Programming Abstractions

Lecture 20: MiniScheme C continued

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Procedure applications

MiniScheme C

EXP → number	parse into `lit-exp`
| symbol	parse into `var-exp`
| (*EXP* *EXP**)	parse into `app-exp`

An `app-exp` is a new data type that stores

- The parse tree for a procedure
- A list of parse trees for the arguments

```
(struct app-exp (proc args) #:transparent)
```

What is returned by `(parse '(* 2 3))`?

A. `((prim-proc '*) 2 3)`

B. `((prim-proc '*) (lit-exp 2) (lit-exp 3))`

C. `(app-exp (prim-proc '*) (list (lit-exp 2) (lit-exp 3)))`

D. `(var-exp '* (lit-exp 2) (lit-exp 3))`

E. `(app-exp (var-exp '*) (list (lit-exp 2) (lit-exp 3)))`

Evaluating an `app-exp`

To evaluate an app-exp

- Evaluate the procedure
- Evaluate the arguments
- Apply the procedure to the arguments

We need to evaluate all of those; add something like the following to `eval-exp`

```
[(app-exp? tree)
 (let ([proc (eval-exp (app-exp-proc tree) e)]
       [args ...])
   (apply-proc proc args))]
```

eval-exp's environment parameter

Evaluating the procedure yields a value

New type whose instances represent primitive procedure values

- `(struct prim-proc (symbol) #:transparent)`

We're going create a bunch of these

- `(prim-proc '+)`
- `(prim-proc '-)`
- `(prim-proc 'car)`
- `(prim-proc 'cdr)`
- `(prim-proc 'null?)`
- ...

Later, we'll support closures too!

We added primitives to our initial environment

```
(define primitive-operators
  '(+ - * /))

(define prim-env
  (env primitive-operators
       (map prim-proc primitive-operators)
       empty-env))

(define init-env
  (env '(x y) '(23 42) prim-env))
```

When evaluating an `app-exp`, the procedure and each of the arguments are evaluated. For example, when evaluating the result of `(parse '(- 20 5))`, there will be three recursive calls to `eval-exp`, the first of which is evaluating `(var-exp '-)`.

What is the result of evaluating `(var-exp '-)`?

A. #<procedure:-> (i.e., the procedure – itself)

B. `(app-exp '-)`

C. `(prim-proc '-)`

D. It's an error because – requires arguments

Evaluating the arguments

In parse, we could simply map parse over the arguments to get a list of trees corresponding to our arguments

We cannot simply use `(map eval-exp (app-exp-args tree))` to evaluate them, why?

What should we map instead?

After evaluating proc and args, need to apply

To evaluate an `app-exp`

- Evaluate the procedure ✔
- Evaluate the arguments ✔
- Apply the procedure to the arguments

We need to evaluate all of those; add something like the following to `eval-exp`

```
[(app-exp? tree)
 (let ([proc (eval-exp (app-exp-proc tree) e)]
       [args (map … (app-exp-args tree)])
   (apply-proc proc args))]
```

Applying a procedure

The `apply-proc` procedure takes an evaluated procedure (a value of some sort) and a list of evaluated arguments (a list of values)

It can look at the procedure and determine if it's a primitive procedure

- If so, it will call `apply-primitive-op`
- If not, it's an error for now; later, we'll add code to deal with non-primitive procedure (i.e., closures produced by evaluating lambdas)

```
(define (apply-proc proc args)
  (cond [(prim-proc? proc)
         (apply-primitive-op (prim-proc-symbol proc) args)]
        [else (error 'apply-proc "Bad proc: ~s" proc)]))
```

Applying primitive operations

(apply-primitive-op op args)

apply-primitive-op takes a symbol (such as `'+` or `'*`) and a list of arguments

You probably want something like

```
(define (apply-primitive-op op args)
  (cond [(eq? op '+) (apply + args)]
        [(eq? op '*) (apply * args)]
        ...
        [else (error ...)]))
```

When implementing cdr, what should we add to apply-primitive-op?

```
(define (apply-primitive-op op args)
  (cond ...
        [(eq? op 'cdr) ???]
        ...
        [else (error ...)]))
```

A. `(cdr args)`

B. `(rest args)`

C. `(cdr (first args))`

D. `(apply cdr args)`

E. More than one of the above works correctly

Adding additional primitive procedures

1. Add the procedure name to `primitive-operators`
2. Add a corresponding line to the `cond` in `apply-primitive-op`

E.g.,

```
[(eq? op 'car) (apply car args)]
[(eq? op 'cdr) (apply cdr args)]
[(eq? op 'list) (apply list args)]
```

What is the result of `(eval-exp (parse '(* 4 5)) empty-env)`?

A. `20`

B. `(app-exp (var-exp '*) (list (lit-exp 4) (lit-exp 5)))`

C. `(prim-proc '* 4 5)`

D. `(prim-proc (var-exp '*) (lit-exp 4) (lit-exp 5))`

E. An error of some sort

What is the result of `(eval-exp (parse '(* 4 5)) init-env)`?

A. `20`

B. `(app-exp (var-exp '*) (list (lit-exp 4) (lit-exp 5)))`

C. `(prim-proc '* 4 5)`

D. `(prim-proc (var-exp '*) (lit-exp 4) (lit-exp 5))`

E. An error of some sort

Why go to all that trouble?

In a later version of MiniScheme, we'll implement lambda

We'll deal with this by adding a line to `apply-proc` that will apply closures

Adding other primitive procedures

In addition (pardon the pun) to `+`, `-`, `*`, and `/`, you'll add several other primitive procedures

- `add1`
- `sub1`
- `negate`
- `list`
- `cons`
- `car`
- `cdr`

And you'll add a new variable `null` bound to the empty list

What can MiniScheme C do?

Numbers

Pre-defined variables

Procedure calls to built-in (primitive) procedures

Testing

You'll need to test your implementation

Make sure you test as you go!

One test file for each MiniScheme module

- `env-tests.rkt`
- `parse-tests.rkt`
- `interp-tests.rkt`

Parser tests

Test that you can parse numbers, symbols, and applications (so far)

```
; Test that (var-exp? (parse 'x)) returns #t
(test-pred "Variable"
           var-exp?
           (parse 'x))

; Test that (parse 'y) returns (var-exp 'y)
(test-equal? "Variable equality"
             (parse 'y)
             (var-exp 'y))
```

Parser tests

```
; Test that (parse '()) raises exception
(test-exn "Invalid syntax ()"
          exn:fail?
          (λ () (parse '())))

; Test that (parse "string") raises exception
(test-exn "Invalid syntax \"string\""
          exn:fail?
          (λ () (parse "string")))
```

Interpreter tests

```
; Construct a test environment
(define test-env
  (env '(foo bar) '(10 23) init-env))

; Test evaluating literals
(test-equal? "Literal"
             (eval-exp (lit-exp 5) test-env)
             5)

; Test evaluating variables
(test-equal? "Variable"
             (eval-exp (var-exp 'foo) test-env)
             10)
```

Interpreter tests

```
; Test primitive procedures
(test-equal? "Primitive cons"
             (eval-exp (var-exp 'cons) test-env)
             (prim-proc 'cons))
```

WARNING

To the greatest extent possible, you want to test eval-exp by passing it a parse tree constructed by hand

```
; Do this
(test-equal? "Apply (- 23 3)"
             (eval-exp (app-exp (var-exp '-)
                                (list (lit-exp 23)
                                      (lit-exp 3)))
                       test-env)
             20)
```

WARNING

```
; Do NOT do this if you can help it
(test-equal? "Apply (- 23 3)"
             (eval-exp (parse '(- 23 3)) test-env)
             20)
```

Two reasons

1. You'll want to test the interpreter separately from the parser
2. It's *extremely* easy to make a mistake:

```
(test-equal? "Apply (- 23 3)"
             (eval-exp (parse (- 23 3)) test-env)
             20)
```

Tests can be run independently or all at once

```
(run-tests env-tests)

(run-tests parse-tests)

(run-tests interp-tests)
```

Running the tests.rkt file will run all tests at once via

```
(run-tests all-tests)
```

Or you can get a gui via

```
(test/gui all-tests)
```