Programs as Data

Announcements

Lambda Expressions

Lambda Expressions

Lambda expressions evaluate to user-defined procedures

```
(lambda (<formal-parameters>) <body>)

(lambda (x) (* x x))
```

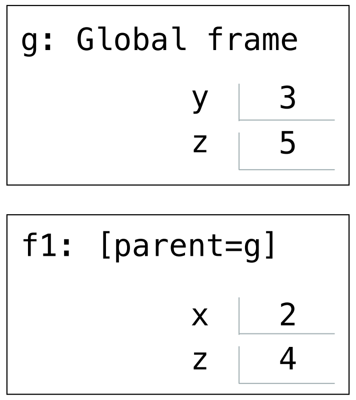
```
class LambdaProcedure:
    def __init__(self, formals, body, env):
        self.formals = formals ··········· A scheme list of symbols
        self.body = body ················· A scheme list of expressions
        self.env = env ··················· A Frame instance
```

Frames and Environments

A frame represents an environment by having a parent frame

Frames are Python instances with methods **lookup** and **define**

In Project 4, Frames do not hold return values



(Demo)

Programs as Data

A Scheme Expression is a Scheme List

Scheme programs consist of expressions, which can be:

- Primitive expressions: `2` `3.3` `true` `+` `quotient`
- Combinations: `(quotient 10 2)` `(not true)`

The built-in Scheme list data structure (which is a linked list) can represent combinations

```
scm> (list 'quotient 10 2)
(quotient 10 2)

scm> (eval (list 'quotient 10 2))
5
```

In such a language, it is straightforward to write a program that writes a program

(Demo)

Discussion Question: Automatically Simplifying Code

```
scm> (* 1 2 (* 3 (* 4)) (+ 5 (* 6 (* 7 8))))
8184
scm> (flatten-nested-* '(* 1 2 (* 3 (* 4)) (+ 5 (* 6 (* 7 8)))))
(* 1 2 3 4 (+ 5 (* 6 7 8)))
scm> (* 1 2 3 4 (+ 5 (* 6 7 8)))
8184
scm> (eval (flatten-nested-* '(* 1 2 (* 3 (* 4)) (+ 5 (* 6 (* 7 8))))))
8184
```

```
(define (is-*-call expr) (and (list? expr) (equal? '* (car expr))))  ; E.g., (* 3 4)
(define (flatten-nested-* expr) ; Return an equivalent expression with no nested calls to *
  (if (not (list? expr)) expr
    (let ((expr (map flatten-nested-* expr))) ; Now expr is (* 1 2 (* 3 4) (+ 5 (* 6 7 8)))
      (if (is-*-call expr)
          (apply append      (map (lambda (e) (if (is-*-call e) (cdr e) (list e))) expr))
          expr))))
```

result of applying append:
(* 1 2 3 4 (+ 5 (* 6 7 8)))

(* 1 2 (* 3 4) (+ 5 (* 6 7 8)))
becomes
((*) (1) (2) (3 4) ((+ 5 (* 6 7 8))))

(* 3 4)
becomes
(3 4)

(+ 5 (* 6 7 8))
becomes
((+ 5 (* 6 7 8)))

Discussion Question: Printing Evaluations

Define `print_evals`, which takes a Scheme expression `expr` that contains only numbers, `+`, `*`, `>`, `if` and parentheses. It prints all of the expressions that are evaluated during the evaluation of `expr` and their values. Print in the **order that evaluation completes.**

Assume every `if` expression has three sub-expressions: predicate, consequence, & alternative.

```
scm> (define expr '(* 2 (if (> 2 (+ 1 1)) (+ 3 4) (* 5 6))))
expr
scm> (eval expr)
60
scm> (print-evals expr)
* => #[*]
2 => 2
> => #[>]
2 => 2
+ => #[+]
1 => 1
1 => 1
(+ 1 1) => 2
(> 2 (+ 1 1)) => #f
* => #[*]
5 => 5
6 => 6
(* 5 6) => 30
(if (> 2 (+ 1 1)) (+ 3 4) (* 5 6)) => 30
(* 2 (if (> 2 (+ 1 1)) (+ 3 4) (* 5 6))) => 60
```

```
(define (print-evals expr)
  (if (list? expr)
      (if (equal? (car expr) 'if )
        (begin
          (print-evals (car (cdr expr)))
           (if (eval (car (cdr expr)))
               (print-evals (car (cdr (cdr expr))))
               (print-evals (car (cdr (cdr (cdr expr)))))))
        (map print-evals expr) ))
  (print expr '=> (eval expr)))
```