A very short introduction to functional programming

Scala and OCaml...

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Outline - Scala

- Functions, Expressions
- Immutability, Recursion
- Class, Objects, Traits
- Scala type system

Functions

- In C++ a typical function application look like:

```
int foo(int a, char b, bool c) {
  // body
}

foo (10, 'x', false);
```

Functions are not first class citizens, it's hard to compose functions, although it's much better with `std::function` and `bind` that came with C++11.

Functions

- In Scala functions can be defined:

  ```
  def foo(a: Int, b: Char, c: Boolean): Int = {
    if (c) a
    else b.toInt
  }
  ```

  or in a curried form:

  ```
  def foo(a: Int)(b: Char)(c: Boolean): Int = {
    if (c) a
    else b.toInt
  }
  ```

  Observe two things. Scala functions do not use `return` keyword as in C++. Scala functions can be defined as a curried function. These are two distinctive features of functional programming.

Functions

- Currying is the process of transforming a function with multiple arguments into chained partial applications, e.g.

```
val f1: Char => Boolean => Int = foo(10)
val value = f1('x')(true) // 10
```

- In OCaml this is much more concise:

```
let f a b c =
  if c then a
  else int_of_char b
> f : int -> char -> bool -> int
let f1 = f 10
let value = f1 'x' true
```

This the beauty of Hindley-Milner type inference.

Expressions

In Scala or functional programming, all expressions result in values, even if the expression is purely side-effecting, the return type is `Unit` which is equivalent to C++'s `void` type.

```
def foo(a: Int) {
  // purely for side effects
  // does not return anything
}
```

The function signature of `foo` is `foo: Int => Unit`.

Immutability

Immutability is an epitome of function programming.

```
val l = List() // empty list => []
val l1 = 10 :: 11 :: 12 :: l // [10, 11, 12]
val l2 = l1.filter(x => x % 2 == 0) // [10, 12]
```

Immutability is achieved by copying and modification is only done to copied item. Unmodified items can be shared, i.e. persistence.

Higher order functions

Functions can be treated as first class values:

```
def valueAtOneQuarter(f: (Double) => Double) = f(0.25)
valueAtOneQuarter(ceil _) // 1.0
valueAtOneQuarter(sqrt _) // 0.5

def mulBy(factor: Double) = (x: Double) => factor * x
val quintuple = mulBy(5)

auto mulBy = [](double factor) {
  return [=](double y) { return factor * y; }
};

auto quintuple = mulby(5);
```

More useful higher order functions

Suppose we have a list:
`val list = List(83, 99, 97, 108, 97)`:

```
list.filter(_ % 2 != 0) // [83, 99, 97, 97]
list.map(_.toChar).mkString // "Scala"
list.reduceLeft(_ * _) // -240049268 - strange!
list.foldLeft(1)(_ * _) // same as above

val f = Future { 10 }; val g = Future { 3 }
f flatMap { (x: Int) => g map { (y: Int) => x + y } }

val h = for {
  x: Int <- f // return result of f: 10
  y: Int <- g // return result of g: 3
} yield x + y
```

Which is better?

Recursion

Recursion is used very extensively in functional programming. Here is a recursive data structure `Tree` and a recursive function `sum`.

```
abstract class Tree[B]
case class Leaf[B](v: B) extends Tree[B]
case class Node[B](l: Tree[B], r: Tree[B])
  extends Tree[B]

type IntTree = Tree[Int]

def sum(t: IntTree): Int = t match {
    case Leaf(v) => v
    case Node(l, r) => sum(l) + sum(r)
}
```

Notice we used pattern match on the tree, but it's not tail recursive, it will overflow the call stack...

Recursion

Can Scala compiler do tail recursive optimization to this function? Answser is "no" due to limitation of JVM. Sometimes if you add `@tailrec` annotation to a function, and the last step of your function calls itself, the Scala compiler can do TCO for you. e.g.

```
import scala.annotation.tailrec
def factorial(n: Int): Int = {
  @tailrec
  def factorialAux(acc: Int, n: Int): Int = {
    if (n <= 1) acc
    else factorialAux(n * acc, n - 1)
  }
  factorialAux(0, n)
}
```

Classes and Objects

- Class definition and companion object. Each class can have one companion object (like a singleton object) where we can define methods/variables shared by the whole class.

```
class Person(age: Int) {
  def speaks = "age is " + age
}

object Person {
  def apply(age: Int): Person {
    new Person(age)
  }
}

val p = Person(99)
p.speaks // prints "age is 99"
```

Traits

Traits are similar to Java interfaces. A class or object can extend multiple traits and the interfaces inherited are linearly stacked. They can be abstract or concrete.

```
trait Quacking {
  def quack() = println("Quack quack quack")
}
trait Swimming {
  def swim() = println("Swim swim swim")
}
class Duck { }
val duck = new Duck with Quacking with Swimming
a.quack() // "Quack quack quack"
a.swim() // "Swim swim swim"
```

This is just a glimpse of traits...

Type Parameters

- Generic classes and functions are like C++ templates

```
class Pair[T, S](val first: T, val second: S)

def getMiddle(a: Array[T]) = ...
```

- Bounds

```
class Pair[T <: Comparable[T]] // lower bound
class Pair[T <% Comparable[T]] // view bound
```

Covariance

If `Student` is a subtype of `Person` then `Pair[Student]` is a subtype of `Pair[Person]` if

```
class Pair[+T](val first: T, val second: T)
```

The above relationship is called covariance.

Contravariance

Variance with the opposite direction of covariance is contravariance. Suppose

```
trait Friend[-T] {
  def befriend(someone: T)
}
```

denotes someone who wants to befriend any type `T`. Now consider

```
def makeFriendsWith(s: Student, f: Friend[Student]) {
  f.befriend(s)
}
class Person extends Friend[Person]
class Student extends Person
val susan = new Student
val fred = new Person
```

Type Projections

Suppose we have the following class definition:

```
class Team {
  class Member(val name: String) {
    val contacts = new ArrayBuffer[Member]
  }
  private val members = new ArrayBuffer[Member]
  def join(name: String) = {
    val m = new Member(name)
    members += m
    m
  }
}
```

Type Projections

Consider the following scenario:

```
val dfm = new Team
val ntps = new Team

val xin = dfm.join("Xin") // dfm.Member
val cloud = ntps.join("Cloud") // ntps.Member

xin.contacts += cloud // does not compile
```

Type Projections

Now consider this:

```
class Team {
  class Member(val name: String) {
    val contacts = new ArrayBuffer[Team#Member]
  }
  ...
}
```

`Team#Member` means "a Member of any Team"

Structural Types

```
def appendLines(target: { def append(str: String): Any },
                lines: Iterable[String]) {
  for (l <- lines) { target.append(l); }
}
```

This function accepts any object that implements `append` method.

Abstract Types

```
traits Reader {
  type Contents
  def read(fileName: String): Contents
}

traits StringReader {
  type Contents = String
  def read(fileName: String): Contents = ...
}
```

Abstract Type using parameters

```
trait Reader[C] {
  def read(fileName: String): C
}

trait StringReader extends Reader[String] {
  def read(fileName: String): String = ...
}

trait ImageReader extends Reader[Image] {
  def read(fileName: String): Image = ...
}
```