CS 461

Programming Language Concepts

Gang Tan
Computer Science and Engineering
Penn State University

* Some slides are adapted from those by Dr. Danfeng Zhang

Supplementary Slides

Chap 11 Functional Languages

Why Study Functional Programming (FP)?

- Expose you to a new programming model
  - FP is drastically different
    - Scheme: no loops; recursion everywhere
- FP has had a long tradition
  - Lisp, Scheme, ML, Haskell, …
  - The debate between FP and imperative programming
- FP continues to influence modern languages
  - Most modern languages are multi-paradigm languages
  - Delegates in C#: higher-order functions
  - Python: FP; OOP; imperative programming
  - Scala: mixes FP and OOP
  - C++11: added lambda functions
  - Java 8: added lambda functions in 2014
  - Erlang: behind WhatsApp

A Brief History of Functional Programming

- Theoretical foundation: Lambda calculus
  - Alonzo Church (1930s)
  - Computability: Lambda calculus = Turing Machine
  - Church-Turing Thesis
- Lisp (McCarthy, 1950s)
  - Directly based on lambda calculus
  - Mostly used for symbolic computation (e.g., symbolic differentiation)
- Scheme (Steele and Sussman, 1970s)
  - A relatively small language that provides constructs at the core of Lisp
- OCaml; Haskell; F#;…

Scheme

Learning Functional Programming in Scheme

- Follow the lectures
- Chap 11 In the textbook
- Online tutorials (links on the course website)
  - Teach Yourself Scheme in Fixnum Days
  - An Introduction to Scheme and its Implementation
    - Long and comprehensive
  - Official Scheme Standard
    - Chapter 6 lists all the predefined procedures

DrRacket

- An interactive, integrated, graphical programming environment for Scheme
- Installation
  - You could install it on your own machines
    - http://racket-lang.org/
- Interactive environment
  - read-eval-print loop
    - try 3.14159, (* 2 3.14159)
  - Compare to typical Java/C development cycle

DrRacket: Configuration

- Be sure that the language “Standard (R5RS)” is selected
  - Click Run
- Select View->Hide Definitions to focus on interpreter today

Functional Programming in Scheme

Scheme Variables

- Variables
  - (define pi 3.14)
  - No need to declare types
- Variables are case insensitive
  - pi is the same as Pi

Scheme Expressions

- Prefix notation (Polish notation):
  - *3+4* is written in Scheme as (+ 3 4)
  - Parentheses are necessary
  - Compare to the infix notation: (3 + 4)
- *4+(5 * 7)* is written as
  - (+ 4 (* 5 7))
  - Parentheses are necessary

Scheme Expressions

- General syntax: $(\underset{\text{Function to invoke}}{E_1}\ \underbrace{E_2\ \ldots\ E_k}_{\text{Function arguments}})$
  - Applying the function E1 to arguments E2, …, Ek
  - Examples: (+ 3 4), (+ 4 (* 5 7))
  - Uniform syntax, easy to parse

Built-in Functions

- +, *
  - take 0 or more parameters
  - applies operation to all parameters together
  - (+ 2 4 5)
  - (* 3 2 4)
  - zero or one parameter?
    - (+)
    - (*)
    - (+ 5)
    - (* 8)

13

User-Defined Functions

- Mathematical functions
  - Take some arguments; return some value
- E.g., $f(x) = x^2$
  - $f(3) = 9; f(10) = 100$
- Scheme syntax
  - (define (square x) (* x x))
- A two-argument function: $f(x,y) = x + y^2$
  - (define (f x y) (+ x (* y y)))
  - calling the function: (f 3 4)

14

Anonymous Functions

- Syntax based on Lambda Calculus: $\lambda x.\ x^2$
- Anonymous functions
  - (lambda (x) (* x x))
  - Can be used only once: ((lambda (x) (* x x)) 3)
  - Introduce names
    - (define square (lambda (x) (* x x)))
    - Same as (define (square x) (* x x))

15

Scheme Parenthesis

- Scheme is very strict on parentheses
  - which is reserved for function call (function invocation)
  - (+ 3 4) vs. (+ (3) 4)
  - (lambda (x) x) vs. (lambda (x) (x))
    - the second treats (x) as a function call
  - (lambda (x) (* x x) vs. (lambda (x) (* (x) x))

Defining Recursive Functions

- (define diverge (lambda (x) (diverge (+ x 1))))
  - Call this a diverge function

Booleans

- Boolean values
  - #t, #f for true and false
- Predicates: funs that evaluate to true or false
  - convention: names of Scheme predicates end in “?”
  - number?: test whether argument is a number
  - equal?
    - ex: (equal? 2 2), (equal? x (* 2 y)), (equal? #t #t)
  - =, >, <, <=, >=
    - = is only for numbers
    - (= #t #t) won’t work
  - and, or, not
    - (and (> 7 5) (< 10 20))

If expressions

- If expressions
  - (if P E1 E2)
    - eval P to a boolean, if it's true then eval E1, else eval E2
  - examples: max
    - (define (max x y) (if (> x y) x y))
  - It does not evaluate both branches
    - (define (f x) (if (> x 0) 0 (diverge x))
    - what is (f 1)? what is (f -1)

Mutual Rec. Functions

- even = true, if n =0
  odd(n-1), otherwise
- odd = false, if n =0
  even(n-1), otherwise

```
(define myeven?
    (lambda (n)
      (if (= n 0) #t (myodd? (- n 1)))))
(define myodd?
    (lambda (n)
      (if (= n 0) #f (myeven? (- n 1)))))
```

Conditionals

- (cond (P_1 E_1)
  ...
  (P_n E_n)
  (else E_{n+1}))
  - "If P E_1 E_2" is a syntactic sugar
- examples
  - Problem: Write a function to assign a grade based on the value of a test score. an A for a score of 90 or above, a B for a score of 80-89, a C for a score of 70-79, a D for 60-69, a F otherwise.

```
(define (testscore x)
  (cond ((>= x 90) 'A)
        ((>= x 80) 'B)
        ((>= x 70) 'C)
        ((>= x 60) 'D)
        (else 'F)))
```

Higher-Order Functions

- Functions that
  - take functions as arguments
  - return functions as results
- Example:
  - $g(f,x) = f(f(x))$
  - if $f_1(x) = x + 1$,
    then $g(f_1,x) = f_1(f_1(x)) = f_1(x+1) = (x+1) + 1 = x + 2$
  - if $f_2(x) = x^2$,
    then $g(f_2,x) = f_2(f_2(x)) = f_2(x^2) = (x^2)^2 = x^4$

22

Higher-Order Functions in Scheme

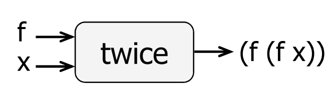
- The ability to write higher-order functions
- Functions are first-class citizens in Scheme
- Examples:

```
(define (twice f x) (f  (f  x)))
(define (plusOne x) (+ 1 x))
(twice plusOne 2)
(twice square 2)
(twice (lambda (x) (+ x 2)) 3)
```

23

A Graphical Representation of Twice

- (define (twice f x) (f (f x)))
  - It takes a function f and an argument x, and returns the result of applying f to x twice

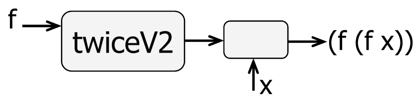


Q: Would Scheme accept (twice plusOne)?

24

Writing Twice in a Different Way

- (define (twiceV2 f)
  (lambda (x) (f (f x))))



- twiceV2 takes a function f as its argument, and returns a function, which takes x as its argument and returns (f (f x))
- Q: Would Scheme accept (twiceV2 plusOne)?

Let constructs

- (let ((x_1 E_1) (x_2 E_2) … (x_k E_k)) E)
  - Semantics
    - E_1, …, E_k are all evaled; then E is evaled, with x_i representing the value of E_i. The result is the value of E
    - The scope of x_1, …, x_k is E
  - Simultaneous assignment
  - examples
    - (* (+ 3 2) (+ 3 2)) is OK, but repetitive
    - writing (let ((x (+ 3 2)) (* x x))) is better
    - (+ (square 3) (square 4)) to
      - (let ((three-sq (square 3)) (four-sq (square 4))) (+ three-sq four-sq))
    - (define x 0)
      (let ((x 2) (y x)) y) to 0

Let* constructs

- (let* ((x1 E1) (x2 E2) … (xk Ek)) E)
  - binds x_i to the val of E_i before E_{i+1} is evaled
  - The scope of x_1 is E_2, E_3,… and E_k and E
  - example:
    (define x 0)
    (let ((x 2) (y x)) y) to 0
    (let* ((x 2) (y x)) y) to 2
  - let* is a syntactic sugar
    - (let* ((x 2) (y x)) y)
    = (let ((x 2)) (let ((y x)) y)

    (define x 0)
    (define y 1)
    (let ((x y) (y x)) y) to 0
    (let* ((x y) (y x)) y) to 1

Letrec constructs

- (letrec ((x1 E1) (x2 E2) … (xk Ek)) E)
  - The scope of x_1 is E_1, E_2,… and E_k and E
- (letrec
  ((fact (lambda (n)
  (if (= n 0) 1 (* n (fact (- n 1)))))))
  (fact 3))

the let won't work