Symbols and S-Expression Trees

CS251 Programming Languages
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Paul Graham's *Revenge of the Nerds*

What made Lisp different

6. **Programs composed of expressions.** Lisp programs are trees of expressions, each of which returns a value. …

7. **A symbol type.** Symbols are effectively pointers to strings stored in a hash table. So you can test equality by comparing a pointer, instead of comparing each character.

8. **A notation for code using trees of symbols and constants.**
*[Lyn adds: these trees are called **symbolic expressions** = **s-expressions**]*

9. **The whole language there all the time.** There is no real distinction between read-time, compile-time, and runtime. … reading at runtime enables programs to communicate using s-expressions, an idea recently reinvented as XML. *[Lyn adds: and JSON!]*

Symbols

Lisp was invented to do **symbolic processing. (**This was thought to be the core of Artificial Intelligence, and distinguished Lisp from Fortran (the other main language at the time), whose strength with **numerical processing**.)

A key Racket value is the **symbol**.

The symbol `cat` is written `(quote cat)` or `'cat`.

Symbols are values and so evaluate to themselves.

```
> 'cat
'cat

; 'thing is just an abbreviation for (quote thing)
> (quote cat)
'cat
```

Symbols are similar to strings, except they're **atomic**; we don't do character manipulations on them.

Testing Symbols for Equality: `eq?`

The key thing we do with symbols is test them for equality with `eq?` (pronounced "eek"). A symbol is `eq?` to itself and nothing else.

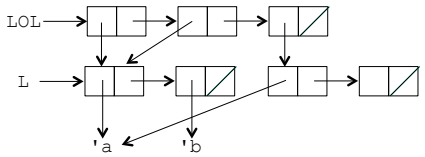
```
> (eq? 'cat 'cat)
#t
> (map (λ (s) (eq? s 'to))
       (list 'to 'be 'or 'not 'to 'be))
'(#t #f #f #f #t #f)
```

`eq?` on Symbols and Lists

`eq?` can be used on any Racket values. It is used to test if two values are the **same object** in memory.

In contrast, `equal?` tests **structural equality** of two values.

```
(define L (list 'a 'b))
(define LOL
  (list L L (list 'a 'b)))
```




```
> (eq? (first L) (second L))
#f
> (eq? (first L) (first (third LOL)))
#t
> (eq? (first LOL) (second LOL))
#t
> (eq? (first LOL) (third LOL))
#f
> (equal? (first LOL) (third LOL))
#t
```


More `eq?` examples

```
> (eq? "cat" "cat")
#t

> (eq? "cat" (string-append "c" "at"))
#f ; Two strings with the same chars not guaranteed eq?

> (equal? "cat" (string-append "c" "at"))
#t ; Two strings with the same chars guaranteed equal?

> (eq? (fact 5) (fact 5))
#t ; For "small" numbers, eq? is same as =

> (eq? (fact 1000) (fact 1000))
#f ; = bignums are not guaranteed eq?, but are equal?

> (eq? 'cat (string->symbol "cat"))
#t ; string->symbol returns unique symbol for a string

> (eq? (string->symbol "cat")
       (string->symbol (string-append "c" "at")))
#t ; only one symbol in memory with a given name
```


Quotation with Lists

As you've seen, a single quote can be used with parenthesized structures to denote lists.

You can think of `'(to be or not to be)` as a sugared form of `(list 'to 'be 'or 'not 'to 'be)`. (Not quite true, but useful.)

A quoted parenthesized structure `(quote (...))` (abbreviated `'(...)`) denotes a list, according to the following desugaring:

`(quote (`*`thing_1`* … *`thing_n`*`))`
desugars to `(list (quote` *`thing_1`*`)` … `(quote` *`thing_n`*`))`

Quoted Atoms

Atomic (indivisible) elements that can appear in list structures areare called ***atoms***. In Racket, atoms include numbers, booleans, and strings in addition to symbols.

```
(define (atom? x)
  (or (number? x) (boolean? x)
      (string? x) (symbol? x))))
```

A quoted atom `(quote` *`atom`*`)` (abbreviated `'`*`atom`*) denotes the atom. For atoms that are not symbols, `(quote` *`atom`*`)` desugars to *`atom`*. For example:

- `(quote 251)` desugars to `251`
- `(quote #t)` desugars to `#t`
- `(quote "Hi there!")` desugars to `"Hi there!"`

Example:
`'(5 #f "cat" dog)` desugars to `(list 5 #f "cat" 'dog)`

Quotation Exercise

1. Give the desugaring of the following quoted expression

```
'((17 foo #f) "bar" (list + (quote quux)))
```

2. Draw the box-and-pointer list structure of the value of this expression.

S-Expressions

Lisp pioneered ***symbolic expressions***, a.k.a. ***s-expressions***, a parenthesized notation for representing trees as nested lists (compare to other tree notations, like XML or JSON).

An s-expression is just a quoted structure that represents a tree of intermediate nodes (lists) with leaves that are atoms.

Example:

```
'((this is (a nested)) list (that (represents a) tree))
```


A sample s-expression

We will do some exercises with this sample s-expression:

```
(define tr '((a (b c) d) e (((f) g h) i j k)))
```

Draw the **tree** (not list structure) associated with this s-expression.

Functions on s-expression trees

Define the following functions that take an s-expression tree as their only arg:

1. `(sexp-num-atoms` *`sexp`*`)` returns the number of atoms (leaves) in the s-expression tree *`sexp`*

```
> (sexp-num-atoms tr)
11
```

2. `(sexp-atoms` *`sexp`*`)` returns a list of the atoms (leaves) encountered in a left-to-right depth first search of the s-expression tree *`sexp`*.

```
> (sexp-atoms tr)
'(a b c d e f g h i j k)
```

3. `(sexp-height` *`sexp`*`)` returns the height of the s-expression tree *`sexp`*.

```
> (sexp-height tr)
4
```

An s-expression Read-Eval-Print Loop (REPL)

```
(define (sexp-repl)
  (begin (display "Please enter an s-expression:")
     (let {[(sexp (read)]} ; read prompts user for sexp
       (if (eq? sexp 'quit)
            'done
            (begin (display (list 'sexp-num-atoms:
                                  (sexp-num-atoms sexp)))
                   (newline)
                   (display (list 'sexp-atoms:
                                  (sexp-atoms sexp)))
                   (newline)
                   (display (list 'sexp-height:
                                  (sexp-height sexp)))
                   (newline)
                   (sexp-repl))))))
```


On to Metaprogramming

A ***metaprogram*** is a program that manipulates another program, such as an interpreter, compiler, type checker, assembler, etc.

Q: In a metaprogram, how could we represent a Racket definition like this?

```
(define avg (lambda (a b) (/ (+ a b) 2)))
```

A: By adding a single quote mark!

```
'(define avg (lambda (a b) (/ (+ a b) 2)))
```

Does this give you a new appreciation for Lisp and what Paul Graham said about it?

Metaprogramming Example 1

Define an `is-valid-lambda` function that takes an sexp and returns #t iff it is a valid Racket lambda expression. Assume parameters *must* be a list of identifiers, and that there is a single body expression. (Racket is actually more flexible than this.)

```
> (is-valid-lambda? '(lambda (a b) (/ (+ a b) 2)))
#t

> (is-valid-lambda? '(lamdba (a b) (/ (+ a b) 2)))
#f

> (is-valid-lambda? '(lambda foo (/ (+ a b) 2)))
#f

> (is-valid-lambda? '(lambda (a b) a b)
#f
```


Metaprogramming Example 2

Define a `desugar-let` function that takes an sexp that is a valid Racket let expression and transforms it to the application of a lambda.

```
> (desugar-let '(let ((a (* 2 3))
                      (b (+ 4 5)))
                  (- (* 10 a) b)))

((lambda (a b) (- (* 10 a) b)) (* 2 3) (+ 4 5))
```