1 Calculator

We are beginning to dive into the realm of interpreting computer programs – that is, writing programs that understand other programs. In order to do so, we'll have to examine programming languages in-depth. The Calculator language, a subset of Scheme, was the first of these examples. In today's discussion, we'll be extending Calculator with variables and user-defined functions.

The Calculator language is a Scheme-syntax language that currently includes only the four basic arithmetic operations: +, −, *, and /. These operations can be nested and can take varying numbers of arguments. A few examples of calculator in action are given on the right.

Our goal now is to write an interpreter for this language, and extend its functionality to variables and user-defined functions. The job of an interpreter is to evaluate expressions. So, let’s talk about expressions. A Calculator expression is just like a Scheme list. To represent Scheme lists in Python, we use Pair objects. For example, the list (+ 1 2) is represented as Pair('+', Pair(1, Pair(2, nil))). The Pair class is the same as the Scheme procedure cons, which would represent the same list as (cons '+ (cons 1 (cons 2 nil))).

Pair is very similar to Link, the class we developed for representing linked lists, except that the second attribute doesn’t have to be a linked list. In addition to Pair objects, we include a nil object to represent the empty list. Pair instances have methods:

1. __len__, which returns the length of the list.
2. __getitem__, which allows indexing into the pair.
3. map, which applies a function, fn, to all of the elements in the list.

nil has the methods __len__, __getitem__, and map. Here's an implementation of what we described:

```python
class nil:
    '''Represents the special empty pair nil in Scheme.'''
    def __repr__(self):
        return 'nil'
    def __len__(self):
        return 0
    def __getitem__(self, i):
        raise IndexError('Index out of range')
    def map(self, fn):
        return nil

nil = nil() # this hides the nil class *forever*
```

```calc> (+ 2 2)
  4
```

```calc> (- 5)
  -5
```

```calc> (* (+ 1 2) (+ 2 3))
  15
```
Questions

1. Translate the following Calculator expressions into calls to the Pair constructor.

   > (+ 1 2 (- 3 4))

   > (+ 1 (* 2 3) 4)

1.2 Translate the following Python representations of Calculator expressions into the proper Scheme syntax:

   >>> Pair('+', Pair(1, Pair(2, Pair(3, Pair(4, nil))))))

   >>> Pair('+', Pair(1, Pair(Pair('+', Pair(2, Pair(3, nil))), nil)))

2 Evaluation

Evaluation discovers the form of an expression and executes a corresponding evaluation rule.

We’ll go over two such expressions now:
1. **Primitive** expressions are evaluated directly. For example, the numbers 3.14 and 165 just evaluate to themselves, and the string “+” evaluates to the `calc_add` function.

2. *Call* expressions are evaluated in the same way you’ve been doing them all semester:
   
   (1) **Evaluate** the operator.
   
   (2) **Evaluate** the operands from left to right.
   
   (3) **Apply** the operator to the operands.

Here’s `calc_eval`:

```python
def calc_eval(exp):
    """Evaluates a Calculator expression represented as a Pair."""
    if isinstance(exp, Pair):
        return calc_apply(calc_eval(exp.first),
                         list(exp.second.map(calc_eval)))
    elif exp in OPERATORS:
        return OPERATORS[exp]
    else:  # Primitive expression
        return exp
```

And here’s `calc_apply`:

```python
def calc_apply(op, args):
    """Applies an operator to a Pair of arguments."""
    return op(*args)
```

**Questions**

2.1 Suppose we typed each of the following expressions into the Calculator interpreter. How many calls to `calc_eval` would they each generate? How many calls to `calc_apply`?

   > (+ 2 4 6 8)

   > (+ 2 (* 4 (- 6 8)))

2.2 Alyssa P. Hacker and Ben Bitdiddle are also tasked with implementing the *and* operator, as in `(and (= 1 2) (< 3 4))`. Ben says this is easy: they just have to follow the same process as in implementing * and /. Alyssa is not so sure. Who’s right?
Now that you’ve had a chance to think about it, you decide to try implementing and yourself. You may assume the conditional operators (e.g. <, >, =, etc) have already been implemented for you.

```python
def calc_eval(exp):

def eval_and(operands):
```
3 Tail-Call Optimization

3.1 Write a tail recursive function that returns the $n$th fibonacci number. We define $\text{fib}(0) = 0$ and $\text{fib}(1) = 1$.

\begin{verbatim}
(define (fib n)
  \ldots
\end{verbatim}

3.2 Write a tail recursive function, \texttt{reverse}, that takes in a Scheme list and returns a reversed copy.

\begin{verbatim}
(define (reverse lst)
  \ldots
\end{verbatim}

3.3 Write a tail recursive function, \texttt{insert}, that takes in a number and a sorted list. The function returns a sorted copy with the number inserted in the correct position.

\begin{verbatim}
(define (insert n lst)
  \ldots
\end{verbatim}

3.4 Write a tail recursive function, \texttt{append}, that takes in two lists and appends them. Make sure that your function is $\Theta(n)$ and tail-recursive.

\begin{verbatim}
(define (append a b)
  \ldots
\end{verbatim}