**Symbols and S-Expression Trees**

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**Paul Graham’s Revenge of the Nerds**

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**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!]

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**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.

```lisp
> 'cat
'cat
> (quote cat)
'cat
```

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

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

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**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.

```lisp
> (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.

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

### More `eq?` examples

<table>
<thead>
<tr>
<th>Expression</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(eq? (first L) (second L))</code></td>
<td>#f</td>
</tr>
<tr>
<td><code>(eq? (first L) (first (third LOL)))</code></td>
<td>#t</td>
</tr>
<tr>
<td><code>(eq? (first LOL) (second LOL))</code></td>
<td>#t</td>
</tr>
<tr>
<td><code>(eq? (first LOL) (third LOL))</code></td>
<td>#f</td>
</tr>
<tr>
<td><code>(equal? (first LOL) (third LOL))</code></td>
<td>#t</td>
</tr>
</tbody>
</table>

### Symbols & S-expressions

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 (...) `(quote thing_1) ... `(quote thing_n))` denotes a list, according to the following desugaring:

```racket
(quote (thing_1 ... thing_n))
```

### Quoted Atoms

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

```racket
(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:

`(quote (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? '(lambda (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))