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# APPLYING THE REACTIVE PROGRAMMING PARADIGM: TOWARD A MORE DECLARATIVE APPLICATION DEVELOPMENT APPROACH

Elaborata nel corso di: Programmazione Avanzata e Paradigmi

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## KEYWORDS

Reactive Programming
Declarative
Streams
State
Side effects

To my family.

# Contents

# Introduction

After almost 10 years from "The Free Lunch Is Over" article, where the need to parallelize programs started to be a real and mainstream issue, a lot of stuffs did happened:

- Processor manufacturers are reaching the physical limits with most of their approaches to boosting CPU performance, and are instead turning to hyperthreading and multicore architectures;
- Applications are increasingly need to support concurrency;
- Programming languages and systems are increasingly forced to deal well with concurrency.

The article concluded by saying that we desperately need a higher-level programming model for concurrency than languages offer today.

This thesis is an attempt to propose an overview of a paradigm that aims to properly abstract the problem of propagating data changes: **Reactive Programming** (RP). This paradigm proposes an **asynchronous non-blocking** approach to concurrency and computations, abstracting from the low-level concurrency mechanisms.

The first chapter of this thesis will introduce the basics of RP, starting from simple abstractions and then exploring their main advantages and drawbacks.

The second chapter will present a detailed overview of some of the most popular and used frameworks that enable the developer to put RP principles in practice. This chapter will present the main abstractions and APIs for each framework, with a particular attention for the style and approach that the framework itself suggests in respect to the host language used.

The third chapter will propose an approach to solve a particular kind of modern applications: mobile applications. This chapter will consider iOS and Android as the reference platforms, and will then explore a common architectural approach to better express and implement mobile applications. It won't be a surprise that RP will have a central role in this chapter.

The fourth chapter will propose an approach to implement event processing application. This kind of applications will have an increasing role in our days, and RP expressiveness can be useful to model and express applications that interact and compute a lot of real-time data.

Finally, the fifth chapter will conclude the thesis, with some final note and comparison.

# Chapter 1

# Reactive programming

When using the imperative programming paradigm, the act of capturing dynamic values is done only indirectly, through **state and mutations**. In this context, the idea of *dynamic/evolving* values is not a first class value in the paradigm. Moreover, the paradigm can only capture discrete evolving values, since the paradigm itself is *temporally discrete*.

Reactive programming is a programming paradigm that aims to provide a more declarative way to abstract computations and mutations.

Wikipedia defines reactive programming as:

> a programming paradigm oriented around data flows and the propagation of change. This means that it should be possible to express static or dynamic data flows with ease in the programming languages used, and that the underlying execution model will automatically propagate changes through the data flow.

In this definition emerges some key concepts:

- expressing computations in terms of **data flows**
- **change is propagated** in a composable way
- the language or framework has to support **declarativeness**
- all the "plumbing work" is done by the execution model, ensuring that the actual computation respects the semantics

One of the best examples to describe reactive programming is to think of a spreadsheet, in which there're three cells, A, B and C and A is defined as the sum of B and C. Whenever B or C changes, A updates itself.

The example is really simple and it's also something that we're used to know. Reactive programming is all about propagating changes throughout a system, automatically.

This chapter will focus on **Functional Reactive Programming** and **Reactive Programming**, in an attempt to provide formal definitions.

## 1.1 Functional Reactive Programming

Functional reactive programming has its origin with *Fran* (Functional reactive animation), a Haskell library for interactive animations by Conal Elliott. Elliott found it difficult to express the *what* of an interactive animation abstracting from the *how*, and built a set of expressive and recursive data types, combined with a declarative programming language.

Informally, **functional reactive programming** is a programming paradigm that brings a notion of **time** in the functional programming paradigm, providing a conceptual framework for implementing reactive systems. In fact, FRP let the application achieve reactivity by providing constructs for specifying *how behaviors change in response to events.*

Elliott says that FRP is all about two main things: *denotative* and *temporally continuos.* Infact, he also likes the term "*denotative, continuous-time programming*" to replace functional reactive programming, since it reduces the confusion.

Always about the **denotative** part, he means that the paradigm should be founded on a precise, simple, implementation-independent, compositional semantics that exactly specifies the meaning of each type and building block. The compositional nature of the semantics then determines the meaning of all type-correct combinations of the building blocks.

From an Elliott's quote:

> Denotative is the heart and essence of functional programming, and is what enables precise and tractable reasoning and thus a foundation for correctness, derivation, and optimization.

About the **continuous time** part, there's some confusion. Some claim that it's an idea somehow unnatural or impossible to implement considering the discrete nature of computers. To these issues, Elliott answers in the following way:

> This line of thinking strikes me as bizarre, especially when coming from Haskellers, for a few reasons: Using lazy functional languages, we casually program with infinite data on finite machines. We get lovely modularity as a result [...]. There are many examples of programming in continuous space, for instance, vector graphics, [...] I like my programs to reflect how I think about the problem space rather than the machine that executes the programs, and I tend to expect other high-level language programmers to share that preference.

Another name that Elliott suggests for continuous is *resolution-independent*, and thus able to be transformed in time and space with ease and without propagating and amplifying sampling artifacts. As an example, he proposes the "finite vs infinite" data structure issue:

> We only access a finite amount of data *in the end*. However, allowing infinite data structures *in the middle* makes for a much more composable programming style. Each event has a stream (finite or infinite) of occurrences. Each occurrence has an associated time and value.

Fran integrates general ideas from synchronous data-flow languages into the non-strict, pure functional language Haskell. It takes a monadic approach and encapsulates operations over time-varying values and discrete events into data structures that are evaluated by an interpreter loop. The main idea of FRP is to model user inputs as functions that change over time.

### 1.1.1 Behaviors and Event Streams

FRP introduces two special abstractions:

- **behaviors or signals**, values that are continuous functions of time.
- **event streams**, values which are discrete functions of time.

**Behaviors** are dynamic/evolving values, and are first class values in themselves. Behaviors can be defined and *combined*, and *passed* into and out of functions.

Behaviors are built up out of a few primitives, like constant (static) behaviors and time (like a clock), and then with sequential and parallel combination. n-behaviors are combined by applying an n-ary function (on static values), "point-wise", i.e., continuously over time.

In other terms, a Behavior simply **sends values over time** until it either **completes**, or **errors out**, at which point it stops sending values forever.

Examples of behaviours are the following:

- time
- a browser window frame
- the cursor position
- the position of an image during an animation
- audio data
- ...

**Events** enable to account for discrete phenomena, and each of it has a stream (finite or infinite) of occurrences. Each occurrence is a value paired with a time. Events are considered *to be improving list of occurrences.*

Formally, the points at which an event stream is defined are termed *events* and events are said to *occur* on an *event stream.*

Examples of event streams are the following:

- timer events
- key presses
- mouse clicks
- MIDI data
- network packets
- ...

Every instance of FRP conceptually includes both behaviors and events. The classic instance of FRP takes behaviors and events as first-class values.

## 1.2 Evaluation model

The core of languages that support Reactive Programming is about **how changes are propagated**. From the programmer's point of view this should be as much transparent as possible. In other words, a change of a value is automatically propagated to all dependent computations without the user has to manually propagate the changes by himself.

At the language level this means that there should be a mechanism that is triggered when there's an event occurrence at an event source. This mechanism will fire a notification about the changes to dependent computations that will possibly trigger a recomputation, and so on.

The issue of *who initiates the propagation of changes* is a really important decision in designing a language or a framework that supports RP.

In simple terms the question is whether the source should *push* new data to its dependents (consumers) or the dependents should *pull* data from the event source (producer).

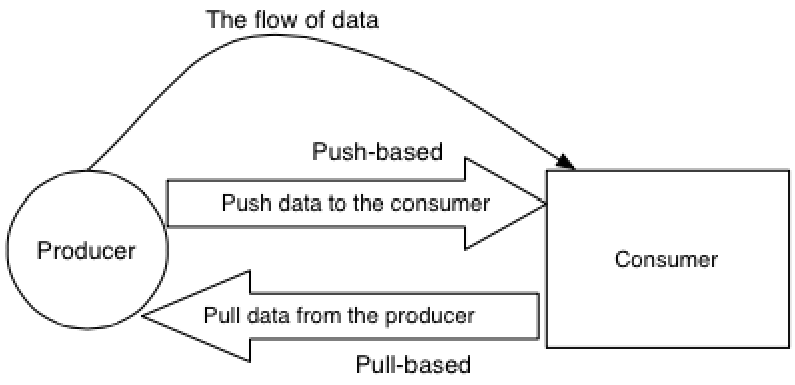


Figure 1.1: Push- Versus Pull-based evaluation model, from the paper "A survey on Reactive Programming"

In the literature there are two main evaluation models:

- **Pull-Based**, in which the computation that requires a value has to pull it from the source. The propagation is said to be *demand-driven.* The pull model has been implemented in Fran, also thanks to the lazy evaluation of Haskell. A main trait of this approach is that the computation requiring the value has the liberty to only pull the new values when it actually needs it. From another point of view, this trait can lead to a significant latency between an occurrence of an event and when its reactions are triggered.

- **Push-Based**, in which when the event source has new data it pushes the data to its dependent computations. The propagation is said to be *data-driven*. An example of a recent implementation that uses this model is Scala.React, that will be introduced later in this thesis. This approach also brings the issue of wasteful recomputation, since every new data that is pushed to the consumer triggers a recomputation.

Typically, reactive programming languages use **either a pull-based or push-based model**, but there are also languages that employ **both** approaches. In latter case there've both the benefits of the push-based model (efficiency and low latency) and those of the pull-based model (flexibility of pulling values based on demand).

## 1.3 Glitches

A **glitch** is a **temporary inconsistency** in the observable state. Due to the fact that updates do not happen instantaneously, but instead take time to compute, the values within a system may be **transiently out of sync** during the update process. This may be a problem, depending on how tolerant the application is of occasional stale inconsistent data. For example, consider a computation that is run before all its dependent expressions are evaluated and that can result in fresh values being combined with stale values.

The paper "A Survey on Reactive Programming" by Bainomugisha et al. depict the problem with the following program:

```
var1 = 1
var2 = var1 * 1
var3 = var1 + var2
```

The image related to the program above shows how the state of the program results incorrect (`var3` is evaluated as 3 instead of 4) and that this also leads to a wasteful recomputation (since `var3` is computed one time more than the necessary).

Glitches only happen when using a *push-based* evaluation model and can be avoided by arranging expressions in a topologically sorted graph. This implementation detail ensures that an expression is always evaluated after all its dependants have been evaluated.

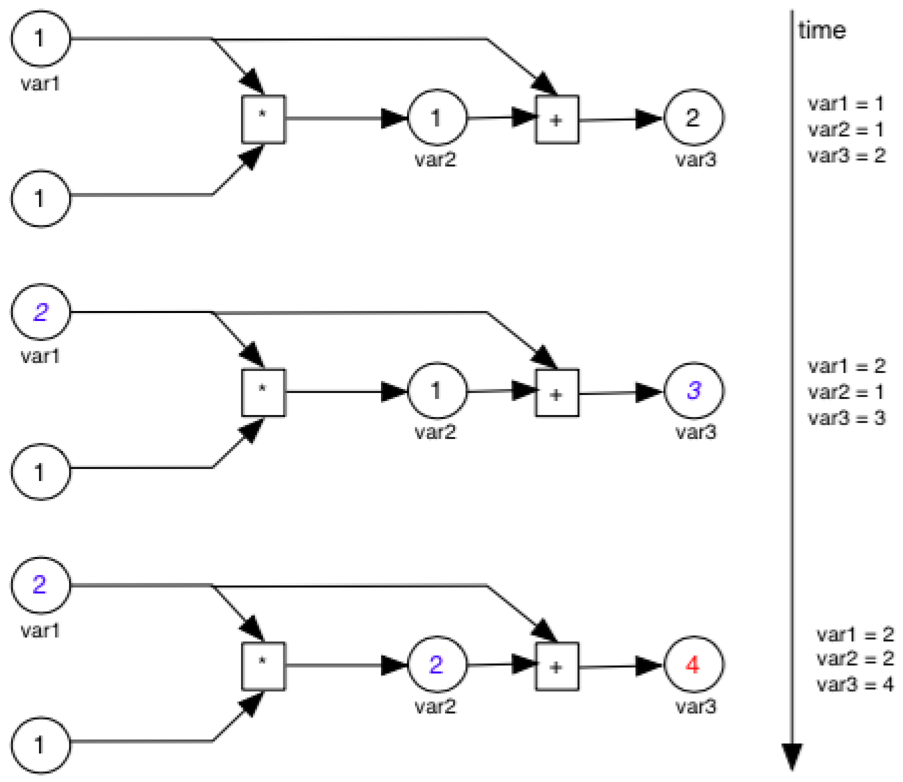


Figure 1.2: Momentary view of inconsistent program state and recomputation.

## 1.4 Lifting

The term *lifting* is used to depict the process of **converting** an ordinary operator to a variant that can operate on behaviors. This process is essential for the end user of the language/framework, since it ensures conciseness and composability. In other words, lifting is used to move from the non-reactive world to reactive behaviors.

Lifting a **value** creates a **constant behavior** while lifting a **function applies the function continuously** to the argument behaviors. There is no similar lifting operation for events, since an event would need an occurrence time as well as a value.

Lifting an operation can be formalized by the following definition, assuming functions that only take one parameter (generalising to functions that take multiple arguments is trivial):

$$lift : f(T) \rightarrow f_{lifted}(Behavior < T >).$$

The $f_{lifted}$ function can now be applied to behaviors that holds values of type $T$. Lifting enables the language or framework to register a dependency graph in the application's dataflow graph.

Starting from the previous definition, the evaluation of a lifted function called with a behavior at the time step $i$ can be formalized as follows:

$$f_{lifted}(Behavior < T >) \rightarrow f(T_i).$$

where $T_i$ is the value of the behavior at the time step $i$.

In the literature there are at least three main lifting strategies:

1. **Implicit lifting**, that happens when an ordinary language operator is applied on behaviour and it is automatically lifted. Dynamically typed languages often use implicit lifting. Formally:

$$f(b1) \rightarrow f_{lifted}(b1).$$

2. **Explicit lifting**, usually used by statically typed languages. In this case the language provides a set of combinators to lift ordinary operators to operate on behaviors. Formally:

$$lift(f)(b1) \rightarrow f_{lifted}(b1).$$

3. **Manual lifting**, when the language does not provide lifting operators. Formally:
$$f(b1) \rightarrow f(currentValue(b1)).$$

## 1.5 Reactive confusion

In these days **reactive programming** and **functional reactive programming** are two terms that create a lot of **confusion**, and maybe are also over-hyped.

The definitions that come from Wikipedia are still pretty vague and only FRP introduced by Connal Elliott has a clear and simple denotative semantics. In advance to this, Elliott himself doesn't like the name he gave to the paradigm.

The concepts behind these newly introduced paradigms are pretty similar. Reactive programming is a paradigm that facilitates the development of applications by providing **abstractions** to express *time-varying values* and automatically propagating the *changes*: behaviors and events. Functional reactive programming can be considered a "sibling" of reactive programming, providing composable abstractions. Elliot identifies the key advantages of the functional reactive programming paradigm as: *clarity, ease of construction, composability, and clean semantics.*

In 2013 Typesafe launched http://www.reactivemanifesto.org, which tried to define what reactive applications are. The reactive manifesto didn't introduce a new programming paradigm nor depicted RP as we intended RP in this thesis. What the reactive manifesto did instead was to depict some really relevant computer science principles about scalability, resilience and event-driven architectures, and RP is one of the tools of the trade.

Erik Meijer, in his talk "Duality and the End of Reactive", concluded that all the hype and the buzzwords around the "reactive world" has no sense, and that the core of the paradigm is **all about composing side effects**. In his talk and related papers, he depicted the **duality** that links enumerables and observables.

In short, an enumerator is basically a getter with the ability to fail and/or terminate. It might also return a future rather than a value. An **iterable** is a getter that returns an **iterator**. If we take the category-theoretic dual of these types we get the **observer** and **observable** types.

Table 1.1: The essential effects in programming

| | **One** | **Many** |
|---|---|---|
| Synchronous | T/Try[T] | Iterable[T] |
| Asynchronous | Future[T] | Observable[T] |

And this conclusion is what let us to relate all the principal effects in programming, where in one axis there's is the nature of the computation (sync or async) and in the other one there's the cardinality of the result (one or many).

# Chapter 2

# State of the union

The previous chapter quickly introduces the basic notions of RP. This chapter will give an overview of the state of the art for RP frameworks.

This thesis author arbitrarily choose four relevant libraries:

- Scala.React
- RxJava
- ReactiveCocoa
- Akka Streams

## 2.1 Scala.React

**Scala.React** is a framework that has been introduced with the paper "Deprecating the Observer Pattern" from Maier, Odersky and Rompf. The key concepts around Scala.React originate in Elliot's FRP, and Scala.React aims to provide a **combinator-based approach for reactive programming**.

The paper depicts how the observer pattern should be considered an anti-pattern, since it violates a lot of software engineering principles such as encapsulation, composability, separation of concerns, scalability, uniformity, abstraction, semantic distance..

The authors aims to provide and depict an efficient use of object-oriented, functional, and data-flow programming principles to overcome the limitations of the existing approaches.

After many years from its presentation, the framework seems to be an academic library that can be neglectable in favor of the RxScala/RxJava library. For the author of this thesis, the paper is really meaningful in the context of this thesis, since it introduces a set of abstractions that are close to the original model of FRP from Elliot.

### 2.1.1 Reactive

Following the idea to provide APIs that starts with basic event handling and ends in an embedded higher-order dataflow language, the framework introduces a generic trait `Reactive`, that factors out the possible concrete abstractions in the following way:

```
trait Reactive[+Msg, +Now] {
    def current(dep: Dependant): Now
    def message(dep: Dependant): Option[Msg]
    def now: Now = current(Dependent.Nil)
    def msg: Msg = message(Dependent.Nil)
}
```

The trait `Reactive` is defined based on two type parameters: one for **the message type an instance emits** and one for **the values it holds**.

Starting from the previous base abstraction, two further types can be defined:

```
trait Signal[+A] extends Reactive[A,A]
trait Events[+A] extends Reactive[A,Unit]
```

The difference between the two types can be seen directly in the types:

- In `Signal`, `Msg` and `Now` types are identical.
- In `Events`, `Msg` and `Now` types differ. In particular, the type for the type parameter `Now` is `Unit`. This means that for an instance of `Events` the notion of "current value" has no sense at all.

The two subclasses need to implement two methods, which obtain reactive's current message or value and create dependencies in a single turn.

The next two sections will better examine the two abstraction introduced here.

NB: the examples and code provided in this chapter have been taken directly from the paper itself.

### Events

The first type to take in consideration is the `Event` type.

To simplify the event handling logic in an application, the framework provides a general and uniform event interface, with `EventSource`. An `EventSource` is an entity that can *raise* or *emit* events at any time. For example:

```
val es = new EventSource[Int]
es raise 1
es raise 2
```

To attach a side-effect in response to an event, an observer has to *observe* the event source, providing a closure. Continuing with the previous example, the following code prints all events from the event source to the console.

```
val ob = observe(es) { x =>
    println("Receiving " + x)
}
...
ob.dispose()
```

`observe( )` returns an handle of the observer,that can be used to uninstall and dispose the observer prematurely, via its `dispose()` method. This is a common pattern in all of the other frameworks/libraries presented in this thesis.

The basic types for events handling are pretty neat and simple to reason about, since they are first-class values. The usage of these types starts to be helpful only if combined with a set of operators, that enables developers to build better and declarative abstraction.

For example, the `Events` trait defines some common operators as follows:

```
def merge[B>:A](that: Events[B]): Events[B]
def map[B](f: A => B): Events[B]
def collect[B](p: PartialFunction[A, B]): Events[B]
```

When building abstractions, the developer doesn't need to take care of the events propagation, since the framework itself provides this.

### Signal

The **Signal** type represents the other half of the story.

In programming a large set of problems is about **synchronizing data that changes over time**, and signals are introduced to overcome these needs.

In simple words, a `Signal` is the **continuous** counterpart of trait `Events` and represents **time-varying values**, maintaining:

- its **current value**
- the current **expression** that defines the signal value
- a set of **observers**: the other signals that depend on its value

A concrete type for `Signal` is the `Var`, that abstract the notion of **variable signal** and is defined as follows:

```
class Var[A](init: A) extends Signal[A] {
    def update(newValue: A): Unit = ...
}
```

A `Var`'s current value can change when somebody calls an `update( )` operation on a it or the value of a dependant signal changes.

**Constant signals** are represented by `Val`:

```
class Val[A](value: A) extends Signal[A]
```

To compose signals, the framework doesn't provide combinator methods at all, but introduce the notion of **signal expressions**, indeed. To better explain the concept, let's look at a simple example.

```
val a = new Var(1)
val b = new Var(2)
val sum = Signal{ a()+b() }

observe(sum) { x => println(x) }

a()= 7
b()= 35
```

Signals are primarily used to create variable dependencies as seen above. In other words, the framework itself already performs all the "plumbing work" of connecting the dependencies and propagating the changes.

The framework and the Scala language provide a convenient and simple syntax to get and update the current value of a Signal, and also to create variable dependencies between signals. For example:

- the code `Signal{ a()+b() }` creates a dependencies that binds the changes from `a` and `b` to be propagated and evaluated in the `sum` signal
- the code `a()= 7` is evaluated as `a.update(7)`
- the framework also provide an implicit converter that enables to create easily `Val` signals

### 2.1.2 Evaluation model

Scala.React's propagation model is **push-driven**, and uses a **topologically ordered dependency graph**. This implementation detail ensures that an expression is always evaluated after all its dependants have been evaluated, so glitches can't happen.

Scala.React proceeds in **propagation cycles**. The system is *either in a propagation cycle or*, if there are no pending changes to any reactive, *idle*. The model of **time** the system use is a **discrete** one.

Every propagation cycle has two phases: first, all reactives are synchronized so that observers, which are run in the second phase, cannot observe inconsistent data. During a propagation cycle, the reactive world is paused, i.e., no new changes are applied and no source reactive emits new events or changes values.

A propagation cycle proceeds as follows:

1. Enter all modified/emitting reactives into a priority queue with the priorities being the reactives' levels.
2. While the queue is not empty, take the reactive on the lowest level and validate its value and message. The reactive decides whether it propagates a message to its dependents. If it does so, its dependents are added to the priority queue as well.

Table 2.1: The essential effects in programming

| | **One** | **Many** |
|---|---|---|
| Synchronous | T/Try[T] | Iterable[T] |
| Asynchronous | Future[T] | **Observable[T]** |

## 2.2 RxJava

The table represents a possible classification of the **effects** in programming.

All the theory and the development of the reactive extensions libraries started with an intuition of Erik Meijer, that theorized that **iterable/iterator** are **dual** to **observable/observer**. And this hypothesis is what let us to relate all the principal effects in programming, where in one axis there's is the nature of the computation (sync or async) and in the other one there's the cardinality of the result (one or many).

The appendix on **futures and promises** covers the case of a computation that returns a **single value**. This chapter will focus on the abstraction of **Observables**, analyzing RxJava as a case of study.

As the title of the repository states, *RxJava is a library for composing asynchronous and event-based programs using observable sequences for the JVM.*

The library was heavily inspired by Rx.NET by Microsoft and is developed by Netflix and other contributors. The code is open source and recently, after 2 years of development, has reached the 1.0 version.

RxJava is also conform to the Reactive Streams initiative (see the appendix), and this means that the hard problem of propagating and reacting to back-pressure has been incorporated in the design of RxJava already, and also that it interoperate seamlessly with all other Reactive Streams implementations.

### 2.2.1 Observable

The fundamental entity of RxJava is the **Observable** type. An observable is a *sequence of ongoing event ordered in time.*

An `Observable` can emit 3 types of item:

- values
- error

- completion event

RxJava provides a really nice documentation, with also some graphical diagrams, called marble diagrams.

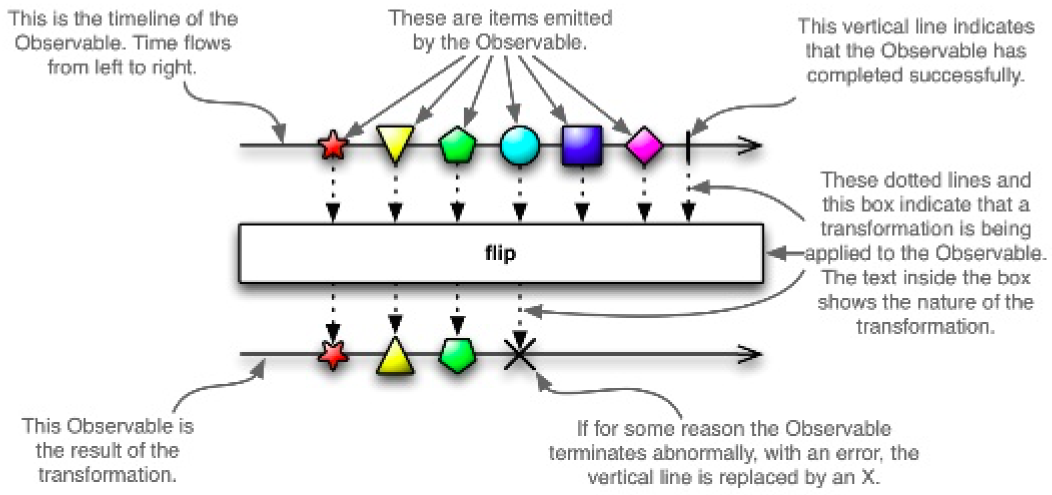

This is the timeline of the Observable. Time flows from left to right.
These are items emitted by the Observable.
This vertical line indicates that the Observable has completed successfully.
These dotted lines and this box indicate that a transformation is being applied to the Observable. The text inside the box shows the nature of the transformation.
flip
This Observable is the result of the transformation.
If for some reason the Observable terminates abnormally, with an error, the vertical line is replaced by an X.

Figure 2.1: A marble diagram

A marble diagram depicts how a an `Observable` and an `Operator` behave:

- observables are timelines with sequence of symbols
- operators are rectangles, that accepts in input the upper observable and return in output the lower one

In RxJava, an `Observable` is defined over a generic type `T`, the type of its values, as follows:

```
class Observable<T> { ... }
```

An `Observable` can emit - in order - **zero, one or more values, an error or a completion event**.

An `Observable` is an **immutable** entity, so the only way to change the sequence of values it emits is through the application of an **operator** and the subsequent creation of a new `Observable`.

An entity can subscribe its interest in the values coming from an `Observalbe` through its `subscribe( )` method, that accepts one, two or three `Action` parameters (that correspond to the `onNext( )`, `onError( )` and `onComplete( )` callbacks).

The classic "Hello, World" example in RxJava and Java 8 is the following:

```
Observable.just("Hello, world!").subscribe(s -> System.out.println(s));
```

The `Observable` type provides some convenience methods that return an observable with the given specification. An incomplete list of these is the following:

- `just( )`: convert an object or several objects into an Observable that emits that object or those objects
- `from( )`: convert an Iterable, a Future, or an Array into an Observable
- `empty( )`: create an Observable that emits nothing and then completes
- `error( )`: create an Observable that emits nothing and then signals an error
- `never( )`: create an Observable that emits nothing at all
- `create( )`: create an Observable from scratch by means of a function
- `defer( )`: do not create the Observable until a Subscriber subscribes; create a fresh Observable on each subscription
- ...

Usually, observables created with these methods are used in conjunction with other observables and operators, to create more complex logics.

#### Operator

In RxJava, operators are what enable the developer to **model** the actual computation. An operator allows performing **almost every type of manipulation** on the source observer in a declarative way.

Expressing a computation in terms of a stream of values is translated in building a **chain of proper operators**. Usually, looking at the signatures and at the types of the operators is really helpful when choosing which operator is the right one for the goal to achieve.

An operator, to be applicable to an Observable, has to implement the `Operator` interface and has to be lifted. The `lift` function lifts a function (inside an `Operator`) to the current Observable and returns a new Observable that when subscribed to will pass the values of the current Observable through the `Operator` function.

Operators are methods of the `Observable` class, so creating a chain of operators starting from a source observable is a pretty straightforward process.

RxJava provides a huge set of operators, and a lot of them is defined in terms of other ones. What follows is only a small introductive subset.

Map

`Map` is an operator that returns an Observable that **applies a specified function to each item** emitted by the source Observable and emits the results of these function applications. Its marble diagram is the following.

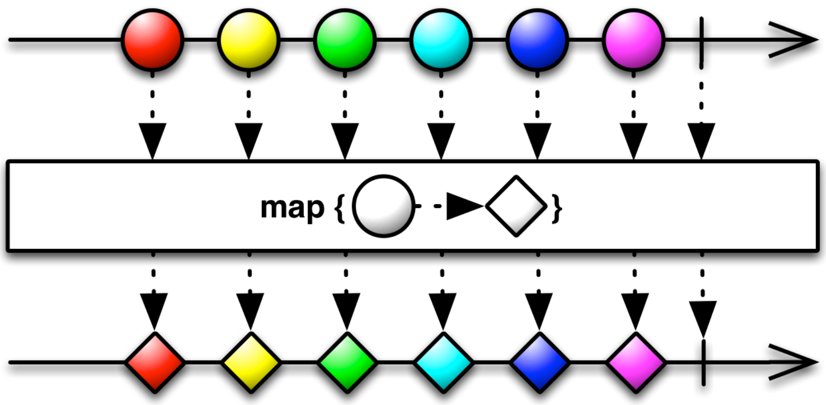


Figure 2.2: Map operator

To better clarify the concept of lifting introduced previously, let's also look at the definition and implementation for `Map`.

```
public final <R> Observable<R> map(Func1<? super T, ? extends R> func) {
  return lift(new OperatorMap<T, R>(func));
}
```

```
...

public final class OperatorMap<T, R> implements Operator<R, T> {

    private final Func1<? super T, ? extends R> transformer;
    public OperatorMap(Func1<? super T, ? extends R> transformer) {
        this.transformer = transformer;
    }

    public Subscriber<? super T> call(final Subscriber<? super R> o) {
        return new Subscriber<T>(o) {

            public void onCompleted() {
                o.onCompleted();
            }

            public void onError(Throwable e) {
                o.onError(e);
            }

            public void onNext(T t) {
                try {
                    o.onNext(transformer.call(t));
                } catch (Throwable e) {
                    onError(OnErrorThrowable.addValueAsLastCause(e, t));
                }
            }
        };
    }
}
```

FlatMap

`FlatMap` returns an Observable that **emits items based on applying a function that is supplied to each item emitted by the source Observable, where that function returns an Observable**, and then merging those resulting Observables and emitting the results of this merger.

Filter

`Filter` is quite obvious.

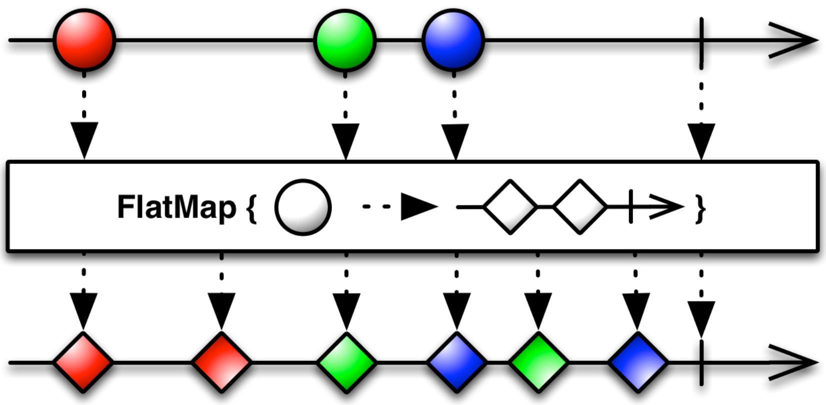


Figure 2.3: FlatMap operator

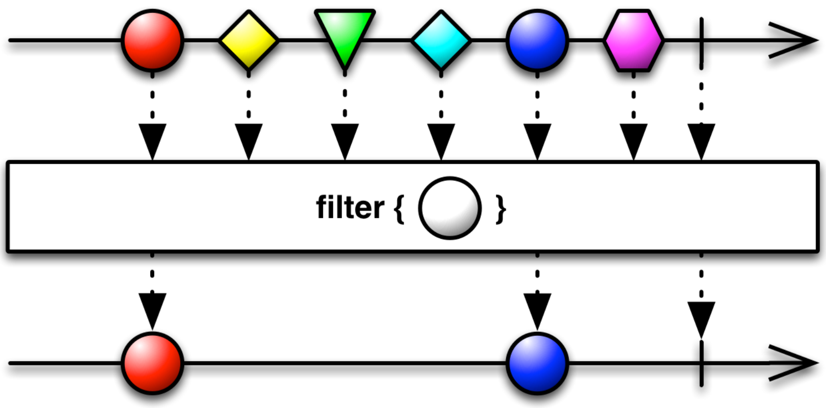


Figure 2.4: Filter operator

Scan

`Scan` returns an Observable that **applies a specified accumulator function** to the first item emitted by a source Observable, then **feeds the result of that function along** with the second item emitted by the source Observable into the same function, and so on until all items have been emitted by the source Observable, and emits the final result from the final call to your function as its sole item.

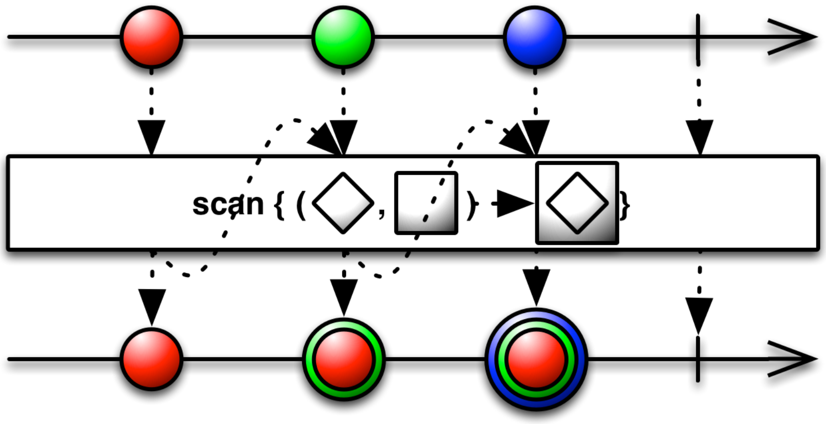


Figure 2.5: Scan operator

Take

`Take` returns an Observable that emits only the first n items emitted by the source Observable.

A complex example

```
// Returns a List of website URLs based on a text search
Observable<List<String>> query(String text) { ... }

// Returns the title of a website, or null if 404
Observable<String> getTitle(String URL){ ... }

query("Hello, world!")                          // -> Observable<List<String>>
  .flatMap(urls -> Observable.from(urls)) // -> Observable<String>
  .flatMap(url -> getTitle(url))          // -> Observable<String>
  .filter(title -> title != null)
  .doOnNext(title -> saveTitle(title))    // extra behavior
```

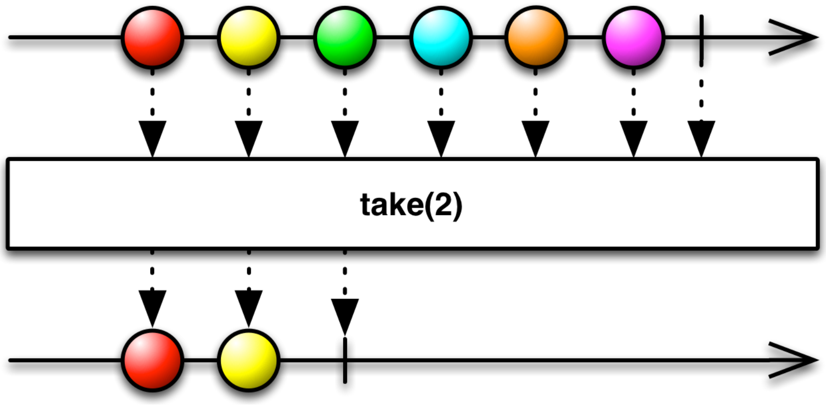


Figure 2.6: Take operator

```
// -> Observable<Pair<Integer, String>>
.map(title -> new Pair<Integer, String>(0, title))
.scan((sum, item) -> new Pair<Integer, Word>(sum.first + 1, item.second))
.take(5)
.subscribe(indexItemPair ->
    System.out.println("Pos: " + indexItemPair.first + ": title:" +
        indexItemPair.second ));
```

The example starts with the hypothesis of having two methods that returns observable, for example coming from the network layer of an application. `query` return a list of url given a text and `getTitle` returns the title of a website or null.

The computation aims to return all the title of the websites that match the “Hello, World!” string.

The code itself is pretty self-explanatory, and shows how concise and elegant a computation can be using the approach suggested by RxJava in respect to its imperative-style counterpart.

### Error handling

The previous sections introduced the basics of `Observable` and `Operator`. This section will introduce how errors are handled in RxJava.

As introduced previously, every Observable ends with either a single call to `onCompleted()` **or** `onError()`.

What follows is an example of a chain of operators that contains some transformation that may also fail.

```
Observable.just("Hello, world!")
  .map(s -> potentialException(s))
  .map(s -> anotherPotentialException(s))
  .subscribe(new Subscriber<String>() {
      @Override
      public void onNext(String s) { System.out.println(s); }

      @Override
      public void onCompleted() { System.out.println("Completed!"); }

      @Override
      public void onError(Throwable e) { System.out.println("Ouch!"); }
    });
```

The `onError()` callback is called if an `Exception` is thrown **at any time** in the chain, thus the operators don't have to handle exceptions in first place since they are **propagated** to the `Subscriber`, which has to manage all the error handling.

### 2.2.2 Subscription

In RxJava, `Subscription` is an abstraction that represents the **link** between an `Observable` and a `Subscriber`.

A subscription is a quite simple type:

```
public interface Subscription {
    public void unsubscribe();
    public boolean isUnsubscribed();
}
```

The main usage for subscription is in its `unsubscribe( )` method, that can be used to *stop* the chain, **terminating wherever it is currently executing code**.

`CompositeSubscription` is another useful type, that simplify the management of multiple and related subscriptions. A composite subscription comes with an algebra that defines the behaviors of its methods:

- `add(Subscription s)`, **adds a new Subscription** to the CompositeSubscription; if this is unsubscribed, will explicitly unsubscribing the new Subscription as well
- `remove(Subscription s)`, **removes a Subscription** from the CompositeSubscription, and unsubscribes the Subscription
- `unsubscribe()`, unsubscribes to **all** subscriptions in the CompositeSubscription
- unsubscribing inner subscriptions has no effect on the composite subscription

### 2.2.3 Scheduler

In the previous sections a lot of concepts have been introduced. This section will cover one of the most important aspects of the framework: **schedulers**.

A scheduler is an *object that schedules unit of work*, and it's implemented through the the `Scheduler` type. This type allows to specify **in which execution context** the chain or part of the chain has to run. In particular, the developer can choose in which thread:

- an `Observable` has to run, with `subscribeOn( )`
- a `Subscriber` has to run, with `observeOn( )`

The framework already provide some schedulers:

- `immediate( )`, that executes work **immediately** on the current thread
- `newThread( )`, that creates a **new Thread** for each job
- `computation( )`, that can be used for **event-loops**, processing callbacks and other computational work
- `io( )`, that is intended for **IO-bound** work, based on an Executor thread-pool that will grow as needed

A really nice feature is the fact that applying the execution of a chain to a particular scheduler doesn't break the chain of operators, keeping the code clean and with a good level of declarativness.

An example of usage of schedulers is the following, in which an image is fetched from the network and then processed. A network request is a typical io-bound operation and it's performed in `io()` scheduler, while a processing operation is a cpu-bound operation and it's performed in a `computation()` scheduler.

```
myObservableServices.retrieveImage(url)
  .subscribeOn(Schedulers.io())
  .observeOn(Schedulers.computation())
  .subscribe(bitmap -> processImage(bitmap));
```

### 2.2.4 Subject

**Subject** is a further entity that is provided by the framework. A `Subject` is a sort of bridge or proxy that acts both as an observer and as an `Observable`:

- because **it is an observer**, it can **subscribe** to one or more observables
- because **it is an Observable**, it can pass through the items it observes by **re-emitting** them, and it can also **emit** new **items**

`Subject` has the "power" of **turning a cold observable hot**. In fact, when a `Subject` subscribes to an `Observable`, it will trigger that `Observable` to begin emitting items (and if that `Observable` is "cold" — that is, if it waits for a subscription before it begins to emit items). This can have the effect of making the resulting `Subject` a "hot" `Observable` variant of the original "cold" `Observable`.

The framework provides a wide range of subjects, each one with its own semantics. What follows is an overview of the main popular and used.

#### PublishSubject

`PublishSubject` emits to an observer only those items that are emitted by the source Observable(s) **subsequent** to the time of the subscription. This means that an observer will not receive the previous emitted items.

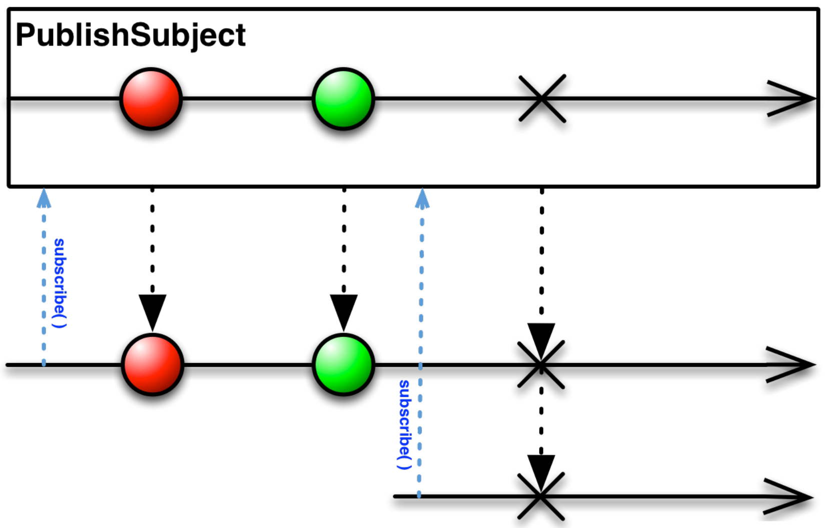


Figure 2.7: PublishSubject

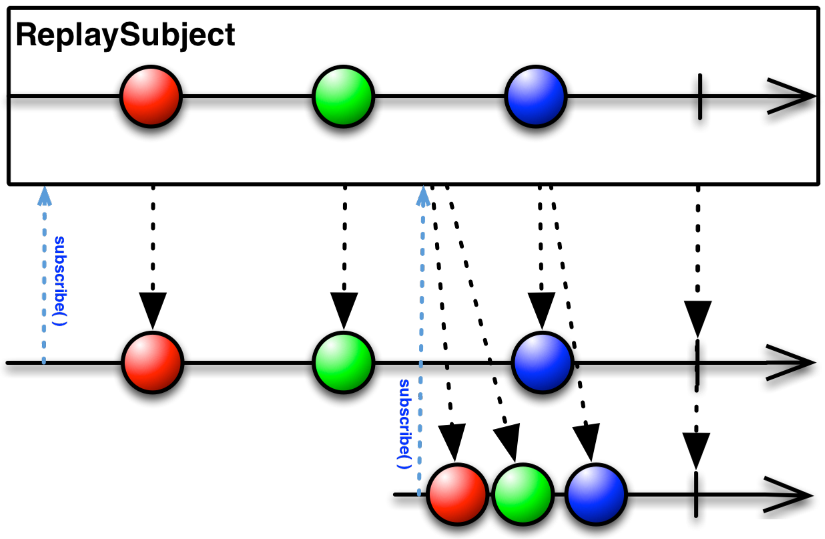


Figure 2.8: ReplaySubject

### ReplaySubject

`ReplaySubject` emits to any observer **all** of the items that were emitted by the source Observable(s), regardless of when the observer subscribes. To keep the memory consumption limited, this subject also use a bounded buffer that enable to discard old items when the limit size has been reached.

### AsyncSubject

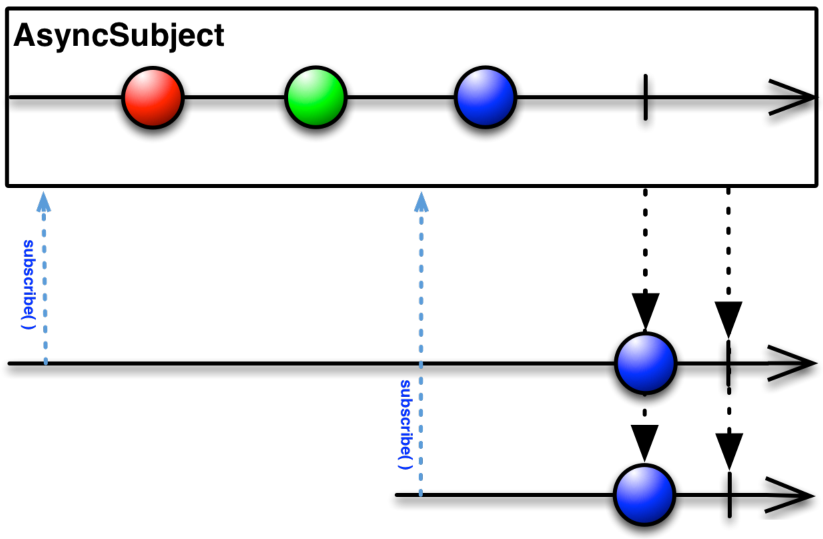


Figure 2.9: AsyncSubject

An `AsyncSubject` caches and only remember the **last** value of the Observable, and only after that source Observable completes emits that value.

### BehaviorSubject

When an observer subscribes to a `BehaviorSubject`, it begins by emitting the item most recently emitted by the source Observable (or a seed/default value if none has yet been emitted) and then continues to emit any other items emitted later by the source Observable(s).

In practice, it's really similar to the **Behavior** notion from Elliot's FRP.

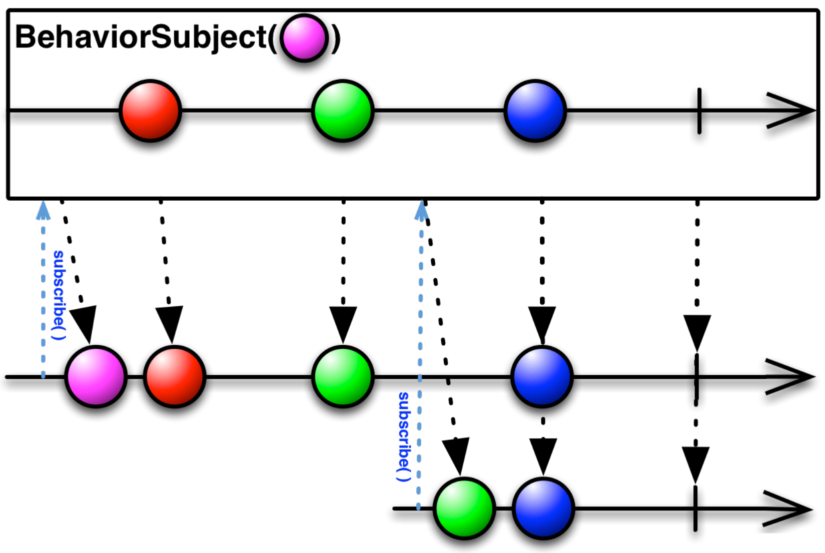


Figure 2.10: BehaviorSubject

### 2.2.5 RxAndroid

The previous sections cover all the main topic of RxJava. This section will go a step further, introducing some additional features that bring RxJava to the Android ecosystem.

**RxAndroid** is a separate module of RxJava that gives some useful bindings to the developer.

The `AndroidSchedulers` package provides some specific scheduler for the *Android threading system*.

The additional schedulers provided are:

- `AndroidSchedulers.mainThread( )`, that will execute an action on the main **Android UI thread**
- `AndroidSchedulers.handlerThread(Handler handler)`, that **uses the provided Handler** to execute an action

A typical example of the usage of `mainThread( )` is the following, that performs a download in the scheduler `io( )` and the show the image to the user:

```
service.getImage(url)
```

```
.subscribeOn(Schedulers.io())
.observeOn(AndroidSchedulers.mainThread())
.subscribe(bitmap -> myImageView.setImageBitmap(bitmap));
```

**ViewObservable** is another feature that adds some bindings for android `View` that returns observables of events that come from the UI, such as:

- `clicks( )`, that emits a new item each time a `View` is **clicked**
- `text( )`, that emits a new item each time a `TextView`'s **text content** is changed
- `input( )`, same as above, for `CompoundButtons`
- `itemClicks( )`, same as above, for `AdapterViews`

These methods are useful to bind the events from the user of an application, reifying its action and reacting with some operation, in a declarative way.

## 2.3 ReactiveCocoa

**ReactiveCocoa** (RAC) is an opensource framework for FRP, developed by Github for the **iOS** and **OS X** platforms. RAC has been around for some years now. It started as an **Objective-C** framework and now it's object of an almost-complete rewrite using the brand new language introduced by Apple, **Swift**.

At the time of writing (may/june/july 2015), RAC 3.0 is in beta. The 3.0 version offers new APIs in Swift, that are also mostly backward compatible with version 2.0 (that is written in Objective-C).

Using Swift, the APIs now have a better and cleaner form. In fact, Swift is a language that allows to build composable abstraction pretty easily, supporting immutability (value types vs reference types), high-order functions, optionals, custom operators, etc...

In the community of iOS and OS X developers RAC is an emerging trend that is clearly gaining the attention of an increasing number of users, confirming the general trend of RP and FRP in our industry.

### 2.3.1 Event and Signal

The first abstraction that the framework introduces is the notion of event. An **event** enables to account for *discrete phenomena*, and each of which has a stream (finite or infinite) of occurrences. Each occurrence is a value paired with a time. Events are considered to be improving list of occurrences. Or, in simpler words, events are things that happen.

In RAC, events are first-class citizens, with the following type:

```
public enum Event<T, E: ErrorType> {
    case Next(Box<T>)
    case Error(Box<E>)
    case Completed
    case Interrupted
}
```

The `Event` type, taken alone, doesn't say much. It's just an enum with some possible related values.

> In Swift, an enum is a value type that defines a common type for a group of related values and enables you to work with those values in a type-safe way within your code.

The other fundamental type in RAC is the `Signal` type, defined as:

```
public final class Signal<T, E: ErrorType>
```

A signal is just a sequence of events in time that is conforms to the grammar `Next* (Error | Completed | Interrupted)?`. The grammar introduces a precise semantics and clarify the meaning of the concrete possible instances for the Event type:

- `.Next` represents an event that carry information of a given type `T`
- `.Error` represents an event that carry an error of a given type `E`
- `.Completed` represents a successful terminal event
- `.Interrupted` represents an event that indicates that the signal has been interrupted

Just like RxJava's Observable, also RAC's signal can be distincted in two main categories: hot and cold signals. The main difference from RxJava's implementation is that in RAC this fundamental distinction can be found directly in the types. In fact, RAC defines `Signal`as hot and `SignalProducer` as cold signals.

*NB*: the previous introduction of Signal is general and applicable on both Signal and SignalProducer.

The next sections will go deeper and explore more on Signals and SignalProducers.

### Signal

As introduced previously, Signal implements the abstraction of **hot signal** as a signal that typically has **no start and no end**.

A typical practical example for this type can be represented by the press events of a button or the arrival of some notifications. They are just events that happens with no relevance of the fact that someone is observing them.

Using a popular philosophical metaphor:

> If a tree falls in a forest and no one is around to hear it, **it does make a sound**.

Looking at the documentation, a Signal is defined as a *push-driven stream that sends Events over time*. Events will be sent to all observers at the same time. So, if a Signal has different observers subscribed to its events, every observer will always see the same sequence of events.

The documentation says another crucial thing that clarifies the modelling choice made by the developers:

> Signals are generally used to represent event streams that are already "in progress", like notifications, user input, etc. To represent streams that must first be *started*, see the SignalProducer type.

The RAC' maintainers decided to keep the distinction between hot and cold Signal at the type level, so RAC offers both the `Signal` and `SignalProducer` types.

The `Signal` type is defined as follows:

```
class Signal<T, E: ErrorType> {
  ...
}
```

Signal is parameterized over `T`, the type of the events emitted by the signal and `E`, the type that denotes the errors.

A Signal can be created by passing to the initializer a generator closure, which is then invoked with a sink of type `SinkOf<Event<String, NoError>>`. The sink is then used by the closure to forward events to the Signal through the `sendNext( )` method. A similar approach has been implemented also by Akka Streams.

**In many cases, a stream of events that has no start and no end can't terminate with an error.** A simple example of this case is a stream of press events from a button. To overcome this possibility, RAC introduces the type `NoError`, meaning that the signal can't error out.

For the "button example", the type for the related signal might be `Signal<Void, NoError>`, which means:

- the user of the signal only cares about the occurrence of the event, no further information will be provided
- the signal can't error out, since in this particular case it has no sense to model the fact that a button press can fail

The button example is just one of many others. If we consider the amount of events that come from the UI, a lot of trivial examples come out quickly:

- a signal that models the changes of a text field
- a signal that models the arrival of notifications (remote, local, etc. . . )
- any other signal created combining other signals
- . . .

An example for the creation of a Signal is the following, taken from a blog post of Colin Eberhardt, where a new String is produced every second.

```
func createSignal() -> Signal<String, NoError> {
  var count = 0
  return Signal {
    sink in
    NSTimer.schedule(repeatInterval: 1.0) { timer in
      sendNext(sink, "tick #\(count++)")
    }
    return nil
  }
}
```

To attach some side effect at each `Next`, `Error` or `Completed` event that is produced by a `Signal`, an observer has to register its interest using **observe**. The `observe` operator accepts some closures or functions for any of the event types the user of the API is interested in.

The real deal in using Signals is their power in term of declarativeness when combining Signals with operators to create new Signals to work with.

In RAC, all **operations** that can be applied to signals are simply **free functions**, in contrast to the "classical-method-definition-on-the-Signal-type approach". As an example, the `map` operator signature is defined as follows, with the Signal on which the transformation will be applied passed as an argument:

```
public func map<T, U, E>(transform: T -> U)
    (signal: Signal<T, E>) -> Signal<U, E> {
    ...
}
```

To keep the APIs fluent RAC also introduces the pipe-forward operator |>, defined as follows:

```
public func |> <T, E, X>(signal: Signal<T, E>,
    transform: Signal<T, E> -> X) -> X {
    return transform(signal)
}
```

The |> operator doesn't do anything special, since it only creates a specification.

RAC already offers a numbers of built in operators as free functions, such as `combineLatest`, `zip`, `takeUntil`, `concat`, ...

A complete but simple example of usage of all of the aspects introduced is the following:

```
createSignal()
  |> map { $0.uppercaseString }
  |> observe(next: { println($0) })
```

The beauty of this approach is that the chain of operations fits the types of each operation, so when the code compiles (and if the user of the APIs has learned the semantics of each operators) the computation acts as expected. All the relevant work for the newcomers of the paradigm consist in taking the time needed to learn the basics and play with the types and the operators.

### SignalProducer

The previous section introduced `Signal` as the type that implements the "hot signal" abstraction. This section will cover the other half of the story.

In RAC, **"cold signals"** are implemented with the `SignalProducer` type, defined as follows:

```
public struct SignalProducer<T, E: ErrorType> {
    ...
}
```

The generic types are the same as its "hot" counterpart, and also the initializer is pretty similar, with a generator closure:

```
func createSignalProducer() -> SignalProducer<String, NoError> {
  var count = 0
  return SignalProducer {
    sink, disposable in
    NSTimer.schedule(repeatInterval: 0.1) { timer in
      sendNext(sink, "tick #\(count++)")
    }
  }
}
```

Using a popular philosophical metaphor, again:

> If a tree falls in a forest and no one is around to hear it, **it doesn't make a sound**.

Or, in other words, if no one subscribes to the SignalProducer, nothing happens. For SignalProducer, the terminology for subscribing to its events is `start( )`.

If more than one observer subscribe to the same SignalProducer, the resources are allocated for each observer. In the example above, every time an observer invoke the `start( )` method on the same SignalProducer instance, a new instance of NSTimer is allocated.

Also on SignalProducers can be applied a wide range of operators. RAC doesn't implement all the operators twice for Signal and SignalOperator, but it offers a pipe-forward operator that lifts the operators and transformation that can be applied to `Signal` to also operate on `SignalProducer`.

The implementation of |>, that applies on the SignalProducer type using Signal's operator, is the following:

```
public func |> <T, E, U, F>(producer: SignalProducer<T, E>,
      transform: Signal<T, E> -> Signal<U, F>) -> SignalProducer<U, F> {
  return producer.lift(transform)
}
```

## 2.3.2 ProperyType

The previous sections introduced the abstractions that RAC offers to describe signal. This section will introduce other collateral but useful types.

`PropertyType` is a protocol that, when applied to a property, **allows the observation of its changes**. Its definition is as follows:

```
public protocol PropertyType {
    typealias Value

    var value: Value { get }
    var producer: SignalProducer<Value, NoError> { get }
}
```

The semantics of this protocol is neat: - the **getter** return the current value of the property - the **producer** return a producer for Signals that will send the property's current value followed by all changes over time

Starting from this protocol, RAC introduces: - `ConstantProperty`, that represents a property that never change - `MutableProperty`, that represents a mutable property - `PropertyOf`, that represents a read-only view to a property

These types are really usefull when used in combination with the <~ operator, that binds properties together. The bind operator comes in three flavors:

```
/// Binds a signal to a property, updating the property's
/// value to the latest value sent by the signal.
public func <~ <P: MutablePropertyType>(property: P, signal:
Signal<P.Value, NoError>) -> Disposable {}

/// Creates a signal from the given producer, which will
/// be immediately bound to the given property, updating the
/// property's value to the latest value sent by the signal.
public func <~ <P: MutablePropertyType>(property: P,
producer: SignalProducer<P.Value, NoError>)
-> Disposable { }

/// Binds `destinationProperty` to the latest values
/// of `sourceProperty`.
public func <~ <Destination: MutablePropertyType,
Source: PropertyType where Source.Value == Destination.Value>
(destinationProperty: Destination,
sourceProperty: Source) -> Disposable { }
```

What these operators do is to create the wires that link each property to each others, in a declarative manner. Each property is observable, through its inner SignalProducer.

### 2.3.3 Action

The last concept that RAC APIs introduce is the notion of `Action`.

An action is something that will do some work in the future. An action will be executed with an input and will return an output or an error. Its type is generic, and it's exposed as:

```
public final class Action<Input, Output, Error: ErrorType>
```

The constructor of an Action accepts a closure or a function that creates a SignalProducer for each input, with the type `Input -> SignalProducer<Output, Error>)`.

A practical and useful use of Action is in conjunction with `CocoaAction`, which is another type that wraps an Action for use by a GUI control, with key-value observing, or with other Cocoa bindings.

## 2.4 Akka Streams

**Akka Streams** is a library that is developed on top akka actors, and aims to provide a better tool for building *ephemeral transformation pipelines.*

Akka actors are used as a building block to build a higher abstraction. Some of the biggest issues on building systems on untyped actor are the following:

- actors does **not compose** well
- actors are **not** completely **type safe**
- dealing with an high number of actors, with also a complex logic behind each behaviors, is really error prone and bring back an evil concept: global **state**.

An actor can be seen as a single *unit of consistency.*

From the introduction of the documentation of akka streams:

> Actors can be seen as dealing with streams as well: they send and receive series of messages in order to transfer knowledge (or data) from one place to another. We have found it tedious and error-prone to implement all the proper measures in order to achieve stable streaming between actors, since in addition to sending and receiving we also need to take care to not overflow any buffers or mailboxes in the process. Another pitfall is that Actor messages can be lost and must be retransmitted in that case lest the stream have holes on the receiving side. When dealing with streams of elements of a fixed given type, Actors also do not currently offer good static guarantees that no wiring errors are made: type-safety could be improved in this case.

To overcome these issues, the developers behind Akka started developing Akka Streams, a set of APIs that offers an intuitive and safe way to build **stream processing pipelines**, with a particular attention to efficiency and bounded resource usage.

Akka Streams is also conform to the Reactive Streams initiative (see the appendix), and this means that the hard problem of propagating and reacting to back-pressure has been incorporated in the design of Akka Streams already, and also that Akka Streams interoperate seamlessly with all other Reactive Streams implementations.

In Akka Streams, a linear processing pipeline can be expressed using the following building blocks:

- **Source**: A processing stage with exactly one output, emitting data elements whenever downstream processing stages are ready to receive them, respecting their demand.
- **Sink**: A processing stage with exactly one input, signalling demand to the upstream and accepting data elements in response, as soon as they're produced.
- **Flow**: A processing stage which has exactly one input and output, which connects its upstream and downstreams by transforming the data elements flowing through it.
- **RunnableFlow**: A Flow that has both ends attached to a Source and Sink respectively, and is ready to be run().

The APIs also offer another core abstraction to build computation graphs:

- **Graphs**: A processing stage with multiple flows connected at a single point.

The next sections will depict all the core abstractions introduced here.

### 2.4.1 Source

In Akka Streams, a **Source** is a set of stream processing steps that has **one open output**. In Scala, the `Source` type is defined as follows:

```
final class Source[Out]
```

The `Out` type is the type of the elements the source produces.

It either can be an atomic source or it can comprise any number of internal sources and transformation that are wired together. Some examples of the former case is given from the following code, that shows some of the utility constructor for the `Source` type.

```
// Create a source from an Iterable
Source(List(1, 2, 3))

// Create a source from a Future
Source(Future.successful("Hello Streams!"))

// Create a source from a single element
Source.single("only one element")

// an empty source
Source.empty
```

An example of the latter case is when a `Flow` is attached to a `Source`, resulting in a composite source, as in the following example.

```
val tweets: Source[Tweet] = Source(...)
val filter: Flow[Tweet, Tweet] = Flow[Tweet].filter(
t => t.hashtags.contains(hashtag))
val compositeSource: Source[Tweet] = tweets.via(filter)
```

The `via( )` method transforms a source by appending the given processing stages, and it's the glue that enables to build composite sources.

### 2.4.2 Sink

The dual to the `Source` type is the **Sink** type, which abstracts a set of stream processing steps that has one open input and an attached output. In Scala the `Sink` type is defined as follows:

```
final class Sink[In]
```

The In type is the type of the elements the sink accepts.

It either can be an atomic sink or it can comprise any number of internal sinks and transformation that are wired together. Some examples of the former case is given from the following code, that shows some of the utility constructor for the Sink type.

```
// Sink that folds over the stream and returns a Future
// of the final result as its materialized value
Sink.fold[Int, Int](0)(_ + _)

// Sink that returns a Future as its materialized value,
// containing the first element of the stream
Sink.head

// A Sink that consumes a stream without doing
// anything with the elements
Sink.ignore

// A Sink that executes a side-effecting call for every
// element of the stream
Sink.foreach[String](println(_))
```

An example of the latter case is given by a Flow that is prepend to a Sink to get a new composite sink, as in the following example:

```
val sum: Flow[(Long, Tweet), (Long, Tweet)] =
Flow[(Long, Tweet)].scan[(Long, Tweet)](0L, EmptyTweet)(
      (state, newValue) => (state._1 + 1L, newValue._2))
val out: Sink[(Long, Tweet)] = Sink.foreach[(Long, Tweet)]({
      case (count, tweet) => println(count + " Current tweet: "
       + tweet.body + " -  " + tweet.author.handle)
    })

val compositeOut: Sink[(Long, Tweet)] = sum.to(out)
```

### 2.4.3 Flow and RunnableFlow

The previous sections introduced the two ends of a computation. This section will introduce the **Flow** abstraction: a processing stage which has exactly one input and one output. In Scala, the `Flow` type is defined as follows.

```
class Flow[In, Out]
```

The `Out` type is the type of the elements the flow returns and the `In` type is the type of the elements the flow accepts.

A **RunnableFlow** is a flow that has both ends attached to a source and sink, and represents *a flow that can run.* A trivial example of `RunnableFlow` in action is the following:

```
val in: Source[Tweet] = Source(...)
val out: Sink[Tweet] = Sink.foreach(println)
val runnableFlow: RunnableFlow = in.to(out)

runnableFlow.run()
```

As already introduced, Akka Streams implements an *asynchronous non-blocking back-pressure protocol* standardised by the Reactive Streams specification, and the user doesn't have to manually manage back-pressure handling code manually since this is already provided by the library itself with a default implementation.

In this regards, there are two main scenarios: **slow publisher with fast subscriber** and **fast publisher with slow subscriber**.

The best scenario is the former, where all the items produced by the publisher are always delivered to the subscriber with no delay due to a lack of demand. In fact, the protocol guarantees that the publisher will never signal more items than the signalled demand, and since the subscriber however is currently faster, it will be signalling demand at a higher rate, so the publisher should not ever have to wait in publishing its items. This scenario is also referred as *push mode*, since the publisher is never delayed in pushing items to the subscriber.

The latter case if more problematic, since the subscriber is not able to keep the pace of the publisher in accepting incoming items and needs to signal its lack of demand to the publisher. Since the protocol guarantees that the publisher will never signal more items than the signalled demand, there the following strategies available:

- not generate items, if it can control its production

- buffering the items within a bounded queue, so the items can be provided when more demand is signalled
- drop items until more demand is signalled
- as an ultimate strategy, tear down the stream if none of the previous strategies are applicable

This latter scenario is also referred as *pull mode*, since the subriber drives the flow of items.

### 2.4.4 Graph

Since not every computation is or can be expressed as a linear processing stage pipeline, Akka Streams also provide a graph-resembling DSL for building stream processing graphs, in which each node can has multiple inputs and outputs.

The documentation refers to graph operation as **junctions**, in which multiple flows are connected at a single point, enabling to perform any kind of *fan-in* or *fan-out.*

The Flow graph APIs provide a pretty straight forward abstraction:

- **Flow**s represent the **connection** within the computation graph
- **Junction**s represent the **fan-in and fan-out** point to which the flows are connected

The APIs already provide some of the most useful juctions, like the following:

- `Merge[In]` - *(N inputs , 1 output)* picks randomly from inputs pushing them one by one to its output
- `Zip[A,B]` – *(2 inputs, 1 output)* is a ZipWith specialised to zipping input streams of A and B into an (A,B) tuple stream
- `Concat[A]` – *(2 inputs, 1 output)* concatenates two streams (first consume one, then the second one)
- `Merge[In]` – *(N inputs , 1 output)* picks randomly from inputs pushing them one by one to its output
- `Broadcast[T]` – *(1 input, N outputs)* given an input element emits to each output

The documentation also provide a simple but brilliant example that illustrates how the DSL provided by the library can be used to express graph computation keeping a great level of declarativeness and code readability.

The following image shows a graph that expresses a computation in which:

- **the edges are flows**
- **the nodes are a sink, a source and two junctions**

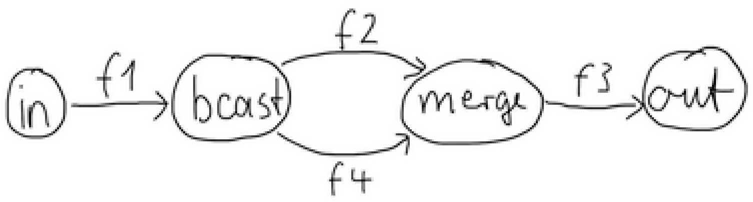


Figure 2.11: A handwritten graph expressing a computation

The corresponding computation can be implemented as follows:

```
val g = FlowGraph.closed() {
implicit builder: FlowGraph.Builder[Unit] =>
  import FlowGraph.Implicits._
  val in = Source(1 to 10)
  val out = Sink.ignore
  val bcast = builder.add(Broadcast[Int](2))
  val merge = builder.add(Merge[Int](2))
  val f1, f2, f3, f4 = Flow[Int].map(_ + 10)
  in ~> f1 ~> bcast ~> f2 ~> merge ~> f3 ~> out
              bcast ~> f4 ~> merge
}
```

When building and connecting each component, the compiler will check for type correctness and this is a really useful things. The check to control whether or not all elements have been properly connected is done at runtime, though.

The framework also provides the notion of partial graph. A **partial graph** is a graph with *undefined sources, sinks or both*, and it's useful to structure the code in different components, that will be then connected with other components. In other words, the usage of partial graphs favours code **composability**.

In many cases it's also possible to expose a complex graph as a simpler structure, such as a Source, Sink or Flow, since these concepts can be viewed as special cases of a partially connected graph:

- a source is a partial flow graph with exactly one output
- a sink is a partial flow graph with exactly one input
- a Flow is a partial flow graph with exactly one input and exactly one output

One last feature that this section will depict and that Akka Stream supports is the possibility to insert **cycles** in flow graphs. This feature is potentially dangerous, since it may lead to deadlock or liveness issues.

The problems quickly arise when there're unbalanced feedback loops in the graph. Since Akka Stream is based on processing items in a bounded manner, if a cycle has an unbounded number of items (for example, when items always get reinjected in the cycle), the back-pressure will deadlock the graph very quickly.

A possible strategy to avoid deadlocks in presence of **unbalanced cycles** is introducing a **dropping element on the feedback arc**, that will drop items when back-pressure begins to act.

A brilliant example from the documentation is the following, where a `buffer( )` is used with a 10 items capacity and a `dropHead` strategy.

```
FlowGraph.closed() { implicit b =>
  import FlowGraph.Implicits._
  val merge = b.add(Merge[Int](2))
  val bcast = b.add(Broadcast[Int](2))

  source ~> merge ~> Flow[Int].map {
s => println(s); s } ~> bcast ~> Sink.ignore
      merge <~ Flow[Int].buffer(10, OverflowStrategy.dropHead) <~ bcast
}
```

An alternative approach in solving the problem is by **building a cycle that is balanced from the beginning**, by using **junctions that balance**

**the inputs**. Thus, the previous example can also be solved in the following manner, with:

- a `ZipWith( )` junction, that will balance the feedback loop with the source
- a `Concat( )` combined with another `Source( )` with an initial element that performs an initial "kick-off". In fact, using a balancing operator to balance a feedback loops require an initial element in the feedback loop, otherwise we fall in the "chicken-and-egg" problem.

```
FlowGraph.closed() { implicit b =>
  import FlowGraph.Implicits._
  val zip = b.add(ZipWith((left: Int, right: Int) => left))
  val bcast = b.add(Broadcast[Int](2))
  val concat = b.add(Concat[Int]())
  val start = Source.single(0)

  source ~> zip.in0
  zip.out.map { s => println(s); s } ~> bcast ~> Sink.ignore
  zip.in1 <~ concat <~ start
             concat        <~          bcast
}
```

# Chapter 3

# Towards reactive mobile application development

The first chapter introduced the literature and the main concepts of the RP paradigm, and the second one depicted some of the main popular and used libraries and framework for RP. This chapter will propose a concrete application of the paradigm to some practical use cases that recur pretty frequently when developing mobile application nowadays.

Thus, this chapter will focus its attention on mobile application development, in both the Android and iOS platforms.

The main idea that brings RP to mobile application development is in the abstraction that considers an app as a function, or as a flow of user inputs that are continuously evaluated, filtered, combined, and so on, producing a some sort of outputs and effects.

## 3.1 Abstracting the retrieval, manipulation and presentation of data

The first use case proposed is about a quite common set of actions, such as the **retrieval, manipulation and presentation of some sort of data**.

Every simple or complex application has at least a part in the app lifecycle in which it queries some provider (a cache, a local database, a Rest API) to fetch some resource, so this initial use case can be considered as a foundational building block for every application.

The abstraction of event streams can be used to model this use case in a pretty straight-forward way.

In the case of a web request, the stream will either emit one value - containing the body of the response - and succeed, or fail with an error.

In the case of more complex request-response configuration (e.g. a request that opens a websocket, that then emits and push new data over a long time) the stream will emit more values, as long as the flow of items continues, or terminate if a failure occurs.

Abstracting the reception of items is only the first part of the scenario introduced. Once the application got some kind of data, a certain number of processing stages can be run over these data. Thus, the notion of event streams and operators fits really nicely also on this part.

To demonstrate a possible solution of this scenario using an approach based on RP, lets introduce a sample use case:

> The application has to query a webservice that returns a list of words for a given month. Each word refers to a specific day, month and year. The application should show all the words in the given month, sorted by date, with the first one highlighted with a different color.

### 3.1.1 On Android

After introducing the use case, the first thing to do is to write down the types involved in the computation and to provide a class that handles the network requests, returning an observable with the response. This class will be part of the network layer of the application, and will expose methods like the following:

```
public Observable<List<Word>> getWords(int month, int year);
```

As a reference, the `Word` type is the following:

```
public class Word {
    public long id;
    public String word;
    public int day;
    public int month;
    public int year;
}
```

The semantics for this observable is pretty simple:

- it *yields* a single results (the response body) or an error (a network error, or a server error, etc..)
- it *starts* the computation each times a consumer *subscribes* itself to the observable

NB: for this kind of request, the behavior would also have been implemented with a future.

Once the network layer is in place, all the transformation needed can be expressed in term of operators.

```
myServiceProvider.getWords(month, year)

    // network operations in io scheduler
    .subscribeOn(Schedulers.io())

    // Observable<List<Word>> -> Observable<Word>
    .flatMap(wordList -> Observable.from(wordList))

    // sort elements
    .toSortedList((l, r) -> { ...sort predicate... })

    // Observable<List<Word>> -> Observable<Word>
    .flatMap(list -> Observable.from(list))

    // build an Observable<Pair<Integer, Word>>
    // (the integer value is the index)
    .map(word -> new Pair<>(0, word))
    .scan((sum, item) -> new Pair<>(sum.first + 1, item.second))

    // build list adapter, highlighting the first element
    // Observable<Pair<Integer, Word>> -> Observable<WordListItem>
    .map(indexItemPair -> {
        WordListAdapter.WordListItem item
```

```
            = new WordListAdapter.WordListItem(indexItemPair.second);
        item.setHighlighted(...); // highlight current day item
        return item;
    })
    .toList() // converting to list, since the adapter need a list

    //  UI update on main thread
    .observeOn(AndroidSchedulers.mainThread())

    // subscribing to items, errors, ...
    .subscribe(
        wordItemList -> {
            setListAdapter(
             new WordListAdapter(wordListActivity, wordItemList));
        },
        throwable -> {
        ...
        }
    );
```

The code shows some transformations and some usage of the most common operators of RxJava.

In the code snippet, `flatMap` is used to transform an `Observable<List<Word>>` to an `Observable<Word>`. This is a pretty common transformation when dealing with list of elements, and since operators like `map`, `filter`, etc.. need to operate on single elements, this operation is essential to build the chain.

Another pattern is the usages of `map` in conjunction with `scan`, to accumulate the result of a computation. The code presented does the trivial job of associating to each element its index in the observable, but it's a use case useful enough to deserve a citation.

The `WordListAdapter` and `WordListItem` classes provide the presentation of the items.

One last thing to note is the usage of `subscribeOn` and `observeOn`, to keep the main thread responsive.

### 3.1.2 On iOS

On iOS, the problem can be solved using the same conceptual abstractions.

Starting with a network provider that expose the call to the APIs with the following method signature:

```
func getWords(month: Int, year: Int) -> SignalProducer<[Word], NSError>
```

As a reference, the type `Word` is defined as follows:

```
public struct Word {

    public let id: Int
    public let word: String
    public let day: Int
    public let month: Int
    public let year: Int

    init(id: Int, word: String, day: Int, month: Int, year: Int){
        self.id = id
        self.word = word
        self.day = day
        self.month = month
        self.year = year
    }
}
```

Also on iOS, the semantics for this signal producer is pretty simple and similar to the android counterpart:

- it *yields* a single results (the response body) or an error (a network error, or a server error, etc..)
- it *starts* the computation each times a consumer *subscribes* itself on the signal producer

```
getWords(month, year)
    // sort
    |> map { words in words.sorted(...) }
```

```
// SignalProducer<[Word]> -> SignalProducer<Word>
|> flatMap(FlattenStrategy.Merge, {
 words in SignalProducer(values: words) })

// build an SignalProducer<(Int, Word)>
// (the integer value is the index)
|> map { word in (0, word) }
|> scan( (0, nil), { (last, current) in (last.0 + 1, current.1) })

// observe on UI thread
|> observeOn(UIScheduler())

// start and subscribe to elements, errors, ...
|> start(next: { elem in self.updateView(elem)})
```

Almost every step of the chain is the same as its android counterpart. The main difference is that RAC doesn't offer a method to sort the elements of a SignalProducer, so, in this case, the elements are filtered at the beginning of the chain using a method of the `Array` type.

## 3.2 Choosing an architectural pattern

This section will explore a fundamental aspect of mobile application development: the architectural pattern.

When developing a mobile applications, usually the target platform implicitly or explicitly suggests an architecture.

### 3.2.1 State of the art in iOS

In the iOS world, Apple encourages the usage of the Model-View-Controller (MVC) architectural pattern. Quoting the "Start Developing iOS Apps Today" Apple's documentation:

> **MVC** assigns the objects in an app to one of three roles: **model**, **view**, or **controller**. In this pattern, models *keep track* of your app's data, views *display* your user interface and *make up the*

*content* of an app, and controllers *manage* your views. By responding to user actions and populating views with content from the data model, controllers serve as a *gateway* for communication between the model and views.

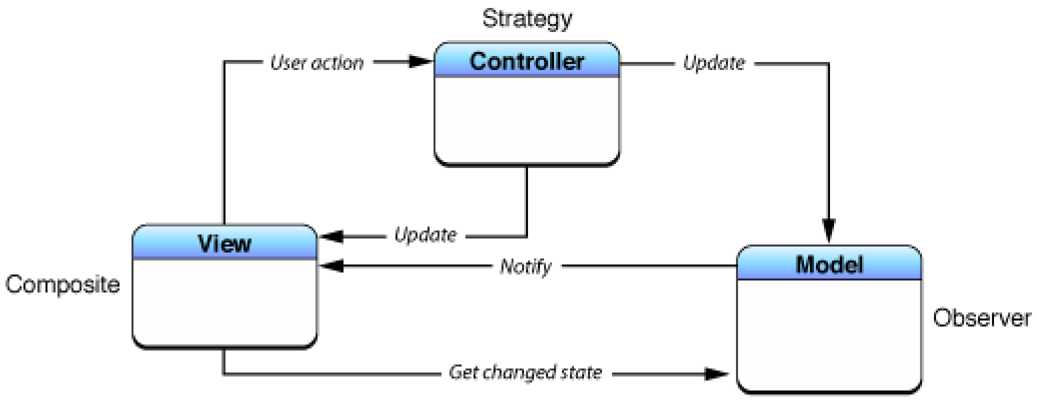


Figure 3.1: Traditional MVC in iOS

In its original abstraction, in MVC:

- the user manipulates a view and, as a result, an event is generated
- a controller receives the event and manage apply an application-specific strategy
- this strategy can consist in requesting a model object to update its state or in requesting a view object to change its appearance.
- the model object notifies all objects who have registered as observers when its state changes; if the observer is a view object, it may update its appearance accordingly.

However, in an attempt to enhance code reusability, Apple suggests developers to adopt a modified version of MVC, in which there's a strong isolation from models and views, and in which controllers act an intermediary between one or more of an application's view objects and one or more of its model objects.

Even if views and view controllers are technically distinct components and Apple suggests to keep these decoupled, they are almost always paired. There are a lot reason that cause this trend of strictly coupling a view and its controller:

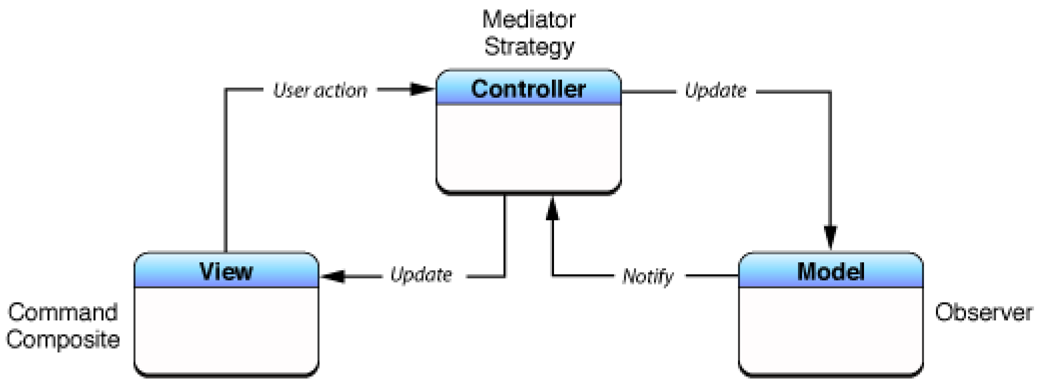


Figure 3.2: Cocoa version of MVC

- the framework provides a big set of components in which a controller already has and manages a view (`UIViewController`, `UITableViewController`, `UICollectionViewController`, `UISplitViewController`, `TabBarController`, . . . )
- the UIViewController class usually contains a lot of UI-related code
- storyboards, that enable developers or designers to define GUIs, reason in term of view controllers and "segue" between view controllers

With this said, it is reasonable to modify the previous model with an update in which the view and the view controller are paired together.

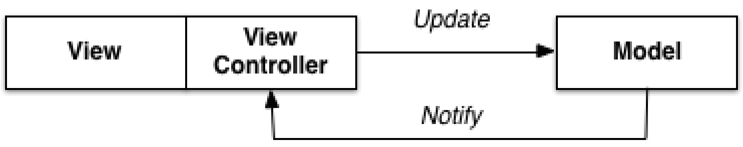


Figure 3.3: A revised iOS application architecture, in which the view and the controller are coupled

The iOS community, during the years, has adopted (also unconsciously) this architectural pattern to design applications. This has often led to what is called the "Massive View Controller" anti-pattern. The term "Massive" is used to denote the use and abuse of the view controller entity to host most of the application logic, grouping functionalities that don't strictly relate to the controller entity.

### 3.2.2 State of the art in Android

Android's documentation is less explicit about the architectural pattern that developers should use.

At first sight, the overall architecture looks similar at iOS's architecture, with the notion of `Activity` that is similar to `UIViewController` and the notion of `View` that is similar to `UIView`.

But, more in depth, things are far more complicated. Thus, the main flaw comes from the assumption that there should be only one running `Activity` at a time, and that this `Activity` should be tied down to a single main view. To overcome this limitation, Android introduced the `Fragment` class. This new abstraction allows an activity to show and manage a certain number of fragments, but still has some limitations like, for example, the possibility of manage stack of fragments.

From this point of view, the iOS platform offers clearer abstractions, with the notion of viewcontrollers, views and viewcontroller containers, which allow the developer to express multi-level view hierarchy in a cleaner way.

Many developers suggest that what Android is offering is a broken abstraction.

Knowing the limitations of the abstractions that the platform offers, the most popular architectural pattern for Android is a variant of MVC (similar to Apple's variant), in which the `Activity` (and related fragments) is both the view and the controller. Google encourages developers to split each view in a fragment, and then each fragment should interact with its parent activity, also to coordinate his actions and commands with other fragments.

### 3.2.3 Toward a common architecture: MVVM

On both the platforms, the MVC architectural pattern and its variations don't seem to be a perfect fit.

In this section and in the following ones a new architectural pattern will be proposed to better model mobile applications: the **Model-View-ViewModel** pattern.

The reason of the introduction of MVVM in this thesis is that this pattern is an application pattern that isolates the user interface from the underlying business logic, and, as introduced in the previous section, one of the biggest issue of the usage of the MVC pattern is the fact that in both

Android and iOS there's not a clear distinction between the view and the controller entities.

The MVVM pattern consists of the following parts:

- the **Model**, which provides a view-independent representation of business entities;
- the **View**, which is the user interface, displaying information to the user and firing events in response to user interactions;
- the **ViewModel**, which is the bridge between the view and the model. Each View has at least a corresponding ViewModel. The ViewModel retrieves data from the Model and manipulates it into the format required by the View, wrapping the presentation logic. It notifies the View if the underlying data in the model is changed, and it updates the data in the Model in response to UI events from the View.

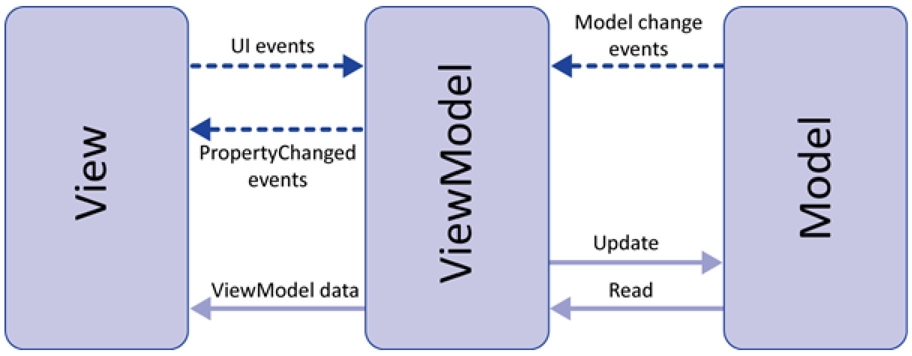


Figure 3.4: The MVVM architectural pattern

Looking at the diagram, it's clear that the view-model:

- sits between the model and the view, **wrapping all the presentation logic**
- receives the events and commands from the view
- **updates the view** once the model has been updated

The main reason to use MVVM is the it **reduces the complexity** of one's viewcontrollers or activities and makes one's presentation logic easier to test.

RP frameworks are a good fit in MVVM, since they allow to **bind the views with their associated view-models**, allowing the proper **synchronization** to reflect the changes in both directions.

## 3.3 A case study

To illustrate the application of the MVVM pattern in conjunction with RP frameworks, let's introduce a simple-but-effective use case.

The use case is an app for iOS and Android, that will:

- fetch a web service to request a list of words;
- each words has a set of attributes, such as: an id, a title, a day, a month and a year which is related to, and an url to an image;
- after querying the web service, the result should be showed in a list. Each list item should display all the attributes, with also the image;
- a detail view should be opened when the user taps on an item.

The requirements are pretty trivial for an experienced developer that use to work following the "standard" way to develop mobile applications, but in this thesis author's opinion is a pretty significative example, since it allows demonstrating a lot of concepts:

- abstracting the retrieval, manipulation and presentation of data (also see the previous dedicated section);
- presenting an uniform abstraction, applicable on both the platforms;
- proper separation of concerns, applying MVVM.

### 3.3.1 A common architecture

Starting from the requirements and with **MVVM** in mind, what follows is the proposed overall system architecture.

NB: the diagram is incomplete, and shows only the relevant building block of the system. The convention used here to express the abstraction of stream of items is the RxJava's `Observable` type.

What immediately emerges looking at the diagram is how the MVVM pattern is applied to model the requirements.

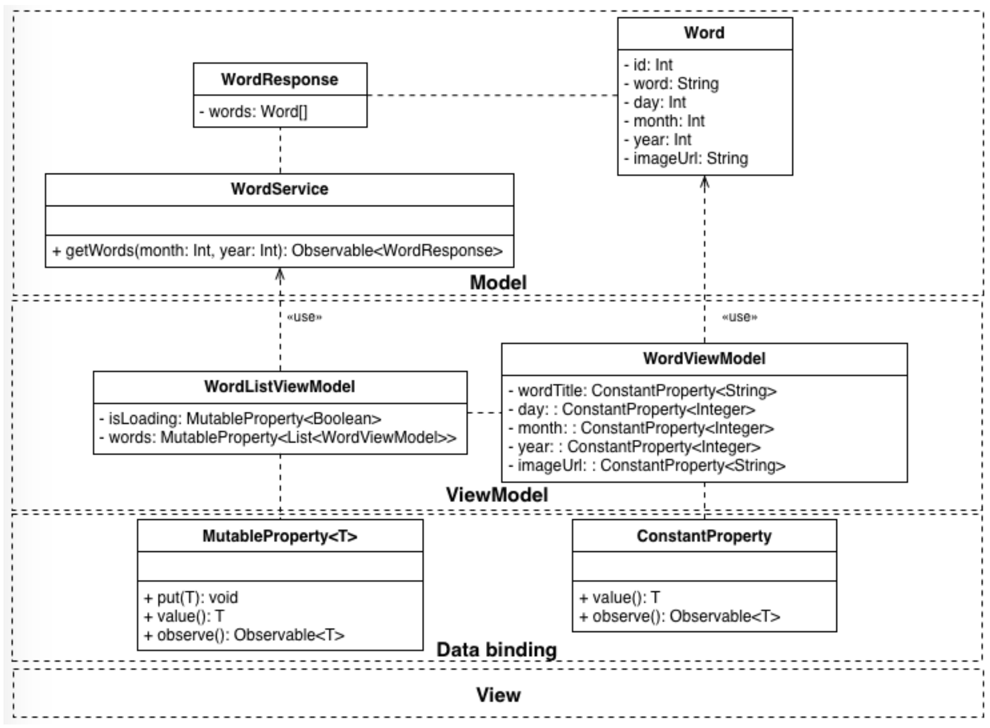

Word
- id: Int
- word: String
- day: Int
- month: Int
- year: Int
- imageUrl: String
WordResponse
- words: Word[]
WordService
+ getWords(month: Int, year: Int): Observable<WordResponse>
Model
«use»
«use»
WordListViewModel
- isLoading: MutableProperty<Boolean>
- words: MutableProperty<List<WordViewModel>>
WordViewModel
- wordTitle: ConstantProperty<String>
- day: : ConstantProperty<Integer>
- month: : ConstantProperty<Integer>
- year: : ConstantProperty<Integer>
- imageUrl: : ConstantProperty<String>
ViewModel
MutableProperty<T>
+ put(T): void
+ value(): T
+ observe(): Observable<T>
ConstantProperty
+ value(): T
+ observe(): Observable<T>
Data binding
View

Figure 3.5: The overall architecture

The **Model** provides a view-independent representation of the business entities. In this case, it's pretty trivial to express the model of the Word class.

The **View** doesn't show something relevant at this stage, since it heavily depends on platform-specific abstractions, and for this reason it will be better depicted in the next two sections.

The **ViewModel** is the bridge between the view and the model, wrapping all the presentation logic. In particular, there are two concrete types of viewmodels:

- `WordListViewModel`, that represent the viewmodel for the list view, as a whole;
- `WordViewModel`, that represent the viewmodel for a single item of the list.

`WordListViewModel` use a `WordService`, that is a class that wraps all the network and parsing operations, returning a `WordResponse`, which contains an array of `Word`. `WordListViewModel` has two `MutableProperty`:

- `isLoading`, that indicates if there's a fetch request running
- `words`, that contains the updated list of words

`WordViewModel` is a pretty simple entity, only containing some `ConstantProperty`, referring to the word attributes. The number of instances of `WordViewModel` will be equal to the number of `Word` returned by the `WordService`.

`MutableProperty` and `ConstantProperty` are two abstractions that help in binding the viewmodel to the view, allowing to set up the automatic update of the view layer when the model gets updated.

Note that this architecture is platform-agnostic and there are no reference to a specific platform or native abstractions, except for the `Observable` type (which can be easily traduced in `SignalProducer`, in this specific context).

### Is this RP?

Looking at the whole architecture, a question may arise. Is this RP?

The answer to this question is not trivial, at first glance. In the introduced architecture RP abstraction are used as building block to compose the overall architecture.

For example, the `WordService` class returns an `Observable`. This immediately suggests a whole set of considerations about the underlying computation.

Other examples are the `MutableProperty` and `ConstantProperty` classes, which under the hood are implemented as `Subject` (or `Signal/SignalProducer`).

In conclusion, RP abstractions can be used as means to properly build the overall architecture.

### 3.3.2 Implementation on Android

The previous section proposed an overall architecture for the use case. This section will depict a possible implementation for the Android platform.

#### Model

Starting from the **model**, things are pretty straightforward.

The `Word` type only contains some read-only properties and a constructor.

```
public class Word {

    public final long id;
    public final String word;
    public final int day;
    public final int month;
    public final int year;
    public final String imageUrl;

    public Word(int id, String word, int day,
        int month, int year, String imageUrl) {

        this.id = id;
        this.word = word;
        this.day = day;
        this.month = month;
        this.year = year;
        this.imageUrl = imageUrl;
    }
}
```

The `WordResponse` class only wraps an array of `Word`, and also the logic for failed requests (that is omitted for the sake of concisness).

```
public class WordResponse {
    final public Word[] words;
    WordResponse(Word[] words) {
        this.words = words;
    }
}
```

Finally, the `WordService` class only exposes a public method that returns an `Observable<WordResponse>`. Also in this case, the real implementation of this method is not important for the purpose of this thesis, and it's omitted. The real important thing of this class is the return type of the method signature.

```
public class WordService {
    public WordService() { ... }
    public Observable<WordResponse>
        getWords(int month, int year) {
        ...
    }
}
```

### Data binding

To better understand the following steps, it's necessary to introduce the abstraction of `MutableProperty` and `ConstantProperty`. On the iOS counterpart, ReactiveCocoa already offers the corresponding abstraction. RxJava and RxAndroid don't directly offer the conceptual equivalent, but it's pretty easy to build the same abstraction starting from a `BehaviorSubject`.

```
public interface Val<T> {
    T value();

    boolean hasValue();
    Observable<T> observe();
}
```

The `Val` interface introduces the notion of a **value** of type `T`.

```
public interface Var<T> extends Val<T> {
    void put(T value);
}
```

The `Var` interface introduces a **variable** of a type `T`.

```
public class MutableProperty<T> implements Var<T> {
    private final BehaviorSubject<T> subject;
    private Val<T> val;

    protected MutableProperty() {
        subject = BehaviorSubject.create();
    }

    protected MutableProperty(T defaultValue) {
        subject = BehaviorSubject.create(defaultValue);
    }

    public static <T> MutableProperty<T> create() {
        return new MutableProperty<>();
    }

    public static <T> MutableProperty<T> create(T defaultValue) {
        return new MutableProperty<>(defaultValue);
    }

    @Override public void put(T value) {
        subject.onNext(value);
    }

    @Override public synchronized Val<T> asVal() {
        if (val == null) {
            val = ConstantProperty.of(this);
        }

        return val;
    }

    @Override public T value() {
        return subject.getValue();
    }

    @Override public boolean hasValue() {
        return subject.hasValue();
    }

    @Override public Observable<T> observe() {
        return subject.asObservable();
    }
}
```

The `MutableProperty` implements the `Var` interface, and represents the abstraction of a property that is **updated over the time**. This kind of property has a notion of current value (that can also be absent) and can be observed, returning an `Observable`.

```
public class ConstantProperty<T> implements Val<T> {
    private final Var<T> var;

    protected ConstantProperty(Var<T> var) {
        this.var = var;
    }

    public static <T> ConstantProperty<T> of(Var<T> var) {
        return new ConstantProperty<>(var);
    }

    public static <T> ConstantProperty<T> create(T val) {
        return ConstantProperty.of(new MutableProperty(val));
    }
    @Override public T value() {
        return var.value();
    }

    @Override public boolean hasValue() {
        return var.hasValue();
    }

    @Override public Observable<T> observe() {
        return var.observe();
    }
}
```

The `ConstantProperty` implement a property that can have a single-assignment (constant) value.

### ViewModel

Moving to the viewmodel layer, things start to become interesting.

```
public class WordListViewModel {

    private static final String TAG
     = WordListViewModel.class.getSimpleName();

    public final MutableProperty<Boolean> isLoading =
        MutableProperty.create(false);
    public final MutableProperty<List<WordViewModel>> words =
        MutableProperty.create(new LinkedList<>());

    public WordListViewModel(WordService wordService) {

        wordService.getWords(1, 2015)
                .doOnSubscribe(() -> this.isLoading.put(true))
                .observeOn(AndroidSchedulers.mainThread())
                .flatMap(wordResponse ->
                    Observable.from(wordResponse.words))
                .map(word -> new WordViewModel(word))
                .toList()
                .subscribe(wordViewModelList -> {
                            this.isLoading.put(false);
                            this.words.put(wordViewModelList);
                        },
                        throwable -> {
                            this.isLoading.put(false);
                            Log.e(TAG, throwable.getMessage());
                        });
    }
}
```

As previously introduced in the architecture diagram, the `WordListViewModel` class has two public `MutableProperties` and exposes a constructor that receives a `WordService`.

When an instance of `WordListViewModel` is created, the viewmodel provides to build the chain of computations needed to perform its job. In this case, it starts a fetch request using the `WordService` instance, and then setting all the proper side-effects.

If everything completes fine, the two mutable properties are updated as follows:

- in `isLoading` is put `false`, so any view that observe that property will be notified of the termination of the request
- in `words` is put a List

```
public class WordViewModel {

    final public ConstantProperty<String> wordTitle;
    final public ConstantProperty<Integer> day;
    final public ConstantProperty<Integer> month;
    final public ConstantProperty<Integer> year;
    final public ConstantProperty<String> imageUrl;

    public WordViewModel(Word word) {
        this.wordTitle = ConstantProperty.create(word.word);
        this.day = ConstantProperty.create(word.day);
        this.month = ConstantProperty.create(word.month);
        this.year = ConstantProperty.create(word.year);
        this.imageUrl = ConstantProperty.create(word.imageUrl);
    }
}
```

The `WordViewModel` class is even simpler, since it only contains a set of `ConstantProperty`, abstracting the set of attributes of the `Word` class.

### View

The view layer is represented by three main components:

- an `Activity`, named `MainActivity`
- a `Fragment`, named `MainActivityFragment`, that is contained in the `MainActivity`
- a RecyclerView.Adapter, named `WordListAdapter`, that is necessary to implement a list view in Android

The `MainActivity`'s only job is to instantiate a `MainActivityFragment`, so its code is omitted.

```
public class MainActivityFragment extends Fragment {
    private RecyclerView mRecyclerView;
    private ProgressBar mProgressBar;
    private WordListAdapter mAdapter;

    ...

    @Override public void onResume() {
        super.onResume();

        if (mRecyclerView.getAdapter() != null) return;
        final WordService wordService = new WordService();
        final WordListViewModel wordListViewModel
         = new WordListViewModel(wordService);

        // bind ui to current loading status
        wordListViewModel.isLoading.observe()
                .observeOn(AndroidSchedulers.mainThread())
                .subscribe(ViewActions.setVisibility(mProgressBar));

        // bind the adapter view with the view model
        mAdapter = new WordListAdapter(wordListViewModel.words.observe());
        mRecyclerView.setAdapter(mAdapter);

        // observe selection event and
        // show another view with the selected content
        mAdapter.getSelectedWordViewModelObservable()
                .observeOn(AndroidSchedulers.mainThread())
                .subscribe(selectedWordViewModel ->
                        Toast.makeText(getActivity(),
                        selectedWordViewModel.wordTitle.value(),
                         Toast.LENGTH_SHORT).show());
    }
}
```

`MainActivityFragment` is a really crucial point of the application. In this class is created a `WordService`, that is then passed to a newly created `WordListViewModel`.

The fragment then binds the viewmodel's properties:

- to set the visibility of a progress bar;
- to show the list of items, through an adapter.

The last thing that the fragment performs is to register its interest in the item selection events from the adapter. In this simple use case, the fragment just shows a message in a `Toast`, but in more real use case scenario this can be the entry point for a fragment transaction or for the launch of a new activity.

```
public class WordListAdapter
    extends RecyclerView.Adapter<WordListAdapter.WordViewHolder> {

    private List<WordViewModel> mViewModels = new LinkedList<>();
    private PublishSubject<WordViewModel> mAdapterSelectedItemSubject;
```

```
/**
 * Constructor that returns a WordListAdapter, with an observable
 * containing a list of viewmodels
 *
 * @param viewModelsObservable an observable with
 * the list of viewmodels
 */
public WordListAdapter(Observable<List<WordViewModel>>
 viewModelsObservable) {

    super();

    viewModelsObservable.subscribe(next -> updateItems(next));
    mAdapterSelectedItemSubject = PublishSubject.create();
}

public void updateItems(List<WordViewModel> items) {
    mViewModels.removeAll(mViewModels);
    mViewModels.addAll(items);
    notifyDataSetChanged();
}

public Observable<WordViewModel>
 getSelectedWordViewModelObservable() {
    return mAdapterSelectedItemSubject.asObservable();
}

@Override
public WordViewHolder
 onCreateViewHolder(ViewGroup viewGroup, int i) {
    View view = LayoutInflater
        .from(viewGroup.getContext())
        .inflate(R.layout.word_list_item, viewGroup, false);
    return new WordViewHolder(view);
}
```

```
@Override
public int getItemCount() { return mViewModels.size(); }

@Override
public void onBindViewHolder(WordViewHolder holder, int i) {
    WordViewModel item = mViewModels.get(i);
    holder.bindItem(item);
}

@Override
public void onViewRecycled(WordViewHolder holder) {
    holder.viewRecycledBehavior.onNext(null);
    holder.viewRecycledBehavior = BehaviorSubject.create();
}

/**
 * ViewHolder for the item
 */
class WordViewHolder extends RecyclerView.ViewHolder
    implements View.OnClickListener {

    private WordViewModel mItem;

    private TextView mDayTextView; private TextView mMonthTextView;
    private TextView mYearTextView; private TextView mWordTextView;
    private ImageView mImageView;

    BehaviorSubject<Void> viewRecycledBehavior;

    public WordViewHolder(View itemView) {
        super(itemView);
        itemView.setOnClickListener(this);
        ... // bind ui elements to fields
    }

    public void bindItem(WordViewModel item) {
        mItem = item;
```

```
            mItem.day.observe().map(d -> d.toString())
                .subscribe(ViewActions.setText(mDayTextView));
            mItem.month.observe().map(m -> m.toString())
                .subscribe(ViewActions.setText(mMonthTextView));
            mItem.year.observe().map(y -> y.toString())
                .subscribe(ViewActions.setText(mYearTextView));
            mItem.wordTitle.observe()
                .subscribe(ViewActions.setText(mWordTextView));

            viewRecycledBehavior = BehaviorSubject.create();

            mImageView.setImageDrawable(null);
            item.imageUrl.observe()
                    .takeUntil(viewRecycledBehavior.asObservable())
                    .subscribeOn(Schedulers.io())
                    .map(url -> downloadImage(url))
                    .observeOn(AndroidSchedulers.mainThread())
                    .subscribe(d -> mImageView.setImageDrawable(d));
        }

        private Drawable downloadImage(String imageUrl) {...}

        @Override public void onClick(View v) {
            mAdapterSelectedItemSubject.onNext(mItem);
        }
    }
}
```

The class `WordListAdapter` contains a lot of boilerplate code that directly depend on the underlying abstractions. The relevant code is in the `ViewHolder` class, in which:

- a `WordViewModel` is used to retrieve the properties that describe a `Word` model class;
- the `onClick` events are pushed through a `PublishSubject<WordViewModel>`. This subject is then exposed as an `Observable<WordViewModel>`,

and will inform each subscriber when the user selects an item of the list;
- given the url of the image, the image is downloaded and showed without blocking the main thread.

### 3.3.3 Implementation on iOS

This final section will depict an implementation on the iOS platform for the introduced architecture.

#### Model

The `Word` type only contains some read-only properties and a constructor, just like the Android counterpart.

```
struct Word {
    let id: Int
    let word: String
    let day: Int
    let month: Int
    let year: Int
    let imageUrl: String

    init(id: Int, word: String, day: Int, month: Int,
        year: Int, imageUrl: String){

        self.id = id
        self.word = word
        self.day = day
        self.month = month
        self.year = year
        self.imageUrl = imageUrl
    }
}
```

The `WordResponse` struct only wraps an array of `Word`, and also the logic for failed requests (that is omitted for the sake of concisness).

```
struct WordResponse {
    let words: [Word]

    init(values: [Word]) {
        words = values
    }
}
```

The `WordService` class only exposes a public method that returns an `SignalProducer`<`WordResponse`>. Also in this case, the real implementation of this method is not important for the purpose of this thesis, and it's omitted.

```
class WordService {
    init() {}

    func getWords(month: Int, year: Int)
        -> SignalProducer<WordResponse, NSError> {
    ...
    }
}
```

### Data binding

The additional data binding layer introduced in Android, in iOS and RAC is already in place, with the `MutableProperty` and `ConstantProperty` types that are already depicted in the section about RAC.

### ViewModel

Also the viewmodel layer is pretty the same as its Android counterpart. All the abstraction used are similar, and even the name are pretty much the same, so there's no need to repeat the description of the code.

The only things that are relevant in this implementation are the types used and the chain of operators.

```
class WordListViewModel {
    let isLoading = MutableProperty<Bool>(false)
    let words = MutableProperty<[WordViewModel]>([WordViewModel]())

    private let wordService: WordService

    init(wordService: WordService) {

        self.wordService = wordService

        // retrieve the words, create a viewmodel for each words,
        // and update the overall view model
        self.wordService.getWords(1, year: 2015)
            |> on(started: { self.isLoading.put(true) })
            |> flatMap(FlattenStrategy.Latest,
                { SignalProducer(values: $0.words) })
            |> map({ WordViewModel(word: $0)})
            |> collect
            |> observeOn(QueueScheduler.mainQueueScheduler)
            |> start(next: {
                wordViewModelList in
                self.isLoading.put(false)
                self.words.put(wordViewModelList)
            }, error: {
                self.isLoading.put(false)
                println("Error \($0)")
            })
    }
}
```

The same arguments are valid for the `WordViewModel` class.

```
class WordViewModel {

    let wordTitle: ConstantProperty<String>
    let day: ConstantProperty<Int>
    let month: ConstantProperty<Int>
    let year: ConstantProperty<Int>
    let imageUrl: ConstantProperty<String>
    init (word: Word) {
        self.wordTitle = ConstantProperty(word.word)
        self.day = ConstantProperty(word.day)
        self.month = ConstantProperty(word.month)
        self.year = ConstantProperty(word.year)
        self.imageUrl = ConstantProperty(word.imageUrl)
    }
}
```

### View

The view layer is represented by three main components: - a `UIViewController`, named `WordsViewController`, that contains a `UITableView`; - a `UITableViewCell`, named `WordCellView`; - an helper class, named `TableViewBindingHelper`, that make it easier to bind a table view with a viewmodel;

The entry point of the application is the `WordsViewController` class, which is shown at app launch. The implementation is pretty similar to the implementation of the `MainActivityFragment` of the previous section.

The view controller creates a `WordService`, which then is passed to a `WordListViewModel`.

After these operations, it binds the viewmodel's properties: - to set the visibility of the load activity indicator; - to show the list of items, through an helper class.

The last thing that the view controller performs is to register its interest in the item selection events from the table view. In this simple use case, the view controller just shows a message in an alert view, but in more real use case scenario this can be the entry point for a presentation of another view controller or other actions.

```
class WordsViewController: UIViewController {

    @IBOutlet weak var loadActivityIndicator: UIActivityIndicatorView!
    @IBOutlet weak var wordsTable: UITableView!

    private var bindingHelper: TableViewBindingHelper<WordViewModel>!

    override func viewDidLoad() {
        super.viewDidLoad()

        let wordService = WordService()
        let viewModel = WordListViewModel(wordService: wordService)

        // bind ui to current loading status
        loadActivityIndicator.rac_hidden
            <~ viewModel.isLoading.producer |> map { !$0 }

        wordsTable.rac_alpha
            <~ viewModel.isLoading.producer
             |> map { $0 ? CGFloat(0.5) : CGFloat(1.0) }

        // bind the table view with the view model
        bindingHelper = TableViewBindingHelper(tableView: wordsTable,
            sourceSignal: viewModel.words.producer, nibName: "WordCell")

        // observe selection event and show another
        // view with the selected content
        bindingHelper.getTableViewSelectedItemSignal()
            |> observeOn(UIScheduler())
            |> observe(next: { self.showWordDetail($0) })
    }

    func showWordDetail(wordViewModel: WordViewModel) {
        // simply showing an alert..
        let alert = UIAlertView(title: "Selection",
            message: "You selected: \(wordViewModel.wordTitle.value)",
            delegate: nil,
            cancelButtonTitle: nil, otherButtonTitles: "Ok")
        alert.show()
    }
}
```

The `WordCellView` class represents a single cell in the table view, and use the property of the viewmodel to which is bind to show the values of the current word.

```
class WordCellView: UITableViewCell, ReactiveView {

    @IBOutlet weak var yearLabel: UILabel!
    ... // other ui stuff

    func bindViewModel(viewModel: AnyObject) {

        let triggerSignal
         = self.rac_prepareForReuseSignal.asSignal() |> toVoidSignal

        if let wordViewModel = viewModel as? WordViewModel {

            // bind the text of the labels to its value
            yearLabel.rac_text <~ wordViewModel.year.producer
             |> map { "\($0)" }

            monthLabel.rac_text <~ wordViewModel.month.producer
             |> map { "\($0)" }

            dayLabel.rac_text <~ wordViewModel.day.producer
             |> map { "\($0)" }

            wordLabel.rac_text <~ wordViewModel.wordTitle.producer

            // download the image
            picImageSignalProducer(wordViewModel.imageUrl.value)
                |> startOn(scheduler)
                |> takeUntil(triggerSignal)
                |> observeOn(QueueScheduler.mainQueueScheduler)
                |> on(started: { self.wordImageView.image = nil })
                |> start(next: {
                     self.wordImageView.image = $0
                })
        }
    }

    private func picImageSignalProducer(imageUrl: String)
```

```
        -> SignalProducer<UIImage, NoError> {
        ...
        // download and returns the image
    }
}
```

The `TableViewBindingHelper` is a helper class, that save the developer a lot of boilerplate code. The relevant part of the code is the following, which illustrates an initializer that takes a `SignalProducer` of items (viewmodels for the cells of the table view) and a public method that returns a Signal of items, representing the items selected by the user.

```
// a helper that makes it easier to bind to UITableView instances
// initial implementation:
// http://www.scottlogic.com/blog/2014/05/11/
class TableViewBindingHelper<T: AnyObject>
: NSObject, UITableViewDelegate {

    //MARK: Properties
    ...

    //MARK: Public API
    init(tableView: UITableView,
        sourceSignal: SignalProducer<[T], NoError>, nibName: String) {
        ...
        sourceSignal.start(next: {
            data in
            // reload the table view each time a new array
            // of viewmodels is set
            self.dataSource.data = data.map { $0 as AnyObject }
            self.tableView.reloadData()
        })
    }

    // returns a Signal which emits the items selected by the user
    func getTableViewSelectedItemSignal() -> Signal<T, NoError> {
         ...
    }
}
```

### 3.3.4 Considerations

The usage of Rx as a gateway to **bind** the viewmodel to the view and as a wrapper for **computations** that imply **latency** and/or possible **failures** seems to be a good fit, even if the problems related to memory leaks and resource disposal have not been taken care with a particular attention. Thus, the code proposed may have some issues and should be considered only a proof of concept at the moment.

Both the implementation of the proposed architecture seems to be pretty elegant and similar in respect of each other. Also the name of each component is consistent over the platforms, where possible.

One could also think to create a *meta-meta-model* that allows describing the architecture of the application with some high-level DSL and then generate the code for both the platforms, but this argument goes outside the scope of this thesis.

# Chapter 4

# Towards reactive event processing

The previous chapter depicted a possible approach to apply RP techniques to the context of mobile applications development.

This chapter will instead introduce a possible application of RP principles and abstractions to a different context: **events processing**.

Event processing is a method of *tracking and analyzing* streams of information about things that happen, and *deriving* a conclusion from them.

Also in this chapter, to better understand and see how RP plays a fundamental role in the game, a use case will be introduced, discussed and solved.

## 4.1 Building a processing pipeline: a case study

The use case proposed to demonstrate the application of RP to the event processing context is an example of sentiment analysis.

From the Wikipedia definition:

> Sentiment analysis (also known as opinion mining) refers to the use of natural language processing, text analysis and computational linguistics to identify and extract subjective information in source materials.

The requirements the the application needs to satisfy are the following:

- the application should monitor and elaborate the sentiment toward two popular brands: Apple and Google;
- the analysis should be performed starting from the information taken from Twitter, by reading and elaborating what people tweets;
- the computation should assign to each tweet a "static score", determined by the relevance of the tweet's author (determined by its number of followers);
- after that, the application should infer if the tweet express a positive or negative comment;
- every tweet should be computed and grouped to the respective brand, and the result should be accumulated, so the users can have an idea of which brand has a better sentiment.

**NB**: This approach to sentiment analysis is for sure oversimplified and not correct at all, but in this thesis author's opinion what really matters about this case study is not the correctness of the analysis method, but the application of the abstractions introduced in this thesis to solve problems.

### 4.1.1 Implementation on Akka streams

Using Akka Streams abstractions, building a processing pipeline that solves the problem introduced by the requirements is a pretty straight-forward process.

In Akka Streams, to build a processing pipeline the first thing to get is a `Source`. In this case, let's start with an utility class that takes care of interacting to Twitter' APIs, exposing a method `listenAndStream` that returns a `Source[Tweet, Unit]`.

```
class TwitterStreamListener(filter: Array[String],
    config: Configuration) {

  // ...

  def listenAndStream: Source[Tweet, Unit] = { ... }
}
```

This method will introduce tweets regarding our two brands as they are published.

Once we get the source of our items, two further steps to performs are the ones that assign to each tweet a “static score”, and then a valuation.

```
val g = FlowGraph.closed() {
  implicit builder: FlowGraph.Builder[Unit] =>
  import akka.stream.scaladsl.FlowGraph.Implicits._

  // our targets brands
  val filters: scala.collection.immutable.List[String]
      = "google" :: "apple" :: List()
  val twitterStreamListener =
      new TwitterStreamListener(filters.toArray, twConfigBuilder.build())

  val in: Source[Tweet, Unit] = twitterStreamListener.listenAndStream

  // assign a "static" score
  val mapToScore: Flow[Tweet, (Tweet, Double), Unit]
      = Flow[Tweet].map(tweet => (tweet,
    (1.0 + 1.01 * tweet.author.followerCount)))

  // extract the "sentiment" from the tweet (not implemented for real..)
  val mapToValutation: Flow[(Tweet, Double), (Tweet, Double), Unit]
      = Flow[(Tweet, Double)].map(tweetScoreTuple =>
          if ( /*... positive or negative content? ...*/)
              (tweetScoreTuple._1, tweetScoreTuple._2)
          else (tweetScoreTuple._1, -tweetScoreTuple._2)
  )

  // build the pipeline
  in ~> mapToScore ~> mapToValutation
}
```

At this point, the last node of the linear graph has type `Flow[(Tweet, Double), (Tweet, Double), Unit]`, meaning that: - it accepts a tuple containing a Tweet and a Double, and it puts out the same type; - looking at the code itself, if returns a stream of pairs of tweets and valuations.

The next step allows to determine in which category (brand) each tweet in the stream belongs to. This step is needed, since the informations that come from the APIs refer to both the brands.

```
// for each tweet, detect in which category the tweet
// has been returned, and return a tuple with this
// additional information  (so we can now group the
// tweet for category)
val mapWithCategory: Flow[(Tweet, Double), (String, Double), Unit]
    = Flow[(Tweet, Double)].mapConcat(tuple =>
  filters
    .filter(f => tuple._1.body.toLowerCase.contains(f.toLowerCase))
    .map(matchedFilter => (matchedFilter, tuple._2)))

// build the pipeline
in ~> mapToScore ~> mapToValutation ~> mapWithCategory
```

Note that now the stream puts out a tuple of `String` and `Double`, that correspond to the current category and valuation for the `Tweet` arrived from the input. At this stage, the other further informations about the tweet are no more necessary.

At this point, the stream of tuples needs to be grouped for brand, and then reduced by applying a function that aggregates all the partial result to compose a result. In this simplified case, this function is a sum.

```
// ...

// groups the tweets for brand and sum the valuations
def sumReducedByKey: Flow[(String, Double), (String, Double), Unit]
    = reduceByKey(
  filters.length,
    groupKey = (elem: (String, Double)) => elem._1,
    foldZero = (key: String) => (0.0))(fold
        = (count: Double, elem: (String, Double)) => elem._2 + count)

  // generic reduce by key function
  def reduceByKey[In, K, Out](maximumGroupSize: Int,
    groupKey: (In) => K,
    foldZero: (K) => Out)(fold: (Out, In) => Out):
        Flow[In, (K, Out), Unit] = {

    val groupStreams = Flow[In].groupBy(groupKey)
    val reducedValues = groupStreams.map {
      case (key, groupStream) =>
        groupStream.runFold((key, foldZero(key))) {
          case ((key, aggregated), elem) =>
            val newAggregated = fold(aggregated, elem)
            // println("Folding: key: " + key +
                " aggregate: " + newAggregated)
            (key, newAggregated)
        }
    }

    reducedValues
        .buffer(maximumGroupSize, OverflowStrategy.fail)
        .mapAsyncUnordered(4)(identity)
}

// build the pipeline
in ~> mapToScore ~> mapToValutation
    ~> mapWithCategory ~> sumReducedByKey ~> out
```

This step of the pipeline is the most difficult to understand at first sight.

By mapping over the groups that contains only the data for a single brand, and using `runFold` (that automatically materializes and runs each sub-stream it is used on) what is returned is a stream with elements of `Future[(String, Double)]`. Finally, this stream is flattened by calling `mapAsyncUnordered(4)(identity)`, that gets the values out of the futures and then injects these values in the returned stream.

One last thing to note is the presence of a buffer between the mapAsyncUnordered and the actual stream of futures.

From the documentation, where the reduceByKey approach has been taken:

> The reason for this is that the substreams produced by groupBy() can only complete when the original upstream source completes.

> This means that mapAsync() cannot pull for more substreams because it still waits on folding futures to finish, but these futures never finish if the additional group streams are not consumed. This typical deadlock situation is resolved by this buffer which either able to contain all the group streams (which ensures that they are already running and folding) or fails with an explicit failure instead of a silent deadlock.

Putting all the pieces together, and adding a limit to 1000 tweets for the sake of brevity, the overall code looks like the following.

```
object MainStreamingExample extends App {

  // ... config twitter APIs and client ...

  // ActorSystem & thread pools
  val execService: ExecutorService
    = Executors.newCachedThreadPool()
  implicit val system: ActorSystem
    = ActorSystem("ciaky")
  implicit val ec: ExecutionContext
    = ExecutionContext.fromExecutorService(execService)
  implicit val materializer = ActorMaterializer()

  val g = FlowGraph.closed() {
    implicit builder: FlowGraph.Builder[Unit] =>

    import akka.stream.scaladsl.FlowGraph.Implicits._

    // our targets brands
    val filters: scala.collection.immutable.List[String]
        = "google" :: "apple" :: List()
    val twitterStreamListener
        = new TwitterStreamListener(filters.toArray, twConfigBuilder.build()

    val in: Source[Tweet, Unit] = twitterStreamListener.listenAndStream
    val out: Sink[(String, Double), Future[Unit]]
        = Sink.foreach[(String, Double)](t =>
      println("[Out] key: " + t._1 + " partial score: " + t._2))

    // limit the elaboration to 1000 tweets
    val take: Flow[Tweet, Tweet, Unit] = Flow[Tweet].take(1000)

    // assign a "static" score
    val mapToScore: Flow[Tweet, (Tweet, Double), Unit]
        = Flow[Tweet].map(tweet => (tweet,
            (1.0 + 1.01 * tweet.author.followerCount)))

    // extract the "sentiment" from the tweet (not implemented for real..)
    val mapToValutation: Flow[(Tweet, Double), (Tweet, Double), Unit]
        = Flow[(Tweet, Double)].map(tweetScoreTuple =>
            if (/*... positive or negative content? ...*/)
                (tweetScoreTuple._1, tweetScoreTuple._2)
            else (tweetScoreTuple._1, -tweetScoreTuple._2)
    )

    // for each tweet, detect in which category the tweet
    // has been returned, and return a tuple with this
    // additional information (so we can now group the tweet for category)
    val mapWithCategory: Flow[(Tweet, Double), (String, Double), Unit]
        = Flow[(Tweet, Double)].mapConcat(tuple =>
      filters
        .filter(f => tuple._1.body.toLowerCase.contains(f.toLowerCase))
        .map(matchedFilter => (matchedFilter, tuple._2))
    )

    // groups the tweets for category and sum the valuations
    def sumReducedByKey: Flow[(String, Double), (String, Double), Unit]
        = reduceByKey(
            filters.length,
            groupKey = (elem: (String, Double)) => elem._1,
            foldZero = (key: String) => (0.0))(
            fold = (count: Double, elem: (String, Double))
             => elem._2 + count)
    // generic reduce by key function
    def reduceByKey[In, K, Out](maximumGroupSize: Int,
      groupKey: (In) => K,
      foldZero: (K) => Out)(fold: (Out, In) => Out)
        : Flow[In, (K, Out), Unit] = {

      val groupStreams = Flow[In].groupBy(groupKey)
      val reducedValues = groupStreams.map {
        case (key, groupStream) =>
          groupStream.runFold((key, foldZero(key))) {
            case ((key, aggregated), elem) =>
              val newAggregated = fold(aggregated, elem)
              println("Folding: key: " + key
                + " aggregate: " + newAggregated)
              (key, newAggregated)
          }
      }

      reducedValues
        .buffer(maximumGroupSize, OverflowStrategy.fail)
        .mapAsyncUnordered(4)(identity)
    }

    // build the pipeline
    in ~> take ~> mapToScore ~> mapToValutation
        ~> mapWithCategory ~> sumReducedByKey ~> out
  }

  g.run()
}
```

Even if Akka Streams processing stages are executed concurrently by default, the approach adopted for the `reduceByKey` function leads to a sequential processing stage for the reduction phase, with no parallelization at all.

## 4.2 Implementation on RxScala

Also using RxScala (RxJava ported to Scala) abstractions, building a processing pipeline that solves the problem introduced by the requirements is a pretty simple process.

To build a processing pipeline the first thing to get is a `Observable`. Following what it was done for the previous implementation, let's start with an utility class that takes care of interacting to Twitter' APIs, exposing a method listenAndStream that returns an `Observable[Tweet]`.

```
class TwitterStreamListener(filter: Array[String],
    config: Configuration) {

  // ...
  def listenAndStream: Observable[Tweet] = { ... }
}
```

Once we get the source of tweets, two further steps to perform are the ones that assign to each tweet a "static score", and then a valuation.

```
val filters: scala.collection.immutable.List[String]
    = "google" :: "apple" :: List() // our targets brands
val twitterStreamListener
    = new TwitterStreamListener(filters.toArray,
        twConfigBuilder.build())

twitterStreamListener.getTweetObservable
    .map(tweet =>
        (tweet, (1.0 + 1.01 * tweet.author.followerCount)))
    .map(tweetScoreTuple =>
      if (/*... positive or negative content? ...*/)
        (tweetScoreTuple._1, tweetScoreTuple._2)
      else (tweetScoreTuple._1, -tweetScoreTuple._2)
    )
```

At this point, the resulting observable has type `Observable[(Tweet, Double)]`, meaning that:

- it accepts a tuple containing a `Tweet` and a `Double`, and it puts out the same type;
- looking at the code itself, if returns a stream of pairs of tweets and valuations.

As in the previous implementation, the next step allows determining in which category (brand) each tweet in the stream belongs to. This step is needed, since the informations that come from the APIs refer to both the brands. To perform the work, a simple flatMap will take care of this job.

```
//...
.flatMap(tuple => {
  val matchedFilters = filters
    .filter(f => tuple._1.body.toLowerCase.contains(f.toLowerCase))
    .map(matchedFilter => (matchedFilter, tuple._2))
  Observable.from(matchedFilters)
})
```

Note that, also with this implementation, now the stream puts out a tuple of `String` and `Double`, that correspond to the current category and valuation for the `Tweet` arrived from the input.

At this point, the stream of tuples needs to be grouped for brand, and then reduced by applying a function that aggregates all the partial result to compose a result. This step has a really short and concise syntax in this RxScala's implementation.

```
val groupKey: ((String, Double)) => String = tuple => tuple._1
val foldZero: (String) => Double = key => 0.0
val fold: (Double, (String, Double)) => Double
  = (count: Double, elem: (String, Double)) => elem._2 + count

  //...
  .groupBy(groupKey)
  .flatMap {
    case (key, groupStream) =>
      groupStream.scan((key, foldZero(key))) {
          case ((key, aggregated), elem) =>
              (key, fold(aggregated, elem))
```

```
        }
    }
```

The groupBy operator creates a new observable for each brand. Each sub-observable is then reduced and flattened.

Putting all pieces together, the overall code is the following.

```
object MainRxExample extends App {

  // ... config twitter APIs and client ...

  val filters: scala.collection.immutable.List[String]
    = "google" :: "apple" :: List() // our targets brands
  val twitterStreamListener
    = new TwitterStreamListener(filters.toArray,
     twConfigBuilder.build())

  val groupKey: ((String, Double)) => String = tuple => tuple._1
  val foldZero: (String) => Double = key => 0.0
  val fold: (Double, (String, Double)) => Double
    = (count: Double, elem: (String, Double)) => elem._2 + count

  twitterStreamListener.getTweetObservable

     // assign a "static" score
    .map(tweet => (tweet, (1.0 + 1.01 * tweet.author.followerCount)))

    // extract the "sentiment" from the tweet
    .map(tweetScoreTuple =>
      if (/*... positive or negative content? ...*/)
        (tweetScoreTuple._1, tweetScoreTuple._2)
      else (tweetScoreTuple._1, -tweetScoreTuple._2)
    )

    // groups the tweets for brand and sum the valuations
    .flatMap(tuple => {
      val matchedFilters = filters
        .filter(f => tuple._1.body.toLowerCase.contains(f.toLowerCase))
        .map(matchedFilter => (matchedFilter, tuple._2))
      Observable.from(matchedFilters)
    })

    // groups the tweets for brand and sum the valuations
    .groupBy(groupKey)
    .flatMap {
      case (key, groupStream) =>
        groupStream.scan((key, foldZero(key))) {
            case ((key, aggregated), elem) =>
                (key, fold(aggregated, elem))
        }
    }

    .subscribe(t => println("[Out] key: " + t._1
        + " partial score: " + t._2))
}
```

### 4.2.1 Considerations

The usage of both the library seems to be a good fit for the simple case study introduced.

The implementation that uses Akka Stream looks a little bit more verbose, since there's some "setup and wiring work" that needs to take place, but the final result looks pretty elegant.

The implementation that uses RxScala is pretty clean and straightforward, indeed.

For both the solutions, the most important thing to note is the fact that all the computations is build starting from the definition of a static-typed chain of operators (or flows).

# Chapter 5

# A conclusive comparison

This thesis started with an overview of RP, that introduced the foundations and the main aspects of the paradigm, and then continued with a detailed overview of some of the most popular or relevant frameworks that allow the application of the paradigm in different platforms and languages, with also some practical use cases.

This final section will attempt to wrap everything up, with a conclusive comparison of each library peculiarities and the approach to RP that each library suggests, with also some subjective opinions.

## 5.1 Operators, Expressions, Declarativness

In regards to **expressing a computation in terms of a flow of intermediate steps**, the approach that Scala.React suggests with its **signal expressions** is the main difference in respect to all other approaches, which are instead based on the presence of **operators**. Scala.React's Signal type has no operator at all, and lets the developer to build a "reactive" computation with an imperative-style code, at least in appearance. In Fact, signal expressions and the magic behind `Var` and `Val` implicit conversion looks natural to a developer with an object oriented background.

All the other libraries introduce an approach based on operators, indeed:

- RxJava offers a wide range of **methods** in the `Observable` type;
- ReactiveCocoa offers a wide range of **free functions**, used in combination with the pipe-forward operator |> on the `Signal` and `SignalProducer`

type to give the user an elegant way to build a chain of operators without losing the purity of the approach based on free functions;
- Akka Streams offers a (still) minimal but effective set of **components**, with the fundamental abstraction defined in terms of the `Flow`, `Sink` and `Source` type, and the ability to build linear or graph computations simply using the to ~> operator.

All the libraries previously introduced presented a high level of declarativness, with a good level of integration in the ecosystem they belong to:

- Scala.React does an amazing job in solving the issues of the "standard" observer pattern leveraging on the construct offered by the Scala language;
- RxJava offer a pretty straight-forward implementation of Rx to the Java ecosystem. Both the implementation and the interfaces really benefitted by the advent of Java 8 and lambda expression (or, in Android, Retrolambda) in the language ecosystem;
- RAC has come a long way from its Objective-C years, and now, with Swift and the current 3.0 version, offers a nice and clean set of interfaces and abstractions;
- Akka Streams is, in this thesis author's opinion, the most impressive approach to modelling computation declaratively. The approach of building a graph-resembling DSL to express not-linear computation is a feature that really helps in keeping the code clean and intuitive, even if the initial learning curve and some of the magic behind the library is a thing to always keep in consideration when evaluating a tool.

## 5.2 Hot and Cold, Push and Pull, Back-pressure

Another aspect that distinguishes the libraries is the way they abstract the notion of **who actually starts the computation**, and thus, the propagation of changes.

In this regards, RAC offer a pretty straight forward abstraction putting this distinction directly at type level: the `Signal` type is producer-driven, so the changes are pushed to the subscribers as they happens/are produced, while the `SignalProducer` type is demand driven, so the changes are pulled.

In RxJava this distinction is not obvious, but there're a set of types and operators that helps when building observables that should be producer-driven or demand-driven. For example, the `Subject` type is usually used to "warm" a cold observable into a hot observable. RxJava is also conforming to Reactive Streams, just like Akka Streams. Being conform to Reactive Streams means that for both libraries is valid the principle that a producer can never send more items than a consumer can handle, using the so called "dynamic push-pull" approach.

In practice, the usage of this feature really depends from the use case to satisfy. For example, for Akka Streams and RxJava the conformation to Reactive Streams was a pretty straight forward process (engineers from Netflix, Typesafe, etc.. all find it problematic having a consumer overwhelmed by a production of items they can handle), since those frameworks are used to process an high number of items and also to build infrastructures and services. In the context of mobile applications, currently RAC doesn't directly solve this issue, since RAC maintainers believe that figuring out the behavior of side effects is far more important, since effects dominate GUI applications.

## 5.3 Solving problems the reactive way

Coming from an OO background, applying RP seems quite unnatural at first, since the way that most developers learnt programming is typically with an imperative approach.

What RP propose is a more declarative approach to solving problems, that leverages to some well defined principles:

- a set of minimal abstractions, that allow to wrap computations in which latency plays a main role, in an elegant way;
- a set of operators with a clear semantics, that allows to build typesafe and statically-typed computation chains, without worrying about classic concurrency issues but focusing mainly on better expressing what each computation should do.

How these principles fits real-world problems is currently a topic of discussion and this thesis only covered two main contexts of modern applications.

# Appendix A

# Functional Programming

As introduced previously, functional programming doesn't allow side effects and mutable state. Mutable **state** may be easily represented by any variable that is not stable or final, and can be changed or updated inside of an application. A **mutation** is the act of updating some state in place.

A simple example that shows how fast the things become *incidentally complex* is given by the following simple example from a Justin Spahr-Summers's talk from Github:

```
var visible     //  2 states
var enabled     //  4 states
var selected    //  8 states
var highlighted //  16 states
```

In other words, state management quickly become hard to maintain and unpredictable. By avoiding mutable state a programmer has the assurance that no one else can possibly have changed his application's state, and can reason about *what a value will be at a given time.*

This chapter will cover just a small introduction of functional domain modelling and immutable data structures using Scala as the reference language.

### A.0.1 Entities and value objects

In functional domain modelling, a system may be represented through the following main domain elements: entities, value objects and services.

Each *entity* has a unique identity. An entity may have many attributes, and each attribute may changes in course of the lifetime of the system. When an attribute within an entity changes, the identity itself is still the same. In this meta-model, attributes are abstracted by *value objects*.

A value object is immutable by definition and can be freely shared across entities. This doesn't mean that an entity's attributes can't change. To clear this concept, let's consider the following example, with an entity person within a system, which is univocally identified by an unique id and that has an "address" attribute. Now the difference between the two concepts is immediate: when we talk of a person we usually refer to a *specific instance* of person, while when we talk of an address we just refer to the *value part*.

Functional programming aims to model **as much immutability as possible**, so a possible approach to model entities and attributes is the following:

- remember that an **entity** has an identity that cannot change, so it's **semantically mutable**
- remember that a **value object** has a value that cannot change, so it's **semantically immutable**

The fact that an entity is semantically mutable doesn't prevent us from using immutable constructs for its implementation.

### A.0.2 Services

The last element of this meta-model is the **service**, which is a more macro level abstraction than entity and value object. In short, a service models a use case, encapsulating a complete operation that has a certain value to user of the system.

A service usually involves multiple entities and value objects, that interact according to specific business rules to deliver specific functionalities.

## A.1 Algebraic data types

From Wikipedia:

> In computer programming, particularly functional programming and type theory, an algebraic data type is a kind of composite

> type, i.e. a type formed by combining other types. Two common classes of algebraic type are product types, i.e. tuples and records, and sum types, also called tagged or disjoint unions or variant types.

The definition introduces some new terminologies: *Sum Type* and *Product Type.*

Wikipedia defines **Sum Type** as:

> a data structure used to hold a value that could take on several different, but fixed types. Only one of the types can be in use at any one time, and a tag field explicitly indicates which one is in use.

An example of a Sum Type in the scala library is Either, that represents a value of one of two possible types. Instances of Either are either an instance of Left or Right. A common use of Either is as an alternative to Option for dealing with possible missing values and convention dictates that Left is used for failure and Right is used for success.

The implementation of Either is something like:

```
sealed abstract class Either[+A, +B]{...}
final case class Left[+A, +B](a: A) extends Either[A, B] {...}
final case class Right[+A, +B](b: B) extends Either[A, B] {...}
```

Basically, Sum Types express an *OR* of types. Remembering that in logic OR is presented by a plus, we can say that algebraically: *type Either = Left + Right.*

Wikipedia defines **Product Type** as:

> another, compounded, type in a structure. The "operands" of the product are types, and the structure of a product type is determined by the fixed order of the operands in the product.

A Product Type is nothing more than a cartesian product of data types. A trivial example may be the following:

```
sealed trait Animal {
    def uniqueId: Long
    def name: String
    def owner: Option[Person]
}

case class Dog(uniqueId: Long, name: String,
    owner: Option[Person], microchipId: String) extends Animal

case class Hamster(uniqueId: Long, name: String,
    owner: Option[Person]) extends Animal

//...
```

In this example, a Dog data type is the collection of all valid combinations of the tuple (Long, String, Option, String). So, algebraically, we can say: *type Dog = Long x String x Option x String*.

Always in this example, we also have that Animal is a Sum Type, since an Animal is a Dog, OR an Hamster, and so on..

Sum Type and Product Type are really important in functional domain modelling, since they provide the abstraction needed for structuring the various data of the domain model.

The values of a Sum Type are typically grouped into several classes, called *variants*. As the name suggests, variants let us model the variations within a specific data type. Each variant has its own constructor, which takes a specified number of arguments with specified types.

Product Types represent a larger abstraction instead, that allows to *clubbing* together some types and *tagging* it with a new data type. This extra tag could also be avoided, simply expressing every Product Type in terms of a tuple of types, but in functional domain modelling it's always convenient to express an entity with a tagged data type.

Values of algebraic data types are analyzed with **pattern matching**, which helps keep functionality local to the respective variant of algebraic data type. Pattern matching identifies a value by its constructor or field names and extracts the data it contains. Starting from the previous example, a trivial example of pattern matching:

```
  var myAnimal: Animal = ???
```

```
val noise = myAnimal match {
  case Dog(uniqueId, name, owner, microchipId) => "bau!"
  case Hamster(uniqueId, name, owner) => "squit!"
}
```

Algebraic data structures, pattern matching and the power of a strongly typed language like Scala really help in the domain modelling phase.

## A.2 ADTs and Immutability

The previous section introduced ADTs as composed types and depicted Sum Type and Product Type. This section will explain how to achieve referentially trasparency through **immutability**, **avoiding in-place mutations**.

The importance of having immutable data structures is to research in the fact that they simplify the management of parallel and concurrent systems. If data structures are immutables, they can be freely shared between different execution contexts, without any fears.

To better understand what does it mean to have an immutable data structure, let's consider the following example from the book "Functional Programming in Scala":

```
// List data type
sealed trait List[+A]

// data constructors
case object Nil extends List[Nothing]
case class Cons[+A](head: A, tail: List[A]) extends List[A]
```

The operation of addition of an element to the front of the list can be performed **without modify or copy** the object itself, just **reusing** the actual list with a new element at the beginning.

```
val initialList:List[Int] = Cons(1, Cons(2, Nil))
val myList = Cons(0, initialList)
```

This approach can be obviously used also to remove an element from the list (in the following example, the 1 to the front).

```
  val initialList:List[Int] = Cons(1, Cons(2, Nil))

  val myList1 = initialList match {
    case Cons(1, xs) => xs
    case l: List[Int] => l
  }
```

This property of reuse object instead of modifying or copying the object itself is called *sharing*.

The introduction of this chapter depicted three elements as the fundamental domain elements: entities, value objects and services. So, how do ADTs relate to these elements? As previously written, a value object is *semantically immutable*, so abstracting this with an ADT is a good choice. For example, let's consider the following example:

[] case class Address(no: String, street: String, city: String, state: String, zip: String)

If an application, at a given time, has an instance of an address and needs to modify an attribute (e.g. the zip code), all it has to do is to **generate a new instance** of the object with the updated attribute, **avoiding in place mutation** (no vars, no setters). Scala also offer a `copy` method to further simplify the job.

```
val initialAddress = Address("10", "Via Sacchi", "Cesena", "IT", "47522")
val newAddress = initialAddress.copy(zip = "47523")
```

This approach may looks nice at a first sight, but doesn't scale well, unfortunately. To see the problem, just consider a new entity that uses the address as a value object.

```
case class Person(id: Long, name: String, address: Address)
```

The entity Person is *semantically mutable*, but it's implemented with an ADT. The first part of this chapter already stated the fact that an entity is semantically mutable doesn't prevent us from using immutable constructs for its implementation, and this is a brilliant proof of concept.

Back to the issues with when using `copy` for creating a new ADTs with modified fields, let's consider the following simple example.

```
val initPerson = Person(0, "Alessandro", initialAddress)
val newPerson = initPerson.copy(address = initPerson.address.copy(zip = "475
```

It immediately appears that the code is getting bad. And things only get worse when there are multiple level of nesting of the objects. A better abstraction to solve this problem is given by *Lenses*. Lenses are ADTs, and in Scala can be implemented as follows:

```
case class Lens[O, V](
    get: O => V,
    set: (O, V) => O
)
```

From the implementation it emerges that **Lenses**:

- are **parametrized** (on O and V types)
- have a **getter** method, which takes an object with type O and return a value of type V
- have a **setter** method, which takes an object of type O and returns a new instance of the object set to the value

To demonstrate that lenses just work as the copy method introduced below, let's consider the following example:

```
val newAddress2 = addressZipLens.set(initialAddress, "47523")
newAddress == newAddress2 //> res0: Boolean = true
```

The compare on the final line asserts that the addresses created with the two different techniques are equals.

To solve the problem related to the multiple level of nesting attribute update it is necessary to introduce a generic `compose` function, implemented as follows:

```
def compose[Outer, Inner, Value](
    outer: Lens[Outer, Inner],
    inner: Lens[Inner, Value]
) = Lens[Outer, Value](
    get = outer.get andThen inner.get,
    set = (obj, value) => outer.set(obj, inner.set(outer.get(obj), value)))
```

Compose, as the name suggests, takes care of composing two lenses. Lens composition is really helpful to maintain the code clean and safe, as the following sample will demonstrate.

```
val personAddressZipLens: Lens[Person,String]
= compose(personAddressLens, addressZipLens)
newPerson2 = personAddressZipLens.set(initPerson, "47523")
newPerson == newPerson2 //> res1: Boolean = true
```

As the previous example, also in this case the result is the same as the case when `copy` was used instead. Lenses offer a *view on data*, allowing to get and modify the data *the functional way*.

## A.3 Referential trasparency

An important concept in functional programming is referential transparency. Referential transparency is a property of programs, which makes it easier to verify, optimize, and parallelize programs.

From Wikipedia's definition:

> **Referential transparency** and **referential opacity** are properties of parts of computer programs. An expression is said to be referentially transparent if it can be replaced with its value without changing the behavior of a program (in other words, yielding a program that has the same effects and output on the same input). The opposite term is referential opaqueness.

A necessary, but not sufficient, condition for referential transparency is the absence of side effects. In simple words, it's all about the fact that an expression can be replaced with its value. This obviously requires that the expression (that could be a function call, for example) has no side effects and always return the same output on the same input.

In other words, referential transparency means that the value of expression can depend only on the values of its parts, and not on any other facts about them or about the execution context.

The opposite of referential transparency is referential opacity, where the value does change when evaluated, and the expression cannot be replaced by a single value without altering the way a program executes.

A trivial but effective example of referential transparency has been introduced in the previous section, with the code snippet about lists. Using immutable lists, the act of adding, removing or updating a value in those data structures results in new lists being created with the changed values, and any part of the program still observing the original lists sees no change.

### A.3.1 Equational reasoning

The previous section introduced and depicted referential transparency. The importance of referential transparency expressions is that they make substitution model work and the substitution model helps **equational reasoning** work.

A possible definition of equational reasoning is *the process of interpreting code by substituting equals-for-equals.*

Equational reasoning is an important property, since it keeps the models easy to reason about and easy to validate. The correctness of the properties of a model that respect equational reasoning can be verified just as the properties of a math theorem.

## A.4 Patterns

The previous sections of this chapter introduced the basics of functional domain modelling, by using **algebraic data types**, and the importance of **referential transparency**.

This final section will go deeper, and cover three functional design pattern: **monoids**, **functors** and **monads**. These patterns are really important to fully understand the usage of algebraic data type to model the domain.

The pattern introduced in this section are *abstract*, meaning that they don't operate on just one specific data type bar on all data types that share a common algebra.

### A.4.1 Monoid

**Monoid** is an ubiquitous pattern that come up frequently in programming, even if we are not aware of it. To introduce monoids, let's consider an example about the concatenation operation for List and String types:

- the concatenation operation is a binary operation and is associative
- both List and String have an identity element and the operation applied with the identity yields the same value as the other argument

The points depicted above are a valid algebra for the abstraction of a monoid. In Scala a monoid can be expressed as follows.

```
trait Monoid[A] {
  def op(a1: A, a2: A): A
  def zero: A
}
```

More formally, a monoid needs to satisfy the following laws:

- *Left identity*: `op(zero, a) == a`
- *Right identity*: `op(a, zero) == a`
- *Associativity*: `op(a1, op(a2, a3)) == op(op(a1, a2), a3)`

Back to the initial example, with the given definition List and String concatenation can be expressed as monoids as follows.

```
val stringMonoid = new Monoid[String] {
  def op(a1: String, a2: String) = a1 + a2
  def zero = ""
}

def listMonoid[A] = new Monoid[List[A]] {
  def op(a1: List[A], a2: List[A]) = a1 ++ a2
  def zero = Nil
}
```

The benefits of having operations that operate on different data types modelled as monoids is given by the fact that monoids offer *parametricity* and the ability to *abstract over behaviors.*

A brilliant example that illustrates the power of monoids is given when they are used in conjunction with lists and list folding functions. Looking at `foldLeft` function definition:

```
def foldLeft[B](z: B)(f: (B, A) => B): B
```

and in the particular case of `A = B`:

```
def foldLeft(z: A)(f: (A, A) => A): A
```

it can be observed that the function signature perfectly matches the signature of `op` operation on the monoid type.

This brings to a really nice proof of concept about the practical usage of monoids, like in the following example.

```
val words = List("Hello", "world")
val t = words.foldLeft(stringMonoid.zero)(stringMonoid.op)
```

### A.4.2 Functor

The previous section introduced an ubiquitous pattern that recurs frequently in programming, monoid. This section will make a further step towards the king abstraction of functional programming, which will be introduced in the next one.

In the Scala standard library there are some classes that provide a `map` function. For example:

```
def map[B](f: (A) => B): List[B]

def map[B](f: (A) => B): Option[B]
```

In the classes of the example, the effect of `map` is:

- for List, `map` applies the function `f` on each element of the list
- for Option, `map` applies the function `f` only if the element is instance of `Some` and return `Some` of the result, otherwise it returns `None`

All these function signatures are pretty the same, with the only difference of the concrete type involved. As always in programming, when there are things that are pretty the same, it's possible that factorize the behavior and create a new abstraction. In this case, the abstraction it's all about a *data type that implements map* and it's called **functor**. In Scala, if a data type `F` implements `map`, `F` is a functor. An implementation of this abstraction can be represented by the following trait.

```
trait Functor[F[_]] {
    def map[A, B](fa: F[A])(f: A => B): F[B]
}
```

**NB**: in the example provided above (from the Scala library), the signatures of the map function are different from the signature of map in the trait introduced below. The reason of this difference is due to the object oriented nature of the classes in the Scala library. The new signature has a more "functional" approach, with an additional parameter (the first one) that takes the object to map on.

With this new abstraction defined, it's possible to define functors explicitly for List and Option in the following way, reusing the object oriented implementation provided by the Scala standard library:

```
def listFunctor: Functor[List] = new Functor[List] {
    def map[A, B](a: List[A])(f: A => B): List[B] = a map f
}

def optionFunctor: Functor[Option] = new Functor[Option] {
    def map[A, B](a: Option[A])(f: A => B): Option[B]
     = a.map(f).orElse(None)
}
```

Functors are nothing more that an abstraction that has the capability of mapping over some data structure, with functions.

### A.4.3 Monad

The concept of monad comes from category theory, and is one of the most important topics in functional programming development.

From Wikipedia:

> In functional programming, a **monad** is a structure that represents computations defined as sequences of steps: a type with a monad structure defines what it means to chain operations, or nest functions of that type together. This allows the programmer to build pipelines that process data in steps, in which

> each action is decorated with additional processing rules provided by the monad. As such, monads have been described as "programmable semicolons"; a semicolon is the operator used to chain together individual statements in many imperative programming languages, thus the expression implies that extra code will be executed between the statements in the pipeline.

From a Erik Meijer's quote:

> Monads are return types that guide you through the happy path.

From a Martin Odersky's quote:

> Monads are parametric types with two operations flatMap and unit that obey some algebraic laws.

An other definition can be: >Monads are abstract computations that help us mimic the effects of typically impure actions like exceptions, IO, continuations etc. while providing a functional interface to the users.

All this quotes and definitions help to give us the idea of what a monad is. Formally, a monad is just a type, and can be defined as follows:

```
trait Monad[M[_]] extends Functor[M] {
  def unit[A](a: => A): M[A]
  def flatMap[A,B](ma: M[A])(f: A => M[B]): M[B]

  def map[A,B](ma: M[A])(f: A => B): M[B] =
    flatMap(ma)(a => unit(f(a)))
}
```

Monad extends functor, implementing `map`. The trait introduced above is generic, so each type that implements a `unit` and a `flatMap` and respects some laws (depicted below) is a monad.

**NB**: in the literature, `flatMap` is often called `bind` and `unit` is often called `return`.

Two examples of monads are represented by `Option` and `List`. Starting from the definition of Monad, they can be defined as follows (reusing the implementation provided by the Scala standard library):

```
val optionMonad = new Monad[Option] {
    def unit[A](a: => A) = Some(a)
    def flatMap[A,B](ma: Option[A])(
     f: A => Option[B]) = ma flatMap f
}

val listMonad = new Monad[List] {
    def unit[A](a: => A) = List(a)
    def flatMap[A,B](ma: List[A])(f: A => List[B]) = ma flatMap f
}
```

From the example, it's easy to note that `unit` is different for each monad. For example, for the `List` type unit is `List(a)` and for the `Option` type unit is `Some(a)`.

A more object oriented definition for monad is the following.

```
trait M[T] {
    def flatMap[U](f: T => M[U]): M[U]
    def unit[T](x: T): M[T]
}
```

with `map` defined as `m flatMap (x => unit(f(x)))`.

As introduced previously, monads need to satisfy three laws: associativity, left unit and right unit.

### Associativity

The associativity law is about the order of **composition**, and demands that for any monad `m`and any two functions `f` and `g`, it must not make a difference whether you apply f to m first and then apply g to the result, or if you first apply g to the result of f and then in turn flatMap this over m. Formally:

```
m flatMap f flatMap g == m flatMap (x => f(x) flatMap g)
```

### Left unit

The left unit law demands that flatMap must behave in such a way that for any function f passed to it, the result is the same as calling f in *isolation*. Formally:

```
unit(x) flatMap f  ==  f(x)
```

The left unit law can be considered the most important law, since it guarantees that flatMap let's you apply a transformation to the value contained in a monad, without leaving the monad. In other words, monads promote and allow *containment* and *chainability* of transformations.

**Right unit**

The right unit law demands that applying unit to a monad has no effects at all (or, better, has the same outcome as not calling it at all). Formally:

```
m flatMap unit  ==  m
```

Usually the term monad is also used *informally*, to describe a type that has `flatMap` and `unit`, without any attention about the monad laws. An example of this is given by the `Try` type, which has a `Success` case that contains a value and a `Failure` case that contains an exception.

```
abstract class Try[+T]
case class Success[T](x: T)       extends Try[T]
case class Failure(ex: Exception) extends Try[Nothing]
```

**Try** is often used to wrap the result of a computation inside a container type. The important thing about Try is that is handles exception, through *materialization*.

```
def map[S](f: T => S): Try[S] = this match {
  case Success(value)       => Try(f(value))
  case failure: Failure(t)  => failure
}


def flatMap[S](f: T => Try[S]): Try[S] = this match {
  case Success(value)       =>
    try { f(value) } catch { case NonFatal(t) => Failure(t) }
  case failure: Failure(t)  => failure
}
```

At first sight Try looks like a monad, implementing `flatMap` (and `unit`), but formally it doesn't respect the left unit law.

# Appendix B

# Future and Promises

The appendix about Functional Programming introduced the main patterns and principles that help when dealing with computations that imply some effects. Moving a step forward, we can consider also the latency as an effect.

The following table represents a possible classification of the effects in programming.

This section will introduce a first abstraction to achieve sequential composition of actions that can take time to complete and that can also fail: `Future[T]`.

**Future** and **Promise** are two really powerful abstractions that can be classified in the *asynchronous programming* category.

Wikipedia defines Futures and Promises as follows:

> In computer science, **future**, **promise**, and **delay** refer to constructs used for synchronization in some concurrent programming languages. They describe an object that acts as a proxy for a result that is initially unknown, usually because the computation of its value is yet incomplete. [. . . ]
>
> A future is a read-only placeholder view of a variable, while a

Table B.1: The essential effects in programming

| | **One** | **Many** |
|---|---|---|
| Synchronous | T/Try[T] | Iterable[T] |
| Asynchronous | **Future[T]** | Observable[T] |

promise is a writable, single assignment container which sets the value of the future.

Futures and Promises promote an asynchronous and non-blocking approach to programming. The scale up to use multiple cores on a machine, but with the currently implementations they don't scale out across nodes.

## B.1 Futures

A Future is an immutable handle to a value or a failure that will become availlable in the future time. Another possible definition is that Futures are monads that handle **exceptions** and **latency**. A fist simple possible definition in Scala is:

```
trait Future[T] {
    def onComplete(callback: Try[T] => Unit)
        (implicit executor: ExecutionContext): Unit
}

object Future {
    def apply(body: => T)
        (implicit context: ExecutionContext): Future[T]
}
```

This first definition put some important concepts directly in the type definitions:

- a Future is parametrized on a type `T`
- a Future may **fail**, returning a `Try.Failure`
- a Future may **succeed** (successfully completed), returning a `Try.Success[T]`

Futures are really useful in defining operations that will be executed at some point in time by some thread (execution context). Futures are immutable from the developer point of view: once an API returns a Future, there's is no way to set a value insede a Future. In other words, a Future may only be assigned once.

A more complete and precise definition for Future is the following:

```
trait Awaitable[T] extends AnyRef {
    abstract def ready(atMost: Duration): Unit
    abstract def result(atMost: Duration): T
}

trait Future[T] extends Awaitable[T] {
    def filter(p: T => Boolean): Future[T]
    def flatMap[S](f: T => Future[S]): Future[U]
    def map[S](f: T => S): Future[S]
    def recoverWith(f: PartialFunction[Throwable, Future[T]]): Future[T]
}

object Future {
    def apply[T](body : => T): Future[T]
}
```

In the scala library, Futures are already implemented in the `scala.concurrent` package. In this package, `Future[T]` is a type which denotes future objects, whereas `future` is a method which creates and schedules an asynchronous computation, and then returns a future object which will be completed with the result of that computation. An example of the usage of Future coming from the Scala documentation is the following:

```
import scala.concurrent._
import ExecutionContext.Implicits.global

val session = socialNetwork.createSessionFor("user", credentials)
val f: Future[List[Friend]] = future {
  session.getFriends()
}
```

The the previous example shows some key points:

- To obtain the list of friends of a user, a request has to be sent over a network, which can take a long time. Wrapping the request inside the `future` method **doesn't block** the rest of the program execution while **waiting** for a response.
- All the computation is performed **asynchronously**.

- The list of friends becomes available in the future once the server responds.
- If the request fails, the future itself will fail.

To obtain the value of a Future, the library offers two main solutions:

- the client **blocks** its computation and wait until the future is completed
- the client **register a callback** by using the `onComplete` method, which was alredy depicted at the beginning of this chapter.

The library also provide the companion methods `onSuccess` and `onFailure`, which usually are used alternatively to `onComplete`. All these three methods have `Unit` as the result type. This is intentional, since the invocations of these methods cannot be chained.

The presence of these callbacks may lead to what is known as "asynchronous spaghetti", where the overall computation is fragmented into asynchronous handlers. To prevent this possibility, futures provide combinators which allow a more straightforward composition, such as `map`, `flatMap`, `filter`, ...

The `map` methods takes a future and a mapping function for the value of the future and produces a new future that is completed with the mapped value once the original future is successfully completed.

The `flatMap` method takes a function that maps the value to a **new future** g, and then returns a future that is completed once g is completed.

The `filter` method creates a new future that contains the value of the original future only if it satisfies some predicate. Otherwise, the new future is failed with a `NoSuchElementException`.

The presence of these methods enable the Future type to also supports for-comprehension. An example, taken from the documentation, of for-comprehension in practice is the following:

```
val usdQuote = future { connection.getCurrentValue(USD) }
val chfQuote = future { connection.getCurrentValue(CHF) }

val purchase: Future[Int] = for {
  usd <- usdQuote
  chf <- chfQuote
  if isProfitable(usd, chf)
} yield connection.buy(amount, chf)

purchase onSuccess {
  case _ => println("Purchased " + amount + " CHF")
}
```

that is translated to:

```
val purchase: Future[Int] = usdQuote flatMap {
  usd =>
  chfQuote
    .withFilter(chf => isProfitable(usd, chf))
    .map(chf => connection.buy(amount, chf))
}
```

For-comprehension is a really elegant and concise way to express **chain of computations**, leveraging the monadic nature of Futures to describe the "**happy path**" of the chain and to propagate (**materialize**) the exceptions.

## B.2 Promises

**Promises** are an interesting and alternative way to create futures. A Promise can be seen as a *writable, single-assignment* container, which completes a Future.

In Scala, a Promise can be represented by the following trait:

```
trait Promise[T] {
  def future: Future[T]
  def complete(result: Try[T]): Unit
  def tryComplete(result: Try[T]): Boolean
}

trait Future[T] {
  def onCompleted(f: Try[T] => Unit): Unit
}
```

A promise `p` can alternatively complete or fail the future returned by `p.future`. In other words, it acts as a **mailbox** for the future that it wraps.

The Scala standard library already implements Promise in the `scala.concurrent` package.

Promises have a *single-assignment* semantics, so they can be completed only once and usually are used to implement other operator on futures.

# Appendix C

# Reactive Streams

> Reactive Streams is an initiative to provide a standard for asynchronous stream processing with non-blocking back pressure. This encompasses efforts aimed at runtime environments (JVM and JavaScript) as well as network protocols.

The project is a collaboration between engineers from Kaazing, Netflix, Pivotal, RedHat, Twitter, Typesafe and many others and is developed and discussed in the open.

The core idea behind the Reactive Stream standard is in the definition of two different channels for the **downstream data** and the **upstream demand**.

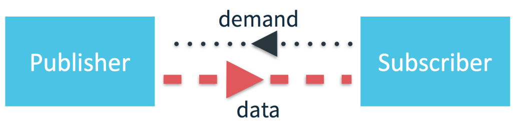


Figure C.1: Two different channels for the downstream data and the upstream demand

This allows overcoming one of the biggest issue of the Rx approaches: **backpressure**. Backpressure is a lack of demand, and is due to the fact that the producer of a stream of items is faster than the consumer, and that difference of speed quickly determines a growing backlog of unconsumed items on the consumer side.

In the literature (and in our everyday life) there's already a protocol that solved a similar problem: TCP. With this in mind, engineers behind Reactive Streams proposed a solution that, in simple terms, works like this:

- A publisher doesn't send data until a request arrives via the demand channel, at which point it can push a certain number of elements (in according to the request) downstream.
- When outstanding demand exists, the publisher is free to push data to the subscriber.
- When demand is exhausted, the publisher cannot send data except as a response to demand signalled from downstream.

Engineers called this technique **dynamic push/pull**. The dynamic terms indicates that the system should **adapt** to the current conditions of its components and that's not safe to only use a *just push* or just *pull approach*.

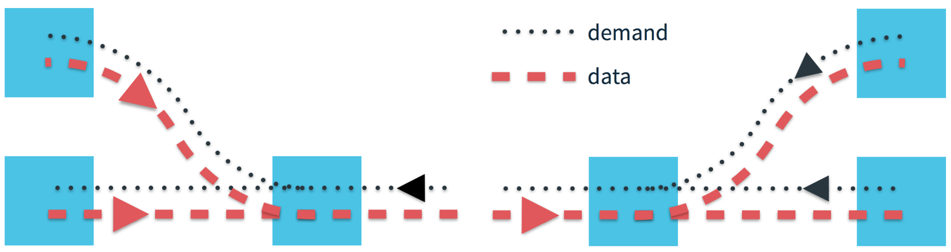
A **just push** approach is not safe when the **subscriber is slow**, since it'll quickly start to be overwhelmed by the offers and will start to:

- drop items, in the case of it use a bounded buffer to store received messages (just like TCP)
- trigger an out of memory error

A **just pull** approach is too slow in the case that the **subscriber is faster** than the publisher.

Two important notes about the fact that data and demand *flows* in different channels and directions are the following:

- **Merging streams splits the upstream demand**
- **Splitting streams merges the downstream demand**



As the main document says, the scope of Reactive Streams is to find a minimal set of interfaces, methods and protocols that will describe the necessary operations and entities to achieve the goal: asynchronous streams of data with non-blocking back pressure. This set of interfaces is a low level specification to which each library should conform.

The API offers the following interfaces that are required to be implemented by each implementation:

- Subscriber
- Subscription
- Publisher
- Processor

## C.1 Subscriber

The **Subscriber** interface abstracts the notion of an entity that consumes items. Its definition is as follows.

```
public interface Subscriber<T> {
    public void onSubscribe(Subscription s);
    public void onNext(T t);
    public void onError(Throwable t);
    public void onComplete();
}
```

A `Subscriber` has the canonical `onNext( )`, `onError( )`, and `onComplete()` methods. When new items are produced by the publisher, a the onNext method is invoked with the new element. If an error was raised while producing values, the publisher would then invoke the onError method with the exception. Finally, when the publisher completes its job, the onComplete method is then invoked.

The `onSubscribe( )` method is invoked when a subscriber is subscribed to a publisher. This method is really important for the framework, since it links the relation between a subscriber and a publisher, via a `Subscription`.

## C.2 Subscription

A **Subscription** abstracts the notion of a subscriber's communication channel back to the publisher. This channel is what enables the subscriber to either cancel the subscription or signal demand. Its definition is as follows.

```
public interface Subscription {
    public void request(long n);
    public void cancel();
}
```

The `request( )` method signals to the publisher that the subscriber can receive more items, also specifying the quantity.

The `cancel( )` method notifies the publisher that the subscriber is no longer interested in receiving items.

This channel between a publisher and a subscriber is what enables to achieve non blocking back-pressure in a Reactive Streams.

## C.3 Publisher

The **Publisher** interface has only one method to implement, and is as follows.

```
public interface Publisher<T> {
    public void subscribe(Subscriber<? super T> s);
}
```

A subscriber is subscribed to a publisher via the `subscribe( )` method. This method doesn't return a `Subscription` as one would expect, but `Unit`. This is a precise design choice, since every method of the interfaces returns `Unit`.

The publisher, after notifying the subscriber that it has been subscribed via its `onSubscribed( )` method, must provide items to the subscriber, that will receive items in its `onNext( )` method. The items received must not exceed the total number of items that the subscriber has signalled demand for.

When the subscriber `cancel( )` the subscription, the publisher must start sending items.

Finally, a publisher must notify to the subscriber through `onError( )` and `onComplete( )` methods if an error is encountered or the stream is successfully completed respectively.

## C.4 Processor

A **Processor** represents a processing stage, which is both a Subscriber and a Publisher and obeys the contracts of both. The interface is defined as follows.

```
public interface Processor<T, R>
    extends Subscriber<T>, Publisher<R> { }
```

A processor is an intermediate abstraction that enables to build **chain of processing stage**, in which each intermediate unit is a processor that can consume, transform and publish items. The importance of this abstraction is in the fact that, obeying to both Subscriber and Publisher interface, it has to **retain back-pressure propagation** with the original stream source.

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