



## MSc thesis

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# Using Model-Based testing to test MCP Instance-Specifications

Rage Against the Finite State Machine: Boats on Parade

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Submitted: February 17, 2020

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**MSc thesis**



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**Abstract**

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**Dansk Resumé**

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# 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 model-based testing will be utilized in order to verify that instances fulfills the requirements set by specifications in the MCP. Model-based testing is a technique that allows for verification of overall *model behavior*, rather than *function correctness*. The idea behind this method is, as the term *model*-based testing suggests, to create models which describe the properties that given test-cases need to reflect. Once an accurate model is created further testing can be streamlined, as a simple test can affirm an entire aspect of the tested software. The goal of the project is to create both a manual and an automatic model-creating module for the MCP. The manual model creator will be run by the execution of commands, each creating different aspects and behaviors of the corresponding model, which, ultimately can be used for model-based testing. The automatic model-creator module, however, will draw information from the MCP specification `xml`-files, creating equivalent models, based on user-defined input. In the case of automatic model creation, idea is that the originators of the maritime service will be the ones to author

the xml-file, outlining the specifications, and in extension hereof create the maritime model.

## 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

This thesis will go into means of creating true and fair representations of models, representing maritime services. All tools, required to create models, both manual and automatic, will be analyzed, summarized and utilized, which will be described in the report.

## 1.4 Limitations

Methods of improvement upon both manual and automatic model-creation modules will be present, however not all will be utilized. This includes monadic parsers, and model verification through quickcheck, however in future work, these topics are relevant to be elaborated upon.

## 1.5 Structure

The remainder of the thesis will consist of 7 chapters, covering the following topics:

### **Chapter 1: Introduction**

This chapter provides a description of the problem statement, the learning objectives and the project itself, as well as containing this list.

### **Chapter 2: Background**

This chapter describes the techniques, theories, and components that are used or analyzed throughout the thesis.

### **Chapter 3: Analysis**

This chapter examines potential solutions to the problem statement, and

how to implement them into the MCP. This chapter contains advantages and disadvantages to each presented solution, which are summed up at the end of the chapter.

**Chapter 4: Work/Design**

This chapter presents the work that went into implementing the desired functionality in the MCP.

**Chapter 5: Results**

This chapter includes the results that came from the implementation, described in the previous chapters.

**Chapter 6: Discussion**

This chapter contains a discussion of the results, described in Chapter 5.

**Chapter 7: Conclusion**

This chapter concludes the thesis and compiles a short summary, highlighting the key takeaways.

# Background

## 2

### 2.1 The Maritime Connectivity Platform

The Maritime Connectivity Platform (MCP), formally known as the Maritime Cloud, is a platform, developed by EfficienSea2 [3], which is led by the Danish Maritime Authority. 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.



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**

The messaging service in the MCP is an exchange of information, that ties systems, connected to the platform to each other. The messaging service accounts for the available means of communication, as well as the geographical coordinates of the destination as well as origin of the information, being sent [3].

## **2.2 Parsing**

Parsing is a widely known tool in computer science. The term expresses a function, taking a string of input, from which it yields a parse tree that it constructs when applying the specific parser logic upon the input string. The parser performs a lexical analysis, meaning that it converts sections of the string to tokens that are ultimately easier to handle by an interpreter. When using Haskell to write parsers a library family known as parser combinators is very popular, in that it allows the programmer to embed domain specific language directly in the parser. The concept of combinatory parsing is using one or more of these libraries of higher-order functions, known as parser combinators. Parser combinators take in parsers of any kind imaginable as input and returns a new set of parsers as an output.

```

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

```

Figure 2.2: Example of Property-Based Testing [4]

### 2.2.1 Monadic Parsing

Before 1995, implementation of top-down parsing, using parser combinators ran in and used both exponential time and space complexity when applied to ambiguous, context free grammars. At that time Frost and Szydlowski demonstrated that memoization can enhance parser combinators in order to optimize time complexity to polynomial [6]. One year later through the use of monads parser combinators were reconstructed by Frost which introduced systematic and correct threading of memoization throughout execution.

## 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.

## 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** is a way of implementing model-based testing that involves predefined models, upon which a number of tests are executed. Creating the tests manually ahead of execution allows the tester to implement an additional layer of complexity to the created models. Furthermore, implementing model testing, following this technique allows for custom-tailored testing, suited to fit issues, unique to the corresponding model. 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. Depending on the developer of, as well as the implementation techniques of models, a relatively high leaning curve may be introduced, leading to exclusions of parties, not qualified to take on this task. Figure 2.3 provides a high-level diagram, describing this principle, using arbitrary measurement units of time consumption, skill level, and model complexity along  $y$ -axis, and amount of models along its  $x$ -axis.

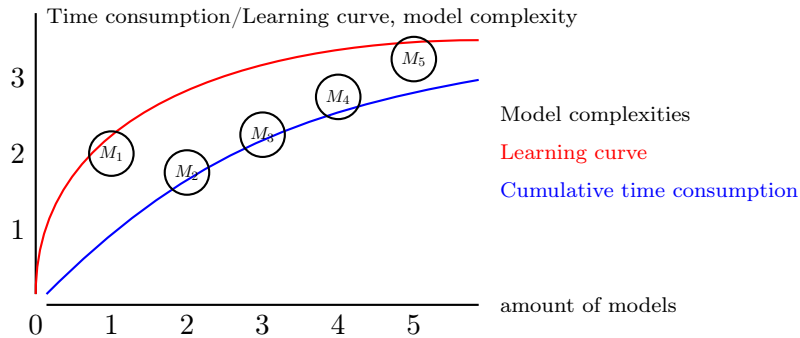


Figure 2.3: Time consumption and complexity restraint of serial model building and testing.

Figure 2.3 shows the time consumption increasing for every model built, while the learning curve initiates very steeply, however diverges, as the creator of the models learns the used techniques.

**Sequential model building- and testing** is a way of implementing model-based testing that involves on-the-fly model creation- and testing. Here a program is designed to take in arguments, 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 functionality, creating the models, does still need some input, that holds all information, that would otherwise be entered manually, thereby not eliminating scalability completely. Figure 2.4 provides a high-level diagram, describing this principle, using arbitrary measurement units of time consumption, skill level, and model complexity along  $y$ -axis, and amount of models along its  $x$ -axis.

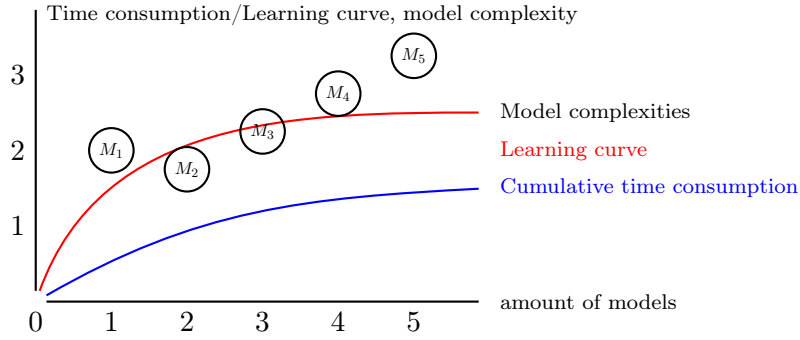


Figure 2.4: Time consumption and complexity restraint of sequential model building and testing.

Like Figure 2.3, Figure 2.4 introduces a learning curve, as the user will need to become familiar with the input needing to be specified, in order for the sequential model creation to start, however this is severely more gradual, while also featuring a lower end-point than the one seen in Figure 2.3. The cumulative time consumption is also lower, compared to serial model building, due to the fact that this process will run semi-automatically, only needing input from a user, before handling all building-related tasks.



### 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 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, which describes the flow of a turnstile, which allows for one pass through, after which it prompts for a coin before allowing another pass through.

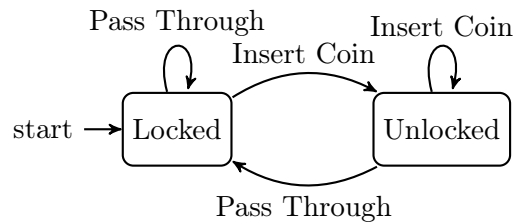


Figure 2.5: Example of a finite state machine, describing a turnstile. Furthermore, this figure describes Table 2.6.

Table 2.6, seen below displays the relationships between the actions, states and output, produced when interacting with the turnstile, using its intended functionality. The table features the four columns, with 'State' describing the state before execution of the 'Action' column. 'Next State' describes the state after the action has taken effect, and the 'Output' column describes the flow of events, leading to the next state. Note that the Output column features event flows that do *not* lead to a change in state, as well as outcomes that do.

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.

# 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 majority of the parser 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. A minority of the grammar has been cut from Figure 3.1 as it was deemed irrelevant, however the parser grammar in its entirety can be seen in Appendix, A.1 and A.2.

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.2.

## 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.

```

ServiceSpecificationSchema ::= specifications

specifications ::= spec specifications
                    | ε

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

authorInfos ::= authorInfo authorInfos
            | ε

authorInfo ::= aSpec authorInfo
            | ε

aSpec ::= id
       | name
       | description
       | contactInfo

requirements ::= requirement requirements
            | ε

requirement ::= rSpec requirement
            | ε

rSpec ::= id
       | name
       | text

serviceDataModel ::= definitionAsXSD

serviceInterfaces ::= serviceInterface serviceInterfaces
                  | ε

oSpec ::= name
       | description
       | returnValueType
       | parameterTypes

```

Figure 3.1: Snippets of full parser grammar of Service Specification Schema.  
(Found in Appendix A.1, A.2)

```

ServiceSpecificationSchema ::= specifications

specifications ::= spec specifications
                  | ε

spec ::= specifications
      | spec
      | ε

spec ::= string

```

Figure 3.2: Reduced parser grammar of Service Specification Schema.

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 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 Example Model Structure

Throughout this report, I will use a mapping service as an example. In this example the maritime service will act as an intermediate, broking between a ship and a company, where the map is being held. The ship will have to submit authentication information to the maritime service in order to get a the requested map. The model, which has been built upon the example protocol has been illustrated in Figure 3.3. The lines numbered 1-6 illustrate interaction between the three entities **Ship**, **Service**, and **Company**, where \*1 and \*2, respectively illustrate a submitting of authentication information, to the service, and the service accepts the information and sends this response. \*3 and \*4 illustrates the service' request of the requested map, and its subsequent receiving hereof. \*5 represents the service informing the ship that the information retrieval has been successful, and that the process will terminate shortly, while \*6 illustrates the forwarding of requested information to the ship.

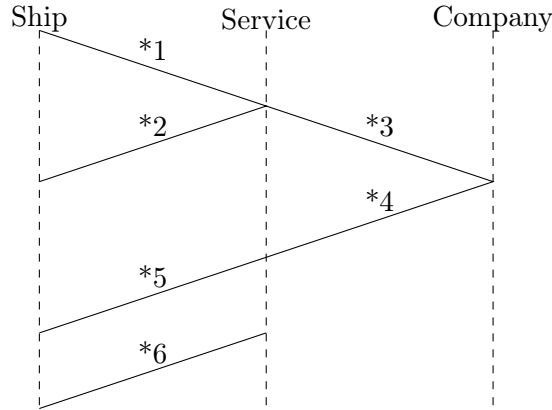


Figure 3.3: Rough draft of a model example, where a ship requests information from a service.

Figure 3.4 represents a FSM, illustrating the **ship** entity in Figure 3.3. The FSM starts in the **No map loaded** state, and has the three available actions **trash map**, **request map**, and **await response**. Performing **trash map** or **await response** in the initial state will yield no results, as no map is available to be trashed and no response is on the way. If **request map** is performed, the state will be changed to the intermediate state **awaiting map**, where **await response** is the only action that will change the state, as no map can be trashed, and requesting another map will change the state to the same, but where a different map is being waited for. The third and final state **map loaded** will allow the actions **trash map**, which will change the state to **no map loaded** and **request map**, which will, respectively, trash the loaded map, and request a new one, changing the state to **awaiting map**.

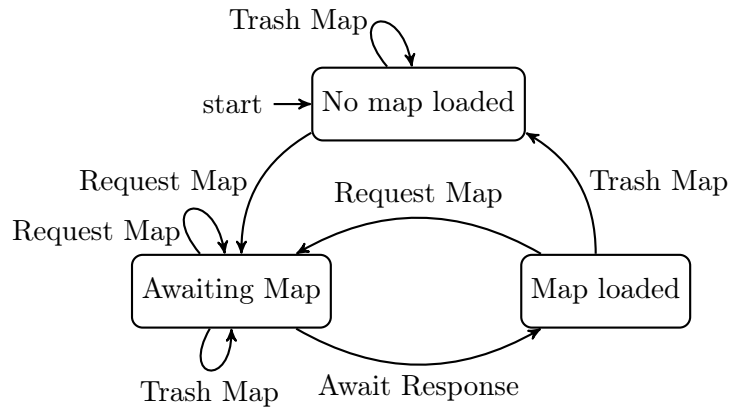


Figure 3.4: FSM, describing the **Ship** entity in Figure 3.3.

Figure 3.5 represents a FSM, illustrating the **service** entity in Figure 3.3. The FSM has the two states **idle** and **active**, the former being the initial state. Whenever the entity receives a valid response the state changes to the **active** state, and when the request has been properly handled, the state changes back to **idle**.

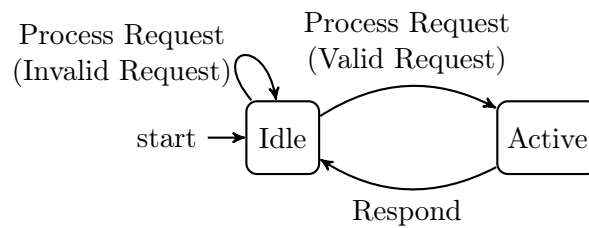


Figure 3.5: FSM, describing the **Service** entity in Figure 3.3.

### 3.5 Uses of model-based testing of the MCP

The main advantage that model-based testing comes from the large variety in testing algorithms which it produces. For a model to be machine readable the techniques which are listed below can be implemented fully automatic - and if not they can still be utilized however manually. The following techniques can be applied to true and fair maritime service-models in the MCP:

### **Finite state machines**

As mentioned in Subsection 2.4.1, a FSM is made up of states, and the ability of a simulating program to change state through a collection of actions. Executable paths are determined, which can be used to create test cases, as well as illustrate the behavior of the system. Furthermore FSMs are closely related to the further techniques, that will be explained in this section.

### **Proving theorems**

Automatic theorem proving is a technique originally produced for proving logical formulas, which is a concept that can be rewritten to suit model-based testing. In order to create test cases, system behavior is assigned to equivalence classes. Following this step, predicates can be formed from equivalence classes and logical consequences of the equivalence classes.

### **Symbolic execution**

Much in the likes of a FSM, a symbolic execution of a program or system will executable paths, along with symbolic values, describing how they can be accessed. A symbolic execution engine will analyze possible variations of input in order to create a map of the software in case. Said map can subsequently be used to better understand, test, and develop the software in question.

### **Model checkers**

Model checkers, also known as property checkers, are methods of determining if a FSM meets a specific set of requirements. The model checkers detects if requirements are met, either by determining examples or counterexamples. When a path, representing either an example or a counterexample is discovered it is logged as a *witness*, which can be mutated upon when generating test cases.

### **Markov chains**

Markov chains are named after the Russian mathematician Andrew Markov, and are also known as usage models. A Markov chain, or usage model, is made up of two primary components; firstly a FSM, which represents every available action of a given system, and secondly an operational profile, which is a statistical indicator of has been or will be used. The FSM is used by the operational profile in order to generate the statistical analysis, and the operational profile is used by the FSM to derive operational tests.

The scope of which features the above techniques will be able to test will be deemed by the actual maritime service model, however the expansive array of methods will cover maritime services extensively.



## 3.6 Summary: Advantages and Disadvantages

Issues will inevitably present themselves with a project such as this, however the scope and nature of these issues will vary with each approach possible. As different approaches offer tailored advantages to circumvent correlating unique concerns, another set of unique concerns will necessarily present themselves. In this section I will sum up the approaches presented throughout Chapter 3, along with their corresponding arising advantages and disadvantages.

### 3.6.1 Manual model-creation

#### Advantages

- Manual model creation will have a shorter initial implementation time, as an arbitrary single model is faster to build than its auto-model-generator counterpart.
- Built maritime service models can be fully customized at once in order to describe all aspects of its maritime service counterparts.
- Having customized each maritime service model to its corresponding maritime service counterpart allows for an equally customized test suite. Following the techniques, described in Section 3.5 will allow for exhaustive tests via manual model-creating.

#### Disadvantages

- The time consumption of manually creating each model will expand near-linearly with each maritime service, that is submitted, and subsequently needs a maritime service model.
- Having each maritime service model being created individually and manually will inevitably introduce much diversity both in the sense of the available standard actions and implementation style of the model.
- The complexity as well as way of implementing testing techniques explained in Section 3.5 varies to an extent, even without consideration of non-uniform models. Elaborating on the case that each maritime service model differs both in purpose, implementation style and exhaustiveness, creating test suites similar to those described in Section 3.5 for each new maritime service will become an extensive project

### 3.6.2 Automatic model-creation

#### Advantages

- The first and foremost advantage of automatic model generation is the scalability, which it provides. This comes as the implementation of *one* maritime service model generator module, ideally, will be able to automatically assemble each maritime model without further interference, as opposed to manual model generating.
- As an automatic model generator abides by a set collection of rules and metrics, and would create models following the instructions of an xml specification-file, generated models will never deviate from the uniformity of the generator.
- The uniformity in the generated models will further show advantage, as this will streamline test suite generation either because of the fact that similar models promote similar manual test suite generation, or because of the fact that it allows for almost total automation.

#### Disadvantages

- The obvious disadvantage that comes with automatic model generation is the lack of customization in models. As the generator should handle all models, that can be described through the xml specification files it needs to be generalized, which in turn means less specific models, which lowers the ability to custom-fit each model to its maritime specification counterpart.
- Another inevitable downside to having automatically generated - however less specific - models is the fact that test suites can become less specific, and in extension hereof less exhaustive of the maritime service.

To sum up, both methods will be advantageous, as they will each allow for extensive testing with the former being more custom-tailored, while a lot more time consuming in the long run, and the latter being more generic, but a lot less time consuming in the long run.

# 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 a model-building module, which is able to simulate given examples of maritime protocols. Furthermore, I will update the structure of the xml specification files, based on which I will introduce a parser/interpreter implementation, thus allowing me to automatically generate maritime models, equivalent to the one that I have created manually.

## 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. This rules out the use of natural language, for reliable model-generation.

One way to implement these changes is make the user able to assign variables, based on a fixed collection of available options. I will now present three fields, which are designed to be used in order to maximize uniformity in model generation as well as give maximum flexibility in future model design.

### Entity

An entity is the most basic component of the models, without which, the models be devoid of all data. These describe the physical real-world objects, which the model is to simulate, and these are also the subjects of all transactions, which occurs throughout execution of a model. At the moment, three entities exist, however implementation of support for additional models is possible. Multiple instances of each entity is allowed in a model.

### **Ship**

If comparing the MCP to the App Store or Google Play, a ship would undertake the role of the user. The user can be the one utilizing the maritime service.

### **Service**

The Service entity represents the maritime service, which is being modeled. If multiple instances of a service entity occurs, this will correspond to cross app interaction, using the same comparison as above.

### **Company**

Company entities serve as nodes, which hold data or similar goods, which can be desired by ship entities for a variety of reasons. If multiple company entities exist at one time, they will not necessarily need a service entity to connect them.

### **Relation**

A relation symbolizes a bond between two entities. In the case of Figure 3.3, relations can be seen between 'Ship' and 'Service' as well as 'Service' and 'Company'.

A ship entity can share a relation with service entities, as they would have no way of communicating with company or ship entities without any prior software. In the case that a ship communicates with another ship, it will need an intermediate service entity to communicate through.

A service entity needs to be able to share a relation with all other entities in order to act as an intermedium between ship entities and company entities, while also being able to interact with other service entities.

A company entity can share a relation with a service entity as well as other company entities. Two company entities do not necessarily need service entities in order to be able to share information similarly to the real world, where companies use different communication channels, when communicating with companies and citizens.

### **Dependency**

A dependency is, as the name suggests, a dependency from one entity to another, and so the first argument of a dependency must be a relation, that describes which two entities are in question, as well as which entity depends on the other. The second argument that a dependency must receive is a constraint function, that describes what the entities require from each other. If two entities co-depend on each other a relation must be made from the first to the second, as well as from the second to the first. As only the constraint function limits what the dependency entails, an entity *can* depend on itself.

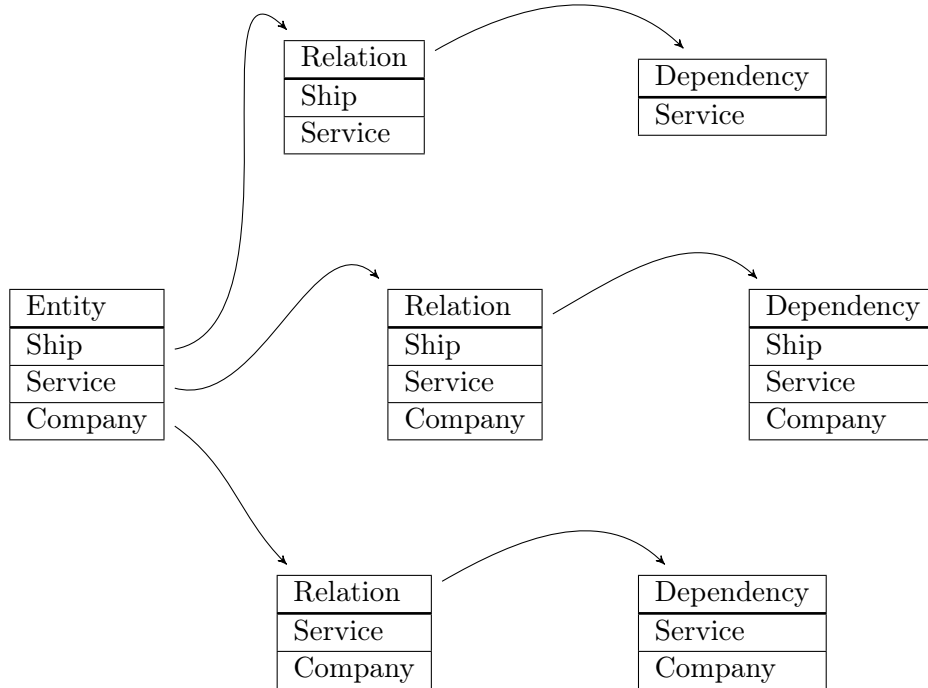


Figure 4.1: Available relations and dependencies for ships, services, and companies

### Information

All entities are able to store information, which is able to be requested, transferred, and deleted. This is meant to represent various data, be it maps, keys, messages or other.

Figure 4.1 describes which options are excluded at selections of entities, relations, and dependencies. As can be seen, Figure 4.1 coincides with 4.3, and therefor the description given in this section describe both figures.

## 4.2 Updated Parser Grammars

The fields described in Section 4.1 furthermore need to be translated into parsable xml, and an example of this is given in Listing 4.3. This parser grammar serves as an updated version of the parser grammar, described in Listing 3.1, however shaved for information<sup>1</sup>, that is irrelevant to the model-generating process. While this information can of course be included in the

<sup>1</sup>aSpec, authorInfo, authorInfos, contactInfo, dataExchangePattern, definitionAsXSD, description, isSpatialExclusive, keywords, oSpec, operation, operations, parameterType, parameterTypes, ptSpec, rSpec, requirement, requirements, returnValueType, serviceData-

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 4.3 is designed to form a clear and unambiguous collection of entities, along with a similarly unambiguous description of relations, exchange-patterns, and security precautions. The parser grammar abides by the rules, presented in Section 4.1 and Figure 4.1.

### 4.2.1 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 4.3, 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 4.3. It can be seen that Listing 4.2 includes all information, stored in Listing 3.2, which indicates that, after implementation of the model-generating process, there is no direct, urgent need to improve or change the parser, given the generalized format of the xml-specification files.

```
ServiceSpecificationSchema ::= specifications

specifications ::= spec specifications
                  |  $\epsilon$ 

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

spec ::= string
```

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

### 4.2.2 Updated Service Specification Grammar

Figure 4.3 displays the updated parser grammar, and subsequently shows the newly added information, which the service specification file will need to include. The added information fields are designed to represent the fields, displayed in Section 4.1.

---

Model, serviceInterface, serviceInterfaces, siSpec, spec, specifications, status, text, typeReference, version

ServiceSpecificationSchema ::= specifications

specifications ::= entities specifications  
|  $\epsilon$

entities ::= ent entities  
|  $\epsilon$

ent ::= type  
| name  
| relations  
| dependencies  
| information  
| requests

type ::= atom

name ::= String

relations ::= relation Relations  
|  $\epsilon$

relation ::= ent

dependencies ::= dependency dependencies  
|  $\epsilon$

dependency ::= relation  
| constraint

constraint ::= function

information ::= info information  
|  $\epsilon$

info ::= variant

requests ::= request requests  
|  $\epsilon$

request ::= relation  
| info  
| answers

answers ::= answer answers  
|  $\epsilon$

answer ::= variant

Figure 4.3: Updated parser grammar of Service Specification Schema

## 4.3 Technical Implementation

The project is implemented in Erlang, and contained in the files `aux.erl`, `interpreter.erl`, `mmods.erl`, (maritime models) `parser.erl`, `tests.erl`, and `main.erl`, along with the `xml`-folder, containing models and simulations in `xml`-format.

### 4.3.1 The `mmods` module

The core of the project is contained in the `mmods.erl` file, which contains the functionality, that creates the finite state machine models. This module creates processes which includes the following fields:

#### Type

This field is described by a single atom, which is only able to take the forms of either `ship`, `service`, or `company`. This is used to check the legality of relations, when adding these.

#### Relations

The `Relations` field is described by a tuple list, containing a set of relations, as well of its corresponding dependencies, if any exist. Dependencies are represented by a list of functions, each evaluating to `true` or `false`.

#### Self

The `Self` field is made up of the corresponding process id.

#### Info

The `Info` field consists of all data representation, which can take any form.

The functions `start/1`, `add_relation/2`, `add_dependency/3`, `add_info/2`, `remove_info/2`, `transfer_info/3`, and `request_info/4`, all add their corresponding self-descriptive functionality through the use of the `gen_statem` (generic state machine) module. The getter-functions `get_state/1`, `get_type/1`, `get_relations/1`, and `get_info/1`, perform the simple task of retrieving relevant informations for the provided process id.

Having implemented this functionality, creating a model is a matter of simply using the functions as building blocks to create the desired maritime models. For examples of how to do this, see files `examples.erl` and `tests.erl`.

### 4.3.2 The `parser` and `interpreter` modules

#### The `parser` module

The `parser` module utilizes the `xmerl` library of functions to standardly



perform well formed parsing of xml files. Additionally, the `xml_parser/1`-function uses the accumulator function `accFun`, which accumulates all field values, that are *not* purely whitespace and/or newline. Along with the hook function `hookFun` that binds the parser output to a tuple, consisting of an atom, describing the parsed node, along with its contents. Furthermore, `hookFun` dictates that pure text contents are just that - not a list, consisting of one string, which it would be otherwise. The parser module is created, following both the `xmerl` reference manual [7] and an example posted online [8], and the parser grammar, described in Figures 4.3 and 4.2.

### The interpreter module

The interpreter module exports the single function `interp/1`. This function takes in an Erlang term of the form, described above <sup>2</sup> and recursively loops the content value in order to exhaust the information, stored in the term. The `interp/1` function adds builds maritime models in the order that is adding entities, info, relations, dependencies, and lastly performing information requests. Each adder function dynamically searches its corresponding keyword rather than retrieving by index in the xml term, which allows for variation in the the structure of the xml along with interchangeability in the order of the adder functions. Two constraints do exist in the order of which components are added to the model, the first being that entity addition must always come first, as no data can be bound to nonexistent entities. The other constraint is that dependencies must be added *after* relations, as a dependency can only be placed on top of an existing relation. Finally the interpreter shows the states of all entities, as is after addition of all data.

### 4.3.3 Executing Instructions

In an Erlang-shell all files can be compiled with `c(file)`, where after manual model generation can be run from the `mmods.erl` file <sup>3</sup>. For automatic model generation, the `main.erl` file gathers the functionality of the parser- and interpreter-modules, which in turn draws upon the `mmods`-module. From here, the user has the possibilities of parsing an xml-file, interpreting an Erlang term, though the uses of `main:parse/1`, `main:interpret/1` or using the combined function `main:parse_and_interpret/1` which fully converts an xml-file to a working maritime model.

---

<sup>2</sup>A tuple

<sup>3</sup>See `tests.erl` and `examples.erl` for examples

If a model is to be generated directly in an Erlang-shell, the same rules apply, that would, if it was run from a file, or compiled from an xml-file. For efficient, exception-free use of the model generators, its functions should be used following this precedence:

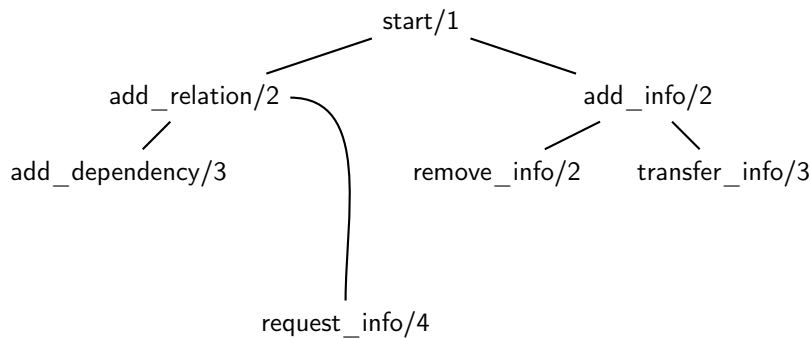


Figure 4.4: Function precedence, when using `mmops.erl`.

Figure 4.4 displays the order that needs to be followed when using the `mmops` module. The reason for this requirement is the fact that a number of the API functions rely on information, given in an earlier function. A relation cannot exist without at least two entities being added to the model beforehand, just as well as a dependency needs a relation, in order to exist. Likewise, information cannot be added to a nonexistent entity, and that same information cannot be removed or transferred, without it having been added first.

An information request, as per the API function `request_info/4`, carries the four arguments, `from(entity)`, `to(entity)`, `requested(information)`, and `answers(list)`. Despite the fact that it would seem like this action would require at least one dependency to be satisfied by `answers`, and that the information needs to exist, neither is the case. As dependency is a (possibly empty) list of constraints, none of these *need* to be added for a request to be made. Likewise, a request can be made for nonexistent information, or information, not stored in the `to`-argument entity, in which case no information will be returned to the requester. This, in turn means that no information needs to be added to a model before a request can be made.

Using a model post-creation both possible though the uses of manual and automatic model-creating, by interacting directly with the Erlang shell, in which the model has been created.

# Results

# 5

In this chapter I will provide a layout of the experiments, which I have set up, in order to verify and present the functionality of the implementation as a whole. This includes testing of all modules, contained in the implementation, as well as the final demonstration, that a model, generated manually can be replicated automatically.

## 5.1 Testing

Testing of the implementation has been divided into two parts, one of which is detailed in Subsection 5.1.1, the other in Subsection 5.1.2.

### 5.1.1 Testing the Manual Model Creator

The manual model creator module, contained in the file `mmods.erl` exports 11 functions, of which 7 are model creation functions<sup>4</sup>, 4 are data-fetching functions<sup>5</sup> and a single one is a simulation function<sup>6</sup>.

All testing of the `mmods` module has been contained in the `tests.erl` file, which includes multiple function-specific tests for each API function, exported from the `mmods` module. After compilation, all tests can be run in an Erlang shell, either as the normal zero-input functions they are, or as the `main_funcs/0` function, which encapsulates all created function-specific test cases. All tests are created to return the atom `true` if they succeed, or the corresponding error message, if they do not. All API-function-specific tests returned true, indicating their correctness. The getter functions were only tested with a single case, `get_all/0`, due to their implementation being extremely simple.

The remaining part of the `tests.erl`-file includes the scenario-oriented tests. As the description entails, these tests describe the outcome of seven

---

<sup>4</sup>`start/1`, `add_relation/2`, `add_dependency/3`, `add_info/2`, `remove_info/2`, `transfer_info/3`

<sup>5</sup>`get_state/1`, `get_type/1`, `get_relations/1`, `get_info/1`

<sup>6</sup>`request_info/4`

scenarios; one for every scenario-function test. The tests, contained in this section of the file are:

#### **multiple\_coms/0**

This test case shows that a single service is able to determine which company to draw information from in an information request. The service **Serv** is connected to the three companies **Com1**, **Com2**, and **Com3**, which hold the atoms **this**, **is**, **correct** respectively. For each request, as **Ship** requests the same service entity **Serv** for the three atoms, **Serv** must select which company to fetch the data from.

#### **multiple\_serv/1**

This test case shows that multiple service entities can link a ship entity and a company entity. The ship entity **Ship** and the company entity **Comp** are linked thrice by the service entities **Ser1**, **Ser2**, and **Ser3**, and the three atoms **this**, **is**, **correct** are requested. The three atoms are requested one at a time, through each relation, and no matter the order, the right combination is fetched. This function is executed six times; one for each permutation of the order in which to request to the three service entities.

#### **service\_choose\_company/0**

This test case shows that when a service entity is linked to several company entities, each containing different data, it is able to determine which company to fetch data from. Here the ship **Ship** is mutually linked to **Serv**, which is then mutually linked to companies **Com[1..5]**. As **Ship** requests the atom **c**, **Serv** will have to determine that **Com1** holds the relevant information, and thus this is transferred to **Ship**.

#### **bad\_connection\_from/0**

This test case shows what happens to a request when the service entity is linked to a company entity, but the connection is not mutual. In this case, as **Shp1** and **Shp2** request **Serv**, **Serv** passes the requests on to **Comp**. **Serv** is able to make the requests, however as no channels of communication are set up from **Comp** to **Serv**, no information is able to be returned, and thus no ships receive information.

#### **bad\_connection\_to/0**

This test case works similar to **bad\_connection\_from/0**, however now it is the connection from **Serv** to **Comp** that is missing. In that case **Serv** finds none to pass the request on, and thus no ships receive information.

#### **ok\_connection/0**

This test case works as the last two test cases should ideally have worked. That is, two ship entities request a service entity, which fetches data from a company entity, and thus, data is returned to the ship entities.

#### **first\_come\_first\_served/0**

This test case shows that information is removed from a service entity, after it is sent. In this case, the two ship entities **Shp1**, and **Shp2** are both mutually connected to the service entity **Serv**. The service entity holds the atom **a\_steak**, and when both ship entities request said atom, it will be distributed to whomever requested first.

The scenario-oriented test cases are all included in the wrapper-function **main\_scenarios/0**, and when run, it yields that all cases pass. The scenarios wrapper function is included in the top-level wrapper-function, and thus, to execute *all* tests, function-oriented or scenario-oriented, simply execute

```
$ tests:main().
```

### **5.1.2 Testing the Automatic Model Creator**

The automatic model creation algorithm makes use of the **mmods** module, and as this has been tested for correctness in Subsection 5.1.1, it is fair to assume that this module will also function correctly in the context of the automatic model creator.

The two modules that distinguishes the automatic model creator from its manual counterpart is the parser and the interpreter. As the parser is a standardized xml-to-Erlang, there is no need to check for edge-cases, correlating directly to the current implementation, as there are none. Therefore the parser is tested with the function **parse\_tests/0**, which includes all test cases. The cases tested for are correct handling of strings, integers, lists, multiple sub-tags in one tag, a tag occurring in another tag with the same name, handling of spaces. The test is run with **tests:parse\_tests()**. in an Erlang shell, which will reveal that all tests pass.

One tests, that does not pass is **test\_interp\_anonymous\_function/0**. This is due to the fact that handling of anonymous functions is not implemented at the time of writing. Support hereof would need to be handled in the **aux:↪ token/1**-function, as this is the mechanism that translates functions in the Erlang-term, resulting from **fparse/1**.

## **5.2 Experiments**

The primary goal of the project is to construct maritime models, describing maritime services, in the shape of finite state machines, both manual and automatic, followed by an assessment of the advantages and disadvantages of each type. As summarized in Section 3.6, manual model-building provides more control to the author, while automatic model building allows for more streamlining in the model-building process. Thus, as each method provides unique advantages to the process, a feasible metric of judging the products of each method is their respective attributes. That is, which FSM is able

to describe scenarios to the highest degree. In order to determine this, I will compare the results of each model building method, starting with the example, given in Figure 3.3.

### 5.2.1 Model Equivalence

Figures 5.1 and 5.2 display the results of manual and automatic model creation respectively. By manually inspecting them, it can be seen that the only variance between the two is the process ids, and despite of this, the relationships between the entities are evidently equal in the two models. Also, from manual inspection, it can be seen that information, types and dependencies, distributed between entities are also equal to that of their manual/automatic counterparts.

```
[{company,[{<0.79.0>,[]}],<0.80.0>,"map"}],
 {service,[{<0.78.0>,[]},{<0.80.0>,[]}],<0.79.0>,[]},
 {ship,[{<0.79.0>,[fun aux:user/1,fun aux:psswd/1]}],
  <0.78.0>,
  ["map"]}]
```

Figure 5.1: Maritime model, resulting of executing the commands, contained within the function `examples:protocol`

```
[{company,[{<0.84.0>,[]}],<0.83.0>,"map"}],
 {service,[{<0.85.0>,[]},{<0.83.0>,[]}],<0.84.0>,[]},
 {ship,[{<0.84.0>,[fun aux:user/1,fun aux:psswd/1]}],
  <0.85.0>,
  ["map"]}]
```

Figure 5.2: Maritime model, resulting of interpreting the file `protocol.xml` with `main:parse_and_interpret('xml/protocol.xml')`

A visual representation of the points, described are displayed in Figure 5.3, where 5.3a represents the manually created model, and 5.3b represents the automatically created model. In both sub-figure, nodes symbolize entities, containing three fields. The first line in each entity node represents its type, the second its unique id, with the third representing the information, held by the entity. All edges in the figures are oriented, symbolizing relations, from one entity to another. Functions, displayed beside a relation represents a dependency, associated with that relation. If not evident in Figures 5.1 and 5.2, Figure 5.3 shows clearly how the collection of entities' states are uniform in relation to their counterparts'.

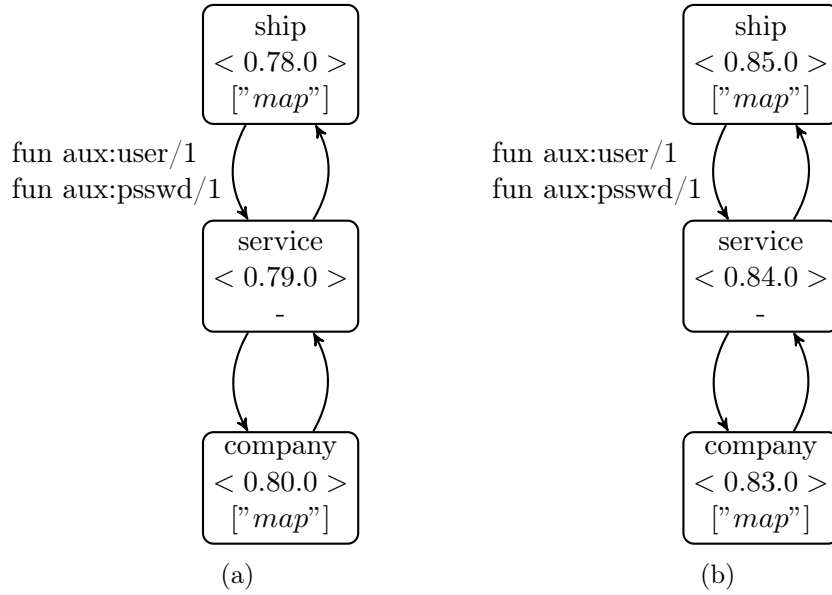


Figure 5.3: Visual representation of Figures 5.1, and 5.2.

Having concluded that the models<sup>7</sup>, described in Figures 5.1, and 5.2 are equal, in order for their FSMs to be equivalent, all available *actions*, correlating to the states must also be equal. To determine if this is the case, I will look to the functionality of the manual, as well as the automatic model creator.

The functionality of the automatic implementation is built to directly utilize the manual model building module, and thus their functionalities are near identical. The only limited by the functionality of the parser and interpreter's ability to feed instructions to `mmods.erl`, such as the example given in Section 5.1.2.

#### 5.2.1.1 Further Examples of Model Equivalence

In order to verify that the example, described above in Section 5.2.1 is not a unique occurrence, the function `equiv_models/2` has been created. This function compares two maritime models, according to the metrics used, when comparing models in Figure 5.3; Types, constraint functions, and information have to exactly match, while relations have to match mapped values. The function `equiv_models_tests/0` utilizes the model comparer function, in order to test that the protocol example holds true with other examples as well. The examples, given to `equiv_models_tests/0` are all models, created manually in the file `examples.erl`, as well as their automatic counterparts, created in the 'xml' folder. All test cases passed, further proving the implementation's ability to create equivalent maritime models.

<sup>7</sup>Collections of all states in the FSM

# Discussion

# 6

## 6.1 Future Use



# Conclusion

# 7

## 7.1 Conclusions

## 7.2 Future work

## 7.3 Summary

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# Appendix



## A.1 ServiceSpecificationSchema

```
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  
             |  $\epsilon$ 
```

Figure A.1: Full parser grammar of Service Specification Schema. (1 of 2)

```

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

```

Figure A.2: Full parser grammar of Service Specification Schema. (2 of 2)

## A.2 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>

```

TODO(s) remaining in the document:

TODOALL: 2

TODOREG: 2