderr, "-------That's all I've got to say about %s:-------\n", which_value ==
          NULL ? "some anonymous variable" : which_value);
48  }
49
50  void debug_print_formula(struct ExtendFormula *fdef) {
51    fprintf(stderr, "-------Everything you ever wanted to know about your favorite
          formula:-------\n");
52    fprintf(stderr, "RowStart varnum: %d %d\n", fdef->rowStart_varnum, fdef->
          fromFirstRow);
53    fprintf(stderr, "RowEnd varnum: %d %d\n", fdef->rowEnd_varnum, fdef->toLastRow);
54    fprintf(stderr, "ColStart varnum: %d %d\n", fdef->colStart_varnum, fdef->
          fromFirstCol);
55    fprintf(stderr, "ColEnd varnum: %d %d\n", fdef->colEnd_varnum, fdef->toLastCol);
56  }
57
58  void debug_print_res_formula(struct ResolvedFormula *rdef) {
59    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);
60  }
61
62  void debug_print_vardefn(struct var_defn *pdef) {
63    fprintf(stderr, "-------Everything you ever wanted to know about var defn %s:-------\n
          ", pdef->name);
64    fprintf(stderr, "Row varnum: %d\n", pdef->rows_varnum);
65    fprintf(stderr, "Col varnum: %d\n", pdef->cols_varnum);
66    fprintf(stderr, "Num formulas: %d\n", pdef->numFormulas);
67    fprintf(stderr, "Formula defs: \n");
68    int i;
69    for (i=0; i < pdef->numFormulas; i++) {
70      debug_print_formula(pdef->formulas + i);
71    }
72    fprintf(stderr, "Is 1x1: %d\n", pdef->isOneByOne);
73  }
74
75  void debug_print_varinst(struct var_instance *inst) {
76    fprintf(stderr, "-------Everything you ever wanted to know about var %s:-------\n",
          inst->name);
77    fprintf(stderr, "Rows: %d\n", inst->rows);
78    fprintf(stderr, "Cols: %d\n", inst->cols);
79    fprintf(stderr, "Num formulas: %d\n", inst->numFormulas);
80    fprintf(stderr, "*****Formulas:*****\n");
81    int i;
82    for (i = 0; i < inst->numFormulas; i++) {
83      debug_print_res_formula(inst->formulas + i);
84    }
85    fprintf(stderr, "**** End of Formulas *** \n");
86    fprintf(stderr, "~~~~~~~~Cells:~~~~~~~\n");
87    fprintf(stderr, "Status memory address: %p\n", inst->status);
88    for (i = 0; i < inst->rows * inst->cols; i++) {
```

```
89      printf("%s[%d,%d]: Status=%d\n", inst->name, i / inst->cols, i % inst->cols, inst
            ->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->
          base_var_offset_col);
101   fprintf(stderr, "Dimensions: [%d,%d]\n", subrng->subrange_num_rows, subrng->
          subrange_num_cols);
102   fprintf(stderr, "Subrange of: \n");
103   debug_print_varinst(subrng->range);
104 }
105
106 void debug_print_index(struct rhs_index *idx) {
107   if (idx == NULL) {
108     fprintf(stderr, "I'd rather not try to print out the contents of a NULL index.\n")
            ;
109     exit(-1);
110   }
111   fprintf(stderr, "Index type: ");
112   switch(idx->rhs_index_type) {
113     case RHS_IDX_ABSOLUTE:
114       fprintf(stderr, "Absolute\n");
115       if (idx->val_of_expr == NULL) {
116         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");
117       } else {
118         debug_print(idx->val_of_expr, "an absolute index");
119       }
120       break;
121     case RHS_IDX_RELATIVE:
122       fprintf(stderr, "Relative\n");
123       if (idx->val_of_expr == NULL) {
124         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");
125       } else {
126         debug_print(idx->val_of_expr, "a relative index");
127       }
128       break;
129     case RHS_IDX_DIM_START:
130       fprintf(stderr, "DimensionStart\n");
131       if (idx->val_of_expr != NULL) {
132         fprintf(stderr, "This definitely isn't supposed to happen — the value pointer
                isn't NULL. You should look into that.\n");
133         exit(-1);
134       }
135       break;
136     case RHS_IDX_DIM_END:
137       fprintf(stderr, "DimensionEnd\n");
```

```
138       if (idx->val_of_expr != NULL) {
139         fprintf(stderr, "This definitely isn't supposed to happen - the value pointer
              isn't NULL. You should look into that.\n");
140         exit(-1);
141       }
142       break;
143   }
144 }
145
146 void debug_print_slice(struct rhs_slice *sl) {
147   if (sl == NULL) {
148     fprintf(stderr, "I'd rather not try to print out the contents of a NULL slice.\n")
          ;
149     exit(-1);
150   }
151   fprintf(stderr, "--------Everything about this slice-------\n");
152   fprintf(stderr, "Start and end index memory addresses: %p and %p\n", sl->
        slice_start_index, sl->slice_end_index);
153   if (sl->slice_start_index != NULL) {
154     fprintf(stderr, "Start index info:\n");
155     debug_print_index(sl->slice_start_index);
156     if (sl->slice_end_index != NULL) {
157       fprintf(stderr, "End index info:\n");
158       debug_print_index(sl->slice_end_index);
159     }
160   } else {
161     if (sl->slice_end_index != NULL) {
162       fprintf(stderr, "Start index is NULL but end index is not NULL. That should
            never happen.\n");
163       fprintf(stderr, "Attempting to print contents anyway:\n");
164       fflush(stderr);
165       debug_print_index(sl->slice_end_index);
166     }
167   }
168 }
169
170 void debug_print_selection(struct rhs_selection *sel) {
171   if (sel == NULL) {
172     fprintf(stderr, "I'd rather not try to print out the contents of a NULL selection
          .\n");
173     exit(-1);
174   }
175   fprintf(stderr, "--------Everything about this selection-------\n");
176   fprintf(stderr, "Slice memory addresses: %p and %p\n", sel->slice1, sel->slice2);
177   if (sel->slice1 != NULL) {
178     fprintf(stderr, "Slice 1 info:\n");
179     debug_print_slice(sel->slice1);
180     if (sel->slice2 != NULL) {
181       fprintf(stderr, "Slice 2 info:\n");
182       debug_print_slice(sel->slice2);
183     }
184   } else {
185     if (sel->slice2 != NULL) {
186       fprintf(stderr, "Slice 1 is NULL but slice 2 is not NULL. That should never
            happen.\n");
187       fprintf(stderr, "Attempting to print contents anyway:\n");
```

```
      fflush(stderr);
      debug_print_slice(sel->slice2);
    }
  }
  fprintf(stderr, "--------That's all I've got about that selection-------\n\n");
}

int rg_eq(value_p val1, value_p val2) {
  int res = 1;
  if(val1->flags != val2->flags) res = 0;
  else if(val1->flags == FLAG_EMPTY) ;
  else if(val1->flags == FLAG_NUMBER && val1->numericVal != val2->numericVal) res = 0;
  else if(val1->flags == FLAG_STRING && strcmp(val1->str->text, val2->str->text)) res
      = 0;
  else if(val1->flags == FLAG_SUBRANGE) {
    subrange_p sr1 = val1->subrange;
    subrange_p sr2 = val2->subrange;
    if(sr1->subrange_num_cols != sr2->subrange_num_cols || sr1->subrange_num_rows !=
        sr2->subrange_num_rows) {
      return 0;
    } else {
      int i, j;
      value_p v1, v2;
      for(i = 0; i < sr1->subrange_num_rows; i++) {
        for(j = 0; j < sr1->subrange_num_cols; j++) {
          v1 = getValSR(sr1, i, j);
          v2 = getValSR(sr2, i, j);
          if(rg_eq(v1, v2) == 0) {
            return 0;
          }
        }
      }
    }
  }
  return res;
}

void incStack() {
  const rlim_t kStackSize = 64L * 1024L * 1024L;
  struct rlimit rl;
  int result;

  result = getrlimit(RLIMIT_STACK, &rl);
  rl.rlim_cur = rl.rlim_max;
  result = setrlimit(RLIMIT_STACK, &rl);
}

double setNumeric(value_p result, double val) {
  result->flags = FLAG_NUMBER;
  return (result->numericVal = val);
}

double setFlag(value_p result, double flag_num) {
  return (result->flags = flag_num);
}

```

```
int assertSingle(value_p value) {
  /* TODO: dereference 1 by 1 subrange */
  return !(value->flags == FLAG_SUBRANGE);
}

int assertSingleNumber(value_p p) {
  if (!assertSingle(p)) {
    return 0;
  }
  return (p->flags == FLAG_NUMBER);
}

int assertText(value_p my_val) {
  return (my_val->flags == FLAG_STRING);
}

int assertSingleString(value_p p) {
  if (!assertSingle(p)) {
    return 0;
  }
  return (p->flags == FLAG_STRING);
}

int assertEmpty(value_p p) {
  if (!assertSingle(p)) {
    return 0;
  }
  return (p->flags == FLAG_EMPTY);
}

value_p new_val() {
  value_p empty_val = malloc(sizeof(struct value_t));
  setFlag(empty_val, FLAG_EMPTY);
  return empty_val;
}

value_p new_number(double val) {
  value_p new_v = malloc(sizeof(struct value_t));
  setFlag(new_v, FLAG_NUMBER);
  setNumeric(new_v, val);
  return new_v;
}

value_p new_string(char *s) {
  if (s == NULL) return new_val();
  value_p new_v = malloc(sizeof(struct value_t));
  setFlag(new_v, FLAG_STRING);
  string_p new_str = malloc(sizeof(struct string_t));
  long len = strlen(s);
  new_str->text = malloc(len+1);
  strcpy(new_str->text, s);
  new_str->length = len;
  new_str->refs = 1;
  new_v->str = new_str;
  return new_v;
}
```

```
298
299 struct ExtendScope *global_scope;
300
301 void null_init(struct ExtendScope *scope_ptr) {
302   int i;
303   for(i = 0; i < scope_ptr->numVars; i++)
304     scope_ptr->vars[i] = NULL;
305 }
306
307 char getIntFromOneByOne(struct ExtendScope *scope_ptr, int varnum, int *result) {
308   if (!scope_ptr->defns[varnum].isOneByOne) {
309     fprintf(stderr, "A variable (%s) that is supposedly one by one is not defined that
          way.\n", scope_ptr->defns[varnum].name);
310     exit(-1);
311   }
312   struct var_instance *inst = get_variable(scope_ptr, varnum);
313   if (inst->rows != 1 || inst->cols != 1) {
314     fprintf(stderr, "A variable (%s) that is defined as one by one is somehow actually
          %d by %d.\n", inst->name, inst->rows, inst->cols);
315     exit(-1);
316   }
317   value_p val = getVal(inst, 0, 0);
318   if (!assertSingleNumber(val) || !isfinite(val->numericVal)) {
319     return 0;
320   }
321   *result = (int) lrint(val->numericVal);
322   return 1;
323 }
324
325 struct var_instance *instantiate_variable(struct ExtendScope *scope_ptr, struct
      var_defn def) {
326   struct var_instance *inst = malloc(sizeof(struct var_instance));
327   if(def.isOneByOne) {
328     inst->rows = 1;
329     inst->cols = 1;
330   } else {
331     if (!getIntFromOneByOne(scope_ptr, def.rows_varnum, &inst->rows)) {
332       fprintf(stderr, "EXITING - The expression for the number of rows of variable %s
            did not evaluate to a finite Number.\n", def.name);
333       exit(-1);
334     }
335     if (!getIntFromOneByOne(scope_ptr, def.cols_varnum, &inst->cols)) {
336       fprintf(stderr, "EXITING - The expression for the number of columns of variable
            %s did not evaluate to a finite Number.\n", def.name);
337       exit(-1);
338     }
339     if (inst->rows <= 0 || inst->cols <= 0) {
340       fprintf(stderr, "EXITING - The requested dimensions for variable %s were [%d, %d
            ]; they must both be greater than zero.\n", def.name, inst->rows, inst->cols)
            ;
341       exit(-1);
342     }
343   }
344   // TODO: do the same thing for each FormulaFP to turn an ExtendFormula into a
        ResolvedFormula
345   inst->numFormulas = def.numFormulas;
```

```
346   inst->closure = scope_ptr;
347   inst->name = def.name;
348   int size = inst->rows * inst->cols;
349   inst->values = malloc(sizeof(value_p) * size);
350   memset(inst->values, 0, sizeof(value_p) * size);
351   inst->status = malloc(sizeof(char) * size);
352   memset(inst->status, 0, sizeof(char) * size);
353   inst->formulas = malloc(sizeof(struct ResolvedFormula) * inst->numFormulas);
354   //debug_print_vardefn(&def);
355   //debug_print_varinst(inst);
356   int i, j;
357   for(i = 0; i < inst->numFormulas; i++) {
358
359     // Set the formula function pointer to the pointer from the definition
360     inst->formulas[i].formula = def.formulas[i].formula;
361
362     if (def.isOneByOne) {
363       inst->formulas[i].rowStart = 0;
364       inst->formulas[i].rowEnd = 1;
365       inst->formulas[i].colStart = 0;
366       inst->formulas[i].colEnd = 1;
367     } else {
368       if(def.formulas[i].fromFirstRow) {
369         inst->formulas[i].rowStart = 0;
370       } else {
371         if (!getIntFromOneByOne(scope_ptr, def.formulas[i].rowStart_varnum, &inst->
              formulas[i].rowStart)) {
372           fprintf(stderr, "EXITING - The requested starting row for formula %d of %s
                did not evaluate to a finite number.\n", i, inst->name);
373           exit(-1);
374         }
375         if (inst->formulas[i].rowStart < 0) {
376           inst->formulas[i].rowStart += inst->rows;
377         }
378         if (inst->formulas[i].rowStart < 0 || inst->formulas[i].rowStart >= inst->rows
              ) {
379           //Doesn't matter, but will never get called
380         }
381       }
382       if (def.formulas[i].isSingleRow) {
383         inst->formulas[i].rowEnd = inst->formulas[i].rowStart + 1;
384       } else if (def.formulas[i].toLastRow) {
385         inst->formulas[i].rowEnd = inst->rows;
386       } else {
387         if (!getIntFromOneByOne(scope_ptr, def.formulas[i].rowEnd_varnum, &inst->
              formulas[i].rowEnd)) {
388           fprintf(stderr, "EXITING - The requested ending row for formula %d of %s did
                  not evaluate to a finite number.\n", i, inst->name);
389           exit(-1);
390         }
391         if (inst->formulas[i].rowEnd < 0) {
392           inst->formulas[i].rowEnd += inst->rows;
393         }
394       }
395       if(def.formulas[i].fromFirstCol) {
396         inst->formulas[i].colStart = 0;
```

```
397       } else {
398         if (!getIntFromOneByOne(scope_ptr, def.formulas[i].colStart_varnum, &inst->
              formulas[i].colStart)) {
399           fprintf(stderr, "EXITING - The requested starting column for formula %d of %
                s did not evaluate to a finite number.\n", i, inst->name);
400           exit(-1);
401         }
402         if (inst->formulas[i].colStart < 0) {
403           inst->formulas[i].colStart += inst->cols;
404         }
405         if (inst->formulas[i].colStart < 0 || inst->formulas[i].colStart >= inst->cols
              ) {
406           //Doesn't matter, but will never get called
407         }
408       }
409       if (def.formulas[i].isSingleCol) {
410         inst->formulas[i].colEnd = inst->formulas[i].colStart + 1;
411       } else if (def.formulas[i].toLastCol) {
412         inst->formulas[i].colEnd = inst->cols;
413       } else {
414         if (!getIntFromOneByOne(scope_ptr, def.formulas[i].colEnd_varnum, &inst->
              formulas[i].colEnd)) {
415           fprintf(stderr, "EXITING - The requested starting column for formula %d of %
                s did not evaluate to a finite number.\n", i, inst->name);
416           exit(-1);
417         }
418         if (inst->formulas[i].colEnd < 0) {
419           inst->formulas[i].colEnd += inst->cols;
420         }
421       }
422     }
423   }
424
425   for (i = 1; i < inst->numFormulas; i++) {
426     for (j = 0; j < i; j++) {
427       int intersectRowStart = (inst->formulas[i].rowStart > inst->formulas[j].rowStart
            ) ? inst->formulas[i].rowStart : inst->formulas[j].rowStart;
428       int intersectColStart = (inst->formulas[i].colStart > inst->formulas[j].colStart
            ) ? inst->formulas[i].colStart : inst->formulas[j].colStart;
429       int intersectRowEnd = (inst->formulas[i].rowEnd < inst->formulas[j].rowEnd) ?
            inst->formulas[i].rowEnd : inst->formulas[j].rowEnd;
430       int intersectColEnd = (inst->formulas[i].colEnd < inst->formulas[j].colEnd) ?
            inst->formulas[i].colEnd : inst->formulas[j].colEnd;
431       if (intersectRowEnd > intersectRowStart && intersectColEnd > intersectColStart)
            {
432         fprintf(stderr, "Runtime error: Multiple formulas were assigned to %s[%d:%d,%d
              :%d].\n", inst->name,
433                         intersectRowStart, intersectRowEnd, intersectColStart,
                              intersectColEnd);
434         exit(-1);
435       }
436     }
437   }
438
439   scope_ptr->refcount++;
440   return inst;
```

```
441 }
442
443 struct var_instance *get_variable(struct ExtendScope *scope_ptr, int varnum) {
444   if (varnum >= scope_ptr->numVars) {
445     fprintf(stderr, "Runtime error: Asked for nonexistant variable number\n");
446     exit(-1);
447   }
448   if (scope_ptr->vars[varnum] == NULL) {
449     scope_ptr->vars[varnum] = instantiate_variable(scope_ptr, scope_ptr->defns[varnum
          ]);
450   }
451   return scope_ptr->vars[varnum];
452 }
453
454 char assertInBounds(struct var_instance *defn, int r, int c) {
455   return (
456     r >= 0 && r < defn->rows &&
457     c >= 0 && c < defn->cols
458   );
459 }
460
461 value_p calcVal(struct var_instance *inst, int r, int c) {
462   int i;
463   for (i = 0; i < inst->numFormulas; i++) {
464     if (
465       r >= inst->formulas[i].rowStart && r < inst->formulas[i].rowEnd &&
466       c >= inst->formulas[i].colStart && c < inst->formulas[i].colEnd
467     ) {
468       return (inst->formulas[i].formula)(inst->closure, r, c);
469     }
470   }
471   return new_val();
472 }
473
474 value_p clone_value(value_p old_value) {
475   value_p new_value = (value_p) malloc(sizeof(struct value_t));
476   new_value->flags = old_value->flags;
477   switch (new_value->flags) {
478     case FLAG_EMPTY:
479       break;
480     case FLAG_NUMBER:
481       new_value->numericVal = old_value->numericVal;
482       break;
483     case FLAG_STRING:
484       new_value->str = old_value->str;
485       new_value->str->refs++;
486       break;
487     case FLAG_SUBRANGE:
488       new_value->subrange = (subrange_p) malloc(sizeof(struct subrange_t));
489       memcpy(new_value->subrange, old_value->subrange, sizeof(struct subrange_t));
490       if (new_value->subrange->range->closure != NULL) {
491         new_value->subrange->range->closure->refcount++; /* Not sure about this one */
492       }
493       break;
494     default:
495       fprintf(stderr, "clone_value(%p): Illegal value of flags: %c\n", old_value,
```

```
          new_value->flags);
      exit(-1);
      break;
  }
  return new_value;
}

void delete_string_p(string_p old_string) {
  old_string->refs--;
  if (old_string->refs == 0) {
    /* free(old_string); */
  }
}

void delete_subrange_p(subrange_p old_subrange) {
  if (old_subrange->range->closure != NULL) {
    old_subrange->range->closure->refcount--;
  }
  free(old_subrange);
}

void delete_value(value_p old_value) {
  switch (old_value->flags) {
    case FLAG_EMPTY:
      break;
    case FLAG_NUMBER:
      break;
    case FLAG_STRING:
      delete_string_p(old_value->str); /* doesn't do anything besides decrement the
          ref count now */
      break;
    case FLAG_SUBRANGE:
      delete_subrange_p(old_value->subrange);
      break;
    default:
      fprintf(stderr, "delete_value(%p): Illegal value of flags: %c\n", old_value,
          old_value->flags);
      exit(-1);
      break;
  }
}

value_p deref_subrange_p(subrange_p subrng) {
  if (subrng == NULL) {
    fprintf(stderr, "Exiting - asked to dereference a NULL pointer.\n");
    exit(-1);
  }
  if (subrng->subrange_num_rows == 1 && subrng->subrange_num_cols == 1) {
    return getVal(subrng->range, subrng->base_var_offset_row, subrng->
        base_var_offset_col);
  } else {
    value_p new_value = (value_p) malloc (sizeof(struct value_t));
    new_value->flags = FLAG_SUBRANGE;
    new_value->numericVal = 0.0;
    new_value->str = NULL;
    new_value->subrange = (subrange_p) malloc (sizeof(struct subrange_t));
```

```
548     memcpy(new_value->subrange, subrng, sizeof(struct subrange_t));
549     if (new_value->subrange->range->closure != NULL) {
550       new_value->subrange->range->closure->refcount++;
551     }
552     return new_value;
553   }
554 }
555
556 value_p new_subrange(int num_rows, int num_cols, value_p *vals) {
557   /* This function does not check its arguments; if you supply fewer
558    * than num_rows * num_cols elements in vals, it will crash.
559    * Only use this function if you know what you're doing. */
560    struct subrange_t sr;
561    sr.range = (struct var_instance *) malloc (sizeof(struct var_instance));
562    sr.base_var_offset_row = 0;
563    sr.base_var_offset_col = 0;
564    sr.subrange_num_rows = num_rows;
565    sr.subrange_num_cols = num_cols;
566    sr.range->rows = num_rows;
567    sr.range->cols = num_cols;
568    sr.range->numFormulas = 0;
569    sr.range->formulas = NULL;
570    sr.range->closure = NULL;
571    sr.range->values = (value_p *) malloc(num_rows * num_cols * sizeof(value_p));
572    sr.range->status = (char *) malloc (num_rows * num_cols * sizeof(char));
573    sr.range->name = NULL;
574    int i;
575    for (i = 0; i < num_rows * num_cols; i++) {
576      sr.range->values[i] = clone_value(vals[i]);
577      sr.range->status[i] = CALCULATED;
578    }
579    return deref_subrange_p(&sr);
580 }
581
582 value_p box_command_line_args(int argc, char **argv) {
583   value_p *vals = (value_p *) malloc (argc * sizeof(value_p));
584   int i;
585   for (i = 0; i < argc; i++) {
586     vals[i] = new_string(argv[i]);
587   }
588   value_p ret = new_subrange(1, argc, vals);
589   for (i = 0; i < argc; i++) {
590     free(vals[i]);
591   }
592   free(vals);
593   return ret;
594 }
595
596 char resolve_rhs_index(struct rhs_index *index, int dimension_len, int
      dimension_cell_num, int *result_ptr) {
597   if (index == NULL) {
598     fprintf(stderr, "Exiting - asked to dereference a NULL index\n");
599     exit(-1);
600   }
601   int i;
602   switch(index->rhs_index_type) {
```

```
603     case RHS_IDX_ABSOLUTE:
604       if (!assertSingleNumber(index->val_of_expr)) return false;
605       i = (int) lrint(index->val_of_expr->numericVal);
606       if (i >= 0) {
607         *result_ptr = i;
608       } else {
609         *result_ptr = i + dimension_len;
610       }
611       return true;
612       break;
613     case RHS_IDX_RELATIVE:
614       if (!assertSingleNumber(index->val_of_expr)) return false;
615       *result_ptr = dimension_cell_num + (int) lrint(index->val_of_expr->numericVal);
616       return true;
617       break;
618     case RHS_IDX_DIM_START:
619       *result_ptr = 0;
620       return true;
621       break;
622     case RHS_IDX_DIM_END:
623       *result_ptr = dimension_len;
624       return true;
625       break;
626     default:
627       fprintf(stderr, "Exiting - illegal index type\n");
628       exit(-1);
629       break;
630   }
631 }
632
633 char resolve_rhs_slice(struct rhs_slice *slice, int dimension_len, int
        dimension_cell_num, int *start_ptr, int *end_ptr) {
634   char start_success, end_success;
635   if (slice == NULL) {
636     fprintf(stderr, "Exiting - asked to dereference a NULL slice\n");
637     exit(-1);
638   }
639   if (slice->slice_start_index == NULL) {
640     if (slice->slice_end_index != NULL) {
641       fprintf(stderr, "Exiting - illegal slice\n");
642       exit(-1);
643     }
644     if (dimension_len == 1) {
645       *start_ptr = 0;
646       *end_ptr = 1;
647       return true;
648     } else {
649       *start_ptr = dimension_cell_num;
650       *end_ptr = dimension_cell_num + 1;
651       return true;
652     }
653   } else {
654     start_success = resolve_rhs_index(slice->slice_start_index, dimension_len,
          dimension_cell_num, start_ptr);
655     if (!start_success) return false;
656     if (slice->slice_end_index == NULL) {
```

```
657       *end_ptr = *start_ptr + 1;
658       return true;
659     } else {
660       end_success = resolve_rhs_index(slice->slice_end_index, dimension_len,
              dimension_cell_num, end_ptr);
661       return end_success;
662     }
663   }
664 }
665
666 value_p extract_selection(value_p expr, struct rhs_selection *sel, int r, int c) {
667   int expr_rows, expr_cols;
668   struct subrange_t subrange;
669   struct rhs_slice *row_slice_p, *col_slice_p;
670   int row_start, row_end, col_start, col_end;
671   char row_slice_success, col_slice_success;
672
673   if (expr == NULL || sel == NULL) {
674     fprintf(stderr, "Exiting - asked to extract a selection using a NULL pointer.\n");
675     exit(-1);
676   }
677   switch(expr->flags) {
678     case FLAG_EMPTY:
679       return new_val();
680       break;
681     case FLAG_NUMBER: case FLAG_STRING:
682       expr_rows = 1;
683       expr_cols = 1;
684       break;
685     case FLAG_SUBRANGE:
686       expr_rows = expr->subrange->subrange_num_rows;
687       expr_cols = expr->subrange->subrange_num_cols;
688       break;
689     default:
690       fprintf(stderr, "Exiting - invalid value type\n");
691       exit(-1);
692       break;
693   }
694   if (sel->slice1 == NULL) {
695     if (sel->slice2 != NULL) {
696       fprintf(stderr, "Exiting - illegal selection\n");
697       exit(-1);
698     }
699     row_slice_p = &corresponding_cell;
700     col_slice_p = &corresponding_cell;
701   } else {
702     if (sel->slice2 == NULL) {
703       if (expr_rows == 1) {
704         row_slice_p = &zero_to_one;
705         col_slice_p = sel->slice1;
706       } else if (expr_cols == 1) {
707         row_slice_p = sel->slice1;
708         col_slice_p = &zero_to_one;
709       } else {
710         return new_val();
711 /*      Alternately:
```

```
712         fprintf(stderr, "Runtime error: Only given one slice for a value with multiple
                rows and multiple columns\n");
713         debug_print(expr);
714         exit(-1); */
715       }
716     } else {
717       row_slice_p = sel->slice1;
718       col_slice_p = sel->slice2;
719     }
720   }
721   row_slice_success = resolve_rhs_slice(row_slice_p, expr_rows, r, &row_start, &
        row_end);
722   col_slice_success = resolve_rhs_slice(col_slice_p, expr_cols, c, &col_start, &
        col_end);
723   if (!row_slice_success || !col_slice_success) return new_val();
724   if (row_start < 0) row_start = 0;
725   if (col_start < 0) col_start = 0;
726   if (row_end > expr_rows) row_end = expr_rows;
727   if (col_end > expr_cols)  col_end = expr_cols;
728   if (row_end <= row_start || col_end <= col_start) return new_val();
729   if (expr->flags == FLAG_NUMBER || expr->flags == FLAG_STRING) {
730     /* You would have thought we could figure this out a lot further up
731      * in the code, but had to be sure that (row_start, row_end, col_start, col_end)
732      * actually ended up as (0, 1, 0, 1) */
733     return clone_value(expr);
734   } else {
735     subrange.range = expr->subrange->range;
736     subrange.base_var_offset_row = expr->subrange->base_var_offset_row + row_start;
737     subrange.base_var_offset_col = expr->subrange->base_var_offset_col + col_start;
738     subrange.subrange_num_rows = row_end - row_start;
739     subrange.subrange_num_cols = col_end - col_start;
740     return deref_subrange_p(&subrange);
741   }
742 }
743
744 value_p getValSR(struct subrange_t *sr, int r, int c) {
745   if(sr->subrange_num_rows <= r || sr->subrange_num_cols <= c || r < 0 || c < 0)
746     return new_val();
747   return getVal(sr->range, r + sr->base_var_offset_row, c + sr->base_var_offset_col);
748 }
749
750 void verify_assert(value_p val, char *fname) {
751   if ((!assertSingleNumber(val)) || val->numericVal != 1.0) {
752     fprintf(stderr, "EXITING - The function %s was called with arguments of the wrong
          dimensions.\n", fname);
753     exit(-1);
754   }
755 }
756
757 value_p getVal(struct var_instance *inst, int r, int c) {
758   /* If we're going to return new_val() then we have to
759    * do clone_value(). Otherwise the receiver won't know
760    * whether or not they can free the value_p they get back.
761    * I think this should return, dangerously, return NULL if it's
762    * invalid, and the callers will have to be careful to check the value.
763    * The alternative is to always clone_value - safer, but much slower
```

```
764     * and makes our memory issues even bigger.
765     * Right now there are only a few places that call this. */
766
767   if(!assertInBounds(inst, r, c)) return NULL;
768   int cell_number = r * inst->cols + c;
769   char cell_status = inst->status[cell_number];
770   switch(cell_status) {
771     case NEVER_EXAMINED:
772       inst->status[cell_number] = IN_PROGRESS;
773       inst->values[cell_number] = calcVal(inst, r, c);
774       if (inst->values[cell_number]->flags == FLAG_SUBRANGE) {
775         int i, j;
776         for (i = 0; i < inst->values[cell_number]->subrange->subrange_num_rows; i++) {
777           for (j = 0; j < inst->values[cell_number]->subrange->subrange_num_cols; j++)
                 {
778             /* Prevent sneaky circular references */
779             getVal(inst->values[cell_number]->subrange->range,
780                    i + inst->values[cell_number]->subrange->base_var_offset_row,
781                    j + inst->values[cell_number]->subrange->base_var_offset_col);
782           }
783         }
784       }
785       inst->status[cell_number] = CALCULATED;
786       break;
787     case IN_PROGRESS:
788       fprintf(stderr, "EXITING - Circular reference in %s[%d,%d]\n", inst->name, r, c)
              ;
789       exit(-1);
790       break;
791     case CALCULATED:
792       if (inst->values[cell_number] == NULL) {
793         fprintf(stderr, "Supposedly, %s[%d,%d] was already calculated, but there is a
                null pointer there.\n", inst->name, r, c);
794         fprintf(stderr, "Attempting to print contents of the variable instance where
                this occurred:\n");
795         fflush(stderr);
796         debug_print_varinst(inst);
797         exit(-1);
798       }
799       break;
800     default:
801       fprintf(stderr, "Unrecognized cell status %d (row %d, col %d)!\n", cell_status,
              r, c);
802       fprintf(stderr, "Attempting to print contents of the variable instance where
              this occurred:\n");
803       fflush(stderr);
804       debug_print_varinst(inst);
805       exit(-1);
806       break;
807   }
808   return inst->values[cell_number];
809 }
```

## 9.12 stdlib.xtnd

```
/* jss2272 ns3158 */

global rounding_cutoff := 1e-7;
global digits_after_decimal := 6;

extern "stdlib.a" {
  sin(val);
  cos(val);
  tan(val);
  acos(val);
  asin(val);
  atan(val);
  sinh(val);
  cosh(val);
  tanh(val);
  exp(val);
  log(val);
  log10(val);
  sqrt(val);
  ceil(val);
  fabs(val);
  floor(val);
  isNaN(val);
  len(str);
  round(val, number_of_digits);
  isInfinite(val);
  get_stdin();
  get_stdout();
  get_stderr();
  open(filename, mode);
  close(file_handle);
  read(file_handle, num_bytes);
  readline(file_handle);
  write(file_handle, buffer);
  toASCII(val);
  fromASCII(val);
  plot(val);
  bar_chart(file_handle, labels, vals);
  line_chart(file_handle, labels, x_vals);
  parseFloat(val);
}

global STDIN := get_stdin();
global STDOUT := get_stdout();
global STDERR := get_stderr();

print_endline(val) {
  return write(STDOUT, toString(val) + "\n");
}

transpose([m,n] rng) {
  [n,m] ret := rng[column(),row()];
  return ret;
}

flatten([m,n] rng) {
```

```
  [1,m*n] ret := rng[floor(column()/n), column()%n];
  return ret;
}

isNumber(x) {
  return typeof(x) == "Number";
}

isEmpty(x) {
  return typeof(x) == "Empty";
}

colRange(start, end) {
  [end-start, 1] ret;
  ret[0,0] = start;
  ret[1:,0] = ret[[-1]] + 1;
  return ret;
}

rowRange(start, end) {
  return transpose(colRange(start,end));
}

matchCol([num_rows, 1] list, val) {
  [num_rows, 1] amt_to_add, final_index;
  amt_to_add[0,0] = val == #list ? 0 : 1;
  amt_to_add[1:,0] = (amt_to_add[[-1]] == 0 || val == #list) ? 0 : 1;
  final_index[0,0] = 0;
  final_index[1:,0] = final_index[[-1]] + amt_to_add[[-1]];
  return amt_to_add[-1] == 0 ? final_index[-1] : empty;
}

matchRow([1, num_cols] list, val) {
  [1, num_cols] amt_to_add, final_index;
  amt_to_add[0,0] = val == #list ? 0 : 1;
  amt_to_add[0,1:] = (amt_to_add[[-1]] == 0 || val == #list) ? 0 : 1;
  final_index[0,0] = 0;
  final_index[0,1:] = final_index[[-1]] + amt_to_add[[-1]];
  return amt_to_add[-1] == 0 ? final_index[-1] : empty;
}

match([m,n] list, val) {
  return m == 1 ? matchRow(list, val) : (n == 1 ? matchCol(list, val) : empty);
}

bsearch([num_rows, 1] list, val) {
  mid := (num_rows - 1) / 2;
  return switch {
    case list[mid] == val:
      mid;
    case list[mid] > val:
      mid > 0 ? bsearch(list[:mid], val) : empty;
    case list[mid] < val:
      num_rows > 1 ? mid + 1 + bsearch(list[mid+1:], val) : empty;
  };
}
```

```
113
114 sum_column([m,1] rng) {
115   [m,1] running_sum;
116   running_sum[0,0] = #rng;
117   running_sum[1:,0] = running_sum[[-1]] + #rng;
118   return running_sum[-1];
119 }
120
121 sum([m,n] rng) {
122   /* Returns the sum of the values in the range, skipping any values that are non-
          numeric */
123   [m,n] numbers := isNumber(#rng) ? #rng : 0;
124   [1,n] column_sums := sum_column(numbers[:,]);
125   return sum_column(transpose(column_sums));
126 }
127
128 nmax(n1, n2) {
129   return n1 > n2 ? n1 : n2;
130 }
131
132 max_column([m,1] rng) {
133   [m,1] running_max;
134   running_max[0,0] = #rng;
135   running_max[1:,0] = running_max[[-1]] > #rng ? running_max[[-1]] : #rng;
136   return running_max[-1];
137 }
138
139 max([m,n] rng) {
140   /* Returns the max of the values in the range, skipping any values that are non-
          numeric */
141   [m,n] numbers := isNumber(#rng) ? #rng : empty;
142   [1,n] column_maxs := max_column(rng[:,]);
143   return max_column(transpose(column_maxs));
144 }
145
146 nmin(n1, n2) {
147   return n1 < n2 ? n1 : n2;
148 }
149
150 min_column([m,1] rng) {
151   [m,1] running_min;
152   running_min[0,0] = #rng;
153   running_min[1:,0] = running_min[[-1]] > #rng ? running_min[[-1]] : #rng;
154   return running_min[-1];
155 }
156
157 min([m,n] rng) {
158   /* Returns the min of the values in the range, skipping any values that are non-
          numeric */
159   [m,n] numbers := isNumber(#rng) ? #rng : empty;
160   [1,n] column_mins := min_column(rng[:,]);
161   return min_column(transpose(column_mins));
162 }
163
164 sign(arg) {
165   return switch {
```

```
    case arg > 0: 1;
    case arg < 0: -1;
    case arg == 0: 0;
  };
}

gcd(m, n) {
  return (n == 0) ? m : gcd(n, m % n);
}

lcm(m, n) {
  return m * n / gcd(m, n);
}

sumsq([m,n] rng) {
  [m,n] squares := #rng * #rng;
  return sum(squares);
}

sumproduct([m,n] rng1, [m,n] rng2) {
  [m,n] products := #rng1 * #rng2;
  return sum(products);
}

sumxmy2([m,n] rng1, [m,n] rng2) {
  [m,n] diffs := #rng1 - #rng2;
  return sumsq(diffs);
}

mmult([m,n] rng1, [n,p] rng2) {
  [m,p] result := sumproduct(rng1[,:],transpose(rng2[:,]));
  return result;
}

linest([p,q] known_ys, [p,q] known_xs) {
  flat_ys := flatten(known_ys);
  flat_xs := flatten(known_xs);

  n := p * q;
  S_x := sum(flat_xs);
  S_y := sum(flat_ys);
  S_xx := sumsq(flat_xs);
  S_yy := sumsq(flat_ys);
  S_xy := sumproduct(flat_xs, flat_ys);

  beta1_hat := (n * S_xy - S_x*S_y)/(n*S_xx - S_x*S_x);
  beta0_hat := S_y / n - beta1_hat * S_x / n;
  [2,2] ret;
  ret[0,0] = "Intercept estimate";
  ret[0,1] = "Slope estimate";
  ret[1,0] = beta0_hat;
  ret[1,1] = beta1_hat;
  return ret;
}

toUpper(text) {
```

```
  val := toASCII(text);
  val_s := size(val);
  [val_s[0],val_s[1]] result := #val >= 97 && #val <= 122 ? #val - 32 : #val;
  return fromASCII(result);
}

toLower(text) {
  val := toASCII(text);
  val_s := size(val);
  [val_s[0],val_s[1]] result := #val >= 65 && #val <= 90 ? #val + 32 : #val;
  return fromASCII(result);
}

left(str, num_chars) {
  return fromASCII(toASCII(str)[:num_chars]);
}

right(str, num_chars) {
  return fromASCII(toASCII(str)[-num_chars:]);
}

substring(str, start, length) {
  return fromASCII(toASCII(str)[start:start+length]);
}

concatRow([1,n] cells, joiner) {
  [1,n] accum;
  accum[0,0] = #cells;
  accum[0,1:] = accum[[-1]] + joiner + #cells;
  return accum[-1];
}

toRangeLiteral([m,n] rng) {
  [m,n] strings := toLiteral(#rng);
  [m,1] rows := concatRow(strings[,:], ", ");
  return "{" + concatRow(transpose(rows), ";\n") + "}";
}

toLiteral(arg) {
  return switch(typeof(arg)) {
    case "Number":
      toString(arg);
    case "String":
      "\"" + arg + "\"";
    case "Empty":
      "empty";
    case "Range":
      toRangeLiteral(arg);
  };
}

repeat(str, num) {
  [1,num] copies := str;
  return concatRow(copies,"");
}
```

```
stringOfPositiveInteger(arg) {
  num_digits := 1 + floor(log10(arg));
  [1,num_digits] digits := floor(arg/10**(num_digits-1-column())) % 10;
  [1,num_digits] ascii_digits := 48 + #digits;
  return arg < 1 ? "0" : fromASCII(ascii_digits);
}

padLeft(str, pad_char, total_length) {
  existing_length := len(str);
  padding := repeat(pad_char, total_length - len(str));
  return existing_length < total_length ? (padding + str) : str;
}

toString(arg) {
  positive_arg := fabs(arg);
  closest_integer := round(positive_arg, 0);
  is_integral_enough := fabs(positive_arg-closest_integer) < rounding_cutoff;
  floating_part := round(10 ** digits_after_decimal * (positive_arg - floor(
      positive_arg)),0);
  positive_part := stringOfPositiveInteger(floor(positive_arg)) + (is_integral_enough
      ? "" : "." + padLeft(stringOfPositiveInteger(floating_part), "0",
      digits_after_decimal));

  return switch(typeof(arg)) {
    case "Number":
      switch {
        case isNaN(arg):
          "NaN";
        case isInfinite(arg) == -1:
          "-Inf";
        case isInfinite(arg) == 1:
          "Inf";
        case sign(arg) == 0:
          "0";
        case sign(arg) == 1:
            positive_part;
        case sign(arg) == -1:
          "-" + positive_part;
        default:
          "Encountered a number that is neither NaN, +Inf, -Inf, 0, positive or
              negative";
      };
    case "String":
      arg;
    case "Empty":
      "empty";
    case "Range":
      toRangeLiteral(arg);
  };
}

numRows(arg) {
  return size(arg)[0];
}

numCols(arg) {
```

```
  return size(arg)[1];
}

splitChars([1,n] stringchars, splitchar) {
  loc := matchRow(stringchars, splitchar);
  firstword := fromASCII(stringchars[:loc]);
  lastwords := splitChars(stringchars[loc+1:],splitchar);
  combined := stack(firstword, lastwords);
  return loc == empty ? fromASCII(stringchars) : combined;
}

split(string, splitter) {
  return splitChars(toASCII(string), toASCII(splitter));
}

splitToRange(string, row_splitter, col_splitter) {
  split_rows := split(string, row_splitter);
  [numRows(split_rows),1] split_cols := split(#split_rows,col_splitter);
  [numRows(split_rows),1] col_lengths := numRows(#split_cols);
  [numRows(split_rows), max(col_lengths)] result := #split_cols[column()];
  return result;
}

isSpace(char) {
  return switch(char) {
    case toASCII(" "), toASCII("\n"), toASCII("\t"), toASCII("\r"):
      1;
    default:
      0;
  };
}

trimChars(chars) {
  return isSpace(chars[0]) ? trimChars(chars[1:]) : chars;
}

ltrim(s) {
  return fromASCII(trimChars(toASCII(s)));
}

reverse(s) {
  chars := toASCII(s);
  l := len(s);
  [1,numCols(chars)] chars_reversed := chars[l-1-column()];
  return l ? fromASCII(chars_reversed) : "";
}

rtrim(s) {
  return reverse(ltrim(reverse(s)));
}

trim(s) {
  return ltrim(rtrim(s));
}

charAt(s, i) {
```

```
  return toASCII(s)[i];
}

parseString(s) {
  trimmed := trim(s);
  rangeSplit := splitToRange(substring(trimmed, 1, len(trimmed) - 2), ";", ",");
  [numRows(rangeSplit), numCols(rangeSplit)] rangeContents := parseString(#rangeSplit)
      ;
  return switch {
    case charAt(trimmed,0) == toASCII("{") && charAt(trimmed,-1) == toASCII("}"):
      rangeContents;
    case charAt(trimmed,0) == toASCII("\"") && charAt(trimmed,-1) == toASCII("\""):
      substring(trimmed, 1, len(trimmed) - 2);
    case trimmed == "empty":
      empty;
    default:
      parseFloat(trimmed);
  };
}

normalize([m,n] arg) {
  [m,n] squared_lengths := #arg * #arg, normalized := #arg / vector_norm;
  vector_norm := sqrt(sum(squared_lengths));
  return normalized;
}

append([m,n] rg1, [p,q] rg2) {
  [nmax(m,p), n+q] res;
  res[:m,:n] = #rg1;
  res[:p,n:n+q] = rg2[,[-n]];
  return res;
}

stack(rg1, rg2) {
  return transpose(append(transpose(rg1), transpose(rg2)));
}
```

# 10. Tests and Output

helloworld.xtnd

```
main(args) {
  foo := print_endline("Hello World") -> 0;
  return foo;
}
```

helloworld.xtnd - Expected Output

```
Hello World
```

test-access-cell.xtnd

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

test-access-cell.xtnd - Expected Output

```
string
```

test-access-column-cell.xtnd

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

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

```
string
```

test-access-column-cells.xtnd

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

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

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

test-access-hashtag-multi-dim.xtnd

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

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

```
string
```

test-access-hashtag-single-dim.xtnd

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

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

```
string
```

test-access-relative-range.xtnd

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

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

```
string
```

test-access-selected-range-1.xtnd

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

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

```
{"string", "string";
"string", "string"}
```

test-access-selected-range-2.xtnd

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

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

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

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

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

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

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

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

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

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

```
{"string";
"string";
"string";
"string"}
```

test-acos.xtnd

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

test-acos.xtnd - Expected Output

```
1.570796
```

test-addition.xtnd

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

test-addition.xtnd - Expected Output

```
12
```

test-addition-empty.xtnd

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

test-addition-empty.xtnd - Expected Output

```
empty
```

test-asin.xtnd

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

test-asin.xtnd - Expected Output

```
0.523599
```

test-atan.xtnd

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

test-atan.xtnd - Expected Output

```
1.548578
```

test-basic-func.xtnd

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

test-basic-func.xtnd - Expected Output

```
0
```

test-bitnot.xtnd

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

test-bitnot.xtnd - Expected Output

```
empty
-2
-1
empty
empty
```

test-bitwise-and.xtnd

```
main([1,1] args){
  return print_endline(23 & 12) -> 0;
}
```

test-bitwise-and.xtnd - Expected Output

```
4
```

test-bitwise-and-empty.xtnd

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

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

```
empty
```

test-bitwise-left.xtnd

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

test-bitwise-left.xtnd - Expected Output

```
56
```

test-bitwise-left-empty.xtnd

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

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

```
empty
```

test-bitwise-not.xtnd

```
main([1,1] args){
  /* Should return -89 */
  return print_endline(~88) -> 0;
}
```

test-bitwise-not.xtnd - Expected Output

```
-89
```

test-bitwise-not-empty.xtnd

```
main([1,1] args){
  /* Should return empty */
  return print_endline( ~empty) -> 0;
}
```

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

```
empty
```

test-bitwise-or.xtnd

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

test-bitwise-or.xtnd - Expected Output

```
14
```

test-bitwise-or-empty.xtnd

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

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

```
empty
```

test-bitwise-right.xtnd

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

test-bitwise-right.xtnd - Expected Output

```
3
```

test-bitwise-right-empty.xtnd

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

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

```
empty
```

test-bitwise-xor.xtnd

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

test-bitwise-xor.xtnd - Expected Output

```
2
```

test-bitwise-xor-empty.xtnd

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

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

```
empty
```

test-boolean-equals.xtnd

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

test-boolean-equals.xtnd - Expected Output

```
0
```

test-boolean-equals-both-empty.xtnd

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

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

```
1
```

test-boolean-equals-harder.xtnd

```
main([1,1] args){
  return
    print_endline( "True cases for ==") ->
    print_endline(  (5 == 5)) ->
    print_endline(  (5 == 5.0)) ->
    print_endline(  (0.5 == 5e-1)) ->
    print_endline(  (50 == 5e1)) ->
    print_endline(  2 + 2 == 4) ->
    print_endline(  "foo" == "foo") ->
    print_endline(  "" == "") ->
    print_endline(  empty == empty) ->
    print_endline(  empty == !empty) ->
    print_endline(  !"foo" == !"bar") ->
    print_endline( (2 ? 3 : 4) == ("foo" ? 3 : "not 4") ) ->

    print_endline( "\nFalse cases for ==") ->
    print_endline(  (5 == 6)) ->
    print_endline(  (5 == 5.01)) ->
    print_endline(  (0.5 == 5e-2)) ->
    print_endline(  (50 == 5e2)) ->
    print_endline(  2 + 2 == 5) ->
    print_endline(  "foo" == "bar") ->
    print_endline(  "" == "foo") ->
    print_endline(  "" == empty) ->
    print_endline(  2 == empty) ->
    print_endline(  empty == 2) ->
    print_endline( (2 ? 3 : 4) == ("foo" ? "not 3" : 4) ) ->

    print_endline( "\nTrue cases for !=") ->
    print_endline(  (5 != 6)) ->
    print_endline(  (5 != 5.01)) ->
    print_endline(  (0.5 != 5e-2)) ->
    print_endline(  (50 != 5e2)) ->
    print_endline(  2 + 2 != 5) ->
    print_endline(  "foo" != "bar") ->
    print_endline(  "" != "foo") ->
    print_endline(  "" != empty) ->
    print_endline(  2 != empty) ->
    print_endline(  empty != 2) ->
    print_endline( (2 ? 3 : 4) != ("foo" ? "not 3" : 4) ) ->

    print_endline( "\nFalse cases for !=") ->
    print_endline(  (5 != 5)) ->
    print_endline(  (5 != 5.0)) ->
    print_endline(  (0.5 != 5e-1)) ->
    print_endline(  (50 != 5e1)) ->
    print_endline(  2 + 2 != 4) ->
    print_endline(  "foo" != "foo") ->
    print_endline(  "" != "") ->
    print_endline(  empty != empty) ->
    print_endline(  empty != !empty) ->
    print_endline(  !"foo" != !"bar") ->
    print_endline( (2 ? 3 : 4) != ("foo" ? 3 : "not 4") ) ->

    0;
```

```
}
```

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

```
True cases for ==
1
1
1
1
1
1
1
1
1
1
1

False cases for ==
0
0
0
0
0
0
0
0
0
0
0

True cases for !=
1
1
1
1
1
1
1
1
1
1
1

False cases for !=
0
0
0
0
0
0
0
0
0
0
0
```

test-boolean-equals-one-empty.xtnd

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

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

```
0
```

test-boolean-logical-not-equals.xtnd

```
main([1,1] args){
  return print_endline( 6 != 7) -> 0;
}
```

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

```
1
```

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

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

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

```
0
```

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

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

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

```
1
```

test-calling-func-from-import.xtnd

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

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

```
5
```

test-ceil.xtnd

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

test-ceil.xtnd - Expected Output

```
11
```

test-cos.xtnd

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

test-cos.xtnd - Expected Output

```
0.525322
```

test-cosh.xtnd

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

test-cosh.xtnd - Expected Output

```
6.132289
```

test-division.xtnd

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

test-division.xtnd - Expected Output

```
4
```

test-division-empty.xtnd

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

test-division-empty.xtnd - Expected Output

```
empty
```

test-exp.xtnd

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

test-exp.xtnd - Expected Output

```
7.389056
```

test-fabs.xtnd

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

test-fabs.xtnd - Expected Output

```
45
```

test-file-close.xtnd

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

test-file-close.xtnd - Expected Output

```
Made it this far
```

test-file-read.xtnd

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

test-file-read.xtnd - Expected Output

```
This
```

test-file-slurp.xtnd

```
main(args){
  return
    write(STDOUT,(read(open("testcases/assets/test_file.txt", "r"),0))) ->
    0;
}
```

test-file-slurp.xtnd - Expected Output

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

test-file-write.xtnd

```
main(args){
  handle := open("testcases/assets/test_file_write.out", "w");
  return
    write(handle, "Hello") ->
    close(handle) ->
    print_endline("Made it this far") ->
    0;
}
```

test-file-write.xtnd - Expected Output

```
Made it this far
```

test-floor.xtnd

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

test-floor.xtnd - Expected Output

```
10
```

test-func-params.xtnd

```
main([1,n] args) {
  return print_endline( foo("string")) -> 0;
}
foo([1,1] arg) {
  return arg;
}
```

test-func-params.xtnd - Expected Output

```
string
```

test-func-params-omit-dim.xtnd

```
main([1,n] args) {
  return print_endline(foo("string")) -> 0;
}
foo([1,1] arg) {
  return arg;
}
```

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

```
string
```

test-global-hello.xtnd

```
bar() {
  foo := 5;
  return 2;
}

global foo := print_endline("Hello Globals!") -> 0;

main(args) {
  return foo;
}
```

test-global-hello.xtnd - Expected Output

```
Hello Globals!
```

test-global-masking.xtnd

```
bar() {
  foo := 5;
  return 2;
}

global foo := print_endline("Hello Globals!") -> 0;

main(args) {
  foo := print_endline("Hello Locals!") -> 0;
  return foo;
}
```

test-global-masking.xtnd - Expected Output

```
Hello Locals!
```

test-globals.xtnd

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

test-globals.xtnd - Expected Output

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

test-globals-between-imports.xtnd

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

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

```
Hello
```

test-greater-than.xtnd

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

test-greater-than.xtnd - Expected Output

```
1
```

test-greater-than-empty.xtnd

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

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

```
empty
```

test-greater-than-or-equal.xtnd

```
main([1,1] args){
  return print_endline( 7 >= 7) -> 0;
}
```

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

```
1
```

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

```
main([1,1] args){
  return print_endline(empty >= 7) -> 0;
}
```

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

```
empty
```

test-less-than.xtnd

```
main([1,1] args){
  return print_endline( 6 < 7) -> 0;
}
```

test-less-than.xtnd - Expected Output

```
1
```

test-less-than-empty.xtnd

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

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

```
empty
```

test-less-than-or-equal.xtnd

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

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

```
0
```

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

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

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

```
empty
```

test-log.xtnd

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

test-log.xtnd - Expected Output

```
2.302585
```

test-log10.xtnd

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

test-log10.xtnd - Expected Output

```
2
```

test-logical-and.xtnd

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

test-logical-and.xtnd - Expected Output

```
1
```

test-logical-and-empty.xtnd

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

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

```
empty
```

test-logical-not.xtnd

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

test-logical-not.xtnd - Expected Output

```
0
```

test-logical-not-empty.xtnd

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

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

```
empty
```

test-logical-or.xtnd

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

test-logical-or.xtnd - Expected Output

```
1
```

test-logical-or-empty.xtnd

```
main([1,1] args){
  return print_endline( empty || 4) -> 0;
}
```

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

```
empty
```

test-modulo.xtnd

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

test-modulo.xtnd - Expected Output

```
1
```

test-modulo-empty.xtnd

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

test-modulo-empty.xtnd - Expected Output

```
empty
```

test-multiple-imports.xtnd

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

test-multiple-imports.xtnd - Expected Output

```
Hello
```

test-multiplication.xtnd

```
main([1,n] args){
  /* Should evaluate to 35 */
  return print_endline(7 * 5) -> 0;
}
```

test-multiplication.xtnd - Expected Output

```
35
```

test-multiplication-empty.xtnd

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

test-multiplication-empty.xtnd - Expected Output

```
empty
```

test-nan-and-infinity.xtnd

```
main(args) {
  should_be_nan := sqrt(-1);
  should_also_be_nan := 0 / 0;
  should_be_plus_inf := 2 / 0;
  should_be_minus_inf := -3 / 0;
  should_be_normal := 4;
  foo := "Hello";
  bar := empty;
  [3,3] baz := row() * column();

  return
    print_endline(typeof(should_be_nan)) -> // "Number"
    print_endline(typeof(should_also_be_nan)) -> // "Number"
    print_endline(typeof(should_be_plus_inf)) -> // "Number"
    print_endline(typeof(should_be_minus_inf)) -> // "Number"
    print_endline(typeof(should_be_normal)) -> // "Number"
    print_endline(typeof(foo)) -> // "String"
    print_endline(typeof(bar)) -> // "Empty"
    print_endline(typeof(baz)) -> // "Range"
    print_endline("") ->

    print_endline(isNaN(should_be_nan)) -> // 1
    print_endline(isNaN(should_also_be_nan)) -> // 1
    print_endline(isNaN(should_be_plus_inf)) -> // 0
    print_endline(isNaN(should_be_minus_inf)) -> // 0
    print_endline(isNaN(should_be_normal)) -> // 0
    print_endline(isNaN(foo)) -> // 0
    print_endline(isNaN(bar)) -> // 0
    print_endline(isNaN(baz)) -> // 0
    print_endline("") ->

    print_endline(isInfinite(should_be_nan)) -> // 0
    print_endline(isInfinite(should_also_be_nan)) -> // 0
    print_endline(isInfinite(should_be_plus_inf)) -> // 1
    print_endline(isInfinite(should_be_minus_inf)) -> // -1
    print_endline(isInfinite(should_be_normal)) -> // 0
    print_endline(isInfinite(foo)) -> // 0
    print_endline(isInfinite(bar)) -> // 0
    print_endline(isInfinite(baz)) -> // 0

    0;
}
```

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

```
Number
Number
Number
Number
Number
String
Empty
Range

1
1
0
```

```
0
0
empty
empty
empty

0
0
1
-1
0
empty
empty
empty
```

test-parse-error.xtnd

```
main(args){
  foo := 5$5;
  return foo;
}
```

test-parse-error.xtnd - Expected Output

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

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

```
main(args){
/* This is a comment spanning multiple lines.
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
                                                  
20 of them, in fact. */
  foo := 5/5;
  bar := $$$$
  return foo;
}
```

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

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

test-parse-error-comment.xtnd

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

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

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

test-parse-error-missing-semicolon.xtnd

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

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

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

test-parse-error-newlines.xtnd

```
main(args){
  foo := 5/5;
  bar := "\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n"$5;
  return foo;
}
```

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

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

test-parse-error-string.xtnd

```
main(args){
  foo := "Hello";$$$;
  return foo;
}
```

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

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

test-power.xtnd

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

test-power.xtnd - Expected Output

```
216
```

test-power-empty.xtnd

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

test-power-empty.xtnd - Expected Output

```
empty
```

test-print-empty.xtnd

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

test-print-empty.xtnd - Expected Output

```
empty
```

test-print-multi-range.xtnd

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

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

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

test-print-multi-str-range.xtnd

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

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

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

test-print-nums.xtnd

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

test-print-nums.xtnd - Expected Output

```
1
```

test-print-oned-range.xtnd

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

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

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

test-print-str.xtnd

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

test-print-str.xtnd - Expected Output

```
string
```

test-range-equality.xtnd

```
main(args) {
  my1 := {"Hello, world", "Goodbye, world"};
  my2 := {"Hello, world", "Goodbye, world"};
  my3 := {3,4,5,{"Hello, world", "Goodbye, world"},6,7,8};
  my4 := {3,empty,5,{"Hello, world", "Goodbye, world"},6,7,8};
  my5 := {3,4,5,{"Hello, world"; "Goodbye, world"},6,7,8};
  [2,2] foo := my1;
  [2,1] bar := my1;
  [3,3] ident := row() == column();
  ident_lit := {1,0,0;0,1,0;0,0,1};
  [3,3] all_ones := 1;
  baz := my2;
  return
    // True cases
    print_endline(my1 == my2) ->
    print_endline(baz == my1) ->
    print_endline(foo[0,0] == my2) ->
    print_endline(foo[0,1] == my2) ->
    print_endline(foo[0,0] == foo[1,1]) ->
    print_endline(foo[:,0] == bar) ->
    print_endline(my3[3] == my1) ->
    print_endline(ident == ident_lit) ->
    print_endline("") ->

    // False cases
```

```
    print_endline(my3 == my5) ->
    print_endline(my3 == my4) ->
    print_endline(foo == bar) ->
    print_endline(foo == foo[0,0]) ->
    print_endline(ident == all_ones) ->
    print_endline(ident == 1) ->
    print_endline(all_ones == 1) ->
    0
    ;
}
```

test-range-equality.xtnd - Expected Output

```
1
1
1
1
1
1
1
1

0
0
0
0
0
0
0
```

test-ref-between-globals.xtnd

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

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

```
1
```

test-short-circuiting-and.xtnd

```
main([1,1] args){
  return 0 && print_endline("FAIL") -> print_endline("PASS") -> 0;
}
```

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

```
PASS
```

test-short-circuiting-and2.xtnd

```
main([1,1] args){
  return 1 && print_endline("PASS1") -> print_endline("PASS2") -> 0;
}
```

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

```
PASS1
PASS2
```

test-short-circuiting-or.xtnd

```
main([1,1] args){
  return 0 || print_endline("PASS1") -> print_endline("PASS2") -> 0;
}
```

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

```
PASS1
PASS2
```

test-short-circuiting-or2.xtnd

```
main([1,1] args){
  return 1 || print_endline("FAIL") -> print_endline("PASS") -> 0;
}
```

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

```
PASS
```

test-signature-vars.xtnd

```
foo([m,n] arg) {
  return "I was called with an argument with " + toString(m) + " rows and " + toString
      (n) + " columns.";
}

main([1,1] args) {
  [42,17] x;
  return print_endline(foo(x)) -> 0;
}
```

test-signature-vars.xtnd - Expected Output

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

test-sin.xtnd

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

test-sin.xtnd - Expected Output

```
0.850904
```

test-sin-through-function.xtnd

```
internal_sin(x,y,z) {
  return sin(z);
}

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

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

```
0.850904
```

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

```
global theta := 45.0;

internal_sin(x,y,z) {
  return sin(z);
}

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

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

```
0.850904
```

test-single-import.xtnd

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

test-single-import.xtnd - Expected Output

```
5
```

test-sinh.xtnd

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

test-sinh.xtnd - Expected Output

```
10.017875
```

test-sqrt.xtnd

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

test-sqrt.xtnd - Expected Output

```
3
```

test-string-concatenation.xtnd

```
main(args) {
  foo :=
    print_endline("Hello " + "World") ->
    print_endline("Hello " + "World") ->
    print_endline("Hello " + ("World" + "")) ->
     0;
  return foo;
}
```

test-string-concatenation.xtnd - Expected Output

```
Hello World
Hello World
Hello World
```

test-subtraction.xtnd

```
main([1,1] args){
  return print_endline( 7 - 5) -> 0;
}
```

test-subtraction.xtnd - Expected Output

```
2
```

test-subtraction-empty.xtnd

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

test-subtraction-empty.xtnd - Expected Output

```
empty
```

test-switch-v1.xtnd

```
main([1,1] args){
  x := switch(1) {
    case 1: 100;
    case 2: 200;
    default: 300;
  };
  return print_endline(x) -> 0;
}
```

test-switch-v1.xtnd - Expected Output

```
100
```

test-switch-v10.xtnd

```
main([1,1] args){
  x := switch {
    case 0: 100;
    case "also true": 200;
    default: 99;
  };
  return print_endline(x) -> 0;
}
```

test-switch-v10.xtnd - Expected Output

```
200
```

test-switch-v11.xtnd

```
main([1,1] args){
  x := switch {
    case 0: 100;
    default: 99;
  };
  return print_endline(x) -> 0;
}
```

test-switch-v11.xtnd - Expected Output

```
99
```

test-switch-v2.xtnd

```
main([1,1] args){
  x := switch(2) {
    case 1: 100;
    case 2: 200;
    default: 300;
  };
  return print_endline(x) -> 0;
}
```

test-switch-v2.xtnd - Expected Output

```
200
```

test-switch-v3.xtnd

```
main([1,1] args){
  x := switch(3) {
    case 1: 100;
    case 2: 200;
    default: 300;
  };
  return print_endline(x) -> 0;
}
```

test-switch-v3.xtnd - Expected Output

```
300
```

test-switch-v4.xtnd

```
main([1,1] args){
  x := switch(2) {
    case 1, 2: 100;
    default: 300;
  };
  return print_endline(x) -> 0;
}
```

test-switch-v4.xtnd - Expected Output

```
100
```

test-switch-v5.xtnd

```
main([1,1] args){
  x := switch(3) {
    case 1, 2: 100;
    default: 300;
  };
  return print_endline(x) -> 0;
}
```

test-switch-v5.xtnd - Expected Output

```
300
```

test-switch-v6.xtnd

```
main([1,1] args){
  x := switch(3) {
    case 1, 2: 100;
    case 0, 3: 200;
    default: 300;
  };
  return print_endline(x) -> 0;
}
```

test-switch-v6.xtnd - Expected Output

```
200
```

test-switch-v7.xtnd

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

test-switch-v7.xtnd - Expected Output

```
empty
```

test-switch-v8.xtnd

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

test-switch-v8.xtnd - Expected Output

```
200
```

test-switch-v9.xtnd

```
main([1,1] args){
  x := switch {
    case "true": 100;
    case "also true": 200;
  };
  return print_endline(x) -> 0;
}
```

test-switch-v9.xtnd - Expected Output

```
100
```

test-tan.xtnd

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

test-tan.xtnd - Expected Output

```
1.619775
```

test-tanh.xtnd

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

test-tanh.xtnd - Expected Output

```
1
```

test-ternary-conditional.xtnd

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

test-ternary-conditional.xtnd - Expected Output

```
2
```

test-ternary-conditional-empty.xtnd

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

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

```
empty
```

test-unary-negation.xtnd

```
main([1,n] args){
  /* Should return -33 */
  return print_endline( -33) -> 0;
}
```

test-unary-negation.xtnd - Expected Output

```
−33
```

test-unary-negation-empty.xtnd

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

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

```
empty
```

# 11. Git Logs

```
a6db867 2016-12-19T20:36:52-05:00 GitHub: Merge pull request #135 from ExtendLang/contrib
900411c 2016-12-19T17:40:28-05:00 GitHub: Merge branch 'master' into contrib
d253e33 2016-12-19T17:39:19-05:00 Nigel Schuster: Assigned contributions
2569ea5 2016-12-19T12:43:20-05:00 GitHub: Merge pull request #134 from ExtendLang/stdlib-additions
47f1167 2016-12-19T12:09:58-05:00 GitHub: Merge branch 'master' into stdlib-additions
2e18028 2016-12-19T12:09:50-05:00 GitHub: Merge pull request #133 from ExtendLang/mergesort
142938e 2016-12-19T11:51:25-05:00 oracleofnj: Couple stdlib additions
3fc2843 2016-12-19T10:17:09-05:00 Nigel Schuster: Mergesort example
0b23496 2016-12-19T09:07:15-05:00 GitHub: Merge pull request #132 from ExtendLang/fixing-tcs
b86d992 2016-12-19T00:38:27-05:00 oracleofnj: Verify samples, compact TSP
e859c75 2016-12-19T00:17:57-05:00 oracleofnj: Final test run with complete stdlib
f02f2da 2016-12-19T00:13:20-05:00 oracleofnj: Remove obselete print flavors
dd65154 2016-12-19T00:08:17-05:00 oracleofnj: Merge branch 'master' into fixing-tcs
82f4ad5 2016-12-19T00:07:45-05:00 oracleofnj: Merge branch 'master' of https://github.com/ExtendLang/Extend
d2cd19e 2016-12-19T00:07:30-05:00 oracleofnj: 125 / 125
8d02537 2016-12-19T00:07:11-05:00 GitHub: Merge pull request #131 from ExtendLang/webgif
453b7f6 2016-12-18T23:33:06-05:00 oracleofnj: Back to passing all previously passing TCs; on to stragglers
6487840 2016-12-18T23:00:01-05:00 Nigel Schuster: Removed webgif from Makefile
84dca34 2016-12-18T22:29:59-05:00 oracleofnj: Ignore webgif
ed204c2 2016-12-18T22:29:32-05:00 oracleofnj: Ignore webgif
1bcb830 2016-12-18T19:48:02-05:00 GitHub: Merge pull request #41 from ExtendLang/plotting
1cd2360 2016-12-18T19:46:21-05:00 GitHub: Merge branch 'master' into plotting
0058659 2016-12-18T19:30:35-05:00 GitHub: Merge pull request #129 from ExtendLang/remove-debug-final
b54f4aa 2016-12-18T18:54:47-05:00 GitHub: Fix MAXFLOAT
9324fb8 2016-12-18T18:50:59-05:00 GitHub: Merge branch 'master' into plotting
f152bc9 2016-12-18T18:32:21-05:00 oracleofnj: Remove Debug()
c069630 2016-12-18T18:15:40-05:00 Nigel Schuster: Linking plotter is optional
e9dbd0f 2016-12-18T17:05:54-05:00 GitHub: Merge pull request #128 from ExtendLang/back-to-parsing
b602263 2016-12-18T14:12:48-05:00 oracleofnj: Merge in cool program
45d14cf 2016-12-18T14:12:28-05:00 GitHub: Merge pull request #127 from ExtendLang/strcat-bug
790bc51 2016-12-18T14:00:48-05:00 oracleofnj: Merge branch 'cool_program' into back-to-parsing
2eba5e5 2016-12-18T13:59:44-05:00 oracleofnj: Replace C extend_parseString with in-
```

```
    language parseString
1b664be 2016-12-18T09:14:51-05:00 Nigel Schuster: Corrected travis file
554b584 2016-12-18T09:13:54-05:00 Nigel Schuster: Cleand up Makefile mess
a222916 2016-12-18T08:19:54-05:00 GitHub: Merge branch 'master' into plotting
d064d8a 2016-12-18T01:49:39-05:00 Ishaan: Cleanup line function
47dace5 2016-12-18T01:48:28-05:00 Ishaan: Test single parameter line chart
8f5cf52 2016-12-18T01:43:49-05:00 Ishaan: Fix the testcase fail
84cd775 2016-12-18T01:41:50-05:00 Ishaan: update testcase
a425775 2016-12-18T01:39:43-05:00 Ishaan: Figure out 2 line issue
ba2c3c1 2016-12-18T01:34:34-05:00 Ishaan: Add y values and update testcase
7ad5986 2016-12-18T01:18:28-05:00 Ishaan: Trying another version of line
b8732dd 2016-12-18T00:42:25-05:00 Ishaan: Fix derp in linechart
20e2c43 2016-12-18T00:40:22-05:00 Ishaan: Added basic linechart function to examine
b404e12 2016-12-17T23:56:16-05:00 Ishaan: Cast to float
e866f68 2016-12-17T23:38:40-05:00 Ishaan: Reverse row and col
8419510 2016-12-17T23:27:13-05:00 oracleofnj: That's a wrap
6ec3e0e 2016-12-17T23:17:46-05:00 oracleofnj: Proof of concept
302af00 2016-12-17T23:09:14-05:00 Ishaan: Updating checks
7b09def 2016-12-17T23:03:14-05:00 Ishaan: Testing bar chart plotting, will clean up
    later
20adaca 2016-12-17T20:40:13-05:00 oracleofnj: Some bugfixes
ad69dcf 2016-12-17T20:12:33-05:00 oracleofnj: Fixed extend side
8f76e59 2016-12-17T20:10:06-05:00 Kevin: Fixed highest_tsp to take in any number of
    players
0707084 2016-12-17T19:53:58-05:00 oracleofnj: Isolating
4479213 2016-12-17T19:47:38-05:00 oracleofnj: much longer
4be857f 2016-12-17T19:41:59-05:00 oracleofnj: seg fault
74358c1 2016-12-17T19:34:18-05:00 Kevin: Interesting program in Extend
ab1e1d2 2016-12-17T16:12:00-05:00 oracleofnj: Add some more stdlib funcs
b53463d 2016-12-17T14:51:24-05:00 GitHub: Merge pull request #125 from ExtendLang/
    stdlib-string
39046bc 2016-12-17T14:39:54-05:00 oracleofnj: Merge branch 'master' into stdlib-string
a01cc84 2016-12-17T14:39:40-05:00 oracleofnj: Use toString in toLiteral
ec7f10d 2016-12-17T14:38:30-05:00 GitHub: Merge pull request #102 from ExtendLang/
    circular-hotfix
73c454b 2016-12-17T14:34:42-05:00 GitHub: Merge branch 'master' into circular-hotfix
8126e2e 2016-12-17T14:24:22-05:00 oracleofnj: native toString
037728d 2016-12-17T13:46:34-05:00 Nigel Schuster: A lot of wrong paths make it work
0a4fd9d 2016-12-17T13:26:34-05:00 Nigel Schuster: Next attempt
56905f8 2016-12-17T13:19:59-05:00 Nigel Schuster: Merge branch 'plotting' of https://
    github.com/ExtendLang/Extend into plotting
fbf3a1e 2016-12-17T13:19:52-05:00 Nigel Schuster: Manual install (maybe?)
1171b71 2016-12-17T13:10:19-05:00 GitHub: Merge branch 'master' into plotting
0dbf85d 2016-12-17T13:07:56-05:00 Nigel Schuster: Added libgd for travis
060ae45 2016-12-17T13:01:35-05:00 oracleofnj: Merge branch 'master' into stdlib-string
4402208 2016-12-17T13:01:24-05:00 oracleofnj: Add round
23c2ae6 2016-12-17T13:00:05-05:00 GitHub: Merge pull request #123 from ExtendLang/size
    -asserts
0ef936b 2016-12-17T12:33:31-05:00 oracleofnj: Fix merge conflicts
4c51203 2016-12-17T11:59:30-05:00 oracleofnj: Right confusion
c05cf61 2016-12-17T11:52:34-05:00 oracleofnj: Fix import dir bug
39edbb4 2016-12-17T11:46:06-05:00 oracleofnj: Merge branch 'master' into size-asserts
339cb1f 2016-12-17T11:45:54-05:00 oracleofnj: Fix merge conflict
7462381 2016-12-17T11:44:50-05:00 GitHub: Merge pull request #122 from ExtendLang/
    split-stdlib
61ac8f2 2016-12-17T11:38:19-05:00 oracleofnj: Size asserts
```

```
606af9f 2016-12-17T11:22:36-05:00 oracleofnj: Transform asserts into more useful form; add calc of assert value to codegen
8743e4c 2016-12-17T11:07:31-05:00 Nigel Schuster: Explicit maxfloat
0f96e70 2016-12-17T11:02:09-05:00 Nigel Schuster: merge master; Keep tc around for testing
1882524 2016-12-17T10:54:10-05:00 Nigel Schuster: Creating archive
ee4f369 2016-12-17T10:40:17-05:00 oracleofnj: Combine asserts into a single expression
0f0f1c8 2016-12-17T10:38:56-05:00 Nigel Schuster: Added right and left to stdlib
4dc1597 2016-12-17T10:35:11-05:00 Nigel Schuster: Made compiling workable
fa43425 2016-12-17T10:30:23-05:00 oracleofnj: Split stdlib
824c53c 2016-12-17T10:11:13-05:00 Nigel Schuster: Added toUpper and toLower
ec24177 2016-12-17T10:02:30-05:00 Nigel Schuster: Implemented to and from ASCII
ab2e8f8 2016-12-17T09:15:39-05:00 GitHub: Merge pull request #116 from ExtendLang/line-plus
5d1610b 2016-12-17T09:08:57-05:00 GitHub: Merge branch 'master' into line-plus
df3a827 2016-12-17T09:08:48-05:00 GitHub: Merge pull request #117 from ExtendLang/cmd-args
32a3487 2016-12-17T09:02:27-05:00 GitHub: Merge branch 'master' into cmd-args
a8f9d33 2016-12-17T09:00:23-05:00 Nigel Schuster: Args
bfccf0c 2016-12-17T08:58:08-05:00 Nigel Schuster: Cut down line count for plus
a6bc89a 2016-12-17T08:48:31-05:00 GitHub: Merge pull request #114 from ExtendLang/only-new-string
5c96b7f 2016-12-17T08:03:27-05:00 GitHub: Merge pull request #109 from ExtendLang/unop-bitnot
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
375bea7 2016-12-16T23:56:35-05:00 oracleofnj: Merge branch 'unop-bitnot' into remove-interpreter
fb1bd77 2016-12-16T23:54:43-05:00 oracleofnj: Clean up; remove interpreter; change DimInt to DimOneByOne
539dd75 2016-12-16T23:46:35-05:00 GitHub: Merge branch 'master' into unop-bitnot
5668e53 2016-12-16T23:43:57-05:00 Nigel Schuster: Using lrint instead of fptosi
45691eb 2016-12-16T23:35:38-05:00 GitHub: Merge pull request #111 from ExtendLang/global-semant
2cdfb8b 2016-12-16T23:33:26-05:00 GitHub: Merge branch 'master' into global-semant
c9500d9 2016-12-16T23:33:14-05:00 GitHub: Merge pull request #112 from ExtendLang/remove-function-signatures
0c24f54 2016-12-16T23:25:23-05:00 oracleofnj: Remove return signature from grammar and all test cases
e7f2864 2016-12-16T23:03:53-05:00 oracleofnj: Merge branch 'cleanup-1' into global-semant
567507e 2016-12-16T22:53:20-05:00 oracleofnj: Check globals; use same symbol_table function for semant and codegen
33e3942 2016-12-16T22:11:13-05:00 GitHub: Merge branch 'master' into plotting
55d8185 2016-12-16T22:00:30-05:00 Nigel Schuster: Removed comments and unneccessary files
629042f 2016-12-16T21:37:07-05:00 GitHub: Merge branch 'master' into unop-bitnot
48b139a 2016-12-16T21:34:09-05:00 Nigel Schuster: Implemented unary bitnot
39b02cd 2016-12-16T21:27:22-05:00 oracleofnj: Merge branch 'master' into global-semant
28c0983 2016-12-16T21:27:05-05:00 oracleofnj: Remove leftover printf
dc182df 2016-12-16T21:09:00-05:00 GitHub: Merge pull request #105 from ExtendLang/rg-eq
8cdf5c4 2016-12-16T19:31:26-05:00 oracleofnj: Expand test cases for range equality
41a3ccc 2016-12-16T19:18:44-05:00 GitHub: Merge branch 'master' into rg-eq
8dbebc1 2016-12-16T19:18:15-05:00 GitHub: Merge pull request #104 from ExtendLang/prevent-overlapping-formulas
```

```
c1431b5 2016-12-16T18:55:07-05:00 Nigel Schuster: Implemented basic subrange comparison
546536e 2016-12-16T18:47:12-05:00 oracleofnj: Detect overlapping formulas and give runtime error if present
3562e1b 2016-12-16T18:45:12-05:00 oracleofnj: Merge branch 'sr-val-fix' into prevent-overlapping-formulas
8713fa0 2016-12-16T18:42:40-05:00 oracleofnj: Checking
77d80b9 2016-12-16T18:26:31-05:00 Nigel Schuster: Fixed check for subrange
69fb0d2 2016-12-16T17:46:48-05:00 oracleofnj: Circular hotfix
4a3ec8d 2016-12-16T17:21:18-05:00 oracleofnj: Add concat
962c744 2016-12-16T12:09:00-05:00 GitHub: Merge pull request #101 from ExtendLang/finishing-these-range-literals
f234e00 2016-12-16T00:21:06-05:00 oracleofnj: Merge branch 'more-stdlib-functions' into finishing-these-range-literals
c9246ce 2016-12-16T00:20:59-05:00 oracleofnj: testing testing
6914039 2016-12-16T00:14:09-05:00 oracleofnj: Third time's the charm
4617e44 2016-12-16T00:01:12-05:00 oracleofnj: It compiles now
1d8e290 2016-12-15T23:42:43-05:00 oracleofnj: Fingers crossed
c9d28d3 2016-12-15T21:50:01-05:00 oracleofnj: Move all initializations into their own function; only box strings once
1cfdd16 2016-12-15T18:47:30-05:00 oracleofnj: Merge branch 'master' into more-stdlib-functions
19c2beb 2016-12-15T18:40:12-05:00 oracleofnj: Try a couple more things out
845cb04 2016-12-15T18:33:07-05:00 GitHub: Merge pull request #96 from ExtendLang/ternary-fix
4bfb3bc 2016-12-15T18:23:00-05:00 oracleofnj: Merge branch 'ternary-fix' into more-stdlib-functions
ae55ca4 2016-12-15T18:21:58-05:00 oracleofnj: Define cell_row, cell_col
30a5db6 2016-12-15T18:19:56-05:00 oracleofnj: Merge branch 'ternary-fix' into more-stdlib-functions
b9f1f10 2016-12-15T18:17:53-05:00 oracleofnj: What is truth?
ac84c2f 2016-12-15T18:15:37-05:00 oracleofnj: Fix ternary to work properly with ranges
1f57d91 2016-12-15T17:03:26-05:00 oracleofnj: Look at this one
437ba46 2016-12-15T16:56:04-05:00 oracleofnj: Try this one
f0edf5b 2016-12-15T16:46:52-05:00 oracleofnj: Fixing bug
5ba31e6 2016-12-15T14:17:52-05:00 GitHub: Merge pull request #94 from ExtendLang/nan-inf
67c5739 2016-12-15T14:17:46-05:00 GitHub: Merge pull request #93 from ExtendLang/type-typeof
48a3d5c 2016-12-15T14:05:37-05:00 oracleofnj: Improve test case
8f08227 2016-12-15T13:58:46-05:00 oracleofnj: Add isNaN and isInfinite to stdlib
cbeec74 2016-12-15T13:30:31-05:00 oracleofnj: Rename token
9582228 2016-12-15T13:18:09-05:00 oracleofnj: Rename type to typeof
d1422c7 2016-12-15T10:42:19-05:00 GitHub: Merge pull request #92 from ExtendLang/compiler
66689bb 2016-12-15T09:08:56-05:00 Nigel Schuster: added working directory option, doing testing completely in tmp
a13ae93 2016-12-15T09:08:31-05:00 GitHub: Merge pull request #91 from ExtendLang/sizeof
a31add9 2016-12-15T09:08:13-05:00 GitHub: Merge pull request #90 from ExtendLang/subselect-C-side
2e67e06 2016-12-15T09:01:06-05:00 Nigel Schuster: Added option to specify compiler, using clang
c171450 2016-12-15T02:33:48-05:00 oracleofnj: SizeOf
c168044 2016-12-15T00:48:35-05:00 oracleofnj: Add row(), column() to codegen, add print_endline() to stdlib.xtnd
```

```
bf9426d 2016-12-15T00:27:13-05:00 oracleofnj: Print subrange
407ce41 2016-12-14T23:02:02-05:00 oracleofnj: Merge in subrange_string
756ea8e 2016-12-14T22:51:00-05:00 oracleofnj: Ranges
27a8e79 2016-12-14T22:16:13-05:00 oracleofnj: Resolve RHS slice
876d056 2016-12-14T22:02:56-05:00 oracleofnj: Resolve RHS index
b59e022 2016-12-14T21:46:00-05:00 Nigel Schuster: Added method to print subragne as
    string
a7d53a8 2016-12-14T19:55:38-05:00 oracleofnj: Merge branch 'master' into subselect-C-
    side
362e85b 2016-12-14T19:55:23-05:00 GitHub: Merge pull request #88 from ExtendLang/
    subselect
4912fa3 2016-12-14T19:40:10-05:00 oracleofnj: Add debug print info for slice
    structures
c1b33f4 2016-12-14T18:58:45-05:00 oracleofnj: Builder to end all builders
5d400c2 2016-12-14T18:55:06-05:00 oracleofnj: Add selection builders
29f6e28 2016-12-14T18:20:51-05:00 oracleofnj: Make additional infix operator for
    populating structure element
046d096 2016-12-14T17:49:19-05:00 oracleofnj: Set up RHS slice types
0d20933 2016-12-14T17:28:38-05:00 GitHub: Merge branch 'master' into plotting
614d84f 2016-12-14T17:25:20-05:00 Nigel Schuster: Dummy commit for travis
0e78574 2016-12-14T17:24:04-05:00 Nigel Schuster: Merge branch 'plotting' of https://
    github.com/ExtendLang/Extend into plotting
2da0d7d 2016-12-14T17:23:56-05:00 Nigel Schuster: Spelling fix
b25c2f5 2016-12-14T16:49:17-05:00 GitHub: Merge pull request #87 from ExtendLang/make-
    a-selection
7a12082 2016-12-14T16:43:38-05:00 oracleofnj: Move selection test cases back into
    inputs
e2c08d5 2016-12-14T16:31:00-05:00 oracleofnj: Make IDs work with deref_subrange
02f2f0c 2016-12-14T15:21:31-05:00 GitHub: Merge pull request #86 from ExtendLang/
    include-stdlib
8b0503f 2016-12-14T15:18:14-05:00 GitHub: Merge branch 'master' into include-stdlib
1f034a0 2016-12-14T15:17:52-05:00 GitHub: Merge pull request #84 from ExtendLang/math-
    linker
1e6dd91 2016-12-14T14:58:44-05:00 oracleofnj: Add expected output for slurp
ff1a5e3 2016-12-14T14:53:38-05:00 oracleofnj: Remove extend_ prefix from all sample
    code
81a2828 2016-12-14T14:48:38-05:00 oracleofnj: Automatically add extend_ prefix to
    external functions
dcc1ed3 2016-12-14T14:30:52-05:00 oracleofnj: Fix samples
9b2c28f 2016-12-14T12:39:45-05:00 oracleofnj: Include stdlib automatically
13650ce 2016-12-14T12:35:21-05:00 Nigel Schuster: Merge branch 'math-linker' of https
    ://github.com/ExtendLang/Extend into math-linker
2e0d90d 2016-12-14T12:35:06-05:00 Nigel Schuster: Merge branch 'math-linker' of https
    ://github.com/ExtendLang/Extend into math-linker
83c689e 2016-12-14T12:34:14-05:00 Nigel Schuster: Merge branch 'math-linker' of https
    ://github.com/ExtendLang/Extend into math-linker
127f600 2016-12-14T12:34:07-05:00 Nigel Schuster: Include sys/resources
b34d97a 2016-12-14T12:03:44-05:00 GitHub: Merge branch 'master' into math-linker
8297f33 2016-12-14T12:01:47-05:00 GitHub: Merge pull request #85 from ExtendLang/put-
    lt-back
6b0c74f 2016-12-14T11:33:45-05:00 Nigel Schuster: Include sys/resources
37470e9 2016-12-14T11:14:06-05:00 oracleofnj: Put back LT, comment out sys/time.h
6bde590 2016-12-14T11:12:16-05:00 Nigel Schuster: Increasing stack size
6acc621 2016-12-14T11:03:31-05:00 Nigel Schuster: Disabled linking math when creating
    an intermediate
d87b73c 2016-12-14T10:51:58-05:00 GitHub: Merge pull request #82 from ExtendLang/hard-
```

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    to-repro-bug
d126e3c 2016-12-14T00:51:00-05:00 oracleofnj: Try with time.h instead of sys/time.h
a535612 2016-12-14T00:48:35-05:00 oracleofnj: Remove lrints
e844853 2016-12-14T00:34:37-05:00 oracleofnj: Initialize all variables and remove
    pointer math; bug appears fixed
4c1a421 2016-12-13T22:55:07-05:00 oracleofnj: Some formula is weird
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
879eaf3 2016-12-13T22:43:17-05:00 oracleofnj: Testing
37f5ce2 2016-12-13T22:42:40-05:00 GitHub: Merge pull request #83 from ExtendLang/
    rounding-for-read
a1cfc5a 2016-12-13T22:34:21-05:00 Nigel Schuster: Added rounding at several places
e20f7e4 2016-12-13T21:36:13-05:00 oracleofnj: Half the time it works
9f97b1a 2016-12-13T20:38:08-05:00 GitHub: Merge branch 'master' into plotting
61bc9b6 2016-12-13T20:33:27-05:00 GitHub: Merge pull request #81 from ExtendLang/fix-
    em-all
4a810df 2016-12-13T19:34:29-05:00 Nigel Schuster: Corrected testcase outputs
ae5b8a8 2016-12-13T19:08:43-05:00 GitHub: Merge pull request #80 from ExtendLang/
    select
70b2704 2016-12-13T19:02:32-05:00 oracleofnj: No C99
15fd762 2016-12-13T18:42:21-05:00 oracleofnj: Merge branch 'master' into select
8e6e9ba 2016-12-13T18:42:05-05:00 GitHub: Merge pull request #78 from ExtendLang/unop-
    unary-minus
7a93885 2016-12-13T18:41:49-05:00 oracleofnj: Calculate all formula indices
07e63dc 2016-12-13T18:19:58-05:00 oracleofnj: Properly build instantiate var
1a29129 2016-12-13T17:24:16-05:00 oracleofnj: Replace bools with chars for
    compatibility between C and LLVM
12e78a3 2016-12-13T17:17:54-05:00 oracleofnj: Added debug output
a483282 2016-12-13T16:13:30-05:00 oracleofnj: Merge branch 'master' into unop-unary-
    minus
f8c9b43 2016-12-13T16:13:09-05:00 oracleofnj: Make TypeOf work
8146d04 2016-12-13T16:12:17-05:00 GitHub: Merge pull request #75 from ExtendLang/fix-
    more-tc
94afc93 2016-12-13T16:02:35-05:00 Nigel Schuster: Corrected expected TC
f6f8276 2016-12-13T16:00:59-05:00 Nigel Schuster: Fixed string.xtnd file
dcd5766 2016-12-13T15:44:38-05:00 GitHub: Merge pull request #74 from ExtendLang/fix-
    tc
bfe1c07 2016-12-13T15:39:45-05:00 oracleofnj: Merge branch 'master' into unop-unary-
    minus
d9abfc0 2016-12-13T15:38:38-05:00 GitHub: Merge branch 'master' into fix-tc
50ed49c 2016-12-13T15:38:04-05:00 oracleofnj: Merging in main
23328f1 2016-12-13T15:37:18-05:00 GitHub: Merge pull request #73 from ExtendLang/and-
    or-xor
324779a 2016-12-13T15:32:26-05:00 Nigel Schuster: Corrected expected value
fafe2e6 2016-12-13T15:29:21-05:00 Nigel Schuster: Fixed string tc
022f05c 2016-12-13T15:23:59-05:00 Nigel Schuster: Fixed testcase
b12fe37 2016-12-13T15:18:57-05:00 Nigel Schuster: Implemented and, or and xor
90cbaa0 2016-12-13T15:16:31-05:00 Nigel Schuster: Added left and right shift
571ee7e 2016-12-13T14:56:05-05:00 Nigel Schuster: Merge branch 'power' of https://
    github.com/ExtendLang/Extend into power
aeab40d 2016-12-13T14:55:57-05:00 Nigel Schuster: Removed unneccessary level of
    indirection
e377567 2016-12-13T14:53:28-05:00 GitHub: Merge branch 'master' into power
6ad8512 2016-12-13T14:53:11-05:00 GitHub: Merge pull request #69 from ExtendLang/unop-
    unary-minus
71f395d 2016-12-13T14:46:27-05:00 Nigel Schuster: Power to the people of Extend
```

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6a04209 2016-12-13T14:45:46-05:00 oracleofnj: Fix merge conflict
edb0ecc 2016-12-13T14:43:32-05:00 oracleofnj: Add unary minus
668a0eb 2016-12-13T14:37:19-05:00 GitHub: Merge pull request #68 from ExtendLang/mod-
    div
866b68f 2016-12-13T14:32:18-05:00 Nigel Schuster: Added modulo and division operation
46d5aa6 2016-12-13T14:26:35-05:00 oracleofnj: Merge branch 'master' into unop-typeof
84dfc33 2016-12-13T14:26:25-05:00 Nigel Schuster: Crunched some code
76210eb 2016-12-13T14:26:18-05:00 oracleofnj: Start on it
f4d5a81 2016-12-13T14:22:12-05:00 Nigel Schuster: Merge branch 'master' into
    simplification
f873242 2016-12-13T14:21:26-05:00 GitHub: Merge pull request #65 from ExtendLang/
    subtraction
fc94112 2016-12-13T14:20:35-05:00 Nigel Schuster: Added multiplication
6c26c2c 2016-12-13T14:19:07-05:00 GitHub: Merge branch 'master' into subtraction
4afd78e 2016-12-13T14:18:55-05:00 GitHub: Merge pull request #64 from ExtendLang/
    refactor-boolean-binops
d4d4388 2016-12-13T14:15:58-05:00 GitHub: Merge branch 'master' into refactor-boolean-
    binops
bd90241 2016-12-13T14:14:17-05:00 GitHub: Merge branch 'master' into subtraction
4042259 2016-12-13T14:13:09-05:00 Nigel Schuster: Added subtraction
663f399 2016-12-13T14:12:57-05:00 oracleofnj: Remove wildcard from BinOp pattern match
82a3db2 2016-12-13T14:11:31-05:00 Nigel Schuster: Merge branch 'master' into
    subtraction
1bf6bed 2016-12-13T14:09:47-05:00 oracleofnj: Add TransformedAway exception for LogAnd
     and LogOr
c7d4162 2016-12-13T14:02:13-05:00 GitHub: Merge pull request #63 from ExtendLang/more-
    binops
952778e 2016-12-13T14:01:54-05:00 oracleofnj: Change Lt, Lte in grammar; implement GTE
97821c8 2016-12-13T13:47:52-05:00 oracleofnj: GT
1e1f973 2016-12-13T13:44:36-05:00 Nigel Schuster: Subtraction
e0a883a 2016-12-13T13:37:57-05:00 oracleofnj: Remove NotEq from AST since != is parsed
     to UnOp(LogNot,BinOp(Eq,...))
cc40008 2016-12-13T12:49:33-05:00 GitHub: Merge pull request #60 from ExtendLang/
    addition2
7123ebc 2016-12-13T12:41:09-05:00 GitHub: Merge branch 'master' into addition2
a656f57 2016-12-13T12:38:12-05:00 GitHub: Merge pull request #61 from ExtendLang/debug
    -unop
c3a96a9 2016-12-13T12:37:31-05:00 Nigel Schuster: Merge branch 'master' into plotting
f59d962 2016-12-13T12:34:49-05:00 Nigel Schuster: Moved make of lib to travis script
eb134b3 2016-12-13T12:29:53-05:00 Nigel Schuster: Moved testcases
044c6bd 2016-12-13T12:29:07-05:00 Nigel Schuster: Fixed off by one error
a64cc15 2016-12-13T12:14:45-05:00 oracleofnj: Add Debug expr
59858a0 2016-12-13T11:33:12-05:00 oracleofnj: Whoops no space
0426f34 2016-12-13T11:30:26-05:00 oracleofnj: Add test case
49ffa86 2016-12-13T11:19:14-05:00 GitHub: Merge branch 'master' into addition2
81533f4 2016-12-13T11:13:44-05:00 GitHub: Merge pull request #59 from ExtendLang/equal
    -rights
3cdaa5a 2016-12-13T11:12:41-05:00 Nigel Schuster: String addition
64d1760 2016-12-13T11:04:55-05:00 oracleofnj: Wake up please, GitHub
840aeaf 2016-12-13T10:48:03-05:00 oracleofnj: Remove usage demonstration
61ff439 2016-12-13T03:26:35-05:00 oracleofnj: Add string equality and test cases
f3112e9 2016-12-13T01:57:10-05:00 oracleofnj: Reduce cut & paste
08ce677 2016-12-13T01:35:46-05:00 oracleofnj: Remove obsolete testing file
ae8a07e 2016-12-13T01:23:26-05:00 oracleofnj: Merge branch 'print_value_p' into equal-
    rights
6090713 2016-12-13T01:22:47-05:00 oracleofnj: Use correct printf specifier
```

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862b38c 2016-12-13T01:19:14-05:00 oracleofnj: Merge branch 'print_value_p' into equal-rights
5e913ad 2016-12-13T01:16:07-05:00 oracleofnj: Add debug_print; remove print statement that was causing us to falsely pass test cases from to_string; show usage in UnOp(Neg)
50281b1 2016-12-13T00:47:28-05:00 oracleofnj: Numeric equality
0f76aa4 2016-12-12T22:30:15-05:00 oracleofnj: Remove print flags
200b8b6 2016-12-12T22:16:15-05:00 GitHub: Merge pull request #57 from ExtendLang/addition2
da7c543 2016-12-12T12:43:31-05:00 Nigel Schuster: Setting flag for addition
7e7276b 2016-12-12T12:37:35-05:00 Nigel Schuster: Merge branch 'master' into addition2
8834635 2016-12-12T10:18:51-05:00 GitHub: Merge pull request #55 from ExtendLang/runtime
53ae9e0 2016-12-12T10:06:24-05:00 GitHub: Merge branch 'master' into runtime
6ed303e 2016-12-12T09:43:57-05:00 GitHub: Merge pull request #56 from ExtendLang/truthy-fix
ae49ce6 2016-12-12T01:15:29-05:00 oracleofnj: Remove extra file
7fe6a22 2016-12-12T01:11:53-05:00 oracleofnj: Falsey fix
d1e196d 2016-12-12T00:23:13-05:00 Nigel Schuster: Extracted runtime into seperate file
ecc620e 2016-12-12T00:17:06-05:00 GitHub: Merge pull request #54 from ExtendLang/final-draft-for-real
4c8caa5 2016-12-12T00:09:16-05:00 GitHub: Merge branch 'master' into final-draft-for-real
04d3b57 2016-12-12T00:00:29-05:00 GitHub: Merge pull request #39 from ExtendLang/more-lrm-ed
39025b0 2016-12-11T23:59:18-05:00 Nigel Schuster: Fixed examples, made small corrections
a875b41 2016-12-11T23:51:30-05:00 GitHub: Merge pull request #53 from ExtendLang/truthy
616dd34 2016-12-11T23:15:54-05:00 oracleofnj: Merge branch 'master' into truthy
0fa8255 2016-12-11T23:14:42-05:00 oracleofnj: Apparently still needs some work
78584d7 2016-12-11T23:09:07-05:00 oracleofnj: Thanks a lot Travis
b5673d2 2016-12-11T22:51:52-05:00 oracleofnj: TERRRRRRRRR NARRRRRRR EEEEEEEEEEEEEEEEEEE
b81bc1b 2016-12-11T22:04:25-05:00 oracleofnj: Maybe Truthy
b95d14f 2016-12-11T21:02:28-05:00 GitHub: Merge pull request #50 from ExtendLang/builder-hotfix
6dea96f 2016-12-11T20:40:47-05:00 oracleofnj: So many builders
8aa125f 2016-12-11T20:15:52-05:00 Nigel Schuster: Made som rpgroess
2a905c7 2016-12-11T19:15:47-05:00 GitHub: Merge pull request #47 from ExtendLang/function-parameter
2bc6c85 2016-12-11T19:11:33-05:00 oracleofnj: Add combined test case
860a11b 2016-12-11T19:04:35-05:00 oracleofnj: Merge branch 'master' into function-parameter
8c3499e 2016-12-11T19:03:39-05:00 oracleofnj: Remove extraneous printlines
99418c0 2016-12-11T19:02:31-05:00 oracleofnj: Make function parameters work
6c00a72 2016-12-11T18:45:46-05:00 Nigel Schuster: Some progress
387559b 2016-12-11T18:39:00-05:00 oracleofnj: First attempt
18fc1be 2016-12-11T18:08:11-05:00 GitHub: Merge pull request #45 from ExtendLang/empty
d7590da 2016-12-11T17:42:46-05:00 GitHub: Merge branch 'master' into plotting
f7e9be8 2016-12-11T16:30:05-05:00 GitHub: Merge branch 'master' into empty
f1dd8a5 2016-12-11T16:18:44-05:00 GitHub: Merge pull request #46 from ExtendLang/actually-make-global-scope
50366f4 2016-12-11T15:38:05-05:00 oracleofnj: Make sure locals are properly masking globals
046c7cc 2016-12-11T15:30:53-05:00 oracleofnj: Make globals work, fix bug
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a844a46 2016-12-11T15:14:09-05:00 oracleofnj: So close
18db166 2016-12-11T15:05:42-05:00 GitHub: Merge branch 'master' into empty
67849f0 2016-12-11T15:01:52-05:00 oracleofnj: Make the global scope object
393d02c 2016-12-11T14:25:02-05:00 Nigel Schuster: Implemented empty, small flag setting fix
3c4681d 2016-12-11T13:31:12-05:00 GitHub: Merge pull request #44 from ExtendLang/float-display-hotfix
7be1001 2016-12-11T13:26:55-05:00 GitHub: Merge branch 'master' into float-display-hotfix
b192a23 2016-12-11T13:26:48-05:00 Nigel Schuster: Added gdchart compile step
abcffd0 2016-12-11T13:19:05-05:00 GitHub: Merge pull request #42 from ExtendLang/encapsulate-build-scope
556da44 2016-12-11T13:18:15-05:00 oracleofnj: Floating point math hotfix
0ad195e 2016-12-11T12:42:42-05:00 oracleofnj: Merge branch 'master' into encapsulate-build-scope
9caf464 2016-12-11T12:41:40-05:00 oracleofnj: Encapsulate a little more of building the scope
1ae8d43 2016-12-11T12:23:04-05:00 Ishaan: Add new gitignore
6278c7b 2016-12-11T12:18:49-05:00 Ishaan: Rebase and add gdchart in lib/
5594687 2016-12-11T12:13:20-05:00 Ishaan: Remove images from version control
294a6db 2016-12-11T12:13:20-05:00 Ishaan: Write to file instead of stdout
08e9f75 2016-12-11T12:11:13-05:00 Ishaan: Add harcoded graph functionality
d65aad4 2016-12-11T12:09:28-05:00 GitHub: Merge pull request #40 from ExtendLang/make-global-scope
b5b33f1 2016-12-11T12:09:12-05:00 Ishaan: Update gitignore to avoid the gdchart package
6746e8a 2016-12-11T12:09:12-05:00 Ishaan: Checking gif
83c2e09 2016-12-11T12:09:12-05:00 Ishaan: Add hardcoded plot function without params or installation
0f5a6ba 2016-12-11T12:04:05-05:00 oracleofnj: Merge branch 'master' into make-global-scope
56b58d9 2016-12-11T12:01:28-05:00 oracleofnj: Encapsulate build_var_defns
f25e5b3 2016-12-11T11:43:19-05:00 oracleofnj: Only construct var_defns once
9cee2fc 2016-12-11T10:07:36-05:00 Nigel Schuster: Testcases (#38)
f3f4bef 2016-12-11T00:45:44-05:00 oracleofnj: Make global variable to hold vardefns
a0ed757 2016-12-10T23:31:38-05:00 Nigel Schuster: Edited explanation for row() and column()
7c50ef2 2016-12-10T23:27:07-05:00 Nigel Schuster: Added info for strings
738e41b 2016-12-10T23:24:20-05:00 Nigel Schuster: Added boolean example
5377fdf 2016-12-10T23:19:26-05:00 Nigel Schuster: Added arithmetic example
a8f4ad9 2016-12-10T21:28:18-05:00 oracleofnj: Isolate the part of building a scope for reuse with global variables
58f7a4d 2016-12-10T18:05:01-05:00 Nigel Schuster: Performing copy before returning, so that memory can be freed with alloca
c0e56aa 2016-12-10T17:07:00-05:00 GitHub: Merge pull request #37 from ExtendLang/dereference
a4b35df 2016-12-10T16:42:17-05:00 Nigel Schuster: Removed obsolete methods
cf08a8c 2016-12-10T16:36:20-05:00 GitHub: Merge branch 'master' into dereference
ef0e5e7 2016-12-10T16:36:03-05:00 GitHub: Merge pull request #36 from ExtendLang/comp-warn
0177dc2 2016-12-10T16:35:50-05:00 GitHub: Merge pull request #35 from ExtendLang/linker
127f99d 2016-12-10T16:35:41-05:00 GitHub: Merge pull request #34 from ExtendLang/rel-import
b2e881d 2016-12-10T16:35:31-05:00 GitHub: Merge pull request #33 from ExtendLang/ts-fix
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ce833d4 2016-12-10T16:14:34-05:00 Nigel Schuster: Dereferencing 1x1 subrange
e259556 2016-12-10T13:53:12-05:00 Nigel Schuster: Removed nodefaultlibs directive
09c3961 2016-12-10T13:50:19-05:00 Nigel Schuster: Modified linker to work for travis
36d662a 2016-12-10T13:37:27-05:00 Nigel Schuster: Attempt to link math
2d4564a 2016-12-10T13:22:14-05:00 Nigel Schuster: Linking math library
38ba6e6 2016-12-10T13:18:39-05:00 Nigel Schuster: Suppressing compiler warnings
9deac9b 2016-12-10T13:06:39-05:00 Nigel Schuster: Modified compile script. Removed
    debug output
d35607b 2016-12-10T13:04:30-05:00 Nigel Schuster: Simpler testscript
d37dac2 2016-12-10T12:36:45-05:00 Nigel Schuster: Fixed duplicate import issue
31c26bc 2016-12-10T12:30:29-05:00 Nigel Schuster: Added cmd args to link file
a350720 2016-12-10T11:40:50-05:00 Nigel Schuster: Switched import style from root
    directory to relative path
90e39b0 2016-12-10T11:24:19-05:00 Nigel Schuster: Fixed issue in testscript that might
     report false results when it fails early
718ecd3 2016-12-10T03:09:18-05:00 oracleofnj: Some changes to LRM; add if(a,b,c)
6a8f836 2016-12-09T18:29:22-05:00 GitHub: Merge pull request #24 from ExtendLang/final
    -draft-lrm
fc886a9 2016-12-09T18:23:52-05:00 oracleofnj: Merge branch 'final-draft-lrm'
cda63cb 2016-12-09T18:23:24-05:00 oracleofnj: Fix merge conflict
eac9e77 2016-12-09T18:04:08-05:00 GitHub: Merge pull request #29 from ExtendLang/
    refactor
fe825f4 2016-12-09T17:55:39-05:00 oracleofnj: Compact last bit
b02dbbe 2016-12-09T17:49:00-05:00 oracleofnj: Give formula functions names
edd7aa4 2016-12-09T17:40:57-05:00 Nigel Schuster: Removed artifcats
9b49e20 2016-12-09T17:37:59-05:00 Nigel Schuster: Fixed I/O testcases
a4ad4b1 2016-12-09T17:18:13-05:00 Nigel Schuster: Merge
b07398b 2016-12-09T17:17:19-05:00 Nigel Schuster: Added macro for function definition
ed01567 2016-12-09T17:17:06-05:00 oracleofnj: Make sizeof not break tests
a0a7054 2016-12-09T17:01:20-05:00 oracleofnj: Use symbol table
56fd61b 2016-12-09T16:11:10-05:00 oracleofnj: Merge branch 'refactor' of https://
    github.com/ExtendLang/Extend into refactor
38aedba 2016-12-09T16:10:35-05:00 oracleofnj: Create symbol table
dfb702e 2016-12-09T16:01:08-05:00 Nigel Schuster: Converted more to value_p from
    subrange_p
e963186 2016-12-09T15:42:35-05:00 Nigel Schuster: Made example TC work
eb76234 2016-12-09T11:14:58-05:00 Nigel Schuster: Made Hello World work again
08aeb70 2016-12-09T02:13:09-05:00 oracleofnj: Done for the night
cb39114 2016-12-09T01:35:36-05:00 oracleofnj: More refactoring
7974bbd 2016-12-08T23:53:31-05:00 oracleofnj: Banish the term extern
49af972 2016-12-08T23:45:30-05:00 oracleofnj: Add a couple comments
0fbf461 2016-12-08T21:52:24-05:00 oracleofnj: Get my bearings
5ecb599 2016-12-08T19:47:51-05:00 Nigel Schuster: Added some documentation
65066fc 2016-12-08T12:18:57-05:00 Nigel Schuster: Added name display for variable
fb18949 2016-12-07T23:44:17-05:00 oracleofnj: Merge branch 'master' into final-draft-
    lrm
4aab3dc 2016-12-07T23:43:25-05:00 oracleofnj: Update PDF
ed44d27 2016-12-07T23:43:01-05:00 oracleofnj: Fix failing test cases
9354fa7 2016-12-07T23:06:36-05:00 oracleofnj: Final draft candidate
78649f4 2016-12-07T18:09:46-05:00 oracleofnj: Almost done
05ded19 2016-12-07T15:47:52-05:00 oracleofnj: More work
f985cc8 2016-12-07T12:14:59-05:00 Nigel Schuster: Merge branch 'finish-transformations
    ' into get-val-rev
4b58ce9 2016-12-07T12:13:23-05:00 Nigel Schuster: Tried to add more instructions
0722412 2016-12-07T11:32:11-05:00 oracleofnj: Working
099efe7 2016-12-07T10:48:35-05:00 Nigel Schuster: Making progress on evaluating
```

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    dimensions
404 fa09df7 2016-12-07T09:51:23-05:00 Nigel Schuster: Finally it works
405 cbb0577 2016-12-07T02:35:06-05:00 oracleofnj: Still WIP
406 e3c9436 2016-12-07T00:44:22-05:00 oracleofnj: WIP
407 b265e74 2016-12-07T00:41:23-05:00 Nigel Schuster: test commit to look at
408 18bb182 2016-12-07T00:35:06-05:00 oracleofnj: Still work in progress
409 a4554c0 2016-12-06T23:14:32-05:00 Nigel Schuster: At least it compiles
410 3432484 2016-12-06T22:42:22-05:00 Nigel Schuster: Getting closer. Need to add var_defn
     wrapper in build_formula
411 05145ca 2016-12-06T21:10:11-05:00 Nigel Schuster: Minor fix
412 af69b92 2016-12-06T17:23:45-05:00 oracleofnj: More updates
413 a65c24e 2016-12-06T16:14:10-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
414 85a4ccb 2016-12-06T16:12:31-05:00 oracleofnj: LRM update part 1
415 174a7b8 2016-12-06T11:09:31-05:00 Nigel Schuster: Made partial progress on
    implementing variable instanciation and such
416 90fc58e 2016-12-05T22:14:41-05:00 GitHub: Merge pull request #23 from ExtendLang/read-
    empty
417 767851d 2016-12-05T16:18:17-05:00 Nigel Schuster: Finished C side implementation of
    getVal
418 6b837d4 2016-12-05T16:06:34-05:00 Nigel Schuster: Merge branch 'master' into get-val
419 04c2c65 2016-12-05T15:53:35-05:00 oracleofnj: Add slurp by passing 0 max bytes
420 d8cf316 2016-12-05T14:46:46-05:00 oracleofnj: Start handling empty
421 910bd01 2016-12-05T14:27:07-05:00 GitHub: Merge pull request #21 from ExtendLang/
    fileio
422 1ce7f83 2016-12-05T14:18:41-05:00 oracleofnj: Create patch file
423 88480fb 2016-12-05T13:36:28-05:00 GitHub: Merge branch 'master' into fileio
424 29d02d9 2016-12-05T13:34:27-05:00 oracleofnj: Fix merge conflict - keep expr_loc
425 52e7a8a 2016-12-05T13:32:54-05:00 GitHub: Merge pull request #22 from ExtendLang/rm-
    micro
426 bfa906b 2016-12-05T13:28:03-05:00 oracleofnj: Fix off-by-one bug
427 eb8dd71 2016-12-05T13:20:03-05:00 oracleofnj: Address issues
428 f1b11ee 2016-12-05T12:46:35-05:00 Nigel Schuster: Skeleton for get_val
429 e4e5e26 2016-12-05T09:25:17-05:00 Nigel Schuster: Removed microc reference
    implementation
430 270da2b 2016-12-05T02:40:59-05:00 GitHub: Merge branch 'master' into fileio
431 b928e98 2016-12-05T02:40:10-05:00 Ishaan: Remove bloat
432 894b511 2016-12-05T02:32:49-05:00 Ishaan: Added testcase
433 62b8e83 2016-12-05T02:30:16-05:00 Ishaan: Added fwrite implementation
434 77a23ae 2016-12-05T01:39:30-05:00 Ishaan: Added read
435 46e9b58 2016-12-05T00:07:16-05:00 Ishaan: Make refactoring changes and new helpers
436 a5b9066 2016-12-04T14:00:30-05:00 GitHub: Merge pull request #20 from ExtendLang/lhs-
    all-ids
437 35e9471 2016-12-04T13:38:44-05:00 oracleofnj: Put back Id(s) as it was
438 641d454 2016-12-04T13:36:36-05:00 oracleofnj: Always transform to ID on LHS, even for
    LitInts
439 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
440 f47f2ba 2016-12-04T10:30:44-05:00 oracleofnj: Add error handling to close() and add a
    couple test cases
441 e95a95a 2016-12-04T10:07:01-05:00 oracleofnj: Add assertSingleNumber and get_number to
     eliminate more copy & paste
442 543e720 2016-12-04T09:47:03-05:00 oracleofnj: Add new_number() to eliminate some copy
    and paste
443 d7f10c9 2016-12-04T02:31:03-05:00 Ishaan: Tentative drafts of fileio functions
444 7d81e43 2016-12-04T00:15:20-05:00 oracleofnj: add diagnostic prinfs
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868d9a4 2016-12-03T23:46:01-05:00 Ishaan: Cleanup
aa1e014 2016-12-03T23:42:46-05:00 Ishaan: Add file pointer array
88d05de 2016-12-03T18:38:34-05:00 Ishaan: Working on fopen
36f5848 2016-12-03T14:07:39-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
2ae2b83 2016-12-03T14:06:40-05:00 GitHub: Merge pull request #15 from ExtendLang/
    stdlib-fun
7c78a23 2016-12-03T14:02:51-05:00 oracleofnj: Move test_fabs out of regression test
    suite
0a8055b 2016-12-03T13:48:19-05:00 oracleofnj: make test | grep REGRESSION
a24742b 2016-12-02T22:50:43-05:00 Kevin: Merged stdlib with master
5243c5a 2016-12-02T18:16:36-05:00 Kevin: Removed magic numbers and add fabs test
330bec3 2016-12-02T13:49:34-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
8a60995 2016-12-01T23:38:54-05:00 GitHub: Merge pull request #18 from ExtendLang/
    parser-error
f0d33e2 2016-12-01T23:18:39-05:00 oracleofnj: Move error handling
3b24c3a 2016-12-01T23:16:53-05:00 oracleofnj: Adjust test script
60a732f 2016-12-01T22:55:28-05:00 oracleofnj: Merge branch 'master' into parser-error
5dec6a2 2016-12-01T22:55:05-05:00 oracleofnj: Thank you Nigel!!!
96a3028 2016-12-01T22:19:21-05:00 GitHub: Merge pull request #16 from ExtendLang/fail-
    silent
6c3696c 2016-12-01T21:59:40-05:00 oracleofnj: Figure out why test is failing
7912d5a 2016-12-01T21:26:03-05:00 GitHub: Merge branch 'master' into fail-silent
9702e5b 2016-12-01T21:14:35-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
5bdd52c 2016-12-01T21:13:45-05:00 GitHub: Merge pull request #17 from ExtendLang/
    lexbuf-pos
8893255 2016-12-01T20:35:04-05:00 oracleofnj: Add a couple test cases
2868653 2016-12-01T20:23:01-05:00 oracleofnj: Use lexbuf.lex_curr_p to calculate
    position
8c7b6ce 2016-12-01T18:59:49-05:00 GitHub: Merge pull request #11 from ExtendLang/
    parse_error
2885ac7 2016-12-01T18:56:15-05:00 Ishaan: Added test case for string
047cfec 2016-12-01T18:42:04-05:00 oracleofnj: Add short circuiting test cases
6acd7f6 2016-12-01T18:31:33-05:00 oracleofnj: Merge remote-tracking branch 'origin/
    fail-silent' into finish-transformations
72360f4 2016-12-01T17:09:08-05:00 Nigel Schuster: Minified error output for outputs
    that have not passed yet
5762112 2016-12-01T16:04:06-05:00 oracleofnj: Get rid of wildcard pattern match in
    interpreter
a90a343 2016-12-01T15:59:40-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
85bc21d 2016-12-01T15:59:05-05:00 oracleofnj: Remove unnecessary file
81fe565 2016-12-01T15:58:40-05:00 oracleofnj: Finish range literals
e9fb1c2 2016-12-01T15:04:03-05:00 Ishaan: Added increment to string buffer and tests
eb7c1e8 2016-12-01T15:04:03-05:00 Ishaan: Add partial character indexing
df09aea 2016-12-01T15:04:03-05:00 Ishaan: Add expected parse testcase intermediate
712a710 2016-12-01T15:04:03-05:00 Ishaan: Added tentative scanner-level line number
bf4ee6c 2016-12-01T15:04:03-05:00 Ishaan: Added SyntaxError Exception at scan level
da41520 2016-12-01T14:54:21-05:00 oracleofnj: So close
7abb394 2016-12-01T14:07:58-05:00 GitHub: Merge pull request #14 from ExtendLang/
    sinner
e0b7fdb 2016-12-01T14:05:38-05:00 Nigel Schuster: Rename empty to new_val
2cabadc 2016-12-01T11:58:03-05:00 oracleofnj: Merge branch 'master' into finish-
    transformations
```

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6ea8cff 2016-12-01T10:10:26-05:00 Nigel Schuster: Using define instead of magic numbers
cd7d261 2016-12-01T10:07:10-05:00 Nigel Schuster: Merge branch 'master' into sinner
13cd317 2016-12-01T10:06:25-05:00 GitHub: Merge pull request #13 from ExtendLang/value_p
cf36f70 2016-12-01T09:47:38-05:00 oracleofnj: Sample digits function
4eeed07 2016-12-01T01:02:56-05:00 Ishaan: Change print return type to empty
fa42f27 2016-12-01T00:41:47-05:00 Kevin: Fixed acos function
53d34ad 2016-12-01T00:29:32-05:00 Nigel Schuster: Moved double values type to numeric
f769c61 2016-12-01T00:18:07-05:00 Nigel Schuster: Merge branch 'sinner' into stdlib-fun
3986f38 2016-12-01T00:17:21-05:00 Nigel Schuster: Merge branch 'value_p' into sinner
5bd87f9 2016-12-01T00:14:45-05:00 Nigel Schuster: Explicitly declaring to link math library
4604545 2016-12-01T00:12:08-05:00 Nigel Schuster: Consistently using floats
38b9824 2016-11-30T23:46:14-05:00 Nigel Schuster: Merge branch 'value_p' into sinner
3303575 2016-11-30T23:45:25-05:00 Nigel Schuster: Explicitly declaring to link math library
31a74ec 2016-11-30T23:35:34-05:00 Nigel Schuster: Merge branch 'master' into value_p
7f0bc86 2016-11-30T23:04:34-05:00 Kevin: Finished remainder of stdlib
cd160df 2016-11-30T22:50:18-05:00 Kevin: Added more c functions to stdlib
e085977 2016-11-30T19:59:57-05:00 Nigel Schuster: Made sin function work
206ee5a 2016-11-30T19:07:28-05:00 Nigel Schuster: Moved all function signatures to value_p return value
effc20b 2016-11-30T18:45:52-05:00 GitHub: Merge pull request #12 from ExtendLang/easy-compile
3b6d7b7 2016-11-30T17:51:19-05:00 Nigel Schuster: Added script to compile and link
febcff8 2016-11-30T15:54:45-05:00 oracleofnj: Add oddball formula test case and try out theory for range literal
4a1ff4f 2016-11-30T14:54:05-05:00 oracleofnj: Finish reducing Ternary to ReducedTernary
8f0a981 2016-11-30T12:35:43-05:00 oracleofnj: Working on reducing ternaries
d3c5812 2016-11-30T02:39:58-05:00 oracleofnj: Finish desugaring switch
0a22713 2016-11-30T00:09:10-05:00 oracleofnj: Getting ready to ternarize switch
84f016a 2016-11-29T21:54:15-05:00 oracleofnj: Fix bug in switch() with default case
d331b7a 2016-11-29T17:33:41-05:00 oracleofnj: Give desugaring variables easier-to-read names for debugging purposes
36f8de5 2016-11-29T16:14:46-05:00 oracleofnj: Missed one
d96da34 2016-11-29T16:13:21-05:00 oracleofnj: Transform &&, || into ternary expressions to support proper short-circuit evaluation
3a8efbc 2016-11-28T23:05:28-05:00 GitHub: Merge pull request #9 from ExtendLang/func-calls
7a2af49 2016-11-28T20:33:53-05:00 Nigel Schuster: Removed another ocaml 4.3 dep
468e79f 2016-11-28T19:50:53-05:00 Nigel Schuster: Added ocaml 4.3 as dep for travis ( hopefully this works)
a408761 2016-11-28T19:35:49-05:00 Nigel Schuster: Fixed String.equal
90c3caf 2016-11-27T22:52:14-05:00 Nigel Schuster: Fixed interpreter for now
a18da78 2016-11-27T22:42:27-05:00 Nigel Schuster: Added accidentally created file
5647312 2016-11-27T22:41:22-05:00 Nigel Schuster: Made extern function calls work
872aa8c 2016-11-27T13:52:44-05:00 Nigel Schuster: Merge branch 'func-calls' of https://github.com/ExtendLang/Extend into func-calls
26ef1cc 2016-11-27T13:51:06-05:00 Nigel Schuster: Merging list of functions
877336f 2016-11-27T12:15:11-05:00 GitHub: Merge branch 'master' into func-calls
5b3edb0 2016-11-27T12:14:43-05:00 GitHub: Merge pull request #8 from ExtendLang/stdlib-template
374273f 2016-11-27T12:13:52-05:00 Nigel Schuster: Function calls work now
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952aab8 2016-11-27T09:54:12-05:00 Nigel Schuster: Merge extern
ac6268f 2016-11-26T23:06:00-05:00 Nigel Schuster: Boxing ints, added unop sizeof, actually returning subrange not dummy object
ca07be3 2016-11-26T21:27:19-05:00 Nigel Schuster: Unboxing hello world to and from subrange
aef6c19 2016-11-26T16:55:48-05:00 Nigel Schuster: Made Hello World somewhat workable
cfb637e 2016-11-25T18:27:37-05:00 Nigel Schuster: Fixed faulty setup on call
ebf926a 2016-11-25T17:48:57-05:00 Nigel Schuster: Added template in C
554fbb2 2016-11-23T22:28:29-05:00 oracleofnj: Better error message for WrongNumberArgs
f09e40e 2016-11-23T12:47:39-05:00 oracleofnj: Make sequence work
053980b 2016-11-22T16:02:27-05:00 oracleofnj: Actually commit all the extern stuff
0e0fa23 2016-11-22T14:36:54-05:00 Nigel Schuster: Added extern in Ast
aac63be 2016-11-21T23:52:25-05:00 oracleofnj: Better duplicate definition checking
08e2d07 2016-11-21T23:29:28-05:00 oracleofnj: Check assertions before evaluating fn return expression
69fa332 2016-11-21T18:01:23-05:00 oracleofnj: Add size assertions
22541c4 2016-11-21T12:48:34-05:00 oracleofnj: Fix bug in Call()
9a1d24b 2016-11-21T12:39:41-05:00 oracleofnj: Working on crazy bug
a485cee 2016-11-20T22:13:46-05:00 oracleofnj: Add test case for foo([m, n] arg)
10afe9a 2016-11-20T22:07:17-05:00 oracleofnj: Expand function signature
325e9ba 2016-11-20T18:53:52-05:00 oracleofnj: Well, this is awkward
0a76dc9 2016-11-20T18:41:12-05:00 oracleofnj: Add check of return value
488e34e 2016-11-20T18:31:39-05:00 oracleofnj: Add sample #1
93eebc5 2016-11-20T18:27:23-05:00 oracleofnj: Add semantic checking to make sure functions and variables on RHS exist
881f164 2016-11-20T17:22:40-05:00 oracleofnj: Check RHS slice to ensure end > start, otherwise evaluate to empty
442ae91 2016-11-20T11:42:54-05:00 GitHub: Merge pull request #73 from Neitsch/interpreter-global
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
367bc2b 2016-11-20T00:33:17-05:00 GitHub: Merge pull request #72 from Neitsch/codegen-part-app-fix
bdca834 2016-11-20T00:31:04-05:00 GitHub: Merge branch 'master' into codegen-part-app-fix
e956238 2016-11-20T00:28:49-05:00 GitHub: Merge pull request #71 from Neitsch/tc-fixes
9b742d1 2016-11-20T00:24:39-05:00 Nigel Schuster: Fixed partial function application warning
32f2989 2016-11-20T00:20:51-05:00 GitHub: Merge branch 'master' into tc-fixes
f87cb94 2016-11-20T00:20:35-05:00 GitHub: Merge pull request #69 from Neitsch/regression-tests
842ee5a 2016-11-20T00:18:56-05:00 GitHub: Merge branch 'master' into regression-tests
6d73717 2016-11-19T23:55:35-05:00 GitHub: Merge pull request #66 from Neitsch/fix-test-cases
05f317a 2016-11-19T22:37:36-05:00 Nigel Schuster: Fixed output on TCs
aa1d974 2016-11-19T22:33:40-05:00 Nigel Schuster: Fixed expected value for ternary
ab7653a 2016-11-19T22:32:27-05:00 Nigel Schuster: Fixed import testcases
848066c 2016-11-19T22:24:55-05:00 Nigel Schuster: Moved testcase asset to asset folder
53c9206 2016-11-19T22:21:48-05:00 Nigel Schuster: Corrected use of global variable in test_globals
5fe74a8 2016-11-19T22:21:00-05:00 Nigel Schuster: Fixed expected output for test_access_column_cells
214ab9d 2016-11-19T22:10:33-05:00 Nigel Schuster: Merge
fb31505 2016-11-19T22:08:42-05:00 Nigel Schuster: Passing testcases are in separate directory. Output of stats
5e39ba7 2016-11-19T21:55:03-05:00 Nigel Schuster: Merge
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25263fe 2016-11-19T21:51:31-05:00 Nigel Schuster: Removed travis from build, removed super verbose output
0554ad9 2016-11-19T21:42:28-05:00 Nigel Schuster: Using precise lli version
04e5c4a 2016-11-19T18:30:32-05:00 oracleofnj: Add more operators to interpreter
e4a190c 2016-11-19T17:14:04-05:00 oracleofnj: Add argument to main and remove _expected from filenames
7cd2b3a 2016-11-19T16:53:12-05:00 oracleofnj: Merge branch 'master' into fix-test-cases
d1fddfd 2016-11-19T16:52:48-05:00 oracleofnj: Merge branch 'fix-test-cases' of https://github.com/Neitsch/plt into fix-test-cases
36f72a1 2016-11-19T16:49:34-05:00 GitHub: Merge pull request #67 from Neitsch/test_cases
c46c87b 2016-11-19T16:47:26-05:00 GitHub: Merge branch 'master' into test_cases
642ce76 2016-11-19T16:39:50-05:00 Kevin: Fixed helloworld bug
ac3d7fa 2016-11-19T16:10:53-05:00 Kevin: Added corresponding AST result for gcd function
7b6b79e 2016-11-19T14:31:39-05:00 GitHub: Merge branch 'master' into fix-test-cases
a9320f3 2016-11-19T14:29:51-05:00 oracleofnj: Merge branch 'master' into fix-test-cases
24a3625 2016-11-19T14:27:48-05:00 oracleofnj: Add switch tests
de262b4 2016-11-19T14:24:39-05:00 GitHub: Merge pull request #60 from Neitsch/box-args
75e3f71 2016-11-18T20:39:23-05:00 oracleofnj: Fix parsing errors in test cases
4e38757 2016-11-18T16:00:10-05:00 GitHub: Merge branch 'master' into box-args
7146dce 2016-11-18T15:59:54-05:00 GitHub: Merge pull request #64 from Neitsch/reorg-test
f483ac7 2016-11-18T14:10:32-05:00 Kevin: Updated print statement for each test
09cb42f 2016-11-18T14:07:39-05:00 oracleofnj: Fix parse difference
39634bb 2016-11-18T14:01:21-05:00 oracleofnj: Remove unnecessary files
d772725 2016-11-18T14:01:02-05:00 oracleofnj: Make inputs work with interpreter
f4456f8 2016-11-18T13:17:25-05:00 GitHub: Merge branch 'master' into test_cases
00aafb7 2016-11-18T13:16:08-05:00 Kevin: Renamed inputs folder
99db652 2016-11-18T12:51:40-05:00 Kevin: Renamed expected output extension and created input folder for test cases
2825ada 2016-11-18T12:51:33-05:00 Nigel Schuster: Added branch to build
aafabb2 2016-11-18T12:50:56-05:00 Nigel Schuster: Verbose output for travis debug
124d61e 2016-11-18T12:44:50-05:00 GitHub: Merge pull request #61 from Neitsch/reorg-test
82cf599 2016-11-18T12:34:57-05:00 oracleofnj: Modify test script to compare interpreter and compiler with expected
faecfa1 2016-11-18T01:48:44-05:00 oracleofnj: Fix merge conflict in box_args
41a81ce 2016-11-18T01:40:11-05:00 oracleofnj: Move argument boxing into a function
6f63e89 2016-11-18T00:48:07-05:00 GitHub: Merge pull request #59 from Neitsch/hello-hello
088dc45 2016-11-18T00:29:45-05:00 Nigel Schuster: Merge
012caaa 2016-11-18T00:12:40-05:00 GitHub: Merge pull request #58 from Neitsch/copy-argv
f84757b 2016-11-18T00:02:34-05:00 Nigel Schuster: Removed unneccessary files
18fbff1 2016-11-18T00:01:49-05:00 Nigel Schuster: Removed dummy arg reading, added printing to interpreter - helloworld TC passes
b866da3 2016-11-17T23:31:42-05:00 Nigel Schuster: Made hello world work
9463afa 2016-11-17T23:12:41-05:00 oracleofnj: Merge branch 'copy-argv' of https://github.com/Neitsch/plt into copy-argv
54858ab 2016-11-17T23:11:29-05:00 oracleofnj: Add => infix operator to cut down on all the build_struct_gep calls
bb11d6d 2016-11-17T23:10:24-05:00 GitHub: Merge branch 'master' into copy-argv
e123652 2016-11-17T22:28:12-05:00 oracleofnj: Add byte for zero
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26a03b7 2016-11-17T22:24:17-05:00 oracleofnj: Add new_string function
b8028f9 2016-11-17T20:27:37-05:00 Kevin: Removed files from test folder
c85d9b7 2016-11-17T20:25:21-05:00 Kevin: Move testcases to testcases directory
f17c6b6 2016-11-17T20:21:38-05:00 Kevin Ye: Complete testcases for List/Range/Function
    /Expression with expected outputs
5e63cee 2016-11-17T17:40:31-05:00 GitHub: Merge pull request #54 from Neitsch/
    operation_tests
4a4a806 2016-11-17T17:19:13-05:00 GitHub: Merge branch 'master' into operation_tests
cafe20e 2016-11-17T17:19:11-05:00 GitHub: Merge pull request #52 from Neitsch/one-main
    -arg
4b28df2 2016-11-17T17:17:44-05:00 GitHub: Merge branch 'master' into operation_tests
b728e2e 2016-11-17T17:16:20-05:00 GitHub: Merge branch 'master' into one-main-arg
d43a87b 2016-11-17T17:15:28-05:00 GitHub: Merge pull request #55 from Neitsch/shell-
    fix
b1238a0 2016-11-17T17:08:56-05:00 Nigel Schuster: Shell is not my strength
a6cc0ea 2016-11-17T17:05:09-05:00 Nigel Schuster: Screw you bourne shell
51fbe67 2016-11-17T16:59:50-05:00 Nigel Schuster: Using bourne shell style redirection
    :
3255e1b 2016-11-17T16:38:53-05:00 Ishaan: Modify test suite specs
f0ab4d8 2016-11-17T16:38:53-05:00 Ishaan: Moved expected output text files to
    directory
06d330c 2016-11-17T16:38:53-05:00 Ishaan: 75% through operator cases
e490548 2016-11-17T15:50:35-05:00 GitHub: Merge branch 'master' into one-main-arg
a4cf367 2016-11-17T15:50:29-05:00 GitHub: Merge pull request #51 from Neitsch/test-
    script
79ee3de 2016-11-17T15:18:58-05:00 oracleofnj: Call main() with first argument <empty>
    in interpreter
c4f7437 2016-11-17T14:39:38-05:00 Nigel Schuster: Removed version specific lli
7b2236b 2016-11-17T14:35:55-05:00 Nigel Schuster: Fixed if no flag is given
e10f656 2016-11-17T14:24:20-05:00 Nigel Schuster: Outputting diff only if -p flag is
    given
2d29597 2016-11-17T14:19:30-05:00 Nigel Schuster: Added it as build target
7af929a 2016-11-17T14:12:19-05:00 GitHub: Merge pull request #50 from Neitsch/test-
    script
6ea43f6 2016-11-17T13:54:55-05:00 Nigel Schuster: Added more env variables to avoid
    copy paste
05f27a2 2016-11-17T12:45:11-05:00 Nigel Schuster: Made simple testscript
aca43c1 2016-11-17T11:08:11-05:00 Nigel Schuster: Removed accidentally added files
9228eac 2016-11-17T04:52:31-05:00 Kevin Ye: Test cases for List of Tests and Range/
    Function/Expression Tests
7feb392 2016-11-17T00:28:53-05:00 GitHub: Merge pull request #48 from Neitsch/
    testing_list
6e42afa 2016-11-17T00:27:13-05:00 GitHub: Merge branch 'master' into testing_list
e40734b 2016-11-16T23:25:01-05:00 Ishaan: Added more test scenarios
41ef578 2016-11-16T17:50:03-05:00 GitHub: Merge pull request #49 from Neitsch/consume-
    command-line-args
3cbf089 2016-11-16T17:45:58-05:00 oracleofnj: Fix merge conflict
1570836 2016-11-16T16:51:05-05:00 GitHub: Merge pull request #45 from Neitsch/doc
a8fbced 2016-11-16T16:38:49-05:00 Nigel Schuster: Fixed minor syntax error
c2f37c8 2016-11-16T16:30:43-05:00 Nigel Schuster: Merge
2fa73be 2016-11-16T16:05:37-05:00 oracleofnj: Set return code to length of argv[1]
bc21af6 2016-11-16T15:54:12-05:00 Ishaan: Added initial testing list
cd0d156 2016-11-16T15:50:39-05:00 oracleofnj: Start processing command line args
4a1fcac 2016-11-16T13:55:46-05:00 GitHub: Merge pull request #46 from Neitsch/number-
    type
f1b481e 2016-11-16T11:04:44-05:00 Nigel Schuster: Added number type that defaults to
```

```
    int
8944b9a 2016-11-16T00:19:33-05:00 GitHub: Merge pull request #44 from Neitsch/fix-arg
92fb7a3 2016-11-15T23:57:37-05:00 Nigel Schuster: Added a little documentation
bcbde36 2016-11-15T23:49:07-05:00 GitHub: Merge branch 'master' into fix-arg
fa1741a 2016-11-15T23:03:23-05:00 GitHub: Merge pull request #43 from Neitsch/more-
    llvm-gen-js
57b2162 2016-11-15T22:39:38-05:00 Nigel Schuster: Using subranges instead of ranges
    everywhere
9407677 2016-11-15T22:31:03-05:00 oracleofnj: Add hash table for common functions and
    add dereference-the-range
46e1fd5 2016-11-15T21:38:51-05:00 oracleofnj: Eliminate some copy & paste
660c049 2016-11-15T20:54:33-05:00 GitHub: Merge pull request #42 from Neitsch/llvm-gen
25b23cd 2016-11-15T17:23:54-05:00 Nigel Schuster: Fixed column retrieval for 1x1
3f02203 2016-11-15T17:17:02-05:00 Nigel Schuster: Fixed tests
26b8fcf 2016-11-15T17:15:08-05:00 Nigel Schuster: Merge
e347a87 2016-11-15T17:12:26-05:00 Nigel Schuster: Using more generic flag for values
aed28b3 2016-11-15T17:08:07-05:00 oracleofnj: Add is_subrange_1x1
cf5cbf0 2016-11-15T14:51:40-05:00 oracleofnj: Merge branch 'llvm-gen' of https://
    github.com/Neitsch/plt into llvm-gen
c71d469 2016-11-15T14:51:19-05:00 oracleofnj: Replace String.equal with =
4b34abd 2016-11-15T14:41:37-05:00 GitHub: Merge branch 'master' into llvm-gen
a80a6d0 2016-11-15T14:41:07-05:00 oracleofnj: Add compile option to main
8ad5a19 2016-11-15T14:33:40-05:00 GitHub: Merge pull request #40 from Neitsch/
    interpreter
3f0362a 2016-11-15T14:28:44-05:00 GitHub: Merge branch 'master' into interpreter
c0c95a2 2016-11-15T14:16:13-05:00 Nigel Schuster: Merge
d5f4024 2016-11-15T13:44:44-05:00 Nigel Schuster: Moved failing TCs
42fd9ef 2016-11-15T12:21:57-05:00 oracleofnj: Fix bug in import
9c567c9 2016-11-15T11:11:30-05:00 Nigel Schuster: Working on imports, fixed most
    testcases
aa61ac9 2016-11-15T09:31:42-05:00 Nigel Schuster: Allocating scope object
cf1ebf9 2016-11-13T23:09:30-05:00 oracleofnj: Rewrite main to take options; fix bug
    where import didn't know about first filename
5749538 2016-11-13T21:59:28-05:00 Nigel Schuster: Added main function
d6daff3 2016-11-13T20:26:14-05:00 GitHub: Merge pull request #41 from Neitsch/
    LRM_String_Update
0a5d484 2016-11-13T18:45:29-05:00 oracleofnj: Revert "Generating function header"
6afe599 2016-11-13T18:44:58-05:00 Ishaan Kolluri: Added changes relating to strings.
137d7e2 2016-11-13T18:39:33-05:00 oracleofnj: Merge branch 'interpreter' of https://
    github.com/Neitsch/plt into interpreter
118bfc5 2016-11-13T18:38:34-05:00 oracleofnj: Allow single slice on RHS; make hashtag
    work
e376270 2016-11-13T17:55:41-05:00 Nigel Schuster: Added type arguments for functions
5cfb519 2016-11-13T17:26:23-05:00 Nigel Schuster: Set more types up
bf1d8bb 2016-11-13T15:30:35-05:00 Nigel Schuster: Merge branch 'interpreter' of https
    ://github.com/Neitsch/plt into interpreter
f83a0bc 2016-11-13T15:30:28-05:00 Nigel Schuster: Generating function header
3addcc8 2016-11-13T14:38:11-05:00 oracleofnj: Make size(expr) an operator instead of
    built-in function
9a74e14 2016-11-13T14:22:44-05:00 oracleofnj: Changing size() to be an operator
d6d2eaa 2016-11-13T00:08:41-05:00 oracleofnj: Add closure to interpreter_variable
64fba82 2016-11-12T22:38:39-05:00 oracleofnj: Added bsearch to show logic bug
66ffdb1 2016-11-12T19:21:07-05:00 oracleofnj: Add alpha version of function calls
376b29a 2016-11-12T17:17:23-05:00 oracleofnj: Add string as value type
08c61ee 2016-11-12T17:14:47-05:00 oracleofnj: Clean up discrepancies
a18d5fc 2016-11-08T11:38:22-05:00 oracleofnj: Fix bug with x[-1]
```

```
962f812 2016-11-07T23:27:08-05:00 oracleofnj: Refactor scope for interpreter; resolve variables on demand; make selections work properly
47bbef1 2016-11-06T22:05:55-05:00 oracleofnj: Minor adjustments to interpreter to work with mapped AST
fddc6bc 2016-11-06T18:32:17-05:00 oracleofnj: Eliminate extraneous nulls in JSON
ffddb17 2016-11-06T18:15:40-05:00 oracleofnj: Turn statement and function lists into StringMaps
6810003 2016-11-05T19:47:57-04:00 oracleofnj: Fix pattern matching warning
7107a46 2016-11-05T18:01:34-04:00 oracleofnj: Add function to check range literals for legality at parse time
80b13d1 2016-11-05T15:13:10-04:00 oracleofnj: Handle selections better
6cbb009 2016-11-04T15:48:58-04:00 oracleofnj: Count to 1,000,000 using tail-recursive versions of List.map and cartesian product
9b2252d 2016-11-04T15:25:13-04:00 oracleofnj: Show enter and exit
3585e43 2016-11-04T02:21:38-04:00 oracleofnj: See how high it can count recursively
38cf541 2016-11-04T02:15:50-04:00 oracleofnj: Get the easy parts of the interpreter working
5d81d6e 2016-11-03T17:17:51-04:00 oracleofnj: Start working on interpreter
0078cee 2016-11-01T23:40:57-04:00 oracleofnj: Got a non-tail-recursive version of topological sort working
85df175 2016-11-01T15:39:10-04:00 oracleofnj: Irrelevant highlighting thing
84c719a 2016-11-01T14:39:49-04:00 oracleofnj: Rearrange nested functions
557dc4e 2016-11-01T13:50:52-04:00 oracleofnj: Add circular import test case
c476798 2016-11-01T13:35:46-04:00 oracleofnj: Fix syntax errors
af5a31d 2016-11-01T13:31:49-04:00 GitHub: Merge pull request #37 from Neitsch/import-rec
d451cc4 2016-11-01T13:31:33-04:00 GitHub: Merge pull request #38 from Neitsch/import-load
02ca24f 2016-11-01T13:30:47-04:00 GitHub: Merge pull request #39 from Neitsch/wild-exc
6fa0e39 2016-10-31T16:43:17-04:00 Neitsch: Raising exceptions on certain values
e673dca 2016-10-31T15:56:43-04:00 Neitsch: Loading data from all imports
6a28c05 2016-10-31T15:40:41-04:00 Neitsch: Recursively looking up dependencies
3f28289 2016-10-31T11:53:10-04:00 GitHub: Merge pull request #36 from Neitsch/import-arrange
4eaef3b 2016-10-31T11:01:00-04:00 Neitsch: Removed obsolete parts
7d7b1e5 2016-10-31T10:59:12-04:00 Neitsch: Added unsorted function, globals and imports
7d70af2 2016-10-30T15:23:04-04:00 oracleofnj: Add some explanatory comments
40d6b16 2016-10-30T15:03:32-04:00 oracleofnj: More expansion samples
af9b01c 2016-10-30T14:48:44-04:00 oracleofnj: Refactor expansion code
903bc3f 2016-10-30T00:19:10-04:00 oracleofnj: Add test output
68b7b03 2016-10-30T00:17:02-04:00 oracleofnj: Add test case
a8bdf33 2016-10-30T00:04:05-04:00 oracleofnj: Add LHS slice expansion
4ee6fdf 2016-10-29T17:36:17-04:00 oracleofnj: Add output
2b8bced 2016-10-29T17:27:22-04:00 oracleofnj: Expand dimension expressions
443a818 2016-10-26T16:31:51-04:00 GitHub: Merge pull request #35 from ishaankolluri/master
9ba3c65 2016-10-26T16:31:00-04:00 Ishaan Kolluri: Add UNIs
022e8cd 2016-10-26T16:25:57-04:00 GitHub: Merge pull request #34 from ishaankolluri/master
808aae5 2016-10-26T16:22:10-04:00 Ishaan Kolluri: Added change to precedence operators
0bd9c4a 2016-10-26T15:59:53-04:00 GitHub: Merge pull request #33 from Neitsch/final-slicing-comments
fb2b382 2016-10-26T15:54:11-04:00 oracleofnj: Thats all for now folks
e7020ec 2016-10-26T15:00:11-04:00 GitHub: Merge pull request #32 from Neitsch/final-lrm-edits
```

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4683f14 2016-10-26T14:48:41-04:00 oracleofnj: Flesh out switch expressions, add precedence
4b7984a 2016-10-26T11:15:03-04:00 GitHub: Merge pull request #31 from Neitsch/more-lrm-edits
3d587c5 2016-10-26T11:10:15-04:00 oracleofnj: Incorporate requested edits and a few more clarifications
0c42b9c 2016-10-26T09:22:08-04:00 GitHub: Merge pull request #30 from ishaankolluri/LRM_update
cd81040 2016-10-26T03:30:20-04:00 ishaankolluri: Added changes to first half of LRM
63fb02b 2016-10-26T02:13:17-04:00 GitHub: Merge pull request #29 from Neitsch/lrm-edits
0941e96 2016-10-26T02:04:47-04:00 oracleofnj: Rebuild PDF
cb04069 2016-10-26T02:04:01-04:00 oracleofnj: Add built in functions
4abf638 2016-10-26T01:56:38-04:00 oracleofnj: Add built in functions
7661925 2016-10-26T00:04:22-04:00 oracleofnj: Initial comments
5932551 2016-10-25T21:30:40-04:00 GitHub: Merge pull request #28 from Neitsch/func-doc-fix
cc66297 2016-10-25T20:14:27-04:00 Nigel Schuster: Fixed mistakes in functions part of the doc
b978f00 2016-10-25T13:04:05-04:00 GitHub: Merge pull request #27 from ishaankolluri/master
125a5bb 2016-10-25T12:49:38-04:00 Ishaan Kolluri: Removed AUX file
2e1ea60 2016-10-25T11:30:35-04:00 GitHub: Merge pull request #26 from Neitsch/better-regexp
84b03ee 2016-10-25T01:22:31-04:00 oracleofnj: Fix let order
91b40c5 2016-10-25T01:14:43-04:00 oracleofnj: Improve regexp
eb24036 2016-10-24T23:55:38-04:00 GitHub: Merge pull request #23 from Neitsch/file-io
991c918 2016-10-24T23:20:12-04:00 oracleofnj: Replace fopen, fclose etc. with open, close etc.
338faa0 2016-10-24T23:14:30-04:00 oracleofnj: Fix file inclusion and rebuild PDF
b24edd3 2016-10-24T23:11:50-04:00 oracleofnj: Merge in expressions section
44a1cc5 2016-10-24T23:06:07-04:00 oracleofnj: Merge scanner changes and add regexp to properly escape strings
2f09a64 2016-10-24T15:52:10-04:00 Kevin: Added the Expression Section 4 to LRM
1ea3c28 2016-10-24T15:26:16-04:00 oracleofnj: Merge branch 'master' into file-io
ec7cc9c 2016-10-24T15:21:23-04:00 Jared Samet: Replace repetitive code with more idiomatic OCaml
8cd39ac 2016-10-24T11:05:33-04:00 Kevin: Added string literals to scanner
e5d2478 2016-10-24T11:00:39-04:00 Kevin: Added string literals to scanner
a692466 2016-10-24T01:09:21-04:00 oracleofnj: Fix tests until strings ready
8553a50 2016-10-24T01:08:29-04:00 oracleofnj: Fix tests until string ready
0ed4ad7 2016-10-24T00:55:08-04:00 oracleofnj: Add File IO, Entry point and Example to LRM
71e0b1c 2016-10-23T22:58:21-04:00 oracleofnj: Fix section reference
92ac506 2016-10-23T22:39:06-04:00 Ishaan Kolluri: Make small change to data type section
6abb290 2016-10-23T22:34:42-04:00 oracleofnj: Initial commit for File I/O section
67b4b65 2016-10-23T19:30:03-04:00 Nigel Schuster: Reduce eye pain
2824ee9 2016-10-23T19:03:24-04:00 GitHub: Merge pull request #20 from Neitsch/samples
f8ae543 2016-10-23T18:23:11-04:00 GitHub: Merge branch 'master' into samples
13d0896 2016-10-23T18:20:03-04:00 GitHub: Merge pull request #19 from Neitsch/sequence-operator
e0c702d 2016-10-23T18:17:58-04:00 Neitsch: Fixed .gitignore
3a2cd60 2016-10-23T18:16:35-04:00 GitHub: Merge branch 'master' into sequence-operator
e42fe94 2016-10-23T18:05:48-04:00 Neitsch: Added code in LRM to test code samples
9d2cd17 2016-10-23T17:24:15-04:00 Neitsch: Merge branch 'master' into samples
```

```
167ddd2 2016-10-23T17:18:35-04:00 Neitsch: Removed test output
57319c4 2016-10-23T17:11:13-04:00 oracleofnj: Remove intermediate files
53824ea 2016-10-23T17:10:39-04:00 oracleofnj: Flip precedence of -> and ?: (?: is now lowest)
7dedf93 2016-10-23T17:05:23-04:00 oracleofnj: Add sequence operator to scanner/parser/AST
9805753 2016-10-23T17:01:31-04:00 GitHub: Merge pull request #17 from Neitsch/make-correction
e0c7aed 2016-10-23T16:59:33-04:00 Neitsch: Fixed test
ec3d682 2016-10-23T16:41:00-04:00 GitHub: Merge branch 'master' into make-correction
ea05658 2016-10-23T16:40:24-04:00 Neitsch: Moved sequence file
0ca56a0 2016-10-23T16:10:14-04:00 Neitsch: Merge
9d1094e 2016-10-23T16:08:59-04:00 Neitsch: Added simple TCs, Moved Makefile to oasis config
0a28413 2016-10-23T16:08:59-04:00 Neitsch: Completed initial functions section doc
0797f32 2016-10-23T16:08:12-04:00 Neitsch: Changed subsection header
9df31f7 2016-10-23T16:08:12-04:00 Neitsch: Added dimension section
8939903 2016-10-23T16:07:26-04:00 Neitsch: Started working on Functions
cae3b37 2016-10-23T16:06:27-04:00 Neitsch: Added dimension section
049c95d 2016-10-23T16:06:08-04:00 Neitsch: Started working on Functions
84d20b5 2016-10-23T16:01:00-04:00 Neitsch: Comparing sample code with correctly parsed code in samples_comp
3f015ee 2016-10-23T15:52:01-04:00 GitHub: Merge pull request #18 from Neitsch/grammar-bug-fixes
7e558c1 2016-10-23T15:44:20-04:00 GitHub: Merge branch 'master' into make-correction
edf3dea 2016-10-23T15:44:20-04:00 GitHub: Merge branch 'master' into grammar-bug-fixes
d4961eb 2016-10-23T15:43:16-04:00 GitHub: Merge pull request #15 from Neitsch/functions-doc
0e0bda5 2016-10-23T15:05:42-04:00 GitHub: Merge branch 'master' into functions-doc
4652c67 2016-10-23T15:00:35-04:00 Neitsch: Added simple TCs, Moved Makefile to oasis config
b45718d 2016-10-23T02:27:36-04:00 oracleofnj: Modify grammar to allow [m,n] foo, bar, baz;
143fcba 2016-10-22T23:23:10-04:00 GitHub: Merge pull request #16 from Neitsch/more-AST
a726236 2016-10-22T20:51:27-04:00 oracleofnj: Add comments and sample program
8db4098 2016-10-22T19:44:48-04:00 oracleofnj: Fix minor grammar bug
80754c3 2016-10-22T18:19:27-04:00 oracleofnj: Hook up scanner and parser
660de8c 2016-10-22T13:54:32-04:00 GitHub: Add stuff to the grammar, minor corrections (#14)
cfe827d 2016-10-21T20:50:51-04:00 Nigel Schuster: Completed initial functions section doc
3609366 2016-10-20T21:14:00-04:00 GitHub: Update scanner.mll
0d57652 2016-10-20T21:10:27-04:00 Kevin: Fixed bug in scanner
1848813 2016-10-20T20:21:49-04:00 Kevin: Made scanner
1b610ac 2016-10-20T13:50:22-04:00 Nigel Schuster: Merge
acb9b93 2016-10-20T13:44:06-04:00 Nigel Schuster: Changed subsection header
b95d039 2016-10-20T13:43:51-04:00 Nigel Schuster: Added dimension section
71b93bb 2016-10-20T13:43:09-04:00 Nigel Schuster: Started working on Functions
a15772c 2016-10-20T13:38:08-04:00 GitHub: Merge pull request #10 from ishaankolluri/LRM
dee63c7 2016-10-20T13:26:28-04:00 GitHub: Merge pull request #1 from Neitsch/grammar-doc
dc93dbf 2016-10-20T13:18:29-04:00 Nigel Schuster: Grammar import
4d763cb 2016-10-20T12:44:52-04:00 Ishaan Kolluri: Made refactor and edits to intro section of LRM
e7443cc 2016-10-20T11:46:54-04:00 Ishaan Kolluri: Merging
```

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7542b5d 2016-10-20T11:16:35-04:00 Nigel Schuster: Added dimension section
995cf83 2016-10-19T12:28:09-04:00 Nigel Schuster: Started working on Functions
40c2a5a 2016-10-19T03:43:06-04:00 ishaankolluri: Initial LRM Commit part 1
02a5c17 2016-10-18T18:38:21-04:00 Ishaan Kolluri: Added LRM initial info
d8794e9 2016-10-17T19:47:42-04:00 GitHub: Merge pull request #9 from Neitsch/
    documentation
70aa1b9 2016-10-16T13:36:23-04:00 Nigel Schuster: Added PDF Latex template
5111202 2016-10-14T19:59:45-04:00 GitHub: Added a bunch of stuff to the grammar: (#8)
da967e4 2016-10-12T13:24:50-04:00 Jared Samet: CFG Grammar (#6)
fea4e4b 2016-10-08T11:42:39-04:00 GitHub: There is no need to constantly build all
    branches. (#2)
7a5ccfc 2016-10-08T11:31:31-04:00 Nigel Schuster: Added greeting and newlines (#4)
10b17f7 2016-10-08T11:31:08-04:00 GitHub: Imported microc (#5)
726456f 2016-09-20T09:45:07-04:00 Nigel Schuster: [test] Add sample greeting to repo
    (#3)
9a2183d 2016-09-15T18:44:00-04:00 Nigel Schuster: Added merlin config
163e176 2016-09-14T18:51:53-04:00 Nigel Schuster: Moved whole build to script
d401eea 2016-09-14T18:43:58-04:00 Nigel Schuster: Added oasis opam package
ba7fd9c 2016-09-14T18:38:58-04:00 Nigel Schuster: Added ocaml configure (maybe this
    helps travis)
a461eae 2016-09-14T18:26:10-04:00 Nigel Schuster: Configuring opam environment for
    travis
ba2df2f 2016-09-14T18:19:26-04:00 Nigel Schuster: Added ocaml native compiler to apt
    package list
a8e5958 2016-09-14T17:24:36-04:00 Nigel Schuster: Added some more (possibly necessary
    opam packages
c54f5e3 2016-09-14T17:18:32-04:00 Nigel Schuster: Missed opam option
b10adf0 2016-09-14T17:13:57-04:00 Nigel Schuster: Fixed opam install
124f7f3 2016-09-14T17:08:09-04:00 Nigel Schuster: Fixed YML error
4909fa8 2016-09-14T17:03:54-04:00 Nigel Schuster: Using avsm source
4b24046 2016-09-14T16:58:33-04:00 Nigel Schuster: Allow sudo
e7b50db 2016-09-14T16:56:57-04:00 Nigel Schuster: Fixed setup order
f6d7ac4 2016-09-14T16:50:02-04:00 Nigel Schuster: Manually installing apt packages
f4084ab 2016-09-14T16:40:55-04:00 Nigel Schuster: Test commit
d7c5e9a 2016-09-14T13:15:43-04:00 Nigel Schuster: Initial commit
```

# 12. 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.