Programming Paradigms CSI2120 – Winter 2018

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Functional Programming in Lisp

- **Language designed by John McCarthy between 1956 - 1959 at MIT for applications related to artificial intelligence**
  - one of the oldest languages still in use
- **LISP = LISt Processor**
- **Derived from λ-calculus.**
  - λ-calculus allows functions to be the values of an expression
- **Many dialects**
  - Lisp 1.5 (1960), Scheme (1975), Common Lisp (1985)…
- **Rich language: functional, symbolic.**
- **Syntax and semantics are simple and uniform**

Creation of Lisp

- **1960: McCarthy published his paper on Lisp**
- **Lisp/Scheme has a few simple operators and a rich notation for functions.**
  - But this is combined with simple data structures
- **As a result we have a full and expressive programming language**

Nine Key Concepts

1. Conditions (if-then-else)
2. Functions as data types
3. Recursions
4. Variables as pointers
5. Automatic garbage collection
6. A program is an expression (not a series of statements)
7. Symbols or atoms
8. Lists and trees
9. Complete language available at all times (read-eval-print)

Pure Functional Programming

- **A program corresponds to a function call**
- **A function is a composition of functions**
- **Functions are non-causal**
  - Depend only on the parameters passed
- **No variables, no assignments**
- **No loops, no control statement**
  - Beyond the if-then-else function

Functional Programming in Practise

- **Some additions to pure functional programming**
  - Local definition of certain values
  - Assignments (lexically scoped variables)
  - Use an execution sequence (in order to break up the program).

Functional Programming in Scheme

- **Scheme is LISP dialect designed at MIT in 1975, mainly for education**
- **Initially small**
  - But it is now a complete language.
- **Standardized by ANSI / IEEE**
  - Language continues to evolve
- **Commonly used as interpreted language**
  - But may also be compiled to be executed efficiently.

Application Area of Functional Programming

- **Applications of symbolic computation, i.e., non-numerical applications**
  - Artificial intelligence (expert systems, natural language interfaces, ...)
  - Automated reasoning (theorem proving, proofs of programs …)
  - Symbolic Computation
  - Games

Basic Concepts

- **The list is the fundamental data structure**
- **Atom: a number, a string or a symbol.**
  - All data types are equal
- **An expression is either an atom or a list**
- **A List is a series of expressions in parenthesis**
  - Including the empty list ()
- **A function is a first class object (first-class data) that can be created, assigned to variables, passed as a parameter or returned as a value.**

Evaluations of Expressions

- **Constants are evaluated to what they are.**
  - numbers

```
> 2    => 2
```

  - strings

```
> "Hello"  => "Hello"
```

- **Identifiers evaluate to the value that is attributed to them.**

> * => #<procedure:*>

- **Lists are evaluated by**
  - first evaluating the head, i.e., the first expression; the value of this expression must be a function
  - The arguments of this function are the values obtained by evaluating the expressions contained in the rest of the list

A First Scheme Session

- **In its simplest form, a Scheme interpreter session uses the interactive READ-EVAL-PRINT programming model (REPL)**
- **Example:**

```
> (+ 3 4)
7
```

- **In the example, we have a list.**
  - The first entry is the function +
  - The rest of the list are constant expressions 3 and 4.
- **The list is read as `(+ 3 4)`, evaluated and then the result `7` printed.**

Scheme Interpreter

- **Classical MIT Scheme interpreter**
  - http://www.gnu.org/software/mit-scheme/
  - While available, not well supported under windows
- **Racket**
  - Another LISP dialect
- **DrRacket**
  - http://racket-lang.org/
  - Convenient and full-fledged programming environment to run LISP dialects

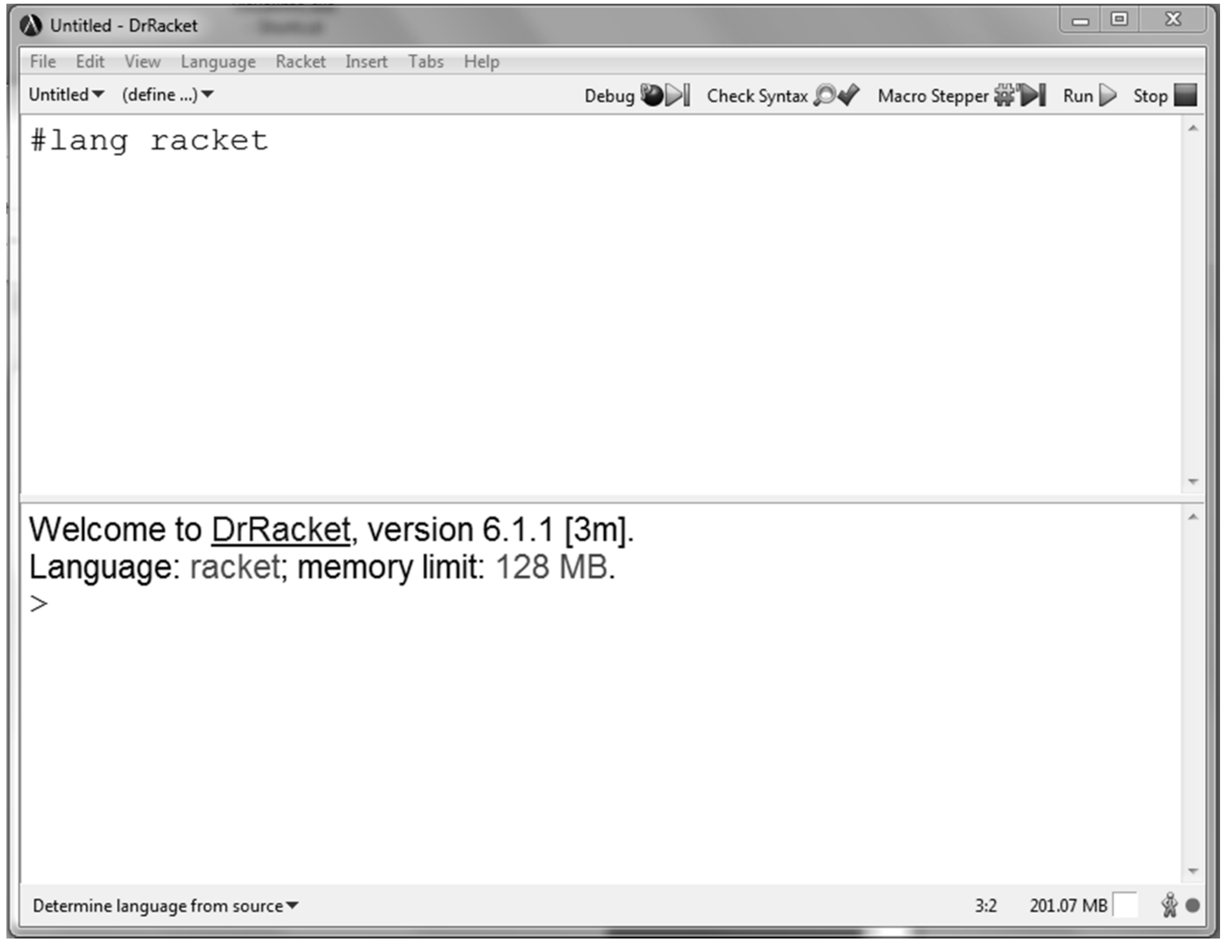
Few Remarks on the IDE

You must select a language in top of window.

Program editor

Bottom window is for running programs

This is the classic REPL Buffer



Evaluation of Expressions

- **The prefix notation is used in expressions**
  – Instead of inline operators as in 3+4*5
  – One needs to write (+ 3 (* 4 5))
- **To evaluate an expression, all sub-expressions must be evaluated first.**
  – The evaluation follows normal order evaluation
  – Brackets determine the order and are not optional

```
(+ 3 (* 4 5))
(+ 3 20)
23
```

Special Syntactic Forms

- **Some expressions do not obey the normal order evaluation, these expressions are said to have a *special syntactic form*.**
- **The evaluation of their arguments is deferred until the required values are known.**
- **The main special syntactic forms are:**
  - if statement
    - conditional branching
  - creation of local scope
  - quotation

Special Syntactic Forms: The Alternative (if statement)

```
(if (=  x  0) infini  (/ 1  x))
```

- **The expression following the if is evaluated first .**
- **If its value is true (# t) then**
  - the second argument is evaluated
  - its value is returned without evaluating the third argument
- **if its value is false (# f) then**
  - the third argument is evaluated and returned

Special Syntactic Forms: 2. Conditional Branching

- **Conditional expressions are similar to `if` but more than two branches can be specified**

```
(cond ((< x xmin) xmin) ((> x xmax) xmax) (#t x))
```

- **The `cond` expression is followed by a series of lists composed of two expressions.**
  - If the first of the two expressions in one of these lists evaluates to #t then the value of the second expression is returned
  - If the first expression evaluates to false, then evaluation proceeds to the next list.
  - If no lists evaluates to #t then nil is returned.

Example: Conditional and Top-level Define

Definition of the function `showIt` taking an argument `pts` and evaluating a conditional

```
(define (showIt pts)
  (cond ((or (<= pts 3) (>= pts 65)) 0)
        ((<= 4 pts 6) 0.5)
        ((<= 7 pts 12) 1.0)
        ((<= 13 pts 15) 1.5)
        ((<= 16 pts 18) 1.8)
        (else 2.0)))
=> showIt
(showIt 25)
=> 2.0
```

Special Syntactic Forms: 3. Creating Local Scope

- **Let Expressions**

```
(let ((a 3) (b 4)) (* a b))
=> 12
```

- The first argument of a let expression is a list of links created between an identifier and a value
- These links are only valid for the evaluation of the following expression(s)
  - There can be several to allow the execution of a sequence.
  - However, it evaluates to the last expression.

```
(let ((a 3) (b 4)) (* a b) (+ a b)
=> 7
```

Special Syntactic Forms: 4. Quotations

- **The quote function ensures that an argument list is not evaluated.**

```
(quote (1 2 3))
=> (1 2 3)
```

  - But the list is rather returned as is.
  - Quotation is necessary here, otherwise the first expression of a list needs to evaluate to a function.

```
`(+ 3 4) => (+ 3 4)
(+ 3 4) => 7
```

  - The quote function can simply written with a ‘ :

```
'(1 2 3)
 => (1 2 3)
```

Quotation Example

```
(let ((a '(1 2 3)) (b '(3 4 5))) (cons a b))
```

equates to

```
(cons '(1 2 3) '(3 4 5))
```

⇒ `((1 2 3) 3 4 5)`

- The function cons is the dot operator for lists, i.e., it puts the first expression as the head of the second list expression
- The list `( 1 2 3 )` becomes the first element in the combined list `((1 2 3) 3 4 5)`
- (Much) more on list processing soon.

Example: Building a List with the Function `list`

```
(list `a `b `c)
⇒ (a b c)

(list `(a b c))
⇒ ((a b c))
```

Lambdas

- **Lambda expressions are "local functions"**

The expression `(lambda(var1, var2, …) exp1 exp2 …)` returns a function and applies it to the variables that are the parameters to the function expressions, e.g.,

```
((lambda (x) (* x x)) 3)
```

⇒ 9

Multiple variables and multiple expression (result of last expression is the evaluation result)

```
((lambda (f x y) (f x x) (f x y) (f y y)) +
2 3 )
```

⇒ 6

Function Definitions

A definition associates a function expression to a name:

```
(define square (lambda (x) (* x x)))
```

or equivalently:

```
(define (square x) (* x x))
```

Use of define, here procedure square:

```
(square 2)
⇒ 4
```

Example: Factorial

Top-level Function Definition

```
(define (fact n)
  ( if (> n 0)
       ( * n (fact (- n 1)))
       1)
  )
=> fact

(fact 35)
=> 10333147966386144929666651337523200000000
```

Another Example Function

Conversion from degrees Fahrenheit to Celsius

```
(define (F-a-C temperature)
      (/ (- temperature 32) 1.8))
=> F-a-c
(F-a-C 95)
=> 35
(define freezing 32)
=> freezing
(F-a-C freezing)
=> 0
```

Function Definitions with Lambdas

- We have seen Lambdas can be combined with top-level defines

```
(define fct (lambda (f x) (f x x)))
(fct + 13)
=> 26
(fct * 4)
=> 16
```

- Combine with let binding: x is a let-bound variable in the enclosing scope

```
(let ((x `a))
  (let ((f (lambda (y) (list x y))))
    (f `b)))
=> (a b)
```

Lambda Expression and Let-Bound Variables

```
(let ((x 2) (y 3)) (+ x y))
```

is equivalent to

```
((lambda (x y) (+ x y)) 2 3)
```

In general:

```
((let (var val) …) expr…) ≡ ((lambda (var …)
   expr…) val…)
```

Example: Greatest Common Divisor (GCD)

- **top level define for gcd function**

```
(define gcd
  (lambda (a b)
    (if (= a b)
      a
       (if (> a b)
           (gcd (- a b) b)
           (gcd a (- b a))))))
=> gcd
(gcd 12 15)
=> 3
```

Summary

- **Introduction to Functional Programming**
- **Basic Scheme**
- **Special Syntactic Forms**
  - Alternative (if then else)
  - Conditional
  - Local Scope
  - Quotation
- **Let-bound variables**
- **Top-level (function) definitions**
- **Lambda expressions**