Yet Another Lisp Interpreting Experiment

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Introduction

One of the historical attractions of the Lisp family of programming languages has been their flexibility. Lisp was one of the first languages to include dynamic typing, and Lisp macros allow the programmer to create new binding forms and control structures. This flexibility is one of the reasons for Lisp's popularity in the AI community. Programmers can implement domain-specific mini-languages without losing the infrastructure of a full language implementation.

Another strength of Lisp is its elegance. The S-expression syntax allows Lisp to treat lists as code. Thus Lisp macros, by constructing and returning lists of symbols, actually return instructions to be executed. This is one of the more confusing aspects of Lisp for newcomers, to be sure, but it also simplifies the language in an important sense. Where most languages have code and data, Lisp has only data. In the long run, fewer "moving parts" means fewer distinct concepts that a programmer needs to keep in mind to understand his language.

More recent developments, however, have seen Lisp fall behind. In particular, the Smalltalk language demonstrated that it is possible to treat everything in a language as an "object." The popular Python and Ruby languages have adopted many concepts from Smalltalk with great success. Several object-oriented variants of Lisp have been developed, including the Common Lisp Object System, but these have not achieved nearly the same popularity. We wish to suggest that one of the failings of various Lisp object systems is that they are built for the wrong reasons.

Through object-orientation, Smalltalk was able to achieve greater flexibility and greater simplicity. These goals are essentially orthogonal to the goal of facilitating an object-oriented programming style. Lisp object systems have attempted the latter, and as a result they have generally made their languages more complicated and less consistent. We believe that object-orientation can greatly enhance Lisp's core strengths, but only if these concepts are introduced consistently throughout the entire language.

This is the intention of Yet Another Lisp Interpreting Experiment (or, "Yalie"). Our goal is to demonstrate a Lisp variant in which everything is an object and all function calls are based on message passing. In doing this, we hope to make the language less complicated, rather than more so. An interactive interpreter for Yalie, written in Python, accompanies this paper. What follows is a formal description of the language implemented in that interpreter. For a more practical description with examples, please see the accompanying README file. This paper assumes the reader is familiar with a modern Lisp dialect such as Scheme or Common Lisp.

Concepts

Object-based Languages

Broadly speaking, there are two major categories of object-oriented languages[1]. The most familiar and widely used are the "class-based" languages, including C++, Java, and Smalltalk. The other category is "object-based" or "prototype-based" languages, like JavaScript and Lua. Class-based languages distinguish classes from the objects that belong to them, and inheritance is accomplished within the class hierarchy. Object-based languages omit this distinction, and instead allow objects to inherit from one another and produce their own clone or child objects. In practice, object-based languages often approximate classes by using certain objects solely for inheritance,

and for that reason—and because of the wider popularity of class-based languages—some have argued that making classes an explicit part of the language is more convenient[2]. Our primary purpose here, though, is simplicity and consistency, so ours will be an object-based semantics.

Message Passing

As a demonstration of the consistency possible with object orientation, all of the semantics of our language aside from literal syntax is based on message passing. This is very different from traditional Lisp semantics and requires some explanation. For an example, suppose we wish to evaluate the S-expression

```
(+ 1 2).
```

That is a list object (a series of cons objects, in fact) containing a symbol object and two integer objects. Evaluation begins by calling the `eval` method of the list. As with all Lisp dialects, S-expressions represent function calls, so the `eval` method of a list calls the `eval` method of its first element, expecting a function or special form object of some kind. The `eval` method of the `+` symbol returns the binding of that symbol in the calling scope, which is indeed a function. The list `eval` then invokes the `call` method of that object, passing the remainder of the list as arguments, and finally returns 3.

Traditionally, S-expressions represented function calls because a central evaluation loop interpreted them that way. Here they represent function calls because their `eval` method carries out a function call. Note also that functions and forms in Yalie are just ordinary objects with a defined `call` method. We will construct a few predefined global functions and forms in Yalie, and these will be just ordinary objects with `call` methods that we define usefully.

Another key difference in this function is the way `+` is defined, which is not immediately visible. Rather than being a builtin operation that knows about integers, `+` simply calls invokes a method of its arguments. This method is also named `+`, though it resides in method tables rather than the global scope as the `+` function does. One of the global functions we will define is `msg`, which allows the user to invoke methods explicitly. Expressed using `msg`, the S-expression we considered above can be rewritten as

```
(msg 1 + 2).
```

That is, adding 1 to 2 means sending the `+` message to the object 1 with the argument 2. In full detail, the `eval` method of that list evaluates the symbol `msg`, whose value is a special form object with a `call` method that passes that messages. When that `call` method is invoked, it evaluates its first argument, the 1 object, and invokes the method named by its second argument, passing the rest of its arguments to that method.

Something to keep in mind as we continue is that anything defined as a method can be invoked explicitly or even redefined by the user. Thus, the first S-expression could be rewritten again as

```
(msg + call 1 2),
```

and the second could even be rewritten

```
(msg msg call 1 + 2).
```

The latter is not particularly useful, but it illustrates what is going on "under the hood." We will discuss the facilities for defining and redefining new methods in later sections.

Semantic Machinery

The semantics of our language will be built from several different components. Persistent, often mutable objects will be the core of our language, so evaluation will use both a scope and a store. A scope is a map from names to positive integer values. We will refer to these integers suggestively as pointers. We denote scopes by the variable φ, with the global scope—that is, the builtin scope in which program evaluation begins—denoted by Φ. A store is then a map from these pointers to objects, and this indirection allows us to mutate objects by modifying the store. We denote a store by the variable σ, and the global store, analogous to the global scope, is denoted by Σ. We will frequently refer to the pointers to certain builtin objects using capitalized names like

ROOT, the primary object at the top of the inheritance hierarchy, or INT, the object from which all integers inherit. The objects to which these pointers refer are then written $\Sigma(\mathsf{ROOT})$ and $\Sigma(\mathsf{INT})$. The actual values of these pointers are arbitrary, so long as they are constant and unique. The only other way we will refer to pointer values is the $\text{next}(\sigma)$ function, whose value is the smallest pointer not currently in the domain of σ. We will generally use the variable ω to denote pointers, though we will also use the variable a to refer to arguments to functions and e to refer to the results of evaluation.

An object has four important properties. It has a parent object from which it inherits method functions, a map of its own from names to method functions, a scope of member elements, and a field for underlying data such as an integer or a name. We will define objects as ordered 4-tuples, written

$$\langle p, \mu, \varphi, d \rangle .$$

For example, the integer five would be represented as

$$\langle \mathsf{INT}, \mu_0, \varphi_0, 5 \rangle ,$$

where μ_0 is the empty function map, and φ_0 is the empty scope. We will frequently use the notation $\mu_{\sigma(\omega)}$ and $\varphi_{\sigma(\omega)}$ to refer to the function map or scope elements of the object $\sigma(\omega)$.

We have already mentioned the function $\text{next}(\sigma)$, but we should like to introduce two more semantic function here that we will use later. The first is our function for looking up methods, using the "message-passing" terminology of Simula and Smalltalk. When a method cannot be found in the method table of a given object, it's parent is queried recursively.

$$\text{lookup}(\text{“msg”}, \sigma, \omega) = \begin{cases} \varphi_{\sigma(\omega)} & \text{if “msg”} \in \text{Domain}(\varphi_{\sigma(\omega)}) \\ \text{lookup}(\text{“msg”}, \sigma, p_{\sigma(\omega)}) & \text{otherwise} \end{cases}$$

The second function we need to define at the moment is the semantic function for invoking methods. We mentioned the global `msg` object in the preceding section, and this semantic function will eventually form the core of that object's `call` method, in addition to being used explicitly by many other methods. The invocation of a method requires the current store and scope as well as pointers to invoking object and all the arguments of the method, the latter expressed as an ordered tuple. Method functions will be defined so that the value of an invocation is a 3-tuple containing the new store and scope and a pointer to the object returned by the method.

$$\text{invoke}(\text{“msg”}, \sigma, \phi, \langle a_1, \ldots a_n \rangle) = (\text{lookup}(\text{“msg”}, \sigma, \omega))(\sigma, \phi, \omega, \langle a_1, \ldots a_n \rangle)$$

Syntax

With the goal of unifying code and data, we will take a two-part approach to specifying the semantics of our language. First, we will describe the translation from syntax to literal objects. Then we will define the methods available to those objects. Invocation of the `eval` methods of our code will be responsible for most of the work done by a program, and ultimately our denotational semantic operator, $[\![-]\!]$, will be the simple combination of the parse and invoke operations with Σ and Φ.

Literal Objects

Yalie contains only three literal objects: integers, symbols, and lists. Integers are written as strings of decimal digits. Symbols are written as any string of characters (other than those defined as punctuation in this section) that is not an integer. Lists are written as a sequence of whitespace-separated literals enclosed by matching parentheses. We define a parsing function that takes as arguments an abstract syntax expression and an initial store, and returns a tuple containing a pointer to the new object and the updated store. Integers are thus parsed as

$$\text{parse}(\texttt{NUM}, \sigma) = \langle \text{next}(\sigma), [\sigma |\, \text{next}(\sigma) \rightarrow \langle \mathsf{INT}, \mu_0, \varphi_{\Sigma(\mathsf{INT})}, \texttt{NUM} \rangle] \rangle ,$$

and symbols are parsed as

$$\text{parse}(\texttt{SYM}, \sigma) = \langle \text{next}(\sigma), [\sigma |\, \text{next}(\sigma) \rightarrow \langle \mathsf{SYMBOL}, \mu_0, \varphi_{\Sigma(\mathsf{SYMBOL})}, \texttt{SYM} \rangle] \rangle .$$

Note that the parent of each new integer or symbol object is the global integer or symbol object, respectively. These objects are created with an empty method table, meaning that they inherit all of their methods by default. They also copy the member scope of their parent, which is empty by default unless modified by the user.

Finally, lists are parsed into "cons" objects, as is traditional for Lisp languages. The underlying data field, d, of these cons objects will be an ordered pair of the form $\langle a, b\rangle$, and they will be chained together to form linked lists terminated in a "nil" object. List parsing will be defined in two steps. First, the empty list is parsed as

$$\text{parse}(\texttt{()}, \sigma) = \langle \text{next}(\sigma), [\sigma |\, \text{next}(\sigma) \rightarrow \left\langle \mathsf{NIL}, \mu_0, \varphi_{\Sigma(\mathsf{NIL})}, \varnothing \right\rangle] \rangle .$$

This is similar to the integer and symbol parsing operations above, though note that the data field of nil objects is ignored. List parsing for nonempty lists can now be defined recursively.

$$\text{parse}(\texttt{(a b ... z)}, \sigma) = \langle \text{next}(\sigma''), [\sigma'' |\, \text{next}(\sigma'') \rightarrow \left\langle \mathsf{CONS}, \mu_0, \varphi_{\Sigma(\mathsf{CONS})}, \langle F, R\rangle \right\rangle] \rangle$$

where

$$\langle F, \sigma' \rangle = \text{parse}(\mathtt{a}, \sigma)$$
$$\langle R, \sigma'' \rangle = \text{parse}(\texttt{(b ... z)}, \sigma')$$

This expression can be slightly confusing. F denotes the pointer to the first parsed object in a list, and σ' is the store after parsing that object. R then denotes the pointer to the rest of the list, acquired recursively, and σ'' is the store after all that parsing is done. The whole list is finally assembled by adding to σ'' the cons cell at the head of the list.

Syntactic Sugar

In addition to these literals, we define some extra translational syntax for convenience. First we give a dot operator for message passing, and second we will provide a quote operator to protect objects from automatic evaluation.

As we mentioned above, message passing is invoked using the `msg` special form, in the manner

```
(msg obj message [args...]).
```

We supply the dot operator to avoid writing that entire S-expression for every method call. Without parentheses, `a.b` translates as

```
a.b → (msg a b).
```

When placed after the first element of an S-expression, the dot operator subsumes the rest of the S-expression as arguments. Thus `(a.b c...)` translates as

```
(a.b c...) → (msg a b c...).
```

Finally, when there are multiple consecutive infix operations at the front of an S-expression, we evaluate from left to right and allow the final infix to capture the expression. Thus `(a.b.c d e)` translates as

```
(a.b.c d e) → (msg (msg a b) c d e).
```

Another global special form that we define is the `quote` operator, which protects objects from evaluation. We define the accompanying grave quote as a prefix operator that takes precedence over the dot, and we translate `‘a` as

```
‘a → (quote a).
```

Accompanying the quote syntax we provide unquote and splice syntax, in the manner of Common Lisp and Scheme. These translate as

```
,a → (unquote a)
;a → (unquote-splice a).
```

Note that `unquote` and `unquote-splice` are not defined as separate operators but are rather ordinary symbols that the `quote` operator looks for and handles itself. Note also that the semicolon is used for splicing in Yalie, instead of the comma-at operator used in other Lisps. Comments in Yalie are denoted by a hash mark, as is common in scripting languages.

Builtin Objects and Methods

This section is incomplete.

A example of a method definition is the `copy` method of the root object, which all other objects inherit. This method returns an exact duplicate of the calling object, with the same parent, methods, members, and underlying data. It is defined as

$$\mu_{\Sigma(\mathsf{ROOT})}(\text{“copy”})(\sigma, \phi, \omega, \langle\rangle) = \langle [\sigma |\, \text{next}(\sigma) \to \sigma(\omega)], \phi, \text{next}(\sigma) \rangle$$

Conclusions

Several different interpreters were created at different stages in this project, but the “call” and “eval” semantics as described in this paper were only conceived for the final version. The ease of coding these semantics relative to the more standard approach (using a central eval loop) was striking, both in reduced programming time and in reduced debugging time. These semantics are also far easier to modify than any previous.

The language is still very small, so some of the benefits of the object-oriented approach are not yet apparent. One tangible benefit is that, despite having gutted the entire language to allow the ubiquitous use of objects, the only difference visible in the global namespace is the existence of the `msg` function. All other object-oriented functionality is confined within the method spaces. If we were to further extend the language—with strings and file handles for example—we would see the same benefits repeated, with new functionality mostly confined to method spaces. Not only does this approach keep the global namespace free of clutter, it also provides helpful documentation in the form of method lists.

The example of adding a factorial method to the entire set of integers (see accompanying README) demonstrates the flexibility of the object-oriented approach, and though the language is still small, the improved consistency of the semantics has already made itself felt during the implementation process. We look forward to finding new ways of leveraging the abstractions of object-orientation, both by themselves and in conjunction with Lisp’s macro system.

References

[1] M. Abadi and L. Cardelli. *A Theory of Objects.* New York: Springer, 1996.

[2] K. B. Bruce. *Foundations of Object-Oriented Languages.* Cambridge, Massachusetts: MIT Press, 2002.