Functional Programming with Go

Concepts of Programming Languages
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Bernhard Saumweber
Rosenheim Technical University

What is Functional Programming?

- the combination of pure functions;
- avoiding shared state, mutable data, and side-effects;
- the prevalence of declarative approach rather than imperative approach.

Functional Programming – Characteristics

The most prominent characteristics of functional programming are as follows

- Functional programming languages are designed on the concept of mathematical functions that use conditional expressions and recursion to perform computation.
- Functional programming supports higher-order functions and lazy evaluation features.
- Functional programming languages don't support flow Controls like loop statements and conditional statements like If-Else and Switch Statements. They directly use the functions and functional calls.
- Like OOP, functional programming languages support popular concepts such as Abstraction, Encapsulation, Inheritance, and Polymorphism

Functional programming languages are categorized into two groups

- **Pure** Functional Languages

These types of functional languages support only the functional paradigms and have no state. For example − Haskell.

- **Impure** Functional Languages

These types of functional languages support the functional paradigms and imperative style programming. For example − LISP.

Functional programming offers the following advantages

- Bugs-Free Code

Functional programming does not support state, so there are no side-effect results and we can write error-free codes.

- Efficiency

Functional programs consist of independent units that can **run concurrently**. As a result, such programs are more efficient.

- Lazy Evaluation

Functional programming supports **lazy evaluation** like Lazy Lists, Lazy Maps, etc.

- Distribution

Functional programming supports distributed computing

Functions are Values

```
func aBlock(i int) {
    fmt.Printf("Entering block: i=%v\n", i)
}

func do(f func(int), loops int) {
    for i := 0; i < loops; i++ {
        f(i)
    }
}

func main() {
    do(aBlock, 5)
}
```

Run

Exercise 5.1 - Warm Up

Write a Go Programm which shows the following concepts:

- Functions as Variables
- Anonymous Lambda Functions
- High Order Functions (functions as parameters or return values)
- Clojures (https://en.wikipedia.org/wiki/Closure_(computer_programming))

Clojures (Only impure if you modify the closed-over variable)

```
// intSeq returns another function, which we define anonymously in the body of intSeq.
// The returned function closes over the variable i to form a closure.
func intSeq() func() int {
    i := 0
    return func() int {
        i++
        return i
    }
}
func main() {
    // We call intSeq, assigning the result (a function) to nextInt.
    // This function value captures its own i value, which will be updated each time we call nextInt.

    nextInt := intSeq()
    // See the effect of the closure by calling nextInt a few times.
    fmt.Println(nextInt())
    fmt.Println(nextInt())

    // To confirm that the state is unique to that particular function, create and test a new one.
    newInts := intSeq()
    fmt.Println(newInts())
}
```

Run

Many Functional Languages only support Single Argument Functions

- Currying : Converting a function with n arguments in n functions with one argument

```
// ADD with 2 parameters
ADD := func(x, y int) int {
    return x + y
}
```

```
ADD(1,2) -> 3
```

```
// Curried ADD
ADDC := func(x int) func(int) int {
    return func(y int) int {
        return x + y
    }
}
```

```
ADDC(1)(2) -> 3
```

Functional Composition

Functions can be composed to new functions

g(f(x)) -> (g ◦ f)(x)

```
// Function f()
f := func(x int) int {
    return x * x
}

// Function g()
g := func(x int) int {
    return x + 1
}

// Functional Composition: (g◦f)(x)
gf := func(x int) int {
    return g(f(x))
}

fmt.Printf("%v\n", gf(2)) // --> 5
```

Exercise 5.2 - Functional Composition (g∘f)(x)

- Write a Go function to compose two unknown unary functions (one argument and one return value)
- The functions to compose should be arguments
- Write a Unit Test for that function

```
// Type any makes the code readable
type any interface{}
type function func(any) any

compose := ???

square := func(x any) any { return x.(int) * x.(int) }

fmt.Printf("%v\n", compose(square, square)(2)) // --> 4*4 = 16
fmt.Printf("%v\n", compose(compose(square, square), square)(2)) // --> 256
```

Functional Composition (2)

Functions can be composed with functions as parameters

g(f(x)) -> (g ◦ f)(x)

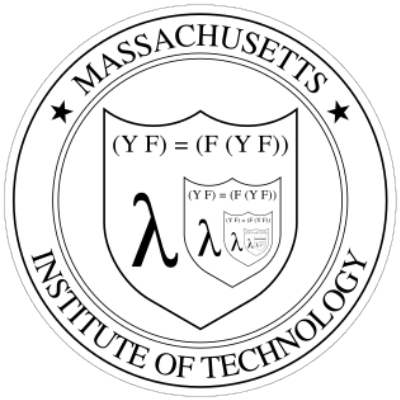
```
// Type any makes the code readable
type any interface{}
type function func(any) any

compose := func(g, f function) function {
    return func(x any) any {
        return g(f(x))
    }
}

square := func(x any) any { return x.(int) * x.(int) }

fmt.Printf("%v\n", compose(square, square)(2)) // --> 4*4 = 16
fmt.Printf("%v\n", compose(compose(square, square), square)(2)) // --> 256
```

History: The Lambda Calculus



- What is it?
- Why is it useful?
- Where did it came from?

Professor Graham Hutton explains the Lambda Calculus (Cool Stuff :-) (https://www.youtube.com/watch?v=eis11j_iGMs)

Hint: To understand this video you will watch it at least three times :-)

Summary of the Introduction to Lambda Calculus

- Pure Functions have no internal state
- The Lambda Calculus is very different to the Turing Machine in this way
- The lambda calculus knows only three primitives: Variables (x,y,z), building functions λx.x, applying functions "(λx.x) 5" with values
- There are no datatypes (number, logical values) - values can be functions, no built-in recursion!
- It can encode any computation (Church-Turing thesis)
- Lambda Calculus is present in most major programming languages

Lambda Calculus in Go

play.golang.org/p/1bLmezdD2zt (https://play.golang.org/p/1bLmezdD2zt)

```
// Lambda Calculus in Golang --> See Video Graham Hutton
// https://www.youtube.com/watch?v=eis11j_iGMs

// This is the key: A Recursive function definition for all functions!!!
type fnf func(fnf) fnf

ID := func(x fnf) fnf { return x }

// TRUE as function: λx.λy.x
True := func(x fnf) fnf {
    return func(y fnf) fnf {
        return x
    }
}

// FALSE as function: λx.λy.y
False := func(x fnf) fnf {
    return func(y fnf) fnf {
        return y
    }
}
```

Application

```
fmt.Printf("Id = %p\n", ID)
fmt.Printf("True = %p\n", True)
fmt.Printf("False = %p\n", False)

// debugging functions
f := func(x fnf) fnf { fmt.Printf("f()\n"); return x }
g := func(y fnf) fnf { fmt.Printf("g()\n"); return y }

// select and call first function f(ID)
False(False)(True)(f)(g)(ID)

// select and call second function g(ID)
True(False)(True)(f)(g)(ID)
```

Lambda Calculus in Go: NOT

```
// NOT as function: λb.b false true
Not := func(b fnf) fnf {
    return b(False)(True)
}

// should print false
fmt.Printf("Not(True) = %p\n", Not(True))

// should print true
fmt.Printf("Not(False) = %p\n", Not(False))

// select and call first function f(ID)
Not(False)(f)(g)(ID)

// select and call second function g(ID)
Not(True)(f)(g)(ID)
```

Functional Numbers

```
// Functional Numbers 1
ONCE := func(f fnf) fnf {
    return func(x fnf) fnf {
        return f(x)
    }
}

// Functional Numbers 2
TWICE := func(f fnf) fnf {
    return func(x fnf) fnf {
        return f(f(x))
    }
}

// Function Numbers 3
THRICE := func(f fnf) fnf {
    return func(x fnf) fnf {
        return f(f(f(x)))
    }
}
```

Functional Numbers

```
// Functional Numbers SUCCESSOR(N) = N + 1
SUCCESSOR := func(w fnf) fnf {
    return func(y fnf) fnf {
        return func(x fnf) fnf {
            return y(w)(y)(x)
        }
    }
}
```

```
Printer := func(x fnf) fnf { fmt.Print("."); return x }
```

```
SUCCESSOR(TWICE)(Printer)(ID)
fmt.Println("SUCCESSOR(TWICE) = 3")

SUCCESSOR(THRICE)(Printer)(ID)
fmt.Println("SUCCESSOR(THRICE) = 4")
```

Lambda Calculus in JavaScript

```
TRUE = a => b => a;
FALSE = a => b => b;
NOT = f => a => b => f(b)(a);

f = x => x + 10
g = x => x + 20

TRUE(f)(g)(3)        // -> 13
FALSE(f)(g)(3)       // -> 23

NOT(TRUE)(f)(g)(3)  // -> 23
NOT(FALSE)(f)(g)(3) // -> 13
```

Fundamentals of Lambda Calculus & Functional Programming in JavaScript

(https://www.youtube.com/watch?v=3VQ382QG-y4)

Famous Functional Languages inspired by the Lamda Calculus

- Haskell

www.youtube.com/watch?v=1jZ7j21g028 (https://www.youtube.com/watch?v=1jZ7j21g028)

- ML
- Clojure
- F#
- Scala
- JavaScript

Palindrome Problem in Functional (pure) Languages

- Haskell

```
is_palindrome x = x == reverse x
```

- Clojure

```
(defn palindrome? [x]
    (= x (clojure.string/reverse x)))
```

Palindrome Problem in Functional (impure) Languages

- F#

```
let isPalindrome (x: string) =
    let arr = x.ToCharArray()
    arr = Array.rev arr
```

- Scala

```
def isPalindrome[A](l: List[A]):Boolean = {
    l == l.reverse
}
```

- Go

```
func IsPalindrome3(x string) bool {
    return x == strings.Reverse(x)
}
```

Functions as First Class Citizens in Go

- Go supports functions as 1st Class Citizens: Clojures und Lambdas
- Functions can be assigned to variables
- Functions can be used as function parameters and return values (High Order Functions)
- Functions can be created inside functions
- The Go standard library uses functional constructs

Sample from the Go Standard Library

- strings.map

```
// Map returns a copy of the string s with all its characters modified
// according to the mapping function. If mapping returns a negative value, the character is
// dropped from the string with no replacement.
func Map(mapping func(rune) rune, s string) string
```

- Usage

```
s := "Hello, world!"
s = strings.Map(func(r rune) rune {
    return r + 1
}, s)
fmt.Println(s) // --> Ifmmp-!xpsme"
```

Go does not have an API similar to Java Streams

- It is possible to build such an API in Go

```
    // array of generic interfaces.
    stringSlice := []Any{"a", "b", "c", "1", "D"}

    // Map/Reduce
    result := ToStream(stringSlice).
        Map(toUpperCase).
        Filter(notDigit).
        Reduce(concat).(string)

    if result != "A,B,C,D" {
        t.Error(fmt.Sprintf("Result should be 'A,B,C,D' but is: %v", result))
    }
    // lambda (inline)
```

Exercise 5.3 - Map / Filter / Reduce

Exercise 5.3 (https://github.com/0xqab/concepts-of-programming-languages/blob/master/docs/exercises/Exercise5.md#exercise-53---map--filter--reduce)

Map/Reduce is a famous functional construct implemented in many parallel and distributed collection frameworks like Hadoop, Apache Spark, Java Streams (not distributed but parallel), C# Linq

- Implement a custom M/R API with the following interface:

```
type Stream interface {
    Map(m Mapper) Stream
    Filter(p Predicate) Stream
    Reduce(a Accumulator) Any
}
```

- What is the type of Mapper, Predicate and Accumulator?
- How can you make the types generic, so they work for any type, not only for string?

Generic Mapper, Predicate and Accumulator

```
// Any is a shortcut for the empty interface{}.
type Any interface{}

// Predicate function returns true if a given element should be filtered.
type Predicate func(Any) bool

// Mapper function maps a value to another value.
type Mapper func(o1 Any) Any

// Accumulator function returns a combined element.
type Accumulator func(Any, Any) Any
```

Exercise 5.4 - Word Count (WC)

Word Count is a famous algorithm for demonstrating the power of distributed collections and functional programming. Word Count counts how often a word (string) occurs in a collection. It is easy to address that problem with shared state (a map), but this solution does not scale well. The question here is how to use a pure functional algorithm to enable parallel and distributed execution.

After running Word Count, you should get the following result:

```
INPUT:  []Any{"a", "a", "b", "b", "D", "a"}
OUTPUT: "a:3, b:2, D:1, "
```

Questions

- How can you implement the problem with the already built Map()/Filter()/Reduce() functions?
- Write an Unit Test to prove that your solution works as expected!

Classic Word Count Sample

```
// Classic wordcount sample
// ========================
//
func TestWordCount(t *testing.T) {
    strings := []Any{"a", "a", "b", "b", "D", "a"}

    // Map/Reduce
    result := ToStream(strings).
        Map(func(o Any) Any {
            result := []Pair{Pair{o, 1}}
            return result
        }).
        Reduce(sumInts).([]Pair)

    for _, e := range result {
        fmt.Printf("%v:%v, ", e.k, e.v) // "a:3, b:2, D:1, "
    }
}
```

Questions

- How can you implement parallel execution for our API?
- How can you implement distributed execution for our API?

Summary

- You can do functional programming with Go
- Generics and type inference for functions are missing (maybe 2.0?)
- Type definitions for functions make code readable
- You can use functional patterns and generic programming with extra casting (type assertions)
- Functional patterns like Map/Filter/Reduce are easy to implement in Go
- Reflection can help to avoid casting, but it is slow!

Thank you

Bernhard Saumweber
Rosenheim Technical University
bernhard.saumweber@qaware.de (mailto:bernhard.saumweber@qaware.de)
http://www.qaware.de (http://www.qaware.de)