CS 314 Principles of Programming Languages

Lecture 13: Functional Programming

Prof. Zheng Zhang

Rutgers University

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Computational Paradigms

Imperative:

Sequence of state-changing actions.

- Manipulate an abstract machine with:
  1. Variables naming memory locations
  2. Arithmetic and logical operations
  3. Reference, evaluate, assign operations
  4. Explicit control flow statements
- Fits the *von Neumann architecture* closely
- Key operations: *Assignment* and *Control Flow*

Computation Paradigms

Functional:

Composition of operations on data.

- No named memory locations
- Value binding through parameter passing
- Key operations: *Function application* and *Function abstraction*
- Basis in *lambda calculus*

Pure Functional Languages

Fundamental concept: **application** of (mathematical) functions to values

1. **Referential transparency**: the value of a function application is independent of the context in which it occurs

   - value of *foo(a, b, c)* depends only on the values of *foo*, *a*, *b* and *c*
   - it does not depend on the global state of the computation

   $\Rightarrow$ all vars in function must be local (or parameters)

2. **The concept of assignment is NOT part of function programming**

   - no explicit assignment statements
   - variables bound to values only through the association of actual parameters to formal parameters in function calls
   - thus no need to consider global states

Pure Functional Languages

3. **Control flow is governed by function calls and conditional expressions**

   $\Rightarrow$ no loop

   $\Rightarrow$ recursion is widely used

4. **All storage management is implicit**
   - needs garbage collection

5. **Functions are $\boxed{\textit{First Class Values}}$**
   - can be returned from a subroutine
   - can be passed as a parameter
   - can be bound to a variable

Pure Functional Languages

A program includes:

1. A set of function definitions
2. An expression to be evaluated

E.g. in scheme,

```
> (define length
        (lambda (x)
            (if (null? x)
                0
                (+ 1 (length (rest x))))))

> (length '(A LIST OF 5 THINGS))

    5
```

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LISP

- Functional language developed by John McCarthy in the mid 50's
- Semantics based on *Lambda Calculus*
- All functions operate on lists or symbols called: "S-expression"
- Only five basic functions:
  list functions ***con***, ***car***, ***cdr***, ***equal***, ***atom***,
  & one conditional construct: ***cond***
- Useful for LISt-Processing (LISP) applications
- Program and data have the same syntactic form
  "S-expression"
- Originally used in Artificial Intelligence

SCHEME

- Developed in 1975 by Gerald J. Sussman and Guy L. Steele
- A dialect of LISP
- Simple syntax, small language
- Closer to initial semantics of LISP as compared to COMMON LISP
- Provide basic list processing tools
- Allows functions to be first class objects

SCHEME

- Expressions are written in prefix, parenthesized form

  (*function* arg_1 arg_2 … arg_n)

  (+ 4 5)

  (+ (* 3 4) (- 5 3))

- Operational semantics:

  In order to evaluate an expression

  1. Evaluate function to a function value
  2. Evaluate each arg_i in order to obtain its value
  3. Apply function value to these values

S-expression

S-expression ::= Atom | (S-expression) | S-expression S-expression
Atom ::= Name | Number | #t | #f | ε

```
#t
()
(a b c)
(a (b c) d)
((a b c) (d e (f)))
(1 (b) 2)
```

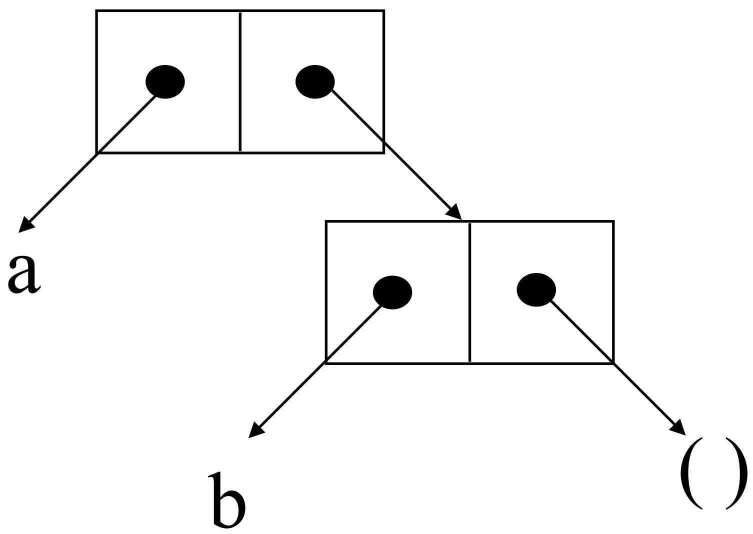
$\boxed{\text{Lists have nested structure!}}$

Lists in Scheme

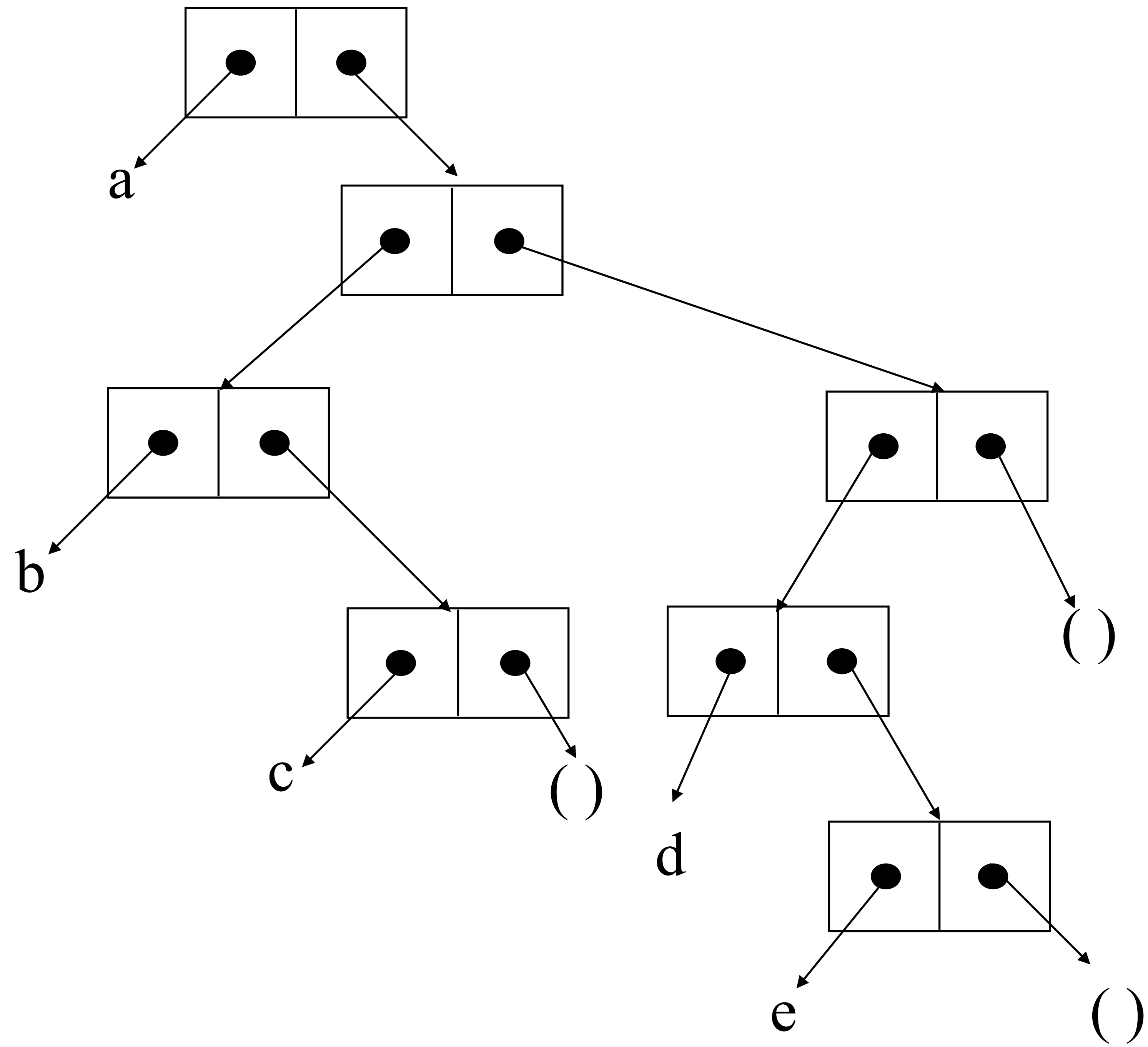
The building blocks for lists are pairs or cons-cells.

Proper lists use the empty list "( )" as an "end-of-list" marker.

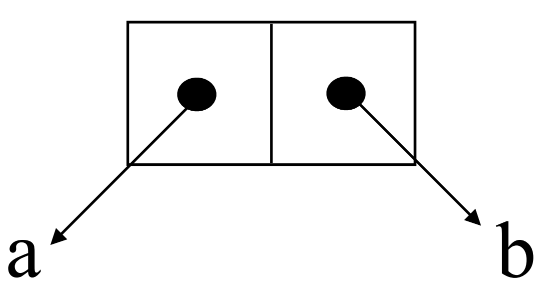
(a b)



(a (b c) (d e))



(a . b)



Special (Primitive) Functions

- **eq?**: identity on names (atoms)
- **null?**: is list empty?
- **car**: select first element of the list
  (contents of address part of register)
- **cdr**: select rest of the list
  (contents of decrement part of register)
- **(cons element list)**: constructs lists by adding **element** to the front of **list**
- **quote or ':** produces constants

Do not evaluate the ' the content after '. Treat them as list of literals.

Quotes Inhibit Evaluation

> (**cons** 'a (**cons** 'b '(c d)))
(a b c d)

;; Now if we quote the second argument
> (**cons** 'a '(cons 'b '(c d)))
(a cons 'b '(c d))

;; If we unquote the first argument
> (**cons** a (**cons** 'b '(c d)))
a: undefined;
 cannot reference undefined identifier
   context …

Special (Primitive) Functions

- '( ) is an empty list
- (car '(a b c)) = a
- (car '((a) b (c d))) = (a)
- (cdr '(a b c)) = (b c)
- (cdr '((a) b (c d))) = (b (c d))

Special (Primitive) Functions

- **car** and **cdr** can break up any list:

  (car (cdr (cdr '((a) b (c d))))) = (c d)

  (cdr '((a) b (c d))) = (b (c d))

- **cons** can construct any list:

  (cons 'a '( )) = (a)

  (cons 'd '(e)) = (d e)

  (cons '(a b) '(c d)) = ((a b) c d)

  (cons '(a b c) '((a) b)) = ((a b c) (a) b)

Other Functions

- +, -, *, / numeric operators, e.g.,
  - (+ 5 3) = 8, (- 5 3) = 2
  - (* 5 3) = 15, (/ 5 3) = 1.6666666
- **= < >** comparisons for numbers
- Explicit type determination and type functions:
  ⇒ All return Boolean values: #f and #t
  - (number? 5) evaluates to #t
  - (zero? 0) evaluates to #t
  - (symbol? 'sam) evaluates to #t
  - (list? '(a b)) evaluates to #t
  - (null? '( )) evaluates to #t

Note: SCHEME is a *strongly typed language.*

Other Functions

- (number? 'sam) evaluates to #f
- (null? '(a)) evaluates to #f
- (zero? (- 3 3)) evaluates to #t
- (zero? '(- 3 3)) ⇒ type error
- (list? (+ 3 4)) evaluates to #f
- (list? '(+ 3 4)) evaluates to #t

READ-EVAL-PRINT Loop

The Scheme interpreters on the ilab machines are called *mzscheme*, *racket*, and Dr*Racket*. “drracket” is an interactive environment, the others are command-line based.

For example: Type racket, and you are in the READ-EVAL PRINT loop. Use “*Control D*” to exit the interpreter.

```
zz124@vi ~> racket
Welcome to Racket v6.5.
>  (define length
(lambda (x)
 (if (null? x)
        0
        (+ 1 (length (rest x))))))
>
(length '(A LIST OF 6 THINGS))
5
>
```

READ-EVAL-PRINT Loop

The Scheme interpreters on the ilab machines are called *mzscheme*, *racket*, and *drracket*. “drracket” is an interactive environment, the others are command-line based.

READ: Read input from user:

A function application

EVAL: Evaluate input:

(f arg_1 arg_2 … arg_n)

1. evaluate function to a function value
2. evaluate each arg_i in order to obtain its value
3. apply function value to these values

PRINT: Print resulting value:

The result of function application

You can write your Scheme program in file <name>.rkts and then read it into the Scheme interpreter by saying at the interpreter prompt:

```
(load "<name>.rkts")
```

READ-EVAL-PRINT Loop Example

> (cons 'a (cons 'b '(c d)))
(a b c d)

1. Read the function application
   (cons 'a (cons 'b '(c d)))
2. Evaluate **cons** to obtain a function
3. Evaluate 'a to obtain a itself
4. Evaluate (**cons** 'b '(c d))
   (i) Evaluate **cons** to obtain a function
   (ii) Evaluate 'b to obtain b itself
   (iii) Evaluate '(c d) to obtain (c d) itself
   (iv) Apply **cons** function to b and (c d) to obtain (b c d)
5. Apply **cons** function to 'a and (b c d) to obtain (a b c d)
6. Print the result of the application: (a b c d)

Defining Global Variables

The **define** constructs extends the current interpreter environment by the new defined (name, value) association

```
> (define foo '(a b c))


> (define bar '(d e f))


> (append foo bar)
(a b c d e f)

> (cons foo bar)
((a b c) d e f)

> (cons 'foo bar)
(foo d e f)
```

Defining Scheme Functions

(define *<fcn-name>* **(lambda (***<fcn-params>***)** *<expression>***))**

<u>Example:</u> Given function **pair?** (true for non-empty lists, false o/w) and function **not** (boolean negation):

```
(define  atom?
         ( lambda (object)
           (not (pair? object) )
         )
  )
```

Evaluating (**atom? '(a)**):

1. Obtain function value for **atom?**
2. Evaluate **'(a)** obtaining **(a)**
3. Evaluate **(not (pair? object))**
   a) Obtain function value for **not**
   b) Evaluate **(pair? object)**
      i. Obtain function value for **pair?**
      ii. Evaluate object obtaining **(a)**
      iii. Evaluates to #t
   c) Evaluates to #f
4. Evaluates to #f

Conditional Execution: if

(if *<condition> <result1> <result2>***)**

1. Evaluate <condition>
2. If the result is a “true value” (i.e., anything but #f), then evaluate and return <result1>
3. Otherwise, evaluate and return <result2>

```
(define abs-val
        ( lambda (x)
            ( if ( >= x 0) x (- x) )
        )
)

(define rest-if-first
        ( lambda (e l)
                ( if ( eq? e (car l) ) ( cdr l ) '() )
        )
)
```

Next Lecture

Things to do:

- Read Scott, Chapter 9.1 - 9.3 (4th Edition)
- Chapter 11.1 - 11.3 (4th Edition)