CS 61A Fall 2021

Scheme, Scheme Lists

Discussion 10: November 3, 2021 Solutions

##Walkthrough Videos

Feel free to try these problems on the worksheet in discussion or on your own, and then come back to reference these walkthrough videos as you study.

To see these videos, you should be logged into your berkeley.edu email.

Introduction

In the next part of the course, we will be working with the **Scheme** programming language. In addition to learning how to write Scheme programs, we will eventually write a Scheme interpreter in Project 4!

Scheme is a famous functional programming language from the 1970s. It is a dialect of Lisp (which stands for LISt Processing). The first observation most people make is the unique syntax, which uses a prefix notation and (often many) nested parentheses (see http://xkcd.com/297/). Scheme features first-class functions and optimized tail-recursion, which were relatively new features at the time.

Primitives and Defining Variables

Scheme has a set of **atomic** primitive expressions. Atomic means that these expressions cannot be divided up.

```
scm> 123
123
scm> #t
True
scm> #f
False
```

Unlike in Python, the only primitive in Scheme that is a false value is `#f` and its equivalents, `false` and `False`. **This means that 0 is not false.**

In Scheme, we can use the `define` special form to bind values to symbols, which we can then use as variables. When a symbol is defined this way, the `define` special form returns the symbol.

- `(define <variable name> <value>)`

Evaluates `<value>` and binds the value to `<variable name>` in the current environment.

WWSD

```
scm> (define a 1)
```

a

```
scm> a
```

1

```
scm> (define b a)
```

b

```
scm> b
```

1

```
scm> (define c 'a)
```

c

```
scm> c
```

a

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Call Expressions

Call expressions apply a procedure to some arguments.

```
(<operator> <operand1> <operand2> ...)
```

Call expressions in Scheme work exactly like they do in Python. To evaluate them:

1. Evaluate the operator to get a procedure.
2. Evaluate each of the operands from left to right.
3. Apply the value of the operator to the evaluated operands.

For example, consider the call expression `(+ 1 2)`. First, we evaluate the symbol `+` to get the built-in addition procedure. Then we evaluate the two operands `1` and `2` to get their corresponding atomic values. Finally, we apply the addition procedure to the values `1` and `2` to get the return value `3`.

Operators may be symbols, such as `+` and `*`, or more complex expressions, as long as they evaluate to procedure values.

Here is a reference for the Scheme Built-In Procedures.

```
scm> (- 1 1)                ; 1 - 1
0
scm> (* (+ 1 2) (+ 1 2))    ; (1 + 2) * (1 + 2)
9
```

WWSD

What would Scheme display? As a reminder, the built-in `quotient` function performs floor division.

```
scm> (define a (+ 1 2))
```

a

```
scm> a
```

3

```
scm> (define b (- (+ (* 3 3) 2) 1))
```

b

```
scm> (+ a b)
```

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```
scm> (= (modulo b a) (quotient 5 3))
```

#t

Special Forms

Special form expressions contain a **special form** as the operator. Special form expressions *do not* follow the same rules of evaluation as call expressions. Each special form has its own rules of evaluation – that's what makes them special! Here's the Scheme Specification to reference the special forms we will cover in this class.

If Expression

An `if` expression looks like this:

`(if <predicate> <if-true> [if-false])`

`<predicate>` and `<if-true>` are required expressions and `[if-false]` is optional.

The rules for evaluation are as follows:

1. Evaluate `<predicate>`.
2. If `<predicate>` evaluates to a truth-y value, evaluate `<if-true>` and return its value. Otherwise, evaluate `[if-false]` if provided and return its value.

`if` is a special form as not all of its operands will be evaluated. The value of the first operand determines whether the second or the third operator is evaluated.

> **Important:** Only `#f` is a false-y value in Scheme; everything else is truth-y, including `0`.

```
scm> (if (< 4 5) 1 2)
1
scm> (if #f (/ 1 0) 42)
42
```

Boolean operators

Like Python, Scheme has the boolean operators `and`, `or`, and `not`. `and` and `or` are special forms because they are short-circuiting operators, while `not` is a builtin procedure.

- `and` takes in any amount of operands and evaluates these operands from left to right until one evaluates to a false-y value. It returns that first false-y value or the value of the last expression if there are no false-y values.
- `or` also evaluates any number of operands from left to right until one evaluates to a truth-y value. It returns that first truth-y value or the value of the last expression if there are no truth-y values.
- `not` takes in a single operand, evaluates it, and returns its opposite truthiness value.

```
scm> (and 25 32)
32
scm> (or 1 (/ 1 0))    ; Short-circuits
1
scm> (not (odd? 10))
#t
```

WWSD

What would Scheme display?

```
scm> (if (or #t (/ 1 0)) 1 (/ 1 0))
```

1

```
scm> ((if (< 4 3) + -) 4 100)
```

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Defining Functions

All Scheme procedures are constructed as lambda procedures.

One way to create a procedure is to use the `lambda` special form.

`(lambda (<param1> <param2> ...) <body>)`

This expression creates a lambda function with the given parameters and body, but does not evaluate the body. As in Python, the body is not evaluated until the function is called and applied to some argument values. The fact that neither the parameters nor the body is evaluated is what makes `lambda` a special form.

We can also assign the value of an expression to a name with a `define` special form:

1. `(define (<name> <param> ...) <body> ...)`
2. `(define <name> (lambda (<param> ...) <body> ...))`

These two expressions are equivalent; the first is a concise version of the second.

```
scm> ; Bind lambda function to square
scm> (define square (lambda (x) (* x x)))
square
scm> (define (square x) (* x x))          ; Same as above
square
scm> square
(lambda (x) (* x x))
scm> (square 4)
16
```

Q1: Virahanka-Fibonacci

Write a function that returns the `n`-th Virahanka-Fibonacci number.

```
(define (vir-fib n)
    (if (<= n 1)
        n
        (+ (vir-fib (- n 1)) (vir-fib (- n 2))))
)

(expect (vir-fib 10) 55)
(expect (vir-fib 1) 1)
```

```
scm> (vir-fib 0)
0
scm> (vir-fib 1)
1
scm> (vir-fib 10)
55
```

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Pairs and Lists

All lists in Scheme are linked lists. Scheme lists are composed of two element pairs. We define a list as being either

- the empty list, `nil`
- a pair whose second element is a list

As in Python, linked lists are recursive data structures. The base case is the empty list.

We use the following procedures to construct and select from lists:

- `(cons first rest)` constructs a list with the given first element and rest of the list. For now, if `rest` is not a pair or `nil` it will error.
- `(car lst)` gets the first item of the list
- `(cdr lst)` gets the rest of the list

To visualize Scheme lists, you can use the `draw` function in code.cs61a.org.

```
scm> nil
()
scm> (define lst (cons 1 (cons 2 (cons 3 nil))))
lst
scm> lst
(1 2 3)
scm> (car lst)
1
scm> (cdr lst)
(2 3)
```

Scheme lists are displayed in a similar way to the Link class we defined in Python. Here is an example in 61A Code.

Two other ways of creating lists are using the built-in `list` procedure or the `quote` special form. More info can be found on the Scheme Specification.

```
scm> (list 1 2 3)
(1 2 3)
scm> (quote (1 x 3))
(1 x 3)
scm> '(1 x 3)   ; Equivalent to the previous quote expression
(1 x 3)
```

=, eq?, equal?

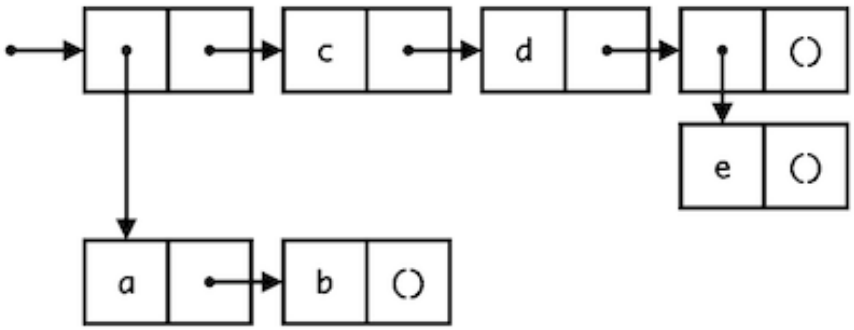
- `(= <a> <b>)` returns true if a equals b. Both must be numbers.
- `(eq? <a> <b>)` returns true if a equals b and they are both numbers. For two objects, `eq?` returns true if both refer to the same object in memory.
- `(equal? <a> <b>)` returns true if a and b are equivalent. For two pairs, they are equivalent if their cars are equivalent and their cdrs are equivalent.

```
scm> (define a '(1 2 3))
a
scm> (= a a)
Error
scm> (equal? a '(1 2 3))
#t
scm> (eq? a '(1 2 3))
#f
```

Q2: List Making

Let's make some Scheme lists. We'll define the same list with `list`, `quote`, and `cons`.

The following list was visualized using the `draw` feature of code.cs61a.org.



First, use `list`:

```
(define with-list
    (list
        (list 'a 'b) 'c 'd (list 'e)
    )
)
(draw with-list)
```

Now use `quote`. What differences are there?

```
(define with-quote
    '(
        (a b) c d (e)
    )

)
(draw with-quote)
```

Now try with `cons`. For convenience, we've defined a `helpful-list` and `another-helpful-list`:

```
(define helpful-list
   (cons 'a (cons 'b nil)))
(draw helpful-list)

(define another-helpful-list
    (cons 'c (cons 'd (cons (cons 'e nil) nil))))
(draw another-helpful-list)

(define with-cons
    (cons
        (cons 'a (cons 'b nil)) (cons 'c (cons 'd (cons (cons 'e nil
    ) nil)))
    )
)
(draw with-cons)
```

Q3: List Concatenation

Write a function which takes two lists and concatenates them.

Notice that simply calling `(cons a b)` would not work because it will create a deep list. Do not call the builtin procedure `append`, since it does the same thing as `list-concat` should do.

```
(define (list-concat a b)
    (if (null? a)
    b
    (cons (car a) (list-concat (cdr a) b)))
)

(expect (list-concat '(1 2 3) '(2 3 4)) (1 2 3 2 3 4))
(expect (list-concat '(3) '(2 1 0)) (3 2 1 0))
```

```
scm> (list-concat '(1 2 3) '(2 3 4))
(1 2 3 2 3 4)
```

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Q4: Map

Write a function that takes a procedure and applies it to every element in a given list.

```
(define (map-fn fn lst)
    (if (null? lst)
        nil
        (cons (fn (car lst)) (map-fn fn (cdr lst))))
)

(map-fn (lambda (x) (* x x)) '(1 2 3))
; expect (1 4 9)
```

```
scm> (map-fn (lambda (x) (* x x)) '(1 2 3))
(1 4 9)
```

Q5: Make Tree

Fill in the following to complete an tree data abstraction:

```
(define (make-tree label branches) (cons label branches))

(define (label tree)
    (car tree)
)

(define (branches tree)
    (cdr tree)
)

(make-tree 1 (list (make-tree 2 '()) (make-tree 3 '())))
; expect (1 (2) (3))
```

Q6: Tree Sum

Using the data abstraction above, write a function that sums up the entries of a tree, assuming that the entries are all numbers.

Hint: You may want to use `map` with a helper function to sum list entries.

```
(define (tree-sum tree)
    (+ (label tree) (sum (map tree-sum (branches tree))))
)

(define (sum lst)
    (if (null? lst) 0 (+ (car lst) (sum (cdr lst))))
)

(define t (make-tree 1 (list (make-tree 2 '()) (make-tree 3 '()))))
(expect (tree-sum t) 6)
```