61A Lecture 26

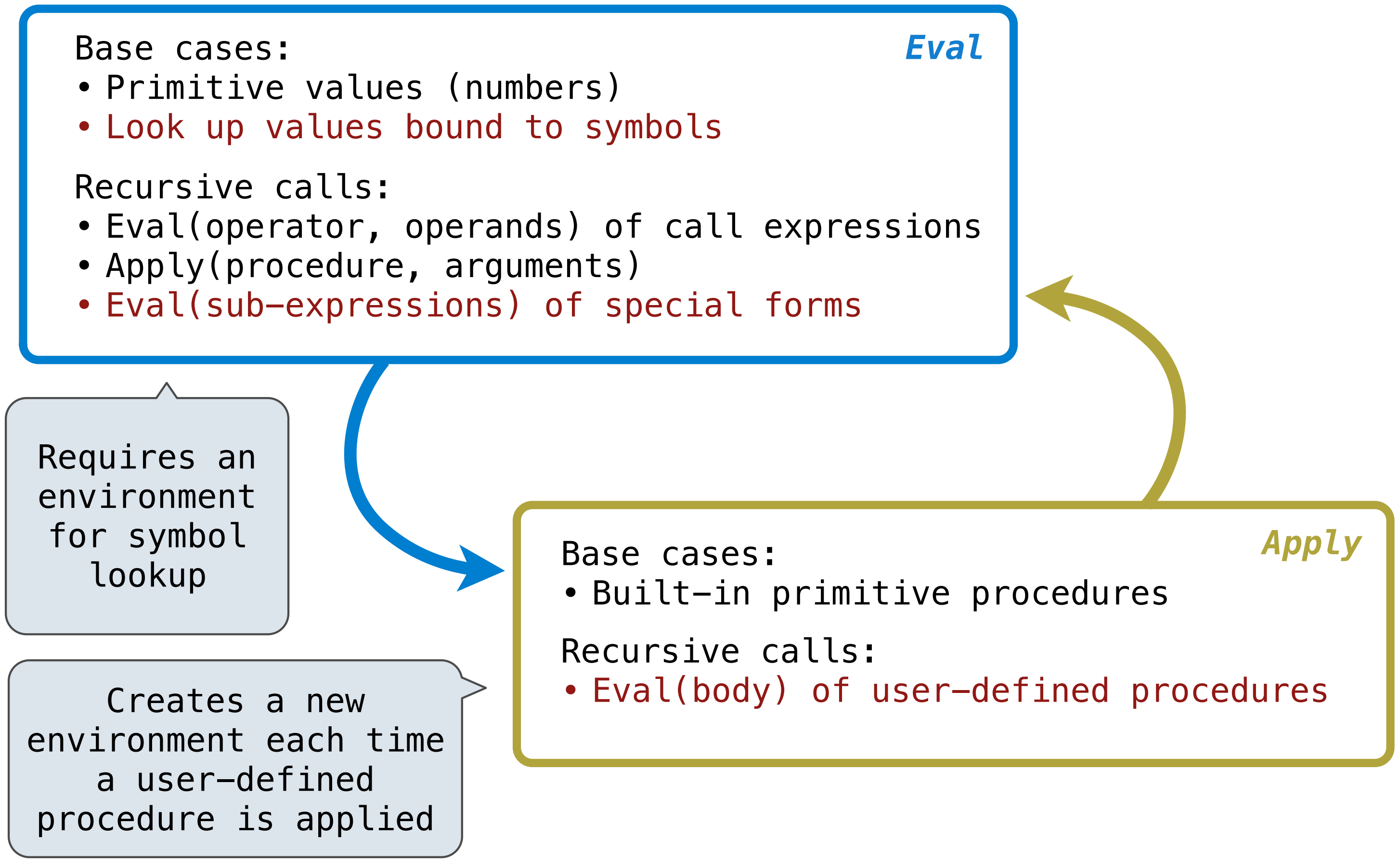
Wednesday, November 6

Announcements

- Project 1 composition revisions due Thursday 11/7 @ 11:59pm.
- Homework 8 due Tuesday 11/12 @ 11:59pm, and it's in Scheme!
- Project 4 due Thursday 11/21 @ 11:59pm, and it's a Scheme interpreter!
- **New Policy:** An improved final exam score can make up for low midterm scores.
  - If you scored less than 60/100 midterm points total, then you can earn some points back.
  - You don't need a perfect score on the final to do so.

Interpreting Scheme

The Structure of an Interpreter



Eval

Base cases:
- Primitive values (numbers)
- Look up values bound to symbols

Recursive calls:
- Eval(operator, operands) of call expressions
- Apply(procedure, arguments)
- Eval(sub-expressions) of special forms

Requires an environment for symbol lookup

Apply

Base cases:
- Built-in primitive procedures

Recursive calls:
- Eval(body) of user-defined procedures

Creates a new environment each time a user-defined procedure is applied

Special Forms

Scheme Evaluation

The scheme_eval function dispatches on expression form:

- Symbols are bound to values in the current environment.
- Self-evaluating expressions are returned.
- All other legal expressions are represented as Scheme lists, called *combinations*.

```
              (if <predicate> <consequent> <alternative>)
                 (lambda (<formal-parameters>) <body>)
                     (define <name> <expression>)
             (<operator> <operand 0> ... <operand k>)
```

Special forms are identified by the first list element

Any combination that is not a known special form is a call expression

```
(define (demo s) (if (null? s) '(3) (cons (car s) (demo (cdr s))) ))

                                  (demo (list 1 2))
```

Logical Forms

Logical Special Forms

Logical forms may only evaluate some sub-expressions.

- **If** expression: `(if <predicate> <consequent> <alternative>)`
- **And** and **or**: `(and <e1> ... <en>)`, `(or <e1> ... <en>)`
- **Cond** expr'n: `(cond (<p1> <e1>) ... (<pn> <en>) (else <e>))`

The value of an **if** expression is the value of a sub-expression.

- Evaluate the predicate.
- Choose a sub-expression: `<consequent>` or `<alternative>`.

do_if_form

- Evaluate that sub-expression in place of the whole expression.

scheme_eval

(Demo)

Quotation

Quotation

The **quote** special form evaluates to the quoted expression, which is **not** evaluated.

`(quote <expression>)` `(quote (+ 1 2))` $\xrightarrow{\text{evaluates to the three-element Scheme list}}$ `(+ 1 2)`

The `<expression>` itself is the value of the whole quote expression.

`'<expression>` is shorthand for `(quote <expression>)`.

`(quote (1 2))` is equivalent to `'(1 2)`

The scheme_read parser converts shorthand to a combination.

(Demo)

Lambda Expressions

Lambda Expressions

Lambda expressions evaluate to user-defined procedures.

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

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

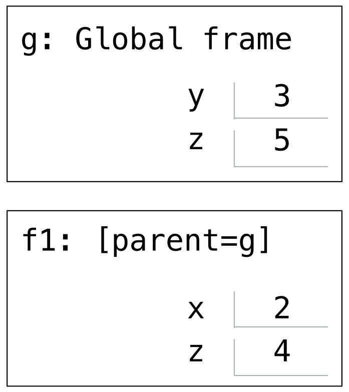
```
class LambdaProcedure:
    def __init__(self, formals, body, env):
        self.formals = formals          A scheme list of symbols
        self.body = body                A scheme expression
        self.env = env                  A Frame instance
```

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)

Define Expressions

Define Expressions

Define binds a symbol to a value in the first frame of the current environment.

```
(define <name> <expression>)
```

1. Evaluate the <expression>.
2. Bind <name> to its value in the current frame.

```
(define x (+ 1 2))
```

Procedure definition is shorthand of define with a lambda expression.

```
(define (<name> <formal parameters>) <body>)

(define <name> (lambda (<formal parameters>) <body>))
```

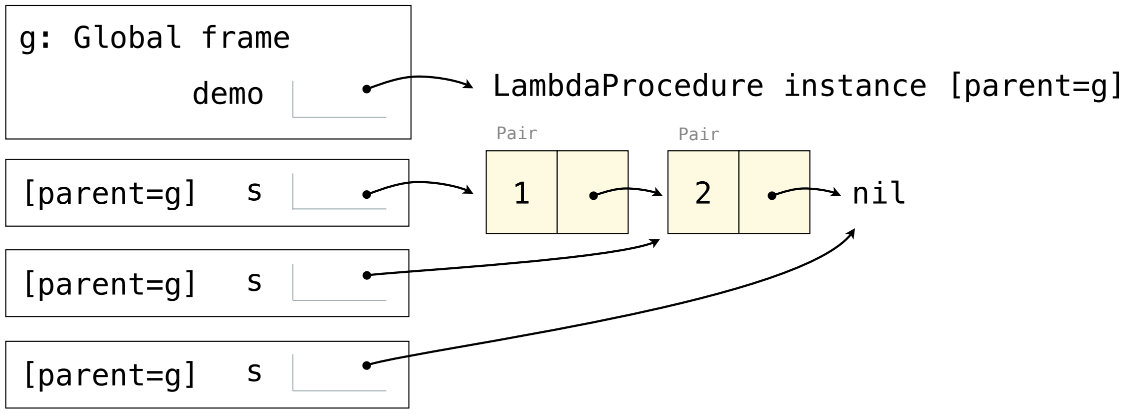
Applying User-Defined Procedures

To apply a user-defined procedure, create a new frame in which formal parameters are bound to argument values, whose parent is the **env** of the procedure.

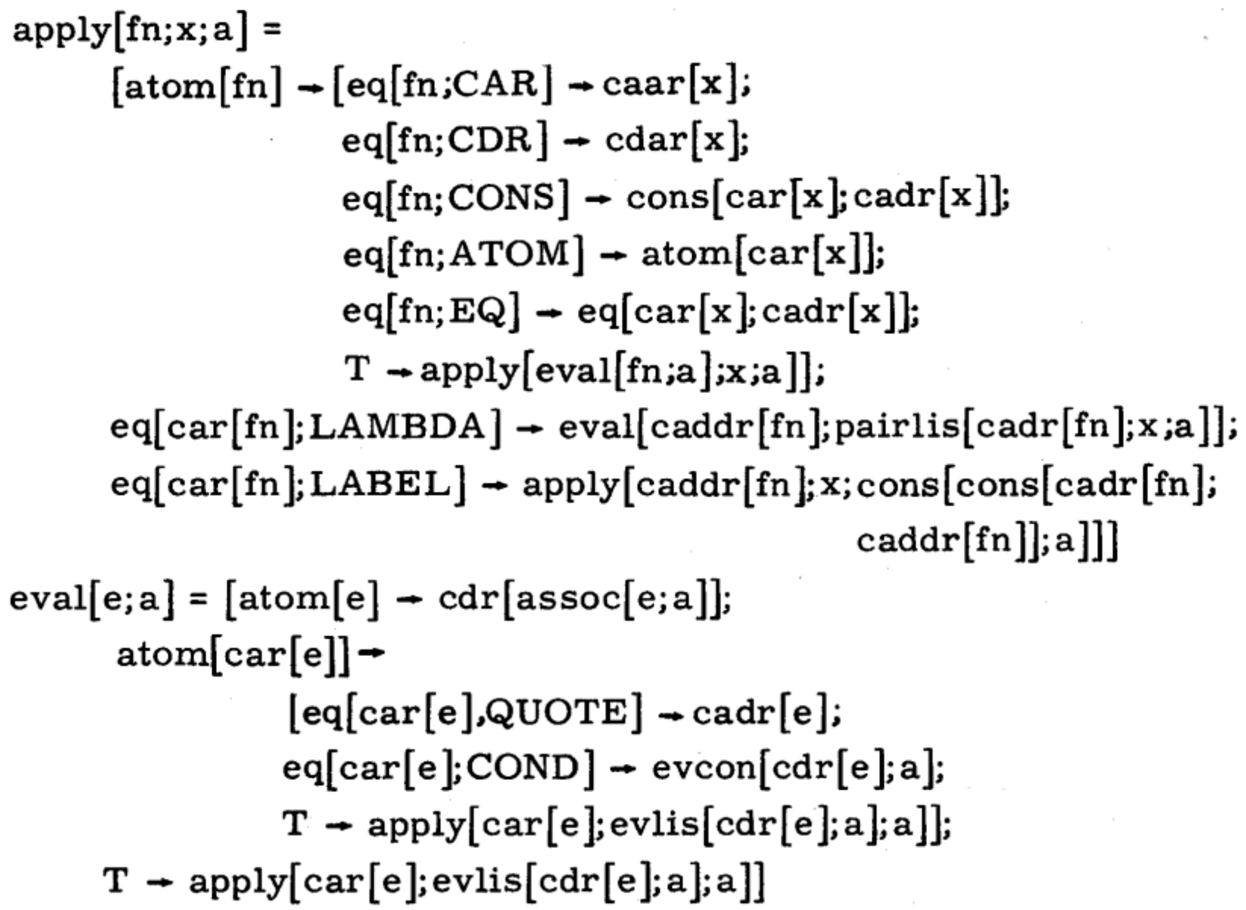
Evaluate the body of the procedure in the environment that starts with this new frame.

```
(define (demo s) (if (null? s) '(3) (cons (car s) (demo (cdr s)))))
```

```
(demo (list 1 2))
```



Eval/Apply in Lisp 1.5



```
apply[fn;x;a] =
        [atom[fn] → [eq[fn;CAR] → caar[x];
                     eq[fn;CDR] → cdar[x];
                     eq[fn;CONS] → cons[car[x];cadr[x]];
                     eq[fn;ATOM] → atom[car[x]];
                     eq[fn;EQ] → eq[car[x];cadr[x]];
                     T → apply[eval[fn;a];x;a]];
        eq[car[fn];LAMBDA] → eval[caddr[fn];pairlis[cadr[fn];x;a]];
        eq[car[fn];LABEL] → apply[caddr[fn];x;cons[cons[cadr[fn];
                                                   caddr[fn]];a]]]
eval[e;a] = [atom[e] → cdr[assoc[e;a]];
        atom[car[e]] →
                  [eq[car[e],QUOTE] → cadr[e];
                  eq[car[e];COND] → evcon[cdr[e];a];
                  T → apply[car[e];evlis[cdr[e];a];a]];
        T → apply[car[e];evlis[cdr[e];a];a]]
```

Dynamic Scope

Dynamic Scope

The way in which names are looked up in Scheme and Python is called *lexical scope* (or *static scope*).

Lexical scope: The parent of a frame is the environment in which a procedure was *defined*.

Dynamic scope: The parent of a frame is the environment in which a procedure was *called*.

Special form to create dynamically scoped procedures

mu

```
(define f (~~lambda~~ (x) (+ x y)))

(define g (lambda (x y) (f (+ x x))))

(g 3 7)
```

Lexical scope: The parent for f's frame is the global frame.

Error: unknown identifier: y

Dynamic scope: The parent for f's frame is g's frame.

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