MACROS, TAIL RECURSION AND INTERPRETERS

COMPUTER SCIENCE MENTORS CS 61A

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1 Let in Scheme

1. **let** is a special form in Scheme which allows you to create local bindings. Consider the example

```
(let ((x 1)) (+ x 1))
```

Here, we assign `x` to `1`, and then evaluate the expression `(+ x 1)` using that binding, returning `2`. However, outside of this expression, `x` would not be bound to anything.
Each `let` special form has a corresponding lambda equivalent. The equivalent lambda expression for the above example is

```
((lambda (x) (+ x 1)) 1)
```

The following line of code does not work. Why? Write the lambda equivalent of the `let` expressions.

```
(let ((foo 3)
      (bar (+ foo 2)))
    (+ foo bar))
```

((lambda (foo bar) (+ foo bar)) 3 (+ foo 2))

2 Macros

1. What will Scheme output?

```
scm> (define x 6)
x
scm> (define y 1)
y
scm> '(x y a)
(x y a)
scm> `(,x ,y a)
(6 1 a)
scm> `(,x y a)
(6 y a)
scm> `(,(if (- 1 2) '+ '-) 1 2)
(+ 1 2)
scm> (eval `(,(if (- 1 2) '+ '-) 1 2))
3
scm> (define (add-expr a1 a2)
             (list '+ a1 a2))
add-expr
scm> (add-expr 3 4)
(+ 3 4)
scm> (eval (add-expr 3 4))
7
scm> (define-macro (add-macro a1 a2)
           (list '+ a1 a2))
add-macro
scm> (add-macro 3 4)
7
```

2. Implement `if-macro`, which behaves similarly to the `if` special form in Scheme but has some additional properties. Here's how the `if-macro` is called:

```
if <cond1> <expr1> elif <cond2> <expr2> else <expr3>
```

If cond1 evaluates to a truth-y value, expr1 is evaluated and returned. Otherwise, if cond2 evaluates to a truth-y value, expr2 is evaluated and returned. If neither condition is true, expr3 is evaluted and returned.

```
;Doctests
scm> (if-macro (= 1 0) 1 elif (= 1 1) 2 else 3)
2
scm> (if-macro (= 1 1) 1 elif (= 2 2) 2 else 3)
1
scm> (if-macro (= 1 0) (/ 1 0) elif (= 2 0) (/ 1 0) else 3)
3
```

```
(define-macro (if-macro cond1 expr1 elif cond2 expr2 else
    expr3)
```

Regular Scheme code

```
(cond (cond1 expr1)
      (cond2 expr2)
      (else expr3))
```

Macro List

```
(list 'cond (list cond1 expr1)
            (list cond2 expr2)
            (list 'else expr3))
)
```

Macro Pseudoquote

```
`(cond (,cond1 ,expr1)
       (,cond2 ,expr2)
       (else ,expr3))
```

3. Could we have implemented `if-macro` using a function instead of a macro? Why or why not?

No, using a function we would always be evaluating each argument once before passing in to func call.

4. Implement `apply-twice`, which is a macro that takes in a call expression with a single argument. It should return the result of applying the operator to the operand twice.

```
;Doctests
scm> (define add-one (lambda (x) (+ x 1)))
add-one
scm> (apply-twice (add-one 1))
3
scm> (apply-twice (print 'hi))
hi
undefined
```

call-expr → (print) → ('hi)

```
(define-macro (apply-twice call-expr)
    `(let ((operator ,(car call-expr)))        → print
           (operand ,(cdr call-expr)))         → 'hi
          (operator (operator operand))))
```

(print (print 'hi))

Tail contexts:
- last body subexp in λ
- subexp 2, 3 in if
- all non-predicate subexp in cond
- last subexp in and or begin let

3 Tail Recursion

1. What is a tail context? What is a tail call? What is a tail recursive function?

func call in tail context

tail recursive func → all recursive calls in tail context

2. Why are tail calls useful for recursive functions?

Θ(1) space

3. Consider the following function:

```
(define (count-instance lst x)
  (cond ((null? lst) 0)
        ((equal? (car lst) x) (+ 1 (count-instance
                                     (cdr lst) x)))
        (else (count-instance (cdr lst) x))))
```

What is the purpose of `count-instance`? Is it tail recursive? Why or why not? Optional: draw out the environment diagram of this sum-list with `lst = (1 2 1)` and `x = 1`.

No, (+ 1 (count-instance (cdr lst) x))

recursive call is one of the arguments of the addition

Doesn't span entire space of tail context
⟹ not a tail call

4. Rewrite count-instance to be tail recursive.

```
(define (count-tail lst x)
    (define (count-tail-tr lst x count)
        (cond ((null? lst) count)
              ((= x (car lst)) (count-tail-tr (cdr lst) x (+ count 1)))
              (else (count-tail-tr (cdr lst) x count)))
        )
    (count-tail-tr lst x 0)
)
```

5. Implement `filter`, which takes in a one-argument function `f` and a list `lst`, and returns a new list containing only the elements in `lst` for which `f` returns true. Your function must be tail recursive.
   You may wish to use the built-in append function, which takes in two lists and returns a new list containing the elements of the first list followed by the elements of the second.

```
;Doctests
scm> (filter (lambda (x) (> x 2)) '(1 2 3 4 5))
(3 4 5)

(define (filter f lst)
    (define (filter-tr f lst retlst)
        (cond ((null? lst) retlst)
              ((f (car lst)) (filter-tr f (cdr lst) (append retlst (cons (car lst) nil))))
              (else (filter-tr f (cdr lst) retlst))
        )
    )
    (filter-tr f lst nil)
)
```

4 Interpreters

1. Circle the number of calls to `scheme_eval` and `scheme_apply` for the code below.

```
(+ 1 2)
```

```
scheme_eval    1  3  4  6
scheme_apply   1  2  3  4
```

2. Write the number of calls to `scheme_eval` and `scheme_apply` for the code below.

```
(if 1 (+ 2 3) (/ 1 0))
```

if : special form

```
scheme_eval    1  3  4  6
scheme_apply   1  2  3  4
```

```
(or #f (and (+ 1 2) 'apple) (- 5 2))
```

or, and, quote: special form

```
scheme_eval    6  8  9  10
scheme_apply   1  2  3  4
```

```
(define (square x) (* x x))
```

define : special form

```
(+ (square 3) (- 3 2))
```

```
scheme_eval    2  5  14  24
scheme_apply   1  2  3  4
```

```
(define (add x y) (+ x y))

(add (- 5 3) (or 0 2))
```

or : special form

13 eval

3 apply