

Functional Programming with Go

Concepts of Programming Languages

26 October 2020

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_\(computer_programming\)](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

$g(f(x)) \rightarrow (g \circ f)(x)$

```
// 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 $(g \circ f)(x)$

- 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

$g(f(x)) \rightarrow (g \circ f)(x)$

```
// 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))
```

```
    }
```

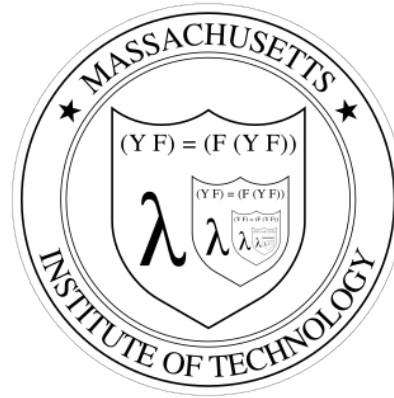
```
}
```

```
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 come from?

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

[v=eis11j_iGMs](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 $\lambda x.x$, applying functions " $(\lambda x.x) 5$ " 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: Combinators

// This is the key: A Recursive function definition for all functions!!!

```
type fnf func(fnf) fnf
```

// Combinators (pure functions, i.e. all variables are bound)

```
I := func(x fnf) fnf { return x }
```

// $\lambda x.x$ = identity

```
M := func(x fnf) fnf { return x(x) }
```

// $\lambda x.xx$ = mocking bird

```
T := func(x fnf) fnf { return func(y fnf) fnf { return x } }
```

// $\lambda x.\lambda y.x$ = kestrel/true/const

```
//F := func(x fnf) fnf { return func(y fnf) fnf { return y } }
```

// $\lambda x.\lambda y.y$ = kite/false

```
F := T(I)
```

```
fmt.Printf("I(I) = %s\n", namer.nameOf(I(I)))
```

```
fmt.Printf("M(I) = %s\n", namer.nameOf(M(I)))
```

```
fmt.Printf("T = %s\n", namer.nameOf(T))
```

```
fmt.Printf("T(I) = %s\n", namer.nameOf(T(I)))
```

```
fmt.Printf("T(M)(I) = %s\n", namer.nameOf(T(M)(I)))
```

```
fmt.Printf("T(I)(I)(M) = %s\n", namer.nameOf(T(I)(I)(M)))
```

```
//fmt.Printf("M(M) = %p\n", M(M)) // omega
```

Run

Lambda Calculus in Go: Helper for printing

```
type namer struct {  
    names map[string]string  
}  
  
func NewNamer() namer {  
    return namer{names: map[string]string{}}  
}  
  
// register a known function (pointer) with a name  
func (n *namer) register(x fnf, name string) {  
    n.names[fmt.Sprintf("%p", x)] = name  
}  
  
// get the name of a function (pointer)  
func (n *namer) nameOf(x fnf) string {  
    s := n.names[fmt.Sprintf("%p", x)]  
    if s == "" {  
        return fmt.Sprintf("%p", x)  
    }  
    return s  
}
```


Lambda Calculus in Go: Boolean Logic

// Boolean Logic

```
NOT := func(p fnf) fnf { return p(F)(T) }
AND := func(p fnf) fnf { return func(q fnf) fnf { return p(q)(p) } }
OR := func(p fnf) fnf { return func(q fnf) fnf { return p(p)(q) } }
EQ := func(p fnf) fnf { return func(q fnf) fnf { return p(q)(NOT(q)) } }
```

```
fmt.Printf("NOT(T) = %s\n", namer.nameOf(NOT(T)))
fmt.Printf("NOT(F) = %s\n", namer.nameOf(NOT(F)))
fmt.Printf("AND(T)(T) = %s\n", namer.nameOf(AND(T)(T)))
fmt.Printf("AND(T)(F) = %s\n", namer.nameOf(AND(T)(F)))
fmt.Printf("AND(F)(T) = %s\n", namer.nameOf(AND(F)(T)))
fmt.Printf("AND(F)(F) = %s\n", namer.nameOf(AND(F)(F)))
fmt.Printf("OR(T)(T) = %s\n", namer.nameOf(OR(T)(T)))
fmt.Printf("OR(T)(F) = %s\n", namer.nameOf(OR(T)(F)))
fmt.Printf("OR(F)(T) = %s\n", namer.nameOf(OR(F)(T)))
fmt.Printf("OR(F)(F) = %s\n", namer.nameOf(OR(F)(F)))
fmt.Printf("EQ(T)(T) = %s\n", namer.nameOf(EQ(T)(T)))
fmt.Printf("EQ(T)(F) = %s\n", namer.nameOf(EQ(T)(F)))
fmt.Printf("EQ(F)(T) = %s\n", namer.nameOf(EQ(F)(T)))
fmt.Printf("EQ(F)(F) = %s\n", namer.nameOf(EQ(F)(F)))
```

Run

Lambda Calculus in Go: Helper (2)

```
// 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(I)  
T(f)(g)(I)  
  
// select and call second function g(I)  
F(f)(g)(I)
```

Run

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))
    }
}

// Functional 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(ONCE)(Printer)(I)  
fmt.Println("SUCCESSOR(ONCE) = 2")
```

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

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

Run

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 Lambda 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)

