Calculator

Announcements

Symbolic Programming

Symbolic Programming

Symbols normally refer to values; how do we refer to symbols?

```
> (define a 1)
> (define b 2)
> (list a b)
(1 2)
```

No sign of “a” and “b” in the resulting value

Quotation is used to refer to symbols directly in Lisp.

```
> (list 'a 'b)
(a b)
> (list 'a b)
(a 2)
```

Short for (quote a), (quote b): Special form to indicate that the expression itself is the value.

Quotation can also be applied to combinations to form lists.

```
> '(a b c)
(a b c)
> (car '(a b c))
a
> (cdr '(a b c))
(b c)
```

(Demo)

List Processing

Built-in List Processing Procedures

(append s t): list the elements of s and t; append can be called on more than 2 lists

(map f s): call a procedure f on each element of a list s and list the results

(filter f s): call a procedure f on each element of a list s and list the elements for which a true value is the result

(apply f s): call a procedure f with the elements of a list s as its arguments

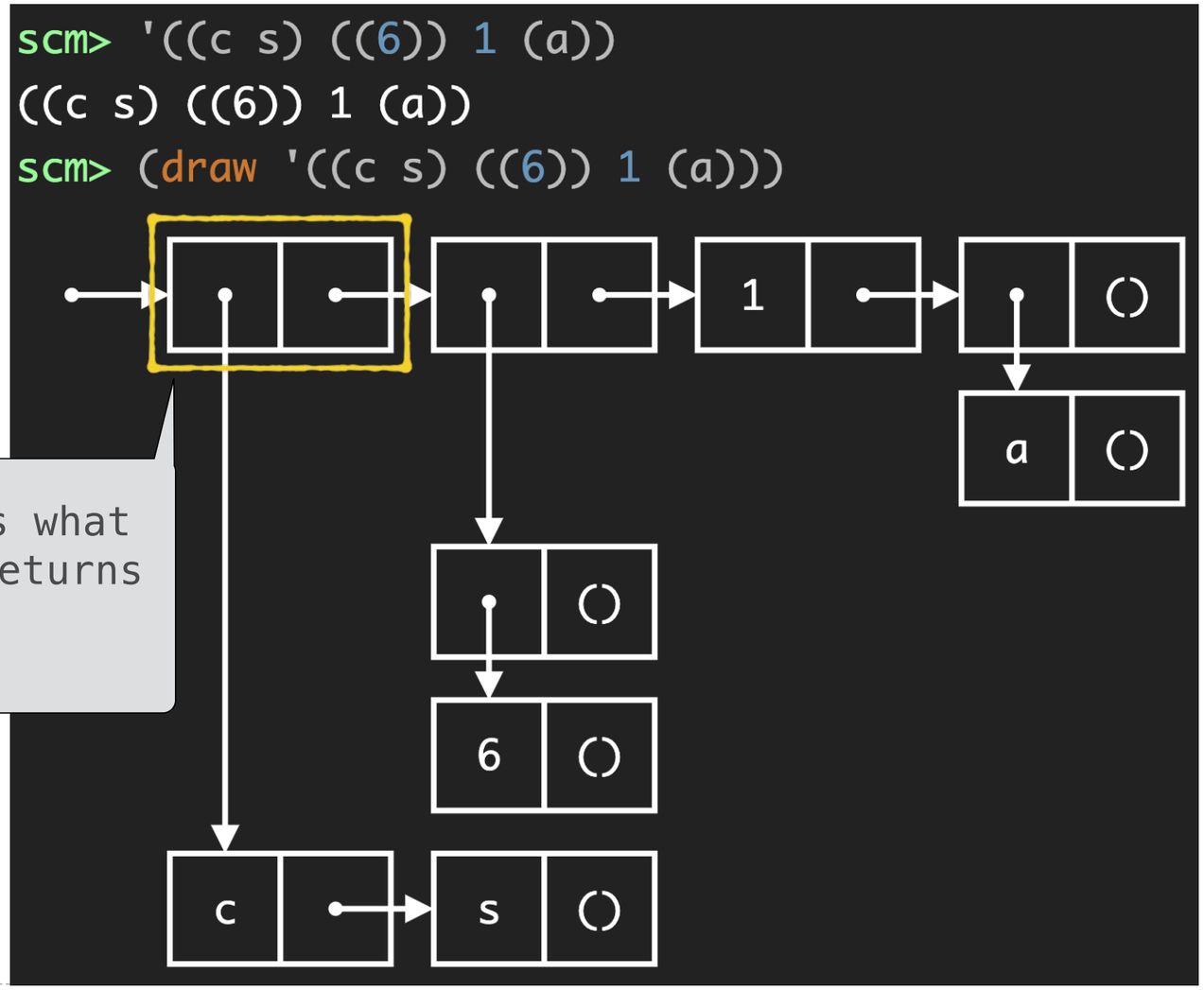
```
(1 2 3 4)                                  ; count
((and a 1) (and a 2) (and a 3) (and a 4)) ; beats
(and a 1 and a 2 and a 3 and a 4)          ; rhythm

(define count (list 1 2 3 4))
(define beats (map (lambda (x) (list 'and 'a x)) count))
(define rhythm (apply append beats))
```

Cons Count

Return how many cons cells appear in the diagram for a value s.

```
(define (cons-count s)
  (if (list? s)
      (+ (length s)
         (apply + (map cons-count s) ))
      0                              ))
```

A "cons cell" is what cons creates & returns



Exceptions

Reducing a Sequence to a Value

```
def reduce(f, s, initial):
    """Combine elements of s pairwise using f, starting with initial.

    E.g., reduce(mul, [2, 4, 8], 1) is equivalent to mul(mul(mul(1, 2), 4), 8).

    >>> reduce(mul, [2, 4, 8], 1)
    64
    """
```

f is ...

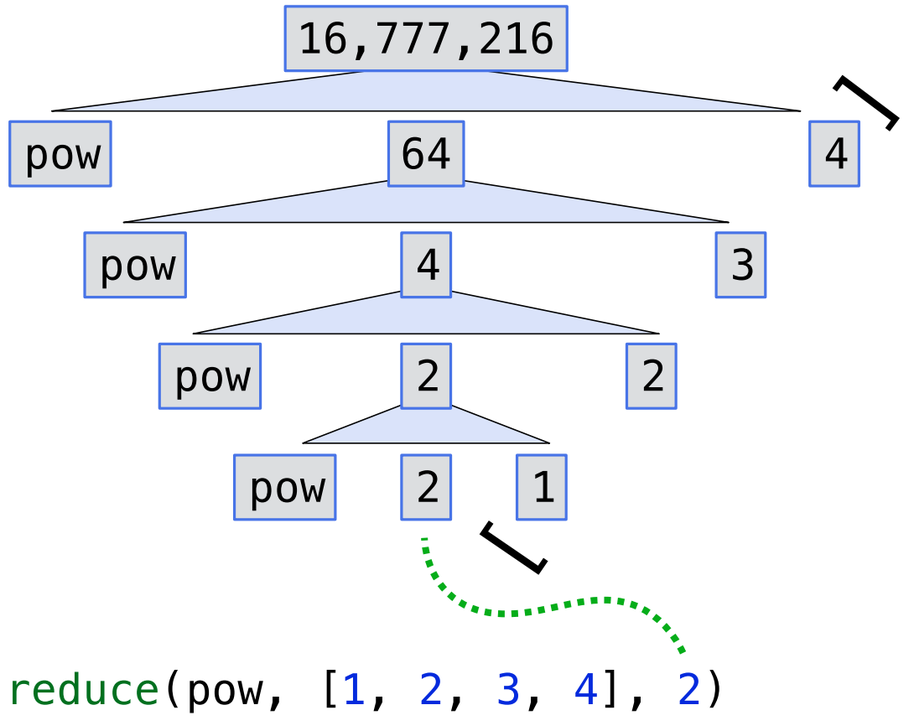
a two-argument function that returns a first argument

s is ...

a sequence of values that can be the second argument

initial is ...

a value that can be the first argument



(Demo)

Reduce Practice

Implement sum_squares, which returns the sum of the square of each number in a list s.

```
def reduce(f, s, initial):
    """Combine elements of s pairwise using f, starting with initial.

    E.g., reduce(mul, [2, 4, 8], 1) is equivalent to mul(mul(mul(1, 2), 4), 8).
>>> reduce(mul, [2, 4, 8], 1)
    64
    """

def sum_squares(s):
    """Return the sum of squares of the numbers in s.

    >>> sum_squares([3, 4, 5])  # 3*3 + 4*4 + 5*5
    50
    """
    return reduce( lambda x, y: x + y * y , s, 0)
```

The Pair Class

(Demo)

Reducing a Pair

A reduce that takes a function, a Scheme list represented as a Pair, and an initial value.

```
def reduce(fn, scheme_list, initial):
    """Reduce a Scheme list made of Pairs using fn and an initial value.

    >>> reduce(add, Pair(1, Pair(2, Pair(3, nil))), 0)
    6
    """
    if scheme_list is nil:
        return initial
    return ____________________________________________________

class Pair:
    def __init__(self, first, rest):
        self.first = first
        self.rest = rest
```

Scheme-Syntax Calculator

(Demo)

Calculator Syntax

The Calculator language has primitive expressions and call expressions. (That's it!)

A primitive expression is a number: 2 -4 5.6

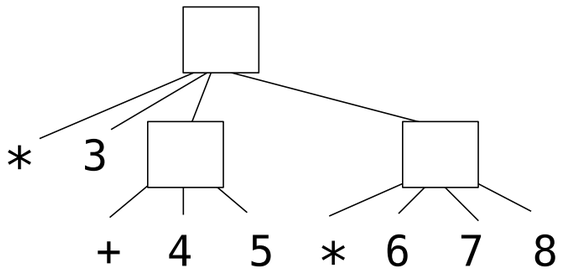
A call expression is a combination that begins with an operator (+, -, *, /) followed by 0 or more expressions: (+ 1 2 3) (/ 3 (+ 4 5))

Expressions are represented as Scheme lists (Pair instances) that encode tree structures.

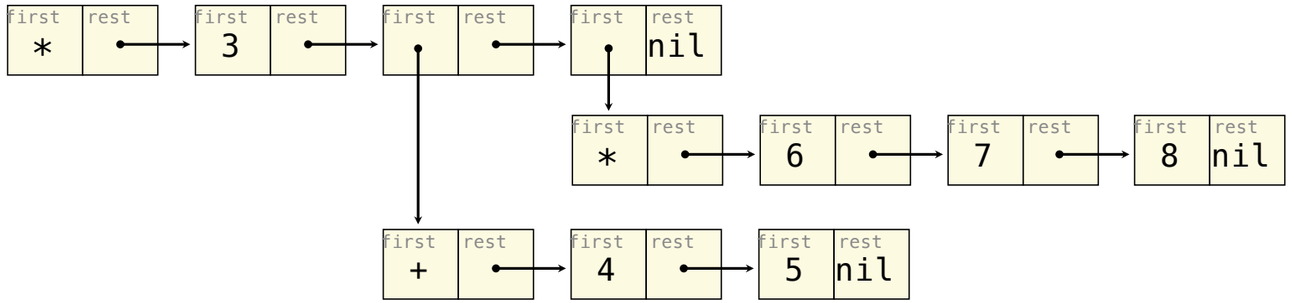
Expression

```
(* 3
   (+ 4 5)
   (* 6 7 8))
```

Expression Tree



Representation as Pairs



Calculator Semantics

The value of a calculator expression is defined recursively.

Primitive: A number evaluates to itself.

Call: A call expression evaluates to its argument values combined by an operator.

+: Sum of the arguments

*****: Product of the arguments

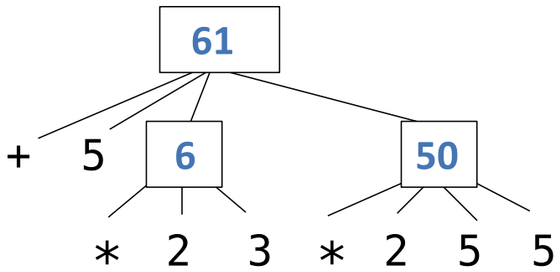
-: If one argument, negate it. If more than one, subtract the rest from the first.

/: If one argument, invert it. If more than one, divide the rest from the first.

Expression

```
(+ 5
   (* 2 3)
   (* 2 5 5))
```

Expression Tree



Evaluation

The Eval Function

The eval function computes the value of an expression, which is always a number

It is a generic function that dispatches on the type of the expression (primitive or call)

Implementation

```
def calc_eval(exp):
    if isinstance(exp, (int, float)):
        return exp
    elif isinstance(exp, Pair):
        arguments = exp.rest.map(calc_eval)
        return calc_apply(exp.first, arguments)
    else:
        raise TypeError
```

Recursive call returns a number for each operand

'+', '-', '*', '/'

A Scheme list of numbers

Language Semantics

A number evaluates...

to itself

A call expression evaluates...

to its argument values

combined by an operator

Applying Built-in Operators

The apply function applies some operation to a (Scheme) list of argument values

In calculator, all operations are named by built-in operators: +, -, *, /

Implementation

```
def calc_apply(operator, args):
    if operator == '+':
        return reduce(add, args, 0)
    elif operator == '-':
        ...
    elif operator == '*':
        ...
    elif operator == '/':
        ...
    else:
        raise TypeError
```

Language Semantics

+:

Sum of the arguments

-:

…

…

(Demo)

Interactive Interpreters

Read-Eval-Print Loop

The user interface for many programming languages is an interactive interpreter

1. Print a prompt
2. **Read** text input from the user
3. Parse the text input into an expression
4. **Evaluate** the expression
5. If any errors occur, report those errors, otherwise
6. **Print** the value of the expression and repeat

(Demo)