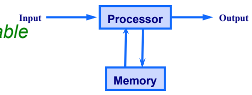
CSCI: 4500/6500 Programming Languages

Functional Programming Languages

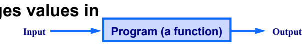
Part 1: Introduction

Thanks again to Profs David Evan's, University Virginia and Prof. Sebesta, author of our other book

Overview Language Perspectives



- **Imperative: Mode of computation -** *a variable (state)*
  - » **Von Neumann Machines**
    - – **modify variables in memory**
  - » **Turing machines - imperative - changes values in cells (variables) on tape**



- **Functional: Mode of computation -** *a function*
  - » **Lambda calculus**
  - » **apply a function (a program) to transform its input (parameters) to output (result)**
- **Relational: Mode of computation -** *constraints*
  - » **programmer writes set of axioms that allow the computer to discover a constructive proof for a particular set of inputs**

Functional Programming

- **Do everything by using functions and evaluate them**
  - » **Great advantages:**
    - – **no side effects**
    - – **no mutable state**
- **Based on "mathematical functions"**
  - » **Historically from Church's model of computation called the lambda calculus (λ - calculus)**
    - – **Study of function application and recursion**
- **Example Languages: LISP, Scheme, FP, ML, Miranda and Haskell**

Functional programming: *Focus on Functions*

- **An object is first class (no restriction on use) when:**
  - » **can be created during execution (run time)**
  - » **stored in data structures or in variables**
  - » **can be used as parameters or inputs to other functions**
  - » **can be returned**
- **Higher order functions (operates on other functions) either or both:**
  - » **Input: can take other functions as arguments**
  - » **Output: and/or return function as results**
- **Higher order functions are building blocks of functional languages.**

History: LISP first functional 'programming' language

ILP – Simon & Newell'd assembly language –first functional based PL

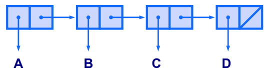
- **LISt Processing Language (McCarthy (MIT) 1959)**
  - » **Processes data in lists**
- **Two objects (originally) or data types:**
  - » **Atoms (number of a symbol) and**
  - » **Lists (sequence of elements)**
  - » **S-expression (atoms and pair) = atom a symbol (upper case), pair was parenthesized.**
  - » **M-expressions (meta variables (lower case) and argument list)**
- **Lists are delimiting their items in parenthesis.**
  - » **Simple list: (A B C)** *// 3 elements*
  - » **Complex list: (foo (bar 1) 2)** *// 3 elements*

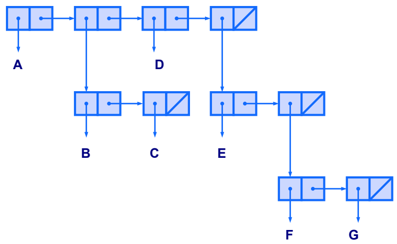
History: LISP first functional 'programming' language

- **Lists are delimiting their items in parenthesis.**
  - » **Simple list: (A B C)** *// 3 elements*
  - » **Complex list (list of lists): (foo (bar 1) 2)** *// 3 elements*
- **Both functions and data are represented in the same form, e.g.:**
  - » **(A B C) as data is a simple list of 3 atoms: A, B and C**
  - » **(A B C) as a function is interpreted as the function named "A" applied to two parameters, B and C, e.g., (+ 4 5)**
    - – **Cambridge Polish (*parenthesized* prefix notation)**
- **Polish Notation :: Prefix notation : + 3 4**
- **Cambridge Notation(add parenthesis) :: (+3 4)**
- **Reverse Polish Notation :: 3 4 +**
  - » **3 6 / -> / 3 6 -> 0.5**
  - » **6 3 / -> / 6 3 -> 2**

LISP (implementation)

- List forms parenthesized collection of *sub* lists and/or atoms:
- Stored as a linked list each node has two pointers
  - » First pointer to a representation of the element (e.g., symbol or number) or another sublist
  - » Second pointer next element of list
- Example:
  - » (A B C D)
  - » (A (B C) D (E (F G)))





Variants of LISP

- Pure (original Lisp)
  - » purely functional
    - – no imperative features (e.g., NO assignment statement)
  - » dynamically scoped (as all early versions of LISP) more on this next slide.
- All other Lisp's have some imperative features (e.g., data is contained in a variable, assignment statement)
- COMMON Lisp (statically scoped)
  - » brought all LISPs under a common umbrella
    - – HUGE, and very complicated, provides dynamic scope as an option
- Scheme a mid-1970s dialect of LISP designed to be cleaner, more modern and simpler version than dialects of Lisps
  - » Statically scoped and tail recursive

Scope: A Preview (what is the value of *a*)

- Static scoping (what we are used to)
  - » Variables refers to its nearest enclosed binding
  - » Lexiographic -- Compile time
- Dynamic scoping:
  - » Refers to the closest active binding
  - » Binding name-object depends on the flow of control at run time and the order subroutines are called,

```
a: integer    // global

procedure first()
  {
  a = 1       // global or local?
  }
procedure second()
  {
  a: integer // local
  first()
  }
a = 2
if read_integer() > 0
  second()    // 2 for dynamic
else
  first()     // 1 for dynamic
print("%d\n", a)
```

```
Static:  always prints 1 : a is global scope
         of a is closest enclosed a, so
         for "first"'s a refers to global a
Dynamic: prints 1 or 2: if we go to second
         first, first's a refers to second's
         local a (closest active binding and
does not change the global a)
```


Introduction to Scheme

- Mid-1970s dialect to Lisp, designed to be cleaner, more modern and simpler than contemporary dialects of LIPS
- Uses static scoping (lexical binding determined by reading program text) and is 'tail recursive'.
- Functions are first class entities
  - » Can be values of expressions and elements of a list
  - » Can be assigned variables and passed as parameters
- Have some imperative features (but will not focus on these).

Scheme

- Is a collection of function definitions and lots of parenthesis.
  - » primitive functions (a form of an expression)
    - – +, - *
    - – (+ 3 4)
    - – ((+ 3 4)) -> error
      - Calls + with 3 and 4 as parameters, then call 7 as a 0 parameter function = a run time error
  - » A simple expression could just be value
    - – 5
    - – 5 is evaluated to be "5"

How do we create more complex functions?

- *Lambda* (λ) expressions – creates functions
  - » (lambda (parameters) expression)
  - » (lambda (x) (* x x))
    - – is a nameless function that returns the square of its parameters (nameless don't need to use it again).
    - – can be applied like normally containing a list that contains the actual parameters

How do we create more complex functions?

- *Lambda* (λ) **expressions – creates functions**
  - » **(lambda (parameters) expression)**
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    - – **is a nameless function that returns the square of its parameters (nameless don't need to use it again).**
    - – **can be applied like normally containing a list that contains the actual parameters**
  - » **How to use: Read, evaluates (applies the function to its parameters) and prints the results**
  - » **((lambda (x) (* x x)) 7). Here x is called a bound variables and does not change after being bound to a parameter (we can bind a name to a lambda expression too, by using define)**
- **((lambda (a b) (if (< a b) a b)) 5 6)**
- **((lambda (a b) (if (< a b) a b)) 6 5)**

Give an expression a name: "*define*"

- **Binds name to a value**
  - » **(define symbol expression)**
  - » **(define pi 3.14159)**
- **Binds a name to a *Lambda* (λ)**
  - » **expression is abbreviated (no word "lambda" is needed)**
  - » **takes two lists as parameters**
    - – **prototype of function**
      - **function name followed by formal parameters**
    - – **one or more expressions to which name is to be bound**
  - » **(define (function_name parameters) expression {expression})**
  - » **Example:**
    - – **(define (square number) (* number number))**
    - – **(square 5)**
      - **displays 25**

Haskell Curry: Combinatory Logic (precursor of lambda calculus). Combinator - higher order function

**Currying

- **Transforms a multiple argument function so that it can be called as a chain of functions each with a single argument.**
  - » **Example: Allows languages to reduce the function (+ 1 4) [plus-one] to a simpler function with one argument. Pre apply the +1 to the function and wait for the "4"**
    - – **++, -- (plus one with a single argument – "1" is removed as an argument.**
  - » `( define curried-plus ( lambda ( a ) ( lambda ( b ) ( + a b ) ) ))`
    - – `( ( curried-plus 1 ) 4 ) ; chain here – one argument at a time.`
    - – `( define plus-1 ( curried-plus 1 ) )`
    - – `( plus-1 4 )`
  - » **Idea: If you "fix" some arguments you get reduce the function arguments to only use the remaining arguments. Another Example:**
    - – **y^x and fix y = 2 then you get the function of one variable 2^x.**
- **What is it really? An incomplete application of arguments to a function**


turmeric


coriander


chile pepper


garlic

Examples: Currying

- `( define curried-plus ( lambda (a) (lambda (b) (+ a b ) ) ) )`
- **(curried-plus 3) : adds 3 to an argument b (not given yet)**
  - » **((curried-plus 3) 4) => 7**
- **(define plus-three (curried-plus 3))**
  - » **(plus-three 4) => 7, (plus-three 5) => 8**
- **General purpose "function" (any operation) that curries its (binary) arguments:**
  - » `(define curry ( lambda ( f ) ( lambda (a ) (lambda (b) ( f a b ))))`
  - » **f can be defined as addition '+' separately**
    - `- (define curried-plus (curry + ) ) -> ((curried-plus 3 ) 4 ) -> 7`
    - `- (define curried-mult (curry * ) ) -> ((curried-mult 3) 4) -> 12`

Currying

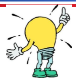
- **Rewriting a function with multiple parameters as a composition of functions of one parameter**
  - » **plus = f(a, b) = a + b f(3, 2) = 5 (not curried)**
  - » **curried_plus = [f(b) => f(a) = a + b]**
    - – **takes a single argument b and returns a function that takes a single argument 'b' and returns the results a + b**
    - – **plus_one = curried_plus(1), and now**
      - **plus_one(5) returns 6 and plus_one(2) returns 3**

Essential Scheme

```
Expression ::= PrimitiveExpression
ApplicationExpression ::= ( Expression MoreExpressions )
MoreExpressions ::= Expression MoreExpressions
MoreExpressions ::=
Expression := ApplicationExpressions
Expression := Name
PrimitiveExpression := Number
PrimitiveExpression ::= + | - | * | / | < | > | =
PrimitiveExpression := … (many other )
```

Grammar is simple, just follow the replacement rules. What does it all mean?

Scheme: Functional programming



What is going on, really?

In General – 2 things (Evaluate and Apply):

- **Evaluate the functions or the expressions then**
- **Apply the value of the first expression (a function) to the values of all the other expressions**

Examples:

- **(+ 655 58), (* 5 7 8), (-24 (* 4 3))**

Evaluation: Expressions and Value

- **Expression has a value (almost always)**
- **When an expression with a value is evaluated its value is produced**
- **How do we evaluate:**
  - » **primitives**
  - » **names**
  - » **applications (expression)**

Evaluating: Primitives

- **Primitives are *self evaluating***
  - » **2**

    2
  - » **#t**

    #t
  - » **+**

    #<primitive:+>

Evaluating: Names

- **Evaluates to the value associated with the name.**

```
>(define two 2)
>two
2
```


Evaluating Applications

Evaluate:

all the sub expressions of the combination

- **Apply the value of the first sub expression to the values of all the other sub expressions**
  - » **(expression expression expression)**

Avoiding Evaluation

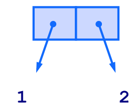
- **Anything inside** parenthesis **are function calls (and therefore are evaluated) unless quoted:**
  - » `QUOTE` **- takes one parameter; returns the parameter without evaluation, abbreviated '**
  - » **e.g.,** `'(A B)` **is equivalent to (**`QUOTE` **(A B))**
- **'(a) returns a (it makes scheme think it is not something of value).**
- **'(a b c) returns (a b c)**

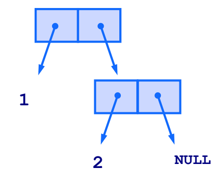
Dealing with Lists

- LISt Processing Language
- Lets talk about how to make lists…

CONS: CONStructs a pair

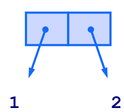
- (cons 1 2)
  - » (1 . 2)
- Creates a dotted pair, consisting of two atoms
- A list
  - '(1 . (2. nil)) -> (1 2)
- CONS builds a list from two parameters, the first is either an atom or a list, the second is usually a list.
  - » (cons '1 '()) -> 1
  - » (cons '1 (cons '2 '()))





Splitting a Pair (car and cdr)

- (car (cons 1 2)) -> 1
- (cdr (cons 1 2)) -> 2



car extracts the first part of a pair

cdr extracts second part of a pair

Why "car" and "cdr"?

- Original (1950s) LISP on IBM 704
  - » stored cons pairs in memory registers
  - » car = "contents of the address part of register"
  - » cdr = "contents of the decrement part of the register ("could-er")
- Think of them as the first and the rest (or head of list and tail of list)
  - » (define first car)
  - » (define rest cdr)

More examples

- `car` takes a list parameter; returns the first element of that list
  - e.g., (car '(A B C)) yields A
  - (car '((A B) C D)) yields (A B)
- `cdr` takes a list parameter; returns the list after removing its first element
  - e.g., (cdr '(A B C)) yields (B C)
  - (cdr '((A B) C D)) yields (C D)
  - (cdr 'A) is an error

Defining Threesomes

A triple is a pair where one of the pairs is a pair

(define (triple a b c) (cons a (cons b c)))

(define (triple-first t) (car t))

(define (triple-second t) (car (cdr t)))

(define (triple-third t) (cdr (cdr t)))

Lists

- List := (cons element list)

- A list is a pair where the second part is a list,
  - » ugh, how do we stop… this only allows infinitely long lists…

- A list is either
  - » a pair where the second pair is a list (cons Element List)
  - » or, empty (null)

Characteristics of "Pure" Functional Languages

- No side effects (e.g. no access to global variables)
- No assignment statements
- Often no variables
- Small concise framework
- Simple uniform syntax
- Recursive (that is how we get things done)
- Interpreted

Next Time

- Tutorial on Scheme