Functional Programming

Lecture 1: Introduction

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...

What is functional programming?

Wikipedia: Functional programming is a **programming paradigm** that treats computation as the evaluation of mathematical functions.

Programming paradigm: a style of building the structure and elements of computer programs.

Goal of the course

1. Improve your programming skills!
   - master recursion
   - master problem decomposition
   - rethink side effects (stateless programs)
   - different perspective to the same problems

2. Learn principles of functional programming
   - has clear benefits for SOME problems
   - it is used in many other languages

Why do I care?

- quickly learn new programming languages
- programming paradigms change and develop
- no side effects is great for
  - parallelization
  - verification
  - communication with many clients
- understanding fundamentals of computation

Does anyone use it?

- Lisp: AutoCAD, Emacs, Gimp
- Haskell: Facebook, Google, Intel
- Scala: Twitter, eBay, Linkedin
- Erlang: Facebook, Pinetrest
- Clojure: Walmart, Atlassian
- Javascript: React (Redux)

Imperative vs. Declarative

- **Instructions** to change the computer's state
  - x:=x+1
  - deleteFile("slides.pdf")
- Are executed
  - have effects
- Run program by following instructions top-down

- Functions used to **declare** dependences between data values:
  - z = g(y)
  - y = f(x)
- Expressions are evaluated
  - result to a value
- Run program by evaluating dependencies

Pure functional programming

- No side effects
  - output of a function depends **only** on its inputs
  - function does not change anything in evaluation
  - can be evaluated in any order (many times, never)
- No mutable data
- More complex function based on recursion
  - no for/while cycles
  - natural problem decomposition
    - mathematical induction

Pure functional programming

- Forbids most of what you use in (C/Java)
  - we will show you do really not loose anything
  - it can be useful for many tasks
  - it often leads to more compact code !?!
- Substantially less time spent debugging
  - encapsulation, repeatability, variety of mistakes
- Focus on operations with symbols
- Easier parallelization and verification
- Generally less computationally efficient

Brief History

- Lambda calculus (1930s)
  - formal theory of computation older than TM
- Lisp = List processor (1950s)
  - early practical programming language
  - second oldest higher level language after Fortran
- ML = Meta language (1970s)
  - Lisp with types, used in compilers
- Haskell = first name of Curry (1990s)
  - standard for functional programming research
- Python, Scala, Java8, C++ 11, ….

What will we learn?

Lisp (Scheme)

Lambda calculus

Haskell

Why LISP?

- Extremely simple
- Reasonably popular
- Allows deriving all concepts from principles
- Directly matches lambda calculus

Why Haskell?

- Purely functional language
  - promotes understanding the paradigm
- Rich syntactic sugar (contrast to Lisp)
- Most popular functional language
- Standard for functional programming research
- Fast prototyping of complex systems

- Why not Scala?

Course organization

- Web: cw.fel.cvut.cz/wiki/courses/fup
- Lectures + Labs
- Homework – every 2 weeks (50 %)
  - 3x10 Scheme
  - 2x10 Haskell
  - must have at least 1 point from each and >= 25
  - Deadlines: -3 + -1 per day until +1 is left
- Programming exam (30 %)
- Test (20 %)

Suggested literature

[1] R. Kent Dybvig: The Scheme Programming Language, Fourth Edition, MIT Press, 2009. https://www.scheme.com/tspl4/

[2] Greg Michaelson: An Introduction to Functional Programming Through Lambda Calculus, Dover edition, 2011.

[3] Harold Abelson and Gerald Jay Sussman and Julie Sussman: Structure and Interpretation of Computer Programs, MIT Press, 1996. https://mitpress.mit.edu/sites/default/files/sicp/full-text/book/book.html

For further resources see CourseWiki

Scheme

- Dialect of Lisp (such as Common Lisp, Racket)
- Created in 1970 at MIT by Steele and Sussman
- Last standard from 2007
  - The Revised^6 Report on the Algorithmic Language Scheme (R6RS)
- Supports imperative programming
  - we will initially not use it (we want to learn FP)
- DrRacket: racket-lang.org
  - text editor + REPL (read-evaluate-print loop)

Scheme syntax

Scheme program is a collection of expressions

1. Primitive expressions
2. Compound expressions
3. Abstractions
4. Comments, conventions

Primitive expressions

Expression	Evaluates to
`5`	`5`
`"abc"`	`"abc"`
`'abc`	`abc`
`#t`	`#t`
`#\A`	`#\A`
`+`	`#<procedure:+>`
`a`	`?`

Basics data types

Numbers (infinite precision, complex, etc.)

```
+, -, *, /, abs, sqrt, number?, <, >, =
```

Logical values

```
#t, #f, and, or, not, boolean?
```

Strings

```
"abc", "Hello !!!", string?, substring
```

Other types

```
symbol?, char?, procedure?, pair?, port?,
vector?
```

Conventions

Special suffixes

- ? for predicates
- ! for procedures with side effects
- -> in procedures that transform a type of an object

Prefix of character / string / vector procedures

- char-, string-, and vector-

Comments

; starts a comment until the end of the line

on the line before the explained expression

;;; still start a comment until the end of the line

used to comment a function or code segment

#| |# delimit block comments

Compound expressions

Infix notation

1+2*5

Prefix notation

+ 1 * 2 5

In Scheme, there are no operator preferences

(+ 1 (* 2 5))

S - expression

(fn arg1 arg2 … argN)

(	“operator of calling a function”
fn	expression that evaluates to a *procedure*
argX	arguments of the function
)	end of function call

Conditional expressions

if

```
(if test-exp then-exp else-exp)
```

cond

```
(cond
   (test-exp1 exp)
   (test-exp2 exp)
   (#t exp)
 ...)
```

Quote

Do not evaluate, just to return the argument

```
(quote exp)
```

Abbreviated by '

A quoted expression can be evaluated by *eval*

```
(eval (quote (+ 1 2))
```

Evaluate part of the argument

```
(quasiquote (* 1 2 3 (unquote (+ 2 2)) 4 5)
```

Abbreviated by ` and , respectively

Define

Naming expressions

```
(define id exp)
```

Defining functions

```
(define (name <formals>) <body>)
```

Nested defines

```
(define (name <formals>)
   (define (fn <formals>)
   <body-using-fn>)
```

Identifiers

Keywords, variables, and symbols may be formed from the following set of characters:

- the lowercase letters a through z,
- the uppercase letters A through Z,
- the digits 0 through 9, and
- the characters ? ! . + - * / < = > : $ % ^ & _ ~@
- cannot start with 0-9, +, -, @ (still usually works)

Recursion

A function calling itself

```
(define (fact n)
  (cond ((= 0 n) 1)
        (#t (* n (fact (- n 1))))
   )
)
```

Avoiding infinite recursion

1. First expression of the function is a `cond`
2. The first test is a termination condition
3. The "then" of the first test is not recursive
4. The `cond` pairs are in increasing order of the amount of work required
5. The last `cond` pair is a recursive call
6. Each recursive call brings computations closer to the termination condition

Recursion

Tail recursion

- Last thing a function does is the recursive call

Analytic / synthetic

- Return value from termination condition / composed

Tree recursion

- Function is called recursively multiple times (qsort)

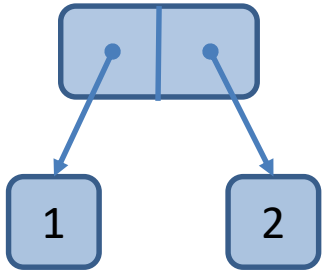
Indirect recursion

- Function A calls function B which calls A

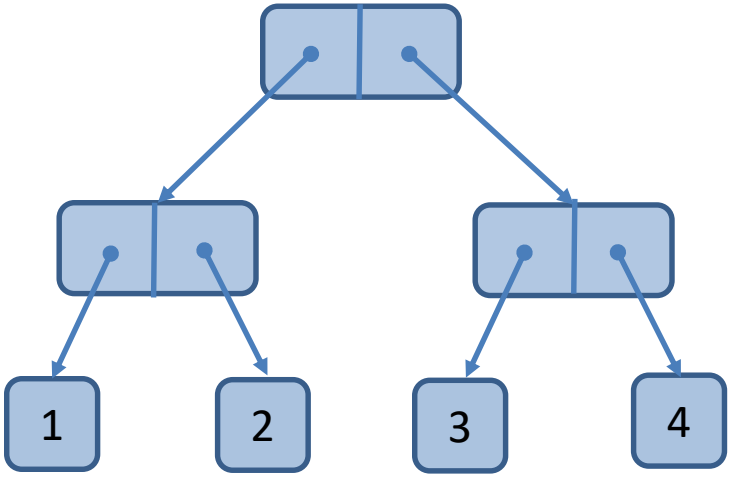
Pairs

Allow to construct compound data structures

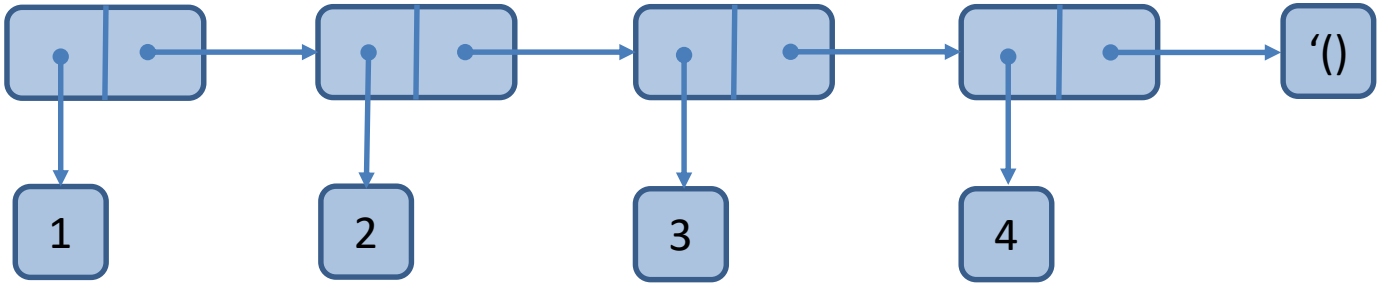
```
(cons 1 2)
    => (1 . 2)
```




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



Lists



Lists are linked lists of pairs with `'()` at the end

S-expressions are just lists

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

Lists can be created by a function `cons` or

```
(list item1 item2 … itemN)
```

Lists

Pairs forming the lists can be decomposed by

- `car` *[car]* first element of the pair
- `cdr` *[could-er]* second element of the pair
- `(caddr x)` shortcut for `(car (cdr (cdr x )))`

Empty list is a null pointer

- `null?` tests whether the argument is the empty list

Last

Return the last element of a list

```
(define (last list)
  (cond
    ((null? (cdr list)) (car list))
    (#t (last (cdr list)))
  )
)
```

What have we learned?

- Functional programming is an alternative programming paradigm
  - no side effects
  - no mutable data structures
  - focus on symbols
- Recursion is the key programming method
- Lists are a key data structure