

Politehnica University Timișoara

Faculty of Automation and Computers

**Department of Computers and Information Technology**

**Benchmark Evaluation of Scale-Up and Scale-Out Techniques on a Functional Programming Based Microservice**

Master Thesis

*Candidate:*

**Arnold Attila HIGYED**

*Supervisor:*

Lect.dr.eng. **Alexandru TOPÎRCEANU**

Timișoara

2020

**Contents**

[1. Introduction 6](#_Toc40616716)

[1.1. Context 6](#_Toc40616717)

[1.2. Problem statement 6](#_Toc40616718)

[1.3. Motivation 6](#_Toc40616719)

[2. State of the art 7](#_Toc40616720)

[2.1. ? 7](#_Toc40616721)

[3. Technical background 8](#_Toc40616722)

[3.1. Scala 8](#_Toc40616723)

[3.2. sbt 9](#_Toc40616724)

[3.3. Play2 9](#_Toc40616725)

[3.4. Akka 9](#_Toc40616726)

[3.5. Cats 10](#_Toc40616727)

[3.6. OR-Tools 10](#_Toc40616728)

[3.7. Docker 10](#_Toc40616729)

[3.8. Gatling 11](#_Toc40616730)

[4. Implementation 12](#_Toc40616731)

[4.1. Business logic 12](#_Toc40616732)

[4.2. System architecture 16](#_Toc40616733)

[4.3. Build and deployment 16](#_Toc40616734)

[4.4. Test scenarios 16](#_Toc40616735)

[4.5. Resource limitation 16](#_Toc40616736)

[5. Results 17](#_Toc40616737)

[6. Conclusions 18](#_Toc40616738)

[6.1. Achievements 18](#_Toc40616739)

[6.2. State of the art comparison 18](#_Toc40616740)

[6.3. Future work 18](#_Toc40616741)

[References 19](#_Toc40616742)

[Appendix 20](#_Toc40616743)

[A – … 20](#_Toc40616744)

[B – … 20](#_Toc40616745)

**List of figures**

[Figure 1: Planning application architecture 13](#_Toc41149067)

[Figure 2: Problems API 15](file:///C:\Users\arnold\Downloads\Master-Thesis\doc\Thesis.docx#_Toc41149068)

[Figure 3: Solutions API 16](file:///C:\Users\arnold\Downloads\Master-Thesis\doc\Thesis.docx#_Toc41149069)

**List of tables**

**No table of figures entries found.**

# Introduction

When data grows too large, the tendency is to either scale-out, by adding nodes to the system or to scale-up, by adding resources to a single node. It is well known that these techniques come with different complexities and bottlenecks, changing significantly the architecture, the API and the business logic of the whole application. This study proposes to capture how these scaling methods perform under different loads, and to define a common boundary between the mentioned scaling practices. It is important to establish whether or not these techniques should be applied separately or altogether, in which for the last case is essential to elaborate a concrete configuration on how the scaling entities should be managed and how the resource allocation should be done. Therefore, this work relies on a microservice architecture, where one service is taken and it is being deployed under different scaling contexts in an isolated environment. Therefore, the resulting measurements and comparisons can give us a valuable insight on how future microservices should be designed and deployed from the very beginning. A service is valuable for the client until the requirements are met, scalability being one of its essential capabilities in the cloud-computing era.

## Context

.

## Problem statement

.

## Motivation

.

# State of the art

.

## ?

.

# Technical background

In this section we mention the technologies and important concepts with which the project implementation and testing was realized. Therefore, it is important to understand the reason behind each component and functionality in order to interpret the final results. Shortly, the programming language in which the microservice was written is Scala, providing support for functional programming. As build tool, sbt was preferred, since it comes with a lot of features and helpers for the Scala ecosystem. Play2 was used for the RESTful API, while Akka for the scale-up technique implemented with the actor model. Cats is a library which provides abstractions for functional programming. For the realization of the business logic, Google OR-Tools represented the most efficient choice, which is a fast and portable software suite for solving combinatorial optimization problems. Docker enabled to deploy the application in containers and last but not least, Gatling allowed to perform load testing on various scaling scenarios of the planning app.

## Scala

The name Scala stands for “scalable language”. The language is so named since it was designed to grow with the demand of its users. It is general-purpose programming language, which gives the ability to its users to write small scripts or to build large systems. Its strength as a language are relieved when designing large systems and frameworks of reusable components [3.1].

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].

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 [3.1]. Singleton objects provide a convenient way to group functions that aren’t members of a class. Furthermore, Scala’s notion of pattern matching naturally extends to the processing of XML data with the help of right-ignoring sequence patterns, by way of general extension via extractor objects. In this context, for comprehensions are useful for formulating queries. These features make Scala ideal for developing applications like web services [3.2].

Scala’s expressive type system enforces, at compile-time, that abstractions are used in a safe and coherent manner. In particular, the type system supports [3.2]:

* Generic classes;
* Variance annotations;
* Upper and lower type bounds;
* Inner classes and abstract type members as object members;
* Compound types;
* Explicitly typed self-references;
* Implicit parameters and conversions;
* Polymorphic methods;

Type inference means the user is not required to annotate code with redundant type information. In combination, these features provide a powerful basis for the safe reuse of programming abstractions and for the type-safe extension of software [3.2].

Scala is designed to interoperate well with the popular Java Runtime Environment (JRE). In particular, the interaction with the mainstream object-oriented Java programming language is as seamless as possible. Newer Java features like SAMs, lambdas, annotations, and generics have direct analogues in Scala. Those Scala features without Java analogues, such as default and named parameters, compile as closely to Java as reasonably possible. Scala has the same compilation model as Java and allows access to thousands of existing high-quality libraries [3.2].

## sbt

The simple build tool (sbt) is used for building Java and Scala projects. Its purpose is to allow users to skillfully perform the basics of building and packaging an application. It gives the developer the freedom to customize as need demands. sbt, at its core, provides a parallel execution engine and configuration system that allow its users to design an efficient and robust script to build the desired software. sbt aims to be consistent in the basic concepts in order to facilitate the creative process. sbt is a highly interactive tool, meant to be used during all stages of the development. It provides interactive help and autocomplete for most services and promotes a type of auto-discovery for builds [3.3]. Its main features are [3.4]:

* Little or no configuration required for simple projects;
* Scala-based build definition that can use the full flexibility of Scala code;
* Accurate incremental recompilation using information extracted from the compiler;
* Continuous compilation and testing with triggered execution;
* Packages and publishes jars;
* Generates documentation with scaladoc;
* Supports mixed Scala/Java projects;
* Supports testing with ScalaCheck, specs, and ScalaTest. JUnit is supported by a plugin;
* Starts the Scala REPL with project classes and dependencies on the classpath;
* Modularization supported with sub-projects;
* External project support;
* Parallel task execution, including parallel test execution;
* Library management support that include inline declarations, external Ivy or Maven configuration files, or manual management;

## Play2

Play is a high-productivity framework for building a wide range of different types of web applications. These are applications that receive requests for data and functionality over HTTP(s). Play aims to make the construction of such applications simple, flexible and intuitive. It incorporates an integrated HTTP Server. It also incorporates a templating framework for the creation of websites and a RESTful web service API for the creation of a service-based implementation. It exploits the facilities within the Scala ecosystem, such as Akka, to ensure that the applications developed are scalable and perform well [3.5].

## Akka

Akka is a Scala-based toolkit that simplifies developing concurrent distributed applications. Perfect for high-volume applications that need to scale rapidly, Akka is an efficient foundation for event-driven systems that want to scale elastically up and out on demand, both on multi-core processors and across server nodes. The framework has at its roots the actor model concept in order to raise the abstraction level that decouples the business logic from the low-level constructs of threads, locks and non-blocking I/O. The framework provides the following features [3.6]:

* Concurrency;
* Scalability;
* Fault tolerance;
* Event-driven architecture;
* Transaction support;
* Location transparency;
* Scala/Java APIs;

## Cats

Cats is a library which provides abstractions for functional programming in the Scala programming language. The name is a playful shortening of the word category. Scala supports both object-oriented and functional programming, and this is reflected in the hybrid approach of the standard library. Cats strives to provide functional programming abstractions that are core, binary compatible, modular, approachable and efficient. A broader goal of the mentioned library is to provide a foundation for an ecosystem of pure and typeful libraries [3.7].

## OR-Tools

Google's Operations Research tools is an open source software for combinatorial optimization, which seeks to find the best solution to a problem out of a very large set of possible solutions. OR-Tools includes solvers for [3.8]:

* Constraint programming: a set of techniques for finding feasible solutions to a problem expressed as constraints;
* Linear and mixed-integer programming: the Glop linear optimizer finds the optimal value of a linear objective function, given a set of linear inequalities as constraints;
* Vehicle routing: a specialized library for identifying the best vehicle routes given in constraints;
* Graph algorithms: code for finding shortest paths in graphs, min and max cost flows, and linear sum assignments;

In most cases, problems like these have a vast number of possible solutions, too many for a computer to search them all. To overcome this, OR-Tools uses state-of-the-art algorithms to narrow down the variance domain of the problem, in order to find optimal or close to optimal solutions [3.8].

## Docker

Docker is a software platform for building applications based on containers. Containers are small and lightweight execution environments that make shared use of the operating system kernel, but otherwise run in isolation from one another. While containers as a concept have been around for some time, Docker is an open source project launched in 2013. It helped to popularize the technology and drove the trend towards containerization and microservices in software development, that has come to be known as cloud-native development [3.9].

Docker brings the following advantages [3.9]:

* Portability: once a containerized application tested, it can be deployed to any other system where Docker is running;
* Performance: virtual machines are an alternative to containers. The fact that containers do not contain an operating system, whereas virtual machines do, means that containers have much smaller footprints than virtual machines. As a result, containers are faster to create, and quicker to start;
* Agility: the portability and performance benefits offered by containers can help its users to make the development process more agile and responsive;
* Isolation: a container that contains an application also includes the relevant versions of any supporting software that the application requires. If other containers contain applications that require different versions of the same supporting software, that isn't a problem because the different containers are totally independent of one other;
* Scalability: when using multiple containers there are a range of management options for achieving horizontal scaling;

## Gatling

Gatling is a highly capable load testing tool. It is designed for ease of use, maintainability and high performance. It takes advantage of its asynchronous architecture, which allows it to implement virtual users as messages instead of dedicated threads, making running numerous simultaneous virtual users less resource heavy than other solutions. Gatling tests are called simulations. They are written in Scala-files and each class represents its own load simulation. We can assign properties such as the URL, parameters and headers that are needed for the HTTP requests into variables using Gatling HTTP protocol builder [3.10].

# Implementation

In the first part of this section the business logic is presented with the request and response API of the microservice. These are accompanied by the validation tests that also serve as examples. Further on the architecture of the microservice is detailed, explaining each package and their scope. Next the build with sbt and the deployment with Docker is discussed, tearing down the whole process in small steps. After that the load test requests and scenarios are described. The proposed scenarios are benchmarked with different parameters generating the final results. For that, the reports obtained by the Gatling framework are explained and interpreted. Last but not least, the resource limitation measures are highlighted. They are meant to achieve an isolated environment, making each test execution encapsulated.

## Business logic

The implemented microservice serves as the solver module of a planning application. Mainly a general planning application is composed by the following parts:

* An input module, which allows the user to input its preferences. This is usually embedded in the frontend;
* A data loader or fetcher, which gathers all the relevant data to construct the search context from one database or more;
* A solver that is responsible for solving the search context guided by the given user preferences;
* An aggregator that communicates and orchestrates the data loader and the solver, performing the necessary transformations and conversions of data;
* An output module, which is embedded alongside with the input module, displaying the final results to the user;

These modules were identified as a result of the separation of concerns principle and as of need of scaling. Figure x1 helps for a better visualization of the whole architecture. As it can be seen each service performs on its own a specific task, being independent of other modules. This provides flexibility to the whole application, since individual parts can be scaled horizontally as the demand requires. Obtaining such separation also brings the benefit of not needing to scale the entire infrastructure if one element fails to cope with an increased load.

Further on the solver service is getting detailed as a matter of its functionality and its input and output APIs. From the data flow perspective, the solver receives data that is already transformed, converted and processed by a higher level microservice, meaning that the only step that it’s left is to solve the given search context. The search context naming is given by the fact that the data is composed of the user’s preferences and the relevant information loaded from the database, forming a so-called context of the search. The communication between the microservices is done by a RESTful API. The solver module accepts a POST operation on the route ‘/solve’ having as an input a ‘Problems’ json and as an output s ‘Solutions’ json. Figure x2 and Figure 3x shows the ‘Problems’, respective the ‘Solutions’ API. On the right of each field there is a comment, that specifies if the field whether or not is optional. The solver engine supports an input with the lack of ‘constraints’ and ‘costs’, solving a general planification problem. The ‘searchInterval’ field helps to normalize the solutions costs when performing variant scaling scenarios. For example, when a user wants to distribute some operations over one or ten days, then the solutions cost will vary in function of the distribution interval. The horizontal and vertical scaling methods must output the same results, whether a result is returned as a whole or aggregated from chunks.

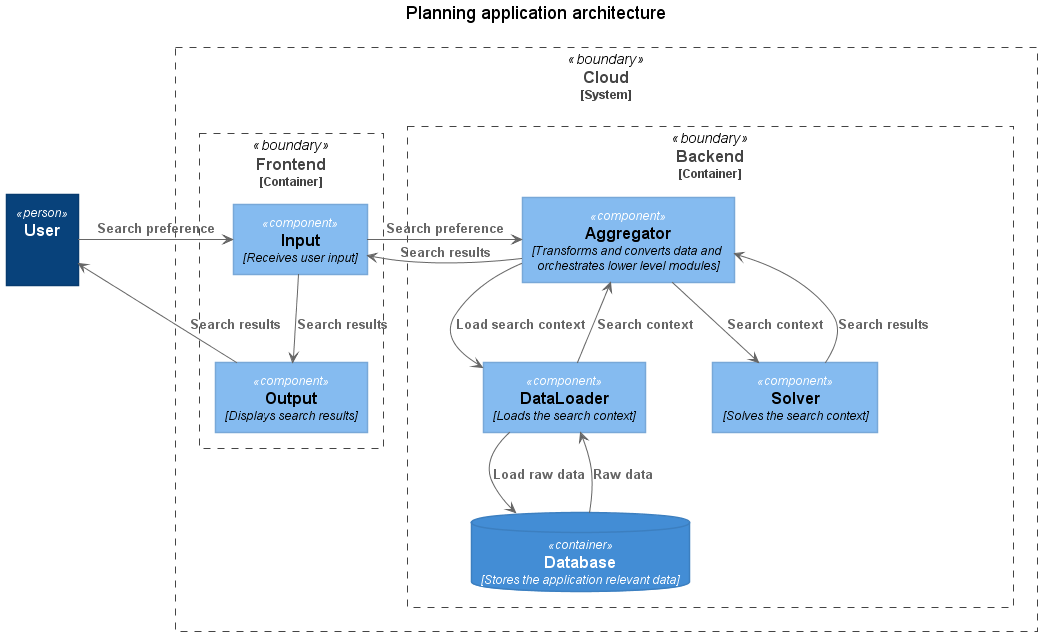


Figure 1: Planning application architecture

T



Figure 2: Problems API

.

.

Figure 3: Solutions API

## System architecture

+ packages

## Build and deployment

+ sbt, config and docker

## Test scenarios

+ gatling and diagram

## Resource limitation

+ docker, container and jvm

# Results

.

# Conclusions

.

## Achievements

.

## State of the art comparison

.

## Future work

.

# References

1. 3.1 Odersky, Martin, Lex Spoon, and Bill Venners. Programming in scala. Artima Inc, 2008.
2. 3.2 Scala documentation: <https://www.scala-lang.org/>
3. 3.3 Suereth, Josh, and Matthew Farwell. SBT in Action: The simple Scala build tool. Manning Publications Co., 2015.
4. 3.4 sbt documentation: <https://www.scala-sbt.org/1.x/docs/>
5. 3.5 Hunt, John. "Play framework." A Beginner's Guide to Scala, Object Orientation and Functional Programming. Springer, Cham, 2018. 431-446.
6. 3.6 Roestenburg, Raymond, Rob Bakker, and Rob Williams. Akka in action. Manning Publications Co., 2015.
7. 3.7 Cats documentation: <https://typelevel.org/cats/>
8. 3.8 Google OR-Tools documentation: <https://developers.google.com/optimization/introduction/overview>
9. 3.9 Anderson, Charles. "Docker [software engineering]." IEEE Software 32.3 (2015): 102-c3.
10. 3.10 Gatling documentation: <https://gatling.io/docs/current>

# Appendix

# A – …

# B – …