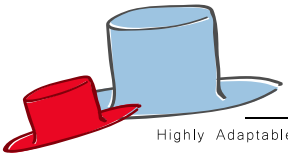

Highly Adaptable and Trustworthy Software using Formal Models

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Project Acronym: **HATS**

Project Title: **Highly Adaptable and Trustworthy Software using Formal Models**

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Evaluation of Core Framework

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Executive Summary:
Evaluation of Core Framework

This document constitutes Deliverable D5.2 of project FP7-231620 (HATS), an Integrated Project supported by the 7th Framework Programme of the EC within the FET (Future and Emerging Technologies) scheme. Full information on this project, including the contents of this deliverable, is available online at `http://www.hats-project.eu`.

The aim of Deliverable D5.2 is twofold: (i) Results of further requirement analysis of Tasks 1.1, 1.2, 2.1, 2.2, 3.1 and 4.2, and (ii) the evaluation of the core framework. Specifically, we refine high level concerns described in Deliverable D5.1 into requirement descriptions with concrete test cases and evaluation criteria. These descriptions are used to validate the deliverable results of work tasks. We also present the evaluation of the core ABS language and the HATS methodology. We specifically test the expressiveness of the core ABS language and investigate the application of the HATS methodology. This forms a part of the validation of the milestone M1 of the HATS project.

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Part I

Evaluation

Chapter 1

Introduction

The goal of Task 5.2 is to test the expressive power of the core ABS language and HATS methodology in the case studies. The activities include extensive requirement analysis of the scenarios defined in Task 5.1 [28]. This task closely cooperated with the activities of Task 1.1, so that the requirement analysis drives the design of the innovative software development method developed in Task 1.1. It is the basis for verification of Milestone M1 "core language and methodology".

Task 5.2 is partitioned into two activities: *requirement analysis* for the other relevant work tasks in the project and the *evaluation* of the core framework (validation of M1). This deliverable report presents the results of these two activities.

1.1 Requirement Analysis

In Task 5.1 [28] we identified a set of high level concerns for each candidate case studies of the project. In this task, we refined these concerns into concrete requirements with concrete test cases and evaluation criteria. These test cases can be used directly to test technical deliverable results from work tasks. The evaluation criteria can then be used to measure whether deliverable results satisfy the intended requirements. Specifically, we conducted a series of interactive requirement analysis sessions with members of technical work tasks. We present the results of these requirement analysis sessions in Chapter 2.

1.2 Evaluation

We test and evaluate the ABS language and the HATS methodology by considering three case studies introduced in D5.1 [28]. For each case study, we present the requirements of some of the components and construct ABS models to describe these components' behaviours. For the Trading System case study, we consider the cash desk component. For the Virtual office of the future case study, we consider the Node management component. For the Fredhopper case study we consider two components in the Fredhopper Access Server (FAS): Fredhopper Interval API and Replication System. The Fredhopper Interval API is an in-house API for expressing mathematical intervals, and the Replication System implements a concurrent protocol for maintaining data consistency in a typical FAS deployment. We now give a brief overview of each case study.

1.2.1 Trading System Case Study

The Trading System is an academic case study of medium size. It is a typical example for a distributed component-based information system. It includes the processes at a single cash desk like scanning products using a bar code scanner or paying by credit card or cash as well as administrative tasks like ordering of running out products or generating reports. The Trading System example was also used in the CoCoME

modelling contest [27, 11], which is based on an idea of Larman [21]. A detailed description is given in D5.1 [28, Chapter 3].

As the Trading System case study is of a medium size, the ultimate goal for HATS is to provide an ABS model for the whole system. In this work task, we use the case study to evaluate the expressiveness of the Core ABS language. This is done by taking the core functionality of the Trading System and model it by using the ABS language using the ABS tools at the current state of completion. The core functionality of the Trading System is covered by the Cash Desk components as well as the Cash Desk Line component, which manages a set of Cash Desks. With these components the basic use cases of the CoCoME requirements [27] are already completely covered. To be able to simulate these components without providing a model for the whole system, we take the approach to make the dependencies of these components explicit by using interfaces and by providing a model for the environment of these components in ABS. This approach proved to be successful and allowed us to test and simulate the core components by simulating the basic use cases of the CoCoME in the Maude runtime system.

1.2.2 Virtual Office of the Future Case Study

The Virtual Office of the Future (VOF) system case study, as described in D5.1 [28, Chapter 4], consists of several components and uses external technologies for communication and user interaction. Furthermore configuration artifacts like deployment descriptors are involved that are crucial to the system's functionality.

To conduct the evaluation we started with the documentation of the VOF System, as it was done in [28, Chapter 4]. Additionally the documentation of the existing implementation [35] was taken into account. After identifying a component that was large enough to test the expressive power of ABS but also small enough to be handled in this experiment the specification was done in a more formal way. To do so the KobrA [5] approach was used. With the help of this semi-formal method ABS interface specifications could be defined. Finally, the implementation was done according to the method specification.

1.2.3 Fredhopper Case Study

The Fredhopper case study is an industrial case study. In this case study we consider the Fredhopper Access Server (FAS). FAS is a component-based, service-oriented and server-based software system, which provides search and merchandising IT services to e-Commerce companies such as large catalogue traders, travel booking, classified advertising etc. A more detailed description of FAS is provided in D5.1 [28, Chapter 5].

In this work task we have chosen to study the Fredhopper Interval API and the Replication System from FAS. They are different in size, application area and in the nature of their behaviours. Specifically, we have selected the Interval API because it represents a single-threaded library providing fundamental services via its interface to other components of the FAS product. We have selected the replication system because it represents a multi-threaded application that supports multiple jobs which transport data through the distributed setup of a typical FAS deployment.

For each component we study its current implementation, understand their informal requirements and derive or mine two layers of models. The first layer are high-level formal specifications of the concrete implementation using existing formalisms, and the second layer is an executable ABS model. We report on this case study in Chapter 5.

1.2.4 Methodological and Language Evaluation

In addition, in all three case study chapters we indicate how the specific modelling approach fits naturally into parts of the HATS methodology. We provide an evaluation of the (core subset of) ABS language and its associated tool support with respect to the requirements identified in D5.1 [28].

1.3 Evaluation Criteria

In this section we present the evaluation criteria for the validation of the core ABS language and the HATS methodology. These criteria are considered by individual case studies. We revisit them in our conclusion in Chapter 6.

1.3.1 Core ABS Language

We evaluate the core ABS language with respect to the following types of criteria.

Requirement descriptions: We evaluate the core ABS language with respect to concrete requirements harvested during Task 5.2. In Task 5.1 we identified high level concerns that the HATS framework should address.[1] These high level concerns are subsequently refined during requirement analysis sessions in Task 5.2 to generate concrete test cases and evaluation criteria. As a result, we elicited Requirements TS-R-1.1-1, FP-R-1.1-1 and FP-R-1.1-2 for the validation of the core ABS language. Their description can be found in Section 2.2.1 of Chapter 2. Specifically, the core ABS language must satisfy the following criteria:

Specification of sequential programs We evaluate the core ABS language with respect to this criterion by conducting a modelling exercise on components extracted from candidate case studies.

Specification of concurrent programs We evaluate the core ABS language with respect to this criterion by conducting a modelling exercise on components extracted from candidate case studies.

Abstraction: We evaluate the core ABS language with respect to the type of abstraction the language provides. Abstraction is important specifically for an abstract modelling language as it encourages scalable analysis and formal reasoning.

Expressivity: We evaluate the core ABS language with respect to the *practical* language expressiveness. In particular we investigate from the user's perspective how readily and concisely the core language allows users to express program structures and behaviour.

1.3.2 HATS Methodology

The HATS methodology is presented in Deliverable 1.1b (D1.1b) [23] and has subsequently been published in the proceedings of FMSPLE [9]. We evaluate the HATS methodology from experimental and requirement perspectives.

Experiment

At this stage of the project it is not possible to consider the complete HATS methodology. Instead in our validation process, we study partially a few steps in the methodology and consider how tasks (requirement elicitation, analysis, design etc.) can fit into these steps. Since each case study is vastly different in scale, application area and contexts, the modelling approach for each case study will be different. As a result each case study considers *some* of the steps in the HATS methodology. Figure 1.1 shows the product line lifecycle in the HATS development methodology and highlights the phases where HATS contributes to it. Specifically, each case study considers *some or all* of the following steps in the methodology: Product Line Requirement Analysis, Reference Architecture, Generic Component Design, Generic Component Realisation, Generic Component Validation, Application Engineering Planning and Product Construction and Integration. Details of these steps can be found in D1.1b [23].

[1] The HATS framework consists of the HATS methodology and the ABS language with associated analysis techniques and tool support.

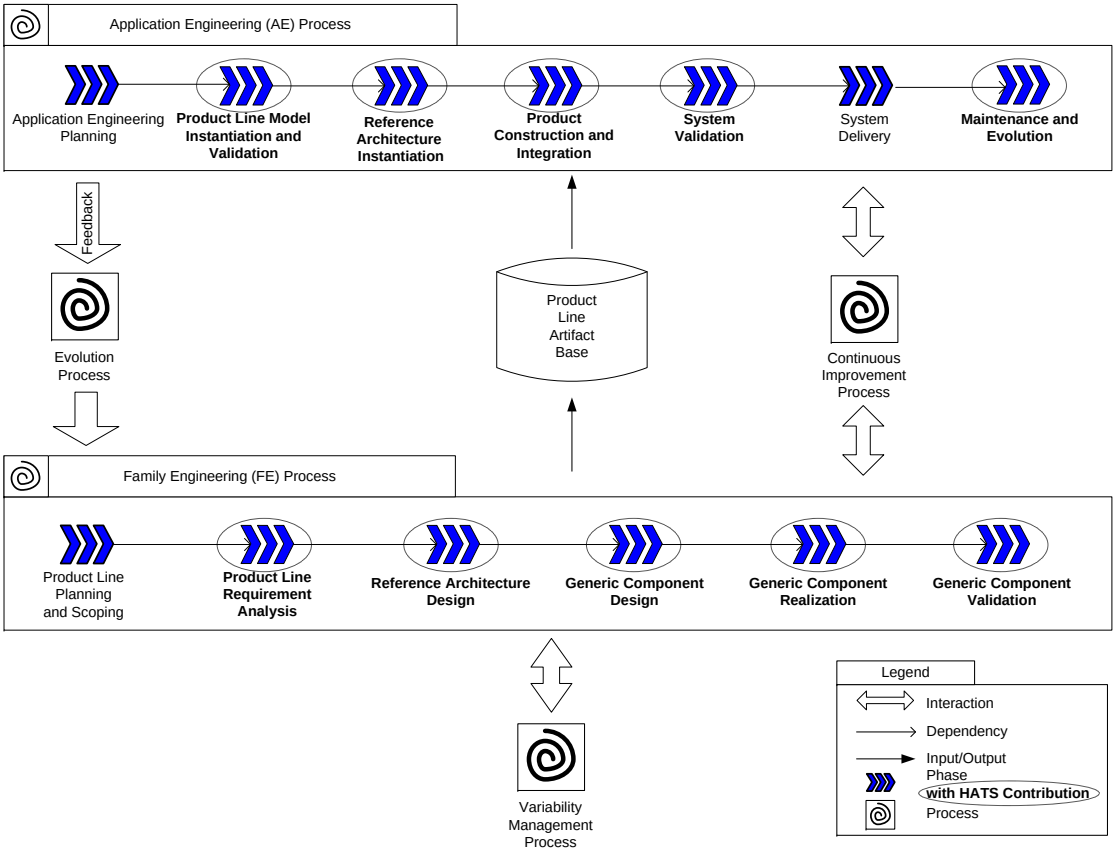


Figure 1.1: Product Line Lifecycle in the HATS Development Methodology

Requirements

Similar to our experiment, at this stage of the project it is not possible to consider all methodological requirements elicited in Task 5.1. In particular we do not consider the requirements that demand the following:

Iterative experiment At this stage of the project, it is not possible to conduct iterative experiments to test the HATS methodology. We hope to evaluate the methodology with respect to this type of requirements at a later validation task (Task 5.4). Specifically we do not consider Requirements MR8, MR9, MR14 and MR23 described in D5.1 [28].

Product line construction As the core ABS language is yet to be extended to handle product line variability, he consideration of requirements, which demand product line construction is relegated to later validation tasks (Tasks 5.3 and 5.4). Specifically, we do not consider Requirements MR1 to MR6 described in D5.1 [28].

ABS language specific features At this stage of the project, the ABS language is not yet complete and not all techniques and tool support have been delivered. We relegate the evaluation of the methodology with respect to this type of requirements at later validation tasks (Tasks 5.3 and 5.4). Specifically we do not consider Requirements MR15, MR16, MR20 and MR21 described in D5.1 [28].

We therefore consider the following requirements when testing the HATS methodology: tailorability (MR7), scalability (MR10), learnability (MR11), usability (MR12), reducing manual effort (MR13), protocol analysis (MR17), integrated environment support (MR18), existing modelling techniques support (MR19), and middleware abstraction (MR22). Note that each case study is vastly different in scale, application area

and context, and each case study considers *some or all* of these requirements. For example, MR17 concerns protocol analysis and will currently be only considered in the industrial Fredhopper case study in Chapter 5. Description of the methodological requirements can be found in Section A.1 in Appendix A.

When consider methodological requirements during evaluation, we also investigate how the core ABS language and associated tool support help satisfying these requirements. Regarding tool support currently there is a Eclipse plug-in that allows users to edit ABS scripts using the Eclipse IDE.[2] The plug-in provides syntax highlighting, basic navigation of ABS scripts based on data type, function, interface and class definitions. In addition, syntax highlighting is provided for Emacs editing.[3] There is also a stand alone type checker. ABS models specified as scripts may be simulated using the Maude engine.[4] A compiler is provided that translate ABS scripts into Maude scripts for simulation. Note that Requirements MR11, MR12, MR13 and MR18 are the basic requirements that guided the design of the core ABS language [1, Section 2.3].

1.4 Scope of Case Studies

For purpose of testing the core ABS language, we do not consider the variability and the evolvability of systems in this deliverable. Specifically, in each case study we construct ABS models to describe the behaviour of components of an existing distributed system. In the case of the Trading System and VOF case studies, this system is a set of *static* informal requirements that describes the system's structure and behaviour. And in the case of the Fredhopper case study, this system is a *single snapshot* of an existing Java implementation that is currently in use and in development. In addition, in this deliverable, we do not consider iterative development approaches in these case studies. Both of these aspects will be considered in Tasks 5.3 and 5.4. This corresponds to our choice of methodological requirements in Section 1.3.2.

For the purpose of references, in Appendix J we provide built-in data type and function definitions of ABS that we use in all three case studies.

1.5 Structure of Deliverable

The structure for this deliverable is as follows: Chapter 2 presents the result of further requirement analyses conducted in Task 5.2. In Chapters 3, 4 and 5, we present the evaluation of the core ABS language by modelling parts of the Trading System, VOF and Fredhopper case studies respectively. We conclude this deliverable in Chapter 6.

[2] `http://www.eclipse.org`
[3] `http://www.gnu.org/software/emacs/`
[4] `http://maude.cs.uiuc.edu/`

Chapter 2

Requirement Analysis

2.1 Introduction

Deliverable 5.1 (D5.1) [28] presents methodological requirements that the HATS framework should meet. D5.1 also presents high level concerns derived from candidate case studies of the HATS project. In Task 5.2, we refined the high level concerns with concrete examples and evaluation criteria. This is so that they can be directly applicable to work tasks.

2.1.1 Analysis

We refined high level concerns documented in D5.1 into *concrete requirements* via a refinement process conducted the form of interactive requirement analysis sessions. While high level concerns are case study oriented and each concern may apply to deliverables of multiple work tasks in the project, a (concrete) requirement, on the other hand, is a concrete description of a particular aspect a work task should meet. Specifically a requirement has the following elements.

- Unique identification of the requirement.
- Reference one or more case study scenarios where the high level concerns were identified.
- Reference to one or more high level concerns from which this requirement refines.
- A textual description of the requirement.
- Concrete test cases that are used to test whether the corresponding work task meets this requirement.
- A list of evaluation criteria that are used to interpret the results of test cases.

Requirements of a work task are defined during a series of interactive requirement analysis sessions. Each session is attended by members of that work task as well as members of Task 5.2. The aim of each session is to generate concrete requirements for the work task and in doing so we strive to answer the following questions.

- Are requirement descriptions complete? That is, do they specify all the requirements for this task?
- Is each requirement cohesive? That is, does each requirement specify one functionality/quality provided by the result of this task)?
- Does everyone in the work task understand each requirement for this task? This ensures clarity and makes explicit the scope control and evaluation criteria of the work task.
- Does each requirement description contain sufficient information and is not ambiguous?

- Does everyone agree on the feasibility of the requirement?
- Is there a priority of requirements? That is, are some requirements mandatory or optional?
- Do all requirement descriptions adhere to the terminology used in the task? This is to ensure requirement descriptions do not get "lost in translation".

2.1.2 Result

Task 5.2 has been scheduled between project month 6 (PM6) and project month 17 (PM17). Some of the work tasks in the project will not begin until after PM17, while other work tasks are more concerned with theoretical foundations that will subsequently be applied in later work tasks to develop techniques and tool support. As a result we have conducted detailed requirement analysis for Tasks 1.1, 1.2, 2.1, 2.2, 3.1 and 4.2. Table 2.1 relates each of these work tasks to its relevant section in this chapter that presents the requirement analysis result of the task.

Task Number and Name	**Results**
T1.1: Core ABS Language	Section 2.2.1
T1.2: Feature Modelling, Platform Models, and Configuration	Section 2.2.2
T2.1: A Configurable Deployment Architecture	Section 2.2.3
T2.2: Feature Integration	Section 2.2.4
T3.1: Evolvable Systems: Modelling and Specification	Section 2.2.5
T4.2: Resource Guarantees	Section 2.2.6

Table 2.1: Requirement Analysis Results

2.1.3 Requirement Description

For the rest of this chapter, the presentation of each requirement analysis result is threefold: We begin by giving a brief description of work task contribution and associated high level concerns. We then present each concrete requirement description in a table format following the template described in Table 2.2. We will also refer to concrete test cases that will be used to evaluate outputs of the work task. Table 2.14 at the end of this chapter relates each requirement to its corresponding scenarios, high level concerns and work tasks.

Name	**Description**
Requirement	Identifier and Name of the requirement
Scenarios	Reference to relevant scenarios in D5.1
High Level Concerns	Reference to relevant high level concerns in D5.1 from which this requirement refines.
Description	Textual description of the requirement
Test Cases	Textual description of the format and nature of test cases.
Accompanying Material	Description of any materials necessary to conduct evaluation of work task's contribution with respect to this requirement. For example, accompanying materials may be the description of the concern and the scenario.
Evaluation Criteria	Criteria against which relevant work tasks would be benchmarked to measure the satisfiability of the requirement.

Table 2.2: Requirement Description Template

Identification Each requirement has a unique identification of the form CS-R-TN-I. Here CS refers the case study where the high level concerns are refined by the requirement. CS takes is one of TS, VF and FR representing Trading system, VOF and Fredhopper case studies respectively. TN refers to the work task of which this requirement is identified. I is a non zero positive integer value, identifies the requirement to be the Ith requirement refined from concerns of a particular case study for a particular work task. For example Requirement TS-R-1.1-1 is the first concrete requirement of Task 1.1 refined from the Trading System case study.

2.2 Requirement Analysis Results

2.2.1 Task 1.1: Core ABS Language

The contribution of Task 1.1 is twofold: The core ABS language and the HATS methodology. Since the requirements of HATS methodology are the methodological requirements described in D5.1 [28, Chapter 2], we therefore focus on the requirement analysis of the core ABS language in this section. In D5.1, there are three high level concerns specific to Task 1.1: TS-C6 [28, Page 23], FP-C1 [28, Page 43] and FP-C11 [28, Pages 50–51].

Name	**Detail**
Requirement	TS-R-1.1-1: Specification of the Cash Desk component
Scenarios	Scenario TS2 [28, Section 3.2.2]
High Level Concerns	Concern TS-C6 [28, Page 23]
Description	The core ABS language should provide language constructs to model the basic Trading System as described by the CoCoME requirements.
Test Cases	Informal requirements of the Trading System from the CoCoME documentation [27].
Accompanying Material	Textual description of Concern TS-C6 [28, Page 23].
Evaluation Criteria	1. It must be possible to define the ABS model of the Cash Desk component. 2. It must be possible to simulate the produced ABS model.

Table 2.3: Requirement TS-R-1.1-1

Concern TS-C6 is identified from the Trading System case study. TS-C6 is concerned with the general modelling of one variation of the Cash Desk component [27]. Table 2.3 shows Requirement TS-R-1.1-1 as a result of analysing high level Concern TS-C6. Using the original CoCoME requirements of the Cash Desk component, we perform an evaluation of the core ABS language. The result of this is presented in Chapter 3 of this deliverable.

Concerns FP-C1 and FP-C11 are identified from the Fredhopper case study. FP-C1 is concerned with the specification of sequential programs and FP-C11 is concerned with the specification of concurrent programs. As a result of the requirement analysis on Task 1.1, we identified the specification of the concrete requirements for evaluating the core ABS language that will be delivered by Task 1.1. Table 2.4 shows Requirement FP-R-1.1-1 as the result of analysing high level Concern FP-C1. Table 2.5 show Requirement FP-R-1.1-2 as the result of analysing high level Concern FP-C11.

We have identified two suitable components of FAS as test cases. For Concern FP-C1, we considered the Fredhopper Interval API as the candidate test case. For Concern FP-C2, we considered the Replication System as the candidate test case. Subsequently we conducted an evaluation of the core ABS language using these test cases. The modelling and evaluation can be found in Chapter 5 of this deliverable.

While no concern specific to Task 1.1 has been elicited from the Virtual office of the future (VOF) case study, we conducted an evaluation of the core ABS language by studying and modelling the Node management component of the VOF platform. The modelling of this component and the corresponding evaluation can be found in Chapter 4 of this deliverable.

Name	Detail
Requirement	FP-R-1.1-1: Specification of Sequential Programs
Scenarios	Scenario FP1 [28, Section 5.2.1]
High Level Concerns	Concern FP-C1 [28, Page 43]
Description	The core ABS language should provide language constructs to: 1. model units of object oriented code, and 2. specify precisely the (behavioural) correctness of units.
Test Cases	1. A stand alone Java source file documenting a class definition with text-based specification of method-level contracts. 2. For any external imports, mocks should be provided with text-based specification of behavioural assumptions.
Accompanying Material	Textual description of Concern FP-C1 [28, Page 43]
Evaluation Criteria	1. It should be possible to define a (core) ABS model(s) of the class definition, and where certain object oriented features are directly not supported, such as class inheritances and global static fields, alternative representation in the core ABS language should be used. 2. It should provide a formal specification of the methods and classes. 3. It should be possible to simulate the produced ABS model(s) to validate the methods' behaviour against their contracts.

Table 2.4: Requirement FP-R-1.1-1

Name	Detail
Requirement	FP-R-1.1-2: Specification of Concurrent Programs
Scenarios	Scenario FP4 [28, Section 5.2.4]
High Level Concerns	Concern FP-C11 [28, Pages 50–51]
Description	The core ABS language should provide language constructs to: 1. model a concurrent (multi-threaded) unit of object oriented code, and 2. specify precisely the (concurrent behavioural) correctness of units.
Test Cases	1. A stand alone Java source file documenting a class definition with text-based specification of method's behaviours. 2. For any external imports, mocks should be provided with text-based specification of behavioural assumptions.
Accompanying Material	Textual description of Concern FP-C11 [28, Pages 50–51]
Evaluation Criteria	1. It should be possible to define a (core) ABS model(s) of the class definition, and where certain object oriented features are directly not supported, such as class inheritances and global static fields, alternative representation in the core ABS language should be used. 2. It should be possible to simulate the produced ABS model(s) to validate the methods' behaviour against their contracts.

Table 2.5: Requirement FP-R-1.1-2

2.2.2 Task 1.2: Feature Modelling, Platform Models, and Configuration

In Task 1.2, the language constructs for expressing feature and platform models for ABS will be developed. This development of language mechanisms goes hand in hand with the concepts of modelling variability and evolvability. The relevant concerns identified from D5.1 are TS-C2 [28, Page 23] and TS-C6 [28, Page 22] from the Trading System case study, and VF-C6 [28, Page 33] and VF-C14 [28, Page 34] from the VOF case study. The result of the requirement analysis session is a set of the textual use case descriptions for variability modelling. These use cases will be used as benchmarks to evaluate the feature modelling

capability of the ABS language delivered by this task.

Name	**Detail**
Requirement	TS-R-1.2-1: Feature Modelling of the Coupon Handling Feature
Scenarios	Scenarios TS1: Coupon Handling Feature [28, Section 3.2.1] Scenarios TS5: Loyalty System [28, Section 3.2.5]
High Level Concerns	Concerns TS-C2 [28, Page 23] and TS-C12 [28, Page 26]
Description	The coupon handling feature described in Scenario TS1 should be modelled as a single feature. It should then be possible to create variants of the Trading System with or without the coupon handling feature. In addition, the loyalty system feature, described in Scenario TS5, should be modelled on top of the coupon handling feature of Scenario TS1. The important point of this requirement is that the ABS language should support feature composition.
Test Cases	Use cases of the coupon handling and the loyalty system features, describing variability focusing on variations, constraints, dependency, assumption, hardware variation, and deployment variation. The use case descriptions can be found in Appendix B.
Accompanying Material	Textual description of Concerns TS-C2 [28, Page 23] and TS-C12 [28, Page 26]
Evaluation Criteria	1. It must be possible to apply the feature modelling capability provided by the ABS language to model the variations, constraints, dependency of the features described in the textual description requirements. 2. Consistency between these features can be formalised and verified under the theory of feature refinement developed in Task 1.2.

Table 2.6: Requirement TS-R-1.2-1

TS-C2 is concerned with the modelling of the coupon handling feature as a variability, while TS-C6 is concerned with the modelling of different variations of the cash desk component. Note that as a result of this further requirement analysis, we extend TS-C2 to include the modelling of the loyalty system feature. The loyalty system feature is described in Scenario TS5 [28, Section 3.2.5] and the modelling of this feature is identified by Concern TS-C12 [28, Page 26]. Table 2.6 shows Requirement TS-R-1.2-1 as the result of analysing high level Concerns TS-C2 and TS-C12, and Table 2.3 shows Requirement TS-R-1.2-2 as the result of analysing high level Concern TS-C6. Corresponding requirement test cases can be found in Appendix B and C respectively.

VF-C6 [28, Page 33] is concerned with the modelling of platform and hardware variability of the VOF framework, while VF-C14 [28, Page 34] is concerned with with the modelling of new functionalities in the VOF framework as variability of the framework. Tables 2.8 shows Requirement VF-R-1.2-1 as the result of analysing high level Concern VF-C6 and Table 2.9 shows Requirement VF-R-1.2-2 as the result of analysing high level Concern VF-C14. Corresponding requirement test cases can be found in Appendices D and E respectively.

Note that as part of results of the further requirement analysis, we have identified that the requirement description from Concerns VF-C6 and VF-C14 and their associated test cases may also be used to test and evaluate the expressiveness of the configuration deployment model, which is a deliverable result of Task 2.1. The requirement analysis of Task 2.1 is described in Section 2.2.3.

2.2.3 Task 2.1: A Configurable Deployment Architecture

Task 2.1 develops a configurable deployment model that can be integrated into the ABS language for specifying platform variability about concurrency, distribution and fault tolerance. At the initial requirement analysis session, we have concluded that it was necessary to perform the following two extensions to the scenarios and concerns described in D5.1.

Name	Detail
Requirement	TS-R-1.2-2: Variability Modelling of Different Cash Desk Variants
Scenarios	Scenario TS2: Cash Desk Variability [28, Section 3.2.2]
High Level Concerns	Concern TS-C6 [28, Page 23]
Description	The feature modelling capability provided by the ABS language should allow one to model the different cash desk variants. For example, different payments options like cash payment and electronic payment may be modelled [28, Page 20]
Test Cases	Use cases about cash desk variability focusing on variations, constraints, dependency, assumption, hardware variation, and deployment variation. Use case descriptions can be found in Appendix C.
Accompanying Material	Textual description of Concern TS-C6 [28, Page 23]
Evaluation Criteria	1. It is possible to apply the feature modelling capability provided by the ABS language to model the variations, constraints, dependency of the features described in the textual description requirements. 2. It should be possible to verify consistency between different views of the feature model.

Table 2.7: Requirement TS-R-1.2-2

Name	Detail
Requirement	VF-R-1.2-1: Platform and Hardware Modelling
Scenarios	Scenario VF2: Add a new device type to the VOF infrastructure [28, Section 4.3.2]
High Level Concerns	Concern VF-C6 [28, Page 33]
Description	Mobile device platforms have specifics that need to be considered when developing applications based on them, for instance, iPhone 3GS does not support multi-tasking for all applications. Hence, the ABS language needs to provide the capability to modelling mobile device platforms at an appropriate level of abstraction.
Test Cases	Use case description of adding various device types to the VOF infrastructure, describing their variabilities in terms of constraints, dependency, assumption, hardware variation, and deployment variation. Use case descriptions can be found in Appendix D.
Accompanying Material	Textual description of Concern VF-C6 [28, Page 33]
Evaluation Criteria	It should be possible for the HATS framework to provide the necessary language constructs (in ABS), modelling techniques and tool supports to specify variability of the platform and hardware as described in the textual description requirements.

Table 2.8: Requirement VF-R-1.2-1

First, we extend Concerns VF-C6 and VF-C14 such that concrete test cases specified for Requirements VF-R-1.2-1 and VF-R-1.2-2 can also be used for evaluation of the deployment model delivered by this task. Concrete test cases of Requirements VF-R-1.2-1 and VF-R-1.2-2 can be found in Appendix D and E respectively.

Second, we extend the Fredhopper case study with Scenario FP7 focusing on the deployment and the maintenance of a physical FAS installation. Subsequently we identified three high level Concerns FP-C22, FP-C23 and FP-C24 on the analysis of service level agreement, and the verification of data consistency and fault tolerance in a FAS installation. A presentation of the FAS deployment architecture and Scenario FP7 can be found in Appendix H.

Following from these extensions, we plan to conduct a second requirement analysis session with Task 2.1. The aim of this second session is twofold. To analyse Concerns FP-C22 and FP-C23 identified by Scenario

Name	Detail
Requirement	VF-R-1.2-2: Platform and Hardware Modelling
Scenarios	Scenario VF5: Integration of new functionality in the VOF P2P Platform [28, Section 4.3.5]
High Level Concerns	Concern VF-C14 [28, Page 34]
Description	Secure communication between nodes in the VOF infrastructure shall be modelled as an optional feature. Furthermore, it should be configurable at run-time, for instance, the level of encryption should be configurable. These optional feature and configuration possibilities must be modelled.
Test Cases	Use case description of secure communication in the VOF infrastructure focusing on variability information such as variations (attributes/cardinality), constraints, dependency, assumption, hardware variation, and deployment variation. Use case descriptions can be found in Appendix E.
Accompanying Material	Textual description of Concern VF-C14 [28, Page 34]
Evaluation Criteria	It should be possible for the HATS framework to provide the necessary language constructs (in ABS), modelling techniques and tool supports to specify variability of the platform and hardware as described in the textual description requirements.

Table 2.9: Requirement VF-R-1.2-2

FP7 of the Fredhopper case study and to refine Concern VF-C19 of VOF case study. We aim to conduct this activity in Task 5.3.

2.2.4 Task 2.2: Feature Integration

Task 2.2 investigates and develops behavioural models of features, feature interaction and feature integration in the ABS language by developing language constructs for manipulating and combining components, based on the variation points. The relevant concerns identified from D5.1 are TS-C2 [28, Page 23] and TS-C6 [28, Page 22] from the Trading System case study. Similar to Task 1.2, the result of the requirement analysis session are textual use case descriptions for modelling feature behaviours. These use cases will be used as benchmarks to evaluate the analysis technique developed in this task.

TS-C2 is concerned with the modelling of the coupon handling feature as a variability, while TS-C6 is concerned with the modelling of different variations of the cash desk component. Note that, similar to Task 1.2, as a result of this further requirement analysis, we extend TS-C2 to include the modelling of the loyalty system feature. The loyalty system feature is described in Scenario TS5 [28, Section 3.2.5] and the modelling of this feature is identified by Concern TS-C12 [28, Page 26]. Tables 2.10 shows Requirement TS-R-1.2-1 as the result of analysing high level Concerns TS-C2 and TS-C12, and Table 2.11 shows Requirement TS-R-1.2-2 as the result of analysing high level Concern TS-C6. Corresponding requirement test cases can be found in Appendices F and G respectively.

2.2.5 Task 3.1: Evolvable Systems: Modelling and Specification

The aim of Task 3.1 is to analyse and model fundamental aspects of system and component evolution, to formally pin down and compare the concepts, construct scenarios, and to build formal execution models that can be subjected to evaluation, theoretical examination, comparison, and simulation.The results of this work task are the theoretical foundation of specifying and modelling evolvable system. These results are to be applied to extend the ABS language with constructs to model evolvability, as part of the deliverable result of Task 1.2. As a result while there are high level concerns identified in D5.1, we do not conduct evaluation directly to results of Task 3.1. Instead, we evaluate results of Task 3.1 indirectly by conducting detailed case studies using the ABS language. This activity will be the main deliverable result of Task 5.3, which begins in project month 18 (PM18).

Name	Detail
Requirement	TS-R-2.2-1: Feature Modelling of the Coupon Handling Feature
Scenarios	Scenarios TS1: Coupon Handling Feature [28, Section 3.2.1] Scenarios TS5: Loyalty System [28, Section 3.2.5]
High Level Concerns	Concerns TS-C2 [28, Page 23] and TS-C12 [28, Page 26]
Description	It should be possible to model and formally establish properties about the behaviours defined by the coupon handling feature and the loyalty system using the ABS language and associated formal techniques.
Test Cases	Use cases about coupon handling feature and loyalty system focusing on the behavioural description of each variation. Use case descriptions can be found in Appendix F.
Accompanying Material	Textual description of the Concerns TS-C2 [28, Page 23] and TS-C12 [28, Page 26]
Evaluation Criteria	1. It should be possible for the HATS feature integration technique to model the behaviour described in the use cases. 2 It should be possible to use the HATS feature integration technique to formalise the textual description and correspondingly formally show (via testing) that the failure isolation property is satisfied.

Table 2.10: Requirement TS-R-2.2-1

Name	Detail
Requirement	TS-R-2.2-2: Variability Modelling of Different Cash Desk Variants
Scenarios	Scenario TS2: Cash Desk Variability [28, Section 3.2.2]
High Level Concerns	Concern TS-C6 [28, Page 23]
Description	It should be possible to model and formally establish properties about the behaviours of different variations of the cash desk component using the ABS language and associated formal techniques.
Test Cases	Use cases about cash desk variability focusing on the behavioural description of each variation. Use case descriptions can be found in Appendix G.
Accompanying Material	Textual description of Concern TS-C6 [28, Page 23]
Evaluation Criteria	It should be possible for the HATS feature integration technique to formalise the behaviour described in the use cases, allowing one to make a formal analysis of the behaviours of features.

Table 2.11: Requirement TS-R-2.2-2

2.2.6 Task 4.2: Resource Guarantees

Task 4.2 is concerned with the development of the cost analysis tool – COSTA [4] to statically inferring *closed-form upper bounds* on the resource usage of program, parametric on some cost model for verifying the bounds. Currently, COSTA has been implemented to support sequential Java bytecode programs. The idea is to extend this technique to support concurrency such that the tool can become applicable in the HATS framework. The task's corresponding high level Concerns are TS-C4 [28, Page 23], FP-C20 and FP-C21 [28, Pages 55–56]. Table 2.12 shows Requirement TS-R-4.2-1 as the result of analysing high level Concern TS-C4. Table 2.13 shows Requirement FP-R-4.2-1 as the result of analysing high level Concerns FP-C20 and FP-C21.

As a result of the requirement analysis session with members of Task 4.2, we have identified the corresponding component from the Trading System and FAS as concrete test cases. For the Trading System, we consider analysing an existing Java implementation of the cash desk component. For FAS, we consider analysing the Java implementation of a part of the *navigation sub-component* of the query engine component

Name	Detail
Requirement	TS-R-4.2-1: Calculation of Resource Consumption
Scenarios	Scenario TS1: Coupon Handling Feature [28, Section 3.2.1]
High Level Concerns	Concern TS-C4 [28, Page 23]
Description	It should be possible to perform cost analysis on an existing Java implementation of the cash desk component of the Trading System.
Test Cases	1. Java source code of an implementation of the Cash Desk component. 2. For any external imports, at least bytecode (.class files) should be provided.
Accompanying Material	1. Textual description of Concern TS-C4 [28, Page 23] 2. CoCoME's non-functional properties [27, Section 3.3].
Evaluation Criteria	1. It should be possible to prove termination and infer asymptotic upper bounds on the number of bytecode instruction executed and memory usage for each concrete method. 2. For methods where termination cannot be proven and/or whose upper bound cannot be inferred, there should be a theoretical justification. For example, at the moment it is not possible in general to infer upper bounds of a method if the method contains a loop that has a non-linear ranking function.

Table 2.12: Requirement TS-R-4.2-1

Name	Detail
Requirement	FP-R-4.2-1: Calculation of Resource Consumption
Scenarios	Scenario FP6: Performance [28, Section 5.2.6]
High Level Concerns	Concerns FP-C20 and FP-C21 [28, Pages 55–56]
Description	It should be possible to perform cost analysis on an existing Java implementation of a component of FAS.
Test Cases	1. Small and medium size Java source code of an implementation of FAS component. 2. For any external imports, at least bytecode (.class files) should be provided.
Accompanying Material	Textual description of Concerns FP-C20 and FP-C21 [28, Pages 55–56]
Evaluation Criteria	1. It should be possible to prove termination and infer asymptotic upper bound on number of bytecode instruction execution and memory usage for each concrete method. 2. For methods where termination cannot be proven and/or whose upper bound cannot be inferred, there should be a theoretical justification. For example, at the moment it is not possible in general to infer upper bounds of a method if the method contains a loop that has a non-linear ranking function.

Table 2.13: Requirement FP-R-4.2-1

of FAS. A brief overview of FAS has been given in D5.1 [28, Section 5.1]. We aim to already conduct and present part of the evaluation of COSTA as part of Deliverable D4.2, while the main evaluation of cost analysis is conducted in Task 5.4.

2.3 Summary

This chapter presented the result of requirement analysis conducted in Task 5.2. We conducted further requirement analyses with members of Tasks 1.1, 1.2, 2.1, 2.2, 3.1 and 4.2. For each work task, we refine corresponding high level concerns identified in D5.1. The results are requirement descriptions containing concrete test cases and evaluation criteria. Table 2.14 shows a summary of requirement descriptions and

their associated work tasks, scenarios and high level concerns. Table 2.15 shows the extra scenario and high level concerns identified during the initial requirement analysis of Task 2.1.

Identifier	**Tasks**	**Scenarios**	**Concerns**	**Description**
TS-R-1.1-1	1.1	TS6	TS-C6	Table 2.3
FP-R-1.1-1	1.1	FP1	FP-C1	Table 2.4
FP-R-1.1-2	1.1	FP4	FP-C11	Table 2.5
TS-R-1.2-1	1.2	TS1, TS5	TS-C2, TS-C12	Table 2.6
TS-R-1.2-2	1.2	TS2	TS-C6	Table 2.7
VF-R-1.2-1	1.2, 2.1	VF2	VF-C6	Table 2.8
VF-R-1.2-2	1.2, 2.1	VF5	VF-C14	Table 2.9
TS-R-2.2-1	2.2	TS1, TS5	TS-C2, TS-C12	Table 2.10
TS-R-2.2-2	2.2	TS2	TS-C6	Table 2.11
TS-R-4.2-1	4.2	TS1	TS-C4	Table 2.12
FP-R-4.2-1	4.2	FP6	FP-C20, FP-C21	Table 2.13

Table 2.14: A summary of concrete requirements

The validation and evaluation processes are partitioned amongst several work tasks. In this deliverable, we present the evaluation of the core ABS language of Task 1.1 with respect to Requirements TS-R-1.1-1, FP-R-1.1-1 and FP-R-1.1-2 in Chapters 3, 4 and 5.

Here we describe our future tentative schedule on further requirement analyses and evaluation of work task deliverables. We will evaluate deliverables of Tasks 1.2 and (indirectly) 3.1 with respect to Requirements TS-R-1.2-1 , TS-R-1.2-2, VF-R-1.2-1 and VF-R-1.2-2 in Task 5.3. We will conduct further requirement analysis with Task 2.1 in Task 5.3 following from the extension of the case studies described in D5.1. We will evaluate deliverables of Task 2.2 with respect to Requirements TS-R-2.2-1 and TS-R-2.2-2 in Task 5.3. While we aim to present a small part of the evaluation of deliverables of Task 4.2 with respect to Requirements TS-R-4.2-1 and TS-R-4.2-2 in Deliverable 4.2, the main evaluation will be conducted in Task 5.4. Further requirement analysis of other work tasks will be conducted in Tasks 5.3 and 5.4.

Req. Identifiers	**Req. Labels**	**Tasks**	**Reference**
FP7: Deploying and maintaining an installation			
FP-C22	Analysis of service level agreement	1.2, 2.1, 1.5, 4.2	Page 141
FP-C23	Verification of replication consistency	1.2, 1.3, 1.4, 1.5, 2.1, 2.2, 4.3	Page 142
FP-C24	Verification of fault tolerance and fairness	1.2, 1.3, 2.1, 1.4, 1.5, 4.3	Page 142

Table 2.15: Extension to high level concerns harvested from the Fredhopper case study [28, Table 5.1]

Chapter 3

Trading System Case Study

In this chapter we evaluate the core ABS language by providing a model for the core of the Trading System (TS) as described in Requirement TS-R-1.1-1 in Table 2.3 on page 16. As TS is the smallest of the three main case studies in HATS, the final goal is to provide a complete ABS model for it and for possible extensions. In order to realise the extended scenarios envisioned in D5.1 in later tasks, we first have to provide an ABS model of the core functionality of the Trading System. This core model can then be used in later evaluation phases as a basis for the extended scenarios described in D5.1 [28]. The core model covers all aspects of the Core ABS language as described in [1] and is thus a reasonable evaluation for it.

The remaining part of this chapter is organised as follows. First, we give a short introduction into the core functionality of the Trading System by introducing the cash desk component in Section 3.1 and present use cases to illustrate the behaviour of this component. We then proceed on how we derived an ABS model from the system description and introduce our modelling approach in Section 3.3. Finally, we present our evaluation of the ABS language and tools in Section 3.4.

3.1 The Cash Desk Line

The core functionality of the Trading System lies in the *Cash Desks* which are organised in a so-called *Cash Desk Line*. The Cash Desk is the place where the Cashier scans the goods the Customer wants to buy and where the paying (either by credit card or cash) is executed. Furthermore it is possible to switch into an express checkout mode which allows only Customers with a few goods and also only cash payment to speed up the clearing. To manage the processes at a Cash Desk a lot of hardware devices are necessary (compare Figure 3.1). Using the Cash Box which is available at each Cash Desk a sale is started and finished. Also the cash payment is handled by the Cash Box. To manage payments by credit card a Card Reader is used. In order to identify all goods the Customer wants to buy the Cashier uses the Bar Code Scanner. At the end of the paying process a bill is produced using a Printer. Each Cash Desk is also equipped with a Light Display to let the Customer know if this Cash Desk is in the express checkout mode or not. The central unit of each Cash Desk is the Cash Desk PC which connects all other components with each other. Also the software which is responsible for handling the sale process for the communication with the Bank is running on that machine. A Store itself contains several Cash Desks whereas the set of Cash Desks is called Cash Desk Line here.

To give a better understanding of the components we modelled, we present Use Cases that show how the different components contribute to realise the system behaviour. We consider the following two use cases, taken from [27].

Use Case 1 – Process Sale

Brief Description At the Cash Desk the products a Customer wants to buy are detected and the payment - either by credit card or cash - is performed.

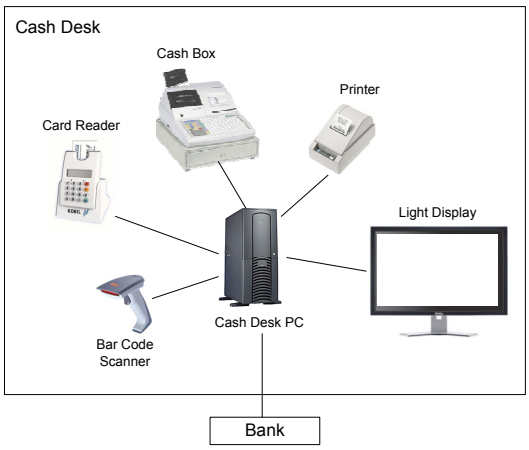


Figure 3.1: Cash Desk

Involved Actors Customer, Cashier, Bank, Printer, Card Reader, Cash Box, Bar Code Scanner, Light Display.

Precondition The Cash Desk and the Cashier are ready to start a new sale.

Trigger Coming to the Cash Desk a Customer wants to pay his chosen product items.

Postcondition The Customer has paid, has received the bill and the sale is registered in the Inventory.

Standard Process

1. The Customer arrives at the Cash Desk with goods to purchase.
2. The Cashier starts a new sale by pressing the button Start New Sale at the Cash Box.
3. The Cashier enters the item identifier. This can be done manually by using the keyboard of the Cash Box or by using the Bar Code Scanner.
4. Using the item identifier the System presents the corresponding product description, price, and running total. The steps 3-4 are repeated until all items are registered.
5. Denoting the end of entering items the Cashier presses the button Sale Finished at the Cash Box.
   (a) To initiate cash payment the Cashier presses the button Cash Payment at the Cash Box.
      i. The Customer hands over the money for payment.
      ii. The Cashier enters the received cash using the Cash Box and confirms this by pressing Enter.
      iii. The Cash Box opens.
      iv. The received money and the change amount are displayed. and the Cashier hands over the change.
      v. The Cashier closes the Cash Box.
   (b) In order to initiate card payment the Cashier presses the button Card Payment at the Cash Box.
      i. The Cashier receives the credit card from the Customer and pulls it through the Card Reader.
      ii. The Customer enters his PIN using the keyboard of the card reader and waits for validation. The step 5.b.ii is repeated until a successful validation or the Cashier presses the button for cash payment.

6. Completed sales are logged by the Trading System and sales information are sent to the Inventory in order to update the stock.
7. The Printer writes the receipt and the Cashier hands it out to the Customer.
8. The Customer leaves the Cash Desk with receipt and goods.

Alternative or Exceptional Processes

- In step 3: Invalid item identifier if the system cannot find it in the Inventory.
  1. The System signals error and rejects this entry.
  2. The Cashier can respond to the error as follows:
     (a) There exists a human-readable item identifier:
        i. The Cashier manually enters the item identifier.
        ii. The System displays the description and price.
     (b) Otherwise the product item is rejected.
- In step 5.b: Card validation fails.
  1. The Cashier and the Customer try again and again.
  2. Otherwise the Cashier requires the Customer to pay cash.
- In step 6: Inventory not available. The System caches each sale and writes them into the Inventory as soon as it is available again.

Use Case 2 – Manage Express Checkout

Brief Description If some conditions are fulfilled a Cash Desk automatically switches into an express mode. The Cashier is able to switch back into normal mode by pressing a button at his Cash Desk. To indicate the mode the Light Display shows different colours.

Involved Actors Cashier, Cash Box, Light Display, Card Reader.

Precondition The Cash Desk is either in normal mode and the latest sale was finished (case 1) or the Cash Desk is in express mode (case 2).

Trigger This use case is triggered by the system itself.

Postcondition The Cash Desk has been switched into express mode or normal mode. The Light Display has changed its colour accordingly.

Standard Process

1. The considered Cash Desk is in normal mode and just finished a sale which matches the condition of an express checkout sale. Now half of all sales during the last 60 minutes fulfil the condition for an express checkout.
   (a) This Cash Desk, which has caused the achievement of the condition, is switched into express mode.
   (b) Furthermore the corresponding Light Display is switched from black into green to indicate the Cash Desk's express mode.

(c) Paying by credit card is not possible anymore.

(d) The maximum of items per sale is reduced to 8 and only paying by cash is allowed.

2. The Cash Desk is in express mode and the Cashier decides to change back into normal mode.

(a) The Cashier presses the button Disable Express Mode.

(b) The colour of the Light Display is changed from green into black colour.

(c) Cash and also card payment is allowed and the Customer is allowed to buy as much goods as he likes.

3.2 Approach

Our approach is rather straightforward. We took the already existing requirements of the Trading System from the CoCoME document [27] and translated these requirements into a behavioural ABS model. The interesting aspects of our approach lie in the ABS model itself. Instead of only modelling the Trading System, we also modelled the configuration, installation, as well as the environment of the Trading System explicitly. This explicit separation has several advantages. First it clearly specifies the interfaces and responsibilities of each aspect and second it enables us to simulate these different aspects in isolation. By rigorously separating the different parts by using interfaces it is easily possible to define different installations, configurations, and environments without changing the model of the core Trading System. The Trading System itself was modelled in a similar fashion by rigorously using interfaces for communication between the different components.

3.3 Model

This section presents the ABS model of the core part of the Trading System case study as described in the previous section and introduces the general approach of how the modelling was conducted. The model was created by a student (no prior experience with ABS) and a HATS employee (experienced with ABS).

3.3.1 Modelling Approach

A crucial aspect of the ABS approach is that we do not only model the system itself, but also its configuration as well as the external dependencies of the system. This allows us precisely to distinguish these different aspects of the model. The complete ABS model consists of four different parts:

lang: a collection of model-independent library data types and functions (e.g. Collections, Pair types etc.). These definitions are now part of a standard library for the ABS language (see Appendix J).

model: containing the actual model of the system (interfaces and implementation) and dependencies on the environment (interfaces).

install: containing ABS files which describe the deployment of the system. Here dependencies to the environment are also given.

env: containing the environment and test drivers for the system.

Structuring our code base in such a way has the additional advantage that our model can be incrementally typechecked (e.g., only the model part without installation and environment) and we can separate the description model from a configuration model (similar to dependency injection frameworks) and from concrete test drivers to run and simulate the system.

We made dependencies between the components explicit by mentioning them in the interfaces.

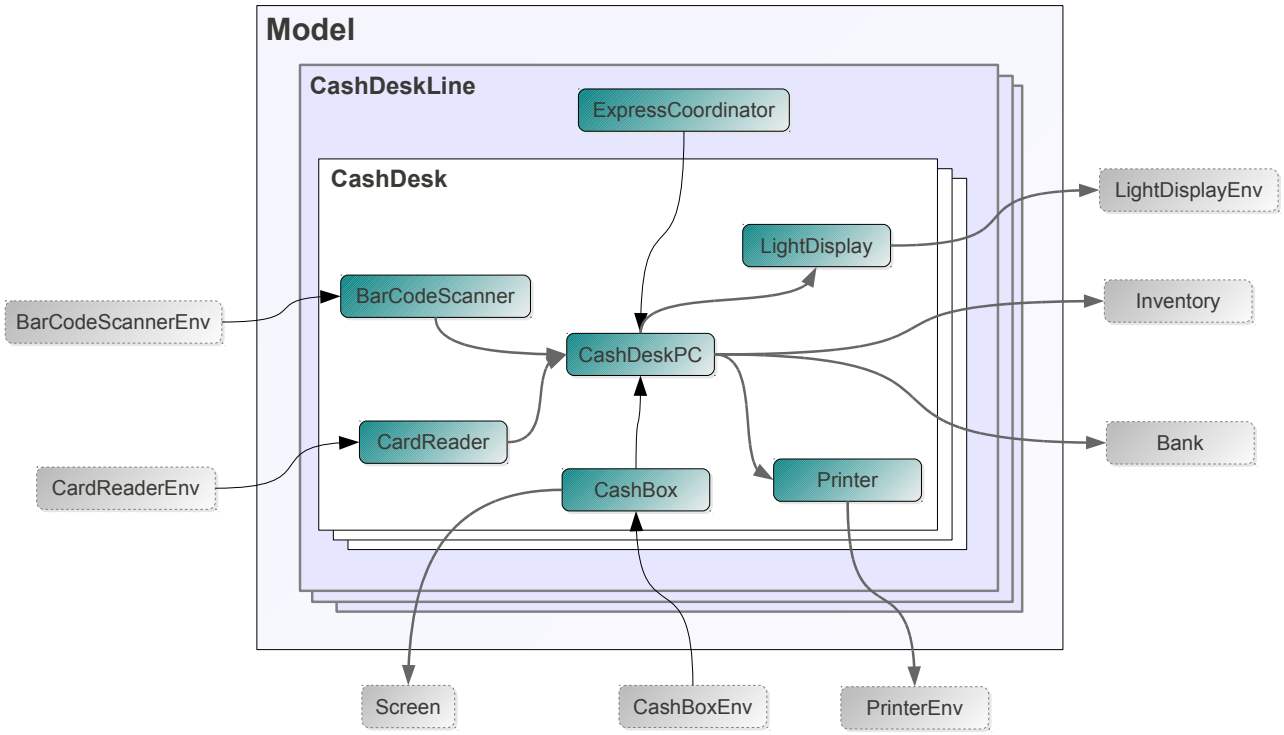


Figure 3.2: System Model

The ABS language provides data types, interfaces and classes to structure and describe the model. We started by describing the interfaces of the components that are part of our system. Based on the types of messages appearing at these interfaces, we derived the data types representing simple values, enumeration types or collections.

3.3.2 Data

ABS provides parametric data types for the modelling of data. This proved to be very useful and we made extensive use of this feature. For example, we defined a data type which can represent the different states a cash desk can be in or which kind of payment mode is chosen.

```
data CashDeskState = INIT | SCANNING | SALE_FINISHED;
data PaymentMode = CASH | CARD;
```

Type aliases allowed us to introduce new domain specific names for otherwise defined types, which makes the model more readable and understandable. For example,

```
type Product = Pair<ProductName, ProductPrice>;
type ProductName = String;
type ProductPrice = ...;
```

3.3.3 Components

Our model contains the following components, which are also shown in Figure 3.2:

BarCodeScanner is used to scan product barcodes.

CardReader is used to read credit card information from a customer.

CashBox manages the keyboard, screen and drawer where the cash is stored.

CashDeskPC implements the main logic of the cash desk system. It stores the current sale information and coordinates communication between the other devices.

LightDisplay shows whether the cash desk is in express mode or not.

Printer manages the formatting of print output (i.e. the receipt).

ExpressCoordinator puts cash desks into express mode if certain conditions are met.

Interfaces can be found in Appendix K.1.2. The implementations of the components can be found in Appendix K.1.3.

Each component of the cash desk is modelled as a concurrent object group. This means that all components run in parallel. As a concrete example for an implementation we present the ABS model of the express coordinator component in Fig 3.3.

```
class ExpressCoordinatorImpl() implements ExpressCoordinator {
  Bool expressModeNeeded = False;
  Int countSales = 0; // All sales
  Int countExpressSales = 0; // All sales, which satisfy the condition for express mode.
  Int threshold = 10;

  Unit saleRegistered(ExpressModeReceiver cashDeskPC,
    List<Product> productList, PaymentMode paymentMode) {
    Fut<Unit> fu;
    countSales = countSales + 1;
    if ((paymentMode == CASH) && (length(productList) < 8))
      countExpressSales = countExpressSales + 1;
    if (countSales >= threshold && countExpressSales > (countSales / 2)) {
      fu = cashDeskPC!changeToExpressMode();
      fu.get;
      countSales = 0;
      countExpressSales = 0;
    }
  }
}
```

Figure 3.3: Implementation of the express coordinator

The express coordinator counts the number of sales happening in the cash desk line, and also the number of sales which satisfy the conditions for express mode (i.e., payment by cash and less than 8 products, see Use Case 2). If more than half of the sales are eligible for the express mode during the last 60 minutes, the last cash desk which reported a sale is switched into express mode and the statistics are reset. As we can not express timing constraints (60 minutes), we require that at least 10 sales (represented by the constant treshold) have been reported.

For describing the internal logic of the cash desk component we use UML sequence diagrams (Figure 3.4, 3.5, 3.6 and 3.7) to illustrate the behaviour of our ABS model. A sale is started (Figure 3.4) by pressing the appropriate button on the keyboard. The CashDeskPC must be in the state INIT, and it properly initializes itself. Scanning items is then triggered by sending the asynchronous method call scanBarCodeButtonPressed to the BarCodeScanner. The BarCodeScanner then triggers the actual barcode scanning and blocks until the barcode is available. Upon success, it sends the barcode to the CashDeskPC. Here, the product information is

fetched from the inventory and the running total calculated and displayed on the screen. The system enters payment mode if the appropriate button on the keyboard is pressed. There are two different possibilities now for payment.

If cash payment is used (Figure 3.5), the cashier must enter the amount of money received from the customer. The change amount is then displayed on the screen and the cash box drawer is opened so that the cashier can return the change amount. When the cash box drawer is closed, the system finishes the sale (Figure 3.7).

If credit card payment is used (Figure 3.6), the customer must enter his pin code. The CardReader then requests additional information from the credit card and sends it to the CashDeskPC. The CashDeskPC then validates the credit card information with the Bank and debits the bank account.

Finishing a sale (Figure 3.7) consists of the following steps. The inventory is updated with new product stock information. The receipt is printed out and a sale success message printed onto the screen. The ExpressCoordinator is also updated with sale information. The CashDeskPC then waits for the ExpressCoordinator to decide whether or not to switch the cash desk into express mode. If the cash desk is switched into express mode, the LightDisplay is turned on.

3.3.4 Configuration Model

We used ABS to describe the installation of our system as displayed in Figure 3.2. To install a cash desk, the installer needs to provide an environment (see Appendix K.2.1). The installation class then proceeds to set the dependencies (from the system to the environment). The detailed ABS descriptions for the installations can be found in Appendix K.2.

3.3.5 Test Drivers

We tested the system using concrete scenarios (see e.g. Use Case 1). We uncovered a lot of bugs in the tools. More than 80 percent of the time was spent on debugging the model. As the tools became more mature over time, this percentage slightly decreased.

The model including test drivers consists of 1,200 lines of ABS code without counting comments. We simulated our use cases with different parameters.

We found during our tests that the Maude backend was relatively slow (for simple system runs where the environment was kept light-weight). To test the Maude backend more rigorously with respect to speed, we used the following test parameters.

Each customer had exactly 5 items to purchase. We fixed the number of customers per cash desk to 4. Half of these customers (2) were paying by cash and half were paying by credit card. We then varied the number of cash desks (which run concurrently). As test platform, we used a Macbook Pro (2.8 Ghz, 4GB RAM). On other platforms where only older Maude distributions were available (i.e. Windows) we saw running times which were up to 10 times higher.

Number of cash desks	Number of customers per cash desk	Running times (seconds)
1	4	5
2	4	17
3	4	35
4	4	60

It becomes apparent that the current translation from ABS to Maude terms needs to be optimized in order to scale to support simulations of more realistic models (e.g. 10,000 lines of ABS code). This is indeed possible, and has been demonstrated by the first tests with the Java code generation backend, which was able to carry out all test scenarios within fractions of a second.

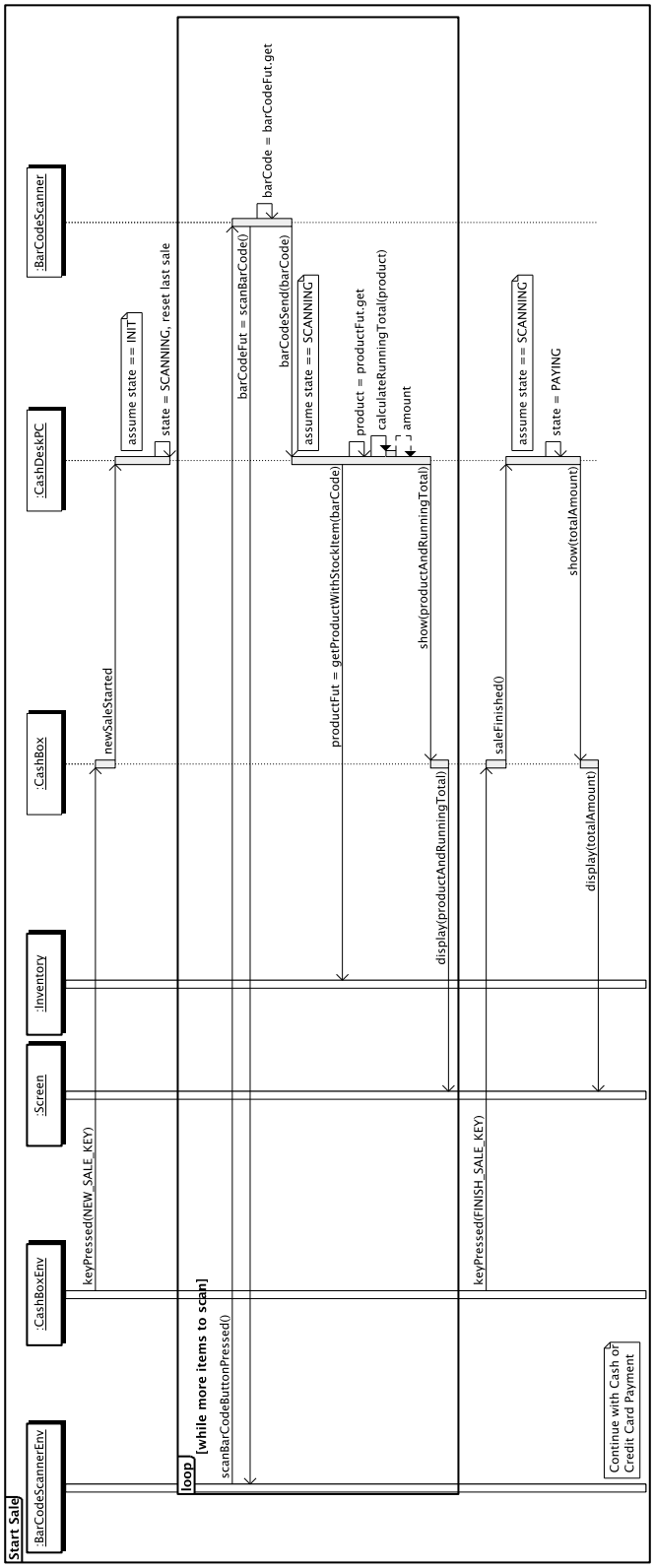


Figure 3.4: Start Sale

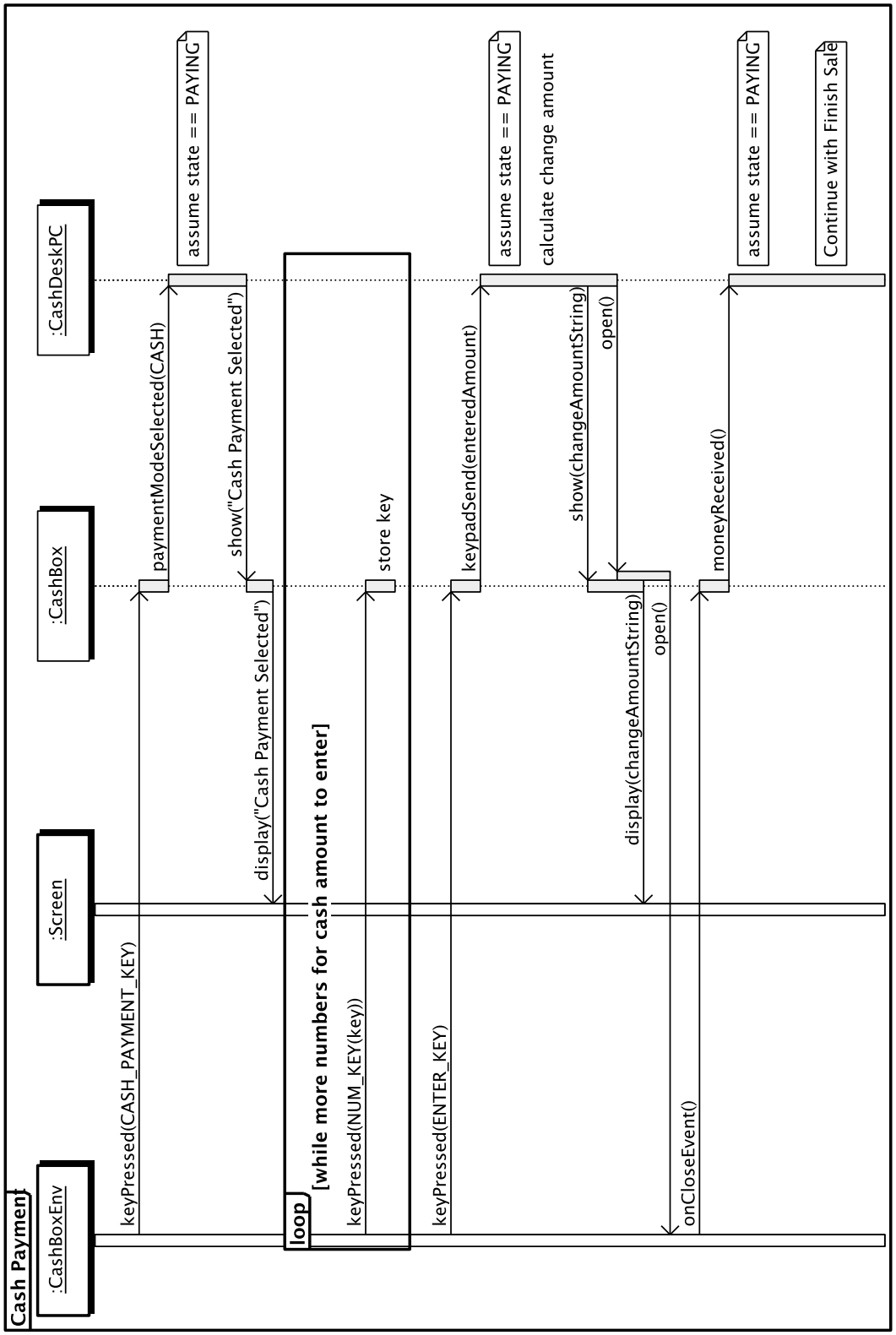


Figure 3.5: Cash Payment

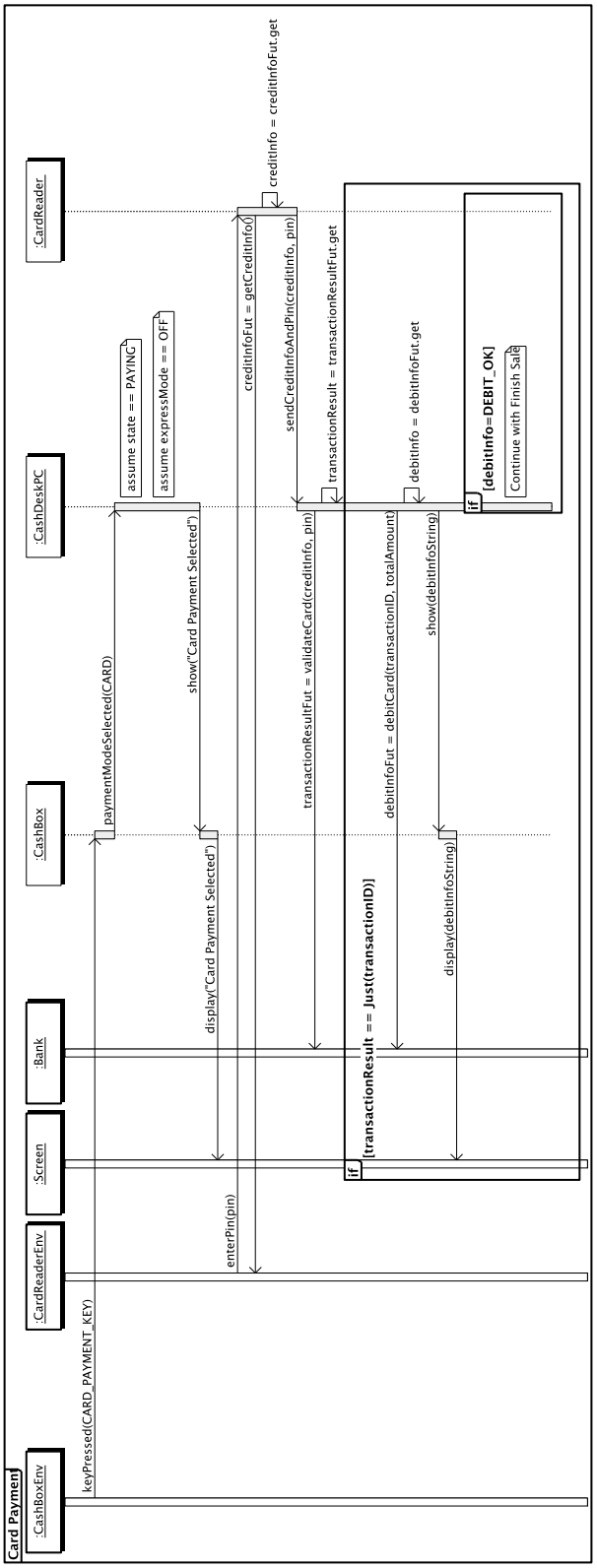


Figure 3.6: Card Payment

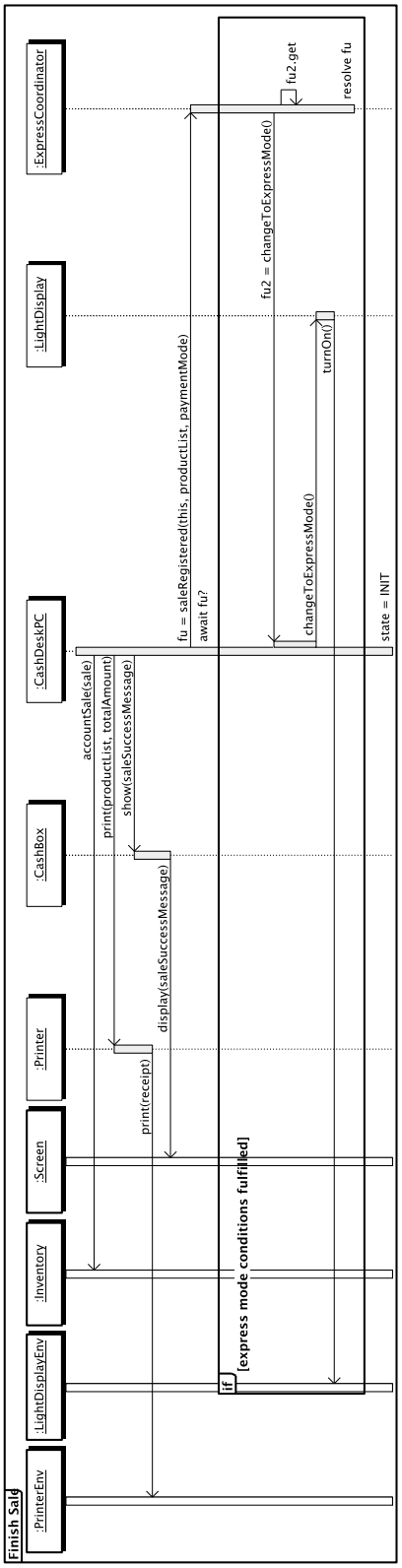


Figure 3.7: Finish Sale

3.3.6 Model Representation

We have a directory which has the ABS files describing the components, one for describing the installation and one for the environment. In each of these directories (see Figure 3.8), we have

- a file `Interfaces.abs` which contains all the interfaces.
- a file `Definitions.abs` which contains all data type and function definitions.
- a file `X.abs` for each implementation class XImpl.

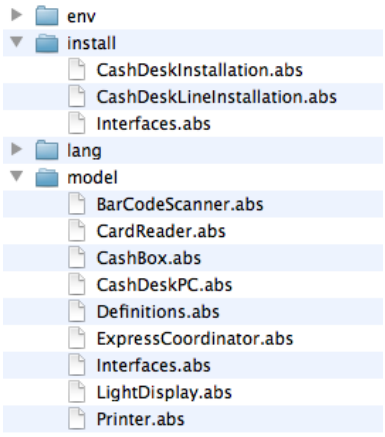


Figure 3.8: File Layout (hiding the `lang` and `env` folder)

3.3.7 Infrastructure

In order to compile and simulate (i.e. run) our model, we devised some build scripts, as such kind of scripts are currently missing from the general ABS tool chain. Our build scripts combine the different source ABS files because the compiler can currently only work on one file. We also used scripts to run our model in the Maude interpreter and dumped the Maude output into log files. We used these log files to debug our model.

3.4 Evaluation

As described by Requirement TS-R-1.1-1 (cf. Table 2.3, page 16), there are two main evaluation criteria: (1) it should be possible to provide an ABS model for the Cash Desk component, and (2) it should possible to simulate that model. Both criteria could be fulfilled by this case study, as shown in the previous section. In this section we additionally present our experiences with the Core ABS language and the HATS methodology that we made during the development of the TS case study, and if possible we make proposals for improvement.

3.4.1 Core ABS Language

This section discusses how the Core ABS language with respect organised by the different features it provides.

Data Types and Functional Language

Core ABS provides parametric data types and a functional language, which is similar to functional languages like ML, for example. This made it possible to model all data that was required in the Trading System. In addition, many functions on that data were easily implemented in the functional language fragment.

However, Core ABS does not provide a mechanism to abstract from concrete data types. An abstract data type has a type domain, whose representation remains unknown to clients, and a set of operations defined on the domain. Currently, it is not possible to hide the representation of a data type. For example, the set data type (from the Prelude in Appendix J) does not hide its representation which allows clients to violate invariants over the representation (e.g. insert items multiple times etc.). It is planned for ABS to provide a module system that allows for hiding the representation of data types.

There is no form of function overloading (see for example the different XtoString functions in Appendix K.1.1). This was no severe problem, however, but only a matter of convenience.

Core ABS does not support high-order functions, which prevents it from defining typical functions known from other functional languages like `map` for example. Writing generic functions that work with different concrete data types is also currently not possible (e.g. generic sort function). This sometimes forced us in the Trading System model to duplicate some functional code. Higher-order and abstraction functionality is currently only provided by the imperative fragment of Core ABS in terms of interfaces and classes.

Sequential, Imperative Language

Core ABS provides a standard imperative statement language. This made it easy to write the sequential behaviour of the Trading System components. We only missed some kind of `for` loop, which currently has to be modelled by using a `while` loop.

Object-Oriented Language Fragment

Core ABS supports object-oriented programming by interfaces and classes. This already allowed us to separately specify the interface and the implementation of the Trading System components, which was very important, to be able to test the individual components in isolation. However, Core ABS does not support class inheritance, which was deliberately left out of the core language. During the modelling of the Trading System we wished to have some comparable form of code reuse. Instead of inheritance, explicit delegating was used for code reuse. It is planned for Task T1.2 to integrate δ-programming features into ABS, which will provide a reuse mechanism.

Concurrency and Communication Model

The concurrency model of ABS, based on concurrent object groups (COGs) made it simple to model the concurrency properties of the Trading System. Each component could simply be made concurrent by putting it into its own COG. This approach is much simpler compared to a standard thread-based approach. Internally, components run in a sequential manner, making it easy to understand the behaviour of each component in isolation. However, currently the Maude simulator does not support COGs with more than one object, which prevented us from using multiple classes to realise the behaviour of a single component.

The asynchronous communication mechanism of ABS is a good match for the communication of the Trading System components. However, we found that it is a problem that ABS provides no ordering guarantees for message delivery. This often forced us to wait for the corresponding futures to ensure that following messages do not overtake previous messages. For example, it is not possible to send several messages to the printer component without waiting for the result of each of them, because the printer might otherwise print the items in a wrong order. Another issue which we experienced is that it is not possible in ABS to explicitly wait for certain messages. This problem came up when implementing the Express Coordinator component, where we wanted in certain states the Cash Desk PC should only accept messages from the Express Coordinator component. We solved this in our model by introducing state variables in the Cash Desk PC component and when receiving a message, it is checked whether the component is in a state where it allows messages of this kind to be received. The ABS language could perhaps provide built-in mechanisms for these kinds of problems.

Summary

The Core ABS language is already in a good state and allows us to completely model and simulate the Cash Desk component of TS. By using the ABS methodology of providing an abstract model of the system, it was possible to concentrate on the main behavioural concerns of the Cash Desk component and abstracting away from concrete platform details. By making all environmental dependencies explicit in the model, we were able to completely describe the externally visible behaviour of the Cash Desk component. The ABS language provides several useful features, which helped us when developing the model. Describing data by using functional data types instead of using objects, as one would do in a standard OO language, makes the distinction of behavioural entities and values explicit and simplifies the modelling. Having a standard class-based imperative language makes it easy to describe the component behaviour in a way, which is familiar to programmers used to object-oriented programming. The concurrency model of ABS, based on object groups and asynchronous method calls was a natural representation for the Trading System as it reflects the asynchronous and distributed nature of the system.

However, there have been some aspects of Core ABS, which we missed during the development and which in our opinion should be addressed in the future. The first issue is that Core ABS does not provide class inheritance and currently has no other mechanism for this kind of code reuse. As Core ABS currently has no module system or comparable mechanisms, it was not possible to specify component-local code that is hidden for other system parts. This was not a real problem in the case study as all model code was written by us, but it is important for the future to allow for modular reasoning in open-world scenarios. Whereas the concurrency model matches nicely with the Trading System, we wished to had more guarantees on the order of message delivery. As currently message delivery is unordered, we often had to ensure that certain messages had been treated by the receiving component, for example, by explicitly waiting for the resulting future. An ordering guarantee would have simplified the model in many cases.

3.4.2 HATS Methodology

In this section we evaluate the HATS methodology from the perspective of the Trading System case study.

From the requirement perspective, we evaluated parts of the HATS methodology with respect to some or all of the following requirements: scalability (MR10), learnability (MR11), and usability (MR12).

MR10: Scalability

The main scalability problem we had with Core ABS is that it did not support to split the model into multiple files or modules at the time of the evaluation.[1] The complete model had to be put into a single file. To circumvent this restriction, we wrote scripts that created a single file out of several input files and used that file as input for the ABS compiler. Another scalability problem appeared when we tried to simulate the Trading System model by using the Maude interpreter. Simple use cases took about 1 minute on a standard machine, but we expect to overcome this problem in the near future.

MR11 and MR12: Learnability and Usability

The learnability of Core ABS was evaluated by letting a Master's student write parts of the model. As ABS has a standard sequential, imperative language part, the student had no problems when writing the behaviour of the components. The data type language and the functional language part was quickly learnt by the student. It took a bit more learning effort for the student to understand the concurrency model and the concept of asynchronous method calls and futures.

The ABS tools are currently mainly used from the command line. They are used like tools known from other languages, so there was not much effort needed to use them. The Eclipse Plugin also behaves like standard plugins and was easy to use. The largest problems appeared in simulating the models in the Maude interpreter. As currently Maude has to be used directly, simulating the model required knowledge of the

[1] Support for multiple input files has been implemented in the meantime.

Maude framework as well as the concrete implementation of ABS in Maude. This low-level simulation view is very difficult to learn and to understand for user without prior knowledge of Maude. Additional tool support here is mandatory, which is planned for Task T2.3.

3.4.3 Trading System Concerns

TS-C6: Variability modelling In Task 5.2, we refined Concern TS-C6 to the concrete Requirement TS-R-1.1-1 (cf. Table 2.3). This requirement is fulfilled as this case study provides the model for one variation of the Cash Desk component. We also successfully simulated the Cash Desk component using the ABS tools.

3.4.4 Outlook on Verification of Software Families

Verification of ABS models and product families are not part of the core framework evaluation and reserved for later stages of the project. Nevertheless, in a joint effort with Task 2.5: *Verification of behavioral properties* and to provide input for other tasks, we investigated also how currently used specification and verification techniques scale with respect to their application on software product families.

We started from a Java application of the trading case study, using the Java Modeling Language (JML) as specification language and the KeY tool in its version for sequential Java as verification system. We focused here on the customization logic of the software responsible for adapting the software system to different deployment scenarios by instantiating feature sets as requested by the customer.

The Java Implementation

In this section we describe the Java implementation of the cash desk component and explain how the variability of the cash desk component is achieved so that for all feature configurations described in Figure 3.9 a corresponding product can be derived. The implementation follows closely the feature diagram shown in

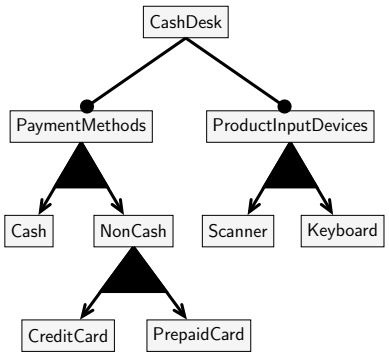
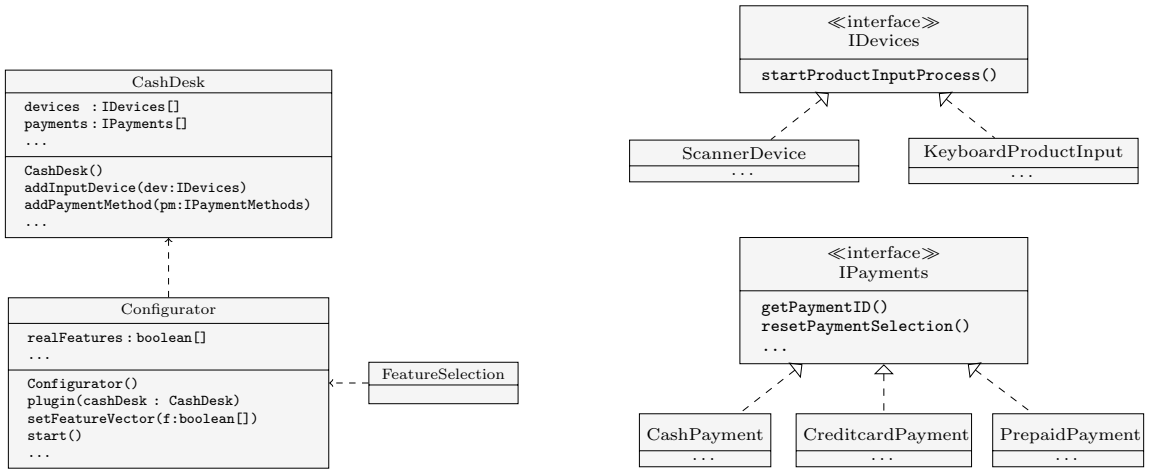


Figure 3.9: Feature diagram of the CoCoME cash desk feature

Figure 3.9. For each node there is a similarly named interface or class that represents or implements the feature. The class `CashDesk` shown in Figure 3.10(a) implements the behavior common to all possible cash desk configurations. A cash desk can be equipped with an arbitrary number of input devices and payment processes. It provides, therefore, methods to add input devices `addInputDevice(IDevices)` and payment methods `addPaymentMethod(IPayments)`. Each input device has to implement the interface `IDevices`. The interface `IDevices` defines the protocol for entering product identification numbers by declaring a common set of methods initiating and finalising the product input process. In our scenario, the supported input devices are keyboards (class `KeyboardProductInput`) and barcode scanners (class `ScannerDevice`) as shown in Figure 3.10(b). Supported payment methods need to implement the `IPayments` interface which defines the common protocol for financial transactions. It provides the `CashDesk` class to implement billing of the customer in a transparent way with respect to the underlying low-level payment protocol.



(a) Class diagram of `CashDesk` controller (b) The feature hierarchy as implemented in Java

Figure 3.10: Selected classes and interfaces of the Java implementation

Our implementation of variability points is substantially different to the CoCoMe implementation in [30] and is an almost complete rewrite of it except for the graphical user interface. In principle, our implementation admits to change the feature configuration of an already deployed system at run-time. This means that resolution of variability points happens dynamically rather than statically. In our case study, however, dynamic variability point resolution is not exploited, but restricted to simulate static resolution. Thus, once the system has been setup, its configuration is considered to be fixed. The dynamic evolution of features after system initialisation are beyond the scope of the report and subject of future work.

We explain now how feature selection and the initialisation of the cash desk system are implemented. At start of the configuration phase the user is asked to customize the system by selecting a feature combination with help of a graphical user interface. When the user finished feature selection the chosen configuration is passed to an instance of the `Configurator` class which is responsible for the cash desk system deployment phase (see Figure 3.10(a)).

The feature configuration is passed as a bitvector (represented as boolean array) to the method `setFeatureVector(boolean[] f)`. The encoding of feature configurations as bitvectors is canonical: the length of the vector is the same as the number of available features and each bitvector element represents exactly one feature (feature f_i is selected iff `f[i]==true`). If the selected feature configuration is invalid, then the configuration phase is aborted and an exception of type `FeatureException` thrown. Otherwise the feature array is assigned to the field `realFeatures`. Subsequent invocation of the `start()` method triggers creation and initialisation of the cash desk system.

First an instance of the class `CashDesk` is created. Then the `plugIn()` method of the `Configurator` is called which equips the created `CashDesk` instance with the chosen features and accessories like keyboards or scanners by creating the respective instances and registering them at the `CashDesk` instance. The presence of this plug-in mechanism makes dynamic feature selection principally possible.

JML Representation of the Feature Model

In a subsequent step we developed an automatic translation of feature diagrams into JML specifications following closely the approach presented in [13] for propositional logic. The approach is explained in detail in [7], we describe here only roughly the basic idea. For a short introduction to JML we refer to Section I.1.

The basic idea is to declare a boolean-array typed model field

```
//@ model public nullable boolean[] feature;
```

where each array component represents one node of the feature tree (graph). A feature is selected if and only if its assigned array component has been set to **true**. The graph structure and, in particular, the different kind

of edges expressing dependencies among the features are then expressed as set of conjunctively connected JML invariants over the model field `feature`. For example, the JML invariant

```
feature[NonCash] ==> feature[CreditCard] || feature[PrepaidCard]
```

expresses that if the feature NonCash is selected then at least one of the features CreditCard or PrepaidCard have to be selected too.

As mentioned before the translation of a feature diagram into a JML specification fragment used to construct class invariants and method specifications is done automatically.

On the specification side the remaining task is to connect the feature diagram JML specification to the actual implementation. For this purpose JML provides the possibility to specify how model fields and their values are reflected in the implementation using the **represents** construct.

We used the generated feature specification then to ensure that

1. the `Configurator` accepts only *valid* feature configurations;
2. the `CashDesk` system built by the `Configurator` has all components required by the selected feature configuration.

Verification

We used the KeY verification system [6] to prove that the feature configuration validity check and the cash desk system setup procedure are implemented faithfully with respect to its specification.

We were in particular interested how well a current state-of-the-art verification tool scales when verifying highly adaptable software as developed in the context of Software Product Families. Before we could start

```
public void plugIn(CashDesk cashDesk) {
  if (realFeatures[SCANNER]) {
    final ScannerDevice scanner = new ScannerDevice(cashDesk);
    cashDesk.addInputDevice(scanner);
    cashDesk.addStateChangeListener(scanner);
  }
  if (realFeatures[NONCASH] && realFeatures[CREDITCARDREADER])
  ...
```

Figure 3.11: If-cascade implementing the cash desk initialisation logic

the verification of our CoCoMe subsystem, we had to adapt the derived JML specification slightly. The reason is that KeY's support for model fields is somewhat rudimentary. Thus we decided to replace the `feature` model field by a ghost field of the same name. As the semantics of model fields is much more complex than that of ghost fields, we had also to change and extend JML specifications referring to the model field to achieve an equivalent and correct specification. Such a replacement is not possible in general but worked here well in our context due to the simple `represents` clause and by assuming a closed system, i.e., that all classes implementing input devices and payment methods are known in advance.

We were able to verify the correctness of the validity check and most parts of the actual cash desk creation and initialisation. In its original version the latter had been a monolithic method (`plugIn()` of class `Configurator`) consisting of if-cascades as shown in Figure 3.11. Verification of this method was infeasible as the proof size exploded. We modularised the monolithic method and separated each if-cascade representing the creation and registration of a device or payment method into different methods. The specification of one of these methods `checkScanner(CashDesk)` is given in Figure 3.12. Afterwards we were able to verify most of the individual methods in isolation. Figure 3.13 shows statistics about the performed proofs and their size.The given numbers are those of the final versions after incorporating a number of optimisations that become imminent when dealing with software product families. Actually, our first proofs had four times the size of those shown here. The lessons we learned during the verification were

```
/*@ public normal_behavior
  @ requires feature!=null && feature[_scanner];
  @ ensures
  @  (\exists ScannerDevice sd; \fresh(sd);
  @    (\exists int i; 0<=i && i< cashDesk.stateChangeListenerSize;
  @       cashDesk.stateChangeListener[i]==sd) &&
  @        (\exists int j; 0<=j && j< cashDesk.devicesSize; cashDesk.devices[j]==sd));
  @ assignable
  @  \object_creation(ScannerDevice),\object_creation(Scanner),
  @  cashDesk.stateChangeListenerSize, cashDesk.stateChangeListener,
  @  cashDesk.stateChangeListener[cashDesk.stateChangeListenerSize],
  @  cashDesk.devicesSize, cashDesk.devices, cashDesk.devices[cashDesk.devicesSize];
  @*/
```

Figure 3.12: Specification of the `checkScanner` method

the following: (i) Feature diagrams realise a compact representation of the feature space. Their encoding in logic is therefore prone to exponential proof size explosions when proof search strategies start to enumerate all possible configurations. Further, the methods for checking validity of configurations and for system initialisation are basically long and deeply nested cascades of conditional statements. The latter makes an efficient symbolic execution engine necessary that is able to merge paths afterwards or to avoid branching by other means like statement local contracts (used here) or partial evaluation [8]. (ii) Incremental verification techniques will be the key to reduce repeated proofs of the same (or highly similar) subproblems.

Method	Nodes	Branches
checkScanner	8366	99
checkCash	3699	34
checkKeyboard	3812	38

(a) Ensure Postcondition

Method	Nodes	Branches
checkScanners	11825	148
checkCash	7411	80
checkKeyboard	7509	77

(b) Preserve Invariant

Method	Nodes	Branches
checkScanners	81047	1666
checkCash	18009	393
checkKeyboard	19443	429

(c) Correct Assignable Clause

Figure 3.13: Proof Statistics

3.5 Conclusion and Recommendations

In this chapter we presented the ABS modelling of the core parts of the Trading System. The ABS modelling language proved to be expressive enough to cover most behavioural aspects. The core model that has been developed in this task can be used in the following tasks as a basis to realise the more advanced use cases given in D5.1 [28]. Some previous work into that direction is already presented in Section 3.4.4.

3.5.1 Recommendations

After the experiences we made during the modelling of the Trading System in ABS, we gained some important insight into the strengths and the weaknesses of the current state of the ABS language. To sum up we give

a set of main recommendations for the future development of the ABS language.

- ABS should provide some kind of code reuse mechanism, comparable to class inheritance. Task 1.2 is currently working on the Delta concept, which could provide this.
- ABS should provide a module system to structure the code into encapsulated units that allow for hiding internal implementations, e.g., concrete data type representations. A module system is currently planned for ABS, its design should incorporate the experiences of this case study.
- ABS should provide more guarantees in the concurrency model, in particular regarding the ordering of messages, but also the scheduling of COG tasks.

Chapter 4

Virtual Office of the Future Case Study

4.1 Introduction

The Virtual Office of the Future (VOF) system case study, as described in D5.1 [28, Section 4], consists of several components and uses external technologies for communication and user interaction. Furthermore, configuration artifacts like deployment descriptors are involved that are crucial to the system's functionality.

We decided to model one of the core components of the system that is responsible for the communication. This component is called *Node Management* and connects nodes among each other and transports messages between them. In terms of platform independability this component is highly interesting since it needs to be deployed on every kind of device that interacts with the system, which can be a workstation with some operating system and network connection or a mobile device. Furthermore it can use different technologies to establish the communication between nodes. These technologies are used as external libraries.

The methodology is not the focus of the evaluation due to the early stage of the project. The goal of this evaluation is to show the feasibility and expressive power of the ABS language and related tools and to collect feedback from practitioners. In order to do so, a single component from the VOF System has been modeled by using ABS.

Since there currently is no specification method defined in the HATS methodology, we decided to use the KobrA approach [5]. There are several reasons for doing so: It can be done in a lightweight way so that it fits in a small example. It allows to specify methods in a semi-formal way which will be a good starting point for the formal ABS language. Since the KobrA approach was not known to the language designers in detail it is a suitable test case for its flexibility.

We will now present the context of the case study, present the chosen component for evaluation and show the result of the specification done with KobrA and UML. There are some important quality aspects of the component that are intended to be addressed by HATS. The next steps are concerning the HATS methodology and their applicability for this small case study. Finally the results of using HATS for this example are evaluated. To do so the fulfillment of the quality objectives elicitated in D5.1 [28] will be assessed. The implementation in ABS can be found in the appendix.

4.2 Context of the Case Study

This section shortly introduces the context in which the component is situated. For this modeling example it is not so important how exactly this context works, but it helps to understand the tasks of the component in a better way. This section does not use ABS for presenting the component.

4.2.1 VOF-Node

A VOF-Node in general is the system's representation of an end device (e.g. Laptop, PC, Mobile Phone, PDA etc.) for users in the Virtual Office. Figure 4.1 displays the conceptual view of a VOF-Node. The

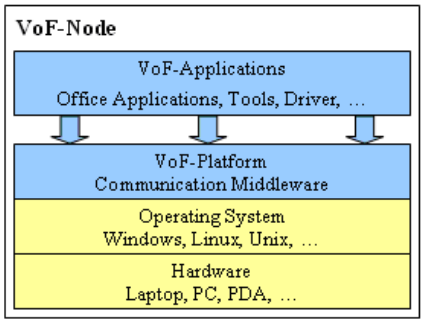


Figure 4.1: Conceptual VOF Node

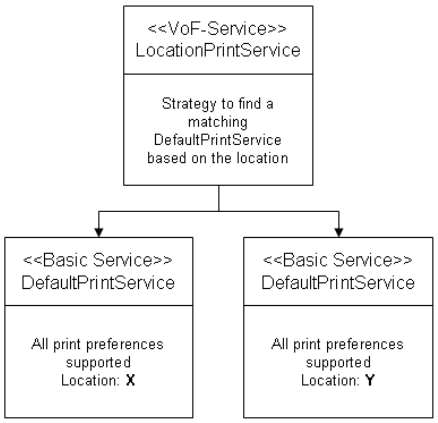


Figure 4.2: Description of a VOF-Service and its corresponding Basic Services

VOF-Platform on top of the operating system is the core component. It is responsible for the communication with other VOF-Nodes in the environment. The VOF-Platform acts as the communication middleware for each node in the VOF-Infrastructure. Further, the platform manages and provides executable services and also an interface for VOF-Applications. These applications are able to use all deployed services within the VOF-Environment [35].

4.2.2 VOF-Service

A Virtual Office Service (VOF-Service) is a service, which can be deployed or undeployed on the VOF-Platform. After the deployment, a service is executable from local and remote VOF-Nodes by using its underlying VOF-Platform. A VOF-Service contains program logic to support a user during his work in an office. By means of several criteria given by a VOF-Application, a VOF-Service chooses a matching underlying Basic Service and delegates the execution. A Basic Service is a fundamental service without a logic block. It is also executable and discoverable but only from VOF-Services. Figure 4.2 illustrates this concept by means of a location based print service. First this VOF-Service requests the current location of the VOF-Platform, afterwards it discovers all Basic Services, which are able to print documents. In the last step the VOF-Service delegates the print job to the underlying Basic Service, which maps to the nearest location [35].

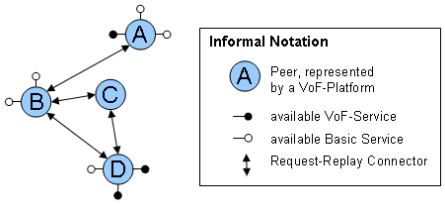


Figure 4.3: Peer-to-Peer View of a Virtual Office Infrastructure

4.2.3 VOF-Environment and Infrastructure

The VOF-Environment is a distributed system based on a decentralized network topology. This means that every member of the VOF-Environment has equivalent capabilities and responsibilities, which is realized as a peer-to-peer (P2P) solution. Inside the system, each VOF-Node provides different executable VOF-Services and Basic Services for other VOF-Nodes in the system. Within the Environment, each provided service can be discovered and executed by other VOF-Nodes. Figure 4.3 displays an example of a VOF-Environment, containing four peers (VOF-Nodes) and their deployed services. The following example illustrates a service call in the VOF-Infrastructure: C is able to discover a VOF-Service located on peer A. The logic containing in those service, discovers a Basic Service on D and delegates the call for execution. The Feedback of D is sent back to C via A [35].

4.3 Specification of Chosen Component

As mentioned above we have chosen the Node Management as the component we want to model with ABS. We decided to specify the component using the KobrA approach [5]. A specification in KobrA consists of a structural, behavioral and functional model, together with non-functional requirements, the quality documentation and a decision model. We did not do a full-fledged specification with all these artifacts, since we just want to focus on a single component that we want to implement using the tools and methods provided by HATS. Details about the purpose of each artifact in the specification are presented in the following sections. The artifacts that are used to specify the component in KobrA are not using ABS.

4.3.1 Component Description

The Node Management, that is available in each node, is responsible for establishing connections to other nodes that are reachable via some network. The communication between nodes can be in synchronous or asynchronous mode. Hence, each Node Management has a synchronous and asynchronous communication channel. It provides the communication infrastructure for all other components in the architecture. That means, each component can communicate with their counterpart on other Nodes. Furthermore, it caches and administrates all other Nodes and their communication channels by a logical id, which maps to its physical destination address.

Currently the component is implemented in Java, consists of 5 classes and interfaces and has a size of $\sim$ 600 LoC.

4.3.2 Structural Model

The structural model, as shown in in figure 4.4, shows the structure of the component's environment in a UML class diagram with a focus on the Node Management. Only components that are directly related are shown.

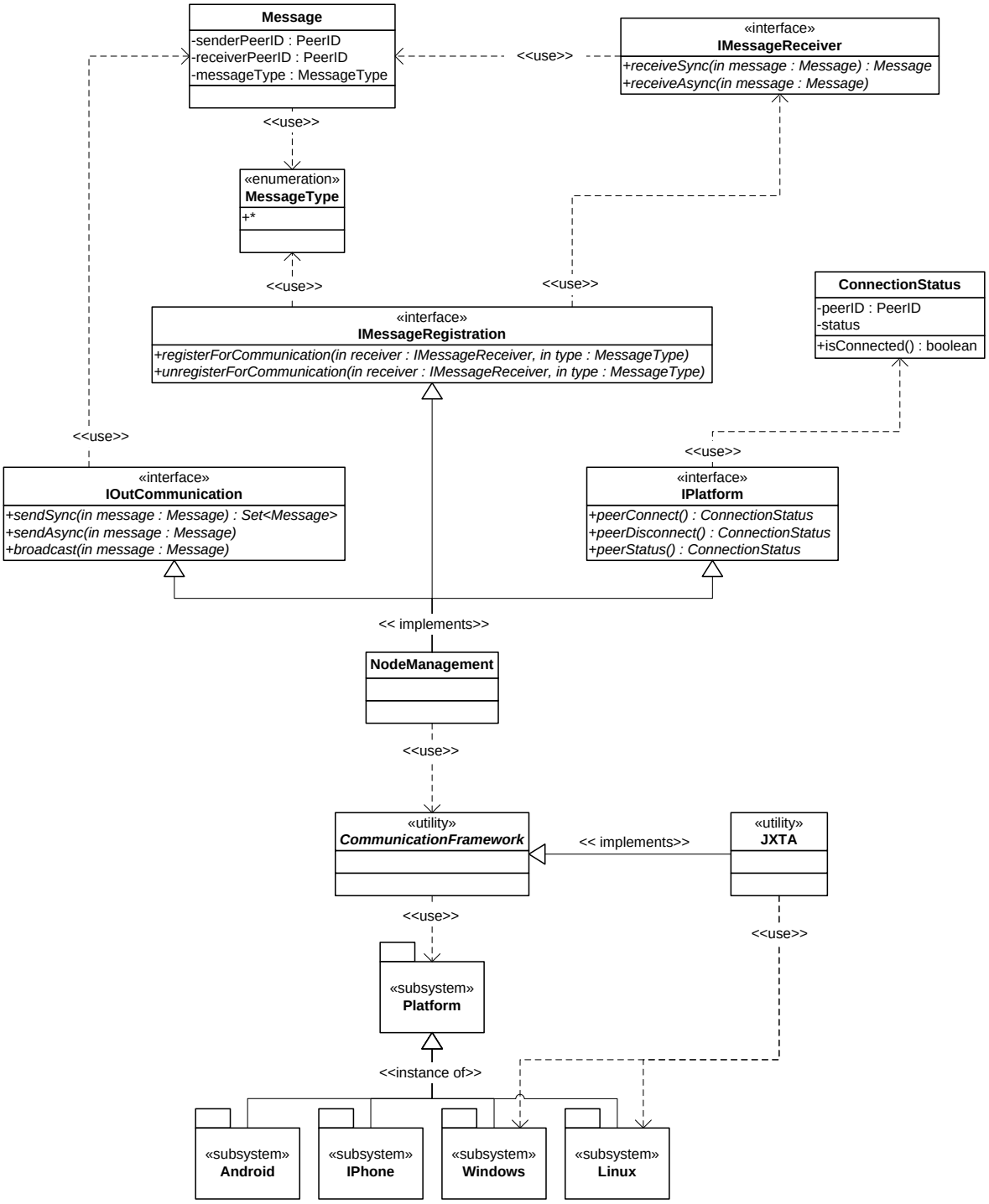


Figure 4.4: Node Management: Structure

4.3.3 Functional Model

This section gives a brief specification of the operations the Node Management offers. Each operation is specified in a template provided by [5] that is shown in Table 4.1. A template for that table is shown in Table 4.1.

The component has several interfaces with different responsibilities which are described in the following sections. Each of the interface represents a role that the component can have.

Operation Specification

The operations of each interface presented above will be specified in the following section. To ease the formal specification of the operations these definitions are made:

Definition 1. *Let $nm(n)$ be the NodeManagement in node n.*

Definition 2. *Let N be the network of all connected nodes with $N{:=}\{n|nm(n).\ getConnectionStatus().isConnected()\}$.*

Definition 3. *Let $id(N)$ be the set of ids of all connected nodes in the network with $id(N) := \{nm(n).\ peerStatus().peerID|n \in N\}$.*

Definition 4. *Let $mr(n)$ be the set of all potential MessageReceivers in node n.*

Definition 5. *Let $mrt(n, mt)$ be the set of all registered MessageReceivers in node n for messages of type mt defined as $mrt(n, m) := \{mr \in mr(n)|nm(n).\ registerForCommunication(mr, mt)$ was called $\}$*

Definition 6. *Let $MRT(mt)$ be the set of all registered MessageReceivers for messages of type mt defined as $MRT(mt) := \{mr \in mrT(n, mt)|n \in N\}$*

Definition 7. *Let $s(m)$ be the sending node of a message m with $nm(s(m)).\ peerStatus().peerID = m.senderPeerID$*

Definition 8. *Let $r(m)$ be the receiving node of a message m with $nm(r(m)).\ peerStatus().peerID = m.receiverPeerID.$*

IOutCommunication

is responsible for sending messages within the P2P-Network. Note that the addressee is an attribute of the message (like a letter in an envelope). Three operations are specified in Tables 4.2, 4.3 and 4.4.

IMessageRegistration

offers the possibility for other components in the system to register or unregister for a specific message type. Two operations are specified in Tables 4.5 and 4.6.

IPlatform

connects or disconnects the platform to the P2P-Network. Two operations are specified in Tables 4.7 and 4.8.

4.3.4 Behavioral Model

The behavioral model of a component shows how it reacts to external stimuli [5]. It can be represented in a textual form or as an UML state-chart diagram. A state-chart diagram that provides the behavioral model of the Node Management is shown in Figure 4.5. The states that are presented there are only conceptual, they do not need to be reflected directly in the realization. The operations that cause a transition between the states of the component are denoted on the edges that connect the states. If an event results in calling operations on other components, the syntax in the diagram is “event / external operations”.

Name	name of the operation
Description	identification of the purpose of the operation, followed by an informal description of the normal and exceptional effects
Constraints	properties that constrain the realization and implementation of the component
Receives	information input to the operation by the invoker
Returns	information returned to the invoker by the operation
Sends	signals the operation sends to imported components; can be events or operation invocations
Reads	externally visible information accessed by the operation
Changes	externally visible information changed by the operation
Rules	rules governing the computation of the result
Assumes	weakest pre-condition on the externally visible state of the component and on the inputs (in receives clause) that must be true for the component to guarantee the post-condition (result clause)
Result	strongest post-condition on the externally visible properties of the component and the returned entities (returns clause) that becomes true after execution of the operation with true assumes clause

Table 4.1: Template for operation specification

Name	sendSync(Message) : Set<Message>
Description	Sends a message synchronously to a known receiver, waits for the response messages and returns them.
Constraints	Waiting on a potentially unreachable receiver needs a smart timeout mechanism to avoid freezing the system.
Receives	A message with the valid identifier of the receiver.
Returns	The response message of the receiver.
Sends	The given message to the receiver in the network.
Reads	-
Changes	-
Rules	The message will be sent only to receivers that are currently available in the network. If the receiver is currently not connected, the message will not be send. The components registered at the receiver for that message type need to calculate results for that message that are returned to the sender. Until these results are received the sender is blocked. In case that several components are registered for that message type the result is a set of messages.
Assumes	The operation peerConnect was executed successfully and no connection interruption happened.
Result	For all messages m where the sending node $s(m) \in N$ and the receiving node $r(m) \in N$ holds that rm, as the set of all messages obtained as the result of the receiveSync(m) operation invoked on all registered MessageReceivers $mrt(r(m), m.\text{messageType})$ is equal to the result of the operation sendSync(m) invoked on the NodeManagement $nm(s(m))$ of the sending node.

Table 4.2: Operation specification: sendSync(Message) : Set<Message>

Name	sendAsync(Message) : void
Description	Sends a message asynchronously to a known receiver without waiting for a response.
Constraints	If the control flow is returned immediately to the sender there might be the need to implement a queueing mechanism.
Receives	A message with the valid identifier of the receiver.
Returns	-
Sends	The given message to the receiver in the network.
Reads	-
Changes	-
Rules	The message will be sent only to receivers that are currently available in the network. If the receiver is currently not connected, the message will not be send. The sender can continue immediately after submitting the message to the Node Management. There is no blocking until the message is send.
Assumes	The operation peerConnect was executed successfully before and no connection interruption happened.
Result	For all messages m where $s(m) \in N$ holds that if $nm(s(m))$.sendAsync(m) is called $\Rightarrow \forall\ mrt(r(m), m.\text{messageType})$ the operation receiveAsync(m) is invoked. is called.

Table 4.3: Operation specification: sendAsync(Message) : void

Name	broadcast(Message) : void
Description	Broadcasts a message to all peers in the P2P-Network. A broadcast is always asynchronous, that means that no response messages are collected.
Constraints	-
Receives	Any message, if a receiver is set, it will be ignored.
Returns	-
Sends	The given message to all reachable peers in the network.
Reads	-
Changes	-
Rules	The message will be sent only to the nodes that are currently available in the network. The sender can continue immediately after submitting the message to the Node Management. There is no blocking until the message is send.
Assumes	The operation peerConnect was executed successfully before and no connection interruption happened.
Result	For all messages m where $s(m) \in N$ holds that if $nm(s(m))$.broadcast(m) is called $\Rightarrow \forall\ \{mrt(n, m.\text{messageType}) \mid n \in N\}$ the operation receiveAsync(m) is invoked.

Table 4.4: Operation specification: broadcast(Message) : void

Name	registerForCommunication(Component, MessageType) : void
Description	registers a component for a specific message type. If a message of this type is received it is forwarded to all registered components.
Constraints	The specifications of sendSync, sendAsync and broadcast need to be fulfilled
Receives	A component that implements the MessageReceiver interface A valid MessageType
Returns	-
Sends	-
Reads	-
Changes	-
Rules	A component cannot register twice, messages are only delivered once per component.
Assumes	-
Result	No direct result is visible.

Table 4.5: Operation specification: registerForCommunication(Component, MessageType) : void

Name	unregisterForCommunication(Component, MessageType) : void
Description	unregisters a component for a certain message type.
Constraints	The specifications of sendSync, sendAsync and broadcast need to be fulfilled, especially that only registered components can receive messages
Receives	A component that implements the MessageReceiver interface A valid MessageType
Returns	-
Sends	-
Reads	-
Changes	-
Rules	A component can only unregister for a message type if it registered for that type before. Unregistering a not registered component will have no effect. If a component unregistered it will not receive any messages of that type after that.
Assumes	-
Result	No direct result is visible.

Table 4.6: Operation specification: unregisterForCommunication(Component, MessageType) : void

Name	peerConnect() : ConnectionStatus
Description	connects the platform to the P2P-Network and returns the status of the connection.
Constraints	For all nodes n holds that if the call $nm(n)$.peerConnect().isConnected() return *true* all future calls of $nm(n)$.peerStatus().isConnected() are *true* if no connection interruption occurs or $nm(n)$.peerDisconnect() is called.
Receives	-
Returns	The ConnectionStatus of the connection to the P2P network that was established.
Sends	Several low-level technical messages will be send, but they are not in the focus of this specification.
Reads	-
Changes	peerStatus() will change if the operation is executed successfully.
Rules	The ConnectionStatus that is returned will only be connected if the connection could be established successfully. Calling peerConnect() on an already connected node will have no effect.
Assumes	-
Result	No direct result is visible.

Table 4.7: Operation specification: peerConnect() : ConnectionStatus

Name	peerDisconnect() : ConnectionStatus
Description	disconnects the platform from the P2P-Network and returns true, if the connection was terminated.
Constraints	For all nodes n holds that if the call $nm(n)$.peerDisconnect().isConnected() returns *false* all future calls of $nm(n)$.peerStatus().isConnected() are *false* if $nm(n)$.peerConnect() is called.
Receives	-
Returns	The ConnectionStatus of the connection to the P2P network that was closed.
Sends	Several low-level technical messages will be send, but they are not in the focus of this specification.
Reads	-
Changes	peerStatus() will change if the operation is executed successfully.
Rules	The ConnectionStatus that is returned will only be disconnected if the connection could be closed successfully. Calling peerDisconnect() on an already disconnected node will have no effect.
Assumes	The operation peerConnect was executed successfully executed before and no connection interruption happened.
Result	No direct result is visible.

Table 4.8: Operation specification: peerDisconnect() : ConnectionStatus

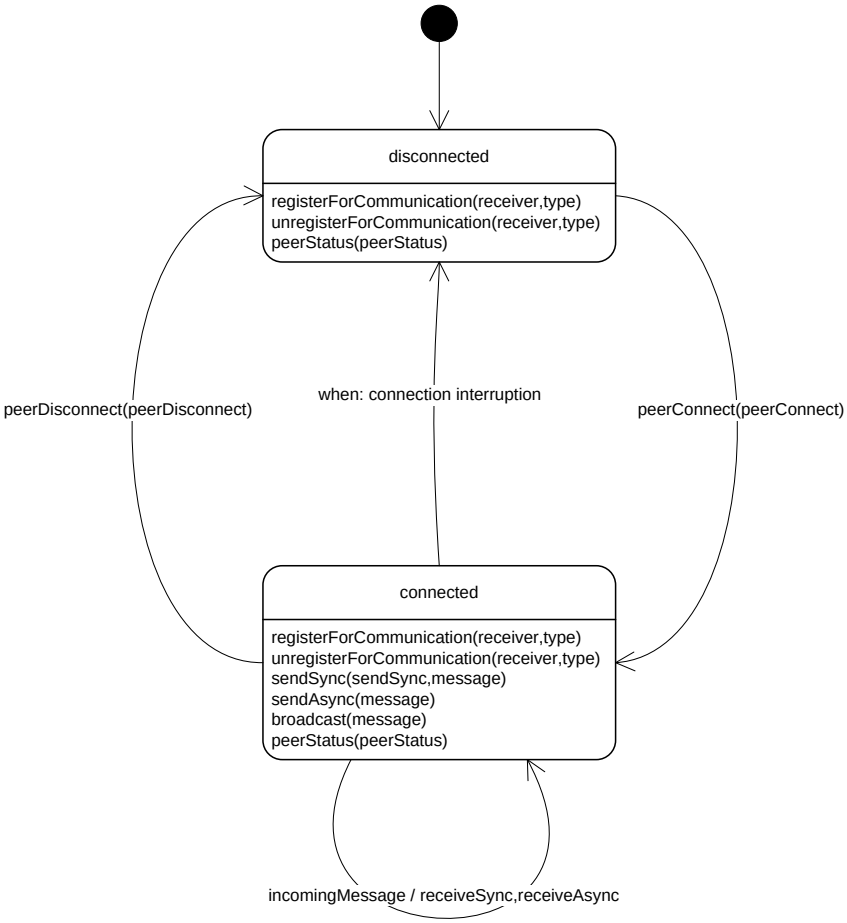


Figure 4.5: Node Management: Behavior

4.4 Spotlight on HATS Methodology

The HATS methodology as described in D1.1.b [23] is intended for running a product line of large scale information systems. In general the VOF system is intended to be a product line. But due to its nature as a research project it was and will most likely never be realized in a complete manner. The example that is used for the evaluation is not a product line, too. We have chosen a part of the system to be realized with the currently available instruments.

At this early stage of the project the evaluation cannot focus on the complete HATS methodology. The chosen example is a small piece taken from the complete VOF case study to show that the ABS language is powerful enough to realize complex components in a short time and in a reproducible way.

Hence the following section will give an idea how the tasks performed during the evaluation can fit in the overall HATS methodology. We do not consider evaluating the methodology with this approach, it just shows that it is broad enough to even map the realization of a single product onto it.

Application Engineering Planning The planning phase, that was done during the evaluation, had the goal to find out which component of the complete VOF case study should be realized with ABS. HATS does not aim to support this planning, as mentioned in [23, Section 3.1.1].

Product Line Requirement Analysis As described in the methodology this phase intends to create a feature model, behavioral types and capture variability in these artifacts using delta models.
The requirements for the component that is realized were taken from existing work [35]. Features were described textually due to the simplicity of the component and to the fact that feature modelling is not fully developed, especially the tool support is not finished. Behavioral types in terms of ABS interfaces were specified in this phase. These types are represented by interfaces in the structural model. Their detailed specification was done with the help of a more expressive notion, which is the operation specification in the functional model (see section 4.3.3). Since there is no variability and the mechanisms in ABS are not yet present, no modeling of variation points was conducted.

Generic Component Design The methodology intends to provide executable components implemented in core ABS as the main design artifacts at the end of this phase. These components contain variation points to reflect the variability in the product line.
As mentioned above, there is no variability in this setting. The component was designed in that step with the help of a state-chart model (see section 4.3.4).
Depending on the viewpoint the ABS code that results from implementing the component can be seen as a design artifact. It can be executed using the Maude compiler and abstracts from the concrete data types in Maude. On the other hand it exposes all algorithms and internal core ABS data types. For future versions of the ABS language there will be a more precise distinction between the ABS model as a design artifact and the ABS code that implements the model.

Generic Component Realization According to the planned methodology this phase produces the implementation of the components either by manually realizing them or with the help of code generation. Similar to the discussion above the ABS code can be seen as the realization of the component or as its design artifact. If the ABS code is considered as its design model, the code that is generated by the Maude compiler would be the implementation. The other perspective is that the ABS code is the final realization, similar to code in a conventional programming language. As mentioned above, there will be a clear separation in future versions of ABS.

Product Construction and Integration Deriving a concrete product with the help of the instantiated product model and the generic components from the product line artifact base is the goal of this step. As mentioned above, we do not have a product line or an artifact base. The production construction roughly consisted of packaging the implementation artifacts together into a bundle of ABS files that can be compiled with the Maude compiler.

4.5 Evaluation

As mentioned above, the goal of this evaluation is not to find out if the methodology fulfills the methodological requirements formulated in [28]. At the current stage of the project, where most of the tasks are not completed and some of them have even not started, an evaluation that concerns one of the core results of the project (i.e., the methodology) can not be done in a sound way. The other core result of HATS, beside the methodology, is the ABS language. Its expressive power is a necessary requirement for the success of the methodology. Since the language is partly ready now, at least in a condition where it can be used, we are evaluating its power by checking if it is feasible to realize a part of the VOF system in ABS. If that is possible we have a clear indicator that the methodology can potentially fulfill its requirements since a necessary precondition (the power of its language) is satisfied.

Nevertheless we want to find indicators how the quality objectives formulated in [28] are currently fulfilled and what needs to be done so that they are satisfied completely. This will be discussed in the following sections.

4.5.1 Quality Objectives

The quality objects that will be taken into account during the evaluation are taken from [28]. They can be found in section A.1 and A.3 of this document, too. Not all objectives can be considered in the context of this example and at this stage of the project, so the following list is a selection of them. A complete evaluation with all objectives needs to be conducted in the following evaluations. The methodological requirements (MR) and the additional high level concerns that are specific for the VOF case study (VF) are the following:

MR7	Tailorability
MR10	Scalability
MR11	Learnability
MR12	Usability
MR13	Reducing manual effort
MR18	Integrated environment support
MR19	Existing modeling techniques support
MR22	Middleware abstraction
VF-C5	Code generation for workflow realization
VF-C6	Portability
VF-C13	Model mining
VF-C17	Code generation
VF-C18	System derivation

Table 4.9: Quality Objectives and Concerns

4.5.2 Execution

Following [34] this evaluation was conducted similar to a synthetic environment experiment in a controlled way. Since the evaluation has the goal to give evidence for the power of the ABS language there is no need to have it conducted in a larger group. It is sufficient to show that the chosen aspect of the case study can be realized in ABS once. The experiment had a more informal nature since it is intended to provide a first feedback about the current status of the project and is not considered as a final evaluation of the project.

As mentioned before we kept the intended methodology in mind and tried to map the tasks in the experiment onto steps in the methodology. Together with the first usage experiences of ABS this will give indications for the fulfillment of the requirements from [28] in the future.

Task	Duration
Specification using KobrA	6 hours
Introduction to ABS	7 hours
First steps with Eclipse editing support	1 hours
Implementation using Eclipse editing support	8 hours
Experiences with Maude Compiler	4 hours

Table 4.10: Experiment: Tasks and Time

The experiment was done by one person that already knew the HATS context and the basic concepts of the ABS language. Furthermore Java, ML [25] and the eclipse IDE including development of plug-ins were known. An overview with the times for each task is shown in table 4.10.

The specification was done using KobrA and it was conducted with the support of paper sketches and drawing tools. This is beyond the scope of the evaluation. It took about 6 hours to do the specification.

Before starting with the implementation of the component an introduction to ABS was needed. This was done using the language specification in D1.1.a [1], the preliminary ABS Tools User Guide with some ABS code examples. Around 7 hours were needed to gain enough experience so that the next task could be processed.

To realize the specified components the HATS tooling was used, which needs to be deployed in the Eclipse IDE. Due to the current development state, it was necessary to generate code manually before it was possible to run the ABS editor. This is likely to be changed in the future. About an hour was necessary to put the tooling in a running state.

After having the tooling environment running, the ABS code was written with the help of an editor that supports syntax highlighting and partially checks for syntactic correctness. The result was a set of ABS files that need to be compiled to finally check their type sanity. The implementation was done in 8 hours.

As a final step the resulting ABS code should be compiled with a prototype of a ABS to Maude compiler. Similar to the editing support there are parts of the compiler that need to be generated before it can be used. A problem in the current version of the compiler is its platform incompatibility. Although it is implemented in Java it can not handle any ABS files when it runs in Windows. Due to that it was not possible to compile the ABS code in that case study. About 4 hours were used for testing the compiler.

4.5.3 Evaluation Results

In this section the quality objectives mentioned in 4.5.1 are discussed. For every objective three aspects are considered:

- How does the HATS methodology currently fulfill the objectives and what work would be necessary for it to, in the future, fulfill all objectives.
- Is the ABS language powerful enough to support the methodology in an appropriate way? Are there any design flaws that might hamper the achievement of the quality goal?
- Does the current tooling support help the users of both the method and ABS? What needs to be improved?

MR7: Tailorability

Methodology Using KobrA for specifying the component that was intended to be modeled in ABS was possible. Especially the *formal operation specification* was helpful since it was to some extent similar to the final ABS code.

Language The *decomposition* in interfaces was completely supported by the ABS language. Since it is a commonly used mechanism for structuring software systems, this support is a clear indicator that the language can have the basic power to handle large scale information systems, as required in [28].

Tooling In general there is currently no technical functionality available that explicitly supports the usage of KobrA. Nevertheless it is *planned for future versions* of the tooling to support users during the first steps in defining an ABS model, like creating interface stubs from previous documentation. This would help in transforming the specifications in KobrA into ABS syntax.

MR10: Scalability

Methodology The example that was implemented using ABS was very small. As a result the methodology could not be applied fully, in fact only a *tiny part* of it was used. The focus was more on the language itself and the current tool support.
The method was planned for much larger systems and product lines, not for such small examples. A clear statement about the scalability of the method cannot be derived in this setting.

Language Currently the language does not support the separation of models in different files. This leads to *large files* with little structuring possibilities. The issue is known to the language experts of the HATS consortium and will be addressed in future versions of the language, in fact it is solved in the newest version. Another issue that might influence the scalability of the language is that *no inheritance on class level* is supported. This decision was taken to reduce the complexity when implementing the language and building validation tools for it. It is intended to help users of ABS by providing smart tool support that avoids the replication of code together with additional reuse mechanisms.

Tooling Since the current tooling is in a prototypical state there are no additional features available that would help to deal with large models. *Future improvements* are planned in parallel to the development of the language.

MR11: Learnability

Methodology This quality could not be measured for the method itself, since, as described above, only tiny parts of the method were used. The method is *based on existing product line approaches* and is in that sense not completely new and existing literature might be used for getting a general insight.

Language The learnability of the language both depends on the intuitivity of the language and on the quality of the documentation. At this stage of the project the documentation is not complete and will be evolved constantly. The main sources for information are the language specification in D1.1A [1], the ABS Tools User Guide that is under development, and the examples implemented in ABS.
The language specification is helpful in understanding the concepts behind the language, but could be presented in a more task-oriented way for learning to use the language. Someone who wants to use ABS for the first time might not be interested in the same details that a language experts wants to know. A *task-oriented guidance* will be helpful for that case and is planned. A helpful artifact to learn using ABS were the examples implemented by the language experts. Since they are used during development of the language they are always up to date and contain all available language constructs. Nevertheless these examples can not be a substitute for a guide.

Tooling The current available artifacts that document the tooling support are in a prototypical state. They exist and will be extended while the tooling itself is further developed. Positive to mention is that the documentation was always *up to date and consistent* with the tools.

MR12: Usability

Methodology During this experiment only some indications about the learnability, which is also a part of the usability, could be retrieved. They are described in the section above.

Language The same fact that was mentioned above for the usability of the methodology holds for the language, too.

Tooling The usability can be evaluated for both the Eclipse editing support and the ABS compiler. During the experiment both tools were used. In the current state of the project they are not integrated. The editing support can be used to write syntactical correct ABS programs, with some limitations. These programs are input for the compiler, a command line tool that is not integrated in eclipse.
Currently the usability of the tools offers possibilities for improvements. The editing support needs more features to speed up writing ABS programs, like code completion and content assist, as it is available in the eclipse Java editors. Furthermore the compiler needs to be integrated in eclipse and made accessible in the same way like other compilers. A good example might be again the integration of the Java compiler, that is seamlessly integrated in the editing support for Java.

MR13: Reducing manual effort

Methodology The methodology aims to help to reduce manual effort when it is used in a *product line* setting. Since this was not done in this experiment no reduction of manual effort by the methodology itself could be observed.

Language As mentioned above, inheritance is not supported on class level, so it might happen that code duplication is needed. Furthermore method signatures need to be copied from the interfaces to their implementing classes. This will be addressed by *future versions of the tooling*.

Tooling Reducing manual effort means that most code is not written by hand but generated by some tool. Currently this is not the case, but intended for future versions. Furthermore the editing support does not highlight inconsistencies that can be introduced by altering existing interfaces without doing these changes in the classes.
These issues are targeted for a *future version of the tooling* support. At this early and prototypical state of the project just a basic editing functionality for ABS artifacts is available.

MR18: Integrated environment support

Methodology The methodology is *currently not integrated* in the tool chain. This will be done later so that the artifacts produced with the tools can be easily mapped to the phases in the methodology.

Language With the help of the current editing support the language is *integrated in the eclipse environment*, which is a first step towards a complete integrated tool chain.

Tooling As mentioned in MR12 and MR13 there are some features that are missing in the current tool chain. These features are planned together with a integration of the tools in *future versions*.

MR19: Existing modeling techniques support

Methodology The specification phase of the experiment was conducted using the KobrA approach, as described in 4.3. Supporting this method was not planned, but the resulting specification could be easily used as input for implementing the component in ABS. This gives a clear indicator that the method is *open enough to support unplanned techniques*. Especially UML diagrams can be directly related to ABS artifacts.

Language The language at this development stage supports all modeling techniques that can be mapped to the interface, operation and class model of ABS. Since this model is quite *common and general* the language is able to cope with most existing modeling techniques.

Tooling Models can *currently not be automatically analyzed* or directly imported in ABS. HATS does not intend to provide a full fledged support for such model imports, but with an integrated tool chain in eclipse these features can be added easily if they are needed.

MR22: Middleware abstraction

Methodology It is intended that the methodology has *specific phases and processes for analyzing the environment* and thus also the middleware that is used by the system that is developed. At this stage of the project the techniques to do so are not yet ready, so there is no process defined now.

Language Currently the language only has basic features and no specific way to abstract from external systems. As the techniques to do so are ready they will be *integrated in the language*, too.

Tooling Since the techniques and the language are not yet in a state where abstraction of middleware technologies can be done the tooling does not offer any features related to that topic. Nevertheless the tooling will provide *specific mechanisms for abstraction* and integration of external systems.

VF-C5: Code generation for workflow realization

This concern was about the generation of code and workflow descriptors when a new workflow is introduced in the system. Since we did not have such a setting in the experiment we can point to the more general requirement *MR13: Reducing manual effort* here.

VF-C6: Portability

Portability is an important issue in the HATS project. Since the strategy for implementing the language includes generating simpler intermediate code from ABS artifacts it is in general possible to have *simple implementations of an intermediate code interpreter* for specific platforms.

VF-C13: Model mining

That concern is a specific instance of the more general requirement *MR22: Middleware abstraction* that is not applicable in the current setting where we do not integrate external systems.

VF-C17: Code generation

Similar to the concern VF-C5 it can be related to the requirement *MR13: Reducing manual effort.*

VF-C18: System derivation

Since we currently do not have middleware abstraction features and code generation functionality there is no way to automatically derive new products according to a change in the environment. This is *envisioned by the HATS project*, but needs the results of tasks that are currently in progress. For this first evaluation we can link the concern to the requirements MR22 and MR13.

Conclusion

As mentioned in the previous sections, HATS and ABS are in an early stage and by far not ready to be used in a broader sense. A lot of features are missing, they are currently under development or at least planned. In general, the results look promising, but at the current stage there are only indicators that the requirements can be fulfilled in the remainder of the project. Future evaluations need to proof that the quality objectives have been addressed in an appropriate way.

Chapter 5

Fredhopper Case Study

In this chapter we evaluate the expressiveness of the core ABS language by modelling two components of the Fredhopper Access Server (FAS). The first component is an application programming interface (API) for constructing multi-dimensional intervals (Fredhopper Interval API). Interval is an abstract data type (ADT) that forms part of the mechanism to facilitate *faceted navigations* over data values in FAS. This API provides methods to FAS that are accessed sequentially. The second component is the *Replication System*. The Replication System is responsible for synchronising the configurations and data from the FAS staging environment to multiple FAS live environments. These two components form the concrete test cases described in Requirements FP-R-1.1-1 and FP-R-1.1-2 in Tables 2.4 on Page 17 and 2.5 on Page 17 respectively.

The rest of this chapter is structured as follows. Section 5.1 gives an overview of FAS and its deployment architecture; Section 5.2 describes the approaches used in this case study to derive core ABS models from existing Java [15] implementations; We present the modelling case studies in Sections 5.3 and 5.4. We discuss our modelling approach with respect to the HATS methodology in Section 5.5, and provide our evaluations of the core language and associated tool support in Section 5.6.

5.1 Overview

The Fredhopper Access Server (FAS) is a component-based, service-oriented and server-based software system, which provides search and merchandising IT services to e-Commerce companies such as large catalogue traders, travel booking, classified advertising etc. Specifically, FAS provides to its clients structured search capabilities within the client's data. This includes text search and structured navigation. Figure 5.1 shows a conceptual overview of FAS architecture, a more detailed informal description of each core component may be found in the requirement elicitation report [28, Section 5.1].

Physically, a FAS installation is deployed to a customer according to the FAS deployment architecture. Figure 5.2 shows an example of a typical FAS's deployment. A FAS deployment consists of a set of "environments", each environment contains one or more components shown in Figure 5.1. In the FAS deployment example shown in Figure 5.2, it consists of 2 live environments, a fail-over environment, a staging environment and a data manager. The figure also depicts interactions between client-side web applications and FAS, while the cloud labelled Internet represents the client's customer. Components in an environment interact by sending and receiving information among each other.

5.1.1 Search, Navigation and Intervals

Interval is a concept related to selection and navigation of data in a FAS deployment. In a FAS deployment, data is related to the information which one could search for. There are two fundamental building blocks for defining data:

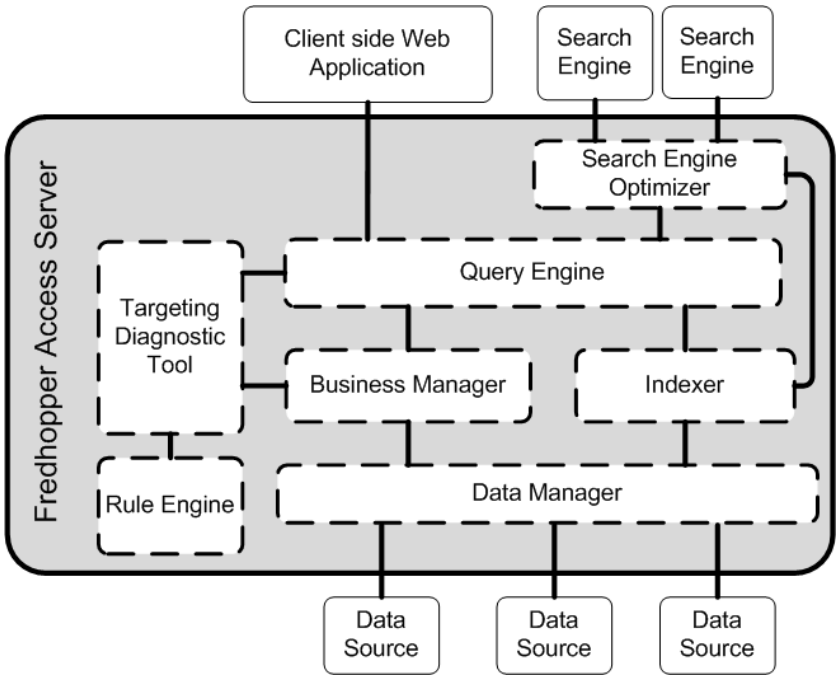


Figure 5.1: An Overview of FAS Architecture

Item An item is the central data element in FAS. It is composed of one or more *attributes*. Each item in a FAS deployment is uniquely identified.

Attribute An attribute has a name, a type (attribute type) and a value associated to it.

Specifically, an interval represents a list of the values an attribute has occupied. Intervals are employed as part of the mechanism for providing faceted navigations over data elements in FAS, such that users may navigate to a specific subset of data items flexibly. The Fredhopper Interval API implements the concept of interval over various types of attributes including numerical values, text, date, set, function and category. In Section 5.3 we provide detailed descriptions of the existing implementation, the specification and the executable model of the Interval API.

5.1.2 Environments and Replications

This section provides a brief overview of various types of FAS environments in a typical deployment architecture as well as the Replication System that ensures data consistency between environments. We provide a more detailed description of the data consistency property in Section 5.4.7. For the purposes of evaluating the core ABS language, we focus on the live and staging environments in a deployment architecture.

A live environment processes queries from client web applications via the Web Services technology. FAS aims to provide a constant query capacity to client-side web applications. In the deployment example in Figure 5.2 there are two live environments.

The primary role of the live environment is to serve queries from client side application via web services. A live environment consists of only two components: the *Query Engine* and the *Synchronisation Client* (SyncClient).

Query Engine The query engine is responsible for processing queries from client-side web applications.

SyncClient The SyncClient has the responsibility to keep up-to-date the index used by the query engine. The SyncClient on a live environment connects to the *Synchronisation Server* (SyncServer) on a staging environment and responds to incoming update changes to both data and configuration.

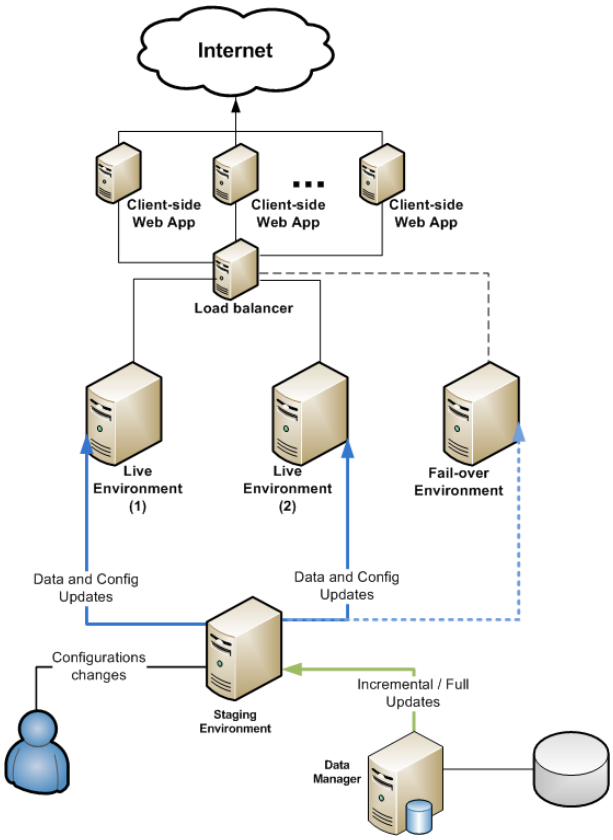


Figure 5.2: An example of a FAS's deployment

A staging environment is responsible for receiving client data updates in XML format, indexing the XML, and distributing the resulting indices across all live environments using the Replication System. In addition, the staging environment may run a business manager component, which allows for changing of the business configuration. A BM user may choose to publish and replicate a changed business configuration to all live instances. In the deployment example in Figure 5.2 there is a single staging environment. The example staging environment consists of a SyncServer, an indexer and a Business Manager (BM). Here we provide an overview of the responsibility of these components in a staging environment.

Indexer An indexer contains a XML loader, a search indexer and a navigation indexer, for processing incoming operation on items, and creating both search and navigation indices.

SyncServer The SyncServer in the example staging environment replicates configuration and data updates to the SyncClients running on the live environments.

Business manager The business manager is a management console. It allows business administrators to configure, monitor and measure how FAS influences their business. Specifically it is where changes to the configuration are made.

The Replication System synchronises the configurations and data from the staging environment to multiple live environments. Specifically the Replication System consists of the synchronisation server (SyncServer) and one or more clients (SyncClient). The replication protocol should guarantee ACID transaction properties [16] when updating both the configuration and data. ACID stands for atomicity, consistency, isolation and durability. It is a set of properites that guarantee correct transactional behaviour.

5.2 Approach

This section describes our approach to evaluate the core ABS language using the Fredhopper case study. Our evaluation consists the following two steps.

1. Extracts high-level formal specifications from the existing implementation of the components.

2. Translates the existing implementation of the components into ABS models based on the high-level specifications.

Step 1 is necessary as the current Java implementations of the components do not have precise specifications. Giving a formal specification helps us to gain a greater understanding of behaviour of the components that we are modelling. Unlike ABS models, high-level specifications are more abstract and are not executable. However, they allow us to carry out formal reasoning using existing tool support. To this end we are already able to establish some correctness properties. For example, we provide a process algebraic model of the replication system and verify that the model is free of both deadlock and livelock for up to ten synchronisation clients.

Furthermore, this approach is in line with the HATS methodology [9] and the development of the ABS language. In the HATS methodology, we understand that requirements of a product line can arise from existing products (legacy systems), we therefore argue the necessity to have a series of models, rather than a single model, each of which provides a different view point of the product that is to be constructed. While the current (core) ABS language is sufficient for constructing executable models, further development of ABS will include a behavioural interface language. The behavioural interface language aims to allow high-level specification of interaction between components (e.g. ABS classes, methods). Here the behavioural interface specification [20] of a component consists of the contracts that its operations must oblige as well as a protocol that describes permitted orders of interactions allowed to that component.

5.2.1 Contract-based Specification

To assist constructing an ABS model for the Interval API, we first derive a formal behavioural contract [24] of the API. Specifically, we define the behavioural contract using the Java Modelling Language (JML) [22]. JML is a specification language for Java programs. It is based on Hoare style pre- and postconditions and invariants [17] and follows the design by contract [24] paradigm. A brief overview of JML is given in Section I.1 of the appendix. We have chosen JML because of the following reasons:

- It is one of the input specification languages for the KeY system [6]. KeY system is one of the target tools that the HATS project aims to utilise for program verification [3], symbolic execution [8] and test case generation. By employing JML we aim to extend our case studies naturally for validating other techniques developed in the project.

- The ABS language is to include a behaviour interface language [1]. We aim to use behavioural interfaces to specify component behaviour at the level of the (reference) architecture [9]. However, at the time of writing, the ABS language has yet to include a behavioural interface language. As a consequence, ongoing work in the project related to behavioural interface specification, such as de Gouw et al.'s work on attribute grammars [14], have been investigated using JML.

- It is the de-facto formal specification language for Java. As a result we are able to directly annotate existing source code with behavioural contracts. Being a formal language with tool support such as KeY [6] and ESC/Java2 [12], we are able to carry out certain validation/verification on the existing implementation. For example, we are able to use KeY to discharge some of the proof obligations about postconditions and invariants, while ESC/Java2 provides warnings on possible violations of pre/postconditions and invariants.

5.2.2 Process-based Specification

To assist constructing an ABS model for the Replication System, we first derive a process algebraic model of the Replication System. In particular our model is specified in the language of Communicating Sequential Processes (CSP) [18, 29]. CSP is a formal language for describing the interactions between potentially non-terminating processes. In particular, we are able to model the Replication System as a parallel combination of processes. A brief overview of CSP is given in Section I.2 of Appendix I. We have chosen CSP because of the following reasons:

- ABS language will include a behavioural interface language. While class and method contracts specify the assumption and obligation on each invocation of a callee's method, behavioural contract in a concurrent setting must also include a precise description of the possible interactions the callee has with other objects during as well as between method invocations. As a result the ABS language will be extended to provide the ability to describe this kind of patterns of behaviours. While the behavioural interface language is under development, for now we choose an existing well-known formalism such as CSP to construct a high-level behavioural model of the Replication System.
- CSP comes with tool support such as the FDR tool [32]. With the appropriate level of abstraction we are already able to prove our replication models to be free of deadlocks and livelocks.

Table 5.1 gives a comparison of the components modelled in this evaluation, the type of high-level models derived from each component, the desirable functional properties that we would like to eventually to be able to verify and the actual validations carried out during evaluation.

Component	Interval API	Replication System
Behaviours	single-threaded	multi-threaded
High-level models	JML contracts	CSP models
Desirable properties	Correctness wrt. method contracts and class invariants	Deadlock and Livelock freedom, Replication consistency, Fault tolerance
Actual validations	Unit testing, Simulation, Functional abstraction	CSP refinement checks, Simulation

Table 5.1: A comparison of the components modelled in the Fredhopper case study

5.2.3 Presentation

To distinguish between different modelling, specification and programming languages used in this chapter, we adopt the following convention: We use the `typewriter` font for displaying Java source code and JML contracts, the Sans Serif font for displaying ABS models and *math* font for displaying CSP definitions. We use UML [26] to describe informally some of the component behaviours.

5.3 Interval

In this section we study the Interval API. We provide behavioural contracts for both interfaces and implementations of the API using JML and provide an executable model in the language of ABS. The interval API consists of three types of objects: `Interval`, `AttributeType` and `ItemVectors`. An `Interval` object defines some mathematical interval $[low, high]$, of an inclusive range of value of a particular attribute. An `AttributeType` object records the type of an attribute, it defines a (possibly infinite) range of values that the attribute value can belong to. An `ItemVectors` object records a vector of items, exposes each item's attribute values according to their attribute types.

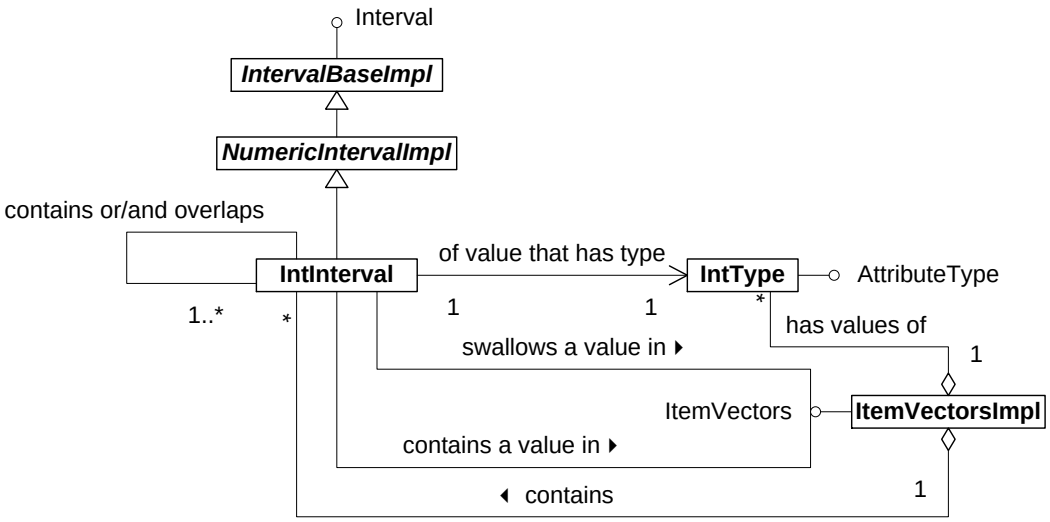


Figure 5.3: UML Class diagram of the Interval API

Figure 5.3 depicts a UML class diagram recording the associations between each types of classes and interfaces in this API. In this section we focus on providing an ABS model for integer interval specification. Integer interval is implemented by the class `IntInterval`. To assist our model construction we define mock interfaces and implementations of `AttributeType` and `ItemVectors`. We introduce them in Sections 5.3.1 and 5.3.2 respectively.

Specifically, we provide an abstract *functional* model of `IntInterval`. A functional definition of this API is an appropriate abstraction: Our model describes the abstract data types with pairs of the form (d, fs) where d is the data type definition and fs is a set of function definitions on d. Note that functional definitions are free of side-effect and are therefore more amenable to formal reasoning.

For each interface, we provide a formal behavioural contract in the language of JML [22]. While ultimately we aim to verify the correctness of the API with respect to its contract, this is beyond the scope of this work task. In this section these contracts are used to inform the construction of ABS models of the interfaces and classes. Note that a behavioural interface language for ABS is to be developed in Task 1.2 as part of the full ABS modelling framework. We hope to carry out some formal as well as empirical comparisons between interface specifications at the level of ABS and JML contracts in later work tasks.

5.3.1 `AttributeType`

Interface `AttributeType` specifies the type of an attribute. There are various implementations of `AttributeType`, each representing a particular attribute type (e.g. integer, function, set, category). Since we are only considering integer intervals, it is sufficient to provide a mock implementation of the integer attribute type `IntType`. Listing 5.1 shows the interface `AttributeType`. This interface provides methods to get name and id of the attribute type.

```
public interface AttributeType {
  //@ ensures \result != null && \result.length() > 0;
  public /*@ pure @*/ String getName();

  //@ ensures \result >= 0;
  public /*@ pure @*/ int getId();
}
```

Listing 5.1: Interface `AttributeType`

Listing 5.2 shows a mock implementation of the integer attribute type `IntType`. Since the preconditions of the constructor method ensures postconditions of the methods, in ABS we define IntType as the following type synonym of a pair of integer and string.

type IntType = Pair<Int,String>

The methods `getId()` and `getName()` are modelled as simply functions fst() and snd() over the parametric data type Pair<A,B> that return the first and second elements respectively.

```
public class IntType implements AttributeType {
  private final int id; //@ invariant id > 0;
  private final String name; //@ invariant name != null && name.length() > 0;

  //@ requires id > 0 && name != null && name.length() > 0;
  public IntType(int id, String name) { this.id = id; this.name = name; }

  //@ ensures \result == id;
  public /*@ pure @*/ int getId() { return id; }

  //@ ensures \result == name;
  public /*@ pure @*/ String getName() { return name; }
}
```

Listing 5.2: Mock implementation of `IntType`

5.3.2 `ItemVectors`

An `ItemVectors` object records a vector of items, and exposes each item's attribute values according to their attribute types.

```
public class ItemVectorsImpl {
  private final Number undef = new Integer(Integer.MIN\_VALUE);
  private int[] typeIds;
  private Object[] valuesAndIntervals;

  /*@ protected normal_behavior
       requires capacity >= 0;
       assignable typeIds, valuesAndIntervals;
       ensures typeIds.length == capacity;
       ensures valuesAndIntervals.length == capacity;
    @*/
  public ItemVectorsImpl(int capacity);
  public Object get(AttributeType attributeType) { .. }
  public int getIntValue(AttributeType attributeType, int i) { .. }
  public Number getNumberValue(AttributeType attributeType, int i) { .. }
  private void put(AttributeType attributeType, Object data) { .. }
  public void put(AttributeType attributeType, Interval data) { put(attributeType,(Object) data); }
  public void put(AttributeType attributeType, Number[] data) { put(attributeType,(Object) data); }
}
```

Listing 5.3: Class `ItemVectorsImpl`

We provide one interface `ItemVectors` and one implementation `ItemVectorsImpl`, that exposes exactly those methods specified by `ItemVectors`. Listing 5.3 shows the signature of the corresponding concrete class implementation `ItemVectorImpl`. Note that the detailed discussion of JML contracts of `ItemVectors` and `ItemVectorsImpl` is beyond the scope of this case study. For the purpose of presentation we consider only the behavioural contract of the constructor and one method. The full JML specification of `ItemVectors` and `ItemVectorsImpl` can be found in Section M.2 of Appendix M on Page 172.

The class `ItemVectorsImpl` has two private fields `typeIds` and `valuesAndIntervals`. The array `typeIds` stores an array of identifiers of attribute types that the item vector has data associated to. The array `valuesAndIntervals` stores the associated data, each element of which could either be a list of `Number` or an `Interval`. The class constructor has a contract if it takes some positive integer `capacity`, it ensures the length of `typeIds` and `valuesAndIntervals` to be `capacity`.

We notice that both public methods `put(AttributeType,Interval)` and `put(AttributeType,Number[])` are defined in terms of the private method `put(AttributeType,Object)`, which updates fields `valuesAndIntervals` and `typeIds`. We therefore consider the behaviours of `put(AttributeType,Object)`, whose JML contract is shown in Listing 5.4.

```
1  /*@ private normal_behavior
2        requires attributeType.getId() >= 0;
3        assignable typeIds, valuesAndIntervals;
4        ensures (\forall int i; 0 <= i && i < typeIds.length;
5            (typeIds[i] == -2 || typeIds[i] == attributeType.getId()) ==> valuesAndIntervals[i] == data);
6        ensures (\forall int i; 0 <= i && i < typeIds.length;
7            (typeIds[i] == -2 ==> typeIds[i] == attributeType.getId()));
8        ensures (\forall int i; 0 <= i && i < typeIds.length;
9            (typeIds[i] != -2 && typeIds[i] != attributeType.getId())
10             ==> valuesAndIntervals[i] == \old(valuesAndIntervals[i]) && typeIds[i] == \old(typeIds[i]));
11   @*/
12 private void put(AttributeType attributeType, Object data) {
13   int typeId = attributeType.getId();
14   for (int i=0; i<typeIds.length; i++)
15     if (typeIds[i] == -2) {
16       valuesAndIntervals[i] = data;
17       typeIds[i] = typeId;
18       return;
19     } else if (typeIds[i] == typeId) {
20       valuesAndIntervals[i] = data;
21       return;
22     }
23 }
```

Listing 5.4: JML specification of `put(AttributeType,Object)`

Specifically the contract specifies that given input `attributeType` has a positive id, the method ensures that for all ith position of `typeIds`, the ith value of `valuesAndIntervals` is updated to `data` if and only if the ith element of `typeIds` is either -2 or the id of input `attributeType`. Otherwise the ith value of `valuesAndIntervals` remains unchanged.

We now consider the ABS model of `ItemVectors`. Specifically, `ItemVectorsImpl` maintains a record of an array of integers `typeIds` and an array of objects `valuesAndIntervals`. In ABS we use the data type definition shown in Listing 5.5 to model `ItemVectorsImpl`.

```
data Number = UndefinedNumber | IntValue(Int);
data ItemVectorData = NullData | IntervalData(IntInterval) | NumberListData(List<Number>);
type ItemVectors = Pair<List<Number>,List<ItemVectorData>>;
```

Listing 5.5: ABS data types for ItemVectors

We define Number, which either models an `Integer` object (IntValue(Int)) or a `null` object (UndefinedNumber). Note that the methods in the class `ItemVectorsImpl` suggest that an object in `valuesAndIntervals` is either an `Interval` or an array of `Number` objects. We therefore define data type ItemVectorData as either IntervalData(IntInterval), denoting an `Interval`, or NumberListData(List<Number>), denoting an array of `Number` objects, or NullData, denoting an `null` object.

An ItemVectors is a pair. The first element is a list of integer List<Number> and it models the array of integers `typeIds`. The second element is a list of ItemVectorData values and it models the array of objects `valuesAndIntervals`.

Listing 5.6 shows the ABS model of `ItemVectorsImpl.put(Attribute,Object data)`, denoted by the function definition putValue(). The function takes an ItemVectors that is to be updated, an IntType and an ItemVectorData, and returns the updated ItemVectors.

```
1  def ItemVectors putValue(ItemVectors iv,IntType it,ItemVectorData item) = putData(iv,it,item,0);
2  def ItemVectors putData(ItemVectors iv,IntType it,ItemVectorData item,Int i) =
3    let (Int j) = i + 1 in
4    case (i < length(fst(iv))) {
5      False => iv;
6      True =>
7        case (nth(fst(iv),i)) {
8          UndefinedNumber => Pair(put(fst(iv),IntValue(id(it)),i),put(snd(iv),item,i));
9          IntValue(s) =>
10           case (s == id(it)) {
11             True => Pair(fst(iv),put(snd(iv),item,i));
12             False => putData(iv,it,item,j);
13           };
14       };
15   };
```

Listing 5.6: ABS model of method `ItemVectorsImpl.put(Attribute,Object data)`

The function putValue evaluates the expression putData(iv,it,item,0), which is recursively defined over the length of first element of iv, that is, the array of attribute type ids.

5.3.3 `Interval`

An interval, notationally represented as $[low, high]$, describes an inclusive range of values of a particular attribute. In FAS, we aim to provide the flexibility to define intervals over numerical values as well as sets, functions and *graph-based values*.[1] Currently, we only consider integer intervals, we envisage intervals of other types of values will be considered as *variabilities* at later work tasks of the project.

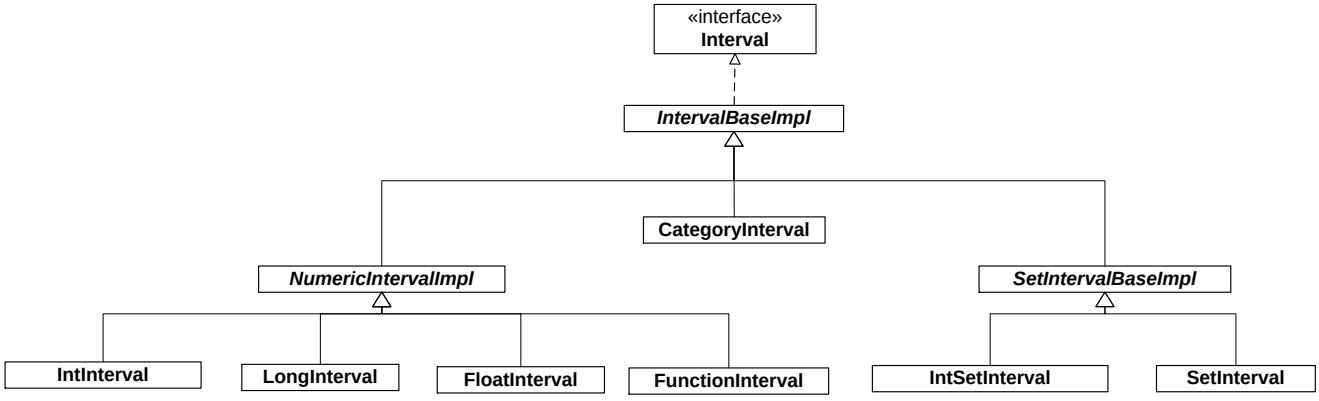


Figure 5.4: Class hierarchy of `Interval`

[1] Each graph-based value represents a node in a directed acyclic graph such that a graph-based value interval $[low, high]$ denotes all the nodes on paths from *low* to *high*

Figure 5.4 depicts a UML class diagram [26] recording the class hierarchy of various implementations of `Interval` that are currently in the Interval API.

For the purpose of the evaluation of the core ABS language, we focus on the class `IntInterval`, which provides an implementation for intervals over integer ranges. We therefore consider the interface `Interval`, two abstract classes `IntervalBasedImpl` and `NumericIntervalImpl`, and the concrete implementation `IntInterval`. Listing 5.7 shows the interface `Interval`.

```
public interface Interval {
  //@ public model instance int undef, highModel, lowModel;
  //@ public model instance boolean hasnull;
  //@ public instance invariant highModel >= lowModel;
  //@ public instance invariant undef < 0;

  public boolean contains(Interval other);
  public boolean containsValue(Number value);
  public boolean containsValue(ItemVectors iv, int index);
  public AttributeType getAttributeType();
  public void setHasNull(boolean hasNull);
  public boolean hasNull();
  public boolean overlaps(Interval other);
  public boolean swallow(ItemVectors iv, int index);

  /*@ public normal_behavior
        requires other == null;
        ensures \result == false && hasnull == true &&
                lowModel == \old(lowModel) && highModel == \old(highModel);
    also
      public normal_behavior
        requires other != null;
        ensures \result == ((undef != other.lowModel) && (other.lowModel < lowModel)) ||
                           (other.highModel > highModel);
        ensures hasnull == \old(hasnull) || other.hasnull;
        ensures
          ((undef != other.lowModel) && (other.lowModel < lowModel) ==> lowModel == other.lowModel) &&
          ((undef == other.lowModel) || (other.lowModel >= lowModel) ==> lowModel == \old(lowModel)) &&
          (other.highModel > highModel ==> highModel == other.highModel) &&
          (other.highModel <= highModel ==> highModel == \old(highModel)); @*/
  public boolean swallow(Interval other);
}
```

Listing 5.7: Interface `Interval`

It exposes standard methods to test whether an interval contains (`contains()`) or overlaps (`overlaps`) another interval. It provides additional methods to test if an interval contains a number or some data value in an indexed position of an item vector (`containsValue()`). An interval may accept null value in its range via method `sethasNull()` and it may swallow or consume another interval or a data value in an indexed position of an item vector (`swallow()`).

We now consider the behaviours of these methods more conceptually. For intervals a, b, we write $contain(a, b)$ and $overlap(a, b)$ to denote the relations "a contains b" and "a overlaps b". We write $swallow(a, b)$ to denote the interval after "a swallows b". Note that the relation *contain* is reflexive and *overlap* is both reflexive and symmetric, while operation *swallow* is commutative. Moreover, we assume neither a nor b is null. A non null interval contains or overlaps a null interval if and only if the method `hasNull()` returns true.

Figure 5.5 shows some example intervals. Each interval $i = [low, high]$ is represented as a line labelled with value i and where black dots at both ends of the line represent the values *low* and *high*. In the figure interval a overlaps with b, c, f and g, interval g overlaps with a, b, c and f. Since *overlap* is a symmetric relation we have just characterised the intervals in the figure with respect to the relation overlap. In terms

of containment, we see interval g contains a and c and interval f contains e. In terms of the operation *swallow*, if we consider intervals a and c, we see $g = swallow(a, c)$.

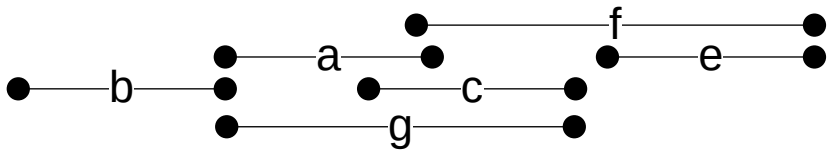


Figure 5.5: Illustrations of Interval

For the purpose of illustration, we consider the method `swallow()`, whose behavioural contracts are defined in Listing 5.7. The full JML specifications of interface `Interval` is shown in Section M.3 of Append M on Page 175.

```
1  public boolean swallow(Interval other) {
2    boolean result;
3    if (other == null) {
4      setHasNull(true);
5      result = false;
6    } else {
7      setHasNull(hasNull() | other.hasNull());
8      result = swallowIntervalInternal(other);
9    }
10   return result;
11 }
12
13 //@ requires other != null;
14 //@ assignable lowModel, highModel;
15 protected abstract boolean swallowIntervalInternal(Interval other);
```

Listing 5.8: Partial implementation of `swallow` by abstract class `IntervalBaseImpl`

```
1  public class IntInterval extends NumericIntervalImpl {
2    private int low; //@ in lowModel;
3    private int high; //@ in highModel;
4    //@ private represents lowModel <- low;
5    //@ private represents highModel <- high;
6    ...
7    protected final boolean swallowIntervalInternal(Interval other) {
8      boolean result = false;
9      IntInterval lother = (IntInterval) other;
10     if (lother.low < low && lother.low > UNDEF) {
11       setLow(lother.low);
12       result = true;
13     }
14     if (lother.high > high) {
15       setHigh(lother.high);
16       result = true;
17     }
18     return result;
19   }
20 }
```

Listing 5.9: Snippet of class `IntInterval` showing the implementation of `swallowIntervalInternal`

Listing 5.8 shows the partial implementation of method `swallow()` by abstract class `IntervalBasedImpl`. We can see how the implementation decomposes the definitions of method `swallow()` into an attribute type independent and an attribute type dependent parts.

Specifically, the contract is split into two parts. The first part of the contract describes how an interval swallows a null object. Given the assumption that the input interval is null, the method ensures that the return Boolean is false, that the model field `hasnull` is true and that no changes are made to endpoints. The second part of the contract describes how an interval swallows a non null interval. Given the assumption that the input interval is not null, the method ensures the followings: The return Boolean is true if and only if the `lowModel` of the input interval is defined and either it is less than `lowModel` of this interval or `highModel` of this interval is less than `lowModel` of the input interval. This interval accepts null objects if either it is already accepting null objects or the input interval does. End points are updated accordingly.

While the first part of the contract may be implemented generically using the corresponding methods `setHasNull()` and `hasNull()`, the second part is an expression over terms that are only at the model level. Therefore at the implementation level, the second part of the contract is implemented at Line 8, which invokes the abstract method `swallowIntervalInternal`. This method is implemented by `IntInterval` as shown in Listing 5.9.

We now consider the ABS model of method `swallow(Interval)`. We first provide data type definition IntInterval to model integer interval. IntInterval is a type synonym for a pair of pairs. The first element is a pair of integers denoting the endpoints of the interval. The second element is a pair Pair<Maybe<IntType>,Bool>, where the first element denotes a possibly null IntType attribute type and the second element denotes the JML model element `hasnull`.

```
type IntInterval = Pair<Pair<Int,Int>,Pair<Maybe<IntType>,Bool>>;
```

We provide the following function definition swallowIntInterval() in ABS over data type IntInterval.

```
def Pair<IntInterval,Bool> swallowIntInterval(IntInterval i, Maybe<IntInterval> other) =
  case other {
    Nothing => Pair(setHasNull(i,True),False);
    Just(o) => swallowIntIntervalInternal(setHasNull(i,snd(snd(i)) || snd(snd(o))),o);
  };

def Pair<IntInterval,Bool> swallowIntIntervalInternal(IntInterval i, IntInterval o) =
  let
    (Pair<IntInterval,Bool> sl) =
      case fst(fst(o)) < fst(fst(i)) {
        True => Pair(setLow(i,fst(fst(o))),True);
        False => Pair(i,False);
      }
  in case (snd(fst(o)) > snd(fst(i))) {
        True => Pair(setHigh(fst(sl),snd(fst(o))),True);
        False => sl;
     };
```

5.3.4 Unit Testing

As part of the quality assurance process at Fredhopper we heavily employ automatic unit testing. Unit tests are written to validate the correctness of the unit and to detect regressions. A unit test exercises a unit of functionality in a system and makes assertions about the state of that system after the unit's execution. Unit tests are written as programs. They are executed automatically when the component containing the units of code changes. To test units individually, unit tests have to make assumptions about the state of the system, that is, the preconditions of the tests.

For the Java implementation of intervals, we have provided unit tests for concrete methods implemented by `IntervalBaseImpl`, `NumericIntervalImplTest`, `IntInterval` and `ItemVectorsImpl`. In Fredhopper we use unit tests to detect regression. These test cases are implemented using the JUnit framework[2]. While the current JUnit test implementation is constructed manually, it can be used to inform the construction of ABS models of the Interval API to ensure that our model at least satisfies the behaviour specified by the test cases. Note that the aim of Task 2.3 "Testing, debugging and visualisation" is to investigate and develop tools for symbolic debugging, visualisation as well as test case generation. We therefore aim to use these existing unit test cases of the API for empirical comparison against automatically generated test cases.

The core ABS language has been given an operational semantics [1] and a Maude code generator waws provided to adapt semantics into the format of rewriting logic, which is executable on the Maude[3] engine. This allows us to simulate our ABS model. We therefore have implemented unit tests for functions: swallow(), swallowIntInterval(), overlaps(), containsInternal() and containsValueByVector(). For presentation purposes we consider the test function for swallowIntInterval().

Specifically, the tests evaluate the expression swallowIntInterval(test,param) and compare the return Interval against a set of test oracles. We first construct test cases. This is a list of triples where each element has the form Triple(Triple(p1,p2,p3),Triple(p4,p5,p6),Triple(p7,p8,p9)). The first component of the triple specifies the interval that performs the swallowing, the second component specifices the interval to be swallowed and the third component specifices the test oracle. Specifically, the first two components are given the following functional specification:

```
test = Pair(Pair(p1,p2),Pair(Nothing,p3));
param = Just(Pair(Pair(p4,p5),Pair(Nothing,p6)));
```

While the third component defines the following tests:

```
p7 == fst(fst(fst(swallowIntInterval(test,param))));
p8 == snd(fst(fst(swallowIntInterval(test,param))));
p9 == snd(snd(fst(swallowIntInterval(test,param))));
```

Here we show some example test cases.

```
Triple(Triple(5,10,False),Triple(6,8,False),Triple(5,10,False));
Triple(Triple(5,10,False),Triple(2,6,False),Triple(2,10,False));
Triple(Triple(5,10,False),Triple(11,12,True),Triple(5,12,True));
Triple(Triple(5,10,False),Triple(2,11,True),Triple(2,11,True));
```

We then define the following test function testSwallowFun.

```
def Int testSwallowIntervalFun(List<SwallowTestInput> testData) =
  case testData {
    Nil => 0;
    Cons(Triple(Triple(e1,e2,e3),Triple(e4,e5,e6),Triple(e7,e8,e9)),tailData) =>
      let (IntInterval iForTest) = Pair(Pair(e1,e2),Pair(Nothing,e3))
      in let (IntInterval iParam) = Pair(Pair(e4,e5),Pair(Nothing,e6))
         in let (IntInterval result) = fst(swallowIntInterval(iForTest,Just(iParam)))
            in case and(and(fst(fst(result)) == e7,snd(fst(result)) == e8),snd(snd(result)) == e9) {
                 True => testSwallowIntervalFun(tailData);
                 False => length(testData);
               };
  };
```

The test function takes a list of test cases testData. For each test case it executes the specified tests, if the function swallowIntInterval() passes all test cases, the function returns 0. Otherwise the function returns some value i where the function fails at length(testData) $-$ ith test case.

[2] `http://www.junit.org`
[3] `http://maude.cs.uiuc.edu/`

5.4 Replication System

FAS provides to its clients structured search capabilities within the client's data. This includes text search and structured faceted navigation. To minimise the possible disruption caused by updates of data and configuration in a FAS installation, a typical FAS deployment splits between live and staging environments. The staging environment is responsible for data and configuration updates and the live environment is responsible for serving queries from client-side web applications. A typical FAS deployment consists of multiple live environments and when there are data and/or configuration updates at the staging environment, FAS employs the Replication System to ensure updates are propagated across live environments. The Replication System consists of a set of *nodes*. One node is the SyncServer an it resides in the staging environment. All the other nodes are SyncClients, and each of which resides in a live environment.

Briefly, the SyncServer is responsible for determining the *schedule* of replication as well as the content of each *replication item* for its staging environment. The SyncClient, on the other hand, is responsible for receiving data and configuration update for its live environment. A replication item is a set of files identified by a *check point* value. A replication item represents a single unit of replicable data.

In the rest of this section we describe components of the replication system and present their ABS models. Throughout this section we employ UML diagrams to illustrate behaviour of individual components as well as interaction between components visually but informally. We will refer the reader to a formal abstract specification of these behaviours defined using the CSP process algebra before presenting a more concrete model in ABS. Note that we do not discuss the CSP specifications in this section as we aim to focus on the ABS models. Interested reader can find the complete CSP model of the Replication System and assertions about the model in Appendix O.7.

5.4.1 Synchronisation Server

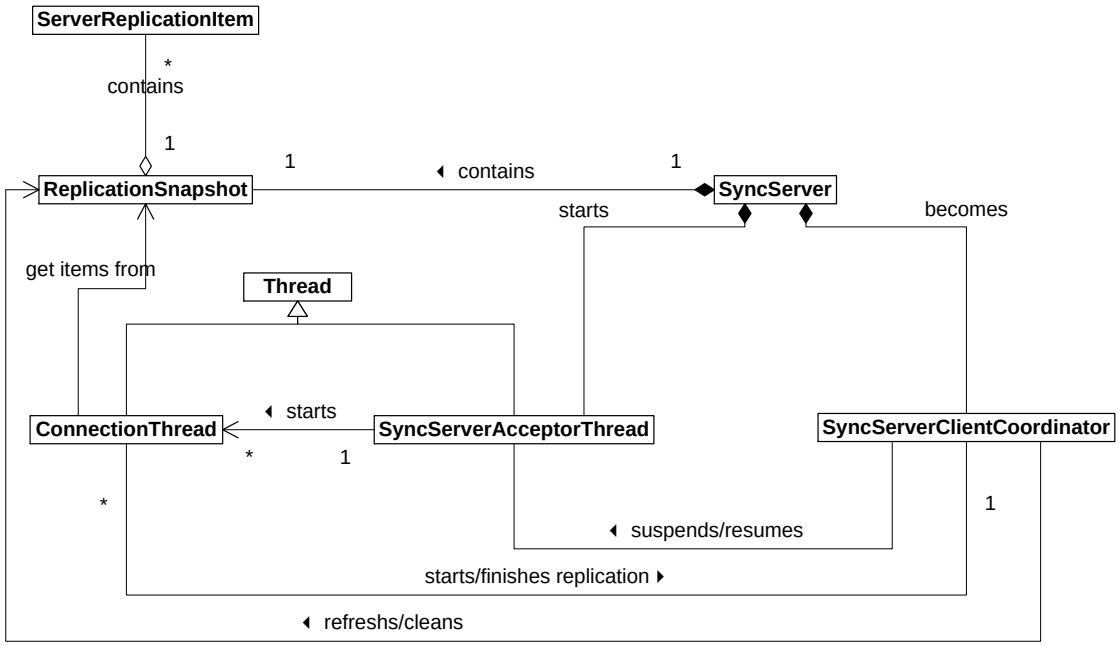


Figure 5.6: UML Class diagram of the synchronisation server

The Synchronisation Server resides in the staging environment. It is responsible for replicating configuration and data updates from the staging environment to the SyncClients running on the live environments. Figure 5.6 shows the class diagram of the synchronisation server. Specifically the synchronisation server consists of the following five main components.

- SyncServerAcceptorThread is implemented by the class `SyncServerAcceptorThread`. The SyncServerAcceptorThread is responsible for accepting connection from SyncClients. We present the behavioural model and the ABS model of SyncServerAcceptorThread in Section 5.4.2.
- ConnectionThread is implemented by the class `ConnectionThread`. Each ConnectionThread is instantiated by the SyncServerAcceptorThread and after SyncServerAcceptorThread accepts a connection from a SyncClient, it instantiates a ConnectionThread to carry out the replication protocol. We present the behavioural model and the ABS model of ConnectionThread in Section 5.4.4.
- SyncServerClientCoordinator is implemented by the class `SyncServerClientCoordinator`. The SyncServerClientCoordinator is responsible for coordinating when SyncServerAcceptorThread may accept connection from SyncClients. This component also provides methods for preparing replication items before a replication session and tidying them up afterwards. We present the behavioural model and the ABS model of SyncServerClientCoordinator in Section 5.4.3.
- SyncServer is implemented by the class `SyncServer` and provides a Java `main()` method for initialisation. Specifically, the SyncServer starts the SyncServerAcceptorThread thread and the SyncServerClientCoordinator. It also keeps a reference to the replication snapshot to be replicated. We present the behavioural model and the ABS model of `SyncServer main()` method in Section 5.4.1.
- ReplicationSnapshot is implemented by the class `ReplicationSnapshot`. ReplicationSnapshot manages the set of replication items and provides methods for *refreshing* and *clearing* them. We present the behavioural model and the ABS model of ReplicationSnapshot in Section 5.4.1.
- ReplicationItem is implemented by the class `ServerReplicationItem`. A replication item is a set of files identified by a *check point* value. A replication item represents a single unit of replicable data. We present the behavioural model and the ABS model of ReplicationItem in Section 5.4.1.

Communication Layer

The SyncClient and SyncServer do not communicate directly. The SyncServer uses *connection threads*, which are Java `Thread` objects as the interface to the server-side of the replication protocol. The SyncClient, on the other hand, schedules *jobs* to handle communications to the client-side of the replication protocol. Specifically, a job is an executable task that is scheduled by a third party scheduler system[4]. Note that while the SyncClient is responsible to establishing jobs to be scheduled, the SyncServer is responsible to specifying the schedule for executing the client jobs. We discuss the modelling of connection threads and jobs in Sections 5.4.4 and 5.4.6 respectively.

File System and File Representation

We use ABS data types for representing files and replication items, thereby providing an abstraction from the underlying representation of files. Listing 5.10 shows the data types and type synonyms used for representing files and replication items.

```
type CheckPoint = Int;
type FileId = Int;
type FileSize = Int;
type File = Pair<FileId,FileSize>;
type ReplicationItem = Pair<CheckPoint,Set<File>>;
```

Listing 5.10: A model of files and replication items using data types

[4]In Fredhopper, third party libraries are used to provide new features at a lower cost. For scheduling, we use Quartz API from OpenSymphony `http://www.quartz-scheduler.org/`

Specifically, we model a file (File) as a pair of integers, where the first integer is the identifier of the file and the second integer is the size of the file; in our ABS model of the replication protocol, only the identifier and the size of a file is required for deciding if and how the file should be replicated from the SyncServer to the SyncClient. A replication item (ReplicationItem) is a pair of its check point and its associated set of files. Specifically, a check point of a replication item identifies when and where the "snapshot" of the item's associated files is taken. Since our ABS model abstract from physical file structure as well as time, our model of the check points (CheckPoint) is a set of integers; it is sufficient for each replication item to be identified uniquely by an integer.

In addition, our model abstracts from the underlying file system of the environment by a simple data base representation. Listing 5.11 shows all possible types of data base in our ABS model of the Replication System. We do not discuss the implementation detail here, An ABS model of the data base can be found in Section P.3.

```
interface DataBase {
  FileSize getLength(FileId fId);
  Set<FileId> listFiles();
}

interface ClientDataBase extends DataBase{
  Bool prepareReplicationItem(CheckPoint cp);
  Unit updateFile(FileId fId, FileSize size);
}

interface ServerDataBase extends DataBase {
  Unit refresh();
  Set<FileId> listCheckPointFiles();
}
```

Listing 5.11: ABS interfaces of a simple data base model

Specifically, all data bases provide methods to list the identifiers of all files in the data base, and to get the length (size) of a file. We provide two subtypes ClientDataBase and ServerDataBase to differentiate between the data bases used by the SyncServer and those by the SyncClient.

The client-side is represented by ClientDataBase. It provides the additional methods to initialise a location in the database for a replication item to be transferred from the SyncServer (prepareReplicationItem()) and to update a file in the data base (updateFile()); the SyncClient is responsible for updating the files in its environment.

The server-side is represented by ServerDataBase. It provides the additional methods to refresh files in the data base and get the list of files (identifiers) from the current check point. The former method models changes to the content of the server-side files while the latter method returns the identifiers of the files that have been updated most recently.

SyncServer and ReplicationSnapshot

The SyncServer component is implemented by the class `SyncServer`. The class signature is shown in Listing 5.12. Specifically SyncServer is responsible for initialising both SyncServerAcceptorThread and SyncServerClientCoordinator. It also provides methods to access ReplicationSnapshot, SyncServerAcceptorThread and SyncServerClientCoordinator components, get shutting down status and request the SyncServer to shut down. We consider the behaviours of SyncServerAcceptorThread and SyncServerClientCoordinator in Sections 5.4.2 and 5.4.3 respectively. We now consider the ReplicationSnapshot.

```
public class SyncServer {
  private final ReplicationSnapshot replicationSnapshot;
  private final SyncServerClientCoordinator clientCoordinator;
  private final SyncServerAcceptorThread acceptorThread;
  public static void main(String[] args) { .. } // initialisation method
  public SyncServerClientCoordinator getClientCoordinator() { .. }
  public final SyncServerAcceptorThread getAcceptorThread() { .. }
  public final ReplicationSnapshot getReplicationSnapshot() { .. }
  public boolean isShutdownRequested() { .. }
  public void setShutdownRequested(boolean shutdownRequested) { .. }
}
```

Listing 5.12: Implementation class `SyncServer`

The ReplicationSnapshot is implemented by the Java class `ReplicationSnapshot` and its signature is shown in Listing 5.13.

```
public class ReplicationSnapshot {
  private boolean clean;
  private final Map<String,List<ServerReplicationItem>> replicationItemsPerSchedule;
  public List<ServerReplicationItem> getItems(String schedule) { .. } // initialisation method
  public void clearSnapshot() { .. }
  public void refreshSnapshot() { .. }
}
```

Listing 5.13: Implementation class `ReplicationSnapshot`

The class `ReplicationSnapshot` keeps track of the list of replication items per schedule and provides methods to access, refresh and clear replication items. Figure 5.7 is a UML activity diagram describing the workflow of how and when the replication snapshot can be refreshed or cleared. A CSP specification of this workflow is defined by the process *ReplicationSnapshot* and can be found in Section O.1.3 on Page 188.

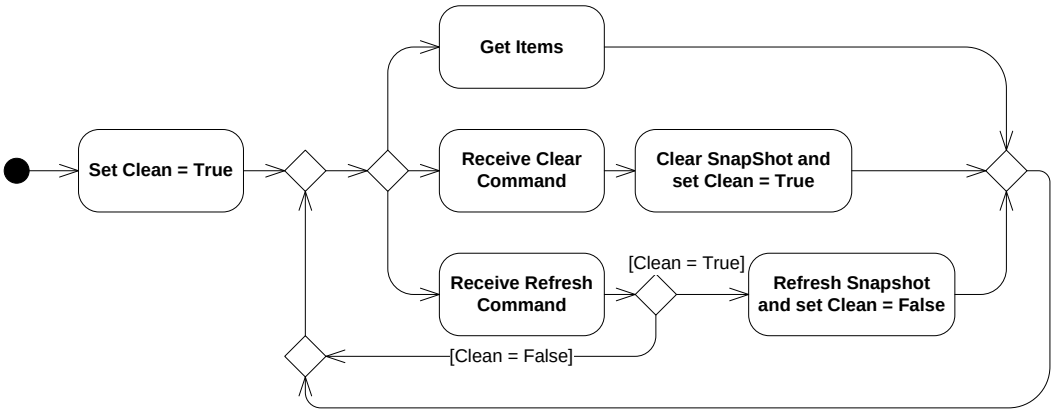


Figure 5.7: UML Activity diagram for refreshing and clearing the replication snapshot

Specifically, the ReplicationSnapshot follows the following workflow steps:

1. The ReplicationSnapshot initially sets field `clean` to true and proceeds to Step 2.
2. The ReplicationSnapshot may receive one of three commands, if the ReplicationSnapshot receives command to get replication items, then it gets items and repeats Step 2. If it receives a clear snapshot command (`clearSnapshot()`), then it proceeds to Step 3. If it receives a refresh snapshot command (`refreshSnapshot()`), then it proceeds to Step 4.

3. The ReplicationSnapshot clears snapshot, sets field `clean` to true and proceeds to Step 2.

4. The ReplicationSnapshot refreshes snapshot, sets field `clean` to false and proceeds to Step 2.

We now consider the ABS model of SyncServer and ReplicationSnapshot components. Listing 5.14 shows the interface SyncServer for modelling `SyncServer`. Note that both SyncServer and SyncClient are subtypes of Node. We consider the model of SyncClient in Section 5.4.5.

```
interface Node {
  DataBase getDataBase();
  Bool isShutdownRequested();
  Unit requestShutDown();
}

interface SyncServer extends Node {
  Unit refreshSnapShot();
  Unit clearSnapShot();
  Set<ReplicationItem> getItems();
  SyncServerAcceptor getAcceptor();
  SyncServerClientCoordinator getCoordinator();
}
```

Listing 5.14: ABS interface of SyncServer

Specifically a Node models a node in the Replication System. Each node has a data base and provides methods to request shut down and to enquire if the node is shutting down. The SyncServer interface extends a general node by providing methods to get a reference to the SyncServerAcceptorThread (getAcceptor()) and to get a reference to the SyncServerClientCoordinator (getCoordinator()). In addition, we integrate ReplicationSnapshot and SyncServer components in our ABS model by providing methods from the SyncServer interface to get the current set of replication items (getItems()), refresh and clear existing snapshot. This is because in ABS, models are untimed and scheduling is non-deterministic. Moreover, it is not possible to denote time progression in the core ABS language. As a result we abstract ReplicationSnapshot to a set of ReplicationItems. Furthermore, our model abstracts from the underlying file system by defining a simple DataBase component (DataBase). It is therefore sufficient to record the set of replicationItems within the SyncServer component and provide methods for accessing, refreshing and clearing these items through the SyncServer interface. We do not go into detail on the implementation of SyncServer here; an ABS model of SyncServer is given in Section P.4 on Page 201.

5.4.2 SyncServerAcceptorThread

The SyncServerAcceptorThread is implemented by the class `SyncServerAcceptorThread`, which implements a Java `Thread` object such that the `run()` method recursively decides whether to accept connection from SyncClients.

Figure 5.8 is a UML Activity diagram showing the work flow of the `run()` method of the `SyncServerAcceptorThread`. A CSP specification of this method is provided by the process *AcceptorThreadRun* in Section O.2 on Page 188. Specifically, upon invocation the `run()` method performs the following steps.

1. If the SyncServer has been requested to shut down, the SyncServerAcceptorThread terminates, otherwise it proceeds to Step 2.

2. The SyncServerAcceptorThread waits to accept a single connection and then proceeds to Step 3 or times out and proceeds to Step 4.

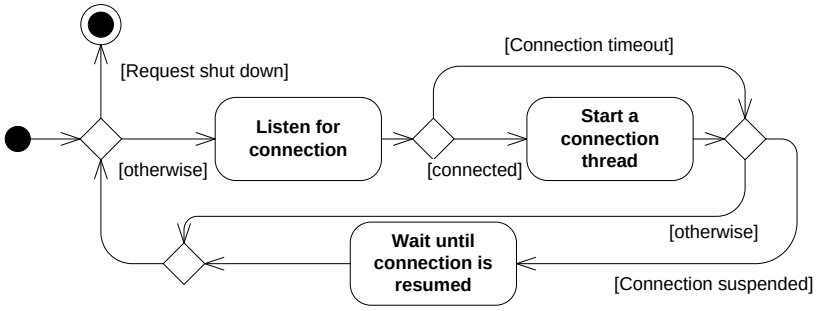


Figure 5.8: UML Activity diagram of method `SyncServerAcceptorThread.run()`

3. If a connection has been accepted, the SyncServerAcceptorThread creates an instance of a ConnectionThread for serving this (client) connection. ConnectionThread is specified and modelled in Section 5.4.4. Once a ConnectionThread instance is created, it proceeds to Step 4.

4. If the server has suspended accepting connection, the SyncServerAcceptorThread waits until it has been resumed again, otherwise it goes back to Step 1. Note that the coordination of whether to accept a connection is determined by the SyncServerClientCoordinator, which is described in Section 5.4.3.

```
public class SyncServerAcceptorThread extends Thread {
  private boolean acceptingConnections;
  public boolean isAcceptingConnections() { .. } // return acceptingConnections.
  public void resumeAcceptingConnections() { .. } // set acceptingConnections to true
  public void run() { .. }
  public void suspendAcceptingConnections() { .. } // set acceptingConnections to false
}
```

Listing 5.15: Implementation class `SyncServerAcceptorThread`

While SyncServerClientCoordinator coordinates whether to accept or to refuse a connection from the client side, the flag that records this decision is implemented by the Boolean field `acceptingConnections` in class `SyncServerAcceptorThread`. Specifically, the signature of class `SyncServerAcceptorThread` is shown in Listing 5.15.

Note that at the implementation level, a SyncClient and a SyncServer communicate to each other via sockets (`java.net.Socket`). Data are passed asynchronously between them via (`DataInputStream` and `DataOutputStream`). The client side and the server side hence identify each other via the combination of IP addresses and port numbers. Our ABS model abstracts from this socket-based communication. Specifically in our ABS model, communications between client-side and server-side are realised via asynchronous method invocation. Each SyncClient identifies the SyncServer via a reference to the acceptor thread object.

```
interface ServerAcceptor { ConnectionThread getConnection(ClientJob job); }
interface SyncServerAcceptor extends ServerAcceptor {
  Bool isAcceptingConnection();
  Unit suspendConnection();
  Unit resumingConnection();
}
```

Listing 5.16: ABS interfaces for SyncServerAcceptorThread

Listing 5.16 defines ABS interfaces for SyncServerAcceptorThread. Specifically, ServerAcceptor interface provides method getConnection() that takes a client job and returns a ConnectionThread. At the level of

ABS, this method establishes the connection between the client side and the server side. The definition of ClientJob is described in Section 5.4.6. The subtype SyncServerAcceptor provides the get and set methods for accepting connections.

Listing 5.17 shows the ABS model for both interfaces SyncServerAcceptor and by extension ServerAcceptor. Note the method isServerShuttingDown() is not visible through either of the interfaces and hence is only used internally. This method communicates asynchronously to the server object and checks if the server is shutting down.

The Java method `SyncServerAcceptorThread.run()` is modelled by the method getConnection() in ABS model SyncServerAcceptor. Specifically, the method getConnection() takes a client job (ClientJob) and returns a null object if the SyncServer is shutting down. Otherwise the method waits until the field accept becomes True and returns a ConnectionThread object, passing the client job and the SyncServer object to the connection thread.

```
class SyncServerAcceptor(SyncServer server) implements SyncServerAcceptor {
  Bool accept = True; Bool shutdown = False; // Shutdown flag

  Bool isServerShuttingDown() {
    Fut<Bool> ss;
    ss = server!isShutdownRequested(); await ss?;
    return ss.get;
  }

  // Return a null thread if server is/has been shutting down
  ConnectionThread getConnection(ClientJob job) {
    ConnectionThread thread = null;
    shutdown = this.isServerShuttingDown();
    if (~ shutdown) {
      await accept;
      thread = new ConnectionThread(job,server);
    }
    return thread;
  }

  Bool isAcceptingConnection() { return accept; }
  Unit suspendConnection() { accept = False; }
  Unit resumingConnection() { accept = True; }
}
```

Listing 5.17: ABS class for SyncServerAcceptorThread

5.4.3 SyncServerClientCoordinator

The SyncServerClientCoordinator is responsible to coordinate SyncClient connections. Specifically, it decides when to suspend and to resume accepting connections from SyncClients. SyncServerClientCoordinator is implemented by the class `SyncServerClientCoordinator`. SyncServerClientCoordinator is implemented by Java class `SyncServerClientCoordinator`. Listing 5.18 shows the signature of Java class `SyncServerClientCoordinator`. It contains method `process()`, which is the main method for coordinating client connections. It has the private field `threads` for keeping a reference to the set of connection threads that are currently serving clients. We model this class by first defining the ABS interface SyncServerClientCoordinator shown in Figure 5.19.

```
public class SyncServerClientCoordinator {
  private Set<ConnectionThread> threads;
  public void startReplicationUpdate(ConnectionThread thread) { .. }
  public void finishReplicationUpdate(ConnectionThread thread) { .. }
  public void process() { .. }
}
```

Listing 5.18: Implementation class `SyncServerClientCoordinator`

```
interface SyncServerClientCoordinator {
  Unit process();
  Unit startReplicationUpdate(ConnectionThread thread);
  Unit finishReplicationUpdate(ConnectionThread thread);
}
```

Listing 5.19: ABS interfaces of SyncServerClientCoordinator

```
class SyncServerClientCoordinator(SyncServer server) implements SyncServerClientCoordinator{
  Bool internal = False; // Models internal choice
  Bool replicationSignal = True; // A flag for creating a scheduling point
  SyncServerAcceptor acceptor = null;
  Set<ConnectionThread> threads = EmptySet;
  Bool isServerShuttingDown() { .. }
  Unit process() { .. }
  Unit startReplicationUpdate(ConnectionThread thread) { .. }
  Unit finishReplicationUpdate(ConnectionThread thread) { .. }
}
```

Listing 5.20: ABS class of SyncServerClientCoordinator

We provide one implementation of SyncServerClientCoordinator and its signature is shown in Listing 5.20. Note that the method isServerShuttingDown() is the same as that defined for SyncServerAcceptorThread in Figure 5.17. We now consider the behavioural model of methods process(), startReplicationUpdate() and finishReplicationUpdate(). respectively.

Method process()

Figure 5.9 shows a UML activity diagram describing the workflow of method `process()`. A CSP specification of this method is provided by the process *Coordinator* in Section O.3 on Page 189. Specifically, upon invocation the `process()` method performs the following steps.

1. If the SyncServer has been requested to shut down, this `SyncServerClientCoordinator` object then waits for all connection threads terminate, otherwise it proceeds to Step 2.

2. If SyncServerAcceptorThread is currently accepting connection, then it proceeds to Step 3, otherwise it proceeds to Step 4.

3. If there are one or more connection threads currently serving SyncClients and they have been active for more than 15 seconds ([suspendCondition]), then it suspends accepting connections, and proceeds back to Step 1.

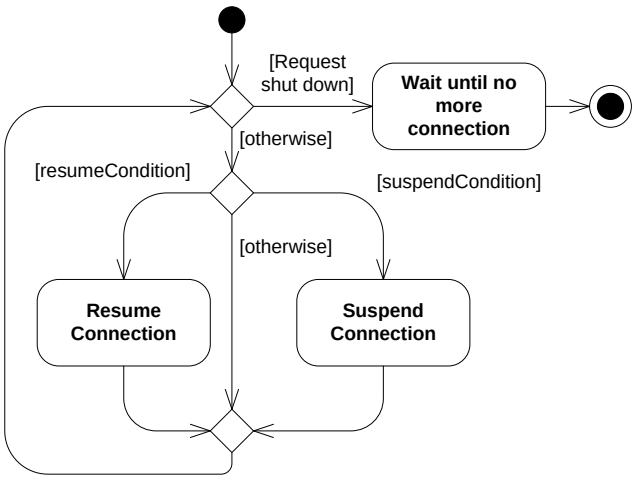


Figure 5.9: UML Activity diagram of `process()`

4. If there are no connection thread currently serving SyncClients ([resumeCondition]) then resume accepting connection, and proceeds back to Step 1.

We therefore model this workflow with the method SyncServerClientCoordinator.process() shown in Figure 5.21. The method first acquires a reference to SyncServerAcceptorThread (SyncServerAcceptor) before engaging in the workflow described in Figure 5.9. It is not possible to model directly Step 3 of the workflow of the method. This is because the core ABS language does not provide construct for time specification. Normally one would abstract timing information by introducing non-determinism. This is particularly the case for the CSP specification *Coordinator* on Page 189, which uses the internal choice operator to introduce this non-determinism. However, the core ABS language does not allow specification of internal choices. Therefore we model this behaviour by using the Boolean field internal and deterministically alternating its value to model the possibility of a connection thread to be active for more than 15 seconds (see Lines 9 - 14 of Listing 5.21) .

```
1  Unit process() {
2    Fut<SyncServerAcceptor> acc; Fut<Bool> ac; Fut<Unit> end;
3    Bool shutdown = False; Bool accept = False;
4    acc = server!getAcceptor(); await acc?; acceptor = acc.get;
5    shutdown = this.isServerShuttingDown();
6    while (~ shutdown) {
7      ac = acceptor!isAcceptingConnection(); await ac?; accept = ac.get;
8      if (accept) {
9        if (~ emptySet(threads) && internal) {
10         acceptor.suspendConnection();
11         internal = False;
12       } else {
13         internal = True;
14       }
15     } else {
16       if (emptySet(threads)) {
17         acceptor.resumingConnection();
18       }
19     }
20     shutdown = this.isServerShuttingDown();
```

```
21    }
22    await threads == EmptySet;
23    acceptor.resumingConnection();
24  }
```

Listing 5.21: ABS Implementation of process()

Method startReplicationUpdate()

Class `SyncServerClientCoordinator` provides method `startReplicationUpdate` for setting up the replication items before a replication session. Figure 5.10 is a UML activity diagrams of the workflow of method `startReplicationUpdate`. The CSP specification is defined by the process *StartReplicationUpdate* in Section O.3 on Page 189.

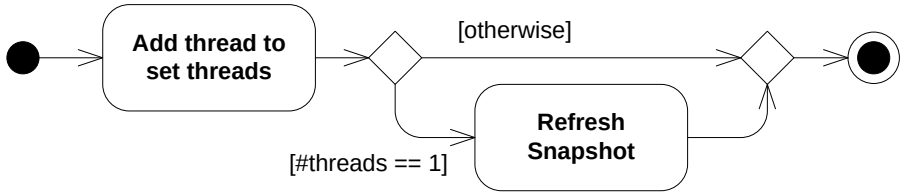


Figure 5.10: UML Activity diagram of `startReplicationUpdate()`

Specifically, upon invocation of `startReplicationUpdate()` with some connection thread (`thread`), the method performs the following steps.

1. Adds thread to the set `threads` and proceeds to Step 2.
2. If size of `threads` is 1 then proceeds to Step 3, otherwise proceeds to Step 1.
3. Refreshes replication snapshot and proceeds to Step 1.

The ABS model of this method can be found in Section P.5 on Page 203.

Method finishReplicationUpdate()

Class `SyncServerClientCoordinator` provides method `finishReplicationUpdate` for tidying up the replication items after a replication session. Figure 5.11 is a UML activity diagram of the workflow of method `finishReplicationUpdate`. The CSP specification of this method is defined by the process *FinishReplicationUpdate* and it is defined in Section O.3 on Page 189.

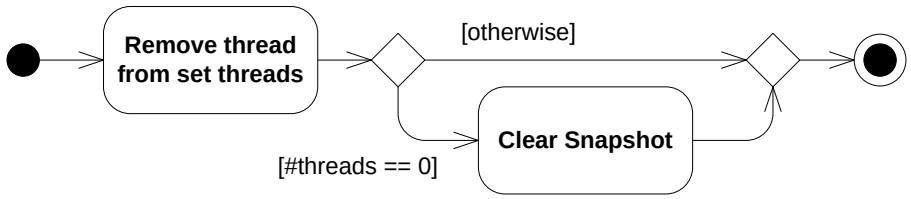


Figure 5.11: UML Activity diagram of `finishReplicationUpdate()`

Specifically, upon invocation of `finishReplicationUpdate()` with some connection thread (`thread`), it performs the following steps.

1. Removes thread to the set `threads` and proceeds to Step 2.

2. If `threads` is empty then proceeds to Step 3, otherwise proceeds to Step 1.

3. Clears replication snapshot and proceeds to Step 1.

The ABS model of this method can be found in Section P.5 on Page 203.

5.4.4 ConnectionThread

The ConnectionThread component is responsible for communicating with SyncClients after the SyncClient has established a connection from SyncServerAcceptorThread. More specifically, each ConnectionThread communicates with one SyncClient via a client job scheduled by that SyncClient. We consider the model of ClientJob in Section 5.4.6. Concretely, the ConnectionThread is implemented by the Java class `ConnectionThread`, which is a subclass of `Thread`, and implements the `run()` that executes the server side of the replication protocol. At the implementation level a connection thread communicates asynchronously with a SyncClient via sockets.

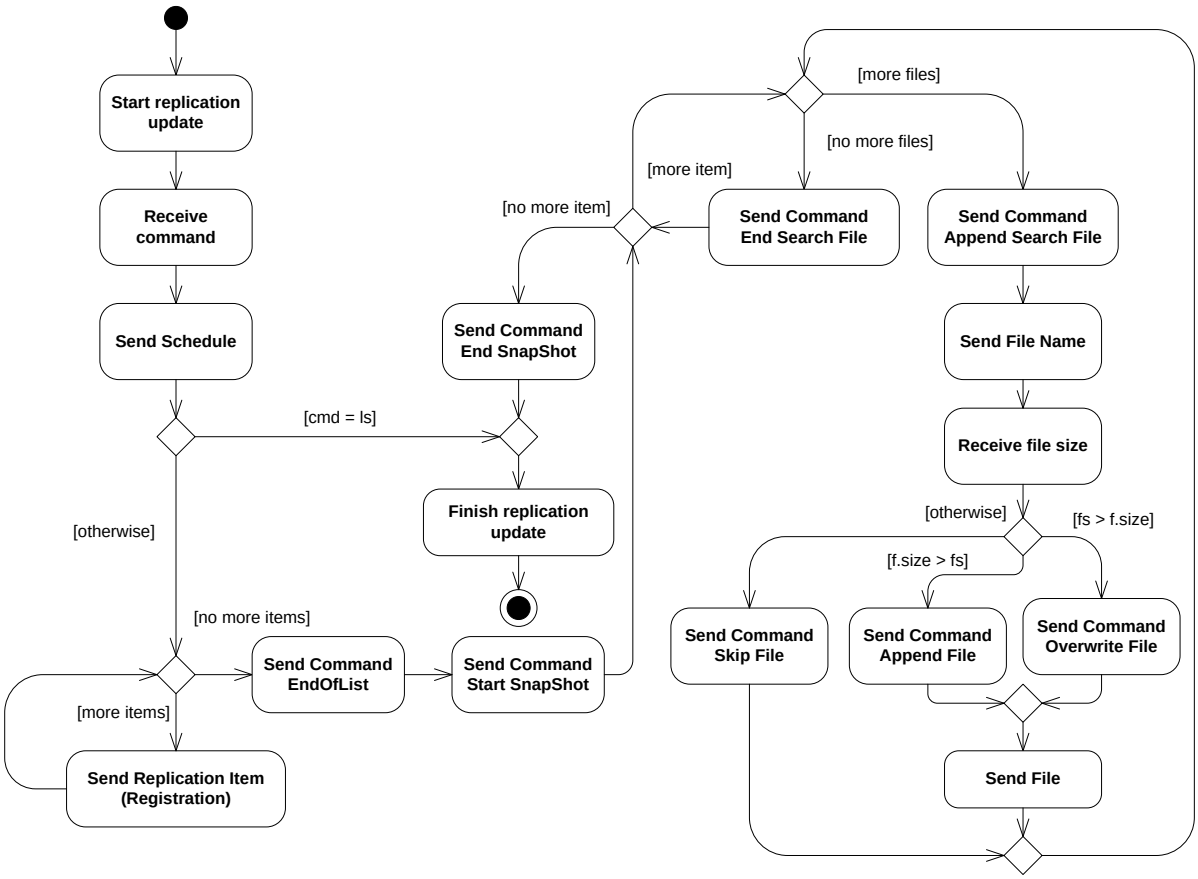


Figure 5.12: UML Activity diagram of `ConnectionThread.run()`

Figure 5.12 shows a UML activity diagram of the workflow of the method `ConnectionThread.run()`. A CSP specification of this method is provided by the process *ConnectionThread*(t) in Section O.4 on Page 191. Specifically, upon invocation the `run()` method performs the following steps.

1. The ConnectionThread prepares the replication update and waits for a command from the client job. Upon receiving a command from the client job the ConnectionThread proceeds to Step 2.

2. Sends replication schedule to the client job and then proceeds to Step 3.
3. If command is listSchedule ([cmd = ls]) then the ConnectionThread proceeds to Step 15, otherwise it proceeds to Step 4.
4. The ConnectionThread gets all replication items and iteratively registers them with the client job. This step also determines which items should be replicated to the SyncClient. It then proceeds to Step 5.
5. The ConnectionThread sends command endOfList to client job to notify the SyncClient the end of registration. It then proceeds to Step 6.
6. It sends command startSnapshot to client job to notify the SyncClient the start of this replication session. It then proceeds to Step 7.
7. It gets the registered items from Step 4 and iterates through the items. For each item it proceeds to Step 8. Once it has iterated through all registered items, it proceeds to Step 15.
8. It iterates over the set of files in the item and for each file in the item and proceeds to Step 9. Once it has iterated through all files, it sends command endSearchFile to notify the SyncClient about the end of a replication of a single item and then it proceeds to Step 7 for more items.
9. It sends command appendSearchFile to notify the SyncClient about the pending replication of a single file. It then sends the identifier of the file to be replicated and then proceeds to Step 10.
10. It waits and receives the size of client side version of the file that is to be be replicated. It then proceeds to Step 11.
11. If the size of the client side version is larger than the server side version ($[fs > f.size]$), then it proceeds to Step 12. If the size of the client side version is smaller than the server side version ($[f.size > fs]$), then it proceeds to Step 13, otherwise it proceeds to Step 14.
12. It sends command overwriteFile to the client job to instruct the SyncClient to overwrite the client version of the file with the content of the upcoming transmission. It then sends content of the file to the client job and proceeds to Step 8 for more files.
13. It sends command appendFile to the client job to instruct the SyncClient to append the client version of the file with the content of the upcoming transmission. It then calculates and sends remaining content of that file to the client job and proceeds to Step 8 for more files.
14. It sends command skipFile to the client job to instruct the SyncClient to keep the client version of the file. It then proceeds to Step 8 for more files.
15. It sends command endSnapshot to the client job to notify the SyncClient the end of this replication session. It then proceeds to Step 16.
16. It tidies up this replication update and terminates.

```
interface CommandReceiver { Unit command(Command command); }
interface ConnectionThread extends CommandReceiver { }
```

Listing 5.22: ABS interfaces of ConnectionThread

We now consider the ABS model of the connection thread. We provide the interfaces CommandReceiver and its subtype ConnectionThread. They are shown in Listing 5.22.

```
data Command =
  StartSnapshot | EndSnapshot | ListSchedule | SearchSchedule | EndSearchFile | AppendSearchFile |
  SkipFile | ContinueFile | OverwriteFile;
```

Listing 5.23: Data type definition of Command

Another subtype of the interface CommandReceiver is ClientJob, which is defined in Section 5.4.6. Specifically, A CommandReceiver object may receive commands via the method command(). Listing 5.23 shows all possible commands that can be sent to a CommandReceiver object. These commands correspond to those used during a replication session between client jobs and connection threads.

The ConnectionThread interface is a subtype of CommandReceiver but it does not provide any extra methods. A ConnectionThread object is an active object and cannot be interacted other than via the method command(). Listing 5.24 shows the class signature of the ABS model of ConnectionThread.

```
class ConnectionThread(ClientJob job, SyncServer server) implements ConnectionThread {
  SyncServerClientCoordinator coord;
  Maybe<Command> cmd = Nothing;
  Unit run() { .. }
  Set<Set<File>> registerItems(Set<ReplicationItem> items) { .. }
  Unit transferItems(Set<File> fileset) { .. }
  Unit command(Command c) { cmd = Just(c); }
}
```

Listing 5.24: ABS class signature of ConnectionThread

```
1  Unit run() {
2    Fut<SyncServerClientCoordinator> c; Fut<Unit> rp; Fut<Set<ReplicationItem>> is;
3    Set<ReplicationItem> items = EmptySet; Set<Set<File>> filesets = EmptySet;
4    c = server!getCoordinator(); await c?; coord = c.get;
5    rp = coord!startReplicationUpdate(this); await rp?;
6    await cmd != Nothing;
7    rp = job!receiveSchedule(); await rp?;
8    if (cmd != Just(ListSchedule)) {
9      is = server!getItems(); await is?; items = is.get;
10     filesets = this.registerItems(items);
11     rp = job!command(StartSnapshot); await rp?;
12     while (hasNext(filesets)) {
13       Set<File> fileset = EmptySet;
14       Pair<Set<Set<File>>,Set<File>> nfs = next(filesets);
15       filesets = fst(nfs);
16       fileset = snd(nfs);
17       this.transferItems(fileset);
18     }
19     rp = job!command(EndSnapshot); await rp?;
20   }
21   rp = coord!finishReplicationUpdate(this); await rp?;
22 }
```

Listing 5.25: ABS model of ConnectionThread.run()

An object of ConnectionThread is created with a reference to the ClientJob object that executes the client side of the replication protocol and a reference to the SyncServer. It implements the method run(), therefore a ConnectionThread object is an active object and the method run() is invoked immediately after object creation.

We now describe our ABS model of ConnectionThread.run(), which is shown in Listing 5.25; we annotate our description with either or both numbers corresponding the line numbers shown on Listing 5.25 and steps number of the workflow respectively. Upon invocation of run(), it waits until it gets a reference of the SyncServerClientCoordinator (Line 4). It then prepares replication update by invoking startReplicationUpdate() (Line 5, Step 1). It then waits for a command from the client (Line 6, Step 2) and sends a schedule to the client via the asynchronous invocation of method receiveSchedule() (Line 7, Step 3). If the command is listSchedule, the method then tidies up replication update by invoking finishReplicationUpdate() (Line 21, Step 16). Otherwise it registers the current replication items with the client by invoking the method registerItems() (Lines 9-10, Step 4). Note that we do not present the ABS model of registerItems() here, the implementation can be found in Section P.7 on Page 206.

The method registerItems() returns a set of file sets that belongs to the replication items which have not been replicated to the SyncClient. Since communications are established via asynchronous method invocations, it is no longer required to send command endOfList (Step 5). Afterwards, the method sends command StartSnapshot to the client (Line 11, Step 6). After the command has been received, the method then iterates over the set of file sets transferring files such that for each file set it invokes the method transferItems() to transfer files in that file set to the client (Lines 12-18, Steps 7- 14). After iterating over the set of file sets, the method invokes then sends the command endSnapshot to the client job (Line 19, Step 15) and tidies up replication update by invoking finishReplicationUpdate() (Line 21, Step 16).

The ABS model of method transferItems is shown in Listing 5.26.

```
1  Unit transferItems(Set<File> fileset) {
2    while (hasNext(fileset)) {
3      Fut<FileSize> fs; Fut<Unit> rp;
4      File file = Pair(−1,−1); FileSize size = −1; FileSize tsize = −1;
5      Pair<Set<File>,File> nf = next(fileset);
6      fileset = fst(nf);
7      file = snd(nf);
8      tsize = snd(file);
9      fs = job!processFile(fst(file)); await fs?; size = fs.get;
10     if (size > tsize) {
11       rp = job!command(OverwriteFile); await rp?;
12       rp = job!processContent(file); await rp?;
13     } else {
14       if (tsize − size > 0) {
15         rp = job!command(ContinueFile); await rp?;
16         file = Pair(fst(file),tsize − size);
17         rp = job!processContent(file); await rp?;
18       } else {
19         rp = job!command(SkipFile); await rp?;
20       }
21     }
22   }
23 }
```

Listing 5.26: ABS model of ConnectionThread.transferItems()

We now describe the behaviour of the method transferItems. This method iterates over the input file set

and for each file it sends the file identifier to the client job, which returns the size of the client side version of that file (Line 9, Steps 9 - 10). Since communications are established via asynchronous method invocations, it is no longer required to send commands AppendSearchFile and EndSearchFile. Upon acquiring the size of the client side version of the file, it decides how and if the content of the file should be sent to the client job (Lines 10 - 20, Steps 11 - 14).

5.4.5 Synchronisation Client

The synchronisation client (SyncClient) has the responsibility to keep up-to-date the index used by the query engine. The SyncClient on a live environment connects to the Synchronisation Server (SyncServer) on a staging environment and responds to incoming updates to both configuration and data.

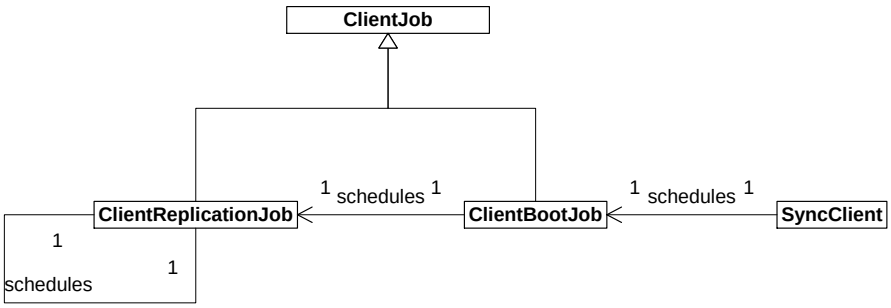


Figure 5.13: UML Class diagram of the synchronisation client

Figure 5.13 shows the class diagram of the SyncClient. Specifically the main Java class of the SyncClient is responsible to set up the client side of the Replication System. The SyncClient communicates with the SyncServer via *job scheduling* as described in Section 5.4.1. At initialisation the SyncClient schedules a BootJob to acquire a *replication schedule* from the SyncServer. Using this schedule, the BootJob creates a ReplicationJob for performing the actual replication. The ReplicationJob is also responsible to request further replication schedule and set up the subsequent ReplicationJob. We consider the behaviour of client jobs in Section 5.4.6.

Listing 5.27 shows the interface definition for modelling the SyncClient in ABS.

```
interface SyncClient extends Node {
  ClientDataBase getClientDataBase();
  Unit setAcceptor(ServerAcceptor acceptor);
  ServerAcceptor getAcceptor();
  Unit becomesState(State state);
}
```

Listing 5.27: ABS interface of SyncClient

Specifically, the interface SyncClient exposes method getClientDataBase() to get the client side data base. It also exposes methods to get and set a ServerAcceptor object. ServerAcceptor is an interface of the SyncServerAcceptorThread and only exposes the method getConnection(). Our ABS model abstracts from the socket-based communication layer. As a result we provide these two methods to pass a reference of SyncServerAcceptorThread to the SyncClient at initialisation and so that client jobs may access this reference to acquire connections with the SyncServer. The method becomeState() allows the SyncClient to transition from one state to the next according to the *SyncClient State Machine*.

SyncClient State Machine

Throughout the execution cycle of the SyncClient and its client jobs, we aim to ensure that the SyncClient conforms to the SyncClient State Machine. A UML state diagram of the SyncClient State Machine is shown in Figure 5.14. A CSP specification of this state machine is given by process *SyncClientSpec* in Section O.7 on Page 196.

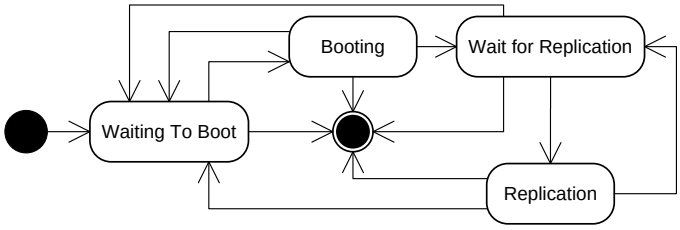


Figure 5.14: UML State diagram of the SyncClient State Machine

Listing 5.28 shows how we model the SyncClient State Machine using data type definition as a map from a State value to a set of State values denoting the possible transition from one state to another.

```
Pair<State,Set<State>> start = Pair(Start, set[WaitToBoot]);
Pair<State,Set<State>> waitToBoot = Pair(WaitToBoot, set[Booting,End]);
Pair<State,Set<State>> booting = Pair(Booting, set[WaitToBoot,WaitToReplicate,End]);
Pair<State,Set<State>> waitToReplicate = Pair(WaitToReplicate, set[WaitToBoot,WorkOnReplicate,End]);
Pair<State,Set<State>> workOnReplicate = Pair(WorkOnReplicate, set[WaitToBoot,WaitToReplicate,End]);
Map<State,Set<State>> machine = map[start,waitToBoot,booting,waitToReplicate,workOnReplicate];
```

Listing 5.28: Data type definition of the SyncClient State Machine

Listing 5.29 shows an ABS model of SyncClient. It takes a state machine on object creation (Line 1) and implements method becomesState to ensure that a transition can be made only according the SyncClient State Machine (Lines 21-22). The core ABS language provides the **assert** statement to check if such the suggested transition is a valid one with respect to the input machine.

SyncClient also implements the run() method. This is a special method and is not exposed through the interfaces; the implementation of run() declares any object of types SyncClient as an active object. Specifically, on object creation, the run() method creates an empty data base (Line 14). It then becomes state WaitToBoot, denoting a state of the SyncClient waiting for BootJob to be executed (Line 15). The method then waits for the acceptor to become available (Line 16) and creates a BootJob (Line 17). Note that acceptor becomes available when it is passed via the setAcceptor() method at the initialisation of the Replication System. This creates a reference from the SyncClient to the SyncServerAcceptorThread. A CSP specification of SyncClient is given by the process *SyncClient* is defined in Section O.6 on Page 193.

```
1  class SyncClient(Map<State,Set<State>> machine) implements SyncClient {
2    ServerAcceptor acceptor = null; State state = Start;
3    ClientDataBase db = null; Bool shutDown = False;
4
5    ClientDataBase getClientDataBase() { return db; }
6    DataBase getDataBase() { return db; }
7    Bool isShutdownRequested() { return shutDown; }
8    Unit requestShutDown() { this.shutDown = True; }
```

```
9     ServerAcceptor getAcceptor() { return acceptor; }
10    Unit setAcceptor(ServerAcceptor acceptor) { this.acceptor = acceptor; }
11
12    Unit run() {
13      Fut<Unit> end;
14      this.db = new DataBaseImpl(EmptyMap);
15      this.becomesState(WaitToBoot);
16      await acceptor != null;
17      new ClientJob(this,Boot);
18    }
19
20    Unit becomesState(State state) {
21      assert(contains(lookup(machine,this.state),state));
22      this.state = state;
23    }
24  }
```

Listing 5.29: ABS model of SyncClient

5.4.6 Client Job and Replication

There are two types of client jobs: boot and replication. A BootJob is responsible for acquiring the first replication schedule and setting up the first ReplicationJob. A ReplicationJob, on the other hand, is responsible for receiving replication items as well as acquiring any further replication schedule and setting up the corresponding ReplicationJob.

In the implementation of the Replication System, we provide an abstract class `ClientJob` that implements a job and provides an interface for one to define the task to be executed (`doExecute()`). Note that for all `ClientJob` objects, the scheduler executes the method `execute()`, which sets up the connection to the SyncServer and invokes the method `doExecute()`. Listing 5.30 shows the signature of the Java abstract class `ClientJob` and two specific implementations `BootJob` and `ReplicationJob`.

```
public abstract class ClientJob implements org.quartz.StatefulJob {
  public void execute(JobExecutionContext context);
  protected abstract void doExecute(JobExecutionContext context);
}
public class BootJob extends ClientJob {
  protected void doExecute(JobExecutionContext context) { .. }
}
public class ReplicationJob extends ClientJob {
  protected void doExecute(JobExecutionContext context) { .. }
  private void receiveItemFragment(DataInputStream serverInput, ReplicationItem item) { .. }
  private void receiveReplicationItems(DataInputStream serverInput, DataOutputStream serverOutput,
                                       byte[] workInputBuffer, int workInputBufferSize,
                                       byte[] workOutputBuffer, int workOutputBufferSize) { .. }
}
```

Listing 5.30: Classes of client jobs

BootJob

Specifically, at initialisation the SyncClient sets up a BootJob for requesting and receiving the replication schedule from the SyncServer. The BootJob is implemented by the concrete class `BootJob` and it will be scheduled to be executed immediately.

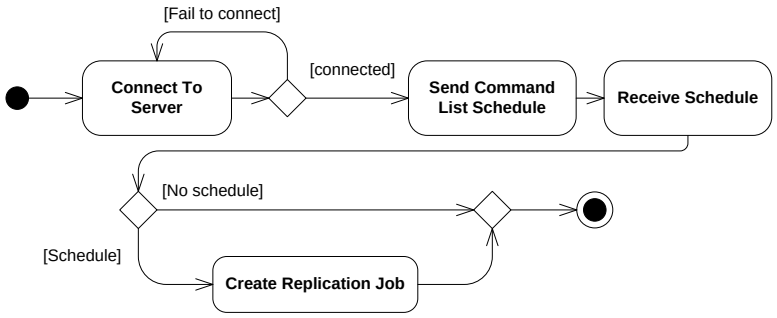


Figure 5.15: UML Activity diagram of the BootJob

Figure 5.15 shows a UML diagram illustrating the control flow of a BootJob. A CSP specification of the BootJob is given by the process *BootJob* and is defined in Section O.6 on Page 193. Figure 5.16 shows a UML sequence diagram describing the *connection* protocol between a ClientJob and a SyncServerAcceptorThread and Figure 5.17 shows a UML sequence diagram describing the *booting* protocol between a BootJob and a ConnectionThread. Specifically, upon invocation `BootJob.execute()` performs the following steps.

1. It repeatedly attempts to connect to server (Connect To Server) via the SyncServerAcceptorThread until it is connected. Upon establishing a connection the SyncServerAcceptorThread creates a ConnectionThread to serve this job. This job then proceeds to Step 2. (Figure 5.16)
2. It sends command listSchedule to request for the replication schedule and waits for the schedule is arrive. It then proceeds to Step 3. (Figure 5.17)
3. If the schedule specifies replication, the BootJob creates a ReplicationJob and terminates. Otherwise it just terminates. (Figure 5.17)

ReplicationJob

A ReplicationJob is responsible for receiving replication items as well as acquiring any further replication schedule and setting up the corresponding ReplicationJob. It implements the client side of the replication protocol. It is implemented by Java class `ClientReplicationJob`, whose signature is shown in Figure 5.30. This class provides two private methods `receiveReplicationItems()` and `receiveItemFragment()` for registering and receiving replication items respectively.

Figure 5.18 on Page 102 shows a UML activity diagram describing the workflow of the method `ClientReplicationJob.doExecute()`. A CSP specification of the ReplicationJob is given by the process *ReplicationJob* and is defined in Section O.6 on Page 193. Figure 5.19 on Page 103 describes the replication protocol between a ReplicationJob and a ConnectionThread. Specifically, upon invocation `ClientReplicationJob.execute()` performs the following steps. Note that Step 1 is part of the connection protocol, which is described in Figure 5.16.

1. Similar to BootJob, the ReplicationJob repeatedly attempts to connect to server (Connect To Server) via the SyncServerAcceptorThread until it is connected. Upon establishing a connection the SyncServerAcceptorThread creates a ConnectionThread to serve this job. This job then proceeds to Step 2.
2. It sends command searchSchedule to request for the replication schedule and to notify the server that it is also to receive replication items. It then waits for the schedule is arrive and proceeds to Step 3.
3. This ReplicationJob creates a next ReplicationJob if the schedule received specifies replication. The ReplicationJob then proceeds to Step 4.

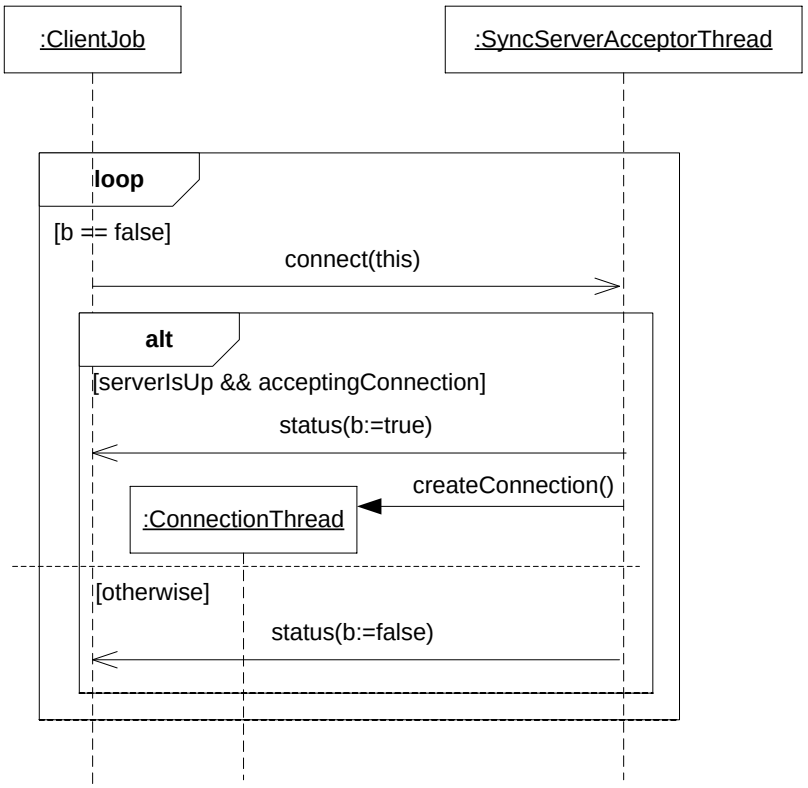


Figure 5.16: UML Sequence diagram of connecting to SyncServer

4. The ReplicationJob now enters the registration phase of the protocol. This is implemented by invoking the method `receiveReplicationItems()`. Specifically the ReplicationJob waits until it receives a command, if the command is a replication identification (CheckPoint) ([cmd=rn]), it then proceeds to Step 5. If the command is endOfList ([cmd=el]), then this signifies all replication items have been registered. The ReplicationJob proceeds to Step 6.

5. The ReplicationJob constructs a registered replication item that the client would expect to receive from the ConnectionThread. The ReplicationJob then proceeds to Step 4.

6. The ReplicationJob waits for one of the following commands: If the command is startSnapshot ([cmd=ss]), then ReplicationJob proceeds to Step 7. If the command is endSnapshot ([cmd=es]), signifying the end of the replication sessions, the ReplicationJob terminates. Otherwise it proceeds to Step 8.

7. The ReplicationJob prepares for the start of a replication session and then proceeds to Step 6.

8. If the received command is endSearchFile ([cmd=ef]) , the command signifies the end of a replication of a single item, the ReplicationJob proceeds to Step 6. If the received command is appendSearchFile ([cmd=af]), the command signifies the start of a replication of a single file, the ReplicationJob proceeds to Step 9.

9. The ReplicationJob receives an identifier of the file to be replicated and sends the size of the client version of this file and proceeds to Step 10. .

10. The ReplicationJob receives a command. If the command is skipFile ([cmd=sf]), the ReplicationJob proceeds to Step 6. Otherwise the ReplicationJob proceeds to Step 11. .

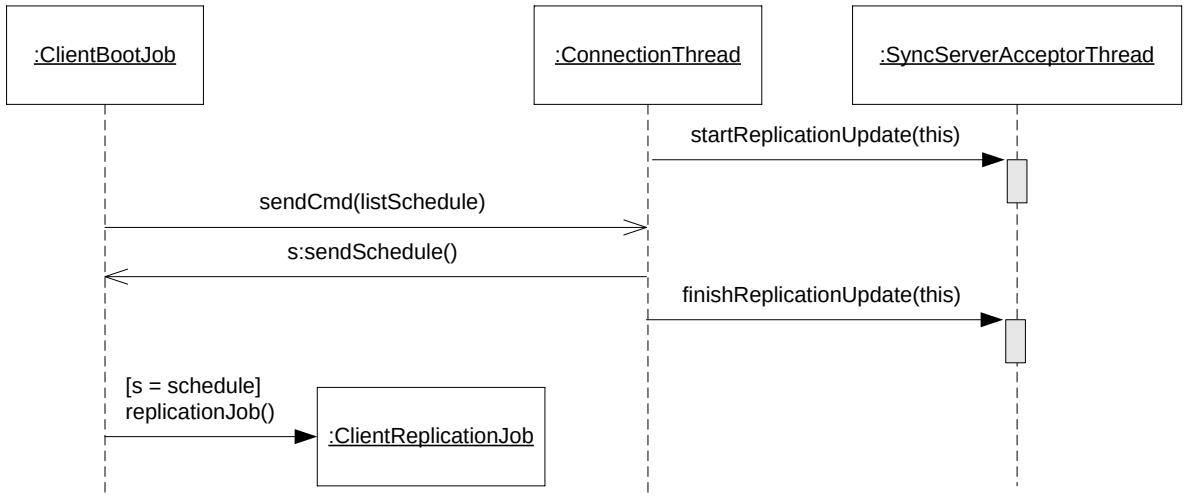


Figure 5.17: UML Sequence diagram of the booting protocol

11. The ReplicationJob receives the content of the file. If the previously received command is continueFile ([cmd=cf]), it appends this content (a stream of bytes) to the client version of the file. Otherwise if the previously received command is overwriteFile ([cmd=of]), it overwrites the client version of the file with the received file. Afterwards the ReplicationJob proceeds back to Step 6. .

While a ReplicationJob is scheduled in Step 3, the current implementation of the client side protocol insists that the scheduled ReplicationJob cannot be executed until there is no more job running for this client. This is also modelled by the CSP specification *ReplicationJob* in Section O.6 on Page 193.

ABS model

We now present the ABS model of the BootJob and the ReplicationJob. Listing 5.31 shows the interface ClientJob that is a subtype of CommandReceiver to model both the BootJob and the ReplicationJob. Therefore both types of ClientJob can receive commands via the method CommandReceiver.command().

```
interface ClientJob extends CommandReceiver {
  Bool registerReplicationItems(CheckPoint checkpoint);
  FileSize processFile(FileId id);
  Unit processContent(File file);
  Unit receiveSchedule();
}
```

Listing 5.31: ABS Interface of ClientJob

The method registerReplicationItems() registers a particular replication item. Specifically, it takes a replication item identifier of type CheckPoint, and returns True if this item should be replicated, and False otherwise. The method processFile() takes an identifier of a file and returns the size of the client version of the file. The method processContent() is invoked to replicate a file through this ClientJob. We do not consider their ABS models here, the full ABS models of these methods can be found in Section P.9 on Page 209. The method receiveSchedule() is invoked to send a replication schedule to ClientJob. Our ABS model abstracts from schedule details. Therefore this method only models the receiving of a schedule without specifying its detail.

```
class ClientJob(SyncClient client, JobType jt) implements ClientJob {
  Command command = EndSnapshot; Bool hasSchedule = False;
  ConnectionThread thread = null; ClientDataBase db;

  Unit run() { .. }
  FileSize processFile(FileId id) { .. }
  Unit overwrite(File file) { .. }
  Unit continue(File file) { .. }
  Unit processContent(File file) { .. }
  Unit command(Command command) { this.command = command; }
  Unit receiveSchedule() { hasSchedule = True; }

  Unit shutDownClient() {
    client.requestShutDown();
    client.becomesState(End);
  }

  Bool registerReplicationItems(CheckPoint checkpoint) {
    return db.prepareReplicationItem(checkpoint);
  }
}
```

Listing 5.32: ABS model of the ClientJob

Listing 5.32 shows the signature of the ABS model of the ClientJob. This model implements the workflows of both UML activity diagrams in Figures 5.15 and 5.18. The class ClientJob is instantiated with a reference to a SyncClient object and a JobType value. The ClientJob provides internal methods overwrite() and continue() to model overwriting and appending client version of a file with the content of the input argument. We do not consider their ABS models here, the full ABS models of these methods can be found in Section P.9 on Page 209. A ClientJob object is an active object and the ABS model of the run() is shown in Listing 5.33. We now describe the behaviour of the run() method.

We annotate this description with either or both line and step numbers corresponding to the line numbers shown in Listing 5.33 and the step numbers of the workflow description. Since ClientJob models both BootJob and ReplicationJob, we refer to UML activity diagram 5.15 as B and 5.18 as R in our annotations. For example, (Line 1, Step 1B) refers the line 1 of the Listing 5.33 and Step 1 of the workflow description of the UML activities diagram 5.15.

Upon invocation the run() method gets the reference of the SyncClient's data base (Line 5). It then waits until a connection has been established with the ServerAcceptor and obtains a reference to a ConnectionThread object (Line 6, Steps 1R and 1B). Here we model the server shutting down by returning a **null** object. If the ConnectionThread object is not **null**, ClientJob checks the value of JobType argument jt (Line 8). jt can have either the value Boot or Replication. We first consider the former.

If jt == Boot, then the ClientJob implements a BootJob. The SyncClient goes to state Booting. The ClientJob sends the command ListSchedule and waits for the schedule to arrive (Lines 9-11, Step 2B). Afterwards, The SyncClient goes to state WaitToReplicate and a new ReplicationJob is created (Lines 19-20, Step 3B). Note that the ABS model abstracts from schedule details hence in the model, a ReplicationJob will always be created in response to a schedule. The ClientJob then terminates.

If jt == Replication, then the ClientJob implements a ReplicationJob. The SyncClient goes to state WorkOnReplicate. The ClientJob sends the command SearchSchedule and waits for the schedule to arrive (Lines 13-15, Step 2R). Afterwards, the ClientJob waits for the command StartSnapshot and then the command EndSnapshot. Since the communications between the ClientJob and the ConnectionThread is via

asynchronous method invocation, it is not necessary to model the commands endOfList, appendSearchFile and endSearchFile. By asynchronously waiting for the command StartSnapshot and then the command EndSnapshot, the ClientJob ensures the replication session is complete, regardless if any item has actually been replicated. After the command EndSnapshot has been received, the SyncClient goes to state WaitToReplicate and a new ReplicationJob is created (Lines 19-20, Step 6R). The ClientJob then terminates.

```
1  Unit run() {
2    Fut<Bool> ep; Fut<ConnectionThread> t; ServerAcceptor acceptor;
3    Bool empty = False; Bool continue = False;
4    acceptor = client.getAcceptor();
5    db = client.getClientDataBase();
6    t = acceptor!getConnection(this); await t?; thread = t.get;
7    if (thread != null) {
8      if (jt == Boot) {
9        client.becomesState(Booting);
10       thread!command(ListSchedule);
11       await hasSchedule == True;
12     } else {
13       client.becomesState(WorkOnReplicate);
14       thread!command(SearchSchedule);
15       await hasSchedule == True;
16       await command == StartSnapshot;
17       await command == EndSnapshot;
18     }
19     client.becomesState(WaitToReplicate);
20     new ClientJob(client,Replication);
21   } else {
22     this.shutDownClient();
23   }
24 }
```

Listing 5.33: ABS model of ClientJob.run()

5.4.7 Replication Consistency

It is important to guarantee that the data and configuration are replicated consistently from the staging environment to any possible number of live environments for any deployment. Replication consistency is an instantiation of the ACID transactional properties [16] over the interacting environments:

- **Atomicity**: Only logically correct blocks of data should be replicated across clients (live environments). There should not be half blocks of data on the client side at the end of the replication.
- **Consistency**: For every completed replication step, the client (live environment) must contain the exact same number of data items in the index as the server environment.
- **Isolation**: Replication must be fail-safe, that is, upon failure of an individual client, the server must still be able to replicate data and configuration completely to the rest of the clients.
- **Durability**: Upon a complete replication, both clients (live environments) and servers (staging environments) should maintain this complete state even in the event of a system failure.

However, current industrial techniques are not exhaustive and cannot verify such guarantee over deployment variabilities. During further requirement analysis we identify the needs for the HATS framework to provide formal analysis techniques for verifying replication consistency. Moreover, the framework should be supported with usable methods and tool support to assist these formal techniques. This is so that formal reasoning can become more amenable to industrial software development.

While verification of ABS models is beyond the scope of this work task, we may perform testing on the files that have been replicated. By ensuring our ABS model terminates during Maude-based simulation, we are able to visualise the object state of all SyncClient at termination and check if all ClientDataBase objects contain the same file set as the ServerDataBase. We automate this procedure by implementing the Tester shown in Listing 5.34. test executions are carried out by creating a Tester object for each SyncClient as follows:

```
new Tester(syncserver,syncclient1); new Tester(syncserver,syncclient2); ...
```

Upon object creation the Tester object asynchronously checks if the SyncClient has shut down and compares each file between the SyncServer and the SyncClient.

```
class Tester(Node server, Node client) {
  Unit run() {
    Fut<Bool> sd; Bool shutdown = False;
    while (~ shutdown) {
      sd = client!isShutdownRequested(); await sd?; shutdown = sd.get;
    }
    this.assertData();
  }

  Unit assertData() {
    DataBase e; DataBase a;
    Map<FileId,FileSize> fse = EmptyMap; Set<FileId> fide = EmptySet;
    Map<FileId,FileSize> fsa = EmptyMap;
    e = server.getDataBase();
    a = client.getDataBase();
    this.checkData(e,a);
    this.checkData(a,e);
  }

  Unit checkData(DataBase e, DataBase a, Bool record) {
    Set<FileId> fids = EmptySet;
    fids = e.listFiles();
    while (hasNext(fids)) {
      FileId id = -1; FileSize es = -1; FileSize as = -1;
      Pair<Set<FileId>,FileId> nd = next(fids);
      fids = fst(nd); id = snd(nd);
      es = e.getLength(id);
      as = a.getLength(id);
      assert(es == as);
    }
  }
}
```

Listing 5.34: Test class for validating replication consistency

5.5 HATS Methodology

In this section we investigate how our modelling approach fits into parts of the HATS methodology. While neither our approach considers FAS as a family of products nor we model Fredhopper's components in terms of commonality and variability, methodologically our approach helps deriving high-level models of Fredhopper components at an appropriate level of abstraction. In particular, we aim to naturally extend these models to capture variability in a software product line for future project validation. Specifically, we investigate the following steps of the HATS methodology. Details of these steps can be found in D1.1b [23, Chapter 3].

5.5.1 Product Line Requirement Analysis

In this case study we derive requirements in the form of formal specifications of the component behaviours. These requirements are obtained by studying the components' existing implementation, and formalising the implementation into an abstract model using existing formalisms (JML and CSP). Our approach can be considered as model mining, and model mining is a technique that HATS project investigates formally. We therefore believe our result in this case study supports comparison and analysis of the model mining techniques developed in the project. In addition, our choice of existing modelling languages aim to support future evaluation of the ABS language, namely the behavioural interface languages. While we only consider one implementation of the components in our case study, our models are defined at the level of abstraction such that it should be natural to extend them to capture variability. For Interval API, we aim to extend our ABS model in future work to capture the variation between implementations for different attribute types. For the Replication System, our ABS model abstracts from the communication layer and the deployment platform. We therefore aim to extend this model in future work to study deployment variability and resource guarantees.

5.5.2 Reference Architecture Design

In the Reference Architecture Design phase, we construct specification of component and system levels. At the component level we provide behavioural interface specification of components, while at the system level we provide cross-cutting specifications. In this case study we focus on behavioural interface specification of components by defining high-level behavioural models of the components. Specifically, we define behavioural interfaces of components in the Interval API using JML and in the Replication System using CSP. Our aim is to map these specifications using ABS's behavioural interface languages in future work, and extend them to describe variability. For example, we aim to extend the behavioural interface of the Interval API using ABS to describe variations in implementations for various attribute types.

In the Reference Architecture Design phase, informal design artifacts (UML diagrams) are also considered. The aim is to link precisely variabilities described in feature models to variation points in these artifacts [23, Section 3.4.2]. In this case study, we also derive informal designs from existing implementations as UML diagrams. Our aim is to reuse these diagrams in future work for linking between component variability. For example, we aim to link UML activity and sequence diagram of the Replication System with deployment variability and resource constraint information.

5.5.3 Generic Component Design

In the Generic Component Design phase, a detailed model of individual components is defined. Models at the level of component designs should describe the behaviours of the component as well as relate to their interface specification and architectural constraints defined at the Reference Architecture Design phase. In our case study we provide design models of components as executable behavioural models in ABS. As soon as the behavioural interface language is provided in ABS, we hope to map and extend existing interface specification to ABS and formally relate each component's design model to its interfaces.

5.5.4 Generic Component Validation

In the HATS methodology, generic components are validated after they are *realised*. Validation in the HATS methodology is a combination of formal verification and testing [23, 3.4.5]. In our case study we conduct some validation on both the Interval API and the Replication System. For the Interval API, we implement tests in ABS as function definitions over test cases (input/output tests). We also use the KeY system to verify and discharge a small set of proof obligations from the JML specifications. For example, we automatically discharged the proof of invariant preservation for the `IntInterval` constructor method. For the Replication System, we implemented tests in ABS to validate data consistency during Maude simulation of the models. Moreover, we are able to prove the interface specification of the Replication System up to ten SyncClients to be free of deadlock and livelock by model checking the CSP models using FDR tools. As soon as the techniques and technologies are available in the HATS framework we aim to map and extend existing specifications to the level of ABS that can capture variability in the product line, and extend our validation of these components to full verification, automatic test case generation and execution.

5.6 Evaluation

This section presents an empirical evaluation of the case study with respect to the use of the core ABS language and parts of the HATS methodology. Our evaluation is split into two parts. The first part concerns our experience. In this part we describe how we establish abstraction in our models using the core ABS language. In the second part, we consider how the core ABS language and parts of the HATS methodology satisfies the specific requirements and concerns identified in Chapter 1.

5.6.1 Experience

Interval API

When modelling the Interval API using the core ABS language, we are able to provide the following abstractions.

- Data – In the Java implementation, data structures representing intervals are defined using classes. In ABS we model these data structures as functional data types. As a result we are able to abstract object states as tuple values.
- Functional – In the Java implementation, operations on intervals are implemented as methods of the classes of the representing objects. In ABS, we model these operations as functions over data types. As a result we are able to define side-effect free operations that would be more amenable to formal reasoning. Moreover, by modelling object states as tuple values, get and set methods over object fields are now simply functions over parametric data types. For example, we model `IntInterval` as a type synonym of Pair (pair of pairs). Methods such as `hasNull()` and `setHasNull()` can be modelled as functions over pairs, encouraging reusability.
- Specification – While we have not provided behavioural contracts over the ABS model of the Interval API, we believe it is possible to give formal specifications of these operations in ABS functionally, using the same underlying functional sublanguage as that for modelling. This means one could reason about these functions as *refinements* of their specification.

Table 5.2 shows the duration of some of the activities, that are taken as part of the process to define an ABS model for the Interval API. Note that this modelling exercise has been carried out by one developer at Fredhopper with prior working knowledge of Java programming, functional programming (Haskell, Standard ML) and certain formal specification languages (Z, CSP). He also has the conceptual knowledge of the core ABS language, and he has a prior working knowledge of using the Eclipse IDE. Here we do not consider the time that it takes to identify and extract the suitable fragment of the Fredhopper Interval API and the time that it takes to gain an informal understanding of the API.

Only a minimal amount of time (1 hour) was required to familiarize with this sequential and functional fragment of the core ABS language. This is because the functional fragment expresses only small subset of any standard functional programming languages, such as Standard ML [25]. Its syntax is also familiar to anyone with a working knowledge of any functional programming languages. Similarly the imperative framgement of the core ABS has a Java-like syntax and semantics, which the developer is very familiar with.

The time that takes to specify the fragment of Interval API in JML and the time that takes to define an ABS behavioural model for that fragment is comparable (7 hours for JML and 8 hours for ABS), as both require the same level of rigour. While it was the developer's first time experience to use both languages, both languages come with some level of tool support such as basic type checking via plug-ins to the Eclipse IDE.

Perhaps most time was spent in simulating, testing and debugging the ABS model using the Maude engine (15 hours). This is because it requires the ABS model to be executable, this means it is necessary to compile the ABS model to Maude terms using the ABS compiler. However, the ABS type checker and compiler to Maude do not always give meaningful messages for errors at compile time. In addition, debugging the ABS model during Maude simulation was carried out by reading textual representation of object states at a particular rewriting step, and it was not easy to interpret this representation.

Activity	**Duration**
Specification using JML	7 hours
Understanding the sequential fragment of core ABS	1 hour
Modelling using Eclipse IDE	8 hours
Simulation, Testing and Debugging using Maude Engine	15 hours

Table 5.2: Duration per activity to model the Interval API

Replication System

When modelling the Replication System using the core ABS language, we are able to provide the following abstractions.

- File – In the Java implementation, both SyncClient and SyncServer interact directly with the physical file systems of the environment via Java API. In our ABS model, physical file interactions are abstracted. As a result the ReplicationSnapshot component is no longer implemented as a separate class. More importantly, this abstraction allows us to reuse this model in future work to capture platform variability and model fault tolerance, thereby helps verifying replication consistency.

- Schedule policy and Time – The core ABS's semantics abstracts from time and scheduling between active objects is non-deterministic.

- Communication layer – Similar to the abstraction of the file system, we abstract socket-based communications in the Java implementation between SyncClients and the SyncServer with asynchronous method invocations. As a result, it is not no longer necessary to model SyncServerAcceptorThread as an active object that iteratively checks if the SyncServer is accepting connection from SyncClients. In our ABS model, it is sufficient to asynchronously wait for the value SyncServerAcceptor.accept to be true before accepting a SyncClient's connection.

- Termination – In the Java implementation, both the execution of SyncClient and SyncServer do not terminate unless by external triggers that are registered via `Runtime.addShutdownHook()`. However, to simulate our ABS model in the Maude engine, our ABS model does terminate. We model termination of SyncServer and SyncClient by detecting when no more file updates are present at the SyncServer. As a result file updates are modelled statically as a finite map of checkpoints and files.

Table 5.3 shows the duration of some of the activities, that are taken as part of the process to define an ABS model for the Replication System. Note that the same developer at Fredhopper, who modelled the Interval API, also modelled the Replication System, and similar to the Interval API, we do not consider the time that takes to identify and extract the suitable fragment of the Replication System and the time that takes to gain an informal understanding of the Replication Protocol.

The concurrent fragment of the core ABS has a vastly different syntax and semantics than that of Java. As a result the familiarisation of this fragment took considerably longer than for the sequential fragment (4 hours), much of which is reading Deliverable 1.1a [1] and working with example ABS models.

The time it took to specify the Replication System in CSP was approximately 7 hours while it took around 13 hours to model the Replication System in ABS. While both require a high level of rigour, the developer has a prior knowledge of CSP and associated tool support. Moreover, the developer is more familiar with Java's concurrency model and switching between this and ABS's concurrency model was a paradigm shift. As a result the time he took much longer to model the Replication System in the core ABS language.

Similar to modelling the Interval API, most time consuming was conducting simulation and debugging using the Maude engine (24 hours). Debugging and understanding the textual representation of object states in the Maude engine is already a time consuming activity. This is exacerbated by the fact that the model exhibits concurrent behaviour. However, from the developer's point of view simulation-based debugging provides better control over the state of the running of the model than the traditional execution-based debugging.

Activity	**Duration**
Specification using CSP	7 hours
Understanding the concurrent fragment of core ABS	4 hours
Modelling using Eclipse IDE	13 hours
Simulation, Testing and Debugging using Maude Engine	24 hours

Table 5.3: Duration per activity to model the Replication System

5.6.2 Evaluation Results

In Task 5.1 we have identified methodological requirements and high level concerns that the HATS framework can address for each case study. In this section we consider a subset of methodological requirements in D5.1 [28, Chapter 2] and a subset of high level concerns (FP-C1, FP-C7 and FP-C11) elicited from the Fredhopper case study [28, Chapter 5]. Details of these requirements and concerns can be found in Appendix A. As a result of further requirement analyses conducted in Task 5.2, we refine Concerns FP-C1 and FP-C11 to concrete Requirements R-FP-1.1.1 and R-FP-1.1.2. Requirement descriptions are provided in Table 2.4 and 2.5 respectively on Page 17 of this deliverable. Note that at this stage of the project it is only possible to consider a small subset of the requirements of the HATS framework. Moreover, the HATS framework is only evaluated with respect to these requirements and concerns in terms of the core ABS language and its associated tool support.

Methodological Requirements

MR7: Tailorability The main programming language that Fredhopper uses to develop FAS is Java and developers in Fredhopper use the Eclipse IDE[5] for software development, dependency and version management. The HATS project implements an Eclipse plug-in that provides syntax highlighting, basic content completion and navigability, and partial type checking on ABS scripts. Syntactically ABS has much in common with Java. As a result from the point of view of constructing a standalone ABS model, the ABS

[5] `http://www.eclipse.org`

language and its tool support can be easily integrated into the Fredhopper software development workflow. However, at the current stage of the project, the HATS framework provides little support for tailoring the Fredhopper context from the point of view of dependency and version management, continuous integration and quality assurance process.

MR10: Scalability From the evaluation with respect to Requirement MR7, it is easy to see that at the current stage of the project, the HATS framework provides little support in terms of scalability. For example, from our experience the parsing carried out by the Eclipse plug-in slows down the response time the Eclipse with its user dramatically after the ABS script being edited has more than 800 lines of code.

MR11: Learnability We consider the capability of the ABS language and its associated tool support to enable developers in Fredhopper to learn how to use them. Due to Fredhopper's familiarity with Java and Eclipse IDE, it is straightforward for developers in Fredhopper to understand and start modelling in the core ABS language and using its associated Eclipse plug-in. Currently, however, there is little support with using the Maude engine and simulating ABS models. The HATS framework will provide better integration of the Maude simulation and visualisation with the Eclipse IDE in future work.

MR12: Usability Similar to learnability, due to Fredhopper's familiarity with Java and Eclipse IDE, it is straightforward for developers in Fredhopper to understand and start modelling in the core ABS language and using its associated Eclipse plug-in. However, at the current state of the project, it is not possible to apply the HATS framework directly to the Fredhopper software development process. Much better support will be provided by the HATS framework in future work for extracting requirements from existing implementations, and for carrying out formal analysis with ABS models such that it can be integrated into the Fredhopper software development process.

MR13: Reducing manual effort At this stage of the project, modelling has to be carried out manually. The Eclipse plug-in that comes with the ABS language currently provides partial content completion and the current version of the ABS compiler provides basic type checking and automatic translation to Maude modules for simulation. As part of future work, automation will be provided by the HATS framework in future work for test case generation and code generation. In addition, we believe it would be beneficial for HATS to provide tool support to translate existing formal specifications such as JML contracts into ABS interface specification and vice versa, as this encourages application of ABS using existing tool support.

MR17: Protocol analysis As mentioned in Section 5.4.7, we do not have the necessary analysis techniques and tool support to verify the replication protocol to be correct with respect to replication consistency. Currently we are able to validate a particular Maude-based simulation to be correct with respect to data consistency. However, in order to conduct full verification of the replication protocol, the HATS framework must provide the necessary language constructs, techniques and tool support to formalise the consistency property and to conduct the verification against the ABS model. Further protocol analysis will be conducted in future work.

MR18: Integrated environment support The HATS framework currently provides an Eclipse plug-in that provides syntax highlighting, basic content completion and code navigation, and partial type checking on ABS scripts. This is a good start from the point of view of integrating the HATS framework in the Fredhopper context as developers in Fredhopper are acquainted with the Eclipse IDE. Further integration is required from the HATS framework to support model validation as well as dependency and version management and continuous integration as part of the Fredhopper software development process.

MR19: Existing modelling techniques support Similar to Requirement MR13, all of the modelling has to be carried out manually. This means there is currently no support for existing modelling techniques. We believe this can be improved if the HATS framework provides tool support to translate existing formal specifications such as JML contracts and various UML diagrams into ABS and vice versa. This also encourages the application of ABS with existing tool support.

MR22: Middleware abstraction In our Replication System case study, we are able to abstract from the implementation of the file systems as well as the communication layer. This is achieved by using ABS's data type and functional sublanguage as well as non-deterministic scheduling. However we believe abstractions will be further improved as the ABS language is extended with a behavioural interface language as well as delta modelling. With interface specifications, it might even be possible to model behaviours specified by an ABS interface without providing a more concrete ABS class implementation. However, we believe it would be beneficial to include other non-deterministic constructs such as the choice operator for modelling exceptions and time outs. Adding exception and time out behaviours allows us to model fault tolerance, which is one of the properties in replication consistency.

Fredhopper Concerns

FP-C1: Specification of sequential programs In Task 5.2, We refined Concern FP-C1 to concrete Requirement FP-R-1.1-1, which is shown in Table 2.4 on Page 17 in Chapter 2. This requirement is satisfied as demonstrated by our Interval API case study. However, we believe the behavioural interface language and delta modelling are necessary parts of the ABS language to specify code reuse and high-level behavioural contracts. As a result Concern FP-C1 will also be considered in Task 5.3, where variability is considered.

FP-C7: Tool support for navigability This concern is partially addressed by Eclipse plug-in provided in the HATS project. This plug-in provides outline view of ABS scripts for navigability. This provides some basic navigability such that one could be directed to a particular data type/function/interface/class/ definition by clicking the corresponding label on the outline view. Moreover, it is possible to go to the definition of an interface that a class implements by clicking on the interface name specified at the class definition. However, we believe navigability can be improved by first providing a module system or syntactic import feature, and second utilising Eclipse's functionalities to allow navigation of ABS model that is defined over multiple ABS scripts.

FP-C11: Specification of concurrent programs In Task 5.2, We refined Concern FP-C11 to concrete Requirement FP-R-1.1-2, which is shown in Table 2.5 on Page 17 in Chapter 2. This requirement is satisfied as demonstrated by our Replication System case study. However, similar to Concern FP-C1, we believe the behavioural interface language and delta modelling are necessary parts of the ABS language to specify code reuse and high-level interface specification. A a result Concern FP-C11 will also be considered in Task 5.3, where variability is considered.

5.7 Conclusion

This chapter evaluated the core ABS language and tests the HATS methodology by studying two components of FAS, namely, the Fredhopper Interval API and the Replication System.

5.7.1 Interval API

When providing an ABS model of the Fredhopper Interval API, we consider only one implementation of `Interval`. We envisage specification of further concrete implementations. Some of these implementations will be specified as variabilities while others will be modelled as *evolutionary steps*. As the development of ABS language and HATS framework continues, we aim to describe and model these variabilities in terms

of deltas [31, 10]. We also aim to model implementations that cause changes to the contracts of the public interfaces as evolutionary steps. We aim to use results from WP3, such as Welsch and Poetzsch-Heffter's work on source compatibility as part of Task 3.1 [33], to infer these evolutionary steps to be consistent. In software evolution, consistency is a general safety property about the evolution. For example an evolution of a software system is consistent if its components remain interoperable.

5.7.2 Replication System

When constructing an ABS model of the Replication System, we abstract from the underlying file system, scheduling policy, time out and user interactions. Similar to modelling the Interval API, we envisage to model these behaviours as platform variability. Platform variability is currently being investigated in Task 2.1. Another variability we would like to investigate and model in future work is the behaviour of SyncClient. Currently each SyncClient exhibits only sequential behaviour, that is ClientJobs are sequentially ordered. We would like to investigate to possibility of construct a concurrent variation of the SyncClient in which ClientJobs' executions are interleaved.

Figure 5.18: UML Activity diagram of the Client Replication job

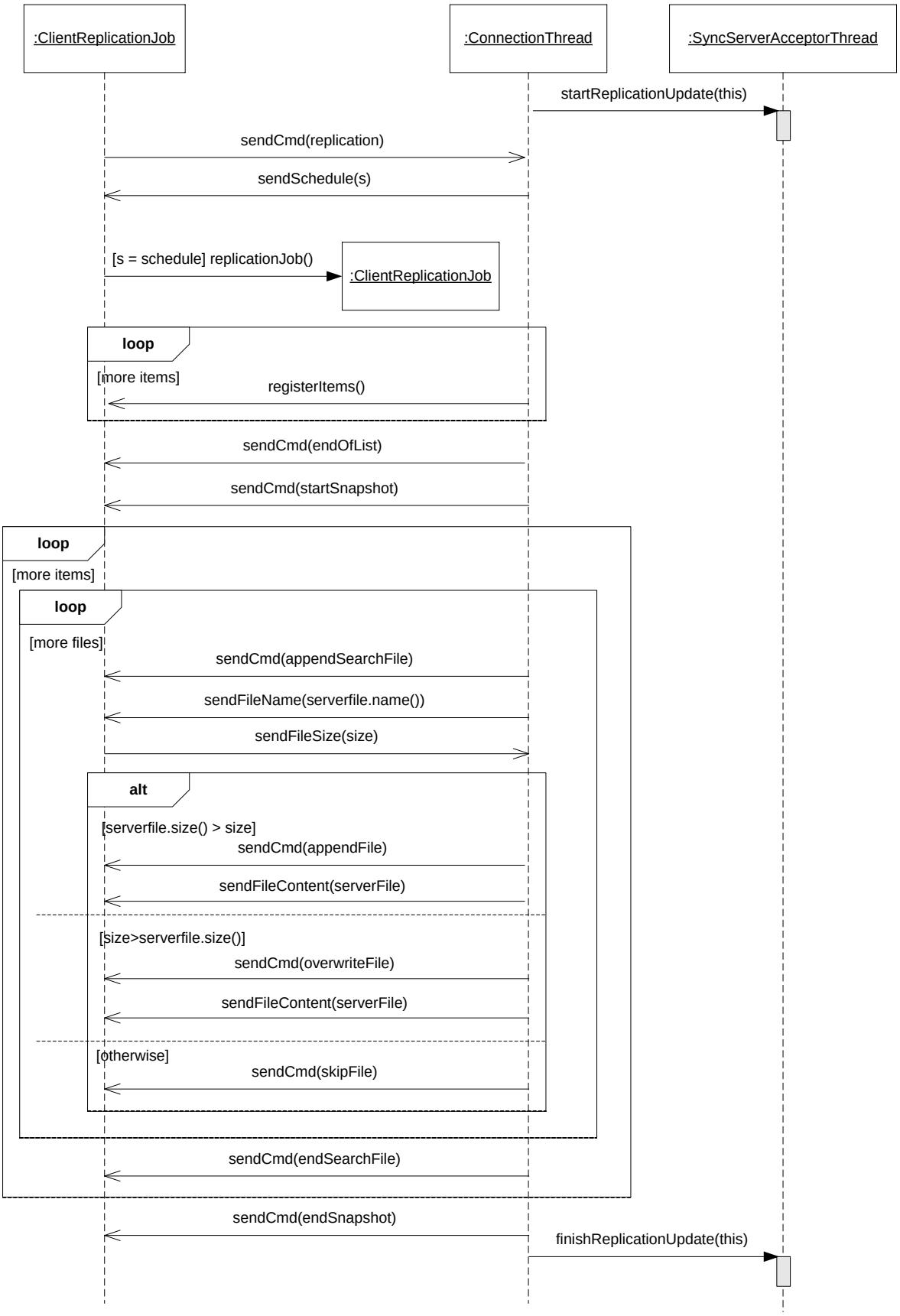


Figure 5.19: UML Sequence diagram of replication

Chapter 6

Conclusion

This chapter concludes this report by providing a summary of chapters and the evaluation results.

6.1 Summary of Report

The contribution of this report is twofold: we presented the result of further requirement analysis, and we tested and evaluated the core ABS language and the HATS methodology.

In Chapter 2 we presented the result of further requirement analysis conducted for Tasks 1.1, 1.2, 2.1, 2.2, 3.1 and 4.2. For each task we identified high level concerns from D5.1 that are relevant to the task. Together with members of the work task, we then defined concrete test cases and evaluation criteria, thereby refining high level concerns into concrete usable requirements. Concrete requirements for Task 1.1 were considered when we tested and evaluated the core ABS language.

In Chapters 3, 4 and 5 we presented our evaluation of the core ABS language and HATS methodology. Based on requirements of Task 1.1, for each case study we chose representative parts as test cases, and modelled them using the core ABS language. In Chapter 3 we also provided an outlook on extending the Trading System case study onto the level of software product line (SPL) as well as verification of SPL.

In Chapter 3 we considered the Trading System case study. In particular, we modelled the cash desk component, and provided an evaluation of the language and methodology. In Chapter 4 we considered the Virtual office of the future (VOF) case study. In particular, we modelled the Node management component of the VOF platform, and provided an evaluation of the language and methodology. In Chapter 5 we considered the Fredhopper case study. Based on Requirement FP-R-1.1-1 and FP-R-1.1-2, we identified the Fredhopper Interval API and the Replication System as the candidate test cases. We modelled these two components and provided an evaluation of the language and methodology.

6.2 Evaluation

In this section we summarise the evaluation results from Chapters 3, 4 and 5, and discuss these results in the context of the overall validation process. Here we consider the evaluation results in terms of the expressiveness of the core ABS language and the HATS methodology.

6.2.1 Core ABS Language

We evaluated the core ABS language with respect to the following types of criteria: requirement descriptions, abstraction and expressivity.

Requirement Descriptions

We evaluated the core ABS language with respect to Requirements TS-R-1.1-1, FP-R-1.1-1 and FP-R-1.1-2. These requirements are indeed satisfied as demonstrated by the case studies in Chapter 3 and Chapter 5. In

addition, we also tested the expressiveness of the core ABS language by studying and modelling the Node management component of the VOF platform. This test enforces the validation of the core ABS language with respect to the concrete requirements.

Abstraction

We evaluated the core ABS language with respect to the types of abstraction the language provides. This aspect has been evaluated by each case study individually. Here we now summarise their results:

Data In each case study, it was possible to construct an ABS model of a component that abstracts from the component's underlying physical environment such as physical file systems and data base. This is achieved by using data type definitions provided by the core ABS language as well as the possibility to underspecify data types.

Concurrency In each case study, we provided a model of the component's concurrent behaviour in terms of asynchronous method invocation. In terms of model construction we saw that the core ABS language is expressive enough to model concurrent behaviour. However, at this point it is not possible to claim that the core ABS language can be used to faithfully model all intended behaviour of a given component. Such a claim amounts to formal verification, which is beyond the scope of this deliverable and will be considered at later work tasks.

Modularity In each case study, it was possible to model components modularly using the core ABS language. This means for each component, the core ABS language is expressive enough to modularly describe each fundamental aspect of the component. For example, in the Trading System case study, it was possible to distinguish between the models of the component and its environment.

Expressivity

We evaluate the practical expressiveness of the core ABS language. Specifically we investigate how readily and concisely the core ABS language expresses various kinds of program structures and behaviours.

- Import or module system – Currently the implementation of the core ABS language does not provide a module system or support for syntactic imports. As a result one has to redefine model independent definitions such as parametric data types and associated functions for all models. A module system for the ABS language is currently under development.

- No higher-order function – The core ABS language does not support higher order functions. This means we cannot define typical functions known from other functional languages like `map` for example.

- No class inheritance – The core ABS language does not provide class inheritance to support code reusability. Two ABS classes that implement a common interface have to implement that interface's method separately. Note that code reusability will be established in future work when delta modelling [10, 31] has been integrated into ABS; Delta modelling is also primary method for handling variability in a software product line.

- Starvation – Due to non-deterministic scheduling, it is not possible to enforce fairness over competing active objects when simulating an ABS model in Maude engine. For example, let's consider the following example ABS model.

```
interface X { Unit setJ(J j); }
interface I { Bool getBool(); }
interface J extends I { Unit finish(); }
class C implements I { Bool getBool() { return True; } }
```

```
class D(I i) implements J {
  Bool l = True;
  Unit run() {
    Fut<Bool> c;
    While (l) { c = i!getBool(); await c?; }
  }
  Unit finish() { l = False; }
  Bool getBool() { return True; }
}

class W(J j) implements X {
  Unit run() {
    Fut<Bool> b; b = j!getBool(); await b?;
    j.finish();
  }
}

{ I c; J d; X w; c = new C(); d = new D(c); w = new W(d); }
```

This model is non-terminating because when the Maude engine simulates this model, it is possible for the simulation to choose an execution path that never gives thread control to object w. Note that it only affects model simulation. Other analysis techniques such as symbolic execution or model checking are not affected as these techniques traverse all possible execution paths. In particular, the example model above is finite state and therefore would be amenable to model checking.

- Syntactic Sugaring – To model communications between active objects in ABS we often define the following sequence of statements in an active object to model invoking method async() of object obj asynchronously, yielding the thread control of its object group and blocking its own execution until the method call returns.

  ```
  A val; Fut<A> f; f = obj!async(); await f?; val = f.get;
  ```

  We believe the usability of the language could be improved by providing syntactic sugaring to this kind of patterns of behaviours.

- Non-determinism – With socket-based communication, the order between two or more consecutive asynchronous messages to the same socket is maintained. The order is maintained via the implementation of input and output stream buffers of the sockets. With the ABS semantics, however, scheduling is non-deterministic. As a result, the order of asynchronous method invocation has to be maintained explicitly. For example consider the following example ABS model.

  ```
  interface I { Unit put(Int i); }

  class C implements I {
    List<Int> ints = Nil;
    Unit put(Int i) { ints = Cons(i,ints); }
  }

  class D(I obj) {
    Unit run() {
      Int i = 1;
      while (i < 100) { obj!put(i); i = i + 1; }
    }
  ```

```
}

{ I c; c = new C(); new D(c); }
```

In this example, object new D(c) iteratively sends numbers 1 to 99 to object c asynchronously. While the method invocations are made in the ascending order of the number, because object new D(c) does not yield control until all 99 invocations are made, the order of the method executions will be non-deterministic. To enforce determinism, object new D(c) has to explicitly wait between asynchronous method invocations as illustrated by the follow modified class D.

```
class D(I obj) {
  Unit run() {
    Int i = 1;
    while (i < 100) { Fut<Unit> u; u = obj!put(i); await u?; i = i + 1; }
  }
}
```

We believe behaviours such as this should be made explicit in the user guide of the core ABS language. In addition, the ABS language should provide built-in mechanisms to give ordering guarantees to improve its practical expressivity.

- No non-deterministic choice – when abstracting certain behavioural details of a system, one often needs non-determinism. Core ABS has no explicit non-deterministic choice operator to express this. It is possible, however, to implement this operator within the ABS language, using the non-determinism of the message scheduling. Nevertheless we think that an explicit operator would made the model more readable and understandable.

- No timing constraints – ABS does not allow for specifying timing constraints. For example, waiting for a future for a certain amount of time. Some requirements in the Trading System case study required this, however. We found no easy way to encode this by using existing ABS language features and thus could not model these aspects.

Validation of Milestone M1

As a result of this evaluation, we have validated that *Milestone M1 of the HATS project has been achieved.*

6.2.2 HATS Methodology

For each case study, we evaluated the HATS methodology from the investigative and the requirement perspectives. From the investigative perspective, we considered how the approach of each case study fits with some or all of the following steps in the HATS methodology: Product Line Requirement Analysis, Reference Architecture, Generic Component Design, Generic Component Realisation, Generic Component Validation, Application Engineering Planning and Product Construction and Integration.

From the requirement perspective, we evaluated parts of the HATS methodology with respect to some or all of the following requirements: tailorability (MR7), scalability (MR10), learnability (MR11), usability (MR12), reducing manual effort (MR13), protocol analysis (MR17), integrated environment support (MR18), existing modelling techniques support (MR19), and middleware abstraction (MR22). Here we summarise these results.

MR7: Tailorability

The HATS project implements an Eclipse plug-in that provides syntax highlighting, basic content completion and navigability on ABS models. Syntactically ABS has much in common with Java. As a result from the point of view of constructing a standalone ABS model, it can be easily integrated with existing

development processes. Nonetheless, we would like to see the HATS framework providing better facilities for the management and configuration of at least some of the following aspects:

- Dependencies between ABS models of multiple components.
- Dependencies between ABS models of the same component, each providing an abstraction from a different perspective of that component.
- Dependencies between versions of the same ABS model.
- Dependencies between an ABS model and the component it models.

Note that as the project progresses, we envisage the HATS framework to provide better integration between the tool support for editing, simulating and analysing ABS models. For example, it would be beneficial to integrate the compilation and simulation into the Eclipse front-end and provide visualisation of object states during simulation. Note that the improvements suggested here also form an integral part of usability and tools integration requirements (MR12 and MR18). However, we believe they also improve the likelihood that the HATS framework can be tailored for different organisational and applicational contexts.

MR10: Scalability

Language. Currently a module system is missing in Core ABS. This means that Core ABS does not provide namespacing or implementation hiding mechanisms, which makes it difficult to handle larger ABS models. This was a problem in all three case studies. As a direct result of the evaluation effort of this Task, a module system for ABS is under development, whose design will be directly influenced by the experiences of the case studies.

Tools. From the evaluation with respect to Requirement MR7, it is easy to see that at the current stage of the project, the HATS framework provides little support in terms of scalability. The current command line tools do not support to specify an ABS model in several files. The complete model has to be provided in a single file. For larger models splitting the model into several files, however, is desirable. In addition, the syntactic parsing carried out by the Eclipse plug-in slows down the response time the Eclipse with its user dramatically after the ABS script being edited has more than 800 lines of code. Similarly, the performance of the Maude simulation has to be improved in the future. Simulating a simple use case in the Trading System case study, for example, took about 1 minute on a standard machine.

MR11: Learnability

Language. The core ABS language is designed to be as easy to learn as possible by building on language constructs well known from mainstream languages. In particular, the syntax and the semantics of the functional and sequential imperative fragments of the core ABS language can be easily acquainted by users with a working knowledge of any functional and object-oriented languages. However, it is not as easy to learn the concurrent fragment of the core ABS language, especially for users who are used to the thread-concurrency model. The current source for learning the core ABS language is by studying Deliverable D1.1a [1] and an incomplete user guide. We have found that a more complete task-oriented user guide will be helpful. This will be similar to a "cookbook" for mainstream programming languages.

Tools. The ABS compiler currently only works from the command line. It is, however, used like compilers known from other languages like Java, for example. So users familiar with the command line have no problem by using the ABS compiler. Similar, the Eclipse plugin behaves like other plugins known from mainstream languages and can be immediately used without a learning effort.

Not surprisingly, the largest problems appeared in simulating the models in the Maude framework. Here, knowledge of Maude is currently required to understand the simulation results. We envisage an integration

of the Maude simulation and visualisation with the Eclipse IDE as future work, that allows users to simulate ABS models, without requiring knowledge of the Maude language.

MR12: Usability

Similar to learnability, it is straightforward for users to understand and start modelling in the core ABS language and using its associated tools. However, in the current state of the project, it is not possible to apply the HATS framework directly to any realistic software development processes. In future work, we envisage the HATS framework to provide much better support for model mining, formal analysis and code generation.

MR13: Reducing manual effort

At this stage of the project, all modelling has to be carried out manually. Currently, the Eclipse plug-in that comes with the ABS language provides partial content completion and the ABS compiler provides basic type checking and automatic translation to Maude modules for simulation. As part of future work, automation will be provided by the HATS framework for test case generation and code generation. In addition, we believe it would be beneficial for HATS to provide tool support to translate existing formal specifications such as JML contracts into ABS interface specification and vice versa, as this encourages application of ABS using existing tool support.

MR17: Protocol analysis

In this deliverable, this methodological requirement is specific to the application area of Fredhopper Access Server. As described in Chapter 5, we envisage that, in future work, HATS framework will provide the necessary language constructs, techniques and tool support to formalise the consistency property and to conduct the verification against the ABS models.

MR18: Integrated environment support

HATS framework currently provides an Eclipse plug-in that provides syntax highlighting, basic content completion and code navigation on ABS models. This is a good start from the point of view of providing integrated environment support. Further integration is required from the HATS framework to support model validation as well as dependency and version management and continuous integration so that the HATS framework can be better integrated to existing software development processes.

MR19: Existing modelling techniques support

Similar to Requirement MR13, all of the modelling has to be carried out manually. This means there is currently no explicit support with existing modelling techniques. Conceptually, however, the core ABS language supports general object oriented modelling techniques other than inheritance. In terms of high level specifications, we envisage that, in future work, the HATS framework will provide tool support for translating existing formal specifications such as JML contracts into ABS interface specification (and vice versa), thereby leveraging existing tool support. This will improve the applicability of ABS in the context of industrial software development.

MR22: Middleware abstraction

In the Fredhopper case study, the ABS model abstracts from the implementation of the file systems as well as the communication layer. We consider this to be an abstraction on the modelling level. However, we believe the HATS framework, and in particular the ABS language can be improved by providing support for abstraction at the language level, as described in the Virtual office of the future case study in Chapter 4. We envisage that the HATS framework will extend the ABS language with a behavioural interface language as

well as delta modelling. In addition, we believe that it would be beneficial to include other non-deterministic constructs such as the choice operator for modelling fault tolerance as part of describing platform variability.

6.3 Summary

We have presented a summary of the case studies and the evaluation results that are specific to each case study. We also discussed the evaluation of aspects that are independent of the case studies, namely the expressivity of the core ABS language and the methodological requirements.

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Glossary

Terms and Abbreviations

ABS Abstract Behavioral Specification language. An executable class-based, concurrent, object-oriented modeling language based on Creol, created for the HATS project.

Communicating sequential processes A formal language for describing patterns of interaction in concurrent systems.

CSP See Communicating sequential processes

HATS framework The combination of the HATS methodology, the full ABS language with its associated analysis techniques and tool support.

Fredhopper Interval API An in-house Java API developed by Fredhopper that implements data structures and operations for representing and manipulating mathematical intervals.

Java modelling language A specification language for Java programs, using Hoare style pre- and post-conditions and invariants, that follows the design by contract paradigm.

JML See Java modelling language

FAS See Fredhopper access server

Fredhopper access server Fredhopper access server is a component-based, service-oriented and server-based software system, which provides search and merchandising IT services to e-Commerce companies such as large catalog traders, travel booking, managers of classified, etc.

Live environment A live environment in the FAS deployment architecture is responsible for processing queries from client web applications via the Web Services technology.

Replication system The Replication System in the FAS deployment architecture synchronises the configurations and data from the staging environment to multiple live environments. Specifically the Replication System consists of the synchronisation server (SyncServer) and one or more clients (SyncClient).

Software Family See Software Product Line.

Software Product Line A family of software systems with well-defined commonalities and variabilities.

SPL Software Product Line

Staging environment A staging environment in the FAS deployment architecture is responsible for receiving client data updates in XML format, indexing the XML, and distributing the resulting indices across all live environments using the Replication System. See Replication System.

Virtual office of the future A P2P framework that enables office workers to perform their office tasks seamlessly independent of their current location.

VOF See Virtual office of the future

Part II

Requirements

Appendix A

Requirements Elicitation

In D5.1 [28] we have harvested a comprehensive set of requirements on the methodological development of the HATS framework. We have also elicited a set of high-level concerns for each case study that the HATS framework should address. In this chapter we enumerate those requirements and concerns that are considered in this deliverable report.

A.1 Methodological Requirements

Requirement (MR7)**.** ***Tailorability****: The HATS methodology must support its tailoring to a specific organizational context. The HATS methodology needs to provide certain adjustment parameters that enable its tailoring to, for instance, the existing development practices in an organization, the application domain, the structure of an organization, or the experience of the developers.*

Requirement (MR10)**.** ***Scalability****: The HATS methodology must be scalable, i.e. it needs to provide high quality results by using reasonable effort in the case of small, medium, and large scale systems. Applying it to larger systems parts or systems with higher complexity should not cause more than linear increase of effort and constantly deliver high quality.*

Requirement (MR11)**.** ***Learnability****: The HATS methodology must be easy to learn. The new concepts to be applied by developers in an organization introducing the HATS methodology should be kept simple to be understandable by developers with average skills and experience. This implies offering of good documentation, tutorials, incremental examples.*

Requirement (MR12)**.** ***Usability****: The HATS methodology must be easy to use. Developers with average skills and experience should be able to apply the HATS methodology with reasonable effort. For example, this implies tools designed for ease of use.*

Requirement (MR13)**.** ***Reducing manual effort****: The HATS methodology must reduce manual effort as well as the error-proneness of manually defined code.*

Requirement (MR17)**.** ***Protocol analysis****: The HATS framework addresses verification and protocol checking issues. From the methodological point of view, it would prove useful to provide an analytical tool that Fredhopper can integrate in its service provisioning process. The tool can support the detection of any protocol violations. Violations may be originated from unanticipated regressions in the Fredhopper product or unanticipated client misuses of the protocol. Furthermore, if such a tool can operate as a runtime component, Fredhopper may provide a proper default handling of the issue automatically during runtime. Note that the possibility for such errors comes from the informal process of producing the Fredhopper product. In addition, Fredhopper does not have control over the remote client, which may abuse the protocol due to own regressions or incorrect implementations.*

Requirement (MR18)**.** ***Integrated environment support****: The tools of the HATS framework have to support usage in an integrated environment. As such these tools have to have:*

Interoperable formats *HATS tools that we expect to use in a sequence, have to speak common formats.*

Common visual representation *HATS tools may have different cores, working with different formalisms. Nevertheless they have to operate in the common visual and easy to use control environment of the IDE.*

Common resources *An IDE manages project resources by building a heterogeneous repository of resources, which one may share among teams and team members. The tools have to take into account versioning and collaborative work.*

Ability to work with large projects *HATS tools have to scale. This may even mean that individual tools and formalisms may have to introduce partitioning of models and splitting and merging of models just for the sake of utilizing work across the team.*

Requirement (MR19)**.** ***Existing modeling techniques support****: The HATS methodology must be able to cope with existing models in organizations. To allow the reuse of models from languages typically used in practice today, for instance, UML activity diagrams with Petri-net semantics, the HATS methodology should provide model-transformations from those models into ABS models.*

Requirement (MR22)**.** ***Middleware abstraction****: The ABS language should be able to abstract from concrete middleware technologies and provide means to describe the expected behavior of middleware solutions.*

A.2 Trading System Case Study

Concern (TS-C6)**.** ***Variability modeling****: The HATS approach should provide support for modeling the variability at the language level (T1.1, T1.2). An adaption of the ABS model to incorporate feature modeling, different platform models and configurations should enable modular description of the presented scenario using the HATS modeling approach (T1.2). It should furthermore be possible to generate different configurations of the cash desks (T1.4).*

A.3 Virtual Office of the Future Case Study

Concern (VF-C5)**.** ***Code generation for workflow realization:*** *Today the realization of a new workflow is concerned with many manual development activities. Code realizing the behavior of a VOF document cannot be generated so far (T1.4).*

Concern (VF-C6)**.** ***Portability:*** *We have to generate and offer different platform applications for different end devices (T1.2).*

Concern (VF-C11)**.** ***Correctness:*** *If the implementation of a service specification changes, the functionality of the service has to be guaranteed (T4.3).*

Concern (VF-C13)**.** ***Model mining:*** *The integration of a new office application like Thunderbird bears the risk that because of incomplete information about the new applications' realization the integration fails or is at least error-prone. Model-mining can provide additional information on an application to be integrated (T3.2).*

Concern (VF-C14)**.** ***Feature modeling:*** *Interfaces should be defined for the new component, as well as the related events to describe the behavior (T1.2).*

Concern (VF-C15)**.** ***Variability:*** *Adapt variation points of existing components to guarantee seamless integration of the new security component (T2.4).*

Concern (VF-C17)**.** ***Code generation:*** *To keep the compliance among the services in the network, it should be specified with ABS how each service should behave with the introduction of a new technology. It means that parts of the source code should be replaced by code generated using ABS specification (T4.3).*

Concern (VF-C18)**.** ***System derivation:*** *Based on the new introduced communication technology, all the proxy components should be replaced in order to achieve the compatibility among the VOF applications and the middleware (T1.4).*

Concern (VF-C19)**.** ***Configurable deployment architecture:*** *Once a new version of the VOF middleware was built, it has to be guaranteed that the version of the VOF middleware was deployed for all the nodes to avoid incompatibilities (T2.1).*

A.4 Fredhopper Case Study

Concern (FP-C1)**.** ***Specification of sequential programs:*** *The HATS framework should provide the mechanism for specifying behavior of units of code precisely, as identified in the concrete example above. One way of providing this is to allow the specification of pre/postconditions of units of code. Traditionally these conditions are asserted as predicate or temporal logic expressions, but this requires knowledge, which cannot be assumed to be accessible to software developers and testers. Therefore HATS should deliver usable techniques and tool support to assist the generation of behavioral properties so that formal specification might become more amenable. In addition HATS should provide the tool support for harvesting behavioral properties from existing unit tests. (T1.1, T1.3, T1.5 and T4.3)*

Concern (FP-C7)**.** ***Tool support for navigability:*** *The HATS framework should provide the tool support for managing the structure of glue code of any two interacting components. Unlike correctness concerns, here we are concerned with improving navigability of the glue code. For example, the HATS framework could provide the tool support to visually relate a piece of glue code to its corresponding behavioral contract. As the glue code and its behavioral contract become complex, the provided tool support should ease the validation and the verification of the glue code. (T1.4, T1.5 and T4.3)*

Concern (FP-C11)**.** ***Specification of concurrent programs:*** *The HATS framework should provide the mechanism for formally specifying units of code that exhibit concurrent behavior. One possible way of achieving this is by providing the language and calculus for modelling concurrent behavior. In the area of formal engineering methods, extensive research has been carried out towards modeling and reasoning about concurrent behavior. Notable area includes* process algebras *[2] in which software systems are modeled as algebraic processes describing their possible behavior. Behavioral property specifications are then provided as either logical expressions or abstract processes. The use of a process algebraic approach requires knowledge in abstraction, and this creates a conceptual gap in between programming and modeling. A complementary approach is the development of implementation level language with rigorous formal foundation. This approach not only facilitates formal reasoning and associated tool support, but it is also much closer to general purpose programming languages like Java [15]. Notable research result includes the development of Creol [19]. Creol is an experimental high-level object-oriented language for distributed objects, and specification in Creol may be translated in Maude, for which various tools such as a theorem prover have been developed. However, either approach requires mathematical knowledge, which cannot be assumed to be accessible to software developers and testers. HATS should therefore incorporate usable techniques and tools to assist the generation of these behavioral properties such that formal specification becomes more amenable. (T1.1, T1.3, T1.5 and T4.3)*

Appendix B

TS-R-1.2-1: Variability Modeling of Cash Desk Variants

B.1 Introduction

This use case concerns the requirement "Variability Modeling of Different Cash Desk Variants". It refers to Scenario TS2 of the Trading System Case Study in Deliverable D5.1 [28, Section 3.2.2] and refines the high level concern TS-C6. Specifically this use case describes the different features of a cash desk in the trading system case study and the dependencies between the different features. It should be possible to model the different cash desk variants in terms of valid combinations of features by the ABS feature modeling language. (T1.2)

B.2 Use Case

Each cash desk in the trading system has different payment options. First, it is possible to pay by cash or by one of the non-cash payment options, i.e., credit card, prepaid card or electronic cash. At least one payment option has to be chosen for a valid configuration. Product information can be entered using a keyboard or a scanner where at least one option has to be selected. Furthermore, the system has optional support to weigh goods, either at the cash desks themselves or at separate facilities.

With respect to deployment, there is the alternative option to have a single-desk system with only one cashier or a multi-desk system with a set of cashiers. The multi-desk system can optionally be in an express mode in which only 8 products are permitted for purchase that have to be paid by cash or in a self-service mode requiring non-cash payment. Otherwise, the system operates in its normal mode where the cashier can enter an arbitrary number of products and accepts all available methods of payment.

Appendix C

TS-R-1.2-2: Coupon Handling and Loyalty System

C.1 Introduction

This test case is related to requirement "Coupon Handing and Loyalty System" and addresses work task T1.2. The test case is derived from the Scenarios TS1 and TS5 from the Trading System Case Study of Deliverable D5.1 [28, Sections 3.2.1 and 3.2.5]. It describes the different features for the coupon handling and the loyalty system as well as valid configurations of features. Deliverable D5.1 is used as a reference for the different terms, so that they are not explained in detail here.

C.2 Test Case

The coupon and loyalty system feature can be summarized under the more general feature "Customer Relation Management" (CRM). The CRM feature adds the possibility to store and manage customer-related information and to give discounts to customers in different ways as described in D5.1.

C.2.1 Coupon Feature

The coupon handling feature adds the possibility to give coupons to customers, which can be redeemed together with a purchase. As described in D5.1 there are two different kinds of coupons: *common coupons* and *unique coupons*. Either only one or both types of coupons can be chosen as a configuration of the coupon feature.

Both types of coupons exist in two variants, namely with or without a barcode. Coupons with barcodes only make sense if the trading system supports barcode scanning. Coupons always have a printed ID which can be entered by a keyboard.

C.2.2 Customer Information Storage Feature

The customer information storage features enables the storage of customer information. The name, address and further information can be stored and queried. This feature has no dependencies on other features.

C.2.3 Loyalty Card Feature

The loyalty card feature enables the possibility to give a customer a loyalty card, which he or she can use at each purchase to get a discount. A loyalty card always has a bar code together with a printed ID and it requires a bar code scanner. The printed ID can be used as a backup functionality. This feature requires the customer information storage feature.

Individual Coupon Feature

Individual coupons are always bound to a certain loyalty card and can only be redeemed together with that card. This feature thus requires the loyalty card feature. Individual coupons always have a barcode and require a barcode scanner.

Appendix D

VF-R-1.2-1: Platform and Hardware Modeling

D.1 Introduction

The general setting in the VOF context is that an office worker can do his daily work while the VOF infrastructure is running in the background and delivers or dispatches documents. The infrastructure itself is a P2P platform for communicating between the workers. A typical communication being performed within VOF is the exchange of a VOF document. Whenever such a document is sent from one worker to another the receiver needs to be notified that such a document has arrived. Furthermore, the document may even be opened automatically. This use case refers to Scenario VF2 (Add a new device type to the VOF infrastructure) and refines the high level Concern VF-C6 in Deliverable 5.1 [28, Section 4.3.2].

Features concerned

Continuous monitoring for incoming documents, Notification of new document arrival, Automatic opening of new document

D.2 Description of Use Case

Mobile device platforms have specific features that need to be considered when developing applications for them. For instance, the iPhone platform does not support multi-tasking for all applications. Hence, the ABS language needs to be capable of modeling and specifying features of mobile device platforms as well as the underlying hardware system.

A problem that is typical for mobile devices is the handling of concurrent running applications and their interaction. For the purpose of this requirement test case, in this scenario we assume that we have the following types of devices:

Windows PC Applications can be run in the background with three possible ways of notifications:

- flashing application icon
- running application gets focus removed
- notification about application that wants to be brought to the front

Linux PC Applications can be run in the background with two possible ways of notifications:

- running application gets focus removed
- notification about application that wants to be brought to the front

iPhone-like mobile device Applications can not completely be run in the background. The only possibility is to run the application without UI in a periodic manner. This means that the application is suspended for 30 seconds after running for 5 seconds. A suspended application is not closed but it can not do any execution. Since its internal state is saved it can be resumed at any time. This type of devices has only one way of notifications:

- closing the running application

Involved Actors

Office worker, VOF infrastructure

Precondition

The VOF infrastructure running with at least one other VOF node online.

Trigger

A new VOF document is arriving.

Postcondition

The Office worker is notified about new document.

Standard Processes

The interaction pattern described below is implemented/modeled once and should be installed on the three different devices. Depending on the devices the user can select a way how he wants to be notified.

1. VOF infrastructure (inbox for VOF documents) listens for incoming documents.
2. Incoming document triggers inbox to notify user.
3. Since there are multiple possibilities to notify the user about an application that was running in the background and wants to be brought to the front it should be possible for the user to decide which one should be used. As mentioned above this depends on the device type on which the application is installed.

Appendix E

VF-R-1.2-2: Platform and Hardware Modeling

E.1 Introduction

The VOF P2P infrastructure is the underlying communication system for exchanging documents between workers. In this use case only this data transmission aspect is considered. This use case refers to Scenario VF5 (Integration of new functionality in the VOF P2P platform) and refines the high level Concern VF-C14 (Feature modeling) in Deliverable 5.1 [28, Section 4.3.5].

Features concerned

Transmission of VOF documents, Encryption of data transfer, Adaption to heterogeneous system landscape

E.2 Description of Use Case

By default, the communication between nodes in the infrastructure is insecure. A node that wants to send some file to another node first sends a notification to the receiver (using the P2P infrastructure) about the availability of data. The receiver then downloads the document from the sender using HTTP.

For this scenario, we are only interested in the downloading of data. Secure communication between nodes in the VOF infrastructure shall be modeled as an optional feature. Furthermore, it should be configurable at run-time, for instance, the level of encryption should be configurable. The ABS language should be capable of modeling such optional feature and configuration possibilities.

As transmission method there are these options (with their number n) available:

1. HTTP
2. HTTP with password (that was generated by the sender and transmitted in the notification before)
3. HTTPS with SSL 3
4. HTTPS with TLS 1.2
5. HTTPS with TLS 1.2 with password

There are two test cases, one for the realization that addresses the constraint between features and one for the usage that mainly focuses on the configuration and variability during runtime.

Involved Actors

Office worker sender, Office worker receiver, VOF infrastructure

Precondition

The VOF infrastructure running with at least one other VOF node online.

Trigger

A VOF document is ready to be sent.

Postcondition

The VOF document has arrived at the receivers system *or* it could not be send.

Standard Processes: Realization

1. Security mechanisms (mentioned above) should be supported by the infrastructure.
2. New mechanisms are implemented for the infrastructure by introducing them as additional features and modeling them based on the existing models.
3. Deployment of the new transmission options does *not* require the complete infrastructure to be shut down:
   - VOF clients keep running during the deployment of the new transmission option.
   - Only the client that is currently updated to support the new transmission option may be shut down.
   - Heterogeneous infrastructure (clients have different versions of the software) is possible during deployment phase. It must be ensured that the communication is still possible. For this reason there needs to be a mechanism that deals with the different available transmission options. Two ways to handle this problem are possible:

     Selection by user: If the sender wants to use a security option that the receiver is not capable of, the user has to decide which option he wants to choose instead.

     Selection by system: If the sender wants to use a security option S that the receiver is not capable of, the system automatically uses an alternative option A. As a constraint the number (as defined above) n of the alternate option has to be greater or equal:

$$n(A) \geq n(S) \tag{E.1}$$

Standard Processes: Usage

1. VOF document is ready to be sent.
2. The User decides on the security status of the document.
3. The System offers the different security levels that are available. In fact, these are the numbers n mentioned above.
4. The User selects one of the offered security levels and decides if he wants the system to select an other security level if it is not available for the receiver. (The details of these options are described in *Test Case Realization.*)
5. The System adapts to the selected security level and transports the document using the according mechanism as defined by n.

6. Receiving user can open the document without manual interaction.
   or
   Sending user gets notified that the receiving user is not capable of the security level.
   (The details of these options are described in *Standard Processes: Realization.*)

Appendix F

TS-R-2.2-1: Variability Modeling of Cash Desk Variants

F.1 Introduction

Here two use cases are described for the requirements for modeling "Different Cash Desk Variants". It refers to Scenario TS2 (Cash desk variability) of the Trading System Case Study in Deliverable D5.1 [28, Section 3.2.2]. The use cases describe the different behavioral and deployment variants of a cash desk in a trading system dependent on the features implemented by the system. This use case refines the high level Concern TS-C2 in Deliverable 5.1

The different features of the trading system and their dependencies are explained in the use case TS-R-2.1-1. A cash desk has the following features: **keyboard, scanner, weigh goods at cash desk, weigh goods separately, cash payment, single-desk system, multi-desk system with or without express-mode or self-service mode, non-cash payment, i.e., credit card, prepaid card, electronic cash**.

It should be possible to model the different behavioral and deployment variants of the cash desk in the ABS language (T2.2).

F.2 Use Case 1

This use case is described by a use case for the sale process that is parametric in the different features implemented by the system. The use case is adapted from The Common Component Modeling Example [27]. The features covered by this use case are: **keyboard, scanner, weigh goods at cash desk, express mode, self-service mode, cash payment, non-cash payment, i.e., credit card, prepaid card, electronic cash**.

Brief Description. At the Cash Desk, the products a Customer wants to buy are entered and the payment is performed. The input of the products and the payment depends on the features implemented by the system.

Involved Actors. Customer, Cashier, Printer, Cash Box, Light Display, if feature **scanner** is implemented: Bar Code Scanner, if a **non-cash payment** feature is implemented: CardReader, if **credit card** or **electronic cash** features are implemented: Bank
The Cash Box contains the following entities dependent on the system features:

- For all feature configurations: Buttons "New Sale", "Sale Finished"
- If feature **keyboard** is implemented: Keyboard

- If feature **cash payment** is implemented: Buttons "Cash Payment", "Enter", Facility to store money in the Cash Box
- If feature **credit card payment** is implemented: Buttons "Credit Card Payment", "Enter"
- If feature **electronic cash payment** is implemented: Button "Electronic Cash Payment"
- If feature **prepaid card payment** is implemented: Button "Prepaid Card Payment"

Precondition. The Cash Desk and the Cashier are ready to start a new sale.

Trigger. Coming to the Cash Desk that a Customer wants to pay his chosen product items.

Postcondition. The Customer has paid, has received the bill, and the sale is registered in the Inventory.

Standard Process. If the **express mode** feature is implemented and the express mode is switched on, only cash payment is possible.
If the **self-service mode** feature is implemented and the cash desk is in self-service mode, the Customer performs all actions of the Cashier and only non-cash payment is possible.

Sales Process.

1. The Customer arrives at the Cash Desk with goods to purchase.
2. The Cashier starts a new sale by pressing the button Start "New Sale" at the Cash Box.
3. The Cashier enters the item identifier. If feature **keyboard** is included in the system, this can be done manually by using the keyboard of the Cash Box. If feature **scanner** is included, this can be done by using the Bar Code Scanner.
4. If the feature **weigh goods at cash desk** is implemented: product can be weighed at cash desk, if applicable.
5. Using the item identifier, the System presents the corresponding product description, price, and running total.

   The steps 3-4 are repeated until all items are registered.
6. To finish the purchase, the Cashier presses the button "Sale Finished" at the Cash Box.
7. Payment:

   (a) If feature **cash payment** is implemented:
      i. To initiate cash payment the Cashier presses the button "Cash Payment" at the Cash Box.
      ii. The Customer hands over the money for payment.
      iii. The Cashier enters the received cash using the Cash Box and confirms this by pressing "Enter".
      iv. The Cash Box opens.
      v. The received money and the change amount are displayed, and the Cashier hands over the change.
      vi. The Cashier closes the Cash Box.

   (b) If feature **non-cash payment** is implemented:
      i. if feature **credit card payment** is implemented:

A. In order to initiate credit card payment, the Cashier presses the button "Credit Card Payment" at the Cash Box.
B. The Cashier receives the credit card from the Customer and pulls it through the CardReader.
C. The credit card has to be validated successfully by the Bank.
D. The Printer prints a credit card statement to be signed by the Customer.
E. The Customer signs the credit card statement and hands it to the cashier.
F. The Cashier finishes the credit card payment by pressing the button "Enter" at the Cash Box.

ii. if feature **electronic cash** is implemented:
A. In order to initiate electronic cash payment, the Cashier presses the button "Electronic Cash Payment" at the Cash Box.
B. The Cashier receives the electronic cash payment card from the Customer and pulls it through the CardReader.
C. The Customer enters his PIN using the keyboard of the CardReader and waits for validation.
D. The card has to be validated successfully by the Bank.

iii. if feature **prepaid card** is implemented:
A. In order to initiate prepaid card payment, the Cashier presses the button "Prepaid Card Payment" at the Cash Box.
B. The Cashier receives the prepaid card from the Customer and puts it into the CardReader.
C. If the amount for the purchase is available on the card, the amount is deducted from the card.

8. Completed sales are logged by the Trading System and sale information are sent to the Inventory in order to update the stock.
9. The Printer writes the receipt and the Cashier hands it out to the Customer.
10. The Customer leaves the Cash Desk with receipt and goods.

Alternative or Exceptional Processes.

- In step 5: Invalid item identifier if the system cannot retrieve it from the Inventory.
  1. The System signals error.
     (a) If the **keyboard** feature is implemented: If there exists a human-readable item identifier, the Cashier manually enters the item identifier, and the System displays the description and price.
     (b) Otherwise the product item is rejected.
- In steps 7(b)iC and 7(b)iiD: Card validation fails.
  1. The Cashier and the Customer try payment again.
  2. The Cashier requires the Customer to pay with another payment method that is implemented in the system.
  3. The purchase is aborted
- In step 7(b)iiiC: There is not enough money on the prepaid card to pay the purchase. In this case, another implemented payment method, if available, has to be chosen. Otherwise, the purchase is aborted.
- In step 8: Inventory not available: The System caches each sale and writes them into the Inventory as soon as it is available again.

F.3 Use Case 2

This use case covers switching a cash desk from its normal mode of operation to the express mode and vice versa. The use case is adapted from [Herold et al. CoCoMe - The Common Component Modeling Example]. It is only applicable if the system implements the **express mode** feature. A prerequiste for this feature is that the system implements the **multi-desk** feature.

Brief Description. If the express mode condition is fulfilled, a Cash Desk automatically switches into the express mode. The Cashier is able to switch back into normal mode by pressing a button at his Cash Desk. To indicate express mode, the Light Display shows different colors.

Involved Actors. Cashier, Cash Box, Light Display, Card Reader.

Precondition. The Cash Desk is either in normal mode and the latest sale is finished (case 1) or the Cash Desk is in express mode (case 2).

Trigger. This use case is triggered by the system itself.

Postcondition. The Cash Desk has been switched into express mode or normal mode. The Light Display has changed its color accordingly.

Standard Process.

1. The considered Cash Desk is in normal mode and just finished a sale which matches the condition of the express mode, i.e., 50% of all sales during the last 60 minutes satisfied the express mode condition.
   (a) The Cash Desk, which has caused that the express mode condition is satisfied, is switched to express mode.
   (b) The corresponding Light Display is switched from black to green to indicate the Cash Desk is in express mode.
   (c) The maximum of items per sale is reduced to 8, and only cash payment is possible.
2. The Cash Desk is in express mode and the Cashier decides to change back into normal mode.
   (a) The Cashier presses the button "Disable Express Mode".
   (b) The color of the Light Display is changed from green to black.
   (c) All implemented payment methods are allowed, and the Customer is allowed to purchase an arbitrary number of products.

F.4 Use Case 3

This use case covers the features **single-desk system** and **multi-desk system**.

- If the **single-desk system** feature is implemented, there is only a single cash desk implementing the behavior described in Section F.2 according to the other features to be implemented in the system.
- If the **multi-desk system** feature is implemented, there can be several cash desks (possibly distributed over several computing nodes) implementing the behavior described in Section F.2. All cash desks in the multi-desk system implement the same behavior according to the features that should be implemented by the system. The communication of each cash desk with the store inventory should be

handled independently and should not interfere with the communication of other cash desks. Each cash desk can be independently switched to express mode, if the **express mode** feature is implemented, or to self-service mode, if the **self-service** feature is implemented.

Appendix G

TS-R-2.2-2: Coupon Handling and Loyality System

G.1 Introduction

This use case is related to requirement "Coupon Handing and Loyalty System" and addresses work task T2.2. The use case is derived from Scenarios TS1 and TS5 and refines the high level Concerns TS-C2 (Failure isolation from standard sales process) and TS-C12 (Feature evolution) from the Trading System Case Study of Deliverable D5.1 [28, Sections 3.2.1 and 3.2.5]. It describes how the coupon handling and loyalty features are integrated into the sales process.

G.2 Use Case

This use case extends UC 1 of the CoCoME description [27]. It describes how the sales process works with respect to the features: Common Coupon (F.CC), Unique Coupon (F.UC), Loyalty Card (F.LC), and Individual Coupon (F.IC).

Brief Description. At the Cash Desk the products a Customer wants to buy are detected and the payment - either by credit card or cash - is performed. In addition, the customer uses a coupon and/or a loyalty card.

Involved Actors. Customer, Cashier, Bank, Printer, Card Reader, Cash Box, Bar Code Scanner, Light Display

Precondition. The Cash Desk and the Cashier are ready to start a new sale.

Trigger. Coming to the Cash Desk a Customer wants to pay his chosen product items, the Customer has at least one coupon or a loyalty card.

Postcondition. The Customer has paid, has received the bill and the sale is registered in the Inventory. The purchase price was reduced according to discounts of the used coupons and/or the loyalty card. All redeemed unique and individual coupons are invalid. If the customer used a loyalty card, the corresponding purchase information is stored in the customer information storage.

Standard Process.

1. The Customer arrives at the Cash Desk with goods to purchase.

2. The Cashier starts a new sale by pressing the button *Start New Sale* at the Cash Box.
3. The Cashier enters the item identifier. This can be done manually by using the keyboard of the Cash Box or by using the Bar Code Scanner.
4. Using the item identifier the System presents the corresponding product description, price, and running total.
   The steps 3-4 are repeated until all items are registered.
5. Denoting the end of entering items the Cashier presses the button *Sale Finished* at the Cash Box.
6. [Only for F.LC]
   (a) The Cashier asks for a loyalty card.
   (b) If the customer gives the Cashier a loyalty card:
      i. The Cashier presses the button *Loyalty Card*.
      ii. The Cashier enters the loyalty card ID, either by using the barcode scanner or by using the keyboard.
      iii. The system checks the validity of the loyalty card ID
      iv. If the loyalty card ID is valid
         A. The system applies possible loyalty card discounts to the running total and displays the applied discount as well as the new running total
      v. If the loyalty card ID is invalid, an error message is presented and the loyalty card is disregarded. The system goes back to step 6 and allows the customer to hand out an alternative loyalty card.
7. [Only for F.CC, F.UC, and F.IC] If the customer has a coupon:
   (a) The Cashier presses the button *Coupon*.
   (b) The Cashier enters the identifier of the coupon, either by using the barcode scanner or by using the keyboard.
      i. [Only for F.CC] If the coupon is a common coupon
         A. The system checks the validity of the coupon.
            - If the coupon is valid, the coupon discount is applied to the running total. The coupon description, the discount, and the new running total is presented.
            - If the coupon is invalid, an error message is presented and the coupon discount is disregarded.
      ii. [Only for F.UC] If the coupon is a unique coupon
         A. The system checks the validity of the coupon.
            - If the coupon is valid, the coupon discount is applied to the running total. The coupon description, the discount, and the new running total is presented.
            - If the coupon is invalid, an error message is presented and the coupon discount is disregarded.
         B. The system invalidates the coupon, so that it cannot be used again.
      iii. [Only for F.IC] If the coupon is an individual coupon
         A. If a loyalty card id has been entered in Step 6
            - The system checks whether the coupon is valid for the loyalty card, and checks the general validity of the coupon.
              – If the coupon is valid, the coupon discount is applied to the running total. The coupon description, the discount, and the new running total is presented.

- If the coupon is invalid, an error message is presented and the coupon discount is disregarded.
- The system invalidates the coupon, so that it cannot be used again.

B. If no loyalty card id has been entered yet, the system goes back to Step 6, disregarding all sub steps of Step 7.

8. To initiate the payment, the Cashier presses either the button *Cash Payment* or the button *Card Payment* at the Cash Box.
   (a) If the Cashier pressed the button *Cash Payment*
      i. The Customer hands over the money for payment.
      ii. The Cashier enters the received cash using the Cash Box and confirms this by pressing Enter.
      iii. The Cash Box opens.
      iv. The received money and the change amount are displayed, and the Cashier hands over the change.
      v. The Cashier closes the Cash Box.
   (b) If the Cashier pressed the button *Card Payment*
      i. The Cashier receives the credit card from the Customer and pulls it through the Card Reader.
      ii. The Customer enters his PIN using the keyboard of the card reader and waits for validation.
      iii. Step 8(b)ii is repeated until a successful validation or the Cashier presses the button for cash payment, in which case the system continues with step 8a.
9. Completed sales are logged by the Trading System and sale information are sent to the Inventory in order to update the stock.
   (a) [Only for F.LC] The complete purchase list together with the loyalty card ID is sent to the customer information storage.
10. [Only for F.IC] If the unique coupons feature is present, the system generates a new unique coupon if it is configured to do so.
    (a) If a unique coupon is generated, the printer prints the coupon and the Cashier hands out the coupon to the Customer.
11. The Printer writes the receipt and the Cashier hands it out to the Customer.
12. The Customer leaves the Cash Desk with receipt, goods, and an optional unique coupon.

Alternative or Exceptional Processes.

- In step 6(b)iv: If the system was not able to check the validity of the loyalty card, because the customer information storage is unavailable.
  1. The system signals an error and rejects the loyalty card.
- In step 9a: If the customer information storage is unavailable, the system caches the corresponding updates and sends them to the customer information storage as soon as it is available again.

For additional, exceptional processes see Test Case 1 for requirement R3.

Appendix H

Fredhopper Deployment Architecture

H.1 Introduction

This chapter describes the deployment architecture of the Fredhopper Access Server (FAS), the industrial software system from Fredhopper. We present a general scenario based on the FAS deployment architecture. We then identify corresponding concerns and hint where in the HATS project these concerns may be addressed.

Specifically in Section H.2 we provide an overview of FAS and the FAS deployment architecture; in Section H.3 we identify variabilities in the deployment architecture; in Section H.4 we present a general scenario that is typical during the deployment and running of a Fredhopper product's installation. From this scenario we detail concerns identified, which may be addressed in the HATS project.

H.2 FAS deployment architecture

FAS provides to its clients structured search capabilities within the client's data. This includes text search and structured navigation. Figure H.1 shows an overview of the Fredhopper Access Server (FAS) architecture, a more detail informal description of each component may be found in the requirement elicitation report [28, Section 5.1].

The FAS deployment architecture describes how we deploy FAS for a customer. Figure H.2 shows an example of a typical FAS's deployment. A FAS deployment consists of a set of "environments", each environment contains one or more components shown in Figure H.1. In the FAS deployment example shown in Figure H.2, it consists of 2 live environments, a fail-over environment, a staging environment and a data manager. The figure also depicts interactions between client-side web applications and FAS, while the cloud labeled Internet represents the client's customer. Components in an environment interact by sending and receiving information among each other. The FAS deployment architecture distinguishes information related to *configuration* and *data*. In the remainder of this section we first describe the distinction between the configuration and data of an installation. We then describe various types of environments in a FAS deployment architecture.

H.2.1 Configuration

Configuration in a FAS deployment may either be data dependent or deployment dependent. Data dependent configuration, known as *business configuration*, concerns with how information is displayed. Deployment dependent configuration, also known as *system configuration*, concerns with various system settings that regulate the efficiency and fault tolerance of FAS execution.

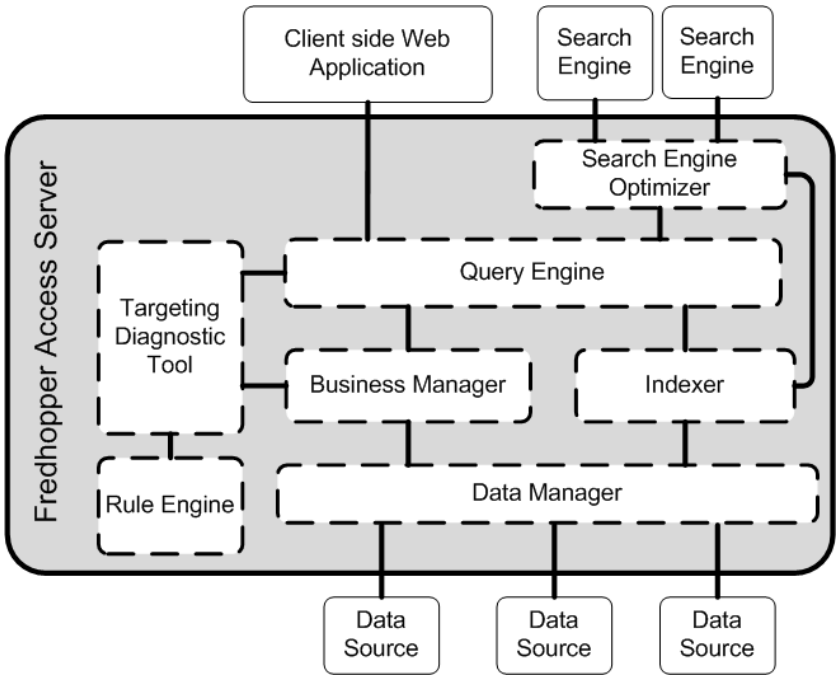

Figure H.1: An Overview of FAS Architecture

H.2.2 Data

Data in a FAS deployment is related to the information for which one can search. An item is the central data element in FAS. It is composed of one or more attributes. Each attribute has a name, a type and a value associated to it. An operation on items could be one of add, delete or update. Operations are grouped together as input XML data and passed to the XML loader for processing. Processed items are stored in an index. Specifically an *add operation* adds items to the index, a *delete operation* removes items from the index; an *update operation* updates the values of an attribute of an item in the index, and a *replace operation* replaces a complete item in the index.

H.2.3 Live

A live environment processes queries from client web applications via the Web Services technology. FAS aims to provide a constant query capacity to client-side web applications. In the deployment example in Figure H.2 there are two live environments.

Description

The primary role of the live environment is to serve queries from client side application via web services. A live environment consists of only two components: the *Query Engine* and the *Synchronization Client* (SyncClient).

Query Engine The query engine is responsible for processing queries from client-side web applications.

SyncClient The SyncClient has the responsibility to keep up-to-date the index used by the query engine. The SyncClient on a live environment connects to the *Synchronization Server* (SyncServer) on a staging environment and responds to incoming update changes to both data and configuration. The staging environment is described in Section H.2.4. Note that there are two models of data updates: incremental and full updates; These models are described in Section H.3.1.

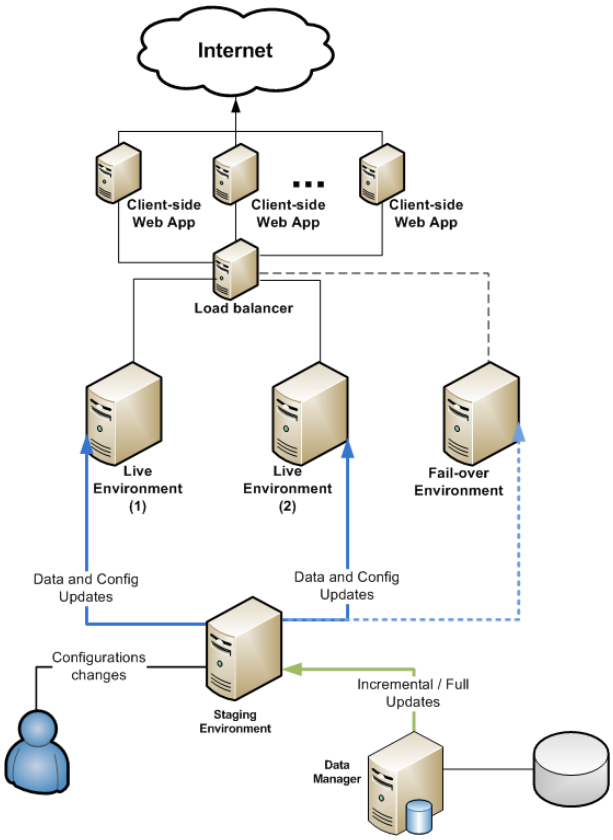

Figure H.2: An example of a FAS's deployment

To ensure a constant query capacity to client-side web applications, a FAS deployment may choose to implement the fail-over strategy. In the example deployment in Figure H.2, a single fail-over environment is used for implementing the fail-over strategy. Fail-over strategy is one way to increase fault tolerance. As we can see fault tolerance is a variability that affects the hardware configuration of a FAS deployment. Variability of a FAS deployment is described in Section H.3.

H.2.4 Staging

A staging environment is responsible for receiving client data updates in XML format, indexing the XML, and distributing the resulting indices across all live environments according to a *replication protocol*. Replication is described in Section H.2.5. In addition, the staging environment may run a business manager component, which allows for changing of the business configuration. A BM user may choose to publish and replicate a changed business configuration to all live instances. In the deployment example in Figure H.2 there is a single staging environment.

Description

The example staging environment consists of a SyncServer, an indexer and a Business Manager (BM). Here we provide an overview of the responsibility of these components in a staging environment.

Indexer An indexer contains a XML loader, a search indexer and a navigation indexer, for processing incoming operation on items, and creating both search and navigation indices.

SyncServer The SyncServer in the example staging environment replicates configuration and data updates to the SyncClients running on the live environments; the replication protocol is described in

Section H.2.5.

Business manager The business manager is a management console. It allows business administrators to configure, monitor and measure how FAS influences their business. Specifically it is where changes to the configuration are made.

H.2.5 Replication system

The replication system synchronizes the configurations and data from the staging environment to multiple live environments. Specifically the replication system consists of the synchronization server (SyncServer) and one or more clients (SyncClient). The replication protocol should guarantee ACID transaction properties [16] when updating both the configuration and data. We discuss in more detail discussion of these properties to the scenario and concerns in Section H.4.

H.3 FAS Deployment variabilities

In a FAS deployment, there are two types of variabilities. There are variabilities that affect how data is updated and there are variabilities that affect hardware configuration. We discuss the former type of variabilities in Section H.3.1 and the latter type in Section H.3.2.

H.3.1 Data updates variability

In Fredhopper we have two types of data updates: Incremental and Full. The types of data updates and the frequencies at which to be performed are driven by the customers' business domain.

Incremental updates

An incremental update is an update of either the configuration or the data. For an incremental data update, only the "update" operations on data item, which updates an attribute of an item in the index, are permitted. Note that unlike a full update, the resulting data from an incremental update does not require to be re-indexed. As a result this type of updates may be performed more at more frequent intervals. Typically incremental updates may be performed on a FAS deployment as often as as once every 15 minutes.

Full updates

A full update is an update of both the configuration or the data. For a full data update, all of the *add*, *delete*, *update* and *replace* operations on data items may be performed. Note that unlike an incremental update, the resulting data from a full update requires to be re-indexed before being replicated to the live environments. As a result this type of updates may be performed more at more frequent intervals. Typically full updates are performed on a FAS deployment once a day.

H.3.2 Variability

Hardware configuration of a FAS deployment specifies the number of physical machines (servers), and the processing power, the amount of physical memory, available disk space and the network speed for each machine. We may derive the hardware configuration for a particular client depending on the following variabilities:

- **Service level agreement** A service level agreement (SLA) for a FAS deployment is a pair (R, Q) where R is *response time* (RT) in millisecond and Q is *queries per second* (QPS). RT is the amount of time in milliseconds that FAS requires to respond to a single query. QPS, on the other hand, is the number of requests completed by FAS per second. For example the SLA $(200, 20)$ promises that FAS takes at most 200 milliseconds to respond to 95% of all queries, while if FAS receives at least 20 queries

per second, then it guarantees completion of at least 20 queries per second. Note that we currently determine a suitable SLA for a particular installation by acquiring the peak page view (PPV) value. PPV is the number of accesses at peak hour to the customer's existing eCommerce solution.

- **Data size** The size of data is determined by the number of items as well as the number of location and language specific settings that clients expect to maintain at a time. Essentially the more data items and location specific settings, the more processing power and physical memory are required to uphold the same SLA. Based on Fredhopper's industrial experience we distinguish deployments with ≤ 100 thousands items from those with > 100 thousands items.
- **Fault tolerance** Customers may choose their FAS deployment to implement a fail-over strategy. In this case at least one additional physical machine is required to implement this strategy. In the example deployment in Figure H.2, there is one fail-over environment for implementing this strategy.

H.4 Scenario FP7: Deploying and maintaining an installation

This scenario covers correctness issues that arise when deploying a FAS installation and updating configuration and data for a running FAS deployment.

H.4.1 Concrete Example

Below we identify the typical steps for deploying a FAS deployment and the workflow of updating both data and configuration of a running installation. For each step we provide an example relating to the concrete example.

1. A customer from a particular business domain describes specific requirements in terms of the peak page views number, the number of data items, the number of localization-specific settings, and fail-over strategy.

   Example 1. *A customer from the online travel sector considers a FAS deployment to handle 30000 peak page views, 200k products and 2 localization-specific settings. This FAS deployment should also implement a fail-over strategy.*

2. Taking the customer requirements, we determine the SLA, the data update frequency and the required number of live, staging and preview environments for the customer's FAS deployment. For each environment we also determine the number of physical machines and their processing power, physical memory and network connection in order to achieve the SLA.

   Example 2. *Based on the customer's requirements, we can determine the following:*

   - *SLA (200,20);*
   - *Daily full updates;*
   - *4 physical machine: 2 machines for hosting live environments, 1 machine for both staging and preview environments, and 1 machine for implementing the fail-over strategy;*
   - *For each machine there should be:*
     - *12 giga-bytes of physical memory;*
     - *250 giga-bytes of disk space;*
     - *1 giga-bits network connection.*

3. A HTTP load balancer is used to distribute queries from client side applications over a non empty set of running live environments. The load balancer implements a round-robin algorithm. Depending on the specific fault tolerance, the load balancing should implement the fail-over strategy for the additional standby live server.

Example 3. *We deploy a HTTP load balancer, which distributes queries from client side applications over 2 live environments, in the event of an unanticipated failure of one of the live environments, the load balancer passes queries to the fail-over machine.*

4. Both data and configuration are updated during the run time of a FAS deployment. A complete update includes an update of the configuration and the index. Typically this takes place once a day. Complete updates are interleaved with incremental updates. Incremental updates could be as frequent as every 15 minutes. Different types of updates determine which data operations are permitted to be performed on the staging environment.

   Example 4. *Based on customer's business domain, Full updates are applied data operations needed to be applied to the staging environment. At the staging environment, updated data and configuration are replicated to all live environments.*

H.4.2 Concerns and envisioned support by HATS

We have identified the following concerns that could be addressed by the HATS framework. These concerns extends those in the original Fredhopper case study [28, Chapter 5] by considering the appropriate level of abstractions for modeling and reasoning about deployment variabilities.

Service level agreement

It is important to be able to formally relate service level agreement over deployment variabilities. To this end we envisage that the HATS framework would provide the theory and tool support for the following:

Concern (FP-C22)**.** ***Analysis of service level agreement****: The HATS framework should provide formal analysis techniques for reasoning about service level agreement (SLA). This concern extends Concerns FP-C20 and FP-C21 [28, Section 5.2.6] by needing to describe and reason about deployment variabilities at an appropriate level of abstraction in order to derive and guarantee SLAs. Furthermore, this concern consider SLA of a complete system rather that units of code. Therefore HATS should incorporate usable methods and tools to assist the application of these techniques, so that formal reasoning becomes more amenable to independent software development in terms of the component parts of the system. (T1.2, T2.1, T1.5, T4.2).*

Replication consistency

It is important to guarantee that the data and configuration are replicated consistently from the staging environment to any possible number of live environments for any deployment. Replication consistency is an instantiation of the ACID transaction properties [16] over the interacting environments:

- **Atomicity**: Only logically correct blocks of data should be replicated across clients (live environments). There should not be half blocks of data on the client side at the end of the replication.
- **Consistency**: For every completed replication step, the client (live environment) must contain the exact same number of data items in the index as the server environment.
- **Isolation**: Replication must be fail-safe, that is, upon failure an individual client, the server must still be able to replicate data and configuration completely to the rest of the clients.
- **Durability**: Upon a complete replication, both clients (live environments) and servers (staging environments) should maintain this complete state even in the event of a system failure.

However, current industrial techniques are not exhaustive and cannot verify such guarantee over deployment variabilities. To this end we envisage that the HATS framework would provide the theory and tool support for the following:

Concern (FP-C23)**.** ***Verification of replication consistency****: The HATS framework should provide formal analysis techniques for verifying replication consistency. This concern extends Concern FP-C3 [28, Section 5.2.2] as it is necessary to describe and reason about deployment variabilities at an level of abstraction such that consistency could be guaranteed. Furthermore, HATS should also incorporate usable methods and tools to assist the application of such techniques so that formal reasoning might become more amenable to software development. (T1.2, T1.3, T1.4, T1.5, T2.1, T4.3)*

Fault tolerance and fairness

Fredhopper product employs a HTTP load balancer to distribute queries from client side applications over running live environments. The load balancer implements a round-robin algorithm. In order to maximize allocated resources, we expect the load balancing algorithm to guarantee fault tolerance as well as certain fairness properties when distributing queries. To this end we envisage the HATS framework would provide the theory and tool support for the following:

Concern (FP-C24)**.** ***Verification of fault tolerance and fairness****: The HATS framework should provide formal analysis techniques for verifying the load balancing algorithm against fault tolerance and certain fairness properties. HATS should also provide a correct abstraction method so that one could reaon about fault tolerance and fairness over all possible deployment variabilities. Furthermore, HATS should incorporate usable methods and tools to assist the application of such techniques so that formal reasoning might become more amenable to software development. (T1.2, T1.3, T2.1, T1.4, T1.5, T4.3)*

Part III

Models

Appendix I

Notations

I.1 Java Modelling Language

The Java Modelling Language (JML) [22] is a specification language for Java programs, using Hoare style pre- and postconditions and invariants, that follows the design by contract paradigm. JML specifications are added to Java source code as annotation comments that either start with `//@` or are enclosed in `/*@` and `@*/`. Listing I.35 shows an excerpt of the definition of interface `Interval` and Listing I.36 shows an excerpt of class `IntInterval`, a concrete implementation of `Interval`. Here we use these excerpts to illustrate how we provide behavioral specifications.

```
public interface Interval {
  //@ public model instance int highModel;
  //@ public model instance int lowModel;
  //@ public instance invariant highModel >= lowModel;

  /*@ public normal_behavior
        requires true;
        ensures (other == null || other.hasNull()) ==> \result <==> hasNull();
        ensures other != null ==> \result <==> (highModel >= other.highModel && lowModel <= other.lowModel);
    @*/
   public /*@ pure @*/ boolean contains(Interval other);
}
```

Listing I.35: An excerpt of the public interface `Interval`

```
public class IntInterval extends NumericIntervalImpl {
  private int low; //@ in lowModel;
  private int high; //@ in highModel;

  //@ private represents lowModel <- low;
  //@ private represents highModel <- high;
}
```

Listing I.36: An excerpt of the class `IntInterval`

I.1.1 Model Fields

For each Java interface we may define model-level variables (fields) that only exist within the model to assist the specification. Model-level variables are declared on the interface using the **model** modifier. For example, in Listing I.35, we have the model variables `highModel` and `lowModel`. Note that **model** variables must be concretized in the implementations of the interface by associating each variable with class fields either functionally or relationally. Syntactically concretizations are denoted by `represent` clauses in class implementations. For example Listing I.36 is an excerpt of the class `IntInterval`, a concrete implementation

of `Interval`. Here the model variables `highModel` and `lowModel` are represented functionally by the private fields `high` and `low` respectively.

I.1.2 Invariants

JML invariants express properties that have to be maintained in all visible states during the lifetime of an object. Invariant annotations can be attached to interfaces or classes. We distinguish further between **static** and **instance** invariants depending whether they are only allowed to refer to static fields or also to instance fields.

JML invariants are added as JML annotations lead-in by the keyword **invariant** (possibly prefixed by a visibility and a **static** or **instance** modifier) and followed by a boolean JML expression expressing the property. JML expressions are a superset of Java expressions adding amongst others existential and universal quantification. In Listing I.35, we have the invariant `highModel >= lowModel` expressing that the upper bound of an interval has always to be greater-or-equal than its lower bound.

I.1.3 Pre- and Postconditions

Method specifications establish a contract between a method and its caller and are basically a pair of pre- and postconditions. Simplified (ignoring termination) their meaning is that if the method is called in a state satisfying the precondition (and the invariants) then the method ensures that the final state reached after its execution satisfies the postcondition.

In JML method specifications pre- and postconditions are denoted using the **requires** and **ensures** clauses respectively. In Listing I.35, we have the precondition **true**, and the post condition constraining the output value **\result** of the method.

We observe further, that the method specification uses two additional JML constructs: (i) the specification is declared as a **normal_behavior** specification, i.e., no exception must be thrown when the caller establishes the precondition. Complementary, JML knows **exceptional_behavior** specifications taking care of the cases when a method throws an exception. (ii) the method is declared to be a pure method using the **pure** modifier. A pure method does not change the state and for our purposes we could have achieved the same result by adding `lowModel == \old(lowModel) && highModel == \old(highModel)` as postcondition.

I.1.4 Tool Support

JML is supported by a wide range of tools providing syntax- and type checking, runtime assertion checking and formal verification[1]. Notably are the KeY system [6] for formal verification and ESC/Java2 [12] for extended static checking. The KeY system is a deductive verification environment for interactive and automatic verification of object-oriented software providing a JML front-end. ESC/Java2, on the other hand, provides extended static (type) checking to find some common run-time errors in JML-annotated Java programs.

I.2 Communicating Sequential Processes

In Communicating Sequential Processes (CSP) [18, 29], a process is a pattern of behaviour; a behaviour consists of events, which are atomic and synchronous between the environment and the process. The environment in this case can be another process. Events can be compound, constructed using the operators '?', '!' and '.'. Event $a?b : T$ denotes receiving some data b of type T through channel a. Event $a!c$ denotes sending data item c through channel a. Event $a.d$ may be considered as a synonym for $a!d$.

[1] see `http://www.eecs.ucf.edu/~leavens/JML/download.shtml`

I.2.1 Syntax

Below is the syntax of the language of CSP.

$$\begin{array}{rcl} P, Q & ::= & P \,|||\, Q \mid P \,[\![\, A \,]\!]\, Q \mid P \,[\![\, A \mid B \,]\!]\, Q \mid P \setminus A \mid P \triangle Q \mid \\ & & P \,\Box\, Q \mid P \sqcap Q \mid P \fatsemi Q \mid e \rightarrow P \mid \mathit{Skip} \mid \mathit{Stop} \\ e & ::= & x \mid x.e \mid x?e \mid x?e : T \mid x!e \end{array}$$

Process $P \,|||\, Q$ denotes the interleaved parallel composition of processes P and Q. Process $P \,[\![\, A \,]\!]\, Q$ denotes the partial interleaving of processes P and Q sharing events in set A. Process $P \,[\![\, A \mid B \,]\!]\, Q$ denotes parallel composition, in which P and Q can evolve independently but must synchronise on every event in the set $A \cap B$; the set A is the alphabet of P and the set B is the alphabet of Q, and no event in A and B can occur without the cooperation of P and Q respectively. We write $|||\, i : I \bullet P(i)$, $\|[A]\, i : I \bullet P(i)$ and $\| \, i : I \bullet A(i) \circ P(i)$ to denote an indexed interleaving, partial interleaving and parallel combination of processes $P(i)$ for i ranging over I.

Process $P \setminus A$ is obtained by hiding all occurrences of events in set A from the environment of P. Process $P \triangle Q$ denotes a process initially behaving as P, but which may be interrupted by Q. Process $P \,\Box\, Q$ denotes the external choice between processes P and Q; the process is ready to behave as either P or Q. An external choice over a set of indexed processes is written $\Box\, i : I \bullet P(i)$. Process $P \sqcap Q$ denotes the internal choice between processes P or Q, ready to behave as at least one of P and Q but not necessarily offer either of them. Similarly an internal choice over a set of indexed processes is written $\sqcap\, i : I \bullet P(i)$.

Process $P \fatsemi Q$ denotes a process ready to behave as P; after P has successfully terminated, the process is ready to behave as Q. Process $e \rightarrow P$ denotes a process capable of performing event e, after which it will behave like process P. The process *Stop* is a deadlocked process and the process *Skip* is a successful termination.

I.2.2 Semantics

CSP has three denotational semantics: traces ($\mathcal{T}$), stable failures ($\mathcal{F}$) and failures-divergences ($\mathcal{N}$) models, in order of increasing precision. In this paper our process definitions are divergence-free, so we will concentrate on the stable failures model. The traces model is insufficient for our purposes, because it does not record the availability of events and hence only models what a process can do and not what it must do [29]. Notable is the semantic equivalence of processes $P \,\Box\, Q$ and $P \sqcap Q$ under the traces model. In order to distinguish these processes, it is necessary to record not only what a process can do, but also what it can refuse to do. This information is preserved in *refusal sets*, sets of events from which a process in a stable state can refuse to communicate no matter how long it is offered. The set $\mathit{refusals}(P)$ is P's initial refusals. A failure therefore is a pair (s, X) where $s \in \mathit{traces}(P)$ is a trace of P leading to a stable state and $X \in \mathit{refusals}(P/s)$ where P/s represents process P after the trace s. We write $\mathit{traces}(P)$ and $\mathit{failures}(P)$ as the set of all P's traces and failures respectively.

We write Σ to denote the set of all event names, and *CSP* to denote the syntactic domain of process terms. We define the semantic function $\mathcal{F}$ to return the set of all traces and the set of all failures of a given process, whereas the semantic function $\mathcal{T}$ returns solely the set of traces of the given process.

$$\begin{array}{rcl} \mathcal{F} & : & \mathit{CSP} \rightarrow (\mathbb{P}\,\mathrm{seq}\,\Sigma \times \mathbb{P}(\mathrm{seq}\,\Sigma \times \mathbb{P}\,\Sigma)) \\ \mathcal{T} & : & \mathit{CSP} \rightarrow \mathbb{P}\,\mathrm{seq}\,\Sigma \end{array}$$

These models admit refinement orderings based upon reverse containment; for example, for all processes P and Q, we have the following ordering with respect to the stable failures model.

$$P \sqsubseteq_{\mathcal{F}} Q \Leftrightarrow \mathit{traces}(P) \supseteq \mathit{traces}(Q) \wedge \mathit{failures}(P) \supseteq \mathit{failures}(Q)$$

While traces only carry information about *safety* conditions, refinement under the stable failures model allows one to make assertions about a system's *safety* and *availability* properties.

I.2.3 Tool Support

Refinement assertions can be automatically proved using a model checker such as FDR [32], exhaustively exploring the state space of a system, either returning one or more counterexamples to a stated property, guaranteeing that no counterexample exists, or until running out of resources.

Appendix J

Data types and Functions

In this chapter we provide definitions of the built-in data types and functions of the core ABS language (ABS). ABS provides data types String, Int, Bool for string, integer and Boolean values. The data type Unit is the return type of methods that do not return a value. The data type **Fut**<A> is the future type parameterised by A. Beside these basic types, ABS also provides the following data types and functions.

Boolean

```
def Bool and(Bool a, Bool b) = case a { True => b; _ => False; };
def Bool not(Bool a) = case a { True => False; False => True; };
```

Maybe

```
data Maybe<A> = Nothing | Just(A);

def A fromJust<A>(Maybe<A> a) = case a { Just(j) => j; };
def Bool isJust<A>(Maybe<A> a) = case a { Just(j) => True; Nothing => False; };
```

Either

```
data Either<A, B> = Left(A) | Right(B);

def A left<A,B>(Either<A, B> val) = case val { Left(x) => x; };
def B right<A,B>(Either<A, B> val) = case val { Right(x) => x; };
def Bool isLeft<A,B>(Either<A, B> val) = case val { Left(x) => True; _ => False; };
def Bool isRight<A,B>(Either<A, B> val) = ~isLeft(val);
```

Pairs

```
data Pair<A, B> = Pair(A, B); // pair

def A fst<A, B>(Pair<A, B> p) = case p { Pair(s, f) => s; };
def B snd<A, B>(Pair<A, B> p) = case p { Pair(s, f) => f; };
```

Triples

```
data Triple<A, B, C> = Triple(A, B, C); // triple

def A fstT<A, B, C>(Triple<A, B, C> p) = case p { Triple(s, f, g) => s; };
def B sndT<A, B, C>(Triple<A, B, C> p) = case p { Triple(s, f, g) => f; };
def C trd<A, B, C>(Triple<A, B, C> p) = case p { Triple(s, f, g) => g; };
```

Set

```
data Set<A> = EmptySet | Insert(A, Set<A>);

// set constructor helper
def Set<A> set<A>(List<A> l) = case l { Nil => EmptySet; Cons(x,xs) => Insert(x,set(xs)); };

def Bool contains<A>(Set<A> ss, A e) = // True if set contains e, False otherwise
  case ss {
    EmptySet => False ;
    Insert(x, xs) =>
        case x == e {
                True => True;
                False => contains(xs, e);
        };
  };

def Bool emptySet<A>(Set<A> xs) = (xs == EmptySet);

// the size of a set
def Int size<A>(Set<A> xs) = case xs { EmptySet => 0 ; Insert(s, ss) => 1 + size(ss); };

def Set<A> remove<A>(Set<A> xs, A e) =
  case xs {
    EmptySet => EmptySet ;
    Insert(s, ss) =>
        case (s == e) {
                True => ss;
                False => Insert(s,remove(ss,e));
        };
  };

// checks whether the input set has more elements to be iterated.
def Bool hasNext<A>(Set<A> s) = ~ emptySet(s);

// Partial function to iterate over a set.
def Pair<Set<A>,A> next<A>(Set<A> s) = case s { Insert(e, set2) => Pair(set2,e); };
```

List

```
data List<A> = Nil | Cons(A, List<A>);

def List<A> list<A>(List<A> l) = l; // list constructor helper
def Int length<A>(List<A> list) = case list { Nil => 0 ; Cons(p, l) => 1 + length(l) ; };
def Bool isEmpty<A>(List<A> list) = list == Nil;
def A head<A>(List<A> list) = case list { Cons(p,l) => p ; };
def List<A> tail<A>(List<A> list) = case list { Cons(p,l) => l ; };
def A nth<A>(List<A> list, Int n) =
  case n == 0 { True => head(list) ; False => nth(tail(list), n−1); };

def List<A> concatenate<A>(List<A> list1, List<A> list2) =
  case list1 { Nil => list2 ; Cons(head, tail) => Cons(head, concatenate(tail, list2)); };
```

```
def List<A> appendright<A>(List<A> list, A p) = concatenate(list, Cons(p, Nil));

def List<A> reverse<A>(List<A> list) =
  case list { Cons(hd, tl) => appendright(reverse(tl), hd); Nil => Nil; };

// n copies of p
def List<A> copy<A>(A p, Int n) = case n { 0 => Nil; m => Cons(p,copy(p,m−1)); };
```

Maps

```
data Map<A, B> = EmptyMap | InsertAssoc(Pair<A, B>, Map<A, B>);

// map constructor helper (does not preserve injectivity)
def Map<A, B> map<A, B>(List<Pair<A, B>> l) =
  case l { Nil => EmptyMap; Cons(hd, tl) => InsertAssoc(hd, map(tl)); };

def Set<A> keys<A, B>(Map<A, B> map) =
  case map { EmptyMap => EmptySet ; InsertAssoc(Pair(a, _), tail) => Insert(a, keys(tail)); };

def B lookup<A, B>(Map<A, B> ms, A k) = // retrieve from the map
  case ms {
        InsertAssoc(Pair(x, y), tm) =>
                case (x == k) {
                        True => y;
                        False => lookup(tm, k);
                };
  };

def B lookupDefault<A, B>(Map<A, B> ms, A k, B d) = // retrieve from the map
  case ms {
        EmptyMap => d;
        InsertAssoc(Pair(x, y), tm) =>
                case (x == k) {
                        True => y;
                        False => lookupDefault(tm, k, d);
                };
  };

// insert a key−value pair to a map (does not preserve injectivity)
def Map insert<A, B>(Map<A, B> map, Pair<A, B> p) = InsertAssoc(p, map);

def Map<A, B> put<A, B>(Map<A, B> ms, A k, B v) = // update a record in the map
  case ms {
    EmptyMap => InsertAssoc(Pair(k, v),EmptyMap);
    InsertAssoc(Pair(x,y),ts) =>
        case x == k {
                True => InsertAssoc(Pair(k,v), ts);
                False => InsertAssoc(Pair(x,y),put(ts,k,v));
        };
  };
```

Conversions between Strings and Integers

```
def String intToString(Int n) =
  case n < 0 {
    True => "−" + intToStringPos(−n);
    False => intToStringPos(n);
  };

def String intToStringPos(Int n) =
  let (Int div) = (n / 10) in
  let (Int res) = (n % 10) in
  case n {
    0 => "0"; 1 => "1"; 2 => "2"; 3 => "3"; 4 => "4";
    5 => "5"; 6 => "6"; 7 => "7"; 8 => "8"; 9 => "9";
    _ => intToStringPos(div) + intToStringPos(res);
  };
```

Appendix K

ABS Model of the Trading System

K.1 Model

K.1.1 Data Types, Type Synonyms and Function Definitions

```
// CashDeskPC States
data CashDeskPCState = INIT | SCANNING | PAYING;

// Payment-Mode : CASH-Payment or CARD-Payment
data PaymentMode = CASH | CARD;

// Only for DEBIT_OK is CARD-Payment valid.
data DebitResult = DEBIT_OK | DEBIT_TRANSACTION_ID_NOT_VALID |
  DEBIT_NOT_ENOUGH_MONEY | NOT_PROCESSED_YET; // Enumeration

// Sale(CashDeskPC, Product List, Total Amount, CASH or CARD)
data Sale = Sale(CashDeskPC, List<Product>, Money, PaymentMode);

data Key = NEW_SALE_KEY | FINISH_SALE_KEY | CASH_PAYMENT_KEY |
  CARD_PAYMENT_KEY | NUM_KEY(Int) | ENTER_KEY | DISABLE_EXPRESS_KEY ;

def Bool isNumKey(Key key) = case key { NUM_KEY(n) => True; _ => False; };
def Int fromNumKey(Key key) = case key { NUM_KEY(n) => n; };

// type synonyms
type Product = Pair<ProductName, ProductPrice>;
def ProductName productName(Product p) = fst(p);
def ProductPrice productPrice(Product p) = snd(p);

type ProductID = Int;
// Simplification : Currently amount of every product is 1, it isn't stored.
type ProductDatabase = Map<ProductID, Product>;
type ProductName = String;
type ProductPrice = Money;

type Euro = Int;
type Cent = Int;
type Money = Pair<Euro, Cent>;
```

```
def Money money(Int euro, Int cent) = Pair(euro, cent);

def Money addMoney(Money m1, Money m2) =
  let (Money result) = Pair(fst(m1) + fst(m2), snd(m1) + snd(m2)) in
  case snd(result) >= 100 {
    True => let (Int div) = snd(result) / 100 in
            let (Int rst) = snd(result) - (div * 100) in
            Pair(fst(result) + div, rst);
    False => result;
  };

def Money subtractMoney(Money m1, Money m2) =
  let (Money result) = Pair(fst(m1) - fst(m2), snd(m1) - snd(m2)) in
  case snd(result) < 0 {
    True => Pair(fst(result) - 1, snd(result) + 100);
    False => result;
  };

def String moneyToString(Money m) = "(" + intToString(fst(m)) + " Euro "
  + intToString(snd(m)) + " Cent),";

def Int numberFromList(List<Int> l) = numberFromListHelper(reverse(l));

def Int numberFromListHelper(List<Int> l) =
  case l {
    Cons(hd, Nil) => hd;
    Cons(hd1, Cons(hd2, tl)) => hd1 + 10 * numberFromListHelper(Cons(hd2,tl));
  };

def Money intToMoney(Int num) =
  let (Int div) = num / 100 in
  let (Int rst) = num - (div * 100) in
  Pair(div, rst);

def String formatProductAndRunningTotal(Product product, Money amount) =
    productToString(product) + "Current Total Amount : " + moneyToString(amount);

def String productToString(Product product) =
  "Product : " + fst(product) + ", Price : " +
    moneyToString(snd(product)) + " ";

def String debitResultToString(DebitResult info) =
  case info {
    DEBIT_OK => "DEBIT_OK";
    DEBIT_TRANSACTION_ID_NOT_VALID => "DEBIT_TRANSACTION_ID_NOT_VALID";
    DEBIT_NOT_ENOUGH_MONEY => "DEBIT_NOT_ENOUGH_MONEY";
  };

type Exception = String;
type CreditInfo = String;
```

```
type Pin = Int;
type TransactionID = String;

type TransactionInfo = Pair<Pin, TransactionID>;
```

K.1.2 Interfaces

```
interface BarCodeScanner {
  Unit setDependencies(BarCodeEventReceiver cashDeskPC,
    BarCodeScannerEnv barCodeScannerEnv);
  Unit scanBarCodeButtonPressed();
}

interface CardReader {
  Unit setDependencies(CardEventReceiver cashDeskPC,
    CardReaderEnv cardReaderEnv);
  Unit enterPin(Int pin); // called from environment
}

interface CashBox {
  Unit setDependencies(CashBoxEventReceiver cashDeskPC, CashBoxEnv cashBoxEnv,
    Screen screen);
  Unit keyPressed(Key key); // called from environment
  Unit onCloseEvent(); // called from environment
  Unit open();
  Unit show(String s);
}

interface BarCodeEventReceiver {
  Unit barCodeSend(Int barCode);
}

interface CardEventReceiver {
  Unit sendCreditInfoAndPin(CreditInfo creditInfo, Int pin);
}

interface CashBoxEventReceiver {
  Unit newSaleStarted();
  Unit saleFinished();
  Unit keypadSend(Int numCode);
  Unit paymentModeSelected(PaymentMode paymentMode);
  Unit moneyReceived();
  Unit changeToNormalMode();
}

interface ExpressModeReceiver {
  Unit changeToExpressMode();
  Unit changeToNormalMode();
}

interface CashDeskPC extends BarCodeEventReceiver, CardEventReceiver,
```

```
  CashBoxEventReceiver, ExpressModeReceiver {
  Unit setDependencies(CashBox cashBox, Printer printer, Inventory inventory,
    Bank bank, ExpressCoordinator expressCoordinator,
    LightDisplay lightDisplay);
}

interface Printer {
  Unit setDependencies(PrinterEnv printerEnv);
  Unit print(List<Product> productList, Money totalAmount);
}

interface LightDisplay {
  Unit setDependencies(LightDisplayEnv lightDisplayEnv);
  Unit changeToExpressMode();
  Unit changeToNormalMode();
}

interface ExpressCoordinator {
  Unit saleRegistered(ExpressModeReceiver cashDeskPC,
    List<Product> productList, PaymentMode paymentMode);
}

//Environment – used interfaces
interface Bank {
  Maybe<TransactionID> validateCard(CreditInfo creditInfo, Int pin);
  DebitResult debitCard(TransactionID transactionID, Money money);
}

interface Inventory {
  Product getProductWithStockItem(Int barcode);
  Unit accountSale(Sale sale);
}

interface PrinterEnv {
  Unit print(String output);
}

interface Screen {
  Unit display(String output);
}

interface LightDisplayEnv {
  Unit turnOn();
  Unit turnOff();
}

interface BarCodeScannerEnv {
  Unit setDependencies(BarCodeScanner barCodeScanner);
  Int scanBarCode();
}
```

```
interface CashBoxEnv {
  Unit setDependencies(CashBox cashBox);
  Unit open();
}

interface CardReaderEnv {
  CreditInfo getCreditInfo();
}
```

K.1.3 Implementations

K.1.3.1 BarCodeScanner

```
class BarCodeScannerImpl() implements BarCodeScanner {
  BarCodeEventReceiver cashDeskPC;
  BarCodeScannerEnv barCodeScannerEnv;

  Unit setDependencies(BarCodeEventReceiver cashDeskPC,
    BarCodeScannerEnv barCodeScannerEnv) {
    this.cashDeskPC = cashDeskPC;
    this.barCodeScannerEnv = barCodeScannerEnv;
  }

  Unit scanBarCodeButtonPressed() {
    Fut<Int> fuint;
    Int barCode = 0;
    fuint = barCodeScannerEnv!scanBarCode();
    barCode = fuint.get;
    cashDeskPC!barCodeSend(barCode);
  }
}
```

K.1.3.2 CardReader

```
class CardReaderImpl() implements CardReader {
  CardEventReceiver cashDeskPC;
  CardReaderEnv cardReaderEnv;

  Unit setDependencies(CardEventReceiver cashDeskPC,
    CardReaderEnv cardReaderEnv) {
    this.cashDeskPC = cashDeskPC;
    this.cardReaderEnv = cardReaderEnv;
  }

  Unit enterPin(Int pin) {
    Fut<CreditInfo> fucredit;
    CreditInfo creditInfo = "";
    fucredit = cardReaderEnv!getCreditInfo();
    creditInfo = fucredit.get;
    cashDeskPC!sendCreditInfoAndPin(creditInfo, pin);
  }
}
```

K.1.3.3 CashBox

```
class CashBoxImpl() implements CashBox {
  CashBoxEventReceiver cashDeskPC;
  CashBoxEnv cashBoxEnv;
  Screen screen;

  List<Int> intBuffer = Nil;

  Unit setDependencies(CashBoxEventReceiver cashDeskPC, CashBoxEnv cashBoxEnv,
    Screen screen) {
    this.cashDeskPC = cashDeskPC;
    this.cashBoxEnv = cashBoxEnv;
    this.screen = screen;
  }

  Unit open() {
    cashBoxEnv!open();
  }

  Unit onCloseEvent() {
    cashDeskPC!moneyReceived();
  }

  Unit keyPressed(Key key) {
    if (key == NEW_SALE_KEY) cashDeskPC!newSaleStarted();
    if (key == FINISH_SALE_KEY) cashDeskPC!saleFinished();
    if (key == CASH_PAYMENT_KEY) cashDeskPC!paymentModeSelected(CASH);
    if (key == CARD_PAYMENT_KEY) cashDeskPC!paymentModeSelected(CARD);
    if (key == DISABLE_EXPRESS_KEY) cashDeskPC!changeToNormalMode();
    if (key == ENTER_KEY) {
      Int numCode = numberFromList(intBuffer);
      intBuffer = Nil;
      cashDeskPC!keypadSend(numCode);
      screen!display("Digits confirmed");
    }
    if (isNumKey(key)) {
      intBuffer = appendright(intBuffer, fromNumKey(key));
      screen!display("Digit entered");
    }
  }

  Unit show(String s) {
    screen!display(s);
  }
}
```

K.1.3.4 CashDeskPC

```
class CashDeskPCImpl() implements CashDeskPC {

  CashBox cashBox;
```

```
Printer printer;
Inventory inventory;
Bank bank;
ExpressCoordinator expressCoordinator;
LightDisplay lightDisplay;

Bool isExpressMode = False;

CashDeskPCState state = INIT;
List<Product> productList = Nil;
Money amount = money(0, 0);
CreditInfo creditInfo = "";
PaymentMode paymentMode = CASH;

Unit setDependencies(CashBox cashBox, Printer printer, Inventory inventory,
  Bank bank, ExpressCoordinator expressCoordinator,
  LightDisplay lightDisplay) {
  this.cashBox = cashBox;
  this.printer = printer;
  this.inventory = inventory;
  this.bank = bank;
  this.expressCoordinator = expressCoordinator;
  this.lightDisplay = lightDisplay;
}

Unit newSaleStarted() {
  if (state == INIT) {
    state = SCANNING;
    this.amount = money(0, 0);
    this.productList = Nil;
    cashBox!show("New Sale started");
  }
}

Unit saleFinished() {
  if (state == SCANNING) {
    state = PAYING;
    cashBox!show("Total Amount : " + moneyToString(amount));
  }
}

Unit barCodeSend(Int barCode) {
  Product product = Pair("", Pair(0, 0)); // NilProduct
  Fut<Product> productF;
  if (state == SCANNING) {
    productF = inventory!getProductWithStockItem(barCode);
    product = productF.get;
    productList = appendright(productList, product);
    this.calculateRunningTotal(product);
  }
}
```

```
// private
Unit calculateRunningTotal(Product product) {
  this.amount = addMoney(productPrice(product), amount);
  cashBox!show(formatProductAndRunningTotal(product, amount));
}

Unit paymentModeSelected(PaymentMode paymentMode) {
  if (state == PAYING) {
    this.paymentMode = paymentMode;
    if (paymentMode == CASH)
      cashBox!show("Cash Payment Selected");
    else {
      if (isExpressMode)
        cashBox!show("Card Payment not possible");
      else
        cashBox!show("Card Payment Selected");
    }
  }
}

Unit keypadSend(Int numCode) {
  if (state == SCANNING) {
    this.barCodeSend(numCode);
  } else if (state == PAYING) {
    this.cashAmountEntered(intToMoney(numCode));
  }
}

Unit cashAmountEntered(Money enteredAmount) {
  if (state == PAYING) {
    Money changeAmount = subtractMoney(enteredAmount, amount);
    //cashBox!amountCalculated(amount, changeAmount);
    cashBox!show("Total amount : " + moneyToString(amount)
        + " Changed amount : " + moneyToString(changeAmount));
    cashBox!open();
  }
}

Unit moneyReceived() {
  if (state == PAYING) {
    this.saleSuccess();
  }
}

Unit changeToExpressMode() {
  isExpressMode = True;
  lightDisplay!changeToExpressMode();
}

Unit changeToNormalMode() {
```

```
      isExpressMode = False;
      lightDisplay!changeToNormalMode();
    }

    Unit sendCreditInfoAndPin(String creditInfo, Int pin) {
      Fut<Maybe<TransactionID>> tid;
      Fut<DebitResult> futDebitResultinfo;
      Fut<Unit> fu;
      Maybe<TransactionID> transactionID = Nothing;
      DebitResult info = DEBIT_TRANSACTION_ID_NOT_VALID;
      if (state == PAYING) {
        tid = bank!validateCard(creditInfo, pin);
        await tid?;
        transactionID = tid.get;
        if (transactionID == Nothing) {
          cashBox!show(debitResultToString(info));
        } else {
          futDebitResultinfo = bank!debitCard(fromJust(transactionID), amount);
          await futDebitResultinfo?;
          info = futDebitResultinfo.get;
          cashBox!show(debitResultToString(info));
          if (info == DEBIT_OK)
            this.saleSuccess();
        }
      }
    }

    // private
    Unit saleSuccess() {
      Fut<Unit> futunit;
      inventory!accountSale(Sale(this, this.productList, this.amount, this.paymentMode));
      printer!print(productList, this.amount);
      cashBox!show("Sale succeeded.. ");
      futunit = expressCoordinator!saleRegistered(this, productList,
        this.paymentMode);
      await futunit?;
      this.state = INIT;
    }
  }
```

K.1.3.5 ExpressCoordinator

```
  class ExpressCoordinatorImpl() implements ExpressCoordinator {
    Bool expressModeNeeded = False;
    Int countSales = 0; // All sales
    Int countExpressSales = 0; // All sales, which satisfy the condition for express mode.
    Int threshold = 2;

    Unit saleRegistered(ExpressModeReceiver cashDeskPC,
      List<Product> productList, PaymentMode paymentMode) {
      Fut<Unit> fu;
```

```
      countSales = countSales + 1;
      if ((paymentMode == CASH) && (length(productList) < 8))
        countExpressSales = countExpressSales + 1;
      if (countSales >= threshold && countExpressSales > (countSales / 2)) {
        fu = cashDeskPC!changeToExpressMode();
        fu.get;
        countSales = 0;
        countExpressSales = 0;
      }
    }
  }
```

K.1.3.6 LightDisplay

```
  class LightDisplayImpl() implements LightDisplay {

    LightDisplayEnv lightDisplayEnv;

    Unit setDependencies(LightDisplayEnv lightDisplayEnv) {
      this.lightDisplayEnv = lightDisplayEnv;
    }

    Unit changeToNormalMode() {
      lightDisplayEnv!turnOff();
    }

    Unit changeToExpressMode() {
      lightDisplayEnv!turnOn();
    }
  }
```

K.1.3.7 Printer

```
  class PrinterImpl() implements Printer {
    PrinterEnv printerEnv;

    Unit setDependencies(PrinterEnv printerEnv) {
      this.printerEnv = printerEnv;
    }

    Unit print(List<Product> productList, Money totalAmount) {
      Int n = 0;
      Fut<Unit> futunit; String ps = "";
      String receipt = "Printing Receipt : ";
      receipt = "Receipt : ";
      while(n < length(productList)) {
        Product product = nth(productList, n);
        ps = productToString(product);
        receipt = receipt + ps;
        n = n + 1;
      }
      receipt = receipt;
```

```
      printerEnv!print(receipt);
    }
  }
```

K.2 Installation

K.2.1 Interfaces

```
interface CashDeskLineInstallation {
  List<CashDeskInstallation> getCashDeskInstallations();
}

interface CashDeskInstallation {
  BarCodeScanner getBarCodeScanner();
  CashBox getCashBox();
  CardReader getCardReader();
}

interface CashDeskEnvironment {
  PrinterEnv getPrinterEnv();
  Screen getScreen();
  CashBoxEnv getCashBoxEnv();
  LightDisplayEnv getLightDisplayEnv();
  BarCodeScannerEnv getBarCodeScannerEnv();
  CardReaderEnv getCardReaderEnv();
  Inventory getInventory();
  Bank getBank();
}
```

K.2.2 Implementations

K.2.2.1 CashDeskInstallation

```
class CashDeskInstallationImpl( ExpressCoordinator expressCoordinator,
                                CashDeskEnvironment env
                              ) implements CashDeskInstallation {

  CashDeskPC cashDeskPC;
  CashBox cashBox;
  BarCodeScanner barCodeScanner;
  Printer printer;
  CardReader cardReader;
  LightDisplay lightDisplay;

  {
    Fut<Unit> fu;
    PrinterEnv printerEnv;
    Screen screen;
    CashBoxEnv cashBoxEnv;
    LightDisplayEnv lightDisplayEnv;
    BarCodeScannerEnv barCodeScannerEnv;
    CardReaderEnv cardReaderEnv;
```

```
    Inventory inventory;
    Bank bank;

    printerEnv = env.getPrinterEnv();
    screen = env.getScreen();
    cashBoxEnv = env.getCashBoxEnv();
    lightDisplayEnv = env.getLightDisplayEnv();
    barCodeScannerEnv = env.getBarCodeScannerEnv();
    cardReaderEnv = env.getCardReaderEnv();
    inventory = env.getInventory();
    bank = env.getBank();

    cashBox = new cog CashBoxImpl();
    cardReader = new cog CardReaderImpl();
    printer = new cog PrinterImpl();
    cashDeskPC = new cog CashDeskPCImpl();
    barCodeScanner = new cog BarCodeScannerImpl();
    lightDisplay = new cog LightDisplayImpl();

    fu = barCodeScanner!setDependencies(cashDeskPC, barCodeScannerEnv); fu.get;
    fu = cashBox!setDependencies(cashDeskPC, cashBoxEnv, screen); fu.get;
    fu = cardReader!setDependencies(cashDeskPC, cardReaderEnv); fu.get;
    fu = printer!setDependencies(printerEnv); fu.get;
    fu = lightDisplay!setDependencies(lightDisplayEnv); fu.get;
    fu = cashDeskPC!setDependencies(cashBox, printer, inventory, bank,
      expressCoordinator, lightDisplay); fu.get;
  }

  BarCodeScanner getBarCodeScanner() { return barCodeScanner; }
  CashBox getCashBox() { return cashBox; }
  CardReader getCardReader() { return cardReader; }
}
```

K.2.2.2 CashDeskLineInstallation

```
class CashDeskLineInstallationImpl( List<CashDeskEnvironment> envs
                                  ) implements CashDeskLineInstallation {

  List<CashDeskInstallation> cashDeskInstallations = Nil;
  ExpressCoordinator expressCoordinator;

  {
    Int i = 0;
    Fut<Unit> fu;
    CashDeskPC cashDeskPC;
    CashDeskInstallation ci;
    expressCoordinator = new cog ExpressCoordinatorImpl();
    while(i < length(envs)) {

      ci = new CashDeskInstallationImpl(expressCoordinator, nth(envs, i));
      cashDeskInstallations = appendright(cashDeskInstallations, ci);
      i = i + 1;
```

```
    }
  }

  List<CashDeskInstallation> getCashDeskInstallations() {
    return cashDeskInstallations;
  }
}
```

Appendix L

ABS Model of the Virtual Office of the Future Component

L.1 Data Types and Operations on Data Types

```
data MessageType = A | B | C;
data BasicMessageType = Sync | Async | Broadcast;
type PeerID = String;


interface Message {
        MessageType getType();
}

interface BasicMessage{
        Message getMessage();
        Int getID();
        Void setID(Int newID);
        BasicMessageType getType();
}

interface ConnectionStatus{
        PeerID getPeerID();
        Boolean isConnected();
        String getStatus();
}

class BasicMessageImpl(Message message, BasicMessageType messageType) implements BasicMessage{
        Int id;

        Message getMessage(){
                return message;
        }

        Int getID(){
                return id;
        }
```

```
        Void setID(Int newID){
                id = newID;
        }

        Int getType(){
                return messageType;
        }

}

class MessageImpl(MessageType messageType){

        MessageType getType(){
                return messageType;
        }
}


class ConnectionStatusImpl(PeerID peerID, Boolean connected, String status){

        PeerID getPeerID(){
                return peerID;
        }

        Boolean isConnected(){
                return connected;
        }

        String getStatus(){
                return status;
        }

}
```

L.2 Interfaces

```
interface CommunicationFramework{
        ConnectionStatus connect(Node node);
        ConnectionStatus disconnect(Node node);
        Set<BasicMessage> sendMessage(BasicMessage message);
        Unit broadcast(BasicMessage message);
}

interface Node{
        PeerID getPeerID();
        Set<BasicMessage> receiveMessage(BasicMessage message);
}

interface IMessageReceiver{
        Message receiveSync(Message message);
        Unit receiveAsync(Message message);
```

```
}

interface IMessageRegistration{
        Unit registerForCommunication(MessageReceiver receiver, MessageType messageType);
        Unit unRegisterForCommunication(MessageReceiver receiver,MessageType messageType);
}

interface IOutCommunication{
        SetOfMessage sendSync(Message message);
        Unit sendAsync(Message message);
        Unit broadcast(Message message);
}

interface IPlatform{
        ConnectionStatus peerConnect();
        ConnectionStatus peerDisconnect();
        ConnectionStatus peerStatus();
}


interface NodeManagement extends
        IOutCommunication,
        IPlatform,
        IMessageRegistration,
        Node{
}
```

L.3 Implementations

L.3.0.3 CommunicationFramework

```
class CommunicationFrameworkImpl(Map<PeerID, Node> connectedNodes)
implements CommunicationFramework{

        ConnectionStatus connect(Node node){
                PeerID peerID;
                peerID = node.getPeerID();
                connectedNodes = InsertAssoc(Pair(peerID, node), connectedNodes);
                return new ConnectionStatusImpl(peerID, true, "connected");
        }

        ConnectionStatus disconnect(Node node){
                PeerID peerID;
                peerID = node.getPeerID();
                connectedNodes = remove(connectedNodes, peerID);
                return new ConnectionStatusImpl(peerID, false, "disconnected");
        }

        Set<BasicMessage> sendMessage(BasicMessage message){
                PeerID receiverID;
                receiverID = message.getID();
```

```
            return internalSendMessage(message, receiverID);
        }

        Set<BasicMessage> internalSendMessage(BasicMessage message, PeerID receiverID){
            Node receiver;
            receiver = lookup(connectedNodes, receiverID);
            return receiver.receiveMessage(message);
        }

        Unit broadcast(BasicMessage message){
            List<Node> receivers;
            receivers = values(connectedNodes);
            return internalBroadcast(message, receivers);
        }

        Unit internalBroadcast(BasicMessage message, List<Node> receivers){
            if(isEmpty(receivers) == false){
                head(receivers).receiveMessage(message);
                return internalBroadcast(message,tail(receivers));
            }
        }

}
```

L.3.0.4 NodeManagement

```
class NodeManagementImpl(PeerID peerID, CommunicationFramework network)
implements NodeManagement{

        ConnectionStatus status;
        Map<MessageType,List<MessageReceiver>> receivers;

        //IOutCommunication
        SetOfMessage sendSync(Message message){
            BasicAsyncMessage bmessage;
            bmessage = new BasicMessageImpl(message,0);
            return network!sendMessage(bmessage);
        }

        Unit sendAsync(Message message){
            BasicAsyncMessage bmessage;
            bmessage = new BasicMessageImpl(message,1);
            network!sendMessage(bmessage);
        }

        Unit broadcast(Message message){
            BasicAsyncMessage bmessage;
            bmessage = new BasicMessageImpl(message,2);
            network!broadcast(bmessage);
        }

        //IPlatform
```

```
ConnectionStatus peerConnect(){
        status = network.connect(this);
        return status;
}

ConnectionStatus peerDisconnect(){
        status = network.disconnect(this);
        return status;
}

ConnectionStatus peerStatus(){
        return status;
}

//IMessageRegistration
Unit registerForCommunication(
        MessageReceiver receiver,
        MessageType messageType){

        List<MessageReceiver> currentReceivers;
        currentReceivers = lookup(receivers, messageType);

        currentReceivers = Cons(receiver, currentReceivers);
        receivers = remove(receivers, messageType);
        receivers = InsertAssoc(Pair(messageType,currentReceivers));
}

Unit unRegisterForCommunication(
        MessageReceiver receiver,
        MessageType messageType){

        List<MessageReceiver> currentReceivers;
        currentReceivers = lookup(receivers, messageType);

        currentReceivers = remove(currentReceivers, receiver);
        receivers = remove(receivers, messageType);
        receivers = InsertAssoc(Pair(messageType,currentReceivers));
}


//Node
PeerID getPeerID(){
        return peerID;
}

Set<BasicMessage> receiveMessage(BasicMessage bmessage){
        Int messageType;

        messageType = message.getType();
        return case messageType {
                Sync => internalReceiveSyncMessage(bmessage);
```

```
                Async => internalReceiveAsyncMessage(bmessage);
                Broadcast => internalReceiveBroadcastMessage(bmessage);
        };
}

Set<BasicMessage> internalReceiveSyncMessage(BasicMessage bmessage){
        List<MessageReceiver> receivers;
        Message message;
        MessageType messageType;

        message = bmessage.getMessage();
        messageType = message.getType();
        receivers = lookup(receivers, messageType);

        return internalReceiveSyncMessage(message, receivers);
}

Set<BasicMessage> internalReceiveAsyncMessage(BasicMessage bmessage){
        List<MessageReceiver> receivers;
        Message message;
        MessageType messageType;

        message = bmessage.getMessage();
        messageType = message.getType();
        receivers = lookup(receivers, messageType);

        return internalProcessAsyncMessage(message, receivers);

}

Set<BasicMessage> internalReceiveBroadcastMessage(BasicMessage bmessage){
        List<MessageReceiver> receivers;
        Message message;
        MessageType messageType;

        message = bmessage.getMessage();
        messageType = message.getType();
        receivers = lookup(receivers, messageType);

        return internalProcessAsyncMessage(message, receivers);

}

Unit internalProcessAsyncMessage(Message message, List<MessageReceiver> receivers){
        if(isEmpty(receivers) == false){
                head(receivers)!receiveAsync(message);
                return internalProcessAsyncMessage(message,tail(receivers));
        }else{
                return EmptySet;
        }
}
```

```
        Set<BasicMessage> internalProcessSyncMessage(
                        Message message, List<MessageReceiver> receivers){

                Message result;
                BasicMessage wrappedResult;
                Fut<Message> futureResult;

                if(isEmpty(receivers) == false){
                        futureResult = head(receivers)!receiveSync(message);
                        await futureResult?;
                        result = futureResult.get;
                        wrappedResult = new BasicMessageImpl(result,Sync);
                        return
                                Insert(wrappedResult,
                                        internalProcessAsyncMessage(message,tail(receivers)));
                }else{
                        return EmptySet;
                }
        }


}
```

Appendix M

JML Specification of Interval API

M.1 Attribute Type

```
public interface AttributeType {
  //@ requires true;
  //@ ensures \result != null && \result.length() > 0;
  public /*@ pure @*/ String getName();

  //@ requires true;
  //@ ensures \result >= 0;
  public /*@ pure @*/ int getId();
}

public class IntType implements AttributeType {
  private final int id; //@ invariant id > 0;
  private final String name; //@ invariant name != null && name.length() > 0;

  //@ requires id > 0 && name != null && name.length() > 0;
  public IntType(int id, String name) { this.id = id; this.name = name; }

  //@ also ensures \result == id;
  public /*@ pure @*/ int getId() { return id; }

  //@ also ensures \result == name;
  public /*@ pure @*/ String getName() { return name; }
}
```

M.2 ItemVectors

M.2.1 Interface ItemVectors

```
public interface ItemVectors {

  //@ public model instance Number[][] matrix ;
  //@ public model instance Number undefModel;

  //@ requires attributeType != null && attributeType.getId() >= 0;
  //@ ensures \result >= 0;
  //@ public pure model int getPos(AttributeType attributeType);

  /*@ public invariant
       (\forall AttributeType a,b; getPos(a) == getPos(b) ==> a.getId() == b.getId());
       (\forall AttributeType a; (\forall int x, y; getPos(a) == x && getPos(a) == y ==> x == y));
    @*/

  //@ requires attributeType != null && i >= 0;
```

```
  //@ ensures \result == getNumberValue(attributeType,i).intValue();
  public /*@ pure @*/ int getIntValue(AttributeType attributeType, int i);

  //@ requires attributeType != null && i >= 0;
  //@ ensures \result == getNumberValue(attributeType,i).intValue();
  public /*@ pure @*/ long getLongValue(AttributeType attributeType, int i);

  //@ requires attributeType != null && i >= 0;
  //@ ensures \result == this.getNumberValue(attributeType,i).floatValue();
  public /*@ pure @*/ float getFloatValue(AttributeType attributeType, int i);

  //@ requires attributeType != null && attributeType.getId() >= 0 && i >= 0;
  /*@ ensures
       ((i >= matrix.length ||
         getPos(attributeType) >= matrix[i].length ||
         matrix[i][getPos(attributeType)] == null)
           ==> \result == undefModel) &&
       ((i < matrix.length &&
         getPos(attributeType) < matrix[i].length &&
         matrix[i][getPos(attributeType)] != null)
           ==> \result == matrix[i][attributeType.getId()]);
    @*/
  public /*@ pure @*/ Number getNumberValue(AttributeType attributeType, int i);

  /*@
     public normal_behavior
        requires attributeType.getId() >= 0 && data.length <= matrix.length;
        assignable matrix;
         ensures (\forall int i;
             getPos(attributeType) < matrix[i].length;
             (0 <= i && i < data.length ==> matrix[i][getPos(attributeType)] == data[i]) &&
             (data.length <= i && i < matrix.length ==>
                  matrix[i][getPos(attributeType)] == \old(matrix[i][getPos(attributeType)])));
    @*/
  public void put(AttributeType attributeType, Number[] data);

  /*@
       public normal_behavior
         requires attributeType.getId() >= 0;
         requires data instanceof NumericIntervalImpl; assignable matrix;
         ensures (\forall int i;
             0 <= i && i < matrix.length && getPos(attributeType) < matrix[i].length;
             matrix[i][getPos(attributeType)] == ((NumericIntervalImpl) data).getRawLow());
    @*/
  public void put(AttributeType attributeType, Interval data);


}
```

M.2.2 Implementation Class `ItemVectorsImpl`

```
public class ItemVectorsImpl {
  private final Number undef = new Integer(Integer.MIN\_VALUE);
  private int[] typeIds;
  private Object[] valuesAndIntervals;

  /*@ private represents
       matrix \such_that
         (\forall int j; 0<=j && j < matrix.length;
           (\forall int k; 0<=k && k < matrix[j].length && k < typeIds.length;
             (\forall int i; 0<=i && i < valuesAndIntervals.length;
               (typeIds[k] == i ==>
                 (valuesAndIntervals[i] != null ==>
```

```
                (((valuesAndIntervals[i] instanceof NumericIntervalImpl)
                  ==> matrix[j][k] == ((NumericIntervalImpl) valuesAndIntervals[i]).getRawLow())) &&
                (((! (valuesAndIntervals[i] instanceof NumericIntervalImpl)) &&
                 j < ((Number[]) valuesAndIntervals[i]).length)
                  ==> matrix[j][k] == ((Number[]) valuesAndIntervals[i])[j])) &&
               (valuesAndIntervals[i] == null ==> matrix[j][k] == valuesAndIntervals[i])))));
  @*/

public Number undef = new Integer(Integer.MIN_VALUE); // in undefModel;

//@ public represents undefModel <- undef;

/*@
    protected invariant
       (\forall int i; 0<=i && i < matrix.length; matrix[i].length == typeIds.length);
       (\forall int i;
         0 <= i && i < valuesAndIntervals.length;
         (valuesAndIntervals[i] == null ||
          valuesAndIntervals[i] instanceof Number[] ||
          valuesAndIntervals[i] instanceof NumericIntervalImpl));
  @*/

/*@
    protected normal_behavior
      requires capacity >= 0;
       assignable typeIds, valuesAndIntervals;
       ensures typeIds.length == capacity;
       ensures valuesAndIntervals.length == capacity;
  @*/
public ItemVectorsImpl(int capacity) {
  typeIds = new int[capacity];
  Arrays.fill(typeIds, -2);
  valuesAndIntervals = new Object[capacity];
}

public /*@ pure @*/ Object get(AttributeType attributeType) {
  final int attId = attributeType.getId();
  for (int i=0; i<typeIds.length; i++) {
    if (typeIds[i] == attId)
      return valuesAndIntervals[i];
  }
  return null;
}

public /*@ pure @*/ int getIntValue(AttributeType attributeType, int i) {
  return getNumberValue(attributeType, i).intValue();
}

/*@
     also
      requires
       get(attributeType) == null ||
       get(attributeType) instanceof NumericIntervalImpl ||
       get(attributeType) instanceof Number[];
  @*/
public /*@ pure @*/ Number getNumberValue(AttributeType attributeType, int i) {
  Object o = get(attributeType);
  if (o == null) return undef;
  if (o instanceof NumericIntervalImpl) {
    return ((NumericIntervalImpl) o).getRawLow();
  }
  Number[] n = (Number[]) o;
```

```
    if (n == null || n.length <= i) {
      return undef;
    }
    return n[i];

  }

  /*@
       private normal_behavior
         requires attributeType.getId() >= 0;
         assignable typeIds, valuesAndIntervals;
         ensures (\forall int i;
             0 <= i && i < typeIds.length;
             (typeIds[i] == -2 || typeIds[i] == attributeType.getId()) ==> valuesAndIntervals[i] == data);
         ensures (\forall int i;
             0 <= i && i < typeIds.length;
             (typeIds[i] == -2 ==> typeIds[i] == attributeType.getId()));
      also
       private normal_behavior
         requires attributeType.getId() >= 0;
         assignable typeIds, valuesAndIntervals;
         ensures (\forall int i;
             0 <= i && i < typeIds.length;
             (typeIds[i] != -2 && typeIds[i] != attributeType.getId())
               ==> valuesAndIntervals[i] == \old(valuesAndIntervals[i]) && typeIds[i] == \old(typeIds[i]));
    @*/
  private void put(AttributeType attributeType, Object data) {
    int typeId = attributeType.getId();
    for (int i=0; i<typeIds.length; i++)
      if (typeIds[i] == -2) {
        valuesAndIntervals[i] = data;
        typeIds[i] = typeId;
        return;
      } else if (typeIds[i] == typeId) {
        valuesAndIntervals[i] = data;
        return;
      }
  }

  /*@ also
       private normal_behavior
         assignable typeIds, valuesAndIntervals;
         ensures \result == this.put(attributeType,(Object) data);
    @*/
  public void put(AttributeType attributeType, Number[] data) { put(attributeType,(Object) data); }

  /*@ also
       private normal_behavior
         assignable typeIds, valuesAndIntervals;
         ensures \result == this.put(attributeType,(Object) data);
    @*/
  public void put(AttributeType attributeType, Interval data) { put(attributeType,(Object) data); }
}
```

M.3 Interval

M.3.1 Interface `Interval`

```
public interface Interval {

 //@ public instance ghost int penalty = 1;
 //@ public instance ghost int undef;
```

```
//@ public instance ghost int highModel;
//@ public instance ghost int lowModel;
//@ public instance ghost boolean hasnull;
//@ public instance ghost AttributeType attributeTypeModel;

//@ public instance invariant highModel >= lowModel;
//@ public instance invariant undef < 0;
//@ public instance invariant penalty > 0;

/*@
    public normal_behavior
      requires true;
      ensures
       ((other == null || other.hasNull()) ==> \result <==> hasNull()) &&
       (other != null ==> \result <==> (highModel >= other.highModel && lowModel <= other.lowModel));
  @*/
public /*@ pure @*/ boolean contains(Interval other);

//@ requires value != null;
//@ ensures \result <==> (highModel >= value.intValue() && lowModel <= value.intValue());
public /*@ pure @*/ boolean containsValue(Number value);

//@ requires iv != null && index >= 0;
//@ ensures \result <==> containsValue(iv.getNumberValue(getAttributeType(),index));
public /*@ pure @*/ boolean containsValue(ItemVectors iv, int index);

//@ requires true;
//@ ensures \result == attributeTypeModel;
public /*@ pure @*/ AttributeType getAttributeType();

//@ requires attributeTypeModel != null;
//@ ensures \result == attributeTypeModel.getId();
public /*@ pure @*/ int getAttributeTypeId();

//@ requires true;
//@ ensures \result == hasnull;
public /*@ pure @*/ boolean hasNull();

//@ requires true;
/*@ ensures
     ((other == null || other.hasNull()) ==> \result == hasNull()) &&
     (other != null ==> \result == ! ((other.highModel < lowModel) || highModel < other.lowModel));
  @*/
public /*@ pure @*/ boolean overlaps(Interval other);

//@ requires true;
//@ ensures hasnull == hasNull;
public void setHasNull(boolean hasNull);

/*@
    public normal_behavior
     requires other == null;
     ensures \result == false;
     ensures hasnull == other.hasNull();
     ensures \old(lowModel) == lowModel && \old(highModel) == highModel;
   also
    public normal_behavior
     requires other != null;
     ensures \result ==
              ((undef != other.lowModel) && (other.lowModel < lowModel)) ||
              (other.highModel > highModel);
     ensures hasnull == (hasNull() || other.hasNull());
```

```
      ensures
       ((undef != other.lowModel) && (other.lowModel < lowModel) ==> lowModel == other.lowModel) &&
       ((undef == other.lowModel) || (other.lowModel >= lowModel) ==> lowModel == \old(lowModel)) &&
       (other.highModel > highModel ==> highModel == other.highModel) &&
       (other.highModel <= highModel ==> highModel == \old(highModel));
    @*/
  public boolean swallow(Interval other);

  /*@
      public normal_behavior
       requires iv != null;
       requires iv.getNumberValue(getAttributeType(),index).intValue() == undef;
       ensures \result == false;
       ensures hasnull == true;
       ensures lowModel == \old(lowModel) && highModel == \old(highModel);
    also
      public normal_behavior
       requires iv != null;
       requires iv.getNumberValue(getAttributeType(),index).intValue() != undef;
       ensures \result <==>
          (iv.getNumberValue(getAttributeType(),index).intValue() < lowModel) ||
          (iv.getNumberValue(getAttributeType(),index).intValue() > highModel);
       ensures
        (iv.getNumberValue(getAttributeType(),index).intValue() < lowModel ==>
             lowModel == iv.getNumberValue(getAttributeType(),index).intValue()) &&
        (iv.getNumberValue(getAttributeType(),index).intValue() >= lowModel ==>
             lowModel == \old(lowModel)) &&
        (iv.getNumberValue(getAttributeType(),index).intValue() > highModel ==>
             highModel == iv.getNumberValue(getAttributeType(),index).intValue()) &&
        (iv.getNumberValue(getAttributeType(),index).intValue() <= highModel ==>
             highModel == \old(highModel));
    @*/
  public boolean swallow(ItemVectors iv, int index);

}
```

M.3.2 Abstract Class IntervalBaseImpl

```
public abstract class IntervalBaseImpl implements Interval {
  private boolean hasNull = false; //@ in hasnull;
  private final AttributeType attributeType; //@ in attributeTypeModel;

  //@ private represents hasnull <- hasNull;
  //@ private represents attributeTypeModel <- attributeType;

  /*@ private normal_behavior
        assignable attributeType, hasNull;
    @*/
  public IntervalBaseImpl(AttributeType at, boolean aHasNull) {
    attributeType = at; hasNull = aHasNull;
  }

  /*@
      also
        public normal_behavior
          ensures
          \result <==>
            (! (obj == null || obj.getClass() != getClass())) &&
            ((Interval) obj).hasNull() == hasNull() &&
             equalsOnLowHigh(((Interval) obj));
    @*/
  public final /*@ pure @*/ boolean equals(/*@ nullable @*/ Object obj) {
    if (obj == null || obj.getClass() != this.getClass())
```

```
    return false;
  Interval oi = (Interval) obj;
  return oi.hasNull() == hasNull()
    && oi.equalsOnLowHigh(this);
}

public final AttributeType getAttributeType() {
  return attributeType;
}

public final boolean contains(Interval other) {
  boolean result;
  if (other == null) {
    result = hasNull();
  } else {
    result = containsIntervalInternal(other);
    if (result) {
      if (other.hasNull()) {
        result = hasNull();
      } else {
        result = true;
      }
    } else {
      result = false;
    }
  }
  return result;
}

//@ requires other != null;
//@ ensures \result <==> other.lowModel >= lowModel && other.highModel <= highModel;
protected /*@ pure @*/ boolean containsIntervalInternal(Interval other) {
  return !lowExcludesContainment(other) && !highExcludesContainment(other);
}

//@ requires other != null;
//@ ensures \result <==> other.lowModel < lowModel;
protected /*@ pure @*/ abstract boolean lowExcludesContainment(Interval other);

//@ requires other != null;
//@ ensures \result <==> other.highModel > highModel;
protected /*@ pure @*/ abstract boolean highExcludesContainment(Interval other);

public final boolean overlaps(Interval other) {
  boolean result;
  if (other == null) {
    result = hasNull();
  } else {
    result = overlapsIntervalInternal(other);
    if (! result) {
      if (other.hasNull()) {
        result = hasNull();
      }
    }
  }
  return result;
}

//@ requires other != null;
//@ ensures \result <==> !lowExcludesOverlapping(other) && !highExcludesOverlapping(other);
protected /*@ pure @*/ boolean overlapsIntervalInternal(Interval other) {
  return !lowExcludesOverlapping(other) && !highExcludesOverlapping(other);
```

```
  }

  //@ requires other != null;
  //@ ensures \result <==> highModel <= other.lowModel;
  protected abstract /*@ pure @*/ boolean highExcludesOverlapping(Interval other);

  //@ requires other != null;
  //@ ensures \result <==> other.highModel <= lowModel;
  protected abstract /*@ pure @*/ boolean lowExcludesOverlapping(Interval other);

  public boolean swallow(Interval other) {
    boolean result;
    if (other == null) {
      setHasNull(true);
      result = false; //Only true for boundary changes.
    } else {
      setHasNull(hasNull() | other.hasNull());
      result = swallowIntervalInternal(other);
    }
    return result;
  }

  //@ requires other != null;
  //@ assignable lowModel, highModel;
  protected abstract boolean swallowIntervalInternal(Interval other);

  public final boolean hasNull() { return hasNull; }

  /*@ also
        private normal_behavior
          assignable this.hasNull;
           ensures this.hasNull == hasNull;
    @*/
  public final void setHasNull(boolean hasNull) { this.hasNull = hasNull; }
}
```

M.3.3 Implementation Class `IntInterval`

```
public class IntInterval extends NumericIntervalImpl {
  public static final int UNDEF = Integer.MIN_VALUE;
  private int low; //@ in lowModel;
  private int high; //@ in highModel;

  //@ private represents undef \such_that undef == UNDEF;
  //@ private represents lowModel <- low;
  //@ private represents highModel <- high;

  //@ private invariant high >= low;
  //@ private invariant high != UNDEF;
  //@ private invariant low != UNDEF;

  /*@
      private normal_behavior
        requires i != UNDEF;
        assignable low, high;
        ensures ! hasNull();
        ensures high == low;
    @*/
  public IntInterval(IntType attributeType, int i) {
    this(attributeType, i, i, false);
  }

  /*@
```

```
    private normal_behavior
      requires low != UNDEF && high != UNDEF && high >= low;
          assignable this.low, this.high;
       ensures hasNull() <==> aHasNull;
       ensures this.high == high && this.low == low;
  @*/
public IntInterval(IntType attributeType, int low, int high, boolean aHasNull) {
  super(attributeType, aHasNull);
  this.low = low;
  this.high = high;
}

//@ also requires other instanceof IntInterval;
protected /*@ pure @*/ boolean highExcludesContainment(Interval other) {
  IntInterval ii = (IntInterval) other;
  return high < ii.high;
}

//@ also requires other instanceof IntInterval;
protected /*@ pure @*/ boolean lowExcludesContainment(Interval other) {
  IntInterval ii = (IntInterval) other;
  return low > ii.low;
}

//@ also requires other instanceof IntInterval;
protected /*@ pure @*/ boolean highExcludesOverlapping(Interval other) {
  IntInterval ii = (IntInterval) other;
  return high < ii.low;
}

//@ also requires other instanceof IntInterval;
protected /*@ pure @*/ boolean lowExcludesOverlapping(Interval other) {
  IntInterval ii = (IntInterval) other;
  return ii.high < low;
}

public /*@ pure @*/ boolean containsValue(ItemVectors iv, int index) {
  return containsValueInternal(iv.getIntValue(getAttributeType(), index));
}

protected /*@ pure @*/ boolean containsValueInternal(int i) {
  boolean result;
  if (i != UNDEF) {
    if (i < low) {
      result = false;
    } else if (i > high) {
      result = false;
    } else {
      result = true;
    }
  } else {
    result = hasNull();
  }
  return result;
}

public final /*@ pure @*/ int getHigh() { return high; }
public final /*@ pure @*/ int getLow() { return low; }
public final /*@ pure @*/ Number getRawLow() { return new Integer(low); }

/*@
    private normal_behavior
```

```
      requires high >= this.low;
      assignable this.high;
      ensures this.high == high;
  @*/
public final void setHigh(int high) { this.high = high; }

/*@
    private normal_behavior
      requires this.high >= low && low != UNDEF;
      assignable this.low;
      ensures this.low == low;
  @*/
public final void setLow(int low) { this.low = low; }

/*@
   also
     private normal_behavior
       requires other != null && other instanceof IntInterval;
       assignable low, high;
       ensures
         ((UNDEF < ((IntInterval) other).low && ((IntInterval) other).low < low)
              ==> low == ((IntInterval) other).low) &&
         ((UNDEF == ((IntInterval) other).low || ((IntInterval) other).low >= low)
              ==> low == \old(low)) &&
         ((((IntInterval) other).high > high) ==> high == ((IntInterval) other).high) &&
         ((((IntInterval) other).high <= high) ==> high == \old(high));
       ensures \result <==>
         (UNDEF < ((IntInterval) other).low && ((IntInterval) other).low < low) ||
         (((IntInterval) other).high > high);
  @*/
protected final boolean swallowIntervalInternal(Interval other) {
  boolean result = false;
  IntInterval lother = (IntInterval) other;
  if (lother.low < low && lother.low > UNDEF) {
    setLow(lother.low);
    result == true;
  }
  if (lother.high > high) {
    setHigh(lother.high);
    result |= true;
  }
  return result;
}

/*@
   also
     private normal_behavior
       assignable low, high, hasnull;
       ensures
         (UNDEF < iv.getIntValue(getAttributeType(), index)
           ==> ((iv.getIntValue(getAttributeType(), index) < low)
               ==> low == iv.getIntValue(getAttributeType(), index) && high == \old(high)) &&
               ((iv.getIntValue(getAttributeType(), index) > high)
               ==> high == iv.getIntValue(getAttributeType(), index) && low == \old(low)));
       ensures \result <==> UNDEF < iv.getIntValue(getAttributeType(), index);
  @*/
public final boolean swallow(ItemVectors iv, int index) {
  boolean result = false;
  int i = iv.getIntValue(getAttributeType(), index);
  if (i > UNDEF) {
    if (i < low) {
      setLow(i);
```

```
        result == true;
      }
      if (i > high) {
        setHigh(i);
        result == true;
      }
    } else {
      setHasNull(true);
    }
    return result;
  }

  //also requires value instanceof Integer;
  public final /*@ pure @*/ boolean containsValue(Number value) {
    return containsValueInternal(((Integer)value).intValue());
  }

}
```

Appendix N

ABS Model of Interval API

N.1 Data Types and Type Synonyms

```
//A data type that supplies different implementation of a numerical value
data Number = UndefinedNumber | IntValue(Int);

// A common data type for encapsulating a piece of data in an item vector
data ItemVectorData = NullData | IntervalData(IntInterval) | NumberListData(List<Number>);

//type of an IntType
type IntType = Pair<Int,String>;

//type for an item vector
type ItemVectors = Pair<List<Number>,List<ItemVectorData>>;

//type for an Interval
type IntInterval = Pair<Pair<Int,Int>,Pair<Maybe<IntType>,Bool>>;

// total Number function
def Bool isInt(Number n) =
  case n {
    IntValue(_) => True;
    _ => False;
  };

// partial Number function
def Int getInt(Number n) = case n { IntValue(i) => i; };
```

N.2 Functions on ItemVectors

```
def ItemVectorData getData(ItemVectors iv, IntType it, Int i) =
  let (Int j) = i + 1 in
  case (i < length(fst(iv))) {
    True => case (nth(fst(iv),i) == IntValue(id(it))) {
          True => nth(snd(iv),i);
          False => getData(iv,it,j);
        };
    False => NullData;
```

```
  };

def Number getValue(ItemVectors iv, IntType it, Int i) =
  case (getData(iv,it,0)) {
    IntervalData(d) => rawLow(d);
    NumberListData(l) =>
      case (length(l) > i) {
        True => nth(l,i);
        False => UndefinedNumber;
      };
    NullData => UndefinedNumber;
  };

def ItemVectors putValue(ItemVectors iv,IntType it,ItemVectorData item) = putData(iv,it,item,0);

def ItemVectors putData(ItemVectors iv, IntType it, ItemVectorData item, Int i) =
  let (Int j) = i + 1 in
  case (i < length(fst(iv))) {
    True =>
      case (nth(fst(iv),i)) {
        UndefinedNumber =>
          Pair(put(fst(iv),IntValue(id(it)),i),put(snd(iv),item,i));
        IntValue(s) =>
          case (s == id(it)) {
            True => Pair(fst(iv),put(snd(iv),item,i));
            False => putData(iv,it,item,j);
          };
      };
    False => iv;
  };
```

N.3 Functions on **IntInterval**

```
def Number rawLow(IntInterval i) = IntValue(fst(fst(i)));

def IntInterval setHigh(IntInterval i, Int nh) =
  case i { Pair(Pair(l,h),o) => Pair(Pair(l,nh),o); };

def IntInterval setLow(IntInterval i, Int nl) =
  case i { Pair(Pair(l,h),o) => Pair(Pair(nl,h),o); };

def IntInterval setHasNull(IntInterval i, Bool nn) =
  case i { Pair(o,Pair(ai,n)) => Pair(o,Pair(ai,nn)); };

def Bool contains(IntInterval i, Maybe<IntInterval> other) =
  case other {
    Nothing => snd(snd(i));
    Just(o) => containsInternal(i,o) && (~snd(snd(o)) || snd(snd(i)));
  };

def Bool containsInternal(IntInterval i, IntInterval other) =
```

```
  fst(fst(i)) <= fst(fst(other)) && snd(fst(other)) <= snd(fst(i));

def Bool containsValueByVector(IntInterval i, ItemVectors iv, Int index) =
  containsNumberValue(i,getValue(iv,fromJust(fst(snd(i))),index));

def Bool containsNumberValue(IntInterval i, Number value) =
  case value {
    UndefinedNumber => snd(snd(i));
    IntValue(s) => s >= fst(fst(i)) && s <= snd(fst(i));
  };

def Bool overlaps(IntInterval i, Maybe<IntInterval> other) =
  case other {
    Nothing => snd(snd(i));
    Just(o) => overlapsInternal(i,o) || (snd(snd(o)) && snd(snd(i)));
  };

def Bool overlapsInternal(IntInterval i, IntInterval other) =
  snd(fst(other)) >= fst(fst(i)) && snd(fst(i)) >= fst(fst(other));

def Pair<IntInterval,Bool> swallow(IntInterval i, ItemVectors iv, Int index) =
  case getValue(iv,fromJust(fst(snd(i))),index) {
    UndefinedNumber => Pair(setHasNull(i,True),False);
    IntValue(s) =>
        let (Pair<IntInterval,Bool> an) =
            case s < fst(fst(i)) {
              True => Pair(setLow(i,s),True);
              False => Pair(i,False);
            }
        in
          case s > snd(fst(i)) {
            True => Pair(setHigh(fst(an),s),True);
            False => an;
          };
    _ => Pair(i,False);
  };

def Pair<IntInterval,Bool> swallowIntInterval(IntInterval i, Maybe<IntInterval> other) =
  case other {
    Nothing => Pair(setHasNull(i,True),False);
    Just(o) => swallowIntIntervalInternal(setHasNull(i,snd(snd(i)) || snd(snd(o))),o);
  };

def Pair<IntInterval,Bool> swallowIntIntervalInternal(IntInterval i, IntInterval o) =
  let
    (Pair<IntInterval,Bool> sl) =
      case fst(fst(o)) < fst(fst(i)) {
        True => Pair(setLow(i,fst(fst(o))),True);
        False => Pair(i,False);
      }
  in
```

```
case (snd(fst(o)) > snd(fst(i))) {
  True => Pair(setHigh(fst(sl),snd(fst(o))),True);
  False => sl;
};
```

Appendix O

CSP Model of the Replication System

O.1 Preliminaries

O.1.1 Types

nametype

$$File == (FileId \times FileSize)$$
$$Items == \mathbb{P}(CheckPoint \times \mathbb{P}\, File)$$
$$Thread == \{1 \,..\, MAXTHREAD\}$$
$$Threads == \{0 \,..\, \#Thread\}$$
$$Client == \{1 \,..\, MAXCLIENT\}$$

The type *File* is a set of files for replication, a file is a pair $(fid, size)$ where *fid* identifies the file and *size* is the size of the file. The type *Items* is the set of possible replication snapshots, each replication snapshot is a set of replication items. Each replication item is a pair (cp, fs) where *cp* is the check point of that replication item and *fs* is the set of files contained in that replication item. The type *Thread* models the set of possible identifiers of connection threads and *Clients* models the set of possible identifiers of SyncClients.

datatype

$$Command = StartSnapshot \mid EndSnapshot \mid ListSchedule \mid SearchSchedule \mid EndSearchFile \mid AppendSearchFile \mid SkipFile \mid ContinueFile \mid OverwriteFile \mid TransferCmd.File \mid FileCmd.FileId.FileSize \mid CheckPointId.CheckPoint.Bool$$

$$State = start \mid waitToBoot \mid booting \mid waitToReplicate \mid workOnReplicate \mid end$$

The data type *Command* models the communication commands between `ConnectionThread` and `ClientJob`. The datatype *State* models the states of the SyncClient state machine.

O.1.2 Connections

channel

$$addClientThread, removeThread : Thread$$
$$containsThread : Thread.Bool$$
$$numberOfClientThread : Threads$$

```
process
  Connections =
    let
      Connections(s) =
        numberOfClientThread!(#s) → Connections(s)
        □ containsThread?n!(n ∈ s) → Connections(s)
        □ addClientThread?n → Connections(s ∪ n)
        □ removeThread?n → Connections(s \ n)
    within
      Connections(∅)
```

The process *Connections* models the set object `SyncServerClientCoordinator.connectionsReplication` to keep a reference of the SyncClients that are currently being served. The process provides the follwing services: addition and removal of some thread t (*addClientThread*.t and *removeThread*.t), checking if a given thread t is in the set (*containsThread*.t.*true*) and retrieval of the number of threads in the set (*numberOfClientThread*.s).

O.1.3 Replication Snapshot

The following process models the private field `SyncServer.replicationSnapshot` of type `ReplicationSnapshot`, as well as the associated methods for accessing the field. A UML activities diagram illustrating this process' control flow is shown in Figure 5.7 on Page 75.

```
channel
  getItems : Items
  refreshSnapshot, clearSnapshot
process
  ReplicationSnapshot =
    let
      ReplicationSnapshot′(items) =
        refreshSnapshot → RefreshSnapshot(items)
        □ clearSnapshot → ReplicationSnapshot′(∅)
        □ getItems.items → ReplicationSnapshot′(items)
      RefreshSnapshot(items) =
        items = ∅ & (⊓ ns : Items • ReplicationSnapshot′(ns))
        □ items ≠ ∅ & ReplicationSnapshot′(items)
    within
      ReplicationSnapshot′(∅)
```

Specifically, it contains a snapshot (a set of *Item* values or an element of *Items*). It can refresh (*refreshSnapshot*), clear (*clearSnapshot*) or get items from (*getItems*) the snapshot. The snapshot only be refreshed if and only if the current snapshot is empty. Refresh is modelled in CSP by process *RefreshSnapshot* that internally chooses a set of items from the type *Items*, which is a finite set of possible items. By insisting *Items* to be a finite set, the resulting CSP process is finite state. Clearing the snapshot empties it.

O.2 Acceptor Thread `SyncServerAcceptorThread`

This section defines the processes that models methods and fields of the class `SyncServerAcceptorThread`.

channel
$isAcceptingConnection, setAcceptingConnection : Bool$
process
$AcceptConnectionCondition =$
let
$AcceptConnection(b) =$
$isAcceptingConnection.b \rightarrow AcceptConnection(b)$
$\Box\ setAcceptingConnection?t : Bool \rightarrow AcceptConnection(t)$
within
$AcceptConnection(true)$

Process *AcceptConnectionCondition* models the private boolean field `acceptingConnections` and its get and set methods `isAcceptingConnections()`, `suspendAcceptingConnections()` and `resumeAcceptingConnections()`.

channel
$acceptorThread$
$createConnectionThread : Thread$
process
$AcceptorThreadRun =$
let
$Listener =$
$(needThread?t : Thread \rightarrow createConnectionThread.t \rightarrow WaitForAcceptConnection)$
$\triangleright\ WaitForAcceptConnection$
$WaitForAcceptConnection = isAcceptingConnection.true \rightarrow Listener$
within
$acceptorThread \rightarrow Listener$

The process *AcceptorThreadRun* models the method `run()`. Event *acceptorThread* denotes the invocation of method `start()`. Once the *acceptorThread* is performed, the process behaves recursively as follows: It initially offers the event *needThread.t* (for any thread t), that is, to accept a single connection from any SyncClient. It could also "timeout" and refuse to accept any connection. Upon accepting a connection, this process instantiates a connection thread (*createConnectionThread.t*). In both cases, the process then waits until the connection is accepted *isAcceptingConnection.true*.

O.3 Coordinator (`SyncServerClientCoordinator`)

The following processes models methods defined by class `SyncServerClientCoordinator`.

process
$Coordinator =$
$isAcceptingConnection?b : Bool \rightarrow numberOfClientThread?n : ThreadSize \rightarrow$
$((b \wedge n > 0)\ \&\ (setAcceptingConnection.false \rightarrow Coordinator \sqcap Coordinator)$
$\Box\ (\neg b \wedge n = 0)\ \&\ setAcceptingConnection.true \rightarrow Coordinator)$
$\Box\ (b \wedge n = 0) \vee (\neg b \wedge n \neq 0)\ \&\ Coordinator$

The process *Coordinator* models method `process()`. Specifically, the process recursively performs the following: It first checks whether a connection is allowed (*isAcceptingConnection.b*). Then the process checks the current number of clients being served (*numberOfClientThread.n*). If the connection is allowed

and there is at least one client currently being served, then the process internally chooses whether to suspend accepting connections (*setAcceptingConnection.false*) or not. If the connection is not allowed and there is no client currently being served, then the process resumes accepting connections (*setAcceptingConnection.true*). Otherwise the process does nothing.

```
process
  FinishReplicationUpdate(t) =
    let
      FinishReplicationUpdateProc =
        containsThread.t.true → removeThread!t → ClearSnapshot
        □ containsThread.t.false → ClearSnapshot

      ClearSnapshot =
        numberOfClientThread?n → ((n = 0) & clearSnapshot → Skip □ (n > 0) & Skip)
    within
      FinishReplicationUpdateProc
```

Process *FinishReplicationUpdate*(t) models method `finishReplicationUpdate()`. The process removes a thread t if t is serving a client (*containsThread.thread.true*). Whether or not t is serving a client, the process proceeds and checks if there are any more threads serving clients. If the check is negative, the process clears the snapshot (*clearSnapshot*). Finally, the process terminates.

```
process
  StartReplicationUpdate(t) =
    let
      Replication(1) = refreshSnapshot → Skip
      Replication(n) = Skip
    within
      addClientThread!t → numberOfClientThread?n → Replication(n)
```

Process *StartReplicationUpdate*(t) models method `startNonAtomicReplicationUpdate()`. The process initially adds thread t. If t is the only thread that is currently serving clients then the process calls the snapshot to be refreshed. The process then terminates.

O.4 Connection Thread (`ConnectionThread`)

```
channel cmd : Clients.Command
process
  Run(t) =
    let
      Boot = cmd.t.ListSchedule → Skip
      Replication = cmd.t.SearchSchedule → RegisterItems
      RegisterItems = getItems?ns : Items → CheckItems(ns, ⟨⟩)
      CheckItems({}, files) = cmd.t.StartSnapshot → TransferItems(files)
      CheckItems(items, files) =
        (⊓ (c, is) : items •
          (cmd.t.CheckPointId.c.true → CheckItems(items \ {(c, is)}, files ⌢ ⟨is⟩)
          □ cmd.t.CheckPointId.c.false → CheckItems(items \ {(c, is)}, files)))
      TransferItems(⟨⟩) = cmd.t.EndSnapshot → Skip
      TransferItems(⟨fs⟩ ⌢ fileseq) = (TransferFile(fs) ⨟ TransferItems(fileseq))
      TransferFile({}) = cmd.t.EndSearchFile → Skip
      TransferFile(fs) =
        (⊓ (i, s) : fs •
          (cmd.t.AppendSearchFile → cmd.t.FileCmd!i?cs : FileSize →
          ((cs > s) & cmd.t.OverwriteFile → cmd.t.TransferCmd!(i, s) → Skip
          □ (cs = s) & cmd.t.SkipFile → Skip
          □ (cs < s) & cmd.t.ContinueFile → cmd.t.TransferCmd!(i, s − cs) → Skip)) ⨟
          TransferFile(fs \ {(i, s)}))
    within
      StartReplicationUpdate(t) ⨟ (Replication □ Boot) ⨟ FinishReplicationUpdate(t)

  ConnectionThread(t) = (createConnectionThread.t → Run(t)) ⨟ ConnectionThread(t)
```

The process *ConnectionThread*(t) models the `run()` method of class `ConnectionThread`. The event *createConnectionThread*.t is used to represent the invocation of method `start()`.

After performing the event *createConnectionThread*.t, the process initialises the replication update by becoming process *StartReplicationUpdate*(t), which models the method `startNonAtomicReplicationUpdate()` of class `SyncServerClientCoordinator` as described in Section O.3. After initialising the replication update, it either receives the command listSchedule (*cmd*.t.*ListSchedule*) and becomes the process *Boot* or searchSchedule (*cmd*.t.*SearchSchedule*) and becomes the process *Replication*. The former command means that the SyncClient only requires the replication schedule, while the latter means that the SyncClient requires both the replication schedule and replication items. After either *Boot* or *Replication* terminates, the process *ConnectionThread*(t) finalises the replication update by becoming process *FinishReplicationUpdate*(t), which models the method `finishReplicationUpdate()` of class `SyncServerClientCoordinator` as described in Section O.3.

We consider now the definition of the processes *Boot* and *Replication*. Both our CSP models are untimed and abstract from specific schedules. Therefore process *Boot* terminates after performing *cmd*.t.*ListSchedule*. Similarly, after performing *cmd*.t.*SearchSchedule*, process *Replication* proceeds to sending replication items to SyncClients for registrations. This is denoted by the process *RegisterItems*. This process gets replication items (*getItems*?*ns*.*Items*) and becomes the process *CheckItems*.

Process *CheckItems* models the method `registerItems()` from the class `ConnectionThread`, which is responsible for determining which files should be replicated to the SyncClient. Specifically process *CheckItems* takes two arguments, where the first is a set of *Items* and the second is the sequence of sets of files that is to be replicated to the SyncClient. The process *CheckItems* recursively sends the check point of each replication

item to the SyncClient. If the SyncClient already has the check point ($cmd.t.CheckPointId.c.false$), the corresponding files are discarded, otherwise ($cmd.t.CheckPointId.c.true$) the corresponding files are appended to the sequence of filesets to be transfered. After obtaining the files to be replicated, the process sends the startSnapshot command ($cmd.t.StartSnapshot$) to SyncClient to notify the client about the beginning of the replication session. The process then becomes *TransferItems*.

Process *TransferItems* models the method `transferItem()` from the class `ConnectionThread`, which is responsible for replicating files to the SyncClient. Specifically, process *TransferItems* takes a sequence of sets of files to be replicated. For each set of files *fs*, the process becomes process *TransferFile*(*fs*). The process *TransferFile*(*fs*), which models `sendFile()`, is responsible for transfering the set of files associated to a single replication item. After iterating the whole sequence, the process *TransferItems* sends command endSnapshot ($cmd.t.EndSnapshot$) to SyncClient, which notifies the SyncClient the end of the replication of all items. The process *TransferItems* then terminates. We explain now the process *TransferFile*(*fs*) in more detail.

Process *TransferFile*(*fs*) recursively performs the following: It internally chooses a file (i, c) from the set *fs*, it then sends the command appendSearchFiles to the SyncClient ($cmd.t.AppendSearchFile$) to notify the SyncClient of the beginning of a single file replication. It then sends the identifier i of the file to the SyncClient and receives the size of this file from the SyncClient ($cmd.t.FileCmd!i?cs : FileSize$). Next it performs one of the following actions:

- If $cs = c$ then the process sends the command skipFile ($cmd.t.SkipFile$).
- If $cs > c$ then the process sends the command overwriteFile ($cmd.t.OverwriteFile$), and transfers the file content to the SynClient. Since our model abstracts from file content. The transfer of the file content is simply denoted by the event $cmd.t.TransferCmd!(i, c)$.
- If $cs < c$ then the process sends the command appendFile ($cmd.t.ContinueFile$), and transfer *the remaining* file content to the SynClient. The remaining file content represent by their different $cmd.t.TransferCmd!(i, c - cs)$.

After iterating through the set of files *fs*, the process *TransferFile* sends the command EndSearchFile to the SyncClient ($cmd.t.EndSearchFile$) to notify the SyncClient the end of replicating one item. The process *TransferFile* then terminates.

$$\text{process } ThreadPools = |||\ t : Thread \bullet ConnectionThread(t)$$

We define process *ThreadPools* to model a pool of *ConnectionThread*. We restrict the number of *ConnectionThread* processes to ensure a finite state model.

O.5 Synchronisation Server

This section defines the process *SyncServer* that models the complete synchronisation server. We model the synchronisation server by considering the *behaviours* and *shared resources* separately. We start with the behaviours.

$$\text{process } SyncServerMain = acceptorThread \rightarrow Coordinator$$

The process *SyncServerMain* models the `main()` method of the class `SyncServer`, which is the initialises the synchronisation server. Specifically, it starts the acceptor thread by performing the event *acceptorThread*. It then invokes the method `process()` of the `SyncServerClientCoordinator` by becoming the process *Coordinator*.

$$\text{process } ThreadAcceptor = AcceptorThreadRun\ [\![\ \{\!|createConnectionThread|\!\}\ ]\!]\ ThreadPools$$

We also model the dependency between `run()` method of `SyncServerAcceptorThread` and the instantiation of `ConnectionThread` as a partial interleaving of *AcceptorThreadRun* and *ThreadPools* synchronising the events $createConnectionThread.t$ for all threads t. The set $\{|c|\}$ denotes the set of possible events associated with c. In the case of $\{|createConnectionThread|\}$, it is equivalent to the following set.

$$\{t : Thread \bullet createConnectionThread.t\}$$

The behavioural aspect of the synchronisation server is hence given by the following parallel combination of processes.

$$\mathsf{process}\ Behaviours = SyncServerMain \ [\![\ acceptorThread\ ]\!]\ ThreadAcceptor$$

We now consider the resource model of the synchronisation server. A synchronisation server has the replication snapshot, the boolean field `acceptingConnections` and the set field `connectionsReplication` as shared resources, we therefore model these resources as the following interleaving.

$$\mathsf{process}\ Resources = AcceptConnectionCondition \ |||\ Connections \ |||\ ReplicationSnapshot$$

The synchronisation server is then modelled by the following process *SyncServer*, defined as a parallel combination of its behaviours and resources, synchronising on all possible events of the resource processes.

$$\mathsf{process}\ SyncServer = Behaviours \ [\![\ ResourcesEvents\ ]\!]\ Resources$$

The set of events *ResourcesEvents* is defined as follows.

$$\begin{array}{l}\mathsf{set}\\ \quad ResourcesEvents =\\ \qquad \{|isAcceptingConnection, setAcceptingConnection, refreshSnapshot, clearSnapshot, getItems,\\ \qquad\quad numberOfClientThread, containsThread, addClientThread, removeThread|\}\end{array}$$

O.6 Synchronisation Client

We now consider the process for modelling the sychronisation client. We define the process *ClientDB* as the client file store, so that our model can relate different replication sessions.

$$\begin{array}{l}\mathsf{channel}\ replaceItem, appendItem : File\\ \mathsf{function}\\ \quad update(c, cps) = \text{if } c \in \text{ran } cps \text{ then } cps \text{ else } cps \frown \langle c\rangle\\ \quad notWithId(q) = \lambda f \bullet fst(f) \neq fst(q)\\ \quad size(i, fs) = \mathsf{let}\ item = \langle s : fs \mid fst(s) = i\rangle\ \mathsf{within}\ (\text{if } item = \langle\rangle \text{ then } 0 \text{ else } snd(head\ item))\\ \quad updateItems(f, ps) = \langle s : ps \mid fst(s) \neq fst(f)\rangle \frown \langle(a, b) : \langle s : ps \mid fst(s) = fst(f)\rangle \bullet (a, (b + snd(f)))\rangle\\ \mathsf{process}\\ \quad ClientDB(cps, fs) =\\ \qquad cmd.i.CheckPointId?c : CheckPoint!(c \notin \text{ran } cps) \rightarrow ClientDB(update(c, cps), fs)\\ \qquad \Box\ cmd.i.FileCmd?fid : FileId!size(fid, fs) \rightarrow ClientDB(cps, fs)\\ \qquad \Box\ replaceItem?f : File \rightarrow ClientDB(cps, filterSeq(notWithId(f))(fs) \frown \langle f\rangle)\\ \qquad \Box\ appendItem?f : File \rightarrow ClientDB(cps, updateItems(f, fs))\end{array}$$

This process takes two arguments *cps* and *fs*, where *cps* is the set of checkpoints of replication items that have already been replicated, and *fs* is the set of files stored at the client side. Specifically, this process offers one of the following behaviours:

The process may perform the event $cmd.i.CheckPointId.c.false$ if the replication item identified by the check point c has already been received by SyncClient i, and $cmd.i.CheckPointId.c.true$ if the item identified by c has not been received by i. In both case the process then becomes $ClientDB(update(c, cps), fs)$, which adds c to *cps* for event $cmd.i.CheckPointId.c.false$.

The process may perform the event $cmd.i.FileCmd.fid.s$, where s is the size of the file identified by *fid* that is currently stored in SyncClient i. Here $s = 0$ if file *fid* does not exist in i. After this event the process becomes $ClientDB(cps, fs)$ without altering *cps* or *fs*.

The process may also perform the events $replaceItem.f$ or $appendItem.f$ for some file f. The former denotes that the client version of f will be overridden by this f, while the latter denotes that the content of f will be appended to the content of the client version f.

We move on to the model of client jobs. This model is defined by the processes $BootJob(i)$ and $ReplicationJob(i)$ for SyncClient i.

channel $state : Client.State$
process
$BootJob(i) =$
$needThread.i \rightarrow state.i.booting \rightarrow cmd.i.ListSchedule \rightarrow$
$state.i.waitToReplicate \rightarrow ReplicationJob(i)$

The process *BootJob* models the class `ClientBootJob` and it is responsible to get the replication schedule from the SyncServer. It first establishes a connection to the synchronisation server ($needThread.i$). It then sends the command requesting the replication schedule ($cmd.i.ListSchedule$). Note our CSP model abstracts from schedule details. The process *BootJob* then becomes the process *ReplicationJob*, which models the scheduling of the `ClientReplicationJob`. A UML activities diagram describing the work flow of `ClientBootJob` can be found in Figure 5.15 on Page 89.

process
$ReplicationJob(i) =$
let
$Register = cmd.i.CheckPointId?c : CheckPoint?b : Bool \rightarrow Register \,\square\, Listener$
$Listener =$
$cmd.i.StartSnapshot \rightarrow Listener$
$\square\ cmd.i.EndSnapshot \rightarrow state.i.waitToReplicate \rightarrow ReplicationJob(i)$
$\square\ ReceiveItem$
$ReceiveItem =$
$cmd.i.AppendSearchFile \rightarrow ProcessFile$
$\square\ cmd.i.EndSearchFile \rightarrow Listener$
$ProcessFile =$
$cmd.i.FileCommand?f : FileId?s : FileSize \rightarrow$
$(cmd.i.OverwriteFile \rightarrow cmd.i.TransferCmd?f : File \rightarrow replaceItem!f \rightarrow Listener$
$\square\ cmd.i.SkipFile \rightarrow Listener$
$\square\ cmd.i.ContinueFile \rightarrow cmd.i.TransferCmd?f : File \rightarrow appendItem!f \rightarrow Listener)$
within
$needThread.i \rightarrow state.i.workOnReplicate \rightarrow cmd.i.SearchSchedule \rightarrow Register$

The process *ReplicationJob* models the class `ClientReplicationJob` and it is responsible for receiving the replication items from the SyncServer and for scheduling new replication jobs (`ClientReplicationJob`).

This process first establishes a connection with the synchronisation server ($needThread.i$). It sends then the command requesting replication items ($cmd.i.SearchSchedule$). While in the implementation of `ClientReplicationJob`, another instance of the replication job is scheduled at this point of execution, the combination of locks used in the implementation forces this scheduled replication job to be executed after the current job has finished. We model this restriction by enabling the scheduled replication job at the end of the execution of the current one.

After requesting replication items, the process *ReplicationJob* iteratively registers replication items by iteratively offering the event $cmd.i.CheckPointId?c : CheckPoint?b : Bool$ or the process *Listener*. After registration of the replication items, the process waits for one of the following commands:

- $cmd.i.StartSnapshot$ (startSnapshot) – this command denotes the start of the replication snapshot.
- $cmd.i.EndSnapshot$ (startSnapshot) – this command denotes the end of the replication snapshot, the client job then terminates and becomes another instance of the replication job, representing the start of the scheduled instance.
- $cmd.i.EndSearchFile$ (appendSearchFile) – this command denotes the end of a replication of a single item
- $cmd.i.AppendSearchFile$ (endSearchFile) – this command denotes the start of a replication of a single file. The process then receives the identifier of the file to be replicated and sends the size of this file at the client side. This is modelled by the event $cmd.i.FileCommand?f : FileId?s : FileSize$, which denotes the file identified by f at SyncClient i has the size s. This process then receives one of commands skipFile $cmd.i.SkipFile$, overwriteFile $cmd.i.OverwriteFile$ and continuteFile $cmd.i.ContinueFile$ indicating that file f should be ignored, overwritten with the SyncServer's content or appended with the SyncServer's content.

A UML activities diagram describing the work flow of `ClientReplicationJob` can be found in Figure 5.18 on Page 102.

We can now define process $SyncClient(i)$ as a parallel combination of *ClientMain* and *ClientDB*, synchronising all data-related communications (*dataEvents*), to model a single synchronisation client. We hide the set of events $\{\!|replaceItem, appendItem|\!\}$ as they correspond internal access to client's file store.

$$
\begin{array}{l}
\mathsf{set}\ dataEvents = \{\!|cmd.i.CheckPointId, cmd.i.FileCommand, replaceItem, appendItem|\!\} \\
\mathsf{process} \\
\quad SyncClient(i) = \\
\qquad \mathsf{let}\ ClientMain = state.i.start \rightarrow state.i.waitToBoot \rightarrow ClientBootJob(i) \\
\qquad \mathsf{within}\ (ClientMain\ [\![\ dataEvents\ ]\!]\ ClientDB(\emptyset, \langle\rangle)) \setminus \{\!|replaceItem, appendItem|\!\}
\end{array}
$$

The process *SyncClients* then denotes the set of SyncClients, where the size is determined by the value *Clients*. This ensures that we have a finite state model.

$$
\mathsf{process}\ SyncClients = |||\ c : Clients \bullet state.c.start \rightarrow SyncClient(c)
$$

O.7 Replication System and Its Properties

Our CSP model of the replication system is given by the process *ReplicationSystem*. It is defined as a parallel combination of the SyncServer (*SyncServer*) and the set of SyncClients (*SyncClients*), synchronising on events $\{|cmd|\} \cup \{|needThread|\}$. The set of events $\{|cmd|\}$ denotes the set of possible communications between SyncClients and connection threads during replications. The set of events $\{|needThread|\}$ denotes the initial request to connect to the SyncServer prior replications.

$$\textsf{process}\ ReplicationSystem = SyncServer\ [\![\ \{|cmd|\} \cup \{|needThread|\}\ ]\!]\ SyncClients$$

We verify that *ReplicationSystem* is free of deadlock and livelock using the FDR tool [32].

$$\begin{array}{l}\textsf{assert}\\ \quad \text{deadlock free}_{\mathcal{F}}\ ReplicationSystem\\ \quad \text{divergence free}\ ReplicationSystem\end{array}$$

Process $SyncClientSpec(c)$ models the state machine of SyncClient c as shown in Figure 5.14 on Page 87.

$$\begin{array}{l}\textsf{process}\\ \quad SyncClientSpec(c) =\\ \qquad \textsf{let}\\ \qquad\quad WaitBootState = state.c.waitToBoot \rightarrow (EndState \sqcap BootState)\\ \qquad\quad BootState = state.c.booting \rightarrow (WaitBootState \sqcap WaitReplicationState \sqcap EndState)\\ \qquad\quad WaitReplicationState =\\ \qquad\qquad\qquad state.c.waitToReplicate \rightarrow (ReplicateState \sqcap WaitBootState \sqcap EndState)\\ \qquad\quad ReplicateState =\\ \qquad\qquad\qquad state.c.workOnReplicate \rightarrow (WaitReplicationState \sqcap WaitBootState \sqcap EndState)\\ \qquad\quad EndState = state.c.end \rightarrow SyncClientSpec(c)\\ \qquad \textsf{within}\\ \qquad\quad state.c.start \rightarrow WaitBootState\end{array}$$

By setting value *MAXTHREAD* and *MAXCLIENT* to 10, we verify that up to 10 clients behave according to their state machines by model checking the following refinement assertion using the FDR tool.

$$\textsf{assert}\ \forall\, c : Client \bullet SyncClientSpec(c) \sqsubseteq_{\mathcal{F}} ReplicationSystem \setminus (\Sigma \setminus \{|state.c|\})$$

Appendix P

ABS Model of the Replication System

P.1 Data Types, Type Synonyms and Function Definitions

```
data JobType = Replication | Boot;
data State = Start | WaitToBoot | Booting | WaitToReplicate| WorkOnReplicate | End;
data Command =
  StartSnapshot | EndSnapshot | ListSchedule | SearchSchedule | EndSearchFile | AppendSearchFile |
  SkipFile | ContinueFile | OverwriteFile;

def Bool isAppendCommand(Command c) =
  case c {
    SkipFile => True;
    ContinueFile => True;
    OverwriteFile => True;
    _ => False;
  };

// Java class com.fredhopper.search.fred.Checkpoint
// For Java method com.fredhopper.replication.server.item.SearchReplicationDirectory.isValid(String, long)
type CheckPoint = Int;

// Used for identifying the file to be replicated
type FileId = Int;

// Java method java.io.File.length()
// Used for identifying file content
type FileSize = Int;

// A file is composed of its identifier and content.
type File = Pair<FileId,FileSize>;

// Java class com.fredhopper.replication.server.item.ServerReplicationItem
type ReplicationItem = Pair<CheckPoint,Set<File>>;
```

The built-in data type Int provides the infix functions +, −, and >. The built-in data types Pair<A,B>, Set<A> and Map<A,B> implement pairs, sets and maps respectively. Functions fst(Pair<A,B>) : A and snd(Pair<A,B>) : B on type Pair<A,B> return the first and the second element of a pair respectively. The type File is a set of files for replication, a file is a Pair of FileId and FileSize. The first element is of type FileId that identifies the file and the second element is of type FileSize recording thee size of the file. The type

ReplicationItem is an replication item and it is a pair Pair of CheckPoint and Set<File>. The first element is the check point of that replication item and the second element is the set of files contained in that replication item.

P.2 Interface Definition

P.2.1 Database

```
/*
 * Common operations to all database:
 * 1. retrieve a file (id)'s file size (content)
 * 2. list all files in the file store
 */
interface DataBase {
    FileSize getLength(FileId fId);
    Set<FileId> listFiles();
}

/*
 * A client database cannot be refreshed
 * but can perform the following:
 * 1. prepare a new replication item;
 * 2 update both internal database and file store with new files
 */
interface ClientDataBase extends DataBase{
  Bool prepareReplicationItem(CheckPoint cp);
  Unit updateFile(FileId fId, FileSize size);
}

/*
 * A database on the server has a readonly internal
 * database and can peform the following:
 * 1. refresh database
 * 2. list file (ids) of the current checkpoint
 */
interface ServerDataBase extends DataBase {
  Unit refresh();
  Set<FileId> listCheckPointFiles();
}
```

P.2.2 Node, SyncServer and SyncClient

```
// One can shut down a node or ask if the node has been shut down.
// Both client and server are nodes
interface Node {
  DataBase getDataBase();
  Bool isShutdownRequested();
  Unit requestShutDown();
}

// CSP model SyncServer(n) ||| ReplicationSnapshot
// Java class com.fredhopper.application.SyncServer
```

```
// Java class com.fredhopper.replication.server.ReplicationSnapshot
interface SyncServer extends Node {
  Unit refreshSnapshot();
  Unit clearSnapshot();
  Set<ReplicationItem> getItems();
  SyncServerAcceptor getAcceptor();
  SyncServerClientCoordinator getCoordinator();
}

// CSP model SyncClient(n)
// Java class com.fredhopper.application.SyncClient
interface SyncClient extends Node {
  ClientDataBase getClientDataBase();
  Unit setAcceptor(ServerAcceptor acceptor);
  ServerAcceptor getAcceptor();
  Unit becomesState(State state);
}
```

P.2.3 Acceptor Thread, Replication Coordinator and Replication Job

```
// CSP model CoordinatorProcess
// Java class com.fredhopper.replication.server.SyncServerClientCoordinator
interface SyncServerClientCoordinator {
  Unit process();
  Unit startReplicationUpdate(ConnectionThread thread);
  Unit finishReplicationUpdate(ConnectionThread thread);
}

// CSP model AcceptorThreadRun(t)
// Java class com.fredhopper.replication.server.SyncServerAcceptorThread
interface ServerAcceptor {
  ConnectionThread getConnectionr(ClientJob job);
}

interface SyncServerAcceptor extends ServerAcceptor {
  Bool isAcceptingConnection();
  Unit suspendConnection();
  Unit resumingConnection();
}

interface CommandReceiver {
  Unit command(Command command);
}

// Java class com.fredhopper.replication.server.ConnectionThread
// CSP model ConnectionThreadRun(n)
interface ConnectionThread extends CommandReceiver { }

// Java class com.fredhopper.replication.client.ClientReplicationJob
// Java class com.fredhopper.replication.client.ClientBootJob
interface ClientJob extends CommandReceiver {
```

```
  Bool registerReplicationItems(CheckPoint checkpoint);

  // ClientReplicationJob.receiveItemFragment()
  FileSize processFile(FileId id);
  Unit processContent(File file);
  Unit receiveSchedule();
}
```

P.3 Database

```
//A simple model of a database that can represent a sequence of file updates.
class DataBase(Map<CheckPoint, Map<FileId,FileSize>> db)
implements ServerDataBase, ClientDataBase {

  CheckPoint ccp = −1;
  Set<CheckPoint> checkPoints = keys(db);

  // Actual file store
  Map<FileId,FileSize> filestore = EmptyMap;

  Bool prepareReplicationItem(CheckPoint p) {
    Bool result = False;
    if (~ contains(checkPoints,p)) {
      checkPoints = Insert(p,checkPoints);
      ccp = p;
      db = InsertAssoc(Pair(p,EmptyMap),db);
      result = True;
    }
    return result;
  }

  Bool advancedCheckPoint() {
    Bool result = False;
    if (hasNext(checkPoints)) {
      Pair<Set<CheckPoint>,CheckPoint> nt = next(checkPoints);
      checkPoints = fst(nt);
      ccp = snd(nt);
      result = True;
    }
    return result;
  }

  // Refresh the file store in this data base
  Bool refresh() {
    Bool more = False;
    Map<FileId,FileSize> updates = EmptyMap;
    Set<FileId> fids = EmptySet;

    // advanced to the next check point;
    more = this.advancedCheckPoint();
    if (more) {
```

```
      updates = lookup(db,ccp);
      fids = keys(updates);
      while(hasNext(fids)) {
        FileId id = −1; FileSize fs = −1;

        Pair<Set<FileId>,FileId> nids = next(fids);
        fids = fst(nids);
        id = snd(nids);

        fs = lookup(updates,id);
        filestore = put(filestore,id,fs);
      }
    }
    return more;
  }

  // Updates both file store and database
  Unit updateFile(FileId fId, FileSize size) {
    Map<FileId,FileSize> checkPointFiles = EmptyMap;
    checkPointFiles = this.checkPointFiles();
    checkPointFiles = put(checkPointFiles,fId,size);
    db = put(db,ccp,checkPointFiles);
     this.storeFile(fId,size);
  }

  Set<FileId> listCheckPointFiles() {
    Map<FileId,FileSize> checkPointFiles = EmptyMap;
    checkPointFiles = this.checkPointFiles();
    return keys(checkPointFiles);
  }

  // Returns 0 if file not found.
  Int getLength(FileId fId) { return lookupDefault(filestore,fId,0); }

    // Updates file store only.
  Unit storeFile(FileId fId, FileSize size) { filestore = put(filestore,fId,size); }
  Map<FileId,FileSize> checkPointFiles() { return lookupDefault(db,ccp,EmptyMap); }
  Set<FileId> listFiles() { return keys(filestore); }

}
```

P.4 Synchronisation Server

```
class SyncServer(ServerDataBase db) implements SyncServer {

  CheckPoint cps = 0;
  Set<ReplicationItem> items = EmptySet;
  Bool shutDown = False;

  SyncServerClientCoordinator coordinator = null;
  SyncServerAcceptor acceptor = null;
```

```
Unit run() {
  coordinator = new SyncServerClientCoordinatorImpl(this);
  acceptor = new SyncServerAcceptorImpl(this);

  // starts coordinator asynchronously
  // this is because coordinator will
  // call back the server!
  coordinator!process();
}

DataBase getDataBase() { return db; }
Set<ReplicationItem> getItems() { return items; }

// Updating replication snapshot
Unit refreshSnapshot() {
  Fut<Set<FileId>> ns; Fut<Bool> rs; Fut<FileSize> fl; Fut<Unit> end;

  // Move this variable to method level
  // because maude complains about this
  // variable being undefined.
  Set<FileId> fids = EmptySet; Set<File> replications = EmptySet;
  Bool refresh = False;

  if (items == EmptySet) {
    cps = cps + 1;
    rs = db!refresh(); await rs?; refresh = rs.get;
    if (refresh) {
      // get all file names for the newest check points
      ns = this!getFileNames(); await ns?; fids = ns.get;
      while (hasNext(fids)) {
        FileSize flength = -1; FileId fid = -1;

        Pair<Set<FileId>,FileId> nt = next(fids);
        fids = fst(nt);
        fid = snd(nt);

        // get the file length of file fid
        fl = this!getFileLength(fid); await fl?; flength = fl.get;

        //create a new item
        replications = Insert(Pair(fid,flength),replications);
      }
      items = Insert(Pair(cps,replications),items);
    } else {
      // shutdown replication if refresh fails (no more new replications)
      end = this!requestShutDown();
      await end?;
    }
  }
}
```

```
    // Cleaning replication snapshot
    Unit clearSnapshot() { items = EmptySet; }

    // Get File length from the data base
    FileSize getFileLength(FileId fid) {
      Fut<FileSize> fl;
      fl = db!getCheckPointFileLength(fid); await fl?;
      return fl.get;
    }

    // Get File names of the current check points
    // from the data base
    Set<FileId> getFileNames() {
      Fut<Set<FileId>> fs;
      fs = db!listCheckPointFiles(); await fs?;
      return fs.get;
    }

    Bool isShutdownRequested() {
      //unfair scheduling at SyncServerAcceptor means for now
      //we insist on yielding control unconditionally
      suspend;
      return shutDown;
    }

    Unit requestShutDown() { this.shutDown = True; }
    SyncServerAcceptor getAcceptor() { return acceptor; }
    SyncServerClientCoordinator getCoordinator() { return coordinator; }

  }
```

P.5 Coordinator

```
  // CSP model CoordinatorProcess
  // Java class com.fredhopper.replication.server.SyncServerClientCoordinator
  class SyncServerClientCoordinator(SyncServer server)
  implements SyncServerClientCoordinator{

    Bool internal = False; // Models internal choice
    Bool replicationSignal = True; // A flag for creating a scheduling point
    SyncServerAcceptor acceptor = null;
    Set<ConnectionThread> threads = EmptySet;

    Unit process() {
      Fut<SyncServerAcceptor> acc; Fut<Bool> ac; Fut<Unit> end;
      Bool shutdown = False; Bool accept = False;

      // get SyncServerAcceptor
      acc = server!getAcceptor(); await acc?; acceptor = acc.get;
```

```
    shutdown = this.isServerShutingDown();
    while (~ shutdown) {
      //try polling on the return boolean value
      ac = acceptor!isAcceptingConnection(); await ac?; accept = ac.get;

      // There is a consideration about how long
      // a connection thread should have been working
      // This is abstracted in this model and
      // so we use a flag to model this.
      if (accept) {
        if (~ emptySet(threads) && internal) {
          acceptor.suspendConnection();
          internal = False;
        } else {
          internal = True;
        }
      } else {
        if (emptySet(threads)) {
          acceptor.resumingConnection();
        }
      }
      shutdown = this.isServerShutingDown();
    }

    // Shutdown sequence
    await threads == EmptySet;
    acceptor.resumingConnection();
  }

  // Internal method to see if the server has signalled shutting down.
  Bool isServerShutingDown() {
    Fut<Bool> sd;
    sd = server!isShutdownRequested(); await sd?;
    return sd.get;
  }

  // Setting up a replication session
  Unit startReplicationUpdate(ConnectionThread thread) {
    Bool result = False;
    await replicationSignal;
    threads = Insert(thread,threads);
    if (size(threads) == 1) {
      Fut<Unit> end;
      replicationSignal = False;
      end = server!refreshSnapshot(); await end?;
      result = True;
      replicationSignal = True;
    }
    return result;
  }
```

```
    // Tidy up after a replication session
    Unit finishReplicationUpdate(ConnectionThread thread) {
      Bool result = False;
      await replicationSignal;
      if (contains(threads,thread)) {
        if (size(threads) == 1) {
          Fut<Unit> end;
          replicationSignal = False;
          end = server!clearSnapshot(); await end?;
          replicationSignal = True;
        }
        threads = remove(threads,thread);
        result = True;
      }
      replicationSignal = True;
      return result;
    }
  }
```

P.6 Acceptor Thread

```
  class SyncServerAcceptor(SyncServer server)
  implements SyncServerAcceptor {

    // A flag representing SyncServerAcceptorThread.waitForResumingSignal
    // A flag representing SyncServerAcceptorThread.acceptingConnections
    Bool accept = True;

    Bool shutdown = False; // Shutdown flag

    Bool isServerShutingDown() {
      Fut<Bool> ss;
      ss = server!isShutdownRequested(); await ss?;
      return ss.get;
    }

    // Return a null thread if server is/has been shutting down
    ConnectionThread getConnection(ClientJob job) {
      ConnectionThread thread = null;
      shutdown = this.isServerShutingDown();
      if (~ shutdown) {
        await accept;
        thread = new ConnectionThread(job,server);
      }
      return thread;
    }

    Bool isAcceptingConnection() { return accept; }
    Unit suspendConnection() { accept = False; }
    Unit resumingConnection() { accept = True; }
  }
```

P.7 Connection Thread

```
class ConnectionThread(ClientJob job, SyncServer server)
implements ConnectionThread {

  SyncServerClientCoordinator coord;
  Maybe<Command> cmd = Nothing;

  Unit run() {
    Fut<SyncServerClientCoordinator> c; Fut<Unit> rp; Fut<Set<ReplicationItem>> is;

    Set<ReplicationItem> items = EmptySet;
    Set<Set<File>> filesets = EmptySet;

    c = server!getCoordinator(); await c?; coord = c.get;

    // register and refresh snapshot
    rp = coord!startReplicationUpdate(this); await rp?;

    // wait for client's command
    await cmd != Nothing;

    // Send schedules
    rp = job!receiveSchedule(); await rp?;

    // Replication if command is not listSchedule
    if (cmd != Just(ListSchedule)) {

      // Get replication items
      is = server!getItems(); await is?; items = is.get;

      // Register replication items with client
      filesets = this.registerItems(items);

      // start snapshot
      rp = job!command(StartSnapshot); await rp?;

      while (hasNext(filesets)) {
        Set<File> fileset = EmptySet;
        Pair<Set<Set<File>>,Set<File>> nfs = next(filesets);
        filesets = fst(nfs);
        fileset = snd(nfs);
        this.transferItems(fileset);
      }

      // end snapshot
      rp = job!command(EndSnapshot); await rp?;

    }
    rp = coord!finishReplicationUpdate(this); await rp?;
  }
```

```
Unit command(Command c) { cmd = Just(c); }

/*
 * Register replication items with client
 * Returns a set of files to be replicated
 */
Set<Set<File>> registerItems(Set<ReplicationItem> items) {
  Set<Set<File>> regs = EmptySet;

  //iterate over possible check points
  while (hasNext(items)) {
    Fut<Bool> b; Bool register = False;
    CheckPoint cp = -1; Maybe<ReplicationItem> item = Nothing;

    Pair<Set<ReplicationItem>,ReplicationItem> nis = next(items);
    items = fst(nis);
    item = Just(snd(nis));
    cp = fst(fromJust(item));

    b = job!registerReplicationItems(cp); await b?; register = b.get;
    if (register) {
        regs = Insert(snd(fromJust(item)),regs);
    }
  }

  return regs;
}

Unit transferItems(Set<File> fileset) {
  while (hasNext(fileset)) {
    Fut<FileSize> fs; Fut<Unit> rp;
    File file = Pair(-1,-1); FileSize size = -1; FileSize tsize = -1;

    Pair<Set<File>,File> nf = next(fileset);

    fileset = fst(nf);
    file = snd(nf);
    tsize = snd(file);

    fs = job!processFile(fst(file));
    await fs?;
    size = fs.get;

    if (size > tsize) {
      rp = job!command(OverwriteFile); await rp?;
      rp = job!processContent(file); await rp?;
    } else {
      // find out how much is still needed to be replicated
      if (tsize - size > 0) {
        rp = job!command(ContinueFile); await rp?;
```

```
            file = Pair(fst(file),tsize − size);
            rp = job!processContent(file); await rp?;
          } else {
            rp = job!command(SkipFile); await rp?;
          }
        }

      }
    }
  }
```

P.8 Synchronisation Client

```
// Implementation of SyncClient
// Java class com.fredhopper.application.SyncClient
class SyncClient(Map<State,Set<State>> machine) implements SyncClient {

  ServerAcceptor acceptor = null;
  State state = Start;
  ClientDataBase db = null;
  Bool shutDown = False;

  Bool isShutdownRequested() { return shutDown; }
  Unit requestShutDown() { this.shutDown = True; }
  ServerAcceptor getAcceptor() { return acceptor; }

  Unit run() {
    Fut<Unit> end;

    // initialize the client side data base
    this.db = new DataBaseImpl(EmptyMap);

    // Makes a transition
    this.becomesState(WaitToBoot);

    // wait for acceptor to be ready
    await acceptor != null;

    new ClientJob(this,Boot);
  }

  ClientDataBase getClientDataBase() { return db; }
  DataBase getDataBase() { return db; }

  Unit becomesState(State state) {
    assert(contains(lookup(machine,this.state),state));
    this.state = state;
  }

  Unit setAcceptor(ServerAcceptor acceptor) { this.acceptor = acceptor; }
}
```

P.9 Client Job

```
// CSP model ClientReplicationJob(n)
// Java class com.fredhopper.replication.client.ClientReplicationJob
class ClientJob(SyncClient client, JobType jt)
implements ClientJob {

  Command command = EndSnapshot;
  Bool hasSchedule = False;
  ConnectionThread thread = null;
  ClientDataBase db;

  Unit run() {
    Fut<Bool> ep; Fut<ConnectionThread> t; Fut<Unit> end;
    Bool empty = False; Bool continue = False;
    ServerAcceptor acceptor;

    acceptor = client.getAcceptor();
    db = client.getClientDataBase();

    // Acquire a connection
    t = acceptor!getConnection(this); await t?; thread = t.get;
    if (thread != null) {
      // Connection successful!
      if (jt == Boot) {
        client.becomesState(Booting);
        end = thread!command(ListSchedule);

        //Wait until replication schedule is received
        await hasSchedule == True;

      } else {
        client.becomesState(WorkOnReplicate);
        end = thread!command(SearchSchedule);

        //Wait until replication schedule is received
        await hasSchedule == True;

        // wait for current job to start then end
        await command == StartSnapshot;
        await command == EndSnapshot;
      }

      client.becomesState(WaitToReplicate);

      // new replication job
      new ClientJob(client,Replication);

    } else {
      // Connection unsuccessful! Perform shutdown
      this.shutDownClient();
```

```
    }
  }

  Unit shutDownClient() {
    client.requestShutDown();
    client.becomesState(End);
  }

  Bool registerReplicationItems(CheckPoint checkpoint) {
    return db.prepareReplicationItem(checkpoint);
  }

  // ClientReplicationJob.receiveItemFragment()
  FileSize processFile(FileId id) {
    FileSize result = −1; Set<FileId> fids = EmptySet;
    fids = db.listFiles();
    if (contains(fids,id)) {
      Fut<FileSize> size;
      size = db!getLength(id); await size?; result = size.get;
    }
    return result;
  }

  Unit overwrite(File file) {
    Fut<Unit> u;
    FileId id = fst(file);
    FileSize size = snd(file);
    u = db!updateFile(id,size); await u?;
  }

  Unit continue(File file) {
    Fut<Unit> u; Fut<FileSize> s; FileSize fsize = −1;

    FileId id = fst(file);
    FileSize size = snd(file);

    s = db!getLength(fst(file)); await s?; fsize = s.get;
    size = size + fsize;
    u = db!updateFile(id,size); await u?;
  }

  Unit processContent(File file) {
    await isAppendCommand(command);
    if (command == SkipFile) { skip; }
    if (command == OverwriteFile) { this.overwrite(file); }
    if (command == ContinueFile) { this.continue(file); }
  }

  Unit command(Command command) { this.command = command; }
  Unit receiveSchedule() { hasSchedule = True; }
```

```
}
```

P.10 Initialisation

```
{
  //Initialise a finite set of updates
  Map<CheckPoint,Map<File,FileSize>> items = ...

  // Defines possible transitions and Creates states machine
  Map<State,Set<State>> machine = ...

  DataBase db; //Database db
  Fut<ServerAcceptor> acc; ServerAcceptor acceptor;

  SyncServer syncserver; // One SyncServer
  SyncClient syncclient1; ... // Specifies a number of client nodes

  syncclient1 = new SyncClient(machine); ... // Initialises client nodes

  db = new DataBase(items); // Initialises server data base
  syncserver = new SyncServer(db); // Initialises the server node

  // wait for the acceptor thread to be ready
  acc = syncserver!getAcceptor(); await acc?; acceptor = acc.get;

  syncclient1.setAcceptor(acceptor); ... // notify clients
}
```