Symbols and S-Expression Trees

SOLUTIONS

CS251 Programming Languages
Fall 2018, Lyn Turbak
Department of Computer Science
Wellesley College

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.

\[
\text{LOL} = \text{list 'a 'b)}
\]

\[
\text{L} = \text{first LOL}
\]

\[
\text{'a} = \text{first L}
\]

\[
\text{'b} = \text{second L}
\]

More `eq?` examples

\[
\text{eq? (first L) (second L))}
\]

#f

\[
\text{eq? (first LOL) (first (third LOL)))}
\]

#t

\[
\text{eq? (first LOL) (second (LOL))}
\]

#t

\[
\text{eq? (first LOL) (third LOL))}
\]

#f

\[
\text{equal? (first LOL) (third LOL))}
\]

#t

\[
\text{eq? ("cat" "cat")}
\]

#t

\[
\text{eq? ("cat" (string-append "c" "at"))}
\]

#f ; Two strings with the same chars not guaranteed eq?

\[
\text{equal? ("cat" (string-append "c" "at"))}
\]

#t ; Two strings with the same chars guaranteed equal?

\[
\text{eq? (fact 5) (fact 5))}
\]

#t ; For "small" numbers, eq? is same as =

\[
\text{eq? (fact 1000) (fact 1000))}
\]

#f ; = bignums are not guaranteed eq?, but are equal?

\[
\text{eq? 'cat (string->symbol "cat")}
\]

#t ; string->symbol returns unique symbol for a string

\[
\text{eq? (string->symbol "cat")}
\]

#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))

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))`

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

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

   ![Box-and-Pointer List Structure Diagram]

   Symbols & S-expressions

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).

In these trees, nodes can have any number of children. Such trees are called rose trees ("rhododendron", in Greek).

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)`

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`

   ```scheme
   (define (sexp-num-atoms sexp)
     (if (atom? sexp)
         1
         (foldr + 0 (map sexp-num-atoms 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`

   ```scheme
   (define (sexp-atoms sexp)
     (if (atom? sexp)
         (list sexp)
         (foldr append '() (map sexp-atoms-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`

   ```scheme
   (define (sexp-height sexp)
     (if (or (atom? sexp) (null? sexp))
         0
         (+ 1 (foldr max 0 (map sexp-height sexp))))))```

   > `(sexp-height tr)`
   4

A sample s-expression

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

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

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

![S-expression Tree Diagram]

Symbols & S-expressions 9

Symbols & S-expressions 10

Symbols & S-expressions 11

Symbols & S-expressions 12
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

(define (is-valid-lambda? sexp)
  (and (list? sexp)
       (= (length sexp) 3)
       (eq? (first sexp) 'lambda)
       (list? (second sexp))
       (forall? symbol? (second sexp))))

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))
                  (c (* 10 a) b))
                  (+ 2 3) (+ 4 5))

'(define (desugar-let sexp)
  (make-call (make-lambda (let-binding-names sexp)
                           (let-body sexp))
             (let-binding-defns sexp)))

;; Note liberal use of readable syntactic abstractions!
(define (desugar-let sexp)
  (make-call (make-lambda (let-binding-names sexp)
                           (let-body sexp))
             (let-binding-defns sexp)))

(define (let-binding-names sexp) (map first (second sexp)))
(define (let-binding-defns sexp) (map second (second sexp)))
(define let-body third)
(define (make-lambda params body) (list 'lambda params body))
(define (make-call funexp argexps) (cons funexp argexps))