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**The advantages of the Scala language in
the context of Infrastructure as code**

Master Thesis

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Dedicato alla mia famiglia e ai miei amici

Sommario

Il presente documento descrive il lavoro svolto durante il periodo di *stage*, della durata di circa trecentoventi ore, dal laureando Alessandro Rizzo presso l'azienda Infocert S.p.A. Gli obiettivi da raggiungere erano molteplici.

In primo luogo era richiesto lo studio e la comprensione dei fondamenti della *Chaos Engineering*.

In secondo luogo era richiesta l'implementazione di una versione rivisitata di un *software* aziendale già esistente, MICO, in seguendo i principi dell'architettura a microservizi e reactive tramite il *framework* Akka. Tale *framework* permette di utilizzare il modello ad attori per gestire il completamento di diversi task simultaneamente e in maniera asincrona. In questo sviluppo andava applicato quanto appreso nella fase di studio per progettare e realizzare un'applicazione il più resiliente possibile.

Infine, una volta completato lo sviluppo, andavano applicati tutti i principi di *Chaos Engineering* appresi durante la fase di studio per aumentare la fiducia nell'applicazione e per scoprire eventuali vulnerabilità non ancora considerate con lo scopo ultimo di aumentare la resilienza e l'affidabilità del prodotto.

“Failures are a given, and everything will eventually fail over time”

— Werner Vogels

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Capitolo 1

Introduction to Infrastructure as Code

An introduction to iac

1.1 Infrastructure as Code

1.1.1 What is IaC

Infrastructure as Code is the process of managing and provisioning computer data centers through machine-readable definition files, rather than physical hardware configuration or interactive configuration tools.

The IT infrastructure managed by this process comprises both physical equipment, such as bare-metal servers, as well as virtual machines, and associated configuration resources.

The definitions may be in a version control system. The code in the definition files may use either scripts or declarative definitions, rather than maintaining the code through manual processes, but IaC more often employs declarative approaches.

Types of approaches

There are generally two approaches to IaC: declarative (functional) vs imperative (procedural). The difference between the declarative and the imperative approach is essentially *what* versus *how*. The declarative approach focuses on what the eventual target configuration should be; the imperative focuses on how the infrastructure is to be changed to meet this. The declarative approach defines the desired state and the system executes what needs to happen to achieve that desired state. Imperative defines specific commands that need to be executed in the appropriate order to end with the desired conclusion.

Methods

There are two methods of IaC: push and pull. The main difference is the manner in which the servers are told how to be configured. In the pull method, the server to be configured will pull its configuration from the controlling server. In the push method, the controlling server pushes the configuration to the destination system.

1.1.2 Advantages of IaC

The value of IaC can be broken down into three measurable categories: **cost**, **speed**, and **risk**. Cost reduction aims at helping not only the enterprise financially, but also in terms of people and effort, meaning that by removing the manual component, people are able to refocus their efforts on other enterprise tasks. Infrastructure automation enables speed through faster execution when configuring your infrastructure and aims at providing visibility to help other teams across the enterprise work quickly and more efficiently. Automation removes the risk associated with human error, like manual misconfiguration; removing this can decrease downtime and increase reliability.

Related to the risk, we could highlight the importance of the **consistency** of such an approach. Through the manual modifications to the infrastructure achieved in a solution without IaC, at some point will be extremely hard to reproduce an exact configuration since some ad-hoc steps were required whilst some others were executed in a different order. Infrastructure as Code enforces consistency by allowing users to represent infrastructure environments using code. Therefore, the deployment and modification of resources will always be consistent and idempotent (i.e. every time a specific operation gets executed, the same result will be generated).

Furthermore, IaC tools usually offer mechanisms to enhance reusability. This feature makes your code base less verbose and more readable while at the same time team members are encouraged to apply best practices.

Finally, another big advantage of IaC is collaboration. Since the infrastructure resources are defined in configuration files it means that these files can be version controlled. At any given time, the team is able to collaborate together in order to modify an environment and even be able to see the history (from commits) of an infrastructure resource. This also makes debugging much easier and accurate.

1.1.3 Challenges of IaC

While IaC offers numerous benefits, there are also several challenges that organizations must address when implementing this approach.

One of the major challenges is the adoption discrepancies that arise when integrating new frameworks with existing technology. This requires careful coordination with other teams, particularly those responsible for security and compliance, and can result in difficulties in determining where resources are being delivered, controlled, and managed. To address these issues, organizations must continually communicate and audit their IaC adoption to minimize infrastructure drift and ensure that security measures remain up to date.

Another challenge is the need for security assessment tools that can effectively evaluate the dynamic nature of IaC. Traditional security measures may require significant cycles to be integrated with IaC, and there may be a need for human checks to ensure that resources are operating correctly and being used by the appropriate applications.

Organizations may need to invest in new tools or capabilities to ensure proper control and monitoring.

The implementation of IaC also requires a high degree of technical competence, which can result in the need for new human capital. Senior executives may face challenges in continually investing in employee skills, particularly if the organization is in the early adoption phase. Outsourcing IaC services may be a viable option for organizations to improve automation processes in terms of cost and overall IT infrastructure quality.

Versioning and traceability of settings can also be a challenge when IaC is utilized widely across an organization with various teams. As IaC becomes more complex, it can be difficult to keep track of infrastructure and identify infra-drift, making it essential to implement effective version control and tracking mechanisms.

1.1.4 Evolution of IaC

Tools designed for Serverless Applications - the first wave

The foundation of IaC in the public clouds is these three cloud vendor-specific tools: AWS CloudFormation in [AWS](#), [Azure Resource Manager](#) (ARM) in [Azure](#), and [Cloud Deployment Manager](#) in [GCP](#). These are YAML or JSON based, declarative tools and have been in cloud toolboxes for a long time and require a fair amount of markup code. Tools with shortcuts or “conventions over configuration” were developed to boost productivity and make distributed microservice applications seem more like a traditional monolithic application or a framework. These tools provide best-practice defaults and enable building and testing your serverless applications locally on your machine.

Serverless Infrastructure as programming language code - the second wave

Declarative language has some limitations when there is the need to do more complex business logic than what parameters, conditions, mappings, and loops (Terraform only) allow to do. Sometimes, there is the need to use external scripting to have the work done. A programming language could address such a problem and let us get around these boundaries and limitations. This second generation tools generate the declarative markup code with the aid of a programming language, or bypass it and utilizes cloud APIs. These kind of tools with programming language support is a rising and trending approach in IaC at the moment.

Capitolo 2

Pulumi, an IaC platform

An introduction to Pulumi

2.1 Introduction to Pulumi

Pulumi is a cloud engineering platform that enables developers and infrastructure teams to build, deploy, and manage cloud-native applications and infrastructure across multiple cloud providers, including AWS, Azure, Google Cloud, and Kubernetes.

Pulumi provides a programming model that allows developers to use familiar languages, such as Python, JavaScript, TypeScript, Go, and (partially) Java to define their IaC and manage it as software. In fact, it belongs to the second generation tools of the IaC. As already mentioned in the [Introduction to Infrastructure as Code](#) chapter, such an approach, makes it easier to automate the deployment and management of infrastructure and applications, as well as to collaborate across teams and projects.

Pulumi offers a range of tools and features to simplify the development and management of cloud infrastructure, including version control, testing, continuous integration and delivery (CI/CD), monitoring, and security. It also provides templates, examples, and libraries for common infrastructure patterns and services, such as containers, serverless functions, databases, and networking.

Overall, Pulumi aims to streamline the process of building and managing modern cloud-native applications and infrastructure, while providing a flexible and developer-friendly experience.

2.1.1 The great advantages of Pulumi as a second generation IaC tool

First of all, as mentioned in the [Serverless Infrastructure as programming language code - the second wave](#) paragraph, all the functionalities that comes along a programming language are letting us achieve more robust and powerful solutions for our infrastructure, rather than what we could achieve with the expressive power of a markup language (like the ones used with [Terraform](#)). Being the focus of this thesis, we'll discuss more about such advantages in the Comparison between the languages for Pulumi and the advantages of Scala Chapter.

Furthermore, as aforementioned, Pulumi is a multi-cloud tool. Thanks to this we can rely on a single IaC tool for managing resources across different cloud platforms. Moreover, Pulumi lets the user choose its favorite programming language, or the one that in its opinion is a best-fit for the need to be addressed. In other words, such a choice can both reduce the requirements placed on the user's knowledge, since it can choose among many different programming languages, and at the same time offer different programming paradigms to choose from, so that for any need there is a programming language that is addressing such a need better than the others. Finally, Pulumi comes with a range of integrated tools and features, such as automatic parallelism, drift detection, and stack references, making it easier to manage complex infrastructure and deployments.

2.2 Pulumi functioning

2.2.1 The stack

When creating a new Pulumi application, the first step is to define a stack. A stack represents a set of cloud resources that can be managed as a cohesive unit. Each stack is associated with a particular cloud provider (such as AWS, Azure, or GCP), and contains a list of the resources that should be created.

The stack definition typically includes information such as the provider, the region in which the resources should be created, and any required configuration settings. This information is used by Pulumi to provision and manage the resources in the stack.

2.2.2 APIs to define the resources to be created

Once the stack is defined, you write code that implements the resource management logic. Pulumi provides libraries for several programming languages, including TypeScript, Python, Go, .NET, and partially Java. You use these libraries to create and configure cloud resources.

In Pulumi, you define resources using a "resource constructor" function. This function takes in the configuration for the resource as input, and returns a reference to the newly-created resource. You can then use this reference to manage the resource throughout its lifecycle.

Pulumi code can also contain logic for managing relationships between resources. For example, you can specify that one resource depends on another, so that Pulumi knows to create the dependent resource first.

2.2.3 Creating and updating resources with Pulumi commands

Once the code is written, you use Pulumi to create the cloud resources specified in the stack definition. Pulumi uses the provider cloud API to create the resources and corresponding configurations. The resource creation process is declarative, which means that Pulumi automatically figures out the order in which resources should be created based on their dependencies.

Pulumi also supports continuous delivery, meaning that changes to your code are automatically detected and used to update existing resources. When a change is detected, Pulumi compares the desired state (based on your code) to the current state

(based on the resources in the cloud) and makes any necessary changes to bring the resources into compliance with the desired state.

2.2.4 Viewing resources state

Pulumi provides a command to view the state of the resources managed by the application: `pulumi stack`. This command shows the created resources, their properties, and their current state. This information can be used to debug issues and ensure that resources are configured correctly.

The state of a resource is maintained by Pulumi in a "state file". This file contains information about the resources that have been created, as well as their current configuration and state. The state file is automatically updated by Pulumi as resources are created, updated, or deleted.

2.2.5 Restoring resources state

In case of issues or errors during resource creation or management, you can use Pulumi to restore the resource state to the last known good state. This ensures that cloud resources are always consistent with the code and stack definition.

Pulumi uses the state file to track the current state of the resources it manages. If the state of a resource becomes inconsistent with the desired state (for example, if a resource is accidentally deleted), you can use Pulumi to recreate the resource based on the information in the state file. This restores the resource to its last known good state and brings it back into compliance with the stack definition.

2.3 Pulumi's Output

In an IaC context, and therefore with Pulumi, the creation of the resources is not immediate. Hence, in our code when we call a constructor for given resource, we are not actually creating it in that exact moment, but we are rather requesting Pulumi to instantiate such a resource on the given cloud provider. So, the usage of that resource is not available until Pulumi will have completed its creation on the cloud provider. How can we perform operations on a resource when we do not know when it will become available? Pulumi addresses such a problem with the `Output` type.

In Pulumi, `Output` values are typically computed asynchronously, so that they can represent resources that are being provisioned by cloud providers. Like a future, an `Output` can be used to chain operations that depend on the completion of other operations. This feature will come handy to chain the definition of resources that depends on other resources.

We'll see how to create a Monad out of the `Output` type so that we'll be able to boost our syntactic sugar in the Scala version of the case study.

Capitolo 3

Scala, a modern functional and object-oriented programming language

Scala brief overview

3.1 Introduction to Scala

3.1.1 Scala, a modern functional and object oriented programming language

Scala is a modern multi-paradigm programming language designed to express common programming patterns in a concise, elegant, and type-safe way. It seamlessly integrates features of object-oriented and functional languages.

3.1.2 Object-orientation

Scala is a pure object-oriented language in the sense that every value is an object. Types and behaviors of objects are described by classes and traits. Classes can be extended by subclassing, and by using a flexible [mixin-based composition](#) mechanism as a clean replacement for multiple inheritance.

3.1.3 Functional paradigm

Scala is also a functional language in the sense that every function is a value. Scala provides a lightweight syntax for defining anonymous functions, it supports higher-order functions, it allows functions to be nested, and it supports currying. Scala's case classes and its built-in support for pattern matching provide the functionality of algebraic types, which are used in many functional languages. Singleton objects provide a convenient way to group functions that aren't members of a class.

3.1.4 Scala functionalities related to the work of the thesis

Higher order functions and currying

Thanks to the functional paradigm of Scala, I used the higher order functions and the currying feature to create a powerful syntactic sugar for the declaration of AWS [EC2](#) IaC resources in a concise and elegant way.

Higher order functions An higher order function is function that either takes one or more functions as arguments or returns a function as return value, or both of them. Such a feature is at the basis of the functional programming paradigm since it lets concatenates function and create more complex and more powerful abstract constructs such as functors, applicatives and monads, so that we can eventually work on data in an immutable, and then safe, way. We'll see more about functors and monads in the [Functor and monads](#) paragraph.

Currying Currying is the transformation of a function with multiple arguments into a sequence of single-argument functions. That means, converting a function like `f(a, b, c, ...)` into a function like `f(a)(b)(c)...`. To give a more detailed example let's consider the following function in Scala:

```
def sum(a: Int, b: Int) : Int =
  a + b
```

Such a function, takes two `Int` parameters as input and returns the sum of them. Therefore, if we call `sum(1, 2)` we get 3 as result. Now let's instead consider the following function:

```
def csum(a: Int)(b: Int) : Int =
  a + b
```

Here we can call the function writing `csum(1)(2)` and we'll get 3, but we could also write `csum(1)` and get, as output, a function that takes a single `Int` in input and sums it to 1 (the `Int` we passed to `csum` previously). The returned function will be analogous to this function:

```
def csum1(b: Int) : Int =
  1 + b
```

So the currying is letting us define and use partial functions, and this feature, combined with the feature of taking functions as parameters, will be a key ingredient for the highly expressive and readable solution achieved and proposed in the [Study case: AWS EC2 resource generation with Pulumi](#) chapter.

Traits

Pattern matching

Pattern matching is a mechanism for checking a value against a pattern. A successful match can also deconstruct a value into its constituent parts. It is a more powerful

version of the switch statement in Java and it can likewise be used in place of a series of if/else statements. Let's now consider the following example, taken from [Tour of Scala - Pattern Matching](#), to have a better idea of the expressiveness of such a feature:

```
sealed trait Device
case class Phone(model: String) extends Device:
  def screenOff = "Turning screen off"

case class Computer(model: String) extends Device:
  def screenSaverOn = "Turning screen saver on..."

def goIdle(device: Device): String = device match
  case p: Phone => p.screenOff
  case c: Computer => c.screenSaverOn
```

We can notice how we are applying the pattern matching on the variable `device` to have a different behavior on the base of its actual type. This is useful when the case needs to call a method on the pattern. In fact, we'll see in the [Study case: AWS EC2 resource generation with Pulumi](#) chapter how this feature of Scala will be used to achieve our solution.

Obviously, in such an example, the right-hand side of the various cases must have a valid return type with respect to the return type given in the declaration of the method, that in this case is `String`.

Extension methods

Extension methods let you add methods to a type after the type is defined, i.e., they let you add new methods to closed classes. Let's consider an example from [Scala 3 Book - Extension Methods](#) about the calculation of the circumference of a circle.

In a file we may have:

```
case class Circle(x: Double, y: Double, radius: Double)
```

And in another:

```
extension (c: Circle)
  def circumference: Double = c.radius * math.Pi * 2
```

Then we could have this code in our main method:

```
val aCircle = Circle(2, 3, 5)
aCircle.circumference
```

We shall notice that such extension methods are letting us extend types without relying on helper classes, letting us elegantly invoke methods on instances of the closed classes or objects we are referring to.

Given and using keywords

`given` has different usages, but we are interested into its capability to automatically construct an instance of a certain type and make it available to contexts in which we are expecting an implicit parameter. To mark a parameter as implicit we have to use the keyword `using`. Doing so, a `given` variable with a matching type to the implicit parameter's one, if present in the scope, will be automatically injected in **at compile time**.

Lets consider an example taken from [Given and Using Clauses in Scala 3 - Rock the JVM](#) to better understand such concepts:

```
given personOrdering: Ordering[Person] with {
  override def compare(x: Person, y: Person): Int =
    x.surname.compareTo(y.surname)
}
```

Here we are creating an instance of `Ordering` for the `Person` type. Now lets consider the following function declaration:

```
def listPeople(persons: Seq[Person])(using ordering: Ordering[Person]) = ...
```

We can notice how the `ordering` parameter has been marked with the `using` keyword. Now, when we'll have to call such a function, it'll require us to just pass the `persons` parameter, since the implicit one (`ordering`) will be automatically injected:

```
// the compiler will inject the ordering at the end of following function call
listPeople(List(Person("Weasley", "Ron", 15), Person("Potter", "Harry", 15)))
```

This is a key functionality that, among with other Scala features, will let us achieve our goal in our thesis as we will see in the [Comparison between the languages for Pulumi and the advantages of Scala](#) chapter.

Functors and monads

Functors A Functor for a type provides the ability for its values to be "mapped over", i.e., apply a function that transforms the value contained in a given context while remembering its shape. We can represent all types that can be "mapped over" with `F`. `F` it's a type constructor: the type of its values becomes concrete when provided a type argument. Therefore we write it `F[_]`, hinting that the type `F` takes another type as argument. The definition of a generic `Functor` would thus be written as:

```
trait Functor[F[_]]:
  extension [A] (x: F[A])
    def map[B](f: A => B): F[B]
```

The instance `Functor` to `List` is:

```
given Functor[List] with
```

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

Here we can notice, as previously mentioned in the [Given and using keywords](#) paragraph, the `given` keyword is letting us create an instance of the `Functor` class for the `List` type.

Lets consider now the following usage of the `map` extension method on a list:

```
val l: List[Int] = List(1, 2, 3)
l.map(x => x * 2) // the output is List(2, 4, 6)
```

The `map` method is now directly used on `l`. It is available as an extension method since `l`'s type is `List[Int]` and a `given` instance for `Functor[List]`, which defines `map`, is in scope (thanks to the `given` keyword).

Monads A `Monad` provides the ability to sequence operations on values of a given type while maintaining the context of each operation. It is a generalization of the `Functor` concept, which allows us to apply a function to a value in a context. Such a generalization is letting us achieve a new level of expressiveness, that can be summarized as the chance to chain operations on a monadic value.

Like `Functors`, `Monads` can be represented by a type constructor `M[_]` that takes another type as an argument. The definition of a `Monad` is typically given in terms of two operations: `pure`, which lifts a value into the monadic context, and `flatMap`, which sequences operations on values in the context.

A generic `Monad` can be defined as follows:

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

And if we want to instantiate a `given` instance for the `List Monad` we shall write:

```
given Monad[List] with {
  def pure[A](a: A): List[A] = List(a)
  extension [A, B](xs: List[A])
    def flatMap[B](f: A => List[B]): List[B] = xs.flatMap(f)
}
```

To conclude consider this example on Lists:

```
val xs = List(1, 2, 3)
val ys = List(4, 5, 6)
xs.flatMap(x => ys.map(y => x + y)) // List(5, 6, 7, 6, 7, 8, 7, 8, 9)
```

The fact we got a `List[Int]` as return type from the `flatMap` operation is letting us the chance to apply immediately after another operation on such a value. Differently, if we use `map` on `xs`, we will obtain the following result:

```
val xs = List(1, 2, 3)
val ys = List(4, 5, 6)
xs.map(x => ys.map(y => x + y)) // List(List(5, 6, 7), List(6, 7, 8), List(7, 8, 9))
```

that is of type `List[List(Int)]`. With this new type, we might have troubles in chaining operations since the data structure has changed.

For comprehension

Scala offers a lightweight notation for expressing [sequence comprehensions](#). Comprehensions have the form `for (enumerators) yield e`, where `enumerators` refers to a semicolon-separated list of enumerators. An `enumerator` is either a generator which introduces new variables, or it is a filter. A comprehension evaluates the body `e` for each binding generated by the `enumerators` and returns a sequence of these values. The `for yield` construct in Scala requires two functions to be defined on the type we are iterating on to work: `map`, and `flatMap`. In fact, it is not a coincidence that we previously introduced the concept of `Functor` and `Monad` and `map` and `flatMap` functions. To better *comprehend* how the `for` comprehension concept works let's consider a brief example:

```
val xs = List("foo", "bar", "baz")
val ys = List("hello", "world")

for {
  x <- xs
  y <- ys
} yield s"$x $y"
// List("foo hello", "foo world", "bar hello", "bar world", "baz hello", "baz world")
```

We can notice how we are iterating on the two lists to generate a `List` of string as result, made of the combinations of the two lists' elements.

The `for yield` construct, in combination with the `Monads`, will be a key feature to improve our Scala syntactic sugar for the Pulumi APIs.

Capitolo 4

Study case: AWS EC2 resource generation with Pulumi

Generation of AWS EC2 resources with Pulumi to compare how various languages supported by Pulumi will differ in the infrastructure resources declaration

4.1 Amazon Web Services

AWS is a wide collection of services with many different purposes and characteristics including compute, storage, databases, analytics, networking, mobile, developer tools, management tools, IoT, security, and enterprise applications: on-demand, available in seconds, with pay-as-you-go pricing. Anyway, for the purpose of the thesis we'll focus only on the EC2 module.

4.1.1 AWS's EC2 module

EC2 provides scalable computing capacity in the Amazon Web Services (AWS) Cloud. Amazon EC2 eliminates the need to invest in hardware up front, so that the development and deployment of the applications is faster. Such a characteristics is a perfect fit for an IaC scenario.

4.2 Case study infrastructure overview

For the thesis, only few components of the vast EC2 module have been selected to create a working infrastructure.
The infrastructure

4.2.1 Components of the infrastructure

The infrastructure we created for the case study of the thesis is an AWS EC2 [VPC](#) hosting 3 private [subnets](#), 3 public subnets, an [internet gateway](#) to let the public subnets connect to the internet and a [routing table](#) to map the public subnets to the internet gateway. The architecture will look like the following:

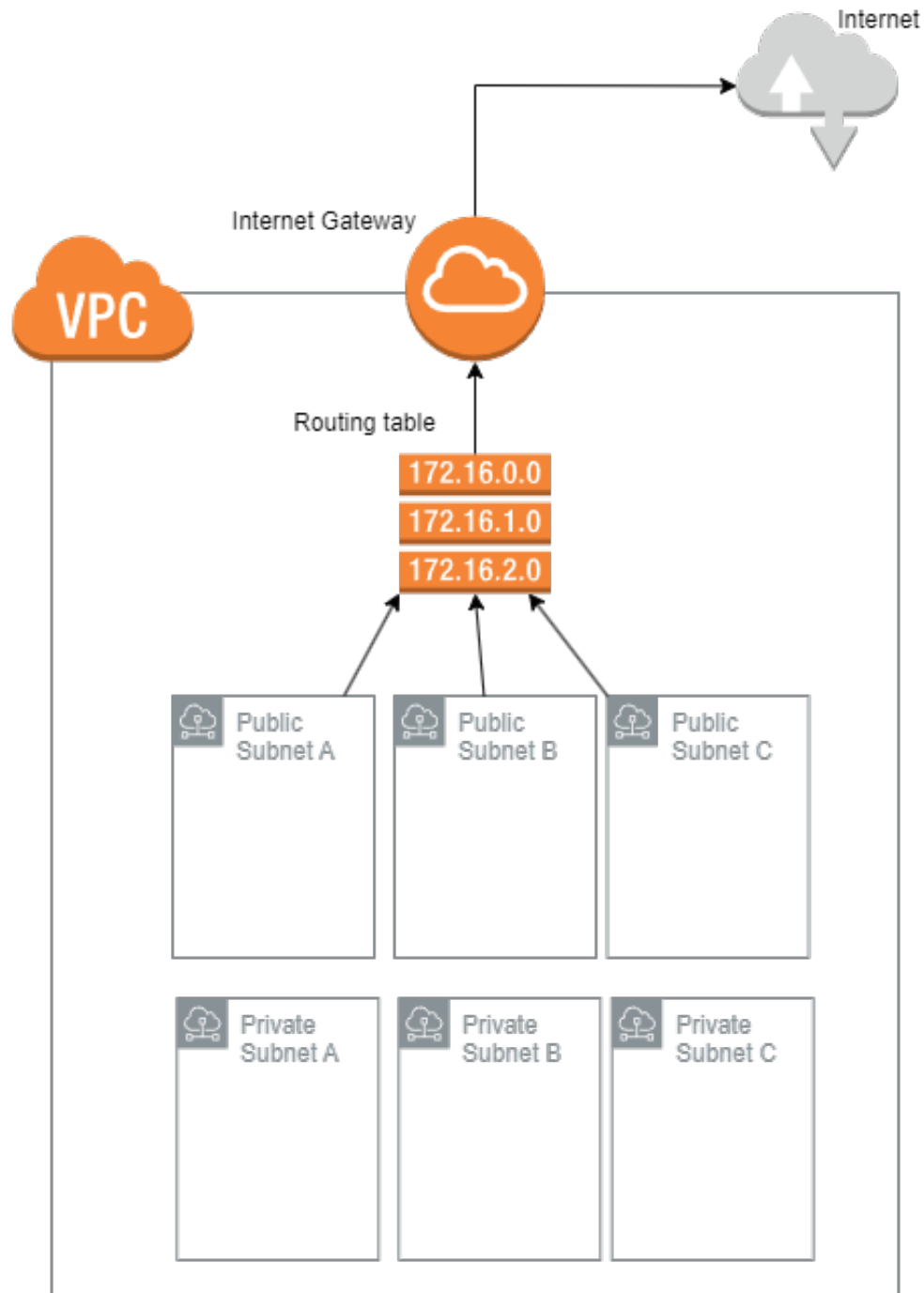


Image 4.1: Infrastructure Architecture

AWS is divided into regions, like us-east-1, eu-central-1, eu-south-1, etc. For the purpose of our thesis eu-south-1 as a region has been chosen. The servers of such a region are located in Milan. Each region can have multiple availability zones, eu-south-1 has 3 different availability zones, and because of this we chose to create 3 couples of public/private subnets (A-A, B-B, C-C). One couple on each availability zone. The purpose of the availability zones is mainly for robustness. If an availability zone becomes temporary unavailable, we can rely on the others to keep our services up.

VPC

The VPC is our "container" for all the other infrastructure resources. We'll define within it the subnets, the internet gateway and the routing table.

The most important setting of our AWS EC2 VPC is the CIDR (Classless Inter-Domain Routing) block. It represents the range of private IP addresses that the VPC can use to create and manage resources within the VPC.

CIDR The CIDR block is used to define the range of IP addresses that the VPC can use. In our case the CIDR block is 10.136.0.0/24, which means that the VPC has access to all IP addresses from 10.136.0.0 to 10.136.0.255. The 24 in the CIDR block is the prefix length, aka the subnet mask, that is used to identify the VPC. The remaining 8 bits of the IP address will be used to identify the hosts in the VPC. We'll assign a name as well to our VPC so that will be easier to recognize it when we'll inspect the AWS Management Console, that is the GUI version of the AWS CLI.

Subnet

The subnets will require the ID of the VPC and the CIDR block that defines their IP scope. For the subnets we'll use the following CIDR blocks:

- * Private Subnet A: 10.136.0.0/27
- * Private Subnet B: 10.136.0.32/27
- * Private Subnet C: 10.136.0.64/27
- * Public Subnet A: 10.136.0.96/27
- * Public Subnet B: 10.136.0.128/27
- * Public Subnet C: 10.136.0.160/27

3 of the 8 bits left out for the hosts identification have been used to identify the subnets. In fact we shall notice that now the subnet mask is not 24 anymore, but 27. Hence, we are left with 5 bits to identify the hosts within each subnet, giving us 32 possible IPs. From such IPs 2 are reserved for the network address and the broadcast address, so we have 30 possible IPs. We won't discuss this topic any further since it isn't essential for the final objective of the thesis.

Moreover, we'll define also the availability zone for each subnet.

InternetGateway

The definition of the internet gateway is actually quite straight forward. The mandatory parameter to assign is the ID of the VPC.

RouteTable

The definition of a route table is required in order to bind the public subnets to the internet gateway, so that they can send and receive data over the internet.

Here, along with the VPC ID, we assign the routes of such routing table. In order to do this we have to provide a CIDR and a target resource to which the packet will be forwarded to, that can be a subnet or the internet gateway in our case. The internet gateway is mapped with the CIDR block 0.0.0.0/0. Obviously also the ID of the internet gateway is required in order to bind it to the routing table.

In a nutshell this means that every packet not directed to a host within the VPC will be routed to the internet gateway and then to the internet.

The association of the public subnets to the routing table will be achieved using the *route table association* resource. Such a resource will require us to provide the id of the subnet and the id of the routing table to establish a connection. The private subnets will not be associated to such a routing table, since we want to keep them private. Differently, without explicitly associating them to a given routing table, AWS will automatically associate them to a default routing table that, being not bound to an internet gateway, will keep them private.

4.3 Typescript implementation of the case study

The first version of the implementation of the previously defined architecture is written using the Typescript APIs of Pulumi. The structure of the project, and this holds for the Java and Scala version as well, is trivial. We have a simple `index.ts` file that defines the entry point for our typescript project, and it is just a couple of lines long:

```
1 import { VPC } from './VPC/VPC';
2
3 const vpc = new MyVPC("Custom VPC");
```

The interesting part relies on the `MyVPC` class. Such a class extends the `ComponentResource` class of Pulumi. In our typescript implementation, we use the constructor of the user-defined `MyVPC` class to call all the class methods that are responsible for the creation of the resources. But this is just mentioned since the interesting part of the code are the actual methods that are responsible for the creation of the resources.

4.3.1 VPC resource creation

The code to the VPC resource creation API of Pulumi is done in this method of the `MyVPC` class:

```
1 protected createVPC() {
2   this.vpc = new Vpc("vpc\_res", {
```

```
3     cidrBlock: "10.136.0.0/24",
4     tags: {
5         Name: "myVPC-typescript",
6     },
7 },
8 {
9     parent: this,
10 });
11 }
```

`vpc_res` is the name that will be given by Pulumi at this resource once on the stack. We can notice how the various parameters are given in a declarative style within the curly brackets. Such a syntax is syntactic sugar for a Map definition. At line 8 the parent of this resource is set. With this specification, we are telling to the stack of Pulumi that the vpc resource `vpc_res` that we are creating is a child resource of the VPC resource identified by the `MyVPC` class.

4.3.2 Internet gateway creation

To create the internet gateway resource we can use the following code:

```
1 protected createIGW(){
2     this.gw = new InternetGateway("gw", {
3         vpcId: this.vpc?.id,
4         tags: {
5             Name: "myIGW-typescript",
6         },
7     },
8     {
9         parent: this.vpc,
10     });
11 }
```

It is really simple since it requires just the ID of the VPC in which it has to be created and optionally a name and a parent for the Pulumi's stack representation.

4.3.3 Subnets creation

To create the private and the public subnets we require a more complex logic. The function that has been used is `protected createAZsSubnets(isPvt: Boolean)`. It is called twice, once with a true value to create the private subnets, and another one with false to instantiate the public ones (and connect them to the routing table bound with the internet gateway).

In the body of the function, first we want to get all the availability zones present in the AWS region we are working on. To achieve this, we will use such a function `this.availableZones = aws.getAvailabilityZonesOutput()`.

Second, we want to create both a private and public subnet in each availability zone acquired with the aforementioned method. The `pulumi.all` function, in combination with the `apply` function will help us in achieving such a goal.

pulumi.all

`pulumi.all` is a utility function in Pulumi that allows you to combine multiple Outputs into a single Output that resolves to an array of the resolved values of each Output. So if we consider the following code:

```
1 pulumi.all([this.availableZones.names, this.vpc!.id])
```

Such a call returns us an `Output<[string[], string]>`. The array of strings is the list of the availability zones names, while the second string represents the ID of our VPC on AWS EC2. Now we have a new Output type that is more suitable to create the subnets based on our VPC ID, because the function `apply` is letting us "open" an `Output` value and access its content.

.apply

Lets extend our code in this way:

```
1 pulumi.all([this.availableZones.names, this.vpc!.id]).apply(([
    azNames, vpcId]) => {
2     // lambda's body to create the subnets here
3 })
```

The `apply` function is letting us access `Output<[string[], string]>` and apply some logic on the inner values.

The apply's lambda Now that we have the access to the list of availability zones and the VPC ID, we can iterate over the availability zones and create the subnets for our VPC. Here is the complete code of the function:

```
1 protected createAZsSubnets(isPvt: Boolean){
2     this.availableZones = aws.getAvailabilityZonesOutput()
3     pulumi.all([this.availableZones.names, this.vpc!.id]).apply(
4         ([azNames, vpcId]) => {
5             let i = 0
6             let listToPushInto: Subnet[] = Array<aws.ec2.Subnet>()
7             azNames.forEach(azName => {
8                 let compName = azName + (isPvt ? "-pvt" : "-pub") + "-
9                     subnet-typescript"
10                listToPushInto.push(new Subnet(compName, {
11                    vpcId: vpcId,
12                    availabilityZone: azName,
13                    cidrBlock: isPvt ? this.pvtSubnetsCidrs[i] : this.
14                        pubSubnetsCidrs[i],
15                    tags: {
16                        Name: compName,
17                    },
18                },
19                {
20                    parent: this.vpc
```

```

18     }
19     ));
20     i++;
21   });
22   if(!isPvt){
23     this.pubSubNets = listToPushInto
24     // attaching the route table to the pub sub nets
25     this.attachRouteTableToPubSubnets()
26   }
27   else
28     this.prvSubNets = listToPushInto
29   });
30 }

```

In the code we instantiate private or public subnets basing on the `isPvt` passed in the `createAZsSubnets`. We can notice that for the creation of a subnet we pass arguments such as `vpcId`, the availability zone name, the CIDR block, and a name (that is a tag) to better identify it on the stack.

Each newly created subnet is then pushed into the class field `this.prvSubNets` or `this.pubSubNets` (that are arrays of subnets), basing on the nature of the subnet. The `this.pubSubNets` will be used by the `this.attachRouteTableToPubSubnets()` function to bind the public subnets to the internet gateway through the routing table. The crucial point here is that in order to bind the public subnets to the routing table, we must call `this.attachRouteTableToPubSubnets()` as the last step in our `pulumi.all` function call. This ensures that we have all the necessary subnets to make the binding, since the call will be done at the completion of the creation of the subnets.

4.3.4 Routing table creation

This is the code to create the routing table resource:

```

1  protected createRouteTable() {
2    this.routeTable = new RouteTable("example", {
3      vpcId: this.vpc!.id,
4      routes: [
5        {
6          cidrBlock: "0.0.0.0/0",
7          gatewayId: this.gw!.id,
8        },
9      ],
10     tags: {
11       Name: "myRouteTable-typescript",
12     },
13   },
14   {
15     parent: this.vpc,
16   });
17 }

```

On top of the classic VPC ID we are assigning here the routes. As we mentioned before in the [RouteTable](#) paragraph, we are defining the route with CIDR 0.0.0.0/0 to

redirect all the packets coming from the public subnets, and not having as destination an IP internal at our VPC, to the internet gateway.

We are also giving a name to the routing table and assigning its parent.

4.3.5 Attaching the public subnets to the internet gateway

As we mentioned previously, we use the `this.attachRouteTableToPubSubnets()` function to attach the public subnets to the internet gateway. Here is the code of the function:

```

1 protected attachRouteTableToPubSubnets(){
2   let i = 0
3   this.pubSubNets.forEach(subNet => {
4     new aws.ec2.RouteTableAssociation(`${i}-
      routeTableAssociation-typescript`, {
5       subnetId: subNet.id,
6       routeTableId: this.routeTable!.id,
7     },
8     {
9       parent: this.vpc
10    });
11    i++
12  });
13 }
```

The code is quite straight forward. We are defining a new `RouteTableAssociation` AWS EC2 resource that requires just the id of the subnet and the id of the routing table to which we want to attach the subnet to.

4.4 Creating the resources with Pulumi

After having seen all the code to create the resources, we'll see what the Pulumi command `pulumi up` will do. The command checks if all the resources that we want to create have valid parameters and there are not circular dependencies among the resources on their creation. If everything is nice and neat, it will shows us the preview of the changes that we are about to get:

```

Previewing update (dev)

View Live: https://app.pulumi.com/Cis8/scala/dev/previews/c7370a40-7d38-41b7-820f-1329afafe1f2

  Type                                         Name                                         Plan
+ pulumi:pulumi:Stack                         scala-dev                                    create
+   └─ VPC                                   My Custom TS VPC                           create
+     └─ aws:ec2:Vpc                         my-vpc-main                               create
+       ├── aws:ec2:InternetGateway          gw                                          create
+       ├── aws:ec2:RouteTable               myRouteTable                             create
+       ├── aws:ec2:Subnet                   eu-south-1a-pub-subnet-typescript         create
+       ├── aws:ec2:Subnet                   eu-south-1a-pvt-subnet-typescript         create
+       ├── aws:ec2:Subnet                   eu-south-1b-pvt-subnet-typescript         create
+       ├── aws:ec2:Subnet                   eu-south-1b-pub-subnet-typescript         create
+       ├── aws:ec2:Subnet                   eu-south-1c-pub-subnet-typescript         create
+       ├── aws:ec2:Subnet                   eu-south-1c-pvt-subnet-typescript         create
+       ├── aws:ec2:RouteTableAssociation    0-assoc-typescript                       create
+       ├── aws:ec2:RouteTableAssociation    1-assoc-typescript                       create
+       └─ aws:ec2:RouteTableAssociation    2-assoc-typescript                       create

Resources:
  + 14 to create

Do you want to perform this update? [Use arrows to move, type to filter]
[experimental] yes, using Update Plans (https://pulumi.com/updateplans)
> yes
  no
  details

```

Image 4.2: pulumi up preview

If we press yes this is the output:

```

Do you want to perform this update? yes
Updating (dev)

View Live: https://app.pulumi.com/Cis8/scala/dev/updates/28

  Type                                         Name                                         Status
+ pulumi:pulumi:Stack                         scala-dev                                    created (0.94s)
+   └─ VPC                                   My Custom TS VPC                           created
+     └─ aws:ec2:Vpc                         my-vpc-main                               created (1s)
+       ├── aws:ec2:InternetGateway          gw                                          created (0.64s)
+       ├── aws:ec2:Subnet                   eu-south-1a-pvt-subnet-typescript         created (0.94s)
+       ├── aws:ec2:Subnet                   eu-south-1a-pub-subnet-typescript         created (1s)
+       ├── aws:ec2:Subnet                   eu-south-1b-pvt-subnet-typescript         created (1s)
+       ├── aws:ec2:Subnet                   eu-south-1b-pub-subnet-typescript         created (1s)
+       ├── aws:ec2:Subnet                   eu-south-1c-pvt-subnet-typescript         created (2s)
+       ├── aws:ec2:Subnet                   eu-south-1c-pub-subnet-typescript         created (2s)
+       ├── aws:ec2:RouteTable               myRouteTable                             created (2s)
+       ├── aws:ec2:RouteTableAssociation    0-assoc-typescript                       created (0.57s)
+       ├── aws:ec2:RouteTableAssociation    1-assoc-typescript                       created (0.86s)
+       └─ aws:ec2:RouteTableAssociation    2-assoc-typescript                       created (1s)

Resources:
  + 14 created

Duration: 22s

```

Image 4.3: pulumi up confirmed

We can notice how the resources created are nested into each other thanks to the parent option that we used. This is helping us in keeping our resources on the stack

nicely ordered and tied up.

4.5 Destroying the resources with Pulumi

Now let's use the `pulumi destroy` command to destroy the resources on our Pulumi's stack. The preview of the changes that we are about to get look like this:

```

Previewing destroy (dev)

View Live: https://app.pulumi.com/Cis8/scala/dev/previews/b9e0652e-9143-4a31-b9cc-f24cbc752bf4

  Type                                         Name                                         Plan
- pulumi:pulumi:Stack                         scala-dev                                     delete
-   └─ VPC                                    My Custom TS VPC                           delete
-     └─ aws:ec2:Vpc                          my-vpc-main                                delete
-       ├── aws:ec2:RouteTableAssociation      2-assoc-typescript                         delete
-       ├── aws:ec2:RouteTableAssociation      0-assoc-typescript                         delete
-       ├── aws:ec2:RouteTableAssociation      1-assoc-typescript                         delete
-       ├── aws:ec2:RouteTable                myRouteTable                              delete
-       ├── aws:ec2:Subnet                    eu-south-1b-pvt-subnet-typescript          delete
-       ├── aws:ec2:Subnet                    eu-south-1a-pub-subnet-typescript          delete
-       ├── aws:ec2:Subnet                    eu-south-1b-pub-subnet-typescript          delete
-       ├── aws:ec2:InternetGateway           gw                                           delete
-       ├── aws:ec2:Subnet                    eu-south-1c-pub-subnet-typescript          delete
-       ├── aws:ec2:Subnet                    eu-south-1c-pvt-subnet-typescript          delete
-       └─ aws:ec2:Subnet                    eu-south-1a-pvt-subnet-typescript          delete

Resources:
- 14 to delete

Do you want to perform this destroy? [Use arrows to move, type to filter]
> yes
  no
  details
  
```

Image 4.4: pulumi destroy preview

If we confirm the changes this is the result:

```

Do you want to perform this destroy? yes
Destroying (dev)

View Live: https://app.pulumi.com/Cis8/scala/dev/updates/29

  Type                                         Name                                         Status
- pulumi:pulumi:Stack                         scala-dev                                     deleted
-   └─ VPC                                    My Custom TS VPC                           deleted
-     └─ aws:ec2:Vpc                          my-vpc-main                                deleted (0.91s)
-       ├── aws:ec2:RouteTableAssociation      2-assoc-typescript                         deleted (0.55s)
-       ├── aws:ec2:RouteTableAssociation      0-assoc-typescript                         deleted (0.73s)
-       ├── aws:ec2:RouteTableAssociation      1-assoc-typescript                         deleted (1s)
-       ├── aws:ec2:RouteTable                myRouteTable                              deleted (0.68s)
-       ├── aws:ec2:InternetGateway           gw                                           deleted (0.62s)
-       ├── aws:ec2:Subnet                    eu-south-1c-pub-subnet-typescript          deleted (0.98s)
-       ├── aws:ec2:Subnet                    eu-south-1b-pub-subnet-typescript          deleted (1s)
-       ├── aws:ec2:Subnet                    eu-south-1a-pvt-subnet-typescript          deleted (1s)
-       ├── aws:ec2:Subnet                    eu-south-1b-pvt-subnet-typescript          deleted (1s)
-       ├── aws:ec2:Subnet                    eu-south-1a-pub-subnet-typescript          deleted (2s)
-       └─ aws:ec2:Subnet                    eu-south-1c-pvt-subnet-typescript          deleted (2s)

Resources:
- 14 deleted

Duration: 10s

The resources in the stack have been deleted, but the history and configuration associated with the stack are still maintained.
If you want to remove the stack completely, run `pulumi stack rm dev`.
  
```


Image 4.5: pulumi destroy confirmed

4.6 My Scala implementation of the case study

Since Scala is not supported by Pulumi, I had to implement it on my own. The Pulumi team is clear on the official way to add the support of a new language for Pulumi, and the procedure is long and laborious, too laborious for a master thesis. The full procedure can be found on [New Language Bring Up](#).

The idea behind the adopted solution is to exploit the compatibility of Scala with the Java libraries to write custom syntactic sugar. Such syntactic sugar will be based on the Pulumi Java's APIs and will provide to the user cool constructs to write readable and expressive code to interact with Pulumi.

The steps of the work done have been the followings:

1. manually write the *sugarized* functions to create the Pulumi resources using Scala
2. use such functions to recreate the Stack obtained with the typescript solution shown before in the [Typescript implementation of the case study](#) section
3. create an automatic code generator for our syntactic sugar functions, so that we can quickly create a library for Scala's Pulumi APIs
4. try to recreate the stack with the automatically generated code

Obviously, the third step is quite wide, and if fact with my work I had the time to generate only the functions for a part of the Java's Pulumi APIs for the AWS EC2 module.

Now the just defined steps will more accurately presented.

4.6.1 Structure of the Java APIs for the constructors of the resources in Pulumi

To understand the syntactic sugar functions that I defined, let's first consider the general structure of the Java APIs for the constructors of the resources.

The constructor of a resource, in general accepts a name and an instance of the corresponding `Args` class of the resource we are creating. Lets consider for example the `Vpc` resource. In Java, to instantiate such a resource we'd call:

```
1 protected Vpc vpc = new Vpc("my-vpc-java", VpcArgs.builder()  
2     .cidrBlock("10.136.0.0/24")  
3     .tags(Map.of("Name", "main"))  
4     .build(),  
5         CustomResourceOptions.builder()  
6             .parent(this)  
7             .build());
```

We can (hardly) see that along with the name to be assigned to the vpc "my-vpc-java", a `VpcArgs` builder and a `CustomResourceOptions` builder are passed by. These builders

will create an instance of the respective classes that will be used to set respectively the parameters and the parent of the Vpc resource. So, for our case study we need to consider: the name to be assigned at the created resource on the Pulumi stack, the builder of the respective `Args` class of the resource, and the `CustomResourceOptions` builder.

4.6.2 Syntactic sugar

Our syntactic sugar is split in 2 categories of functions. The first is about the functions that represent the constructors of the resources. The second is for the methods available within the builders of the `Args` classes and for the `CustomResourceOptions` builder functions. The idea to create a resource is to call the *sugarized* function that represent the constructor of that resource, and then call the Builder methods to assign the various parameters to the resource.

Vpc creation

This is how a Vpc resource can be created with my syntactic sugar:

```
1 val myVpc: Vpc = vpc("scala-main") ({
2   cidrBlock("10.136.0.0/24")
3   tags("Name" -> "myVpcScala")
4 },{
5   parent(this)
6 })
```

At line 1, the `vpc` function is the actual *sugarized* function for the VPC resource constructor. In fact we can notice that we have a curried function. The first parenthesis is taking the parameter for the resource name on the Pulumi stack, while the second one is containing two lambdas (defined by the curly brackets). These lambdas are respectively used to call all the builder methods of the `VpcArgs` class and the ones for the `CustomResourceOptions`.

We can notice that we didn't explicitly defined an instance of the builders of such classes. We will soon see how we achieved such a syntactic sugar trick.

The `cidrBlock` and the `tags` methods are the generated methods for builder of the `VpcArgs` class.

The `parent` method instead is the generated method for the builder of the `CustomResourceOptions` class.

Moreover, we can also notice that inside tags, that expects a `Map[String, String]` type, the instantiation of a `Map[String, String]` containing a single elements isn't required. This other trick will be explained later as well.

Internet gateway creation

Much similar to the VPC resource, we have this code for the internet gateway creation:

```
1 val myIGW: InternetGateway = internetGateway("gw") ({
2   vpcId(myVpc.getId())
3   tags("Name" -> "myIGWScala")
4 },{
5   parent(myVpc)
```

```
6 })
```

The code won't be commented since is analogous to the VPC case.

Routing table creation

The code to create a routing table:

```
1 val myRouteTable = routeTable("myRouteTable") ({
2   vpcId(myVpc.getId())
3   routes(
4     routeTableRouteArgs(){
5       cidrBlock("0.0.0.0/0")
6       gatewayId(myIGW.getId())
7     })
8   tags("Name" -> "myRouteTableScala")
9 },{
10  parent(myVpc)
11 })
```

The only thing that is worth to mention here is that the `routes` function, at line 3, expects a `List[RouteTableRouteArgs]`, but we are providing only a `RouteTableRouteArgs`. As for the case of the `Map[String, String]` with the `parent` method mentioned above, the same trick has been used to provide syntactic sugar that lifts us from the need of instantiate a singleton `List[RouteTableRouteArgs]` manually.

Subnets creation

Much different from the other resources is the function to create the subnets:

```
1 def createAzSubnets(isPvt: Boolean) =
2   availabilityZonesNames().map((az: GetAvailabilityZonesResult) =>
3     for
4       (name, cidr) <- az.names().zip(if isPvt then pvtSubnetsCidrs else
5         pubSubnetsCidrs)
6     yield
7       val compName = name + "-" + (if isPvt then "pvt" else "pub") + "-
8         subnet-scala"
9       subnet(compName) ({
10        vpcId(myVpc.getId())
11        availabilityZone(name)
12        cidrBlock(cidr)
13        tags("Name" -> compName)
14      },{
15        parent(myVpc)
16      })
17   )
```

Syntactic sugar for the builders

Syntactic sugar for the constructors of the resources

Functor and Monads for the Output type

4.6.3 Automatic code generation for the syntactic sugar

What Pulumi asks for the official support of a new Language

Raw automatic code generation with JavaParser

Usage of the generated code as a library

Possible future improvements for the code generation with Scalameta

Capitolo 5

Comparison between the languages for Pulumì and the advantages of Scala

Here all the advantages detected while using Scala for our study case will be presented, along with further considerations and comparisons about the pros and the cons in using a language instead of another one.

5.1 Typescript solution observations

5.1.1 Advantages of using Pulumi's Typescript APIs

Quite readable code

5.1.2 Disadvantages of using Pulumi's Typescript APIs

Poor tools to act on groups of Outputs

5.2 Java solution observations

5.2.1 Advantages of using Pulumi's Java APIs

5.2.2 Disadvantages of using Pulumi's Java APIs

Verbose code

5.3 My Scala solution observations

5.3.1 Advantages of using my Scala syntactic sugar

Very concise code

Very readable and elegant code

More powerful constructs thanks to the for-comprehension and the monads to act on groups of Outputs

5.3.2 Disadvantages of using my Scala syntactic sugar

Partial solution, not all the corner cases have been considered

5.4 Final thoughts on the Scala solution

Bibliography

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