1 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 dialect of the Lisp programming language, a language dating back to 1958. The popularity of Scheme within the programming language community stems from its simplicity – in fact, previous versions of CS 61A were taught in the Scheme language.

2 Primitives

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

```
scm> 123
123
scm> 123.123
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. The define special form defines variables and procedures by binding a value to a variable, just like the assignment statement in Python. When a variable is defined, the define special form returns a symbol of its name. A procedure is what we call a function in Scheme!

The syntax to define a variable and procedure are:

- `(define <variable name> <value>)`
- `(define (<function name> <parameters>) <function body>)`
Questions

2.1 What would Scheme display?

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

(scm> a)

(scm> (define b a))

(scm> b)

(scm> (define c 'a))

(scm> c)
```

3 Call Expressions

To call a function in Scheme, you first need a set of parentheses. Inside the parentheses, you specify an operator expression, then zero or more operand subexpressions (remember the spaces!).

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

```scheme
(scm> (- 1 1)) ; 1 - 1
0

(scm> (/ 8 4 2)) ; 8 / 4 / 2
1

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

Evaluating a Scheme function call works just like Python:

1. Evaluate the operator (the first expression after the ()), then evaluate each of the operands.

2. Apply the operator to those evaluated operands.

When you evaluate (+ 1 2), you evaluate the + symbol, which is bound to a built-in addition function. Then, you evaluate 1 and 2, which are primitives. Finally, you apply the addition function to 1 and 2.
Questions

3.1 What would Scheme display?

```
scm> (+ 1)
```

```
scm> (* 3)
```

```
scm> (+ (* 3 3) (* 4 4))
```

```
scm> (define a (define b 3))
```

```
scm> a
```

```
scm> b
```

4 Special Forms

There are certain expressions that look like function calls, but *don’t* follow the rule for order of evaluation. These are called *special forms*. You’ve already seen one — `define`, where the first argument, the variable name, doesn’t actually get evaluated to a value.

4.1 If Expression

Another common special form is the *if* form. An *if* expression looks like:

```
(if <condition> <then> <else>
```

where `<condition>`, `<then>`, and `<else>` are expressions. First, `<condition>` is evaluated. If it evaluates to `#t`, then `<then>` is evaluated. Otherwise, `<else>` is evaluated.

Remember that only `#f` is a false-y value (also `False` for our interpreter); everything else is truth-y.

```
scm> (if (< 4 5) 1 2) 1
```

```
scm> (if #f (/ 1 0) 42) 42
```
4.2 Boolean Operators

Much like Python, Scheme also has the boolean operators **and**, **or**, and **not**. In addition, **and** and **or** are also special forms because they are short-circuiting operators.

```
scm> (and 25 32)
32
scm> (or 1 2)
1
```

Questions

4.1 What would Scheme display?

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

```
scm> (if (> 4 3) (+ 1 2 3 4) (+ 3 4 (* 3 2)))
```

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

```
scm> (if 0 1 2)
```

4.3 Lambdas and Defining Functions

Scheme has lambdas too! The syntax is

```
(lambda (<PARAMETERS>) <EXPR>)
```

Like in Python, lambdas are function values. Also like in Python, when a lambda expression is called in Scheme, a new frame is created where the parameters are bound to the arguments passed in. Then, <EXPR> is evaluated in this new frame. Note that <EXPR> is not evaluated until the lambda function is called.

Like in Python, lambda functions are also values! So you can do this to define functions:

```
scm> (define (square x) (* x x)) ; Create function square using define special form
square
scm> (define square (lambda (x) (* x x))) ; Equivalently, bind the name square to a lambda function
square
scm> (square 4)
16
```
let is another special form based around lambda. The structure of let is as follows:

(let ( (<SYMBOL1> <EXPR1>)
      ...
       (/<SYMBOLN> <EXPRN>) )
       <BODY> )

This binds the results of evaluating expressions 1 through n to their associated symbols, creating temporary variables. Finally, the body of the let is evaluated.

This special form is really just equivalent to:

( (lambda (<SYMBOL1> ... <SYMBOLN>) <BODY>) <EXPR1> ... <EXPRN> )

Think of the temporary variables as being the parameters of a lambda function. Then, the arguments are the values of the expressions, which we bind to the temporary variables by calling the lambda.

Consider the following example:

(let ((x 1)
       (y 2))
       (+ x y))

This is equivalent to:

((lambda (x y) (+ x y)) 1 2)

Questions

4.1 Write a function that returns the factorial of a number.

(define (factorial x)

4.2 Write a function that returns the \( n^{th} \) Fibonacci number.

(define (fib n)
  (if (or (= n 0) (= n 1))
      n
      +

  )

  n


5 Pairs and Lists

To construct a (linked) list in Scheme, you can use the constructor \texttt{cons} (which takes two arguments). \texttt{nil} represents the empty list. If you have a linked list in Scheme, you can use selector \texttt{car} to get the first element and selector \texttt{cdr} to get the rest of the list. (\texttt{car} and \texttt{cdr} don’t stand for anything anymore, but if you want the history go to \url{http://en.wikipedia.org/wiki/CAR} and \url{CDR}).

\begin{verbatim}
smc> nil ()
scm> (null? nil) #t
scm> (cons 2 nil) (2)
scm> (cons 3 (cons 2 nil)) (3 2)
scm> (define a (cons 3 (cons 2 nil))) a
scm> (car a) 3
scm> (cdr a) (2)
scm> (car (cdr a)) 2
scm> (define (len a)
   (if (null? a)
       0
       (+ 1 (len (cdr a)))))
len
scm> (len a) 2
\end{verbatim}

If a list is a “good looking” list, like the ones above where the second element is always a linked list, we call it a \textbf{well-formed list}. Interestingly, in Scheme, the second element does not have to be a linked list. You can supply something else instead, creating a \textbf{malformed list}. The difference is shown with a dot:

\begin{verbatim}
smc> (cons 2 3) (2 . 3)
smc> (cons 2 (cons 3 nil)) (2 3)
smc> (cdr (cons 2 3)) 3
scm> (cdr (cons 2 (cons 3 nil))) (3)
\end{verbatim}

In general, the rule for displaying a pair is as follows: use the dot to separate the \texttt{car} and \texttt{cdr} fields of a pair, but if the dot is immediately followed by an open
parenthesis, then remove the dot and the parenthesis pair. Thus, \((\emptyset . (1 . 2))\) becomes \((\emptyset 1 . 2)\)

There are many useful operations and shorthands on lists. \texttt{list} takes zero or more arguments and returns a list of its arguments.

This typically behaves much like quoting a list, except that quoting will not evaluate the list you have quoted which can result in some different outcomes.

\begin{verbatim}
scm> (list 1 2 3)
(1 2 3)
scm> '(1 2 3)
(1 2 3)
scm> (car '(1 2 3))
1
scm> (equal? '(1 2 3) (list 1 2 3))
#t
scm> '(1 . (2 3))
(1 2 3)
scm> (define (square x) (* x x))
(define (square x) (* x x))
scm> square ; We didn't actually define square above because of the quote
Error
scm> (list (cons 1 2))
((1 . 2))
scm> '((cons 1 2))
((cons 1 2))

=, eq?, equal?

- \texttt{=} can only be used for comparing numbers.
- \texttt{eq?} behaves like == in Python for comparing two non-pairs (numbers, booleans, etc.). Otherwise, \texttt{eq?} behaves like \texttt{is} in Python.
- \texttt{equal?} compares pairs by determining if their \texttt{car}s are \texttt{equal?} and their \texttt{cdr}s are \texttt{equal?}(that is, they have the same contents). Otherwise, \texttt{equal?} behaves like \texttt{eq?}.

\begin{verbatim}
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
scm> (define b a)
b
scm> (eq? a b)
#t
\end{verbatim}
Questions

5.1 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.

(define (concat a b))

(scm> (concat '(1 2 3) '(2 3 4))
(1 2 3 2 3 4)

5.2 Write a function that takes an element x and a non-negative integer n, and returns a list with x repeated n times.

(define (replicate x n))

(scm> (replicate 5 3)
(5 5 5))
5.3 A run-length encoding is a method of compressing a sequence of letters. The list `(a a a b a a a a)` can be compressed to `((a 3) (b 1) (a 4))`, where the compressed version of the sequence keeps track of how many letters appear consecutively.

Write a function that takes a compressed sequence and expands it into the original sequence. *Hint:* You may want to use `concat` and `replicate`.

```scheme
(define (uncompress s)
  (define (uncompress-rest rest)
    (cond ((null? rest) '())
          ((number? (car rest))
           (cons (make-list (cadr (car rest)) (caddr (car rest)))
                 (uncompress-rest (cadr rest))))
          (else (uncompress-rest rest))))

  (uncompress-rest s))
```

```
scm> (uncompress '((a 1) (b 2) (c 3)))
(a b b c c c)
```

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

```scheme
(define (map fn lst)
  (define (map-rest rest)
    (if (null? rest) '()
        (cons (apply fn (car rest))
              (map-rest (cadr rest)))))

  (map-rest lst))
```

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

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

The result should be a nested list with the same structure as the input list, but with each element replaced by the result of applying the procedure to that element.

Use the built-in `list?` procedure to detect whether a value is a list.

```scheme
(define (deep-map fn lst)
  (define (deep-map-rest rest)
    (if (null? rest) '()
        (cons (apply fn rest)
              (deep-map-rest (cadr rest))))

  (deep-map-rest lst))
```

```
scm> (deep-map (lambda (x) (* x x)) '(1 2 3))
(1 4 9)
scm> (deep-map (lambda (x) (* x x)) '(1 ((4) 5) 9))
(1 ((16) 25) 81)
```
6 Extra Questions

6.1 Fill in the following to complete an abstract tree data type:

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

(define (label tree)
  
(define (branches tree)

6.2 Using the abstract data type 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 the map function you defined above, and also write a helper function for summing up the entries of a list.

(define (tree-sum tree)

6.3 Using the abstract data type above, write a function that creates a new tree where the entries are the product of the entries along the path to the root in the original tree.

Hint: you may want to write a helper function that keeps track of the current product.

(define (path-product-tree t)

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

(define (tree-sum tree)

(define (path-product-tree t)
```