Extend

Language Reference Manual

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1. Introduction to Extend

Extend is a domain-specific programming language used to designate ranges of cells as reusable functions. It abstracts dependencies between cells and models a dependency graph during compilation. In order to offer great performance for any size of datasets, 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.

2. Structure of an Extend Program

An Extend program consists of one or more source files. A source file consists of an optional set of import directives, an optional set of global variable declarations, and an optional set of function declarations, in that order. The grammar for a source file is displayed below:

```
/* Ocamlyacc parser for Extend */

%{
open Ast
%}

%token LSQBRACK RSQBRACK LPAREN RPAREN LBRACE RBRACE HASH
%token COLON COMMA QUESTION GETS ASN SEMI PRECEDES UNDERSCORE
%token SWITCH CASE DEFAULT
%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
%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 HASH LSQBRACK

%start program
%type <Ast.program> program

%%

program:
    imports globals func_decls EOF { (List.rev $1, List.rev $2, List.rev $3) }

imports:
    /* nothing */ {[]}
  | imports import {$2 :: $1}

import:
    IMPORT LIT_STRING SEMI {$2}

globals:
    /* nothing */ {[]}
  | globals global {$2 :: $1}

global:
    GLOBAL vardecl {$2}

func_decls:
    /* nothing */ {[]}
  | func_decls func_decl {$2 :: $1}

func_decl:
    ID LPAREN func_param_list RPAREN LBRACE opt_stmt_list ret_stmt RBRACE
    { {
      name = $1;
      params = $3;
      body = $6;
      ret_val = ((None, None), $7)
    } }
  | ret_dim ID LPAREN func_param_list RPAREN LBRACE opt_stmt_list ret_stmt RBRACE
    { {
      name = $2;
      params = $4;
      body = $7;
      ret_val = ($1, $8);
    } }
```

```
opt_stmt_list:
    /* nothing */ { [] }
  | stmt_list { List.rev $1 }

stmt_list:
    stmt { [$1] }
  | stmt_list stmt { $2 :: $1 }

stmt:
    vardecl { $1 } |  assign { $1 }

ret_stmt:
    RETURN expr SEMI {$2}

vardecl:
    var_list SEMI { Vardecl((None, None), List.rev $1) }
  | dim var_list SEMI { Vardecl($1, List.rev $2) }

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

varassign:
    /* nothing */ { None }
  | GETS expr { Some $2 }

assign:
    ID lhs_sel ASN expr SEMI { Assign($1, $2, Some $4) }

expr:
    expr rhs_sel        { Selection($1, $2) }
  | HASH expr           { Selection($2, (None, None)) }
  | op_expr             { $1 }
  | ternary_expr        { $1 }
  | switch_expr         { $1 }
  | func_expr           { $1 }
  | range_expr          { $1 }
  | expr PRECEDES expr  { Precedence($1, $3) }
  | LPAREN expr RPAREN  { $2 }
  | ID                  { Id($1) }
  | LIT_INT             { LitInt($1) }
  | LIT_FLOAT           { LitFlt($1) }
  | LIT_STRING          { LitString($1) }
  | EMPTY               { Empty }

op_expr:
    expr PLUS expr      { BinOp($1, Plus, $3) }
  | expr MINUS expr     { BinOp($1, Minus, $3) }
  | expr TIMES expr     { BinOp($1, Times, $3) }
  | expr DIVIDE expr    { BinOp($1, Divide, $3) }
  | expr MOD expr       { BinOp($1, Mod, $3) }
  | expr POWER expr     { BinOp($1, Pow, $3) }
  | expr LSHIFT expr    { BinOp($1, LShift, $3) }
  | expr RSHIFT expr    { BinOp($1, RShift, $3) }
  | expr LOGAND expr    { BinOp($1, LogAnd, $3) }
  | expr LOGOR expr     { BinOp($1, LogOr, $3) }
  | expr BITXOR expr    { BinOp($1, BitXor, $3) }
  | expr BITAND expr    { BinOp($1, BitAnd, $3) }
  | expr BITOR expr     { BinOp($1, BitOr, $3) }
  | expr EQ expr        { BinOp($1, Eq, $3) }
  | expr NOTEQ expr     { BinOp($1, NotEq, $3) }
  | expr GT expr        { BinOp($1, Gt, $3) }
  | expr LT expr        { BinOp($1, Lt, $3) }
  | expr GTEQ expr      { BinOp($1, GtEq, $3) }
  | expr LTEQ expr      { BinOp($1, LtEq, $3) }
  | MINUS expr %prec NEG  { UnOp(Neg, $2) }
  | LOGNOT expr           { UnOp(LogNot, $2) }
  | BITNOT expr           { UnOp(BitNot, $2) }

ternary_expr:
  /* commented out optional part for now */
    expr QUESTION expr COLON expr %prec QUESTION { Ternary($1, $3, $5) }

switch_expr:
```

```
    SWITCH LPAREN switch_cond RPAREN LBRACE case_list RBRACE { Switch($3, List.rev $6) }

switch_cond:
    /* nothing */ { None }
  | expr { Some $1 }

case_list:
    case_stmt { [$1] }
  | case_list case_stmt { $2 :: $1 }

case_stmt:
    DEFAULT COLON expr SEMI { (None, $3) }
  | CASE case_expr_list COLON expr SEMI { (Some (List.rev $2), $4) }

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

func_expr:
    ID LPAREN opt_arg_list RPAREN { Call($1, $3) }

range_expr:
    LBRACE row_list RBRACE { LitRange(List.rev $2) }

row_list:
    col_list {[List.rev $1]}
  | row_list SEMI col_list {$3 :: $1}

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

opt_arg_list:
    /* nothing */ {[]}
  | arg_list { List.rev $1 }

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

lhs_sel:
    /* nothing */                         { (None, None) }
  | LSQBRACK lslice RSQBRACK              { (Some $2, None) }
  | LSQBRACK lslice COMMA lslice RSQBRACK { (Some $2, Some $4) }

rhs_sel:
    LSQBRACK rslice RSQBRACK              { (Some $2, None) }
  | LSQBRACK rslice COMMA rslice RSQBRACK { (Some $2, Some $4) }

lslice:
    /* nothing */                         { (None, None) }
  | lslice_val                            { (Some $1, None) }
  | lslice_val COLON lslice_val           { (Some $1, Some $3) }
  | lslice_val COLON                      { (Some $1, Some DimensionEnd) }
  | COLON lslice_val                      { (Some DimensionStart, Some $2) }
  | COLON                                 { (Some DimensionStart, Some DimensionEnd) }

rslice:
    /* nothing */                         { (None, None) }
  | rslice_val                            { (Some $1, None) }
  | rslice_val COLON rslice_val           { (Some $1, Some $3) }
  | rslice_val COLON                      { (Some $1, Some DimensionEnd) }
  | COLON rslice_val                      { (Some DimensionStart, Some $2) }
  | COLON                                 { (Some DimensionStart, Some DimensionEnd) }

lslice_val:
    expr { Abs($1) }

rslice_val:
    expr { Abs($1) }
  | LSQBRACK expr RSQBRACK { Rel($2) }

func_param_list:
    /* nothing */ { [] }
```

```
  | func_param_int_list { List.rev $1 }

func_param_int_list:
    func_sin_param { [$1] }
  | func_param_int_list COMMA func_sin_param { $3 :: $1 }

func_sin_param:
    ID { ((None, None), $1) }
  | dim ID { ($1, $2) }

dim:
    LSQBRACK expr RSQBRACK { (Some $2, None) }
  | LSQBRACK expr COMMA expr RSQBRACK { (Some $2, Some $4) }

ret_dim:
    LSQBRACK ret_sin RSQBRACK { ($2, None) }
  | LSQBRACK ret_sin COMMA ret_sin RSQBRACK { ($2,$4) }

ret_sin:
    expr { Some $1 }
  | UNDERSCORE { Some Wild }
```

2.1. 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:

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

Extend imports act like `#include` in C, except that multiple imports of the same file are ignored, and Extend rearranges the initial import and global statements to properly compile. The imports are all aggregated into a single namespace.

2.2. 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 same form as a variable declaration within a function as described in section 5.2.

2.3. Function Declarations

Function declarations are described in detail in section 5.

3. Types and Literals

3.1. Primitive Data Types

Extend has two primitive data types, **numbers** and **empty**. In the vein of Javascript, numbers are primitive values 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. The **empty** type can be written as the keyword `empty` or the empty string `""`, and serves a similar function to `NULL` in SQL.

Primitives	**Examples**
Number	`42 or -5 or 2.71828 or 314159e-5`
Empty	`empty or ""`

3.2. Ranges

Extend has one composite type, the **range**. A range borrows conceptually from spreadsheets; it is a group of cells with two dimensions, described as rows and columns. Each cell contains a formula that either evaluates to a number or another range. Cell formulas are described in detail in section 5.3. A range can either be declared as described in section 5.2 or with a range literal expression.

3.2.1. Range and String Literals

A range literal is a semicolon-delimited list of rows, enclosed in curly brackets. Each row is a comma-delimited list of numbers or ranges. In addition, a range literal can be written in the form of a string literal, which represents a 1-by-n range corresponding to the ASCII values of the contents of the string. A few examples follow:

```
{2,3,4} /* A range consisting of 1 row and 3 columns */
{1,0,0;0,1,0;0,0,1} /* A range corresponding to the 3x3 identity matrix */
"hello" /* Equivalent to {104,101,108,108,111} */
{"hello";"world"} /* A range with 2 rows and 1 column;
both cells of the range contain a range */
```

4. Expressions

Expressions in Extend allows for arithmetic and boolean operations, function calls, conditional branching, and extraction of contents of other variables. The expressions allowed by the grammar presented in section 2 are explained in detail below. The boolean and conditional operators refer to truthy and falsey values. Any number besides zero is truthy; zero is falsey. **empty** is neither truthy nor falsey.

4.1. Arithmetic Operators

The arithmetic operators listed below take one or two expressions and return a number, if neither expression is empty, or empty, if either expression is empty. 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, with the exception of exponentiation, are left-associative. Exponentiation, bitwise negation, and unary negation are right-associative.

<table>
<tr><th>Operator</th><th>Description</th><th>Definition</th></tr>
<tr><td>~</td><td>Bitwise NOT</td><td>Performs a bitwise negation on the binary representation of an expression.</td></tr>
<tr><td>-</td><td>Unary negation</td><td>A simple negative sign to negate expressions.</td></tr>
<tr><td>**</td><td>Power</td><td>Returns the first expression raised to the power of the second expression</td></tr>
<tr><td>*</td><td>Multiplication</td><td>Multiplies two expressions</td></tr>
<tr><td>/</td><td>Division</td><td>Divides first expression by second.</td></tr>
<tr><td>%</td><td>Modulo</td><td>Finds the remainder by dividing the expression on the left side of the modulo by the right side expression.</td></tr>
<tr><td>«</td><td>Left Shift</td><td>Performs a bitwise left shift on the binary representation of an expression.</td></tr>
<tr><td>»</td><td>Right Shift</td><td>Performs a bitwise right shift on the binary representation of an expression.</td></tr>
<tr><td>&</td><td>Bitwise AND</td><td>Performs a bitwise AND between two expressions. If both expressions have a 1 at the same digit, the resultant expression will have a 1 there; otherwise, it is 0.</td></tr>
<tr><td>+</td><td>Addition</td><td>Adds two expressions together.</td></tr>
<tr><td>-</td><td>Subtraction</td><td>Subtracts second expression from first.</td></tr>
<tr><td>|</td><td>Bitwise OR</td><td>Performs a bitwise OR between two expressions. If at least one of the expressions has a one at the same digit, the resultant expression will have a 1 there; otherwise, it is 0.</td></tr>
<tr><td>^</td><td>Bitwise XOR</td><td>Performs a bitwise exclusive OR between two expressions. If exactly one of the expressions has a one in the same digit, the resultant expression will have a 1 there; otherwise it is 0.</td></tr>
</table>

4.2. Boolean Operators

These operators take one or two expressions and evaluate to empty, if either expression is empty, or to 0 or 1 if both expressions are numeric. 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 left-associative.

Operator	Description	Definition
`!`	`Logical NOT`	Returns 0 given a truthy values false and 1 given a falsey value.

`==`
`!=`
`<`
`>`
`<=`
`>=`
	`Equals`
	`Not equals`
	`Less than`
	`Greater than`
	`Less than or equals to`
	`Greater than or equals to`
		Evaluates to 1 if the two expressions have the same value
		Evaluates to 1 if the expressions are not the same.
		Evaluates to 1 if the first expression is less than the first.
		Evaluates to 1 if the first expression is greater than the first..
		Evaluates to 1 if the first expression is less than or equals to the second.
		Evaluates to 1 if the first expression is less than or equals to the second.

`&&`	`Logical AND`	Returns 1 if both expressions evaluate to truthy values, otherwise 0.
`||`	`Logical OR`	Returns 1 if at least one of the two expressions evaluate to a truthy value, otherwise 0.

4.3. Conditional Operators

Expressions that evaluate to a specified expression based on the truthiness of a specified expression. There are two types of conditional expressions, ternary expressions and `switch` expressions.

A ternary expression, written as `cond-expr ? expr-if-true : expr-if-false` works like an if-else conditional statement. It evaluates to `expr-if-true` if `cond-expr` is numeric and truthy, or `expr-if-false` if `cond-expr` is numeric and falsey. If `cond-expr` is empty, the expression evaluates to empty.

The `switch` statement takes a optional parameter, and a list of cases that correspond with case statements should the case evaluate to true. In the event that multiple cases are true, the statement of the first true case encountered will be evaluated. An example is provided below:

```
[1,1] foo := 3;
return switch() {
        case foo == 2:
                "foo is 2";
        case foo == 3, foo == 4:
                "foo is 3 or 4";
        default:
                "none of the above";
}
/* Equivalently: */
return switch (foo) {
        case 2: "foo is 2";
        case 3,4: "foo is 3 or 4";
        default: "none of the above";
}
```

4.4. Range Slicing

As mentioned earlier, the composite **range** type has the ability to slice in both an absolute and relative fashion. Slicing allows the programmer to capture a portion of the range in either dimension, with the first dimension specified being inclusive and the second being exclusive. There are multiple ways to slice ranges, which are illustrated below.

```
foo[1,2] /* This evaluates to the cell value at row 1, column 2. */
foo[1,] /* Evaluates to the range of cells in row 1. */
foo[,2] /* Evaluates to the range of cells in column 2.*/
foo[,[1]] /* The internal brackets denote RELATIVE notation.
In this case, 1 column right of the one currently being operated on. */
foo[5:, 7:] /* 5th row down, and 7th column from the absolute origin.
foo[[1:2], [5:7]]
/* Selects the rows between the 1st and 2nd row from current row */
/* Selects the columns between 5th and 7th column from current column */
```

It's important to note that the value of a range that is not 1 by 1 is a range, but the value of a 1 by 1 range is dereferenced to the result of the cell formula.

5. Functions

Functions lie at Extend's core; however, they are not *first class objects.* Since it can be verbose to write certain operations in Extend, the language will feature a small number of built-in functions and and a comprehensive standard library. An important set of built-in functions will handle I/O (see section 6.4). Besides the built-in file I/O functions, all functions in Extend are free of side effects.

5.1. Format

Every function in Extend follows the same format, but allows some optional declarations. As in most programming languages, the header of the function declares the parameters it accepts and the dimensions of the return value. 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:

```
[1,1] foo([1,1] arg) {
  return arg;
}
```

The leading `[1,1]` marks the return dimensions. `foo` is the function name. In parentheses the function arguments are declared, again with dimensions of the input. The body of the function follows, which in this case is only the return statement.

5.2. Variable Declaration

A variable declaration associates an identifier with a range 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 1x1 range, and if only a single dimension is listed instead of two, the identifier will be associated with a range consisting of one row and the specified number of columns. 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 either as literal integers or as expressions that evaluate to integers.

```
[2, 5] foo; // Declares foo as a range with 2 rows and 5 columns
[m, n] bar; // Declares bar as a range with m rows and n columns
baz; // Declares baz as a 1x1 range
[10] ham, eggs, spam; // Declares ham, eggs and spam as distinct 1x10 ranges
```

5.3. 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. The slices specifying the cell subset can contain arbitrary expressions, as long as the expression taken as a whole evaluates to an integer.

```
[5, 2] foo, bar;
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
```

```
/* The next line assigns foo[[-1],0] + 1 to every cell in
   both columns of foo, besides the first row */
foo[1:,0:1] = 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. Although this may appear wasteful, intermediate values can be garbage collected once they are no longer needed to calculate the function's return value.

5.3.1. 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.

```
/* 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;
```

5.4. Dimension Assignment

Extend will feature gradual typing for function declarations. This will enable users with a weak experience in typing to use the language, while allowing more sophisticated developers to enforce type checking at compile time. In addition, it allows the developer to return ranges whose size is an unpredictable or complex function of the inputs.

To avoid specifying the precise return dimensions, an underscore can be used. This marks a variable range. Thus our function now looks like this:

```
[_,1] foo([5,5] arg1, [1,1] arg2) {
  return arg1[0:arg2 ,0];
}
```

Here we are selecting a range from arg1 that depends on the value of arg2 and can therefore not be known ahead of time.

5.5. Parameter Declarations

If a parameter is declared with an identifier for the dimensions, instead of an integer literal, that identifier will contain the dimension size of the argument inside the function. In addition, expressions consisting solely of other identifiers are allowed, and will cause a run-time error if the sizes of the arguments are not consistent.

However Extend will feature even more options to specify ranges. If a certain operation should be applied to a range of numbers of unknown size, the size can be inferred at runtime and match the return size:

```
[m,1] foo([m,1] arg) {
  return arg[0:m, 0] + 1;
}
```

This function will add 1 to each element in arg. Notice, that `m` is used across the function as a variable identifier to apply the operation to the range.

Summarizing, we have 3 ways of specifying a return range:

Type	Symbol Example	Description
Number	3	A number is the simplest descriptor. It specifies the absolute return size
Expression	bar * 2	An expression that can be anything, ranging from a simple arithmetic operation to a function call. To use this, any identifier used, must also be present as a range descriptor in a function parameter.
Underscore	_	This marker is unique, since it is a wildcard. While the other options aim to be specific, the underscore circumvents declaring the range size.

5.6. Application on Ranges

Extend gives the developer the power to easily apply operations in a functional style on ranges. As outlined in the section above, there are various ways to apply functions to ranges. A feature unique to Extend is the powerful operation on values and ranges. To apply a function on a per cell basis, the corresponding variable needs to be preceded by "#". The following function applies cell wise addition:

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

If we want to apply a function to the whole range at once we drop the leading symbol. Thus matrix addition takes the following shape:

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

While both function above result in the same value, and only show the syntactical difference. If we wanted each cell to to be the square root divided by the sum of the input we have the following:

```
[m] foo([m] arg) {
  [m] bar := sqrt(#arg) / sum(arg);
  return bar;
}
```

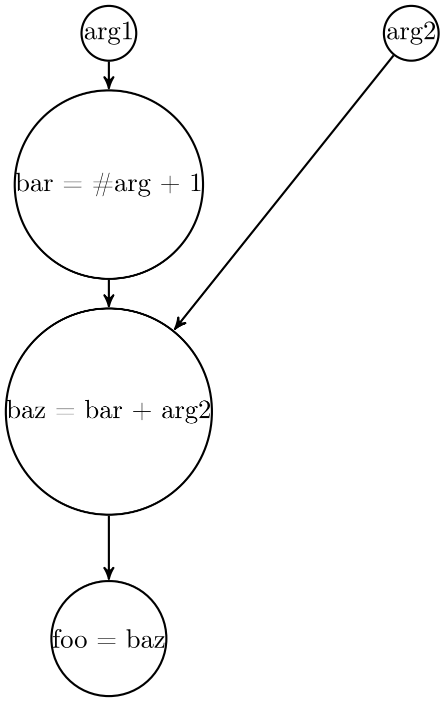
Notice that `arg` is only once preceded by `#`.

5.7. Dependencies Illustrated

The dependency resolution is another asset that sets Extend apart from other languages. Most languages compile ordinarily and execute the given commands sequentially. Extend builds a dependency graph. The advantage of this is that only relevant code segments will be executed. Given the function

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

The dependency graph will look like this:



Notice that `faz` does not appear in the graph, because it is not relevant for the return value. Ultimately this graph enables Extend to find the leaves, evaluate code paths in the best configuration and even in parallel.

6. Built-In Functions

6.1. isEmpty

Since `empty` cannot be compared to any other value using the boolean operators, the built-in function `isEmpty(expr)` can be used to determine whether the supplied expression evaluates to `empty`. It returns 1 if the supplied argument is empty and 0 otherwise.

6.2. Dimension and Position Functions

The built-in function `size(expr)` returns a 1x2 range containing the number of rows and columns, in that order, of the value of that expression. `size(empty)` returns `{0, 0}`. The built-in functions `row()` and `column()` return the row index or column index of the cell in which they are evaluated. Examples include:

```
/* The 5x5 identity matrix */
[5,5] id := row() == column() ? 1 : 0;
```

```
/* A 1x10 range in which the first 5 cells evaluate to "left"
   and the next 5 cells evaluate to "right" */
[1,10] left_half := column() < 5 ? "left" : "right";
```

6.3. Serialization and Deserialization

The built in functions `toString(expr)` and `fromString(s)` will serialize an expression to a string and vice versa. If expr is a range, `toString()` will evaluate the value of every cell in the range, proceeding from left to right within a row and from top to bottom within the range, and will produce a string that could be used as a range literal in a source file. `fromString()` will do the reverse. Note that these functions do not comprise an eval() function; toString() will only have numbers in its result, and fromString() will not deserialize a string containing anything besides literal values. They are provided mainly for convenience in loading and parsing complex datasets.

6.4. File I/O

Although the anticipated use cases of Extend generally do not include highly interactive programs, the language has built-in functions that allow the developer to read from and write to files, including standard input, output, and error. These functions are the only part of the language with side effects; as a result, the dependencies between expressions referencing the file I/O functions should be carefully analyzed by the developer to ensure that the program behaves as intended. The precedence operator -> can be used to create an artificial dependency between expressions to enforce the correct order of evaluation.

6.4.1. File Pointers

The built-in `open` and `close` functions open and close file pointers for reading and writing. An attempt to open a nonexistent file, or a file that the user does not have permission to read and write, will result in a runtime error causing the program to halt, as will an attempt to close a file pointer that is not open. The return value of `open` is a range that can be supplied as the file pointer argument to `close`, `read`, or `write`. The return value of `close` is `empty`. The built-in variables STDIN, STDOUT, and STDERR refer to file pointers that do not need to be opened or closed.

6.4.2. Reading and Writing

The built-in read, readline, and write functions read from and write to an open file pointer. read takes a maximum number of bytes and a file pointer as arguments and returns a 1-by-n range, where n is the lesser of the number of bytes actually read and the maximum number of bytes requested. If the maximum number of bytes requested is empty, the entire contents of the file are returned. readline takes a file pointer as argument and returns a 1-by-n range, where n is the number of bytes between the current position of the file pointer and the first newline encountered or EOF, whichever occurs first. The newline, if present, is included in the returned range. The arguments to write are a 1-by-n range and a file pointer and the return value is empty.

6.4.3. Example using the precedence operator

```
bmi() {
  q1 := write("What is your height in inches?\n", STDOUT);
  height := q1 -> parseFloat(readline(STDIN));
  q2 := height -> write("What is your weight in pounds?\n", STDOUT);
  weight := q2 -> parseFloat(readline(STDIN));
  return weight * 703 / height ** 2;
}
```

7. Entry Point

7.1. `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. If the function declaration includes parameters, the first argument will be a 1-by-n range containing the command line arguments. Any other parameters, if declared, will evaluate to empty.

8. Example Program

```
main([1,n] args) {
  seqFP := open(args[0]);
  seq1 := readline(seqFP)[:-2]; // discard newline
  seq2 := seq1 -> readline(seqFP)[:-2];
  alignment := computeSequenceAlignment(seq1, seq2, 1, -1, -3);
  output := write(alignment[:,0], STDOUT) ->
            write(alignment[:,1], STDOUT) ->
            close(seqFP);
  return output;
}

[_,2] computeSequenceAlignment([m,1] seq1, [n,1] seq2,
  matchReward, mismatchPenalty, gapPenalty) {

  [m, n] scoreFromMatch, scoreFromLeft, scoreFromTop;
  [m, n] step, path;
  [1,n] seq2T := transpose(seq2);
  [m+1,n+1] score;

  score[0, 0] = 0;
  score[1:,0] = score[[-1],] + gapPenalty;
  score[0,1:] = score[,[-1]] + gapPenalty;
  score[1:,1:] = nmax(scoreFromMatch[[-1],[-1]],
      nmax(scoreFromLeft[[-1],[-1]], scoreFromTop[[-1],[-1]]));

  scoreFromMatch = #score + ((#seq1 == #seq2T) ? matchReward : mismatchPenalty);
  scoreFromLeft = score[[1],] + gapPenalty;
  scoreFromTop = score[,[1]] + gapPenalty;

  step = (#scoreFromMatch >= #scoreFromLeft) ?
      ((#scoreFromMatch >= #scoreFromTop) ? DDD : TTT) :
      ((#scoreFromLeft  >= #scoreFromTop) ? LLL : TTT);

  path[-1,-1] = 1;
  path[-1,:-1] = (step[,[1]] == LLL && !isEmpty(path[,[1]])) ? 1 + path[,[1]] : empty;
  path[:-1,-1] = (step[[1],] == TTT && !isEmpty(path[[1],])) ? 1 + path[[1],] : empty;
  path[:-1,:-1] = switch () {
    case step[[1],[1]] == DDD && !isEmpty(path[[1],[1]]):
      1 + path[[1],[1]];
    case step[,[1]] == LLL && !isEmpty(path[,[1]]):
      1 + path[,[1]];
    case step[[1],] == TTT && !isEmpty(path[[1],]):
      1 + path[[1],];
  };

  pathLen := path[0,0];
  [m, 1] seq1Positions := pathLen - rmax(path[,:]);
  [1, n] seq2PositionsT := pathLen - rmax(path[:,]);
  [n, 1] seq2Positions := transpose(seq2PositionsT);
  [pathLen, 1] resIdx := colRange(0, pathLength);
  [pathLen, 1] seq1Loc := match(resIdx, seq1Positions);
  [pathLen, 1] seq2Loc := match(resIdx, seq2Positions);

  [pathLength, 2] results;
  results[:,0] = seq1[seq1Loc];
  results[:,1] = seq2[seq2Loc];

  return results;
}
```