CSE 3302
Programming Languages

Functional Programming Language
(Introduction and Scheme)

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Fall 2007

Disclaimer

- Many of the slides are based on "Introduction to Functional Programming" by Graham Hutton, lecture notes from Oscar Nierstrasz, and lecture notes of Kenneth C. Louden.

Resources

- Textbook: Chapter 11
- Tutorial:
  - The Scheme Programming Language http://www.scheme.com/tspl3/ (Chapter 1-2)
  - Yet Another Haskell Tutorial http://www.cs.utah.edu/~hal/htut (Chapter 1-4, 7)
- Implementation:
  - (Optional) DrScheme http://www.drscheme.org/
  - (Required) Hugs http://www.haskell.org/hugs/ (download WinHugs)
- (Optional) Further reading:
  - Reference manual: Haskell 98 Report http://haskell.org/haskellwiki/Definition
  - A Gentle Introduction to Haskell 98 http://www.haskell.org/tutorial/

History

Lambda Calculus (Church, 1932-33)	formal model of computation
Lisp (McCarthy, 1960) ***Scheme***, 70s	symbolic computations with lists
APL (Iverson, 1962)	algebraic programming with arrays
ISWIM (Landin, 1966)	let and where clauses equational reasoning; birth of "pure" functional programming ...
ML (Edinburgh, 1979) ***Caml*** 1985, ***Ocaml***	originally meta language for theorem proving
SASL, KRC, Miranda (Turner, 1976-85)	lazy evaluation
Haskell (Hudak, Wadler, et al., 1988)	"Grand Unification" of functional languages ...

Functional Programming

- Functional programming is a style of programming:

  Imperative Programming:
  – Program = Data + Algorithms

  OO Programming:
  – Program = Object. message (object)

  Functional Programming:
  – Program = Functions Functions

- Computation is done by application of functions

Functional Programming Languages

- A functional language supports and advocates for the style of FP.
- Important Features:
- ***Everything is function*** (input->function->output)
- ***No variables or assignments*** (only constant values, arguments, and returned values. Thus no notion of state, memory location)
- ***No loops*** (only recursive functions)
- ***No side-effect*** (Referential Transparency): the value of a function depends only on the values of its parameters. Evaluating a function with the same parameters gets the same results. There is no state. Evaluation order or execution path don't matter. (random() and getchar() are not referentially transparent.)
- **Functions are *first-class values:*** *functions are values, can be parameters and return values, can be composed.*

We can use functional programming in imperative languages

- Imperative style

```
int sumto(int n)
 { int i, sum = 0;
   for(i = 1; i <= n; i++) sum += i;
   return sum;
 }
```

- Functional style:

```
int sumto(int n)
 { if (n <= 0) return 0;
   else return sumto(n-1) + n;
 }
```


Why does it matter, anyway?

The advantages of functional programming languages:

- Simple semantics, concise, flexible
- ``No'' side effect
- Less bugs

It does have drawbacks:

- Execution efficiency
- More abstract and mathematical, thus more difficult to learn and use.

Even if we don't use FP languages:

- Features of recursion and higher-order functions have gotten into most programming languages.

Functional Programming Languages in Use

Popular in prototyping, mathematical proof systems, AI and logic applications, research and education.

Scheme:
- Document Style Semantics and Specification Language (SGML stylesheets)
- GIMP
- Guile (GNU's official scripting language)
- Emacs

Haskell
- Linspire (commerical Debian-based Linux distribution)
- Xmonad (X Window Manager)

XSLT (Extensible Stylesheet Language Transformations)

Scheme

Scheme: Lisp dialect

- Syntax (slightly simplified):

expression-sequence → *expression* *expression-sequence* | *expression*
expression → *atom* | *list*
atom → *number* | *string* | *identifier* | *character* | *boolean*
list → '(' *expression-sequence* ')'

- Everything is an expression: programs, data, …
- Only 2 basic kinds of expressions:
  - atoms: unstructured
  - lists: the only structure (a slight simplification).

Expressions

`42`	—a number
`"hello"`	—a string
`#T`	—the Boolean value "true"
`#\a`	—the character 'a'
`(2.1 2.2 3.1)`	—a list of numbers
`hello`	—a identifier
`(+ 2 3)`	—a list (identifier "+" and two numbers)
`(* (+ 2 3) (/ 6 2))`	—a list (identifier "*" and two lists)

Eager Evaluation

- A list is evaluated by recursively evaluating each element in the list as an expression (in some unspecified order); the first expression in the list must evaluate to a function. This function is then applied to the evaluated values of the rest of the list. (*prefix form*).

```
E.g.
3 + 4 * 5                (+ 3 (* 4 5))
(a == b)&&(a != 0)       (and (= a b) (not (= a 0)))
gcd(10,35)               (gcd 10 35)
```

- Most expressions use applicative order evaluation (eager evaluation): arguments are evaluated at a call site before they are passed to the called function.

Lazy Evaluation: Special Forms

- `if` function `(if a b c)`:
  `a` is always evaluated
  one of `b` and `c` is evaluated and returned as result.

- `cond`:
  `(cond (e1 v1) (e2 v2) ... (else vn))`

Lazy Evaluation: Special Forms

- `define` function:
  `(define a b)`: define a name
  `(define (a …) b1 b2 …)`: define a function

  the first expression is never evaluated.

  e.g.,
  - `define x (+ 2 3)`
  - ```
    (define (gcd u v)
        (if (= v 0) u (gcd v (remainder u v))))
    ```


Lazy Evaluation: Special Forms

- `Quote`, or `'` for short, has as its whole purpose to *not* evaluate its argument:
  `(quote (2 3 4))` or `'(2 3 4)` returns just `(2 3 4)`.

- `eval` function: get evaluation back
  `(eval '(+ 2 3))` returns `5`
  `(cons max '(1 3 2)` returns `(max '(1 3 2))`
  `(eval (cons max '(1 3 2))` returns `3`

Other Special Forms

- `let` function:
  create a binding list, then evaluate an expression

  `(let ((n1 e1) (n2 e2) …) v1 v2 …)`

Lists

List
- Only data structure
- Used to construct other data structures.

- `cons:` construct a list
  `(1 2 3)` = `(cons 1 (cons 2 (cons 3 '())))`
  `(1 2 3)` = `(cons 1 '(2 3))`
- `car`: the first element (head)
  `(car '(1 2 3))` = `1`
- `cdr:` the tail
  `(cdr '(1 2 3))` = `(2 3)`
    ```

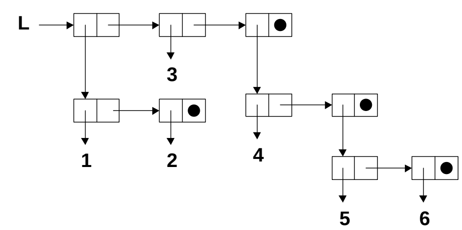
Data structures

```
(define L '((1 2) 3 (4 (5 6))))
(car (car L))
(cdr (car L))
(car (car (cdr (cdr L))))
```

Note:
```
car(car = caar
cdr(car = cdr
car(car(cdr(cdr = caaddr
```


Box diagrams

- L = ((1 2) 3 (4 (5 6))) looks as follows in memory



Lambda expressions /function values

- A function can be created dynamically using a `lambda` expression, which returns a value that is a function:
  `(lambda (x) (* x x))`
- The syntax of a `lambda` expression:
  (lambda *list-of-parameters* *exp1* *exp2* …)
- Indeed, the "function" form of `define` is just syntactic sugar for a `lambda`:
  `(define (f x) (* x x))`
  is equivalent to:
  `(define f (lambda (x) (* x x)))`

Function values as data

- The result of a `lambda` can be manipulated as ordinary data:

```
> ((lambda (x) (* x x)) 5)
25

> (define (add-x x) (lambda(y)(+ x y)))
> (define add-2 (add-x 2))
> (add-2 15)
17
```


Higher-order functions

- higher-order function:
  a function that returns a function as its value
  or takes a function as a parameter
  or both
- E.g.:
  - `add-x`
  - `compose` (next slide)

Higher-order functions

```
(define (compose f g)
  (lambda (x) (f (g x))))

(define (map f L)
  (if (null? L) L
      (cons (f (car L))(map f (cdr L)))))

(define (filter p L)
  (cond
    ((null? L) L)
    ((p (car L)) (cons (car L)
                       (filter p (cdr L))))
    (else (filter p (cdr L)))))
```

`let` expressions as lambdas:

- A `let` expression is really just a lambda applied immediately:
  `(let ((x 2) (y 3)) (+ x y))`
  is the same as
  `((lambda (x y) (+ x y)) 2 3)`
- This is why the following `let` expression is an error if we want x = 2 throughout:
  `(let ((x 2) (y (+ x 1))) (+ x y))`
- Nested `let` (lexical scoping)
  `(let ((x 2)) (let ((y (+ x 1))) (+ x y)))`