

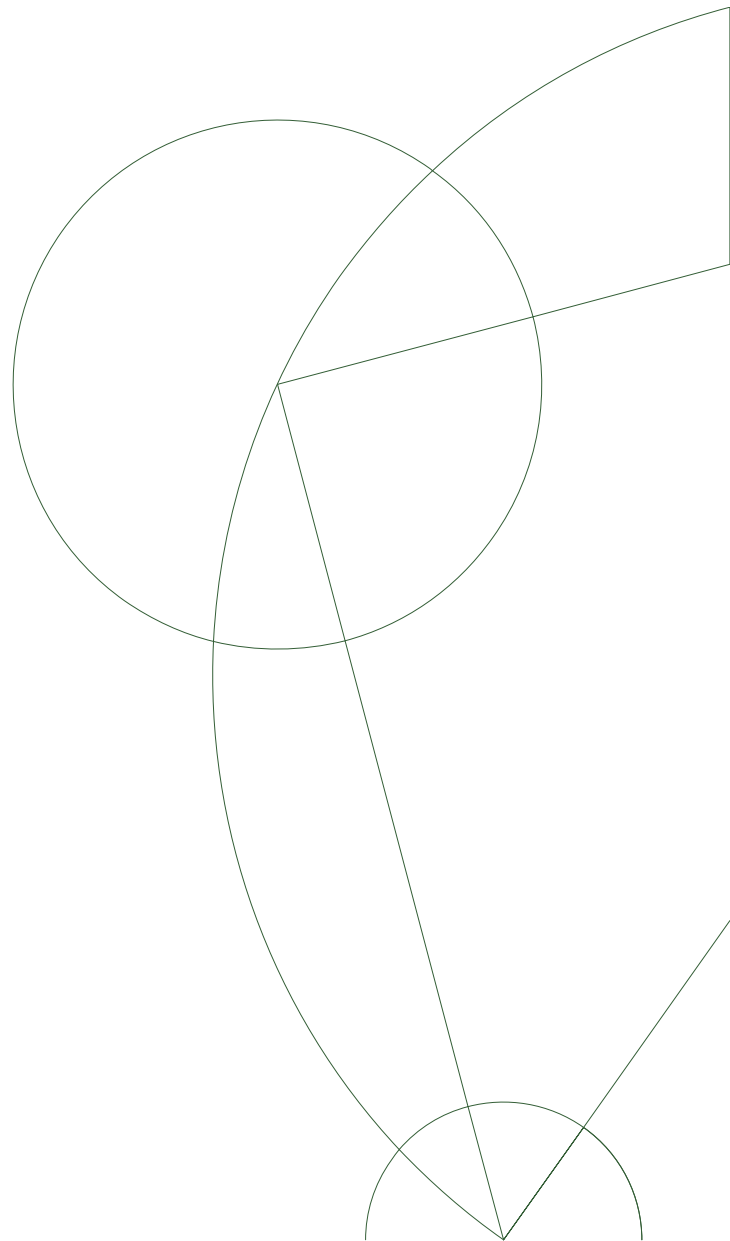


MSc thesis

Søren Lund Hess-Petersen - pws412

Using Model-Based testing to test MCP Instance-Specifications

Academic advisor: Michael Kirkedal Thomsen
<m.kirkedal@di.ku.dk>
Submitted: December 5, 2019



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Søren Lund Hess-Petersen - pws412

DIKU, Department of Computer Science,
University of Copenhagen, Denmark

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Author: Søren Lund Hess-Petersen - pws412

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University of Copenhagen, Denmark

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<m.kirkedal@di.ku.dk>

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Abstract

Dansk Resumé

Preface

This Master's thesis is submitted in fulfilment of the master programme in Computer Science at the University of Copenhagen for Søren Lund Hess-Petersen.

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Introduction

1

The Maritime Connectivity Platform [1] (MCP) is, as the name suggests a platform that connects maritime services, functioning as a common infrastructure by offering safe and reliable information exchange between various maritime actors. A particular way of utilizing this is that a user of the MCP is able to develop his or her own software, and distribute it across the world. Such digital maritime components, however needs to be thoroughly tested, which often is not adequately done through simple unit testing. Thus, software components, distributed through the MCP need a thorough test-suite, for which the obvious solution is to implement model-based testing. The MCP has provided specifications, which describe rules that software needs to adhere to. These specifications will be used to create the model, that will verify the software. The specifications are provided in `xml`-format, and are, as of now, not used in any formal degree. Ideally, the provided specifications should be used to automatically generate models, which can be used to verify that a certain piece of software adheres to the specification.

1.1 Description of the Project

In this project, QuickCheck [2] will be utilized in order to verify that instances fulfills the requirements set by specifications in the MCP. QuickCheck is a library, which allows for model-based testing of software. Originally, QuickCheck was written in Haskell, but has since been extended to more than 50 programming languages. The idea behind this method is, as the term *model*-based testing suggests, to create models which describe the properties that the test-cases need to reflect. This means that in stead of conducting unit-tests, the model should reflect what needs to happen with an arbitrary input- and function-combination, and ideally catch every special case that either has not been accounted for in the model or in the analysed software. Once an accurate model is created further testing can be streamlined, as a simple test can affirm an entire aspect of the tested software, in stead of just *one* particular example. The goal of the project is to create an automatic test suite for the MCP, which performs better than a unit-based test suite. In the long run, such a test suite has the capacity to increase reliability, efficiency

and ultimately make way for better distributed, and more uniformly created software components in the Maritime Connectivity Platform.

1.2 Learning Objectives

- Utilizing QuickCheck in creating viable models, that describe the specifications, provided in MCP specifications.
- Interpreting MCP specifications in order to generate relevant tests.
- Parsing MCP specifications in order to generate relevant models.
- Applying property-based testing of functions and specifications in a maritime environment.

1.3 Scope

1.4 Limitations

1.5 Structure

- **Chapter 2: Background**
This chapter describes the techniques, theories, and components that are used or analyzed throughout the thesis.
- **Chapter 3: Analysis**
- **Chapter 4: Work/Design**
- **Chapter 5: Results**
- **Chapter 6: Discussion**
- **Chapter 7: Conclusion**

Background

2

2.1 The Maritime Connectivity Platform

The Maritime Connectivity Platform (MCP), which is formally known as the Maritime Cloud is a platform, developed by EfficienSea2 [3], which is led by the Danish Maritime Consortium. MCP is a communication framework, that is to ensure efficient, reliable and secure communication, and exchange of information in the maritime sector. The goal of the platform is to connect maritime stakeholders with maritime information services. A high-level diagram, describing the structure of the MCP can be seen in Figure 2.1. Here it is shown that maritime stakeholders are connected with the maritime services through the Identity Registry, the Service Registry and the Messaging Service. The diagram also shows that the platform is open source and provides contextual geolocated information to the stakeholders and services.

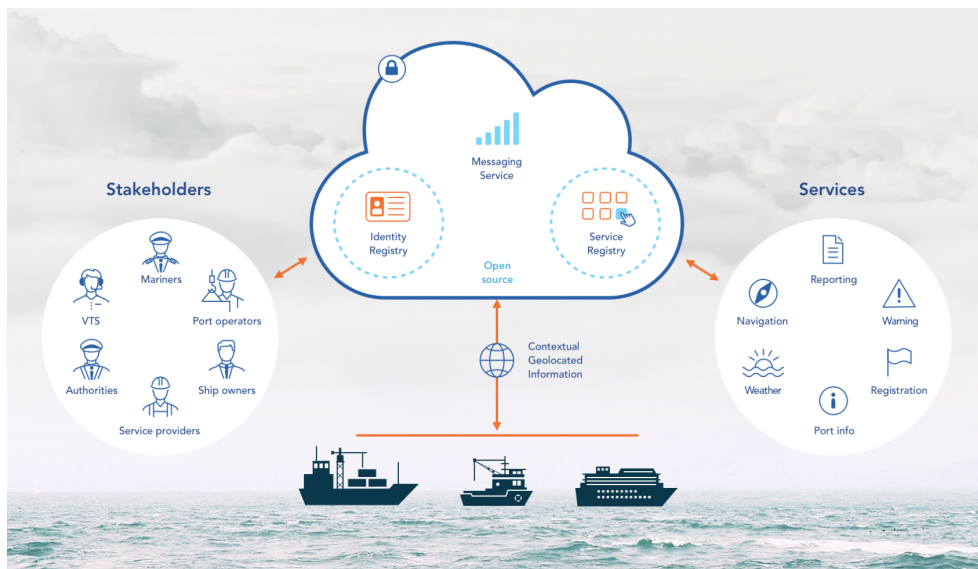


Figure 2.1: Diagram, describing the structure of MCP. [3]

2.1.1 Identity Registry

Here the relevant information regarding maritime stakeholders are stored. This information needs to be authorized and stored at a safe location in order for the security of the MCP to be sufficient. The Identity Registry on the MCP is equivalent to the Central Person Registry of a country. The Identity Registry is vital to the MCP in it ensures the solution's authenticity, integrity, and confidentiality. Maritime stakeholders are, through the Identity Registry provided with a single login to all Maritime Services. [3]

2.1.2 Service Registry

The Service Registry acts to Maritime Services as the Identity Registry acts to the Maritime Stakeholders. Here all Maritime Services are registered and stored. The Service Registry holds both commercial and non-commercial, as well as authorized and non-authorized services, either free of charge or for a fee. The Service Registry is comparable with the App Store or Google Play in that it distributes services of all kinds to registered users. [3]

2.1.3 Messaging Service

"An information broker that intelligently exchanges information between communication systems connected to the platform, taking into account the current geographical position and communication links available to the recipient." [3]

2.2 Monadic Parsing

Text parsing is a functionality, supported in virtually every programming language.

2.3 Property-Based Testing

Property based testing, also known as Automation Testing, is the principle of testing properties of code, rather than instances, as is done in manual unit testing. Unit tests are fast and easy to set up and execute, however, in most instances they only provide coverage to a certain degree. Depending on the complexity of the given program, most programmers can come up with tests, covering most of the given program, however many edge-cases are unintuitive and would require extensive testing to determine manually.

Property-based testing solves this problem by setting up test cases that take into account mathematical models, describing the desired behavior of the code. Once such a test case has been created, semi-random execution instances can be run to the point of literal exhaustion, and thus a relatively small program can test for thousands of occurrences at once.

An example of this can be seen in Listing 2.2, that describe a snippet of Haskell quicksort code. A property of quicksort is that a list, sorted once is equivalent to a list, sorted twice, which is what the function `prop_idempotent` validates.

```
import Test.QuickCheck
import Data.List

qsort :: Ord a => [a] -> [a]
qsort [] = []
qsort (x:xs) = qsort lhs ++ [x] ++ qsort rhs
    where lhs = filter (< x) xs
          rhs = filter (>= x) xs

prop_idempotent xs = qsort (qsort xs) == qsort xs
```

Listing 2.2: Example of Property-Based Testing. [4]

2.4 Model-Based Testing

The principle of Model-based testing is to check behavior of software against predictions made by a model. Behavior can be described in a variety of manners, including data flow, control flow, dependencies, decision trees/cycles, and state transition machines. Model-based testing is good at describing the behavior of a system, when it reacts to a specific action, which is determined by another specific model. Using this technique, the behavior of a system can easily be determined and validated. Currently there are two main types of model-based testing-techniques:

- **Serial model building- and testing:**

This way of implementing model-based testing involves predefined models, upon which a number of tests are executed. Creating the model ahead of execution allows the tester to implement an additional layer of complexity to the created models. Depending on the amount of models, this is, however, a significantly slower process than the alternative, in that each model requires a similar amount of time to construct. Figure 2.3 provides a high-level diagram, describing this principle, using arbitrary units of measurement along its x - and y -axis.

Figure 2.3 shows the time consumption increasing for every model built, while the model complexity is directly matching the requirement, set by each specific model.

- **Sequential model building- and testing:**

This way of implementing model-based testing involves on-the-fly model creation- and testing. Here a program is designed to take in arguments,

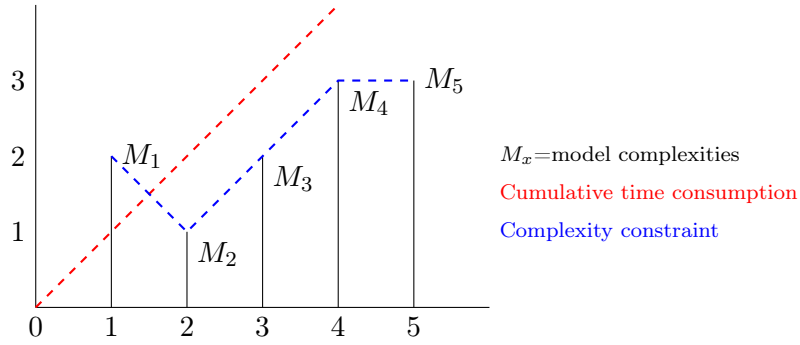


Figure 2.3: Time consumption and complexity restraint of serial model building and testing.

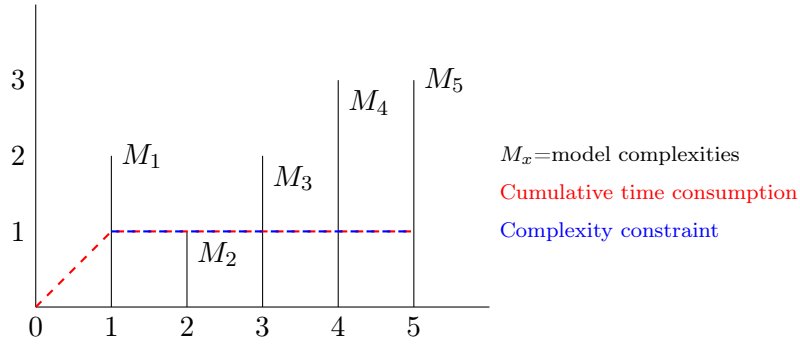


Figure 2.4: Time consumption and complexity restraint of sequential model building and testing.

describing different model behaviors, upon the basis of which the program tests the models immediately after they are generated. Compared with the implementation described above, this technique scales to a much better degree, as the program will only need to be written once in order to create a virtually infinite amount of models. The created models are, however, constrained to the lowest common complexity level, shared across all of the generated models. Figure 2.4 provides a high-level diagram, describing this principle, using arbitrary units of measurement along its x - and y -axis. Figure 2.4 shows that the time consumption halts to a stop when one model is built with the drawback that the model complexity constraint is set to the lowest common model.

2.4.1 Finite State Machines (FSM)

A finite state machine is, as the name suggests, a mathematical machine, consisting of a collection of states. An arbitrary FSM has a start state along

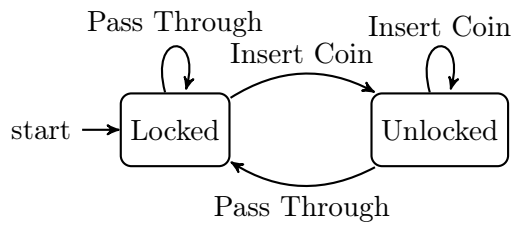


Figure 2.5: Example of a finite state machine, describing a turnstile. Furthermore, this figure describes Table 2.6.

with a collection of states that are accessed through various status- and/or input-combinations. An example of this can be seen in Figure 2.5 as well as Table 2.6. These describe the control flow of a turnstile, which allows for one pass through, after which it prompts for a coin before allowing another pass through.

State	action	Next State	Output
Locked	Insert Coin	Unlocked	Unlocks turnstile, allowing passage.
Locked	Push	Locked	Blocks passage.
Unlocked	Insert Coin	Unlocked	Returns coin.
Unlocked	Push	Locked	Allows passage, locks.

Table 2.6: Example of a finite state machine, describing a turnstile. Furthermore, this table describes Figure 2.5.

2.4.2 State Charts

Analysis

3

In this chapter, I will present and analyze the data made available by the MCP in the three documents **E2 - NW-NM DMA Service Instance**, **E2 - NW-NM REST Service Technical Design**, and **E2 - NW-NM Service Specification**, which represent all data, made available to me. Furthermore, I will explain the necessity of testing the MCP, as well as present a description of a favorable model structure.

3.1 Data

To provide a holistic description of a service instance, three documents are necessarily provided. Below are the descriptions of the documents with the service instance **E2 - NW-NM DMA** as an example.

- **E2 - NW-NM DMA Service Instance**
The purpose of this service instance document and its xml-defined counterpart is to describe a DMA instance of the REST-based technical design of the MW- NM service specification, according to the guidelines given in the Service Description Guidelines.
- **E2 - NW-NM REST Service Technical Design**
The purpose of this service technical design document and its xml-defined counterpart is to describe a REST-based technical design of the MW-NM service specification, according to the guidelines given in the Service Description Guidelines.
- **E2 - NW-NM Service Specification**
The purpose of this service specification document and its xml-defined counterpart is to provide a holistic overview of the MW-NM service and its building blocks in a technology-independent way, according to the guidelines given in the Service Description Guidelines.

Of the three documents, only the last, **Service Specification** is to be used to describe specifications of the service, and as such only this will be studied closer.

3.2 Service Specification grammar

The service specification document is constructed using a general xml-format. The grammar of the document can be seen in Listing 3.1 as well as in Listing 3.2, while the latter is in a severely reduced and generalized form.

```
ServiceSpecificationSchema ::= specifications

specifications ::= spec specifications
                  |  $\epsilon$ 

spec ::= name
      | status
      | id
      | version
      | description
      | keywords
      | isSpatialExclusive
      | authorInfos
      | requirements
      | serviceDataModel
      | serviceInterfaces

authorInfos ::= authorInfo authorInfos
            |  $\epsilon$ 

authorInfo ::= aSpec authorInfo
            |  $\epsilon$ 

aSpec ::= id
       | name
       | description
       | contactInfo

requirements ::= requirement requirements
              |  $\epsilon$ 

requirement ::= rSpec requirement
             |  $\epsilon$ 

rSpec ::= id
        | name
        | text

serviceDataModel ::= definitionAsXSD

definitionAsXSD ::=  $\epsilon$ 

serviceInterfaces ::= serviceInterface serviceInterfaces
                  |  $\epsilon$ 
```



```

serviceInterface ::= siSpec serviceInterface
                  |  $\epsilon$ 

siSpec ::= name
         | description
         | dataExchangePattern
         | operations

operations ::= operation operations
           |  $\epsilon$ 

operation ::= oSpec operation
           |  $\epsilon$ 

oSpec ::= name
        | description
        | returnValueType
        | parameterTypes

returnValueType ::= typeReference

parameterTypes ::= parameterType parameterTypes
               |  $\epsilon$ 

parameterType ::= ptSpec parameterType
               |  $\epsilon$ 

ptSpec ::= typeReference

```

Listing 3.1: Full parser grammar of Service Specification Schema

```

ServiceSpecificationSchema ::= specifications

specifications ::= spec specifications
                |  $\epsilon$ 

spec ::= specifications
      | spec
      |  $\epsilon$ 

spec ::= string

```

Listing 3.2: Reduced parser grammar of Service Specification Schema

As mentioned above, the service specification is to be used to verify the behavior of the maritime service from a technical stand point. At the moment, the xml-document provides a technical description of its corresponding

maritime service, but the most commonly used expression method is free text. As this is a very non-technical design choice, a large portion of the obvious technical advantages, provided by the xml-format are lost.

As it is possible to utilize free text though the use of natural language processing [5], no modifications are strictly necessary, however even with utilization of such or similar method, implementation hereof would be unstable in terms of usability. This is due to the fact that free language formulation varies at an unforeseeable degree, and as such creating uniform model based on this would add a great layer of complexity.

For a more sustainable solution to the problem, see Section 4.1.

The xml-version of the service specification can be found in appendix A.1.

3.3 Testing the MCP

The core principle in the MCP is to restructure and streamlining maritime software sharing in a manner that can be done the world over, and the very nature of this statement dictates that the platform must be highly scalable. This adds the necessity of running quality-checks on all of the maritime services that are uploaded to the platform. To accommodate this issue, model-based testing immediately seems like the obvious solution, as this technique covers most of the required desired functionality. If implemented satisfyingly, a model-based testing suite for the MCP would be able to

1. Present or verify behavior of maritime services.

There are many obvious common behavioral traits of maritime services, such as adding ships and maritime stakeholders, as well as removing them, however other behavioral patterns will often vary to the point of lowered manageability. A model, describing the maritime service in question will provide a clear and undeniable description of the service's behavior.

2. Visualize functionality of maritime services.

Just as well as behavioral traits, functionality will differ greatly from one maritime service to another, and therefore it is very useful for a model to visualize said functionality, as well as verifying that it works as intended.

3. Present the structures of maritime services.

This trait will be used to visualize the structural components of maritime services. Just as point 1 and two, this functionality will be useful for creating a quick and clear projection of how the maritime service behaves.

4. Increase reliability and efficiency of maritime services.

Through correct implementation of points 1-3 it is possible to elevate

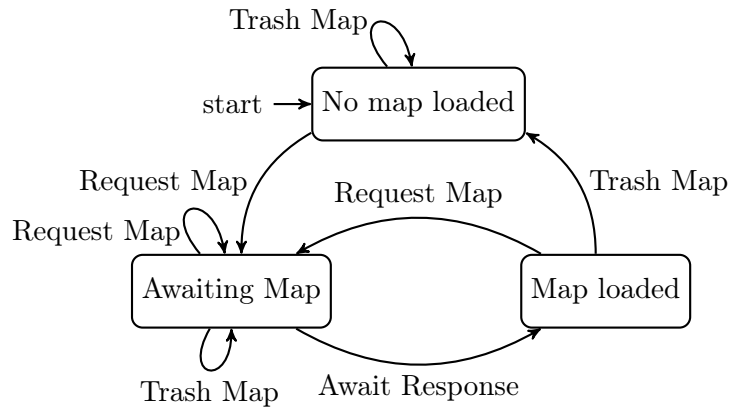


Figure 3.4: Final state machine, describing the **Ship** entity in Figure 2.6.

the reliability and efficiency of the maritime services found on the MCP. This is due to the same reasoning that all testing is conducted on the basis of: the need for safe, consistent, and correct code.

As stated in Section 2.4 there are two main types of model-based testing techniques: serial and sequential model building-and testing, and as these two techniques both provide different advantages utilizing either one will be a trade-off.

3.4 Model Structure

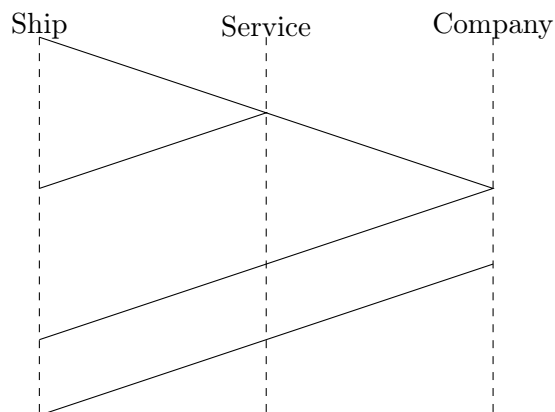


Figure 3.3: Rough draft of a model example, where a ship requests something from a service (could be a weather update)

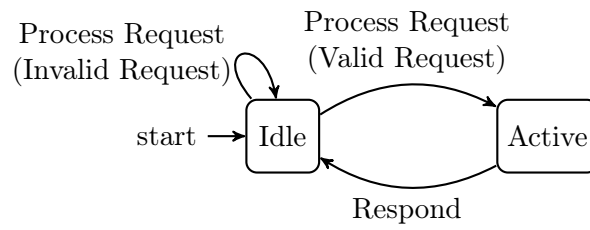


Figure 3.5: Final state machine, describing the **Service** entity in Figure 2.6.

3.5 Model-Based testing of MCP

3.6 Issues

Work/Design

4

In this chapter I will describe the work I have done in order to implement model-based testing into the MCP. The workload that is contained in the implementation and description herein includes implementation of a monadic parser that reads the xml-specification files, an update of the fields and contents of fields in the xml-specification files, as well as a model, that is built upon the foundation of aforementioned updated xml-specification.

4.1 Updated Data

As discussed in Section 3.1, in order to create uniform models, upon which to execute tests, the structure of the xml-specification files needs to be altered in a manner that adds uniformity to the xml-specification files.

4.2 Updated Parser Grammars

4.2.1 Updated Service Specification Grammar

One way to implement these changes is make the user able to assign variables, based on a fixed collection of available options. An example of execution of this is given in Listing 4.1. This parser grammar serves as an updated version of the parser grammar, described in Listing 3.1, however shaved for information¹, that is irrelevant to the model-generating process. While this information can of course be included in the xml-specification file, it will be deemed irrelevant after parsing, and thus not included further in the model-generating process. The parser grammar presented in Listing 4.1 is designed to form a clear and unambiguous collection of entities, along with a similarly unambiguous description of relations, exchange-patterns, and security precautions.

¹aSpec, authorInfo, authorInfos, contactInfo, dataExchangePattern, definitionAsXSD, description, isSpatialExclusive, keywords, oSpec, operation, operations, parameterType, parameterTypes, ptSpec, rSpec, requirement, requirements, returnValueType, serviceDataModel, serviceInterface, serviceInterfaces, siSpec, spec, specifications, status, text, typeReference, version

```
ServiceSpecificationSchema ::= specifications
```

```
specifications ::= spec specifications  
                |  $\epsilon$ 
```

```
spec ::= name  
      | status  
      | id  
      | Entities
```

```
Entities ::= ESPEC Entities  
          |  $\epsilon$ 
```

```
ESPEC ::= Ship  
        | Service  
        | Company
```

```
Ship ::= name  
       | id  
       | Relations
```

```
Service ::= name  
          | id  
          | Relations  
          | Dependencies
```

```
Company ::= name  
          | id  
          | Relations
```

```
Relations ::= RSpec Relations  
            |  $\epsilon$ 
```

```
RSpec ::= ESPEC ESPEC
```

```
Dependencies ::= DSpec Dependencies  
              |  $\epsilon$ 
```

```
DSPEC ::= Dependency RSpec
```

Listing 4.1: Updated parser grammar of Service Specification Schema

4.2.2 Updated General Grammar

The updated xml-specification files will be limiting the flexibility of the models in some aspects, as not all maritime services would follow the structure given in Listing 4.1, however the example given is the earliest version of the domain-

specific language. Following complex structures of various maritime services, the domain-specific language of the specification files can scale in complexity with the requirements set up by the maritime services.

Listing 4.2 describes a reduced form of Listing 4.1. It can be seen that Listing 4.2 is identical to Listing 3.2, which proves that, after implementation of the model-generating process, there is no direct, urgent need to improve or change the parser.

```
ServiceSpecificationSchema ::= specifications

specifications ::= spec specifications
                  |  $\epsilon$ 

spec ::= specifications
       | spec
       |  $\epsilon$ 

spec ::= string
```

Listing 4.2: Reduced parser grammar of the updated Service Specification Schema

4.3 Implementation in the MCP

4.4 Technical Implementation

4.4.1 Executing Instructions

4.5 Testing

Results

5

Discussion

6

Conclusion

7

7.1 Conclusions

7.2 Future work

7.3 Summary

Bibliography

- [1] Maritime Connectivity Platform, <https://maritimeconnectivity.net/>
- [2] QuickCheck, <http://hackage.haskell.org/package/QuickCheck>
- [3] EfficienSea2's website, <https://efficiensea2.org/solution/maritime-connectivity-platform/>
- [4] Real World Haskell, Bryan O'Sullivan, Don Stewart, and John Goerzen, Chapter 11, <http://book.realworldhaskell.org/read/testing-and-quality-assurance.html>
- [5] Natural Language Processing, Elizabeth D. Liddy, Syracuse University, liddy@syr.edu <http://surface.syr.edu/cgi/viewcontent.cgi?article=1019&context=cnlp>

Appendix



A.1 E2 - NW-NM Service Specification

```
<?xml version="1.0" encoding="UTF-8"?>
<ServiceSpecificationSchema:serviceSpecification
  xmlns:ServiceSpecificationSchema="http://efficiensea2.org/maritime-cloud/
    ↳ service-registry/v1/ServiceSpecificationSchema.xsd"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://efficiensea2.org/maritime-cloud/service-registry/
    ↳ v1/ServiceSpecificationSchema.xsd ServiceSpecificationSchema.xsd "
  xmlns:xs="http://www.w3.org/2001/XMLSchema" >
  <name>NW-NM TP Maritime Cloud Service</name>
  <status>provisional</status>
  <id>urn:mrn:mcl:service:specification:dma:nw-nm</id>
  <version>0.3</version>
  <description>The NW-NM service specification defines a combined NW-NM TP
    ↳ model along with the actual service API used for accessing NW-NM data,
    ↳ as registered in the Maritime Cloud service catalogue.</description>

  <keywords>pNW, NM, Navigational Warnings, Notices to Mariners, MSI, Maritime
    ↳ Cloud Service</keywords>
  <isSpatialExclusive>>false</isSpatialExclusive>

  <authorInfos>
    <authorInfo>
      <id>urn:mrn:mcl:user:dma:mcb</id>
      <name>Mads Bentzen Billesoe</name>
      <description>Responsible for the NW-NM service</description>
      <contactInfo>mcb@dma.dk</contactInfo>
    </authorInfo>
  </authorInfos>

  <requirements>
    <requirement>
      <id>urn:mrn:mcl:requirement:nw-nm:1</id>
      <name>Combined NW-NM model</name>
      <text>The data model should encapsulate a combined NW-NM model.</text>
      ↳ >
```

```

</requirement>
<requirement>
  <id>urn:mrn:mcl:requirement:nw-nm:2</id>
  <name>Return all published NW-NM messages.</name>
  <text>The NW-NM service should make it possible to retrieve all published
    ↪ NW-NM messages from the given service provider.</text>
</requirement>
</requirements>

<serviceDataModel>
  <definitionAsXSD>
    <!-- Too extensive -- included in the "NW-NM Service Specification"
      ↪ document, Appendix B -->
  </definitionAsXSD>
</serviceDataModel>

<serviceInterfaces>
  <serviceInterface>
    <name>MessageService</name>
    <description>Works according to the request response pattern.</description>
    <dataExchangePattern>REQUEST_RESPONSE</dataExchangePattern>

    <operations>
      <operation>
        <name>get</name>
        <description>Retrieves an published NW-NM messages.</description>
        <returnValueType>
          <typeReference>Message[]</typeReference>
        </returnValueType>
        <parameterTypes>
          <parameterType>
            <typeReference>String</typeReference>
          </parameterType>
        </parameterTypes>
      </operation>
    </operations>

  </serviceInterface>
</serviceInterfaces>

</ServiceSpecificationSchema:serviceSpecification>

```