USING ABSTRACT STATE MACHINES TO MODEL A GRAPHICAL USER INTERFACE SYSTEM

by

Ming (Mike) Su

B.Sc., University of Ottawa, 2001

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
in the School
of
Computing Science

© Ming (Mike) Su 2006
SIMON FRASER UNIVERSITY
Spring 2006

All rights reserved. This work may not be
reproduced in whole or in part, by photocopy
or other means, without the permission of the author.

APPROVAL

Name:	Ming (Mike) Su
Degree:	Master of Science
Title of thesis:	Using Abstract State Machines to Model a Graphical User Interface System

Examining Committee: Dr. Jiangchuan Liu
Chair

____

Dr. Uwe Glässer, Senior Supervisor

____

Dr. Arthur (Ted) Kirkpatrick, Supervisor

____

Dr. Fred Popowich, SFU Examiner

Date Approved: Apr. 4/06.

SIMON FRASER UNIVERSITY library

DECLARATION OF
PARTIAL COPYRIGHT LICENCE

The author, whose copyright is declared on the title page of this work, has granted to Simon Fraser University the right to lend this thesis, project or extended essay to users of the Simon Fraser University Library, and to make partial or single copies only for such users or in response to a request from the library of any other university, or other educational institution, on its own behalf or for one of its users.

The author has further granted permission to Simon Fraser University to keep or make a digital copy for use in its circulating collection, and, without changing the content, to translate the thesis/project or extended essays, if technically possible, to any medium or format for the purpose of preservation of the digital work.

The author has further agreed that permission for multiple copying of this work for scholarly purposes may be granted by either the author or the Dean of Graduate Studies.

It is understood that copying or publication of this work for financial gain shall not be allowed without the author's written permission.

Permission for public performance, or limited permission for private scholarly use, of any multimedia materials forming part of this work, may have been granted by the author. This information may be found on the separately catalogued multimedia material and in the signed Partial Copyright Licence.

The original Partial Copyright Licence attesting to these terms, and signed by this author, may be found in the original bound copy of this work, retained in the Simon Fraser University Archive.

Simon Fraser University Library
Burnaby, BC, Canada

Abstract

A graphical user interface (GUI) system is a visual tool for users to operate computer applications. In the software engineering world, verifying that the functions of a GUI system satisfy the perspective of users is one important goal. System modeling provides an opportunity to verify the functionality of the system before implementing it.

In this thesis, we model the GUI system of the CoreASM language debugger based on the abstract state machine (ASM) paradigm, and give a formal specification to the GUI system. This GUI system model provides a formal mathematical foundation to specify the architecture and the function form of the GUI system and to specify the interactive actions between the users and the computer application (the CoreASM engine). The design approach in this work incorporates both object-oriented and task-oriented approaches. A process of level-wise refinement is used to solve particular design problems.

This thesis is dedicated, with love, to my parents and my brother!

"Life is finite, while knowledge is infinite."

— *Zhuang Zi*

Acknowledgments

Many thanks to all the members of my committee for their guidance and thanks to colleagues working in the CoreASM project for discussion and feedback.

In particular, I would like to thank the following:

Dr. Uwe Glässer, whose guidance enabled me to complete this thesis.

Dr. Arthur (Ted) Kirkpatrick, whose advices assisted me to think over my work from expectations as an HCI reader.

Mr. Roozbeh Farahbod and Mr. Mashaal Memon. It is much appreciated in the discussions of the project and to work together.

Additional, I thank my parents and my brother for their patience and supports.

Contents

List of Tables

List of Figures

List of Specs

Abbreviations

API	application program interface
ASM	abstract state machine
DASM	distributed ASM
GUI	graphical user interface
HCI	human-computer interaction
JFC	Java Foundation Classes
MVC	model-view-controller
PAC	presentation-abstraction-control
UI	user interface
UIDS	user interface development system
UIMS	user interface management system
UML	unified modeling language
VM	virtual machine

Chapter 1

Introduction

This thesis introduces a model for the graphical user interface application created for the CoreASM project, and gives the formal specification for it. As part of the project, the Software Technology Lab at Simon Fraser University is developing an executable working environment [Section 5.1] for the CoreASM language, a language that extends from pure abstract state machine principles [14]. CoreASM is still under development in the Software Technology Lab. The graphical user interface application is one tool in the working environment of the CoreASM language. It provides for interactive visualization and control of CoreASM simulation runs.

A graphical user interface application is one type of human-computer interaction system. Human-computer interaction is a huge research field. Computer science, psychology, information science, and engineering all influence research in this field. This field focuses on the interactions between computer systems and human users. Designing computer systems to better present information and to improve user work performance are some of the goals of this research work.

The CoreASM language comes from the original, basic definition of abstract state machines given in the Lipari Guide [18]. Abstract state machines are practical for modeling hardware and software architectures, programming languages, network protocols, etc. Some applications of ASM-based modeling include the ITU-T standard for SDL [19], the IEEE language VHDL [5], the programming languages Java [28] and C# [4], and communication architectures [15] [16].

1.1 Motivation and objectives

Abstract state machine (ASM) methodologies have been proven practical for modeling complex systems. Application examples mostly involve existing systems. One way to make ASMs practical in industry is to use ASM methodologies to model predictively during the design phase, rather than for analyzing systems that already exist.

ASM methodologies, such as ground model [8][6] and stepwise refinement [7][30], can be applied in predictive modeling as well. We need tools to apply these practical methodologies to industrial designs. The CoreASM project is a step toward applying ASMs in industry. The project provides a supporting tool environment to make ASMs executable. Software engineers can do high-level design, experimental validation, and formal verification of abstract system models in the early design phases with the CoreASM supporting tool environment.

The graphical user interface application presents execution information for abstract system models. It is a component of the CoreASM supporting tool environment [Section 5.1]. The purpose of this thesis is to apply ASM methodologies in designing an interactive system, specifically to the graphical user interface application of the CoreASM language debugger, using the model-based design approach. The formal specification of the application is given as the part of the design documents. The formal specification describes the application on three aspects, the architecture, the functionality and the interfaces between the user and the graphical user interface (GUI) application and the underlying CoreASM engine.

The first task of this thesis research is to apply a specification approach based on the ASM paradigm to formally specify the architecture and the functionality of the new user interface system. The graphical user interface application did not exist prior to the project. The development of the application requires predicting the application features. These features can be captured and be documented as informal user requirements. The model in the thesis formally specifies these informal user requirements. After the application is built, the model can be used to verify the prediction on the application features, and to validate the interfaces (APIs) between systems specified in the second task. The thesis will present the formal model [Chapter 5] and explain the specification approach applied in the process building the formal model. The user requirement capture and the verification of the application feature prediction and the validation of the APIs are not covered in the thesis. As the specific approach applied in the modeling process, the mixed approach of an object-oriented approach and a task-oriented approach [Section 4.2], and level-wise refinement [Section 6.1] will be discussed in this thesis.

The second task of this thesis research is to use ASM methodologies to specify interactions between systems. The interactions have been specified as a set of activities [Section 5.4]. Each activity interacts between the user, the GUI application and the CoreASM engine. The purpose of specifying these interactions is to know the information objects exchanged during interactions and the methods used to exchange these information objects. The above knowledge assists us in specifying interfaces (APIs) between systems [Section 5.5].

1.2 Thesis organization

The thesis is organized as follows.

Chapter 2 briefly overviews general design strategies and processes applied in the development of human-computer interaction systems. Chapter 3 introduces abstract state machine paradigms. The definitions of basic ASM terms are given in this chapter. These ASM terms are used to describe the execution processes and the states of ASM abstract models. The specification approach applied in this thesis is subsequently explained in Chapter 4. Chapter 5 describes three aspects of the GUI ASM model: the architecture, the activities, and the interfaces. Chapter 6 provides a discussion of the formal modeling process carried out during this thesis work. Chapter 7 introduces the implementation of CASM_GUI, a visual CoreASM language debugger, and then experiments an actual CoreASM model, the ATM model. Chapter 8 concludes the thesis and discusses possible future work.

1.3 Related works

It is widely recognized that designing a GUI system is difficult. Some researchers are starting to use formal modeling to design and test GUI systems.

Myers enumerated several reasons why a GUI system is difficult to design in his technical report [23]. In addition to designing any complex system, GUI system design has the following specific problems.

- Designers have difficulty learning the user's tasks.
- The tasks and domains are complex.
- There are many different aspects to the design which must all be balanced, such as standards, graphic design, technical writing, internationalization, performance, multiple levels of detail, social factors, legal issues, and implementation time.
- The existing theories and guidelines are not sufficient. They are too general or too specific, and no one theory or one guideline can address all issues.
- Iterative design is difficult. There are a few important issues needed to be considered. To get real users who actually use the system is important in iterative design. Also, it may be taken many times to do iterative testing on one particular problem in order to make sure the solution to that problem is correct.

Formal model specifications can be used for communication between designer and implementer, and for analysis about the system and behaviors of the system. Designer and implementer would have a better understanding about user tasks after reading the formal model specifications.

Standard software engineering formalisms can be used to specify an interactive system. There are three brands of formalism, model based, algebraic formalisms, temporal and deontic logics. Model-based specifications define the state of a system and the operations which change the state. Model-based formalisms use precisely defined mathematical notations to describe the behavior of a system in an abstract language. The major model-oriented specification notations are *Z* and *VDM* and *ASM*. For example, *Z* has been used to specify the GUI system, the presenter [31]. Algebraic specifications describe the effects of sequences of actions. The architecture of the system will not be specified with algebraic specification notations. The algebraic specification notations include *Larch* and *ACT-ONE*. *ACT-ONE* is the functional part of the ISO standard language *LOTOS*. Temporal and deontic logics have been used to specify certain properties of actions. Temporal logics describe when actions happen, and deontic logics describe permitted actions and responsibility.

Some formal models for GUIs have been proposed [22][31]. They mostly model the actions of a GUI's internal objects. One example of this kind of model was developed by Atif M. Memon, Martha E. Pollack and Mary Lou Soffa [22]. Their GUI model is constructed with a set of objects, a set of properties of these objects, and a set of actions on the change in the properties of these objects. The objects in their model are windows, menus, buttons, etc. This type of GUI models describes the detailed design of a GUI system through the actions of the GUI objects. The interaction between the GUI and other systems is not the model's concern. By contrast, the GUI model introduced in this thesis makes the interaction between the GUI application and the CoreASM engine a key resarch issue.

There are some researchers in the ASM field currently working on an executable ASM environment. They include the Spec# programming system project (successor to the ASML project) [1] and the XASM project [2], etc. The GUI application is a component of the tool developed in these projects. This is similar to the GUI tool developed in this thesis work. However, the GUI tools in the above projects are simple implementations. No ASM-based models are provided with them.

1.4 Significance of work

The GUI application described in this thesis was modeled with the help of ASM methodologies, specificially through a mixture approach of object-oriented design and task-oriented design approaches, and level-wise refinement. ASM methodologies have been used here to specify the functions of a graphical user interface system. They are also used to define interfaces between interactive systems. The work shows that the ASM methodologies specified in this thesis can be applied to predictively model a general interactive system.

The GUI model described in this thesis was constructed as a foundation for analyzing the function form of a GUI system. The GUI components in the model execute independently. The functions of the interactive system are specified as activities. Each activity can be refined with its own detailed specification. This kind of independence provides the ability for the GUI model to customize the architecture and the functions of a GUI system according to requirements.

The GUI model can be used to compare the behavior of the model to the implementation of the system through the use of scenarios and to discover any errors after the GUI model gets well-refined for execution. This evaluation can be done in the testing phase.

Chapter 2

Human computer interactive systems

Graphical user interface is one type of human-computer interaction (HCI) system. The basic goal of HCI is to make computers more user-friendly and easier to use. Some methodologies and design processes can help developers achieve this goal when they design a HCI system, such as task analysis, scenario design and software development life cycle models.

2.1 General introduction to HCI

The term *human-computer interaction* has been widely used in computer research since the 1980s. During the past three decades, many different types of computing devices have come into popular use, especially after the introduction of the personal computer in the 1980s and the spread of the Internet during the 1990s. Computing devices and the computer technologies behind these devices are changing people's work and personal lives.

Computing devices are becoming an important communications medium. People use computers at work to keep in contact with colleagues or customers and to communicate with their relatives and their friends off work. One significant research field is to studying on the ways that humans use or interact with computers. This research field is not limited to computer science; psychology and engineering technologies are being applied in this research field as well. Lately, information science is also influencing HCI research. The computer can collect information and analyze it. Managing information during interactions between humans and computers is one issue in this field. Researchers are doing their work to improve user work performance and to figure out how to use theories to design better computer systems.

Human-computer interaction is defined as the interaction between user and computer. A *user* is not necessarily one human user. It may be a group of human users. These days the term *computer* is similarly not restricted to a simple computer. More and more machines have integrated with computers. These computing-enabled machines offer users more functions, and require more types of interactions with users. Researchers view any system that consists of computing-enabled components as a kind of *computer.*

2.2 Graphical user interfaces

A *Graphical User Interface* (abbreviated as GUI) is one type of interface in human-computer interaction. Generally, a GUI is a visual operation display that takes advantage of a computer's graphical capabilities on a monitor screen to offer the computer operator the ability to operate computer applications or computer systems. The computer operator commands computer applications through the Graphical User Interface.

A *Graphical User Interface* assists the user to reduce the memory time required to remember the complex command language of computer applications. It can provide the user with a certain degree of guidance to do the next operation. For example, some buttons are disabled after a user does an operation. This forces the user to operate in the correct way and lets the user handle problems directly. A wizard is a good example of a way to guide a user's operations.

A *Graphical User Interface* has three main components, a windowing system, an imaging model and an application program interface (API) [21]. The windowing system builds windows, menus, buttons, dialog boxes and other components. The imaging model defines graphics and fonts for a system. The application program interface for the GUI enables a system to draw graphical components on screen. There are a few common characteristics to a graphical user interface. They include a pointer (a cursor on a screen), a pointing device, icons, buttons, toolbars, menus, a desktop, windows, and dialog boxes. These common characteristics of a graphical user interface reduce the learning curves when users move from one application to another.

The first graphical user interface was designed by Xerox Corporation's Palo Alto Research Center in the 1970s. It did not gain commercial success. Apple Computer brought the graphical user interface to its Apple Macintosh and made the graphical user interface the most popular interface for the modern personal computer. Over the past three decades, the graphical user interface has spread from the personal computer to other computer devices, such as handheld devices.

There are three main paradigms influencing modern graphical user interface standards. Apple Macintosh was the first popular GUI on a personal computer. It introduced some common graphical user interface elements, such as menus, point-and-click and mouse-driven processes. The IBM SAA invented keyboard short-cut keys for the graphical user interface. The X-windows system, mostly used by Unix and its successor Linux, works directly with a network. The display and the applications can run on separate computers in a network. The three paradigms have different Look-and-Feel, but share most of the same graphical user interface characteristics. [21]

2.3 User interface management systems

Some research has been done toward providing a design platform for programmers developing interactive systems. This interactive system design platform consists of a set of services, including a conceptual architecture for interactive environments and techniques for implementing application semantics and its presentations [12]. This

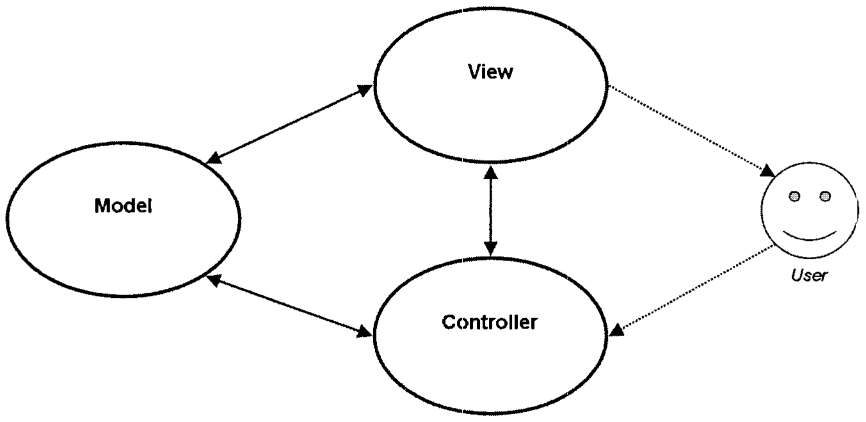


Figure 2.1: The *Model-View-Controller* model

design platform is called *User Interface Management Systems* (*UIMS*). Some people prefer another term, *User Interface Development Systems* (*UIDS*)[12].

One popular model for UIMS is the *model-view-controller* paradigm, or the *MVC* paradigm. This paradigm comes from the Smalltalk programming environment. The central architecture of the Java Foundation Classes (JFC) also relies on the MVC paradigm.

A system making use of the *Model-View-Controller* paradigm has three elements.

- *Model*: the application logic of the program. It is an abstraction that represents the nature and state of a user interface object.
- *View*: the representation of a user interface object to users.
- *Controller*: the component that synchronizes the model and its view. It keeps the view representative of the model's nature and state. It also accepts user inputs to update the model.

The *model* is the internal logic of the application. It maintains the states of a user interface object during interactions.

The *view* presents users with the nature or the state of a user interface object. In a GUI, the view renders user interface objects on the screen.

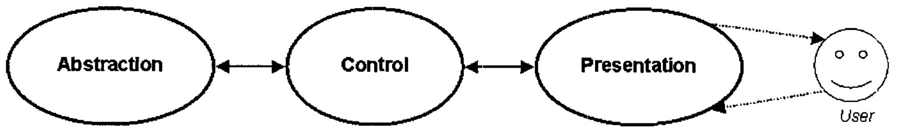


Figure 2.2: The *Presentation-Abstraction-Control* model

The view must present the model. Therefore, a *controller* is added to manage both the view and the model, and to provide a communication bridge between them. When the model is updated and the state of a user interface object is changed, the controller notices the view and refreshes the view to match the change in the model.

In this *Model-View-Controller* model, the view is the output channel to the user, presenting user interface objects. The input channel is the controller. Receiving input is the secondary role of the controller, which mainly acts as a bridge between the view and the model. The controller receives user inputs and then updates the model. The view may refresh with each model update.

The main idea in this *Model-View-Controller* paradigm is to separate the nature of a user interface object from the presentation of it. One model can bind with different pairs of input-output channels, views and controllers. The model is reusable, portable, and independent of devices. It therefore can reduce the development cost. In addition, the view-controller pair is customizable.

The Model-View-Controller is linked to a particular programming language environment. Coutaz suggests a more conceptual architecture than the MVC model. The architecture suggested by Coutaz is the *Presentation-Abstraction-Control* model, or *PAC* model [10].

The *PAC* model follows the *MVC* paradigm in that it separates the application semantics from the presentation of the application. The *abstraction* in the *PAC* model

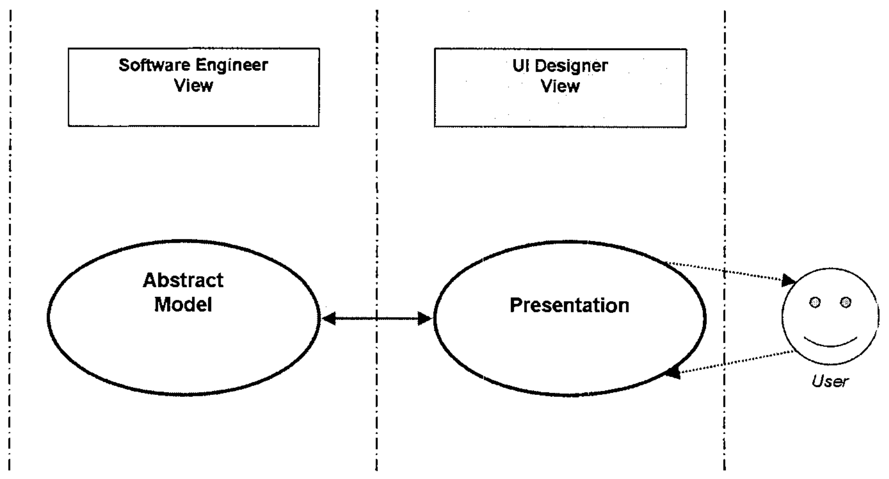


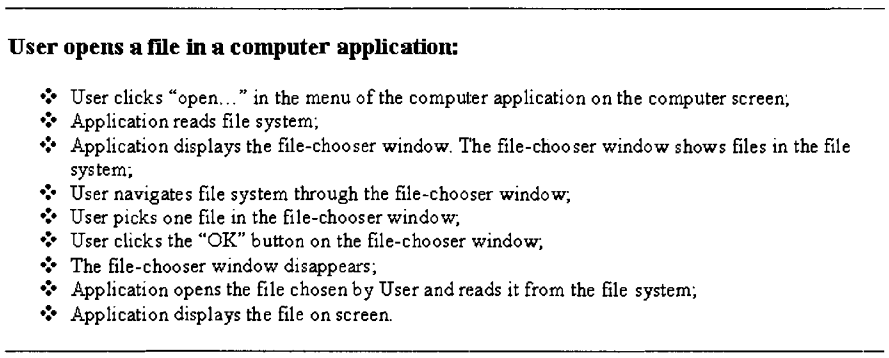
Figure 2.3: User Inteface (UI) design with an ASM approach

abstracts the application's semantics. The *presentation* takes charge of the view of the application. Both the *abstraction* and its *presentation* need the *control* to keep consistent with each other. In the *PAC* model, the input and output channels are both grouped into the presentation. The user does not interact with the control directly.

Both the MVC model and the PAC model are proposed for the implementation of a user interface system. To a software designer, the *abstract model* and its *presentation* are two important issues in developing a user interaction system. The controller in the above two models becomes the programming language that supports the communication between the abstract model and its presentation. It becomes a choice among implementation platforms and programming languages in the implementation phase.

The abstract model abstracts the internal logic and states of an application. It is obvious to a software designer. There is another set of abstractions supporting the presentation. The presentation abstraction is visible to the user. It should also be meaningful to the user. The GUI designer should bridge the two sets of abstractions together and keep them consistent.

The abstract model is the core of an application. A system designer should focus on the abstract model at the beginning of development. The GUI ASM model discussed



User opens a file in a computer application:

- User clicks "open..." in the menu of the computer application on the computer screen;
- Application reads file system;
- Application displays the file-chooser window. The file-chooser window shows files in the file system;
- User navigates file system through the file-chooser window;
- User picks one file in the file-chooser window;
- User clicks the "OK" button on the file-chooser window;
- The file-chooser window disappears;
- Application opens the file chosen by User and reads it from the file system;
- Application displays the file on screen.

Figure 2.4: An example of scenario notation

in this thesis is this abstract model [Chapter 5]. The presentation for the system, with specific GUI control elements, is left for the GUI designer.

2.4 Scenarios

Scenarios are stories of interaction processes. Software engineers write scenarios to record a set of interactions between systems and their environments. Scenarios are informal descriptions of these interaction processes. They are a well-known technique in the HCI field. Like a story, a scenario has actors and a description of interaction behaviors. Readers can learn and understand a system's interaction processes and figure out some functions of the system. Figure 2.4 gives an example of a scenario written in plain text. Scenarios can also be combined with sketches and screen shots. These are called *story boards*, and are used to provide details about interaction processes.

Scenarios can be useful throughout the system development life cycle. Scenarios

- Verify that the design of a system makes sense to both the user and the designer at the design phase;
- Enable communication with other parties, including users, designers, programmers and testers, during the entire development process;
- Validate other models of the same system. Testers can also design test cases dependent on scenarios.

2.5 Task analysis in HCI

Task analysis is often used in the specification phase of design. Hierarchical task analysis and use case task analysis are two popular task analysis techniques.

2.5.1 Introduction to task analysis

Task analysis is a process that involves the analysis of a task performed in a system and its environment. The term *Task* refers to a unit of activities. These activities are performed to achieve certain goals. To analyze tasks in HCI, it is necessary to analyze the activity that happens between an application and a user.

Task analysis can be applied in various fields, not only in computer science. Therefore, computer devices are not essential components in a system when we talk about task analysis.

Another thing should be clarified about systems. A system in task analysis is not a single system or application to be developed. It is a combination of an application, users, the system that supports the application, and other environmental factors.

A task has individual goals to achieve. We link a series of tasks to realize longer-term goals. This series of tasks is called a *process*, sometimes called a *business process*. One example of a business process is sending a piece of regular mail to a receiver. There are three main tasks in this process. Sender drops mail in a post office box; postal company delivers mail; receiver receives mail.

Task analysis is normally applied to analyze an existing system. The system exists, and analyst learns the system by observing the system's behaviors. However, task analysis is also useful when developing a new system. The analyst can often observe a similar existing system and then design a new system. This observe-design process contributes to the specification phase of development.

Task analysis has the following objects.

- Goal: understand the individual and overall task goals.
- Actors: understand who acts in each task.
- Environment: understand the environment that a task is performed in.

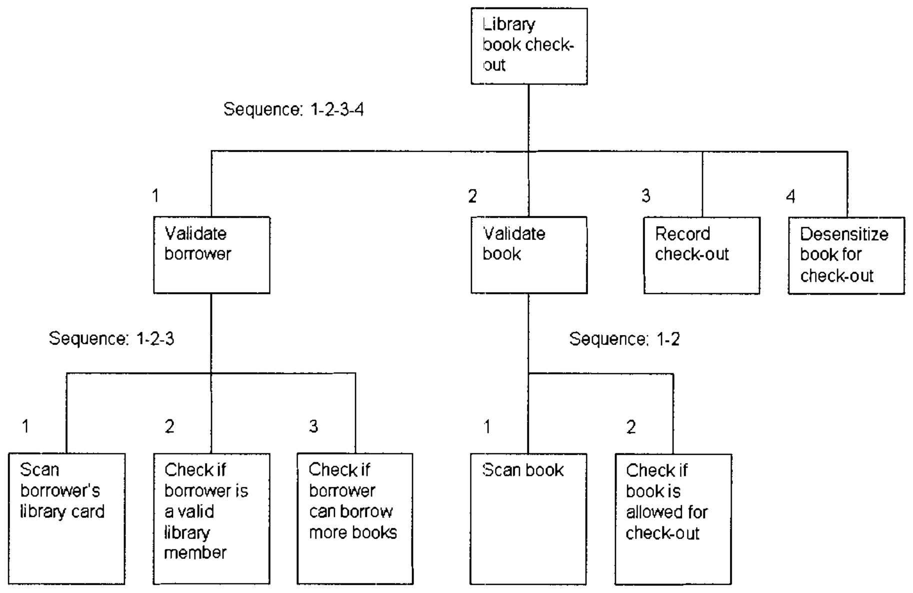

Library book check-out
Sequence: 1-2-3-4
1
Validate borrower
2
Validate book
3
Record check-out
4
Desensitize book for check-out
Sequence: 1-2-3
1
Scan borrower's library card
2
Check if borrower is a valid library member
3
Check if borrower can borrow more books
Sequence: 1-2
1
Scan book
2
Check if book is allowed for check-out

Figure 2.5: Hierarchical task analysis

- Actions: understand the actions in task and the order of those actions.
- Precondition: understand when and if preconditions exist when a task starts.

2.5.2 Hierarchical task analysis

Hierarchical task analysis is one standard approach to decomposing tasks. It involves dividing a main task into a few subtasks. The completeness of all subtasks ensures that the main task is completed. Subtasks can be divided into sub-subtasks, until the details of each task reach an acceptable abstract level. The analyst needs to do the following analysis: identify actors and actions for the tasks, plan the tasks, and analyze the preconditions of the tasks.

Tasks are organized by their goals. Certain subtasks are completed to achieve a goal one level up in the hierarchy. Hierarchical task analysis makes the to-be-analyzed tasks organized. An analyst can easily track the tasks. The relationships of the subtasks are clear. If an analyst applies hierarchical task analysis during the design phase, it helps to plan the tasks in the process. Some subtasks can be performed simultaneously with other subtasks; some cannot because their parent tasks should be processed in a sequential way. This is one example of how an analyst can assess system performance by making comparative predictions as to the sequences of actions with the help of hierarchical task analysis.

2.5.3 Use case task analysis

The term *use case task analysis* [20] [3] is employed by some object-oriented software design methodologies. One example is building a task model with use cases in UML modeling [25].

Use case task analysis has two objects, actors and use cases.

Actors:

An *actor* is basically a user of the system. It is actually a user type or category. As defined here, a user is not a specific person. The important concern with actors is the role of users in the system operation.

Use Cases:

A *use case* is a scenario that describes a use of the system by actors, interacting with the system to accomplish a goal. A scenario is used to identify the main tasks that should be performed by actors.

The use case task analysis is normally undertaken to determine if a new system is satisfactory from the user's perspective. A use case should describe the way the tasks are performed when the new system is in place. A use case should also be documented in a way that is easy to understand for non-technical persons since a use case is usually a medium for developers and customers to confirm that the new system satisfies the customer's needs.

Use cases can be refined incrementally [26]. Analysts can set up a use case at the beginning, and then decompose it into separate small use cases. Each time, the analyst can pay attention to individual use cases.

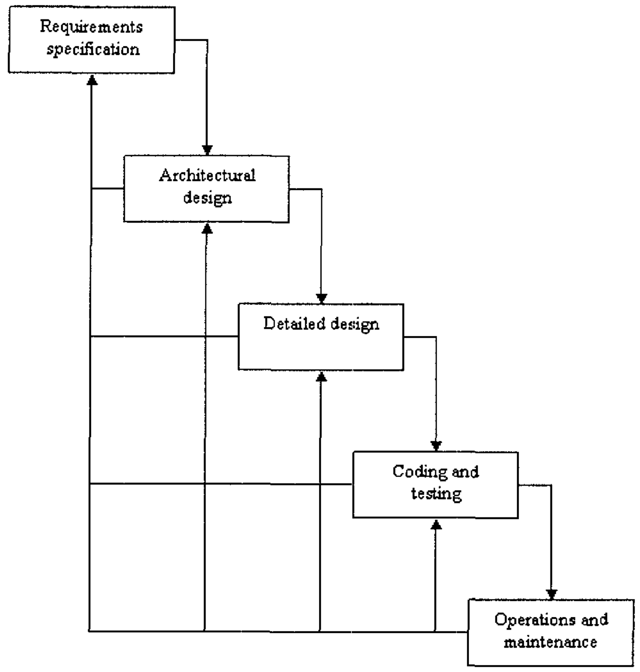


Figure 2.6: Software development process: the waterfall model

2.6 Software development life cycle in HCI

Software engineers have developed techniques to manage the software development process. A few models have been built, such as the *Waterfall Model*, the *Spiral Model* and the *Evolutionary Model*. These techniques can also be applied to describe the process of the development of a human-computer interaction system. I am going to use the *Waterfall model* to discuss the software development life cycle in HCI.

The waterfall model displayed in the Figure 2.6 is an improved version of the original waterfall model. The need for improvement stems from the fact that the requirement-capturing activity in the requirement specification phase is often not properly carried out. The requirement specification may be inconsistent or incomplete. This situation exists normally in a real development process. The developer may go back and change both the specification and the design even during the late phases of the project.

System specification modeling can make it possible to start the evaluation process at a much earlier stage of the development. In order to test the usability properties of a design, the developer needs a working system to observe interactions between users and this working system and then to evaluate this working system to measure its performance. It is not wise to delay the evaluation until the system is fully implemented. By contrast, system specification modeling can generate a working model for an evaluation before complete system implementation. This working model makes evaluation possible at a much earlier development stage. Users can now be invited to do evaluation on the system specification model at an early stage. Early stage evaluation reduces errors in the requirement specification. Therefore it can also reduce the number of times that the designer has to revisit the earlier development phases.

System specification modeling assists the developer to efficiently build a correct system. Normally, the developer attempts to capture requirements based on a user's perspective. However, the user normally cannot imagine how to interact with a system that does not exist. Nor does the user generally have a clear understanding of the tasks and activities performed by the new system. The developer in turn cannot gain a clear sense of the user requirements. Dix, Finlay, Abowd, and Beale described this chicken-and-egg puzzle in their book [12]. System specification modeling may be a solution to this puzzle. First, capture requirements that derive from what users imagine about the new system. The developer builds a specification model for these requirements and then invites users to evaluate it. The model is continually corrected through discussions between users and the developer, until the model agrees with the users' views. The GUI ASM model built in this thesis is this kind of specification model, that has been built in order to verify the prediction about a new system.

2.7 System design in HCI

Human computer interactive system design needs to involve multiple design methodologies and design processes. ASM modeling design is one agile methodology to design an interactive system at the early design phase. An ASM model can be used to describe the business logic of a system and to abstract the appearance description from

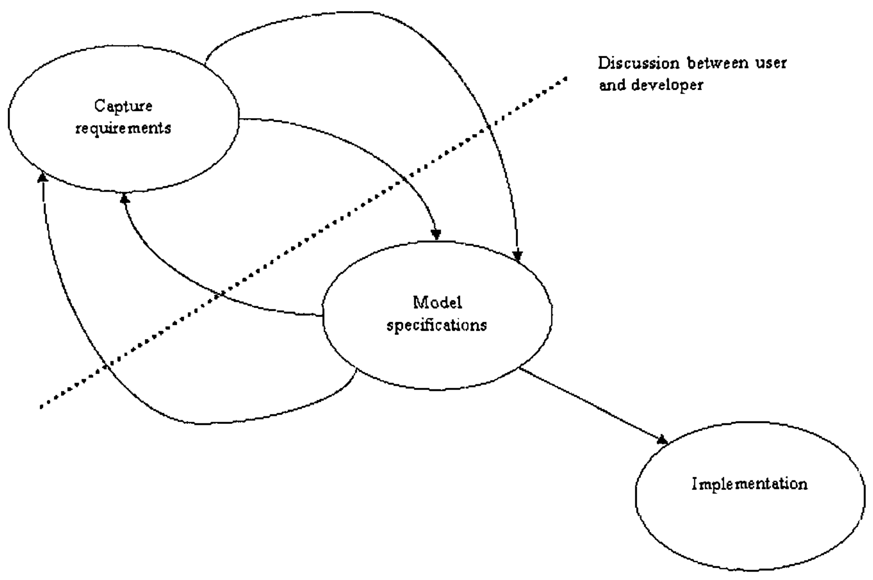


Figure 2.7: Discussion of system specification model

the system design documentations. It separates the work between system designer and UI designer and provides UI designer a design freedom. Many task analysis technologies are design tools for system designers and assist them to refine their work. Scenarios design is another tool for system testers to build test cases. System testers can use these test cases to validate the consistence of the ASM model and the implementation of the system.

Chapter 3

Abstract state machines

The *Abstract State Machine* (abbreviated as *ASM*) paradigm, introduced by Yuri Gurevich in 1988 [17], offers a framework for high-level system design and analysis. It has been proved that ASM methodologies are practical in modeling and analyzing different sizes of systems, from small to complex. A few research groups have been applying ASM techniques in different areas, such as hardware and software architectures, programming languages, network protocols and algorithm verification.

ASMs offer methods for specifying systems at a highly abstract level. ASMs are both abstract and executable. Their abstract nature allows the system designer to focus on system concepts and not to be disturbed by the details. ASMs can specify a system at different abstract levels. The system designer can refine the system from a more abstract level to a less abstract level by providing more details and making more design decisions. The executability of a well-refined ASM assists system designers to verify and validate designed systems before coding. ASMs have precise semantics. They are constructed mathematically and logically.

ASMs can be applied to a predictive model or be used to describe an existing system. Many ASM researchers have successfully validated existing systems, such as Java [28], with ASM methodology. ASMs can also be employed to model new systems. The GUI ASM model introduced in this thesis is an exercise in modeling such a predictive system. System designers do not usually know or understand most of the details of new systems at the beginning. They do not want to make many design decisions in the early design phases. Abstraction is a good tool for system designers to start their work with.

3.1 Abstract state machines

A basic *Abstract State Machine* (*ASM*) is defined as a set of transition rules of a form

if *Condition* **then** *Updates*

which specify the transition between two abstract states. These two abstract states are the states before and after an abstract state machine executes.

A *condition* (also called as *guard*) is a first-order formula without free variables. A condition evaluates to *true* or *false*. The term *updates* refers to a finite set of updates of functions with a form

$$f(t_1, \ \ldots \ ,t_n) := t$$

Functions with certain parameters get updated in parallel. The value of a function is changed (updated) to a new value. Briefly, *updates* occur when a finite set of functions change their values during the transition process from one state to another state.

The execution of an ASM machine is an update process. Starting from a given state, the values of finite functions with indicated parameters update in parallel to new values, according to rules specified by the ASM. If the updates of these functions are consistent, then a new state is achieved.

An ASM model has two objects: an ASM machine and its environment. The ASM machine is a core object in ASM modeling. The ASM machine always executes in an environment. The environment constrains that ASM machine. The ASM machine communicates with its environment through an interface. This interface will be discussed in the section Function [Section 3.2.2].

An ASM machine consists of three components.

- Vocabulary : definitions of functions and universes [Section 3.2.3].
- Initial state: the beginning state of the ASM machine.
- Program: the main rule of the ASM machine.

3.2 Some definitions used in ASMs

This section introduces some terms used in ASMs. People use these terms to describe the execution of an abstract state machine. Because the GUI ASM model is built to specify a GUI application tool, that helps users of the tool to explore executions of an ASM machine, we will see these terms many times in the description of the GUI ASM model.

3.2.1 Universe

Universe is a set of elements used in an ASM machine. Some books call it the *domain.* An ASM machine can have multiple universes existing in it, such as an integer universe or a character universe.

$$U_1 \equiv \{ 'a', 'b', 'c', 't', 'k', 'o' \}$$

3.2.2 Function

A *function* is expressed in a form

$$f(x_1, \;\dots\; , x_n)$$

A *function* is identified with its function name and its arguments (*arities*). This identification is the signature of a function. When arguments have been assigned, a function returns a certain value. A function signature and its indicated parameters and the value of the function with those parameters construct a *location.* A location is like a memory unit. The combination of function signature and indicated parameters is the location name. The value of the function with those indicated parameters is the value stored in that location. We say that value is the *value* of that location.

With particular parameter values $(t_1, \ldots, t_n)$, the location for the function $f(x_1, \ldots, x_n)$ is ($f(x_1, \ldots, x_n)$, $(t_1, \ldots, t_n)$), or more concisely $f(t_1, \ldots, t_n)$. The value of the location is the value of $f(t_1, \ldots, t_n)$.

Functions in ASMs are classified into two groups, *static* functions and *dynamic* functions.

A *static* function does not change its value during the execution of an ASM machine. This means that the value of a function with given parameters does not depend on the state of the ASM machine. The values of static functions are constant in all states.

A *dynamic* function can change its value during the execution of an ASM machine. The values of these dynamic functions may differ according to the state of the ASM machine.

Dynamic functions can be divided to three subclasses further, depending on the communication methods between an ASM machine M and its environment.

Dynamic functions [1] can be described as

- Controlled,
- Monitored,
- Shared.

A *controlled* function can be updated but only updated by the ASM machine M. It is internal for M.

A *monitored* function can be updated and only updated by the environment. The ASM machine M can read the value of the monitored function. The function is external for M.

[1] Some books declare there is another subclass of dynamic function, the *out* function. An *out* function is updated but not read by ASMs machine M and is read but not updated by the environment or other agents. These out functions are most used in multi-agent systems. They are a kind of controlled function [9]. Therefore, the *out* function is not listed here.

A *shared* function can be updated by both the ASM machine M and its environment, and can be read by both.

Controlled functions, *monitored* functions and *shared* functions construct the interface between the ASM machine M and its environment. They provide channels for both communication and interaction.

3.2.3 Vocabulary

A *vocabulary* is a finite collection of signatures of functions and universes. The signature of a function contains the function name and a fixed number of arities. Two signatures of functions follow:

$$sum(\ a\ :\ Integer,\ b\ :\ Integer)$$

and

$$sum(\ a\ :\ Integer,\ b\ :\ Float)$$

In strong-typed ASMs, two functions are different because of the difference in the types of the arities b; in weak-typed ASMs, two signatures identify the same function since the function names are the same and the number of arities are the same.

The Lipari guide [18] does not mention whether ASM is strong-typed or weak-typed. Most of the ASM tools available have incorporated a strong-typed system into their specification languages (Spec# [1] and XASM [2]). Strong typing makes these languages possible to do type checking at compile time, and helps modelers of ASM find errors at the earlier time, in contrast to the run-time error checking. Weak-typed ASM relies heavily on run-time error checking to produce correct programs. The CoreASM language and its toolset focus on early phases of the software development process. It is recommended to build a rapid prototype with ASMs, starting with abstract and weak-typed models in early analysis and specification, with the CoreASM language. Weak-typed ASM satisfies this purpose. Modelers of ASM now have an ability to ignore typing restrictions when building ASM models. One particular example is that identifiers can be used without declaration. Therefore, the CoreASM language has been developed as a weak-typed ASM language.

3.2.4 State

State is the notion of mathematical structures of elements from *universes*. A state A is a nonempty set X together with functions in vocabulary and the predicates. The set X is called the *base set* or *superuniverse* of A. A function signature with arity t is interpreted as t-ary operation over X.

3.2.5 Update set

An *update* of A is the pair of a location *loc* of A and an element v of A, $(loc,\ v)$. It is in an assignment form $f(t_1,\ \ldots,\ t_n) := v$, read as changing a value v in a location *loc* (*loc* is $f(t_1,\ \ldots,\ t_n)$).

Two updates $(loc_1,\ v_1)$ and $(loc_2,\ v_2)$ *clash* if $loc_1 = loc_2$ but $v_1 \neq v_2$.

An ASM machine M may fire a set of updates simultaneously from a state A_1 to reach another state A_2. This set of updates is called an *Update Set*. In the state A_1, the value of the location $f(t_1,\ \ldots,\ t_n)$ is v_1. To fire the update, the value of the location $f(t_1,\ \ldots,\ t_n)$ is changed to v_2. Because updates are fired simultaneously, M may assign different values to one location. If the clash happens during updating, we call this update set *inconsistent*. The new state of M will not be reached when an inconsistent update set exists.

3.2.6 Step and run

An ASM computation *step* is the process in which ASM machine M simultaneously fires all updates for all transition rules in a given state to reach a new state. If the update set in this process is consistent, then a new state of M is reached. If at least a pair of updates clashes, M will halt. The new state cannot be achieved at this step.

A *run* is a sequence of *steps* completed by an ASM machine M on a timeline. The ASM machine M changes from one state to another state. The number of *steps* in a *run* may be endless. Therefore, the number of states of the ASM machine M may be infinite in one *run*.

3.2.7 Rule and program

As per the definition of ASMs [Section 3.1], the basic rule in ASMs is the if-then transition rule. Generally, a *rule* in ASMs is one of the following basic rules or one compounded rule constructed from these basic rules.

The basic rules include the following.

- Skip rule: " **skip** ". Causes no change.
- Update rule: "$f(t_1, \ldots, t_n)$:= v". Assigns an element or expression to a location.
- Conditional rule: " ***if*** e ***then*** R_1 ***else*** R_2". A branch operation. Here e is a Boolean expression. To execute this conditional rule, check e. If e is true, execute R_1. If e is false, execute R_2.
- Block rule: " ***do in-parallel*** R_1 R_2". Executes rules R_1, R_2 simultaneously.
- Import rule: " ***import*** x $R_1(x)$". Discovers any element x of the reserve and executes the rule $R_1(x)$.

Rule is used usually to describe the behaviors of ASM machine M. *Function* in an ASM machine is different than a *rule* at this point. A *function* in an ASM machine is a formula, computing expression of values of the locations and elements in the universes. It does not describe the execution of ASM machine M. The meaning of *function* at this point is different than it is in other computing languages such as C.

Program is the main rule of ASM machine M. It describes one step of M. It executes repeatedly until the state does not change or no rule is applicable any more or the update set fired in one step is empty [9] (successful termination). A program may halt because of an inconsistent update set (failed termination).

3.3 Parallel abstract state machines

When we list the Block rule (**do-in-parallel** rule) as one of basic rules in ASMs, it declares that an ASM machine possesses a simultaneous execution ability. It is an important feature to support refinement in parallel or distributed implementations.

A **do-forall** rule is introduced here to enrich the notion of ASM rules.

- Do-forall rule: " ***forall*** x ***with*** ϕ ***do*** $R_1(x)$". It executes the rule $R_1(x)$ for each x satisfying a given condition ϕ. x will have some free occurrences in R.

For each rule $R_1(x)$, there is a parallel ASM to simulate the given rule step for step.

3.4 Non-deterministic abstract state machines

In contrast, there is another kind of execution. An ASM machine chooses an x to execute the rule $R_1(x)$, rather than executing for all x.

A **choose** rule is introduced here.

- Choose rule: " ***choose*** x ***with*** ϕ ***do*** $R_1(x)$". Executes the rule $\mathrm{R}_1(\mathrm{x})$ for an x satisfying a given selection property ϕ.

The choose rule causes non-determinism in ASMs. The choose method is not specified in the choose rule. It produces a problem. The user can not predict which x will be picked up without executing the ASM machine actually. There is a positive side to this non-determinism in ASM methodology. It helps the designer to avoid dealing with the details of the scheduling of rule executions. In the CoreASM supporting tool environment, a designer can provide a particular choose method by supplying a plug-in [14].

3.5 Distributed abstract state machines

Basic ASM (*sequential* ASM) and *parallel* ASM are ASM with a single agent. *Distributed Abstract State Machines* (*DASMs*) have a set of agents. *Agent* is an abstract state machine executed on its own local state. The agents interact by reading and writing on the shared locations in the global state of this distributed abstract state machine.

A *run* of distributed abstract state machines is defined as a partial order of moves of finite numbers of agents. A single computation step of an agent is called a *move* of this agent. The moves of a single agent can be atomic or durative. Agents in distributed ASM may execute their computation steps concurrently.

Formally, a run ρ of a distributed ASM M is given by a triple (M, λ, δ) satisfying all of the following four conditions [18]:

1. M is a partially ordered set of moves where each move has only finitely many predecessors.

2. λ is a function on M associating agents with moves such that the moves of any single agent of A are linearly ordered.

3. δ assigns a state of A to each initial segment Y of M, where $\delta(Y)$ is the result of performing all moves in Y; $\delta(Y)$ is an initial state if Y is empty.

4. The coherence condition: if x is a maximal element in a finite initial segment X of M and $Y = X$ - $\{x\}$ then $\lambda(x)$ is an agent $\delta(Y)$ and $\delta(X)$ is obtained from $\delta(Y)$ by firing $\lambda(x)$ at $\delta(Y)$.

The definition of a run of a distributed ASM did not specify the order of executions of different agents. This offers a benefit to model builders, a freedom to design and analyze models for distributed systems without a prior commitment of scheduling.

The GUI ASM model in this thesis describes a GUI application system with multiple internal components and multiple actors (CASM_User, CASM_Engine, File Storage, and CASM_GUI). Each actor is one agent in the distributed system. An amount of synchronous and asynchronous interactions exist between internal components and actors [Section 6.2.3]. In order to simplify the model, internal components are specified as parallel ASMs at the very high abstraction level. According to requirements about the system, internal components have been refined to distributed ASMs at the lower abstraction level. One example is refining the model by applying the special synchronization and communication concepts. Activities specified in the GUI ASM model are synchronous interactions and asynchronous interactions between internal components and actors. At the third abstraction level [Section 6.1.3] of the GUI ASM model, the moves of the agents are atomic. Then, the moves of the agents have been refined to durative moves when the concurrency problem of the activities [Section 6.2.2] needs to be discussed at the fourth abstraction level of the GUI ASM model.

The internal components and the actors in the GUI ASM model can be refined as agents in distributed ASMs. This offers some independence to these components and actors in the two aspects, the architecture and the execution. This kind of independence provides the ability for the GUI ASM model to customize the architecture and the functions of a GUI application system according to requirements.

3.6 Turbo abstract state machines

Turbo Abstract State Machines (*Turbo ASMs*) provide a practical composition and structuring principle that extends the basic ASM. The execution of a turbo ASM merges all update sets generated in individual sub-machines. A *sub-machine* is denoted as a rule $R(t_1, t_2, \ldots, t_n)$. Each sub-machine is treated as a black box, hiding its local states and local updates. The state of a turbo ASM cannot be updated until the merging of all update sets generated by all sub-machines is successful. If a local update set in a sub-machine is inconsistent or the merging of update sets generated by the sub-machines fails, the turbo ASM halts (failed termination).

The turbo ASM has introduced some structuring programming principles into basic ASM, such as seq, iterate, sub-machine, recursion and value-return. The **seq** - construct has been used in the GUI ASM model in this thesis to specify the sequence of activities.

The turbo ASM **seq** -construct combines the simultaneous atomic updates of basic ASMs in a global state with sequential execution.

- Seq-construct: "R_1 ***seq*** R_2". Starts to execute the rule R_2 only when the rule R_1 is completed and the update sets in R_1 are consistent.

The merging of update sets generated by rules R_1 and R_2 is defined as the following. One update is (*loc*, v), where *loc* is a location and v is the value in that location. U is the update set generated by the rule R_1; V is the update set generated by the rule R_2; W is the update set that results from the merging of U and V. W is also the update set of the turbo ASM in that step.

$$W = \begin{cases} \{(loc, v) \in U \mid loc \notin Locations(V)\} \cup V & \text{if U is consistent} \\ U & \text{otherwise} \end{cases}$$

The definition implies that turbo ASM will get stuck at the first inconsistent rule.

3.7 Summary

Abstract state machine is used to build a model of a system and to describe the behaviors of the system. Parallel ASM, distributed ASM, and turbo ASM have been used in the thesis to build the GUI ASM model. After the ASM model is built, system designer can validate experimentally by executing the model in the CoreASM supporting tool environment and watching states and update sets of the ASM model in different *runs*.

Chapter 4

Formal modeling approaches

Formal modeling helps build more robust systems. ASM methodology was applied in the thesis research to formally specify a GUI system.

4.1 Formal modeling approaches in GUI architecture and functionality design

People often build a model before implementing an interactive system. The model is a structural description of the relevant information about the interactive system. A designer can use this model to specify and analyze the interactive system to be developed. This approach is often called the model-based design approach. UML is one technique applied in this kind of modeling.

In design, designers can use a few kinds of models to describe the system to be designed. These kinds of models include, but are not be limited to task models, user models and interaction models. These models provide particle views about the system. Not a kind of model can represent all the information about the system. Task model describes information about tasks that the system performs [32][13]. User model can offer information about user preferences and about forms of interaction [11].

Interaction model can offer information about interaction and about user interface elements [22][31]. The GUI ASM model in this thesis has captured the architecture of the GUI application system and the tasks of that system. Each task is specified as an activity in the GUI ASM model. The interactions between users and the GUI application in each activity have been described at the third abstraction level of the model [Section 6.1.3]. There exists a difference between the GUI ASM model and an interaction model. No actual user interface elements have been specified in the GUI ASM model when talking about interactions. And, this thesis has not discussed the user model of the GUI application system. At a high abstraction level, the GUI ASM model in this thesis is more like a task model. A task model can be usually modeled in either of two approaches, the object-oriented approach and the task-based approach.

The traditional approach in UML is object-oriented. Designers identify the objects of the proposed interactive system and then analyze the activities of these objects. This very successful approach is currently being widely applied in the computer industry. In recent years, the model-based design approach has developed a new trend. Designers now focus on the tasks and the users of an interactive system. The tasks of the interactive system are identified first, and then the objects involved are manipulated. This approach is called a task-based approach. [29]

4.2 A specification approach of GUI modeling in the CoreASM project

The object-oriented approach and the task-oriented approach are both applied throughout the whole modeling process, in different stages. Then a process of refinement is used to solve development problems level by level [Section 6.1]. The combination of the two approaches, plus level-wise refinement, makes the system designer consider the specification of such a system without resorting to heavyweight formal models at the beginning stages. Most designers would prefer to consider lightweight models in the initial interaction design [27].

At the beginning stage of modeling, an object-oriented approach using UML is applied in this project just as it would be with a traditional approach. The first step is to identify the actors in the system. One of main purposes of GUI modeling in this project is to identify the functions and the communications between the GUI application and its environment, especially between the GUI application and the CoreASM Engine. Therefore, they are two important steps to identify the actors and to build the overall architecture of the system, before working out the communication functions that exist among the actors. The object-oriented modeling approach is suitable for this architectural stage.

At the second stage of modeling, the task-based modeling approach is used to model CASM_GUI itself. As specified for the first level of GUI ASM model [Section 6.1.1], the activities are listed and minimally specified. These activities are the user-centered tasks of CASM_GUI. In a user's view, each activity is the task that CASM_GUI should complete to achieve one user goal, such as viewing a state or processing one step. Each activity involves different actors in the system, even different components inside CASM_GUI. The way how involved these actors and CASM_GUI components would be analyzed in each activity one by one.

The GUI model can be refined when the developer is ready to pay detailed attention to each activity in turn. The following questions will be answered in the refined GUI model. What actors and/or CASM_GUI components are involved in a particular activity? What data is exchanged between these actors and CASM_GUI components? What is the sequence of actions in this activity? The answers are a resource for defining the GUI APIs. The GUI APIs created can then be verified after the GUI model is built.

ASM methodology is good for modeling complex systems, such as interactive systems, providing the developer with the ability to model a system at different levels of abstraction [Section 6.1].

4.3 Summary

The GUI ASM model is built with a mixed model-based design approach of the object-oriented approach and the task-oriented approach. Both approaches were applied separately at different levels of the model. This kind of modeling technique invites system architecture design into the task model building process. It also makes the GUI ASM model to be a foundation to analyze the interactions between systems.

Chapter 5

The GUI ASM model in the CoreASM project

The GUI ASM model explained in this thesis was built as part of my research for the CoreASM project. This GUI ASM model is one part of the CoreASM project. Formal methods were used to produce a design of the user-interface tool. An analysis of the interaction processes and their effect on human psychology is not an objective of this research.

5.1 Architecture of the CoreASM supporting tool environment

The abstract state machine method offers a framework for high-level system design and analysis. After specifying user requirements and building a model to match these requirements, the ASM approach can provide system designers with the valuable option of executing the model without implementing it in real programming code. The executability of an ASM-based model enables the system designers to discover system faults at an early development stage, assisting with verification and validation.

In the CoreASM project, we are using an ASM approach to construct a supporting tool environment that allows agile formalizing and high-level design and analysis of a system. A set of easy-to-use tools is provided in this supporting tool environment. This toolset includes an interpreter, CoreASM abstract storage, a debugger, a validator and more. The language parser, the interpreter, the CoreASM abstract storage, and the scheduler constitute the CoreASM engine. The CoreASM engine interprets ground models built with the CoreASM language. With the help of the scheduler, the CoreASM engine can execute not only sequential ASM ground models, but also parallel ASM ground models. The CoreASM supporting tool environment defines a set of GUI $\leftrightarrow$ Engine APIs for the CoreASM engine. Third party applications can control and access the CoreASM engine through the GUI $\leftrightarrow$ Engine APIs .

The GUI ASM model in this thesis specifies a graphical debugger application tool in the CoreASM supporting tool environment. This GUI ASM model has been used to design the graphical debugger and to validate the set of GUI $\leftrightarrow$ Engine APIs involved in the communications between the GUI tool and the engine. A graphical debugger implemented in Java will also be provided to apply the set of GUI $\leftrightarrow$ Engine APIs described in this project.

The CoreASM supporting tool environment provides an environment in this project to build graphical user interface tools for the CoreASM engine. The CoreASM engine is a running system for interpreting CoreASM models, and lacks the ability to assist system designers to understand the execution processes of the models. There are a few kinds of tools that can aid engineers to supervise the execution processes, such as a debugger and an animator. A graphical debugger offers a visual presentation of the execution processes of a model.

The GUI $\leftrightarrow$ Engine APIs provided in the CoreASM supporting tool environment form a bridge between the graphical user interface tool and the CoreASM engine. This bridge includes two main sets of functions, the control for the CoreASM engine and the access to the model entities. Everyone, including third parties, can build graphical tools to monitor ASM execution through this set of GUI $\leftrightarrow$ Engine APIs . Tool designers can decide on their own how to visually present an ASM model. A graphical debugger implemented in Java will be provided in this thesis as a working

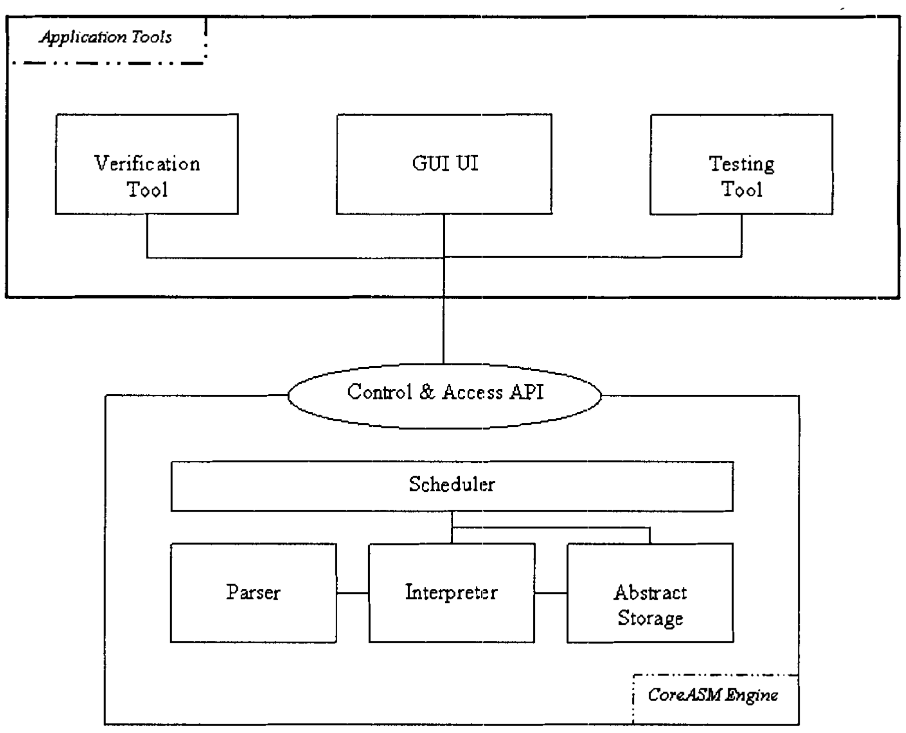


Figure 5.1: CoreASM supporting tool environment architecture

example. This debugger will help engineers to explore the updates of an ASM model at each step and to trace function values at each step.

The CoreASM project has an important expandable feature. Yuri Gurevich introduced ASM principles and ASM language semi-formal definitions. The CoreASM language applied in this project comes from the basic ASM principles and provides only the core functions of the general ASM language. Anyone can extend our CoreASM language to their own ASM language by following ASM principles. In the same way, third party groups can extend our CoreASM engine to their own ASM engines for their specified ASM languages through plug-ins [14]. Then again, the graphical tools implemented for CoreASM may not satisfy other new extended ASM languages. Therefore, we have separated the graphical user interface tools from the CoreASM engine and provided the GUI $\leftrightarrow$ Engine APIs as one basis of the CoreASM supporting tool environment. Third party groups can extend the GUI $\leftrightarrow$ Engine APIs as well as the CoreASM engine and build a new GUI on the extended GUI $\leftrightarrow$ Engine APIs . There is a second reason to separate the GUI and the CoreASM engine. Each research group may have its own ideas as to how to visually present its ASM models and their execution and may require different graphical tools to build, verify, test and validate the models. Other groups can build their own graphical tools on the top of the GUI $\leftrightarrow$ Engine APIs provided in this project in order to satisfy their requirements.

5.2 Actors in the GUI ASM model

There are four actors in the GUI ASM model.

- CASM_User
- CASM_GUI
- CASM_Engine
- File Storage

The actor CASM_GUI is the research object of this thesis. It will be specified in detail with ASMs (**main rule** *CoreASMGUIProgram*). The other three actors,

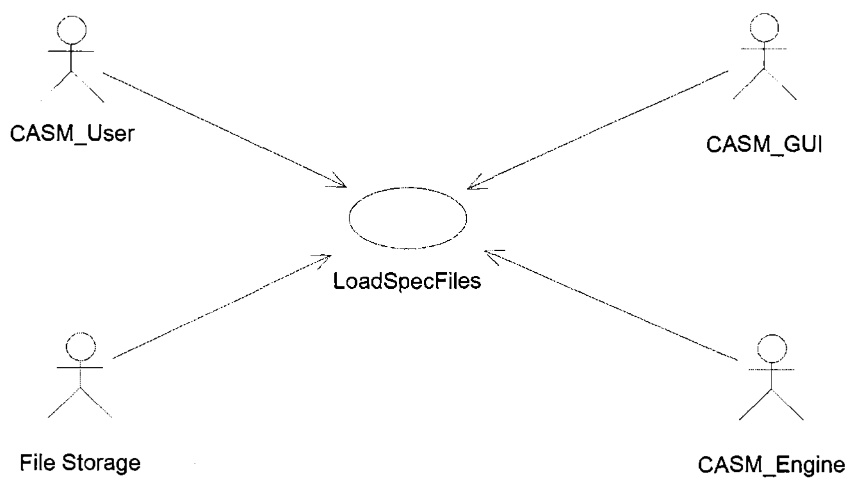


Figure 5.2: Actors in one use case

CASM_User, CASM_Engine and File Storage, are the environment for the ASMs machine CASM_GUI.

CASM_User

The human users of the CASM toolsets. The target users are software engineers, system analysts, and testers.

CASM_GUI

The graphical user interface toolset of the CoreASM project. It is the GUI of the visual CoreASM language debugger exactly as described in this thesis. CASM_User can load CoreASM models in CASM_GUI, and execute and explore (view) the models. CASM_GUI provides the visual representation of information about these models.

CASM_Engine

The engine to interpret CoreASM programs and to execute CoreASM models. Each CoreASM model is executed in CASM_Engine. CASM_GUI controls and accesses these models in CASM_Engine.

File Storage

The storage device to store CoreASM specification files. This device may be a local storage disk, or be a network storage device.

Human-computer interaction happens mainly between two actors, CASM_User and CASM_GUI. CASM_User does not access the CASM_Engine directly. CASM_GUI is the bridge connecting CASM_User and CASM_Engine.

The interactions between CASM_User and CASM_GUI are specified by activities activated by commands that CASM_User sends to CASM_GUI. An activity is a set of behaviors by the four actors. The details of the activities belonging to CASM_GUI have been specified in the GUI ASM model [Section 5.4]. The behaviors of CASM_User in an activity are specified abstractly as ASM rules, such as the rule *getFileURIToLoad (aUser: CoreASM-User , aFileStorage : CoreASM-FileStorage)*. These rules also identify the information data entities exchanged in interactions; for example, the file *uri* is needed in the rule *getFileURIToLoad (aUser: CoreASM-User , aFileStorage : CoreASM-FileStorage)*.

These actions are specified by ASM rules, not by ASM functions, since these are specifications of interaction behaviors. A system designer can refine these rules to analyze these interactions between human and computer.

The interactions between CASM_GUI and CASM_Engine are specified as GUI $\leftrightarrow$ Engine APIs in the GUI ASM model [Section 5.5.1]. We will see how these APIs are applied in activities.

5.3 Architecture of CASM_GUI

CASM_GUI consists of a few components. Each component has its own features. A component in CASM_GUI communicates to another component by sending signals to the signal pool of the second component.

5.3.1 Components of CASM_GUI

CASM_GUI consists of these components.

- *control panel*
- *output view*

- *message view*
- *program view*
- *run view*
- *vocab view*
- *state view*
- *updateset view*
- *history manager*

Each component has its own features.

control panel:

The control panel is the control component of CASM_GUI. It controls other components of CASM_GUI. One major task for the control panel is to respond to activity requests from CASM_User and to activate related activity in CASM_GUI.

output view:

The output view displays the printout from the CoreASM machine executing.

message view:

The message view displays any warning/error messages produced during the execution of the CoreASM machine.

program view:

The program view displays the code for the CoreASM machine.

run view:

The run view displays a run in the execution of the CoreASM machine.

vocab view:

The vocab view displays the vocabulary of the CoreASM machine.

state view:

The state view displays a state of the CoreASM machine.

updateset view:

The update set view displays an update set during the execution of the CoreASM machine.

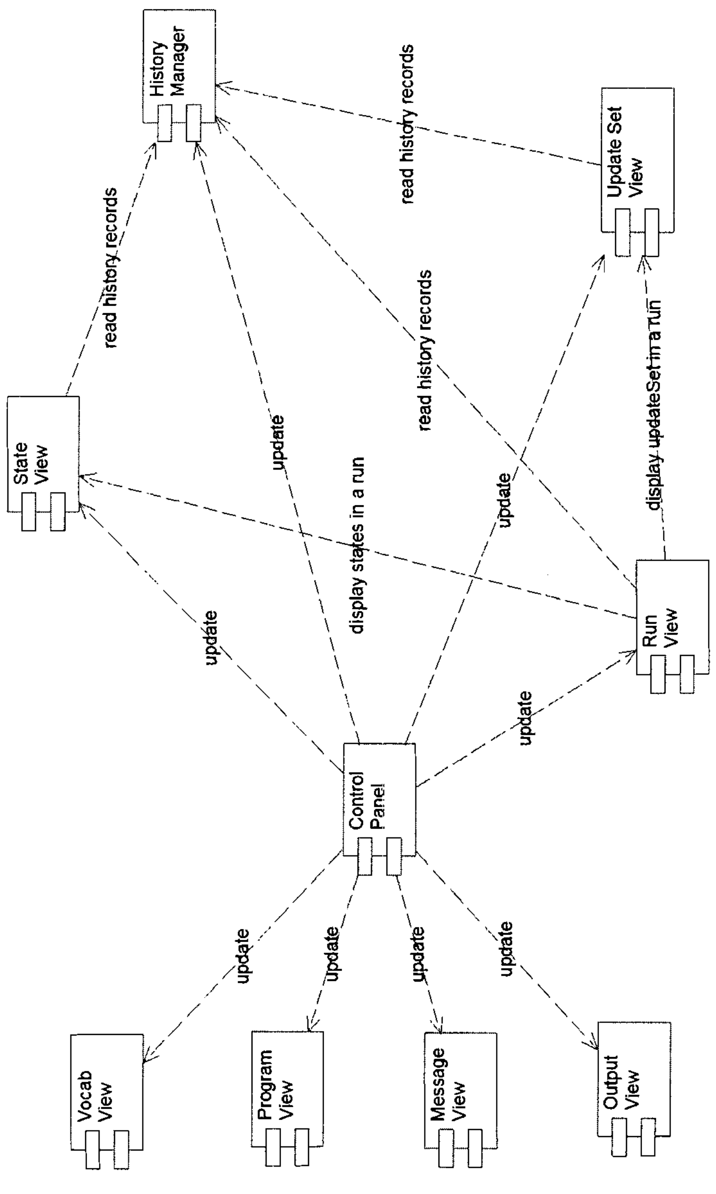


Figure 5.3: Internal components of CASM_GUI

history manager:

The history manager stores the history records of a run. The history records are mainly about states and update sets. The history manager collects the information about a run of a CoreASM machine and stores it into the history records, and then offers these history records to the run view in the background. The run view uses these history records to rebuild the trail of the run. Now, CASM_User can review the run of that CoreASM machine in the run view. In contrast to the run view, the history manager is invisible to CASM_User.

Each component is specified as an ASM rule. A component has behaviors and provides certain features for CASM_User. For example, the message view can display messages or can clear all messages in the view [Spec 5.1]. The history manager can add a history record or delete a history record or even clear all history records.

```
rule $MessageViewProgram$
    choose $aSignal$ from $messagevSignalPool$
    remove $aSignal$ from $messagevSignalPool$
    case $firstOf(aSignal)$ of
        $messagevcDisp \rightarrow$
            $displayMsginMessageV(secondOf(aSignal))$
        $messagevcClearDisplay \rightarrow$
            $clearDisplayinMessageV$
```

Spec 5.1: Features of *message view* : display messages and clear messages

All components are executed in a parallel way in the actor CASM_GUI. The CASM_GUIis specified as a parallel ASM machine [Section 3.3]. If model designer needs to specify more details of the components, such as the architecture of components and the communications between these components, each component can be refined from a simple ASM rule in a parallel ASM to an agent in a distributed ASM [Section 3.5]. The time to refine components as distributed ASMs is decided by model designer, based on how abstractly the model designer wants to specify those components.

CASM_GUI Component	CoreASM Specification
control panel	rule ControlPanelProgram
output view	rule OutputViewProgram
message view	rule MessageViewProgram
program view	rule ProgramViewProgram
run view	rule RunViewProgram
vocab view	rule VocabViewProgram
state view	rule StateViewProgram
updateset view	rule UpdatesetViewProgram
history manager	rule HistoryManagerProgram

Table 5.1: Components in CASM_GUI

The ability to specify the features of a component in an ASM rule and the ability to execute components in a parallel way provide the independence to components. They make model designer to create or remove a component easily from the GUI system. The addition or the removing of a component will not affect other components in the system.

5.3.2 Communication structure in CASM_GUI

Each component in CASM_GUI has a signal pool. Other components send signals into that signal pool. The CASM_User in the environment sends signals of the type USER_ACTIVITYREQUEST into the *control panel*'s signal pool. Each component checks its own signal pool and activates an activity or a set of activities if a signal is found. Each component has only one signal pool for incoming signals. There is no outgoing signal pool. The sending process from one component in CASM_GUI or CASM_User in the environment to another is atomic and completed immediately.

A signal pool is an abstract data structure. It may be a queue or a stack. For this specific GUI ASM model, a queue would be a better choice. When the designer makes the choose mechanism for the signal pool [Spec 5.4], the designer should make sure that the first-incoming signal is served first. In order to abstract this GUI ASM model, the type of the data structure required for the signal pool [Spec 5.3] and the

```
//-- Main rule of the CoreASM GUI ---
main rule CoreASMGUIProgram =

  //GUI component programs
  VocabViewProgram
  OutputViewProgram
  MessageViewProgram
  ProgramViewProgram
  RunViewProgram
  StateViewProgram
  UpdatesetViewProgram
  HistoryManagerProgram
  ControlPanelProgram
```

Spec 5.2: The components in CASM_GUI

details of the signal pool's choose mechanism [Spec 5.4] do not have been specified in the thesis. These design decisions are left for the designer to make later.

The signal pool is specified abstractly as a list of signals.

```
messagevSignalPool : list of GUI_Signal
```

Spec 5.3: Specification of a signal pool

The choose mechanism for each signal pool has not been specified. The **choose** rule is used generally to describe this choose behavior.

The sending process for signals is specified as a rule, *signalingTo(aSignalPool : SignalPoolName, aSignal : GUI_Signal)*. This rule checks the destination by signal pool name and then inserts the signal into the correct signal pool.

The signal is an abstract data structure. In the GUI ASM model, all signals are of the type GUI_Signal. A signal consists of two types of objects: command objects

Component	Signal Pool	Signal Pool Name
CONTROL PANEL	controlpanelSignalPool	controlpanel
OUTPUT VIEW	outputvSignalPool	outputv
MESSAGE VIEW	messagevSignalPool	messagev
PROGRAM VIEW	programvSignalPool	programv
RUN VIEW	runvSignalPool	runv
VOCAB VIEW	vocabvSignalPool	vocabv
STATE VIEW	statevSignalPool	statev
UPDATESET VIEW	updatesetvSignalPool	updatesetv
HISTORY MANAGER	historymanagerSignalPool	historymanager

Table 5.2: Signal pools in components

```
choose aSignal from messagevSignalPool
```

Spec 5.4: Choosing a signal from the signal pool of *message view*

and data objects.

The GUI_Signal is a tuple. Two functions defined for the data structure tuple are used to interpret signal values. The first value is the command. Its type is one of the defined signal types. The second value in GUI_Signal is a data object. The data object is the content of the signal.

The function to get the first value from a signal is defined as *firstOf(signal:tuple).* It returns the signal type.

The function to get the second value from a signal is defined as *secondOf(signal:tuple).* It returns the signal data object.

Signal types:

- PROGRAMV_COMMAND,
- MESSAGEV_COMMAND,
- OUTPUTV_COMMAND,

```
rule $signalingTo(aSignalPool : \text{SignalPoolName},\ aSignal : \text{GUI\_Signal})$ =
  case $aSignalPool$ of
    $programv \longrightarrow$
      add $aSignal$ to $programvSignalPool$
    $messagev \longrightarrow$
      add $aSignal$ to $messagevSignalPool$
    $outputv \longrightarrow$
      add $aSignal$ to $outputvSignalPool$
    $statev \longrightarrow$
      add $aSignal$ to $statevSignalPool$
    $updatesetv \longrightarrow$
      add $aSignal$ to $updatesetvSignalPool$
    $runv \longrightarrow$
      add $aSignal$ to $runvSignalPool$
    $historymanager \longrightarrow$
      add $aSignal$ to $historymanagerSignalPool$
    $vocabv \longrightarrow$
      add $aSignal$ to $vocabvSignalPool$
    $controlpanel \longrightarrow$
      add $aSignal$ to $controlpanelSignalPool$
```

Spec 5.5: Sending a signal

- RUNV_COMMAND,
- STATEV_COMMAND,
- UPDATESETV_COMMAND,
- HISTORYV_COMMAND,
- VOCABV_COMMAND,
- USER_ACTIVITYREQUEST.

5.4 Activities in CASM_GUI

An *activity* is a series of actions performed by an actor or actors to achieve a certain objective. In an interactive system, the interaction between actors during an activity that is performed by these actors must be considered.

An activity is performed to achieve an objective. There are a few ways to identify activities in a system: for example, by the actions performed by individual actors, or by the actions performed by the whole system. A human-computer interaction system is designed for human use. Satisfying users is an important goal in HCI design. Therefore, it is good to identity activities from a user perspective. Activities in this GUI ASM model are identified in terms of the objectives that a user might expect that the system could complete. These activities include *ForwardRunActivity* (making the engine advance the run one step), *ViewLastStateActivity* (viewing a state) and so on. The objectives that a user might expect that the system could complete are analyzed and are achieved from the informal requirements. In the GUI ASM model, the objective of an activity represents the result of a certain feature of the GUI system.

In the GUI ASM model, an *activity* is specified in a way that seems all actions in the activity are completed by one actor CASM_GUI. In fact, an activity is often performed by more than one actor. Interactions do exist in an activity. The other actors, CASM_User, CASM_Engine, File Storage, are the environment for the actor CASM_GUI. Actions completed by these environment actors are abstracted from the activity. Interactions between all actors are specified as interfaces (APIs). CASM_GUI interacts with other actors by applying these interfaces (APIs) while performing activities.

An activity in the GUI ASM model represents a feature of the GUI system. At this point it is similar to describe an activity of an object in the object-oriented design. The difference between an activity in the GUI ASM model and an activity in the object-oriented designing is that an activity in the GUI ASM model is the interactions between actors, but an activity in the object-oriented design focuses on actions performed by one object.

An activity is described as a hierarchy of sub-activities. Each sub-activity consists of some actions. We define activity (sub-activity as well) as a rule. An activity is labeled as ****Activity. A sub-activity is labeled as ****SA.

The activity to load a file, called *LoadFileActivity*, is a rule. A sub-activity of the activity *LoadFileActivity*, *getFileURIToLoadSA*, obtains the file to be loaded, and is also a rule.

```
rule LoadFileActivity
rule getFileURIToLoadSA
```

Spec 5.6: Activity and sub-activity

The sub-activities of one activity may form a sequence of actions. When analyzing interactions in a HCI system, such sequences are often found. The next action does not start until the previous action is completed. CASM_GUI does not know which specification file is to be opened until CASM_User chooses a specification file to load. Therefore, CASM_GUI performs the sub-activity *loadFileSA* following the sub-activity *getFileURIToLoadSA*.

Sequenced activities can be specified as

$$AActivity = subactivity1SA \; seq \; subactivity2SA$$

AActivity is performed by completing sub activity *subactivity2SA* after the completion of sub activity *subactivity1SA*.

5.4.1 Activity specifications

Activities in the GUI ASM model include the following.

StartupActivity

This activity starts up the CoreASM work environment. The CoreASM work environment includes CASM_GUI and CASM_Engine. The activity creates the GUI

Activity	**Command to activate the activity**
StartupActivity	userStartup
LoadFileActivity	userLoadFile
CheckSpecActivity	userCheckSpec
InitActivity	userInit
ForwardRunActivity	userForwardRun
RollbackActivity	userRollback
StopActivity	userStop
InterruptActivity	userInterrupt
ViewProgramCodeActivity	userViewProgramCode
ViewLastOutputActivity	userViewLastOutput
ViewOutputInHistoryActivity	userViewOutputInHistory
ViewLastMsgActivity	userViewLastMsg
ViewMsgInHistoryActivity	userViewMsgInHistory
ViewLastUpdatesetActivity	userViewLastUpdateset
ViewLastStateActivity	userViewLastState
ViewUpdatesetInHistory	userViewUpdatesetInHistoryActivity
ViewStateInHistoryActivity	userViewStateInHistory
AddWatchActivity	userAddWatch
DeleteWatchActivity	userDeleteWatch
QuitActivity	userQuit

Table 5.3: Activities and signals to activate these activities

and the engine, then links them together. The CoreASM workspace environment is ready after this activity.

```
rule StartupActivity
    createGUISA seq createLinkEngineSA
```

LoadFileActivity

This activity loads a CoreASM specification file into CASM_GUI and displays the file in the *program view*. There are two sub activities, getting the URI of the file, and loading the file from File Storage. Two data objects are received by CASM_GUI from its environment, through interfaces (APIs). They are the URI (*guiAFileURI*) of the file that CASM_User wants to load and the file (*guiAFile*). The object *guiAFileURI* is received by CASM_GUI from CASM_User and File Storage. The object *guiAFile* is received by CASM_GUI from File Storage.

```
rule LoadFileActivity
    getFileURIToLoadSA seq loadFileSA
```

CheckSpecActivity

This activity sends a CoreASM specification file to CASM_Engine by CASM_GUI, and then requires CASM_Engine to check for syntax or other specification errors in this specification program. It then displays feedback on CASM_GUI. The sending operation and the check-requesting operation are completed in the sub activity *checkSpecSA(currentEngine, guiAFile)*. The data object *guiAFile* is sent to CASM_Engine. The feedback (output) is then received from CASM_Engine.

```
rule CheckSpecActivity
    checkSpecSA(currentEngine, guiAFile) seq getCSFeedbackSA
```

InitActivity

This activity initializes the ASM machine in CASM_Engine and then displays any feedback in CASM_GUI (the initial state is displayed in the *state view*, the vocabulary in the *vocab view*, error messages or warning messages, if any, in the *message view*).

```
rule InitActivity
    initSpecSA(currentEngine, guiAFile) seq getISFeedbackSA
```

ForwardRunActivity

This activity advances the CoreASM machine a few of steps in CASM_Engine and then displays any feedback in CASM_GUI (Messages appear in the *message view*, print outs in the *output view*, states in the *state view*, update sets in the *update set view*, error messages or warning messages, if any, in the *message view*). The first sub-activity gets the number of steps that CASM_User wants the CoreASM machine to go forward (*guiNumStepsToForward*). The value of *guiNumStepsToForward* is received by CASM_GUI from CASM_User after this sub-activity completes. Then, the CASM_GUI requires CASM_Engine to execute the ASM machine in the second sub-activity and receives feedback from CASM_Engine in the third sub-activity.

```
rule ForwardRunActivity
    getNumForwardStepsRequestedSA seq forwardRunSA seq getFRFeedbackSA
```

RollbackActivity

This activity rolls back a CoreASM machine held in CASM_Engine and then displays the machine's current state in *state view*. The first sub-activity gets the state id that CASM_User wants the machine to roll back to. The value of *guiStateIdBackTo* is received by CASM_GUI from CASM_User after this sub-activity is completed. Then CASM_GUI rolls back the machine in CASM_Engine. In contrast to the activity *ForwardRunActivity*, there is no sub-activity *getFeedbackSA* in *RollbackActivity*. The desired rolled back state can be found in the internal component *history manager* in CASM_GUI. It is not necessary in this case for CASM_GUI to interact with CASM_Engine.

```
rule RollbackActivity
    getStateIdBackToSA seq rollbackSA
```

StopActivity

This activity stops the running of the CoreASM specification machine. The machine stays at the last state and cannot be executed without reinitialization.

```
rule StopActivity
```

InterruptActivity

This activity interrupts the execution of the CoreASM machine in CASM_Engine.

```
rule InterruptActivity
    interrupt(currentEngine) := true
```

ViewProgramCodeActivity

This activity allows CASM_User to view program source code in the *program view.*

```
rule ViewProgramCodeActivity
```

ViewLastOutputActivity

This activity allows CASM_User to view the output of the most recent step in the *output view.*

```
rule ViewLastOutputActivity
```

ViewOutputInHistoryActivity

This activity allows CASM_User to view the output of a completed step in the history.

```
rule ViewOutputInHistoryActivity
```

ViewLastMsgActivity

This activity allows CASM_User to view the error/warning messages for the most recent step.

```
rule ViewLastMsgActivity
```

ViewMsgInHistoryActivity

This activity allows CASM_User to view the error/warning messages for a completed step in the history.

```
rule ViewMsgInHistoryActivity
```

ViewLastUpdatesetActivity

This activity allows CASM_User to view the update set for the most recent step.

```
rule ViewLastUpdatesetActivity
```

ViewLastStateActivity

This activity allows CASM_User to view the newest state.

```
rule ViewLastStateActivity
```

ViewUpdatesetInHistoryActivity

This activity allows CASM_User to view one update set in the history. The activity has two actors, CASM_User and CASM_GUI, who interact. There are two sub-activities. The sub-activity *getUpdateSetIdViewInHistorySA* gets the update set id of the update set that CASM_User wants to view from the history. The value of *guiUpdateSetIdViewInHistory* is assigned by CASM_User after this sub-activity completes execution. The next sub-activity allows CASM_User to view the update set.

```
rule ViewUpdatesetInHistoryActivity
  getUpdateSetIdViewInHistorySA
     seq
       viewUpdatesetInHistorySA(guiUpdateSetIdToViewInHistory)
```

ViewStateInHistoryActivity

This activity allows CASM_User to view one state in the history. Interaction takes place in this activity. Two actors are involved, CASM_User and CASM_GUI. The sub-activity *getStateIdViewInHistorySA* gets the id for the state that CASM_User wants to view from the history. The value of *guiStateIdToViewInHistory* is assigned by CASM_User after this sub-activity completes execution. The next sub-activity allows CASM_User to view the state.

```
rule ViewStateInHistoryActivity
    getStateIdViewInHistorySA
        seq
            viewStateInHistorySA(guiStateIdToViewInHistory)
```

AddWatchActivity

This activity allows CASM_User to add a watch in CASM_GUI. A *watch* is a label of a function, a function whose values CASM_User wants to watch during a run.

```
rule AddWatchActivity
    createAWatch(currentUser, guiVocab)
```

DeleteWatchActivity

This activity allows CASM_User to remove a watch in CASM_GUI.

```
rule DeleteWatchActivity
    selectAWatchToDel(currentUser)
```

QuitActivity

This activity destroys CASM_Engine and CASM_GUI to terminate the CoreASM work environment.

```
rule QuitActivity
    killEngineSA(currentEngine) seq killGUISA
```

5.5 Interfaces in the GUI ASM model

CASM_GUI, CASM_Engine, CASM_User, and File Storage communicate through interfaces.

5.5.1 Interfaces in the GUI ASM model

The GUI ASM model is an application system. It interacts with other actors through interfaces. The interfaces in this GUI ASM model include the GUI $\leftrightarrow$ User interface, the GUI $\leftrightarrow$ FileStorage interface, and the GUI $\leftrightarrow$ Engine interface. The GUI $\leftrightarrow$ User interface is a good object for researchers to analyze interactions between human and computer. The GUI $\leftrightarrow$ Engine interface specifed with ASMs assists the designer to design the APIs (Application Program Interfaces) for the engine. The designer can validate these APIs through the GUI ASM model.

The *interface* can provide communication channels for two systems. A system can exchange information with another system through an interface. It can also use the interface to activate another system to carry out operations. The GUI $\leftrightarrow$ User interface can offer the following opportunities. A user can activate activities in the GUI system by sending activity requests [Section 5.4] through the GUI $\leftrightarrow$ User interface. A user can view information about a machine in the engine with the assistance of the GUI system. This view operation needs the GUI system to communicate with the engine through the GUI $\leftrightarrow$ Engine interface. The GUI system also needs the user to provide certain information about operations through the GUI $\leftrightarrow$ User interface, such as the number of steps that the user wants the machine in the engine to go forward.

In the GUI ASM model, the *interface* is specified as ASM rules and ASM functions.

If a feature of an interface is specified as an ASM rule, the feature requires an actor to execute certain actions. For instance in the GUI $\leftrightarrow$ Engine interface, CASM_GUI requires CASM_Engine to execute the CoreASM machine in the CASM_Engine for a certain number of steps (*rule step (aEngine : CoreASM-Engine , anI : Integer)*). This operation needs CASM_Engine to perform actions to compute results. Therefore, it is specified as a *rule*. Similarly, in the GUI $\leftrightarrow$ User interface, the rule *getNumForwardStepsRequested (aUser : CoreASM-User)* needs CASM_User to operate on CASM_GUI, in order to provide the number of steps that CASM_User requests the machine in CASM_Engine go forward. These operations of CASM_User on CASM_GUI include choosing a textbox on the GUI, typing the number of steps and notifying CASM_GUI to receive the value.

An ASM function in an interface is used to get a value when an actor is in a state. The function *getLastUpdateSet : GUI_Watch* $\rightarrow$ *GUI_UpdateSets* gets an update set after the machine in CASM_Engine has been updated consistently. At that moment, CASM_Engine is in a state between executions (steps).

Depending on the way the value of ASM functions are updated, the ASM functions in an interface can be *controlled*, *monitored* or *shared.*

A controlled function updates a value in the environment. For instance, it is possible to interrupt CASM_Engine by setting the value "interrupt" in CASM_Engine to be true. The interrupt function is specified as a controlled function.

controlled *interrupt* : CoreASM-Engine $\rightarrow$ Boolean

Spec 5.7: Controlled function example

A monitored function allows the environment to update a value in the system model specified. CASM_Engine sets the value of *guiAnUpdateset* in CASM_GUI. CASM_Engine sends a value to CASM_GUI through an interface.

monitored *getLastUpdateSet* : CoreASM-Engine $\rightarrow$ GUI_UpdateSets

Spec 5.8: Monitored function example

A shared function updates a value shared by both an environment and the specified system model. There is no example of a shared function in this GUI ASM model.

5.5.2 The GUI ↔ User interface

The GUI ↔ User interface specified in the GUI ASM model consists of the commands to activate the activities and the operations of CASM_User on CASM_GUI. The analysis in this interface deals with the information data exchanged between CASM_User and CASM_GUI, such as the command signals and the number of steps that the user wants the machine to go forward.

CASM_User sends these activity commands to CASM_GUI through the GUI ↔ User interface.

enum domain USER_ACTIVITYREQUEST = $\{userStartup,$
$userLoadFile, userCheckSpec, userInit,$
$userForwardRun, userRollback, userStop,$
$userInterrupt,$
$userViewProgramCode,$
$userViewLastOutput, userViewOutputInHistory,$
$userViewLastMsg, userViewMsgInHistory,$
$userViewLastUpdateset, userViewUpdatesetInHistory,$
$userViewLastState, userViewStateInHistory,$
$userAddWatch, userDeleteWatch, userQuit\}$

Spec 5.9: Activity commands

The CASM_User provides the information data to CASM_GUI through the GUI ↔ User interface.

5.5.3 The GUI ↔ Engine interface

The GUI ↔ Engine interface consists of a *control* interface and an *access* interface.

CASM_GUI can control executions of CASM_Engine and can check the properties of CASM_Engine through the *control* interface. The control operations on

```
rule getFileURIToLoad (aUser : CoreASM-User ,
                                        aFileStorage : CoreASM-FileStorage)
rule getNumForwardStepsRequested (aUser : CoreASM-User)
rule getStateIdBackTo (aUser : CoreASM-User)
rule getStateIdViewInHistory (aUser : CoreASM-User)
rule getUpdateSetIdViewInHistory (aUser : CoreASM-User)
rule createAWatch (aUser : CoreASM-User , aVocab : GUI_VOCAB)
rule selectAWatchToDel (aUser : CoreASM-User)
```

Spec 5.10: Rules in the GUI ↔ User interface

CASM_Engine include checking a specification in CASM_Engine, initializing a specification machine in CASM_Engine, forwarding, rollbacking, interrupting, creating a CASM_Engine and terminating a CASM_Engine [Spec 5.11].

The *access* interface enables CASM_GUI to access information entities about the CoreASM machine being executed in CASM_Engine, obtaining information such as the states of the CoreASM machine or the value of a function in the CoreASM machine [Spec 5.12].

```
rule checkSpecification (aEngine : CoreASM-Engine , aFile : File)
rule initSpecification (aEngine : CoreASM-Engine)
rule step (aEngine : CoreASM-Engine , anI : Integer)
rule rollback (aEngine : CoreASM-Engine , anId : StateID)
rule createEngine
rule killEngine (aEngine : CoreASM-Engine)
controlled interrupt : CoreASM-Engine → Boolean
monitored getEngineMode : CoreASM-Engine → ENGINE-MODE
```

Spec 5.11: Rules and functions in the *control* interface of GUI ↔ Engine interface

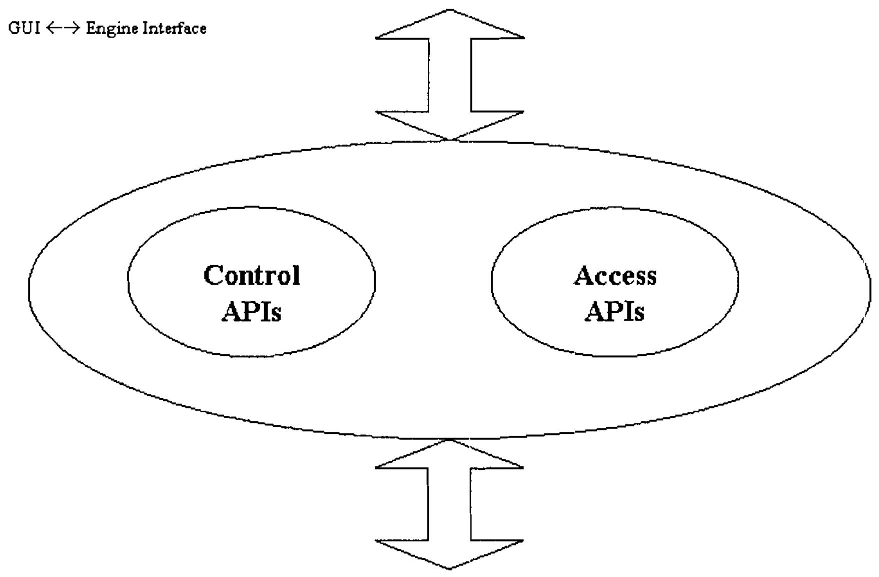


Figure 5.4: GUI $\leftrightarrow$ Engine interface

5.6 Conclusion

The GUI ASM model has specified the architecture and the functionality of a GUI application system, with ASM methodologies. During the refinement process, the GUI ASM model has assisted to define interfaces between systems. Two objectives [Section 1.1] have been fulfilled in this chapter. The functions of the GUI application system are specified as twenty activities. Each activity represents a sequence of interactions. The internal components of CASM_GUI and the actors in the GUI ASM model are specified as parallel ASM or distributed ASM. Communications between internal components are transferred through the signal type communication structure. The exchanges of information between systems rely heavily on the interfaces of the systems.

monitored *getGUI_VOCAB* : CoreASM-Engine $\rightarrow$ GUI_VOCAB
monitored *getOutput* : CoreASM-Engine $\rightarrow$ GUI_Outputs
monitored *getCurrentGUI_State* : CoreASM-Engine $\rightarrow$ GUI_States
monitored *getLastUpdateSet* : CoreASM-Engine $\rightarrow$ GUI_UpdateSets
monitored *getPreviousGUI_State* : CoreASM-Engine
$*$ GUI_Watch $*$ StateID
$\rightarrow$ GUI_States
monitored *getPreviousUpdateSet* : CoreASM-Engine
$*$ GUI_Watch $*$ UpdateSetID
$\rightarrow$ GUI_UpdateSets
monitored *getSpec* : CoreASM-Engine $\rightarrow$ File

Spec 5.12: Rules in the *access* interface of GUI $\leftrightarrow$ Engine interface

Chapter 6

Discussion

This chapter discusses in depth two issues that were carried out in the formal modeling process and gives solutions for these two issues. These two issues are level-refinement in the modeling process and the concurrency issue in the graphical user interface application.

6.1 Four abstraction levels for the GUI ASM model

At the beginning of the modeling stage, a system designer faced with too many informal requirements and no clear idea where to start might feel overwhelmed. One common methodology to overcome the previous problem is top-down development. ASM methodology gives the power of abstraction to top-down modeling, allowing the designer to model the system at different levels of abstraction. The system designer is able to focus on solving different questions at different levels of abstraction. The levels have a top-down relationship as the system designer refines the system model from a highly abstract level to a less abstract level. The goal of this refinement is to provide more implementation details to satisfy particular requirement specification and these implementation details should be appropriate to each level of abstraction.

The GUI ASM model developed for the CoreASM project has four abstraction levels. The model has been refined from level 1 to level 4, in a top-down development process. The four abstraction levels of specification cover the CASM_GUI architectures, features, and interface design.

6.1.1 The first abstraction level - (the features)

The first abstraction level of the GUI ASM model specifies the activities to be performed by the system. The GUI system is viewed as a whole. The architecture of the GUI system is not analyzed at this level. The activities specified in the model at this point are user-oriented, intended to achieve certain user goals through the system operations. The activity, *ViewLastStateActivity*, would be an example of this. The objective of modeling at this abstraction level is to see what the system can do. The activities specified here are abstract activities. No implementation is specified as to how these activities are to be performed. These activities can be treated as major features of the GUI system. The model also specifies all signals that can activate the above activities.

6.1.2 The second abstraction level - (the interface design)

The second abstraction level of the GUI ASM model specifies the model's interactions. The main problems solved are what are the interactions between systems in the GUI ASM model and what are the data objects and control signals exchanged in these interactions. To answer these questions, the first step is to specify the architecture of the GUI ASM model and to identify the actors in it [Section 5.1].

An ASM model usually consists of a machine and its environment. As the research target of this thesis, the actor CASM_GUI is the machine in this model. Other actors, CASM_User, CASM_Engine and File Storage, form the environment of the ASM machine. The interactions in the model are the interactions between CASM_GUI and its environment.

The analysis of the interactions and the data objects exchanged in these interactions is important. We can define API functions through these interactions, and the data objects that serve as their parameters. One of the objectives in building the GUI

ASM model is to define the APIs. The GUI ASM model can also verify these API functions as satisfying the requirements of the CoreASM GUI system.

6.1.3 The third abstraction level - (the internal architecture)

The third abstraction level of the GUI ASM model refines CASM_GUI by building the architecture of CASM_GUI itself [Section 5.3]. The internal components of CASM_GUI include the *control panel*, the *output view*, the *message view*, the *program view*, the *run view*, the *state view*, the *updateset view*, the *history manager*, and the *vocab view*. Each component provides certain features to be defined at this level of the GUI ASM model. A component in CASM_GUI is a collection of behaviors and functions. It is specified as an ASM rule in the model. A component is an abstract concept. At a later point, the GUI designer can find a GUI object to implement a component, such as JEditorPane in Swing or RichTextBox in C#, or even a television screen. In the ASM model, a component abstracts behaviors and functions from the actual objects. Therefore, a model using ASMs will not limit the GUI designer's imagination when it comes to visually representing that component.

The components are specified with Distributed ASM notation. Each component executes independently. All components execute in parallel inside CASM_GUI. These components are specified as distributed ASMs to satisfy concurrency issues which are intrinsic to GUI systems. More discussion of concurrency issues can be found in Section 6.2.2.

This third abstraction level introduces a signal communication structure to the GUI ASM model. Each component has one incoming signal pool. A component checks the signal in its signal pool at each step of the ASM's execution run and activates the relevant activities or operations if a signal is found. To communicate between components, a component inserts a signal into another component's signal pool. Two kinds of information are contained in a signal: the command that indicates what activities or operations should be activated by the signal, and the data objects that are needed for execution of the activities or operations activated. As an example, the activity *InitActivity* involves the interaction of certain components, including the *control panel*, the *message view*, *run view*, the *state view*, the *history manager* and the *vocab view*. After initialization, the *control panel* will update the *vocab view*. The *control panel* sends the *vocab view* a request to update the vocabulary through the command *vocabvcDisp*. The data object vocabulary, *guiVOCAB*, is attached in the same request signal. A similar mailbox-like communication mechanism in a distributed system is specified in [15] [16].

6.1.4 The fourth abstraction level - (the concurrency problem)

The model designer can discuss individual issues at this abstraction level generally. In this GUI ASM model, we pay attention to the problem of two concurrent activities taking place in CASM_GUI. The GUI application is a multithreading application. It can respond to user requests simultaneously; therefore one activity can be activated before a previous activity has been completed. One question arises, what kind of activities in CASM_GUI can be executed simultaneously? For example, it does not seem reasonable that *ForwardRunActivity* and *RollbackActivity* can be performed concurrently. Not all activities can execute concurrently with other activities. The GUI ASM model will specify this constraint as part of the fourth abstraction level [Section 6.2.3].

6.1.5 An example of refining a model in four abstraction levels

The activity *ForwardRunActivity* serves here as an example to show how to specify and refine an interaction in four abstraction levels. In the activity, the user requires the machine in the engine to execute forward a few of steps, and then the GUI displays the results of these steps. This activity involves three actors, CASM_User, CASM_GUI and CASM_Engine, and consists of three sub-activities, *getNumForwardStepsRequestedSA*, *forwardRunSA* and *getFRFeedbackSA*

The first abstraction level of the GUI ASM model specifies activities performed by CASM_GUI. The activity *ForwardRunActivity* is defined as an ASM rule. That means this activity is a set of operations in CASM_GUI. At this abstraction level, we specify that this activity exists. The details of the operations in the activity are not of concern at this level. Therefore the operations are not specified here.

```
//Activity Rule
rule ForwardRunActivity
```

Spec 6.1: The activity *ForwardRunActivity*

At this abstraction level, the GUI ASM model also specifies how the activity is activated. The command in the signal, *userForwardRun*, activates the activity *ForwardRunActivity*. This happens inside the actor CASM_GUI.

```
// - - Main rule of the CoreASM GUI - --
main rule CoreASMGUIProgram =

  //Signal handling by CASM_GUI
  case nextUserActivityRequest( ) of

    userForwardRun →
      rule ForwardRunActivity
```

Spec 6.2: The activity *ForwardRunActivity* is activated in the main rule

At the second abstraction level of the GUI ASM model, there are two objectives: to define the APIs and to verify their necessity in the model. Analyzing the interactions in the system is the beginning point for defining APIs. The first step is to specify the actors in these interactions, CASM_Engine, CASM_User and File Storage, in addition to CASM_GUI itself.

```
domain CoreASM-Engine        //The actorCASM_Engine
domain CoreASM-User        //The actorCASM_User
domain CoreASM-FileStorage        //The actorFileStorage

//actors in the environment
currentUser : CoreASM-User        //The actorCASM_User
currentEngine : CoreASM-Engine        //The actorCASM_Engine
currentFileStorage : CoreASM-FileStorage        //The actorFileStorage
```

Spec 6.3: The actors in the activity *ForwardRunActivity*

Next, we refine the activity *ForwardRunActivity* by analyzing this interaction. The activity *ForwardRunActivity* has three sub-activities, *getNumForwardStepsRequestedSA* and *forwardRunSA* and *getFRFeedbackSA*. They execute in sequential order.

```
//Activity : ForwardRunActivity
rule ForwardRunActivity
  getNumForwardStepsRequestedSA
    seq forwardRunSA
      seq getFRFeedbackSA
```

Spec 6.4: The sequential execution of sub-activities in the activity *ForwardRunActivity*

The sub-activity is also an ASM rule. We specify API functions and their parameters in each sub-activity rule. The sub-activity *getNumForwardStepsRequestedSA* gets the number of steps that CASM_User wants the machine to go forward. This is an interaction between CASM_GUI and CASM_User. The data object *guiNumStepsToForward* is needed in the sub-activity. The function *monitored getNumForwardStepsRequested : CoreASM-User $\rightarrow$ Integer* obtains the data object needed from CASM_User.

```
//subactivity : getNumForwardStepsRequestedSA
rule getNumForwardStepsRequestedSA
  guiNumStepsToForward := getNumForwardStepsRequested(currentUser)
```

Spec 6.5: The sub-activity *getNumForwardStepsRequestedSA*

The second sub-activity *forwardRunSA* forwards CASM_Engine *guiNumStepsToForward* steps, by executing the rule *step(currentEngine, guiNumStepsToForward)* defined in the GUI $\leftrightarrow$ Engine interface.

```
//subactivity : forwardRunSA
rule forwardRunSA
  step(currentEngine, guiNumStepsToForward)
```

Spec 6.6: The sub-activity *forwardRunSA*

The third sub-activity *getFRFeedbackSA* makes CASM_GUI to receive feedback from CASM_Engine about the state, the update set and the output.

```
//subactivity : getFRFeedbackSA
rule getFRFeedbackSA
  guiAnOutput := getOutput(currentEngine)
  guiAState := getCurrentGUI_State(currentEngine)
  guiAnUpdateset := getLastUpdateSet(currentEngine)
```

Spec 6.7: The sub-activity *getFRFeedbackSA*

After verifying the functions specified in the activities, we can list these functions safely at the beginning of the GUI ASM model.

```
//Vocabulary of the model CoreASM − GUI − − − − − − −
vocabulary :
  //Interface of GUI − − − − − − − − − − − − − − − − − − − − − −
  //User ↔ GUI Functions

  //get the number of steps that theCASM_User requests
  // the model to forward
  rule getNumForwardStepsRequested (aUser : CoreASM-User)

  //GUI ↔ Engine Functions
  // − − Control Functions − − − − − − − − − − − − − − − − − − − −
  monitored  step : CoreASM-Engine × Integer → Boolean

  // − − Access Functions − − − − − − − − − − − − − − − − − − − − −
  monitored  getOutput : CoreASM-Engine → GUI_Outputs
  monitored  getCurrentGUI_State : CoreASM-Engine → GUI_States
  monitored  getLastUpdateSet : CoreASM-Engine → GUI_UpdateSets
```

Spec 6.8: API functions used in the activity *ForwardRunActivity*

The ASM rules and the ASM functions in the code section GUI ↔ Engine Interfaces are API functions we need to define in this project.

At the third abstraction level, the GUI ASM model has specified the architecture of CASM_GUI and has introduced a communication structure between the internal components of CASM_GUI. We now need to answer the following questions. What internal components of CASM_GUI are involved in the activity *ForwardRunActivity*? How do these components react in the activity *ForwardRunActivity*? What behaviors do these components perform to complete the activity *ForwardRunActivity*?

The GUI ASM model has to be refined to answer the above questions.

The activation of the activity *ForwardRunActivity* is managed in the internal component *control panel*. The component *control panel* executes in parallel with other internal components in CASM_GUI. Therefore, the main rule of CASM_GUI, *CoreASMGUIProgram*, has been written and refined as parallel executions of internal components (Spec 6.2 to Spec 6.9). The component *control panel* handles activations of activities.

```
main rule CoreASMGUIProgram =
  VocabViewProgram
  OutputViewProgram
  MessageViewProgram
  ProgramViewProgram
  RunViewProgram
  StateViewProgram
  UpdatesetViewProgram
  HistoryManagerProgram
  ControlPanelProgram


  rule ControlPanelProgram
    //Signal handling by control panel in CASM_GUI
    case nextUserActivityRequest( ) of

      userForwardRun →
        ForwardRunActivity
```

Spec 6.9: The activity *ForwardRunActivity* is activated in the *control panel*

We add a group of operations into the activity rule *ForwardRunActivity*. The component *control panel* requests other components in CASM_GUI to display the results after the sub-activity *forwardRunSA* completes. The display requests are sent through the communication structure by signaling other internal components in CASM_GUI.

Other components receive the signal and then perform the display requests. For example, the component *state view* finds that the request signal is the *statevcDisp* command. Then the *state view* executes the rule *displayStateinStateV(secondOf(aSignal))* to display the new state.

As the third abstraction level of the GUI ASM model shows, a system designer can find answers for the questions asked in the page 70. The internal components *control panel*, *message view*, *run view*, *state view* and *history manager* are involved in the

```
//Activity : ForwardRunActivity
rule ForwardRunActivity
  getNumForwardStepsRequestedSA
    seq forwardRunSA
    seq
      signalingTo( messagev, ( messagevcDisp, guiAnOutput ) )
      signalingTo( outputv, ( outputvcDisp, guiAnOutput ) )
      signalingTo( statev, ( statevcDisp, guiAState ) )
      signalingTo( updatesetv, ( updatesetvcDisp, guiAnUpdateset ) )
      signalingTo( runv, ( runvcDisp, getCurrentStepID( ) ) )
      signalingTo( historymanager,
                  ( historymanagercAddAStep, getCurrentStepID( ) ) )
```

Spec 6.10: Sending requests to other components in activity *ForwardRunActivity*

activity *ForwardRunActivity* since *control panel* communicates to these components in the activity rule ForwardRunActivity [Spec 6.10]. The components react to the request from *control panel* by checking the received signals in their signal pool and executing the relevant behaviors ([Spec 6.10] and [Spec 6.11]). The component *state view* performs the behavior *displayStateinStateV(secondOf(aSignal))* to display the result of the activity *ForwardRunActivity.*

The fourth abstraction level of the GUI ASM model concentrates on solving the activity concurrency problem. Some kinds of activity in CASM_GUI cannot be interrupted by another activity and must be completed before quitting (The activity *InterruptActivity* is a special case). The GUI system specified in this model is a multithread application. It can respond to multiple user requests simultaneously. Therefore activity concurrency exists in this GUI ASM model. In this kind of multithread application, we know at least one constraint exists: the activity *ForwardRunActivity* cannot start when CASM_Engine is executing forwarding or rollbacking actions. When refining this abstraction level, we add a constraint into the GUI ASM model. The *control panel* checks whether a forward or rollback action is executing before

```
//-- STATE VIEW ----
rule StateViewProgram
  choose aSignal from statevSignalPool
  remove aSignal from statevSignalPool
  case firstOf(aSignal) of
    statevcDisp →
      displayStateinStateV(secondOf(aSignal))
    statevcClearDisplay →
      clearDisplayinStateV
```

Spec 6.11: The component *state view*

activating an activity *ForwardRunActivity.* The checking is done in the function *isSynchronousActivityRunning().*

```
//-- CONTROL PANEL ----
rule ControlPanelProgram
  //if a synchronous activity is in process, no other synchronous
  // activity can run except interruptions.

  case nextUserActivityRequest( ) of
    userForwardRun →
      if not isSynchronousActivityRunning( ) then
        ForwardRunActivity
```

Spec 6.12: The constraint to activate the activity *ForwardRunActivity*

We have assigned each activity a flag (guiSAMode_***A) to label the activity states *has-not-started*, *in-process* and *completed.* The function *isSynchronousActivityRunning()* checks whether an initialization or execution activity, such as activity *ForwardRunActivity* or activity *RollbackActivity*, is executing in CASM_GUI. The flag helps the *control panel* to detect the activity execution. We refine the activity rule

ForwardRunActivity by assigning the activity state *guiACompleted* to the activity flag *guiSAMode_ForwardRunA* at the end of the activity *ForwardRunActivity*.

```
guiSAMode_ForwardRunA := guiACompleted
```

Spec 6.13: State of the activity *ForwardRunActivity*

The refinement of the activity *ForwardRunActivity* in the four different abstraction levels of GUI ASM model is a process to make design decisions. These design decisions help to build a system that satisfies the requirements. The GUI ASM model has answered the following questions during the refinement process. Is the activity *ForwardRunActivity* one behavior of CASM_GUI? How does CASM_GUI interact with other actors (the environment) in the activity *ForwardRunActivity* and what are the API functions in the interaction? What internal components in CASM_GUI are involved in the activity *ForwardRunActivity* and what roles do they play? Can the activity *ForwardRunActivity* execute in parallel with other activities in CASM_GUI?

6.1.6 Benefit of refinement by levels

When a system designer specifies a complex system, he or she would probably like to start from a high level of design; during the system development life cycle, the designer will also likely prefer that the specified system model be easily modified several times, whenever new detailed questions arise or when the requirements are changed.

This thesis introduces a mixed model-building approach that applies ASM methodology [Section 4.2]. In this approach, the system designer starts with the traditional object-oriented approach to build the architecture of the system as a whole and to point out the actors in the system and the roles of these actors. The system designer takes a global view of the complex system and decides its boundaries. Then the system designer switches to a task-based approach, analyzing the tasks that the system can perform. The task analysis at this stage is user-oriented if the system is interactive. The tasks analyzed in the model should complete certain user goals. The specified model receives continuing refinement at each of the different abstraction levels, enabling the designer to analyze the behaviors of the system and to match specification requirements. Each abstraction level should focus on a specific group of questions. The system designer should decide the number of abstraction levels and objectives of each abstraction level depending on the projects.

A mixed development approach helps system designers to specify a complex system model from the top to the bottom. System designers can think about the main objectives at the beginning and prevent marginal and detailed questions from obstructing decision making. ASM methodology is another tool to assist system designers. It has the power to abstract behaviors and functions of objects at a high level. In a graphical user interface system, ASM methodology can abstract an object in a model's behaviors and functions from its appearance. This type of specification model leaves the graphics designer a considerable amount of freedom in designing the interface's graphic appearance. The refinement process in the ASM methodology also makes it possible to modify the model if the requirements should change.

6.2 Concurrency issues in the GUI system

A GUI system is normally a multithreading system. The concurrency issues in GUI application design can be solved by defining a few constraints and by taking advantage of distributed ASMs.

6.2.1 GUI ASM model constraints in concurrency issue

In some activities, CASM_GUI would send requests to an outside actor in the environment, such as CASM_Engine, and wait for a response. It may take a long time for CASM_GUI to receive a response. For instance, requesting CASM_Engine to execute a step and this step takes a long time. During this waiting time, CASM_GUI is supposed to be available to respond to some user requests, such as a request to view program code.

Activity Concurrency Policy:

1. CASM_GUI cannot receive any user request for execution or initialization when a user request for execution or initialization is already in process;

2. Multiple instances of an activity cannot be processed in CASM_GUI simultaneously;

We have specified that there is only one CASM_User in the system environment. This single CASM_User interacts with a single CASM_GUI. CASM_User cannot execute the same activities simultaneously with one CASM_GUI. It is safe to say two activities, for example two uses of *ViewProgramCodeActivity*, initiated by one user will not occur at the same time.

There is another situation needed to be discussed here. The case might exist where CASM_User requests CASM_GUI to process an activity when the previous instance of the same activity is in process. For example, CASM_User might change his or her mind and want to view a previous state record when he or she is already viewing a different previous state record. Both activities are the activity *ViewStateInHistoryActivity*. In this situation, the second activity instance interrupts the previous one if this activity instance is the same kind of view activity. We introduce the policy 2 to avoid the situation that might occur if multiple instances of one activity simultaneously execute. The second instance of an activity cannot be processed if the previous activity instance is still alive (Spec 6.14). This keeps the GUI ASM model simple at this fourth level of abstraction. Execution or initialization activities, such as *InitActivity*, *ForwardRunActivity*, *RollbackActivity* and so on, are non-interruptible by user requests for the same activity. The policy 2 satisfies the needs of initialization or execution activities too.

One execution or initialization activity should not be interrupted by the same activity, and it normally should not be interrupted by other execution or initialization activities, either (there is an exception: *userInterrupt*). To satisfy these two requirements, there are two solutions. One is to hold the second execution or initialization activity user request in CASM_GUI until the previous execution or initialization activity has been completed. The second solution is to ensure that CASM_GUI cannot

```
**case** $nextUserActivityRequest(\ )$ **of**

  $userViewStateInHistory \rightarrow$
    **if** $guiSAMode\_ViewStateInHistoryA\ =\ undef$ **then**
      $ViewStateInHistoryActivity$
```

Spec 6.14: The activation of an activity

receive another execution or initialization activity user request during the period of time when CASM_GUI is dealing with an execution or initialization activity. For this GUI ASM model, the second option was selected (policy 1). At times, a GUI designer normally sets up the system to close the input channel to prevent CASM_User from sending an activity user request. For example, at certain times, the Forward button might be disabled.

6.2.2 GUI ASM model components

The GUI ASM model in this thesis consists of nine components expressed as ASM rules, seven *ViewPrograms* and one *HistoryManagerProgram* and one *ControlPanelProgram.* All components execute in parallel. They are specified as distributed abstract state machines (DASMS).

The *ViewProgram* provides functions for CASM_User to view the executing specification model on CASM_GUI. The *HistoryManagerProgram* manages the state history records and update set history records in CASM_GUI. The *ControlPanelProgram* is the program controlling CASM_GUI. It has interfaces for the environment (CASM_User, CASM_Engine, File Storage) to interact with CASM_GUI. One important task for the control panel is to respond to *UserActivityRequests* from CASM_User and to activate the corresponding activities in CASM_GUI. In GUI design, the *control panel* is a collection of GUI controls located on the GUI, including the initializing button, the step button, etc.

All components should work in parallel. One component in an execution state does not block another component's execution. Each component is an ASM rule and has its own behaviors. All components execute in parallel according to the main rule *CoreASMGUIProgram* of CASM_GUI (Spec 6.15).

```
// -- Main rule of the CoreASM GUI ---
main rule CoreASMGUIProgram =

    VocabViewProgram
    OutputViewProgram
    MessageViewProgram
    ProgramViewProgram
    RunViewProgram
    StateViewProgram
    UpdatesetViewProgram
    HistoryManagerProgram
    ControlPanelProgram
```

Spec 6.15: The parallel executing components

The component *control panel* is specified as the only component in CASM_GUI to handle user requests from CASM_User and to send and receive responses from CASM_Engine. The *control panel* dispatches activities in response to user requests. It is this approach that guarantees that the processes are thread-safe.

6.2.3 Activities in ControlPanelProgram

The GUI component *control panel* dispatches activities in response to user requests and controls these activities. On one step of ASM rule *ControlPanelProgram*, *control panel* handles one user request and dispatches the corresponding activity. The second response of the *control panel* is to keep uncompleted previous activities executing.

There are two kinds of activities in CASM_GUI, synchronous activity and asynchronous activity. A synchronous activity is an activity that should be executed without interruption from another activity. For example, *ForwardRunActivity* has to complete before *RollbackActivity* starts. *ForwardRunActivity* is a synchronous activity. Most synchronous activities in this GUI ASM model are those activities that involve execution by CASM_Engine. By contrast, *InterruptActivity* is a special activity. It can interrupt other synchronous activities.

In the *ViewStateInHistoryActivity*, CASM_GUI gets the state from the *history manager* and displays that state in the *state view*. This activity does not need CASM_GUI to communicate with CASM_Engine. Therefore, we treat the activity *ViewStateInHistoryActivity* as an asynchronous activity. An asynchronous activity is an activity that can be interrupted by another activity and the interruption will not affect the execution of the CoreASM machine.

Asynchronous Activity	**Synchronous Activity**
ViewProgramCodeActivity	LoadFileActivity
ViewLastOutputActivity	CheckSpecActivity
ViewOutputInHistoryActivity	InitActivity
ViewLastMsgActivity	ForwardRunActivity
ViewMsgInHistoryActivity	RollbackActivity
ViewLastUpdatesetActivity	StopActivity
ViewLastStateActivity	InterruptActivity *
ViewUpdatesetInHistoryActivity	
ViewStateInHistoryActivity	
StartupActivity	
QuitActivity	
AddWatchActivity	
DeleteWatchActivity	

Table 6.1: Asynchronous activities and synchronous activities

An activity is activated by a user request in the *control panel*. If this activity is an asynchronous activity, *control panel* allows the activity to process when the same activity is not being executed at the same time ($guiSAMode\_****A = undef$) (Spec 6.16) (Policy 2).

If the activity is a synchronous activity, *control panel* allows that activity to be

```
case nextUserActivityRequest( ) of
  //if the model is not processing the activity ViewStateInHistory,
  // then process it.

  userViewStateInHistory →
    if guiSAMode_ViewStateInHistoryA = undef then
      ViewStateInHistoryActivity
```

Spec 6.16: The constraint to activate an asynchronous activity

activated only when no other synchronous activity is executing in CASM_GUI at the time (Spec 6.17).

```
case nextUserActivityRequest( ) of
  //if the model is not processing a synchronous activity
  // then process it.

  userForwardRun →
    if not isSynchronousActivityRunning( ) then
      ForwardRunActivity
```

Spec 6.17: The constraint to activate a synchronous activity

The next task for *control panel* is to keep uncompleted activities in CASM_GUI executing. The GUI ASM model applies parallel ASMs here again and executes all uncompleted activities in parallel (Spec 6.18)

An asynchronous activity does not require the result of the activity to display on the GUI immediately. Two asynchronous activities can overlap each other. For instance, a user can interrupt a viewing state and switch to viewing program code, then switch back. The CASM_GUI executes the uncompleted activities *ViewProgramCodeActivity* and *ViewStateInHistoryActivity* in parallel to specify this situation

(Spec 6.18). The only constraint is to make sure no identical activity is executing currently (Spec 6.16). This does satisfy the policy 2.

A synchronous activity cannot be interrupted by another synchronous activity. The policy 1 is defined to satisfy this requirement. The system checks whether a synchronous activity is being executed currently before activating a synchronous activity. Two synchronous activities, *ForwardRunActivity* and *RollbackActivity*, seem as if they can execute in parallel (Spec 6.18). In fact, this will not happen given the constraint (Policy 1).

One synchronous activity may take a long time to complete and at the same time it may hold an important resource, an outside actor, such as CASM_Engine or File Storage. This produces one problem. The CASM_User may want to stop a synchronous activity if it takes too long. *InterruptActivity* is introduced as a special synchronous activity to interrupt other synchronous activities.

An asynchronous activity and a synchronous activity are allowed to be executed simultaneously. For example, a user can view program code while waiting for the engine processes one step. The activities *ViewProgramCodeActivity* and *ForwardRunActivity* execute in parallel (Spec 6.18). CASM_GUI will not freeze when a synchronous activity is running. The *control panel* will activate an asynchronous activity when a user request for the asynchronous activity is incoming, even if a synchronous activity is running in CASM_GUI (Spec 6.16). A synchronous activity will not block other incoming asynchronous activity requests.

6.3 Summary

This chapter discussed the level-refinement during the modeling process and the concurrency issue in the graphical user interface application.

Level-refinement refined the GUI ASM model at abstraction levels in a top-down development process. Each abstraction level had particular requirement specification goals. The activity *ForwardRunActivity* was used as an example to explain the level-refinement process.

Concurrency issue normally exists in a GUI system. The GUI ASM model took advantage of distributed ASMs to model GUI components that execute in parallel. An activity concurrency policy was also given in the GUI ASM model to solve the activity concurrency problem in GUI systems.

```
//synchronous activity
if guiSAMode_RollbackA = guiACompleted then
  // quits this activity
  guiSAMode_RollbackA := undef
else
  // if the activity is in process, continue the activity
  if not (guiSAMode_RollbackA = undef) then
    RollbackActivity

//synchronous activity
if guiSAMode_ForwardRunA = guiACompleted then
  // quits this activity
  guiSAMode_ForwardRunA := undef
else
  // if the activity is in process, continue the activity
  if not (guiSAMode_ForwardRunA = undef) then
    ForwardRunActivity

//asynchronous activity
if guiSAMode_ViewProgramCodeA = guiACompleted then
  // quits this activity
  guiSAMode_ViewProgramCodeA := undef
else
  // if the activity is in process, continue the activity
  if not (guiSAMode_ViewProgramCodeA = undef) then
    ViewProgramCodeActivity

//asynchronous activity
if guiSAMode_ViewStateInHistoryA = guiACompleted then
  // quits this activity
  guiSAMode_ViewStateInHistoryA := undef
else
  // if the activity is in process, continue the activity
  if not (guiSAMode_ViewStateInHistoryA = undef) then
    ViewStateInHistoryActivity
```

Spec 6.18: Synchronous activities and asynchronous activities

Chapter 7

Implementation

This chapter introduces the implementation of the GUI ASM model, a visual Core-ASM language debugger, and then experiments an actual CoreASM model, the ATM model.

7.1 Visual CoreASM language debugger

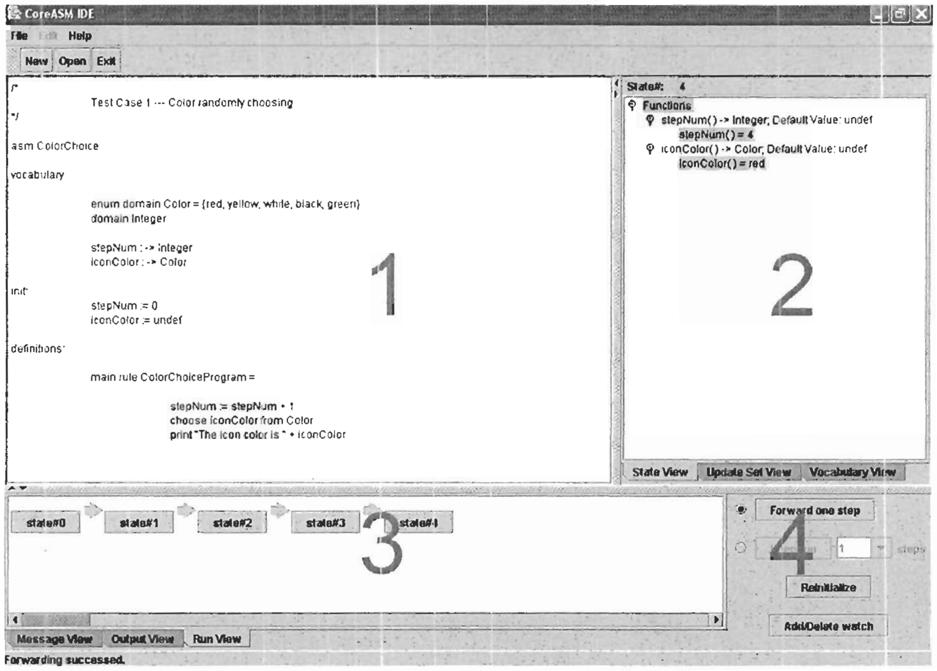
A visual CoreASM language debugger is currently under development. The GUI of the debugger is the implementation of CASM_GUI described in Chapter 5.

The programming language used to implement the debugger is Java. The reason to choose Java as the programming language is to allow the visual debugger to be cross-platform. The minimum Java virtual machine required to execute the GUI of the debugger is the version 1.2 or higher. The GUI is implemented with the Swing technology.

7.1.1 Function areas on the GUI

There are four main function areas on the GUI.

– *Program Edit Area*: the area where the user can edit the code of a CoreASM



```
/*
            Test Case 1 --- Color randomly choosing
*/

asm ColorChoice

vocabulary

            enum domain Color = {red, yellow, white, black, green}
            domain Integer

            stepNum : -> Integer
            iconColor : -> Color

init:
            stepNum := 0
            iconColor := undef

definitions:

            main rule ColorChoiceProgram =

                        stepNum := stepNum + 1
                        choose iconColor from Color
                        print "The icon color is " + iconColor
```

```
State#: 4
Functions
    stepNum() -> Integer; Default Value: undef
        stepNum() = 4
    iconColor() -> Color; Default Value: undef
        iconColor() = red
```

```
Forwarding successed.
```

Figure 7.1: The graphical user interface of the visual CoreASM language debugger

machine in. It locates on the upper-left corner of the GUI (labeled by 1 in Figure 7.1).

- *Machine View Area*: the area that displays the properties of a CoreASM machine. The properties of the machine are vocabulary, states and update sets. This area locates on the upper-right corner of the GUI (labeled by 2 in Figure 7.1).
- *Execution Information Area*: the area that displays the information of the execution of a CoreASM machine. The information includes the messages about the execution of the machine and the output of the machine and the history of a *run* of the machine. This area locates on the lower-left corner of the GUI (labeled by 3 in the Figure 7.1).
- *Control Panel Area*: the area where the user can operate to execute a CoreASM machine in. This area locates on the lower-right corner of the GUI (labeled by 4 in Figure 7.1).

The views of most components of CASM_GUI can be found on this GUI implementation. The table 7.1 shows these components and the function areas where the views of these components are in.

CASM_GUI Component	**Function Area**
program view	*Program Edit Area*
vocab view	*Machine View Area*
state view	*Machine View Area*
updateset view	*Machine View Area*
message view	*Execution Information Area*
output view	*Execution Information Area*
run view	*Execution Information Area*
control panel	*Control Panel Area*
history manager	

Table 7.1: The components and the function areas in where the views of these components are

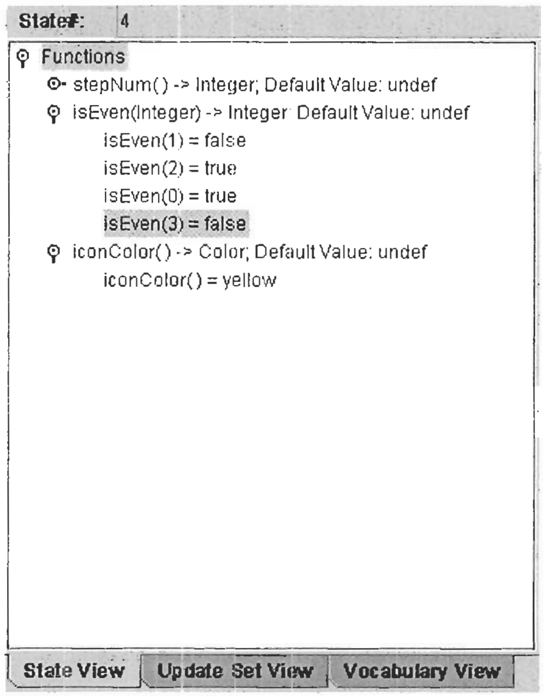
The *history manager* is invisible to CASM_User. Therefore, it does not have a view on the GUI.

7.1.2 Information organized in a tree structure

Users learn a CoreASM machine by observing the states and the updates of the machine in a *run*. A state is a set of elements together with functions. An update set in an update is a set of locations and elements. The function signatures can be used to identify the locations. Therefore, all the information items in a state or an update set can be grouped by functions. A tree view is a good representation of this kind of information organization.

In Figure 7.2, the information of the state is classified to three groups, the function *stepNum*, the function *isEven* and the function *iconColor*. Four locations, *isEven(0)*, *isEven(1)*, *isEven(2)*, and *isEven(3)* are in the group of the function *isEven*.

The information is organized in a tree structure. This applies to both views, the state view and the update set view. The purpose of the information organization is


State#: 4

Functions
stepNum() -> Integer; Default Value: undef
isEven(Integer) -> Integer Default Value: undef
isEven(1) = false
isEven(2) = true
isEven(0) = true
isEven(3) = false
iconColor() -> Color; Default Value: undef
iconColor() = yellow

Figure 7.2: The view of a state

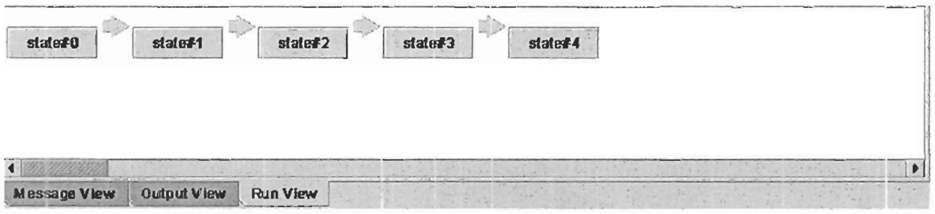


Figure 7.3: The run view

for users to find a particular location and its value easily.

7.1.3 Run view

The run view displays the trail of a *run* of a CoreASM machine. A user clicks one state button in the run view, then the information about the machine at that state will display in the state view and in the update set view.

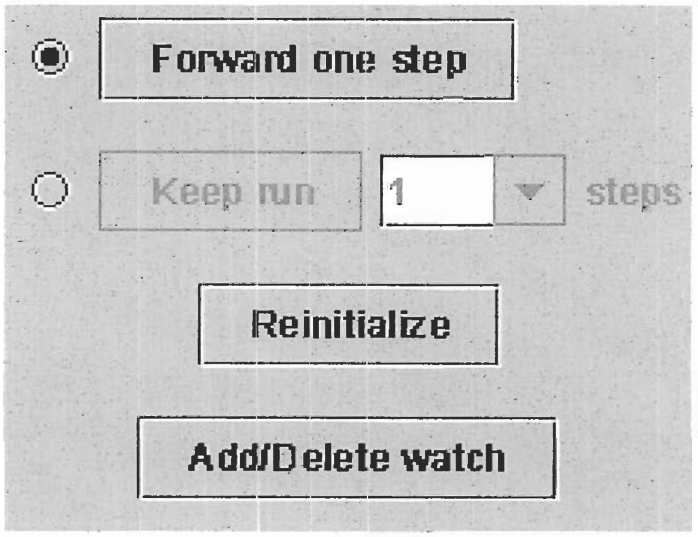


Figure 7.4: The control panel

7.1.4 Control panel

In the GUI ASM model, the component *control panel* responds all activity requests from CASM_User. In the implementation, the panel in the *Control Panel Area* on the GUI is only a partial view of the component *control panel*, because most, but not all, of the activity request buttons can be found in the *Control Panel Area*. The initialization request button and the execution request buttons are in the *Control Panel Area*. The other activity requests, such as view requests, are going to be received in the other function areas on the GUI. For instance, a user needs to click on one state button in the run view if he/she wants to view the history record about that state.

7.2 Experiment of the ATM model

We chose an actual CoreASM model to test the GUI implemented in Java. This CoreASM model is the ATM model.

7.2.1 ATM model

The ATM model abstractly models a cash machine control. There are three separate active entities that are involved in ATM operations. The active entities are an ATM manager, and an authentication manager, and an account manager. To simplify the model, the ATM manager is specified as a CoreASM machine, and the authentication manager and the account manager are in the system environment.

The withdrawal operation of the ATM should follow these steps:

1. Input the bank card and the PIN code.
2. Check the validity of the bank card and the PIN code.
3. Input the amount to be withdrawn.
4. Check the account balance against the credit line.
5. On approval update the account balance.
6. Output cash or notification about denial of transaction.

The timeout mechanisms of the ATM may cause the cancellation of transactions at any time.

The ATM model is given in Spec 7.1, with refinement. So the ATM model can be experimented in the visual CoreASM language debugger [Section 7.1].

There are a few simplifying assumptions in this ATM model.

- The bank card and the PIN code are input in the same step.
- The bank card and the PIN code are always authenticated.
- The transaction is always valid.
- The mode of the ATM is always idle at the initial state.
- It is known in advance at the initial state whether *CancellationEvent* will occur during the withdrawal operation.

7.2.2 Experiments

The ATM model is ready to be executed in the visual CoreASM language debugger. To experiment the perspective of the ATM on the withdrawal operation, a few test cases were prepared.

Test case: successful operation

The ATM is in the idle mode and is activated at the initial state. No *CancellationEvent* will occur.

The initial state in the test case:

```
init :
    mode := idle
    isActivated := true
    isCancelled := false
```

The states of the ATM model in a withdrawal operation are displayed in Figure 7.5 on the page 93.

The output of the ATM model in a withdrawal operation are displayed in Figure 7.6 on the page 94.

In this test case, the ATM manager starts from the idle mode, then turns into the processing mode, finally goes back to the idle mode. This is a test case for a successful operation. The changes of the mode are same as the perspective of the ATM. The output of the ATM model in the second step [Figure 7.6] also matches the perspective of the ATM.

Test case: inactivated ATM

The ATM is in the idle mode, but it is not activated at the initial state. No *CancellationEvent* will occur.

The initial state in the test case:

```
init :
  mode := idle
  isActivated := false
  isCancelled := false
```

The states of the ATM model in a withdrawal operation are displayed in Figure 7.7 on the page 95.

There is no output of the ATM model in a withdrawal operation.

In this test case, the ATM manager is inactivated. The mode keeps being idle during steps. No further actions are to be performed. This matches the perspective of the ATM. The withdrawal operation cannot be performed if the ATM is not activated.

7.2.3 Conclusion

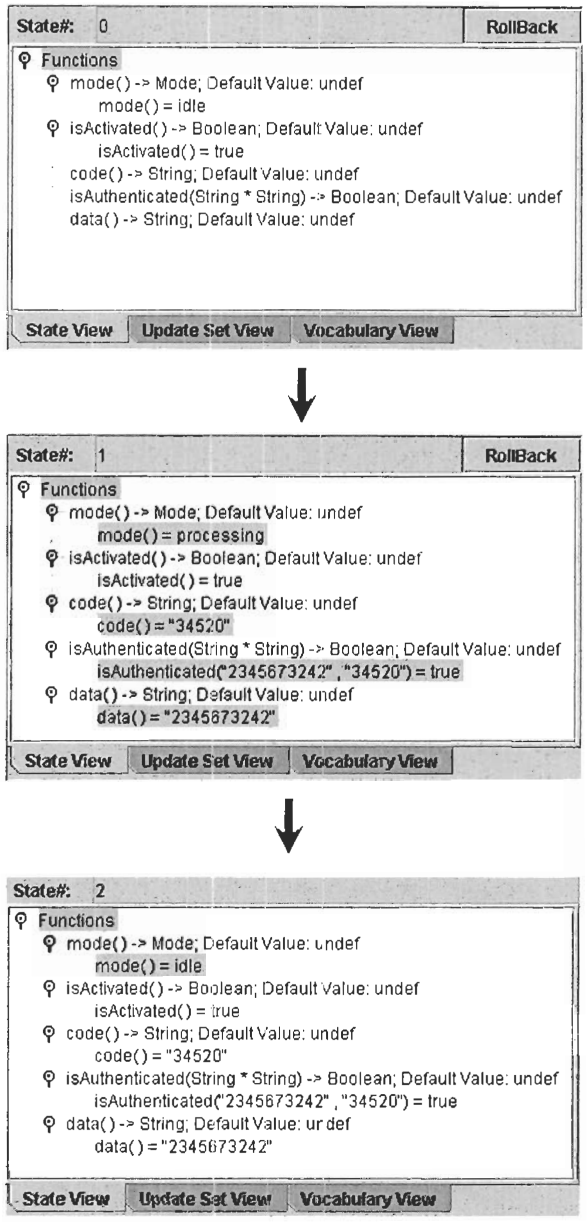
In the previous experiment, it shows that the visual CoreASM language debugger can be used to experiment the perspective of a system by running test cases. The test cases are developed from the scenarios that written in the specification phase [Figure 2.6]. If the ATM model gets further refinement, for instance, refining the function *isAuthenticated*, more test cases can be prepared. Then, the designer can explore more behaviors of the ATM.

```
asm   ATMmanager

vocabulary  :
    enum domain Mode = {idle, processing}

definitions  :
   main rule CoreASMGUIProgram =
      if Idle and ActivationEvent then
         data := getCardData
         code := getPinCode
         amount := getAmount
         mode := processing
      if Processing and IsAuthenticated(data, code) then
         if IsValidTransaction(data, amount) then
            ReleaseCash(amount)
            UpdateAccountBalance(data, amount)
         else
            OutputCancellationNotification
         mode := idle
      if Processing and ( not (IsAuthenticated(data, code)) or CancellationEvent)
        then
         OutputCancellationNotification
         mode := idle
      where
         rule Idle
            mode = idle
         rule Processing
            mode = processing
         rule ActivationEvent
            isActivated = true
         rule CancellationEvent
            isCancelled = true
         rule IsAuthenticated(data, code)
            isAuthenticated(data, code) = true
         rule IsValidTransaction(data, amount)
            isValidTransaction(data, amount) = true
```

Spec 7.1: The ATM model

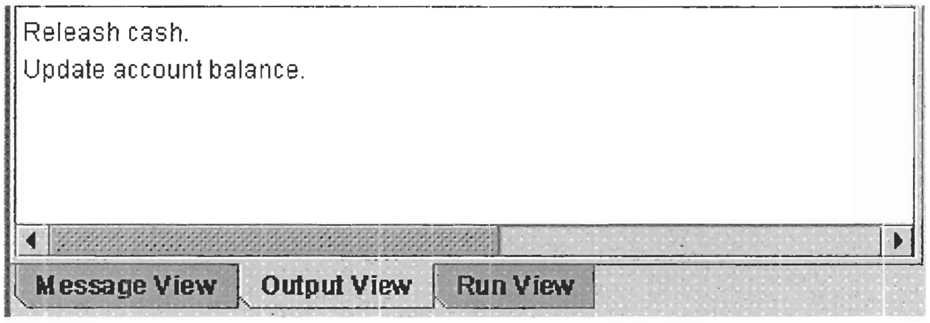


```
State#: 0
Functions
    mode() -> Mode; Default Value: undef
        mode() = idle
    isActivated() -> Boolean; Default Value: undef
        isActivated() = true
    code() -> String; Default Value: undef
    isAuthenticated(String * String) -> Boolean; Default Value: undef
    data() -> String; Default Value: undef
```

```
State#: 1
Functions
    mode() -> Mode; Default Value: undef
        mode() = processing
    isActivated() -> Boolean; Default Value: undef
        isActivated() = true
    code() -> String; Default Value: undef
        code() = "34520"
    isAuthenticated(String * String) -> Boolean; Default Value: undef
        isAuthenticated("2345673242" , "34520") = true
    data() -> String; Default Value: undef
        data() = "2345673242"
```

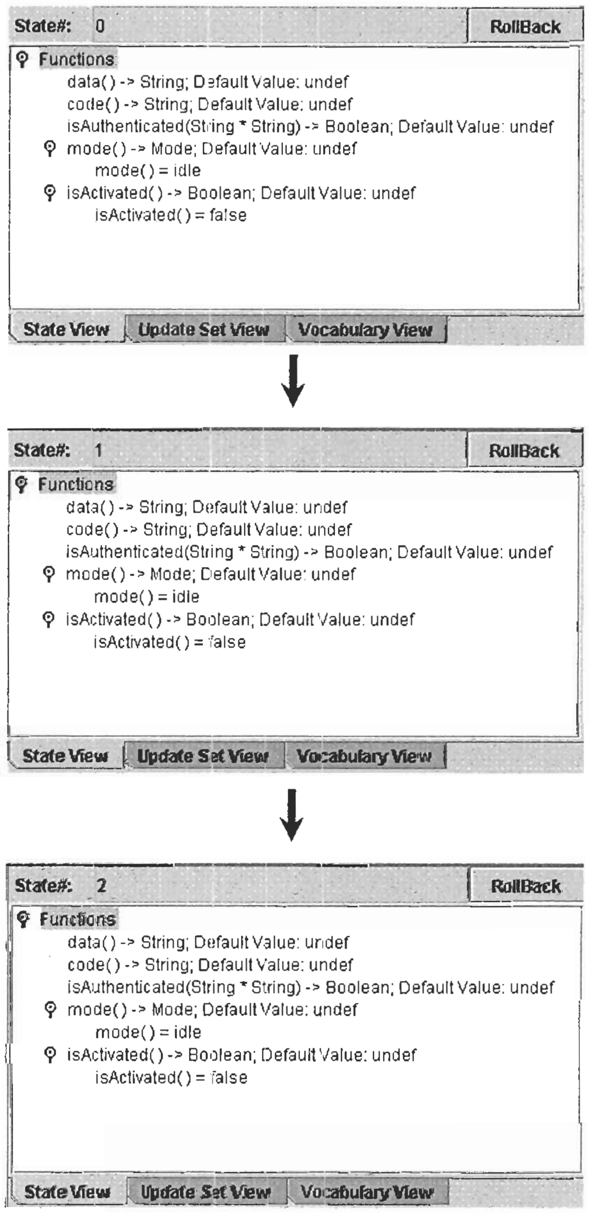
```
State#: 2
Functions
    mode() -> Mode; Default Value: undef
        mode() = idle
    isActivated() -> Boolean; Default Value: undef
        isActivated() = true
    code() -> String; Default Value: undef
        code() = "34520"
    isAuthenticated(String * String) -> Boolean; Default Value: undef
        isAuthenticated("2345673242" , "34520") = true
    data() -> String; Default Value: undef
        data() = "2345673242"
```

Figure 7.5: The states in a successful run



```
Releash cash.
Update account balance.
```

Figure 7.6: The output in the second step in a successful run



State#: 0 RollBack

Functions
- data() -> String; Default Value: undef
- code() -> String; Default Value: undef
- isAuthenticated(String * String) -> Boolean; Default Value: undef
- mode() -> Mode; Default Value: undef
  - mode() = idle
- isActivated() -> Boolean; Default Value: undef
  - isActivated() = false

State View | Update Set View | Vocabulary View

State#: 1 RollBack

Functions
- data() -> String; Default Value: undef
- code() -> String; Default Value: undef
- isAuthenticated(String * String) -> Boolean; Default Value: undef
- mode() -> Mode; Default Value: undef
  - mode() = idle
- isActivated() -> Boolean; Default Value: undef
  - isActivated() = false

State View | Update Set View | Vocabulary View

State#: 2 RollBack

Functions
- data() -> String; Default Value: undef
- code() -> String; Default Value: undef
- isAuthenticated(String * String) -> Boolean; Default Value: undef
- mode() -> Mode; Default Value: undef
  - mode() = idle
- isActivated() -> Boolean; Default Value: undef
  - isActivated() = false

State View | Update Set View | Vocabulary View

Figure 7.7: The states of an inactived ATM

Chapter 8

Conclusion

8.1 Conclusion

This thesis presents the work of designing a GUI application system at a high abstract level with model-based design. Abstract state machines methodologies have been applied in the modeling process. The GUI ASM model is specified with the CoreASM language. It provides a formal mathematical foundation to specify the architecture and the function form of the GUI system and to specify the interactive actions between the user and the CoreASM engine.

The formalization of the functions of the GUI system shows the ASM model is a precise semantic foundation to model human-computer interaction system at a high abstract level. The GUI ASM model describes the architecture of the system and specifies the functions of the system as activities. This model is a formal foundation for analysts to analyze GUI system behaviors and is a formal model for designers to validate the GUI system by walk-through inspection. The inspection can be switched to experimental validation through simulation and testing and formal verification when the CoreASM working environment is ready.

The GUI ASM model is built with a mixed design approach of the object-oriented approach and the task-oriented approach [Section 4.2]. The object-oriented design creates the architecture of the CoreASM supporting tool environment and the architecture of the GUI application system (CASM_GUI) at the beginning. The task-oriented design guides the system designer to focus on one core object in the GUI system, CASM_GUI. As the design process progresses, level-wise refinement can push the GUI ASM model to become more detailed. An ASM model is scalable. With multiple levels, each level is concerned with particular features of the system and keeps other features abstracted. The higher level of specification can be easier proved. The lower level needs only be proven correct with respect to the previous higher level. Level-wise refinement makes the design process traceable and manageable.

One challenge of this project research in the graphical user interface design is to present users with information about execution of a CoreASM machine. This challenge consists of two questions. 1. What is this information? 2. How should this information be presented visually? The thesis shows a way to collect the information in the second abstraction level of the GUI ASM model as well as a way to create APIs (GUI $\leftrightarrow$ Engine interface) with these information. The Java implementation of the graphical debugger for the CoreASM language is an example of the visual presentation of this set of information.

8.2 Future work

The GUI ASM model in this thesis has captured the architecture and functions of the GUI application system. This model is built on the informal requirements of a GUI application system in the CoreASM project. To define the requirements for interactive systems, William M. Newman and Michael G. Lamming suggested that the requirements should be defined in such areas: defining functional form, identifying the users and setting performance requirements [24]. The GUI ASM model in this thesis has specified the functional form of the GUI system and has identified the users. The users are specified as CASM_User in the GUI ASM model and are identified (/abstracted) by their behaviors and functions that they provide for CASM_GUI. More studies can be done to formally model the users in their behaviors and to analyze the interactions between the users and the GUI system. To specify the performance requirements with ASMs would be another challenge.

Appendix A

List of terms used in the GUI ASM model

This appendix presents the terms defined in the GUI ASM model.

A.1 Actors in the GUI ASM model

The actors:

- CASM_User
- CASM_GUI
- CASM_Engine
- File Storage

A.2 Components of CASM_GUI

The internal components of CASM_GUI:

- *control panel*
- *output view*

- *message view*
- *program view*
- *run view*
- *vocab view*
- *state view*
- *updateset view*
- *history manager*

A.3 Signal pools in the components

The following table shows the signal pool in each component.

Signal Pool	**Signal Pool Name**	**Component**
controlpanelSignalPool	controlpanel	*control panel*
outputvSignalPool	outputv	*output view*
messagevSignalPool	messagev	*message view*
programvSignalPool	programv	*program view*
runvSignalPool	runv	*run view*
vocabvSignalPool	vocabv	*vocab view*
statevSignalPool	statev	*state view*
updatesetvSignalPool	updatesetv	*updateset view*
historymanagerSignalPool	historymanager	*history manager*

Table A.1: Signal pools in components

A.4 Activities in CASM_GUI

The activities in CASM_GUI are classified into two groups, synchronous activity and asynchronous activity.

The synchronous activities:

- LoadFileActivity
- CheckSpecActivity
- InitActivity
- ForwardRunActivity
- RollbackActivity
- StopActivity
- InterruptActivity

The asynchronous activities:

- ViewProgramCodeActivity
- ViewLastOutputActivity
- ViewOutputInHistoryActivity
- ViewLastMsgActivity
- ViewMsgInHistoryActivity
- ViewLastUpdatesetActivity
- ViewLastStateActivity
- ViewUpdatesetInHistoryActivity
- ViewStateInHistoryActivity
- StartupActivity
- QuitActivity
- AddWatchActivity
- DeleteWatchActivity

Each activity has three modes. Each mode is defined as the following.

- undef : The activity does not exist in the machine.
- guiAInProcess : The activity is in process
- guiACompleted : The activity is completed, but still exists in the machine.

A.5 Signals in CASM_GUI

Signals are used to activate certain activities.

The types of these signals are,

- USER_ACTIVITYREQUEST
- PROGRAMV_COMMAND
- MESSAGEV_COMMAND
- OUTPUTV_COMMAND
- RUNV_COMMAND
- STATEV_COMMAND
- UPDATESETV_COMMAND
- HISTORYV_COMMAND
- VOCABV_COMMAND

A.5.1 USER_ACTIVITYREQUEST

These signals are the signals that activate the activities of CASM_GUI. They are sent by CASM_User.

The signals are,

- userStartup
- userLoadFile
- userCheckSpec
- userInit
- userForwardRun
- userRollback
- userStop
- userInterrupt

- userViewProgramCode
- userViewLastOutput
- userViewOutputInHistory
- userViewLastMsg
- userViewMsgInHistory
- userViewLastUpdateset
- userViewLastState
- userViewUpdatesetInHistory
- userViewStateInHistory
- userAddWatch
- userDeleteWatch
- userQuit

A.5.2 PROGRAMV_COMMAND

These signals are the signals that activate the activities of *program view*. They are received by *program view*.

The signals are,

- programvcDisplayFile: to display the CoreASM machine code in *program view*;
- programvcClearDisplay: to clear the display in *program view*.

A.5.3 MESSAGEV_COMMAND

These signals are the signals that activate the activities of *message view*. They are received by *message view*.

The signals are,

- messagevcDisp: to display the warning/error messages in *message view*;
- messagevcClearDisplay: to clear the display in *message view*.

A.5.4 OUTPUTV_COMMAND

These signals are the signals that activate the activities of *output view.* They are received by *output view.*

The signals are,

- outputvcDisp: to display the printout in *output view*;
- outputvcClearDisplay: to clear the display in *output view.*

A.5.5 RUNV_COMMAND

These signals are the signals that activate the activities of *run view.* They are received by *run view.*

The signals are,

- runvcAddAStep: to add a new state icon in *run view*;
- runvcDelSteps: to delete icons in *run view*;
- runvcHighlightAStep: to highlight an icon in *run view*;
- runvcClearDisplay: to clear the display in *run view.*

A.5.6 STATEV_COMMAND

These signals are the signals that activate the activities of *state view.* They are received by *state view.*

The signals are,

- statevcDisp: to display a state of the CoreASM machine in *state view*;
- statevcClearDisplay: to clear the display in *state view.*

A.5.7 UPDATESETV_COMMAND

These signals are the signals that activate the activities of *updateset view.* They are received by *updateset view.*

The signals are,

- updatesetvcDisp: to display an update set in *updateset view*;
- updatesetvcClearDisplay: to clear the display in *updateset view.*

A.5.8 HISTORYV_COMMAND

These signals are the signals that activate the activities of *history manager.* They are received by *history manager.*

The signals are,

- historymanagercAddAStep: to add a history record into *history manager*;
- historymanagercDelSteps: to delete history records from *history manager*;
- historymanagercClear: to clear all history records in *history manager.*

A.5.9 VOCABV_COMMAND

These signals are the signals that activate the activities of *vocab view.* They are received by *vocab view.*

The signals are,

- vocabvcDisp: to display the vocabulary of the CoreASM machine in *vocab view*;
- vocabvcClearDisplay: to clear the display in *vocab view.*

Appendix B

Abstract model of CASM_GUI

This appendix presents the GUI ASM model at the fourth abstraction level.

B.1 Actors in the GUI ASM model

There are four actors in the GUI ASM model, CASM_User, CASM_GUI, CASM_Engine, and File Storage.

CASM_GUI is specified as an ASM machine.

```
asm  CASM_GUI
```

The other three actors are the environment for CASM_GUI.

```
vocabulary  :

    domain CoreASM-Engine        //The actor CASM_Engine
    domain CoreASM-User          //The actor CASM_User
    domain CoreASM-FileStorage   //The actor FileStorage
```

B.2 Components of CASM_GUI

CASM_GUI consists of nine components, *output view*, *message view*, *program view*, *run view*, *vocab view*, *state view*, *updateset view*, *history manager*, and *control panel*.

Component: *output view*

The tasks of the output view:

- Display the printout from the CoreASM machine executing;
- Clear the display in the view.

```
rule OutputViewProgram
  choose aSignal from outputvSignalPool
  remove aSignal from outputvSignalPool
  case firstOf(aSignal) of
    outputvcDisp →
      displayMsginOutputV(secondOf(aSignal))
    outputvcClearDisplay →
      clearDisplayinOutputV
```

Component: *message view*

The tasks of the message view:

- Display any warning/error messages produced during the execution of the CoreASM machine;
- Clear the display in the view.

```
rule MessageViewProgram
    choose aSignal from messagevSignalPool
    remove aSignal from messagevSignalPool
    case firstOf(aSignal) of
        messagevcDisp →
            displayMsginMessageV(secondOf(aSignal))
        messagevcClearDisplay →
            clearDisplayinMessageV
```

Component: *program view*
The tasks of the program view:

- Display the code of the CoreASM machine;
- Clear the display in the view.

```
rule ProgramViewProgram
    choose aSignal from programvSignalPool
    remove aSignal from programvSignalPool
    case firstOf(aSignal) of
        programvcDisplayFile →
            displayFileinProgramV(secondOf(aSignal))
        programvcClearDisplay →
            clearDisplayinProgramV
```

Component: *run view*
The tasks of the run view:

- Add a new state icon in the view;
- Delete icons in the view;

- Highlight an icon in the view;
- Clear the display in the view.

```
rule $RunViewProgram$
  choose $aSignal$ from $runvSignalPool$
  remove $aSignal$ from $runvSignalPool$
  case $firstOf(aSignal)$ of
    $runvcAddAStep \rightarrow$
      $addARunViewElementinRunV(secondOf(aSignal))$
    $runvcDelSteps \rightarrow$
      $delRunViewElementsinRunV(secondOf(aSignal))$
    $runvcHighlightAStep \rightarrow$
      $hightlightRunViewElementinRunV(secondOf(aSignal))$
    $runvcClearDisplay \rightarrow$
      $clearDisplayinRunV$
```

Component: *vocab view*
The tasks of the vocab view:

- Display the vocabulary of the CoreASM machine;
- Clear the display in the view.

```
rule $VocabViewProgram$
  choose $aSignal$ from $vocabvSignalPool$
  remove $aSignal$ from $vocabvSignalPool$
  case $firstOf(aSignal)$ of
    $vocabvcDisp \rightarrow$
      $diaplayVocabinVocabV(secondOf(aSignal))$
    $vocabvcClearDisplay \rightarrow$
      $clearDisplayinVocabV$
```

Component: *state view*
The tasks of the state view:

- Display a state of the CoreASM machine;
- Clear the display in the view.

```
rule $StateViewProgram$
  choose $aSignal$ from $statevSignalPool$
  remove $aSignal$ from $statevSignalPool$
  case $firstOf(aSignal)$ of
    $statevcDisp \rightarrow$
      $displayStateinStateV(secondOf(aSignal))$
    $statevcClearDisplay \rightarrow$
      $clearDisplayinStateV$
```

Component: *updateset view*
The tasks of the update set view:

- Display an update set produced during the execution of the CoreASM machine;

– Clear the display in the view.

```
rule UpdatesetViewProgram
    choose aSignal from updatesetvSignalPool
    remove aSignal from updatesetvSignalPool
    case firstOf(aSignal) of
        updatesetvcDisp →
            displaySetinUpdatesetV(secondOf(aSignal))
        updatesetvcClearDisplay →
            clearDisplayinUpdatesetV
```

Component: *history manager*
The tasks of the history manager:

– Add a history record into the history manager;

– Delete history records from the history manager;

– Clear all history records in the history manager.

```
rule HistoryManagerProgram
    choose aSignal from historymanagerSignalPool
    remove aSignal from historymanagerSignalPool
    case firstOf(aSignal) of
        historymanagercAddAStep →
            addARuninHistoryManager(secondOf(aSignal))
        historymanagercDelSteps →
            delRunsinHistoryManager(secondOf(aSignal))
        historymanagercClear →
            clearinHistoryManager
```

Component: *control panel*

The tasks of the control panel:

- Activate an activity;

```
rule ControlPanelProgram

  case nextUserActivityRequest( ) of

    userStartup →
      if guiSAMode_StarupA = undef then StartupActivity

    //if a synchronous activity is in process, no other synchronous
    //activity can run except interruptions.

    userLoadFile →
      if not isSynchronousActivityRunning( ) then LoadFileActivity
    userCheckSpec →
      if not isSynchronousActivityRunning( ) then CheckSpecActivity
    userInit →
      if not isSynchronousActivityRunning( ) then InitActivity
    userForwardRun →
      if not isSynchronousActivityRunning( ) then ForwardRunActivity
    userRollback →
      if not isSynchronousActivityRunning( ) then RollbackActivity
    userStop →
      if not isSynchronousActivityRunning( ) then StopActivity
    userInterrupt →
      if guiSAMode_InterruptA = undef then InterruptActivity
```

```
$userViewProgramCode \longrightarrow$
    if $guiSAMode\_ViewProgramCodeA = undef$ then
        $ViewProgramCodeActivity$
$userViewLastOutput \longrightarrow$
    if $guiSAMode\_ViewLastOutputA = undef$ then
        $ViewLastOutputActivity$
$userViewOutputInHistory \longrightarrow$
    if $guiSAMode\_ViewOutputInHistoryA = undef$ then
        $ViewOutputInHistoryActivity$
$userViewLastMsg \longrightarrow$
    if $guiSAMode\_ViewLastMsgA = undef$ then $ViewLastMsgActivity$
$userViewMsgInHistory \longrightarrow$
    if $guiSAMode\_ViewMsgInHistoryA = undef$ then
        $ViewMsgInHistoryActivity$
$userViewLastUpdateset \longrightarrow$
    if $guiSAMode\_ViewLastUpdatesetA = undef$ then
        $ViewLastUpdatesetActivity$
$userViewLastState \longrightarrow$
    if $guiSAMode\_ViewLastStateA = undef$ then
        $ViewLastStateActivity$
$userViewUpdatesetInHistory \longrightarrow$
    if $guiSAMode\_ViewUpdatesetInHistoryA = undef$ then
        $ViewUpdatesetInHistoryActivity$
$userViewStateInHistory \longrightarrow$
    if $guiSAMode\_ViewStateInHistoryA = undef$ then
        $ViewStateInHistoryActivity$
$userAddWatch \longrightarrow$
    if $guiSAMode\_AddWatchA = undef$ then $AddWatchActivity$
$userDeleteWatch \longrightarrow$
    if $guiSAMode\_DeleteWatchA = undef$ then $DeleteWatchActivity$
$userQuit \longrightarrow$
    if $guiSAMode\_QuitA = undef$ then $QuitActivity$
```

B.3 Main rule of CASM_GUI

The machine of the CASM_GUI model is specified as parallel executions of components.

```
main rule CoreASMGUIProgram =

    //GUI component programs
    VocabViewProgram
    OutputViewProgram
    MessageViewProgram
    ProgramViewProgram
    RunViewProgram
    StateViewProgram
    UpdatesetViewProgram
    HistoryManagerProgram

    ControlPanelProgram
```

B.4 Signals in CASM_GUI

These signals are the activity requests from CASM_User to activate the activities of CASM_GUI.

vocabulary :

enum domain USER_ACTIVITYREQUEST $= \{userStartup,$
$userLoadFile, userCheckSpec, userInit,$
$userForwardRun, userRollback, userStop,$
$userInterrupt,$
$userViewProgramCode,$
$userViewLastOutput, userViewOutputInHistory,$
$userViewLastMsg, userViewMsgInHistory,$
$userViewLastUpdateset, userViewUpdatesetInHistory,$
$userViewLastState, userViewStateInHistory,$
$userAddWatch, userDeleteWatch, userQuit\}$

The following signals are the signals that are transferred between internal components of CASM_GUI.

vocabulary :

enum domain PROGRAMV_COMMAND = {
programvcDisplayFile, *programvcClearDisplay*}

enum domain VOCABV_COMMAND = {
vocabvcDisp, *vocabvcClearDisplay*}

enum domain MESSAGEV_COMMAND = {
messagevcDisp, *messagevcClearDisplay*}

enum domain OUTPUTV_COMMAND = {
outputvcDisp, *outputvcClearDisplay*}

enum domain STATEV_COMMAND = {
statevcDisp, *statevcClearDisplay*}

enum domain UPDATESETV_COMMAND = {
updatesetvcDisp, *updatesetvcClearDisplay*}

enum domain RUNV_COMMAND = {
runvcAddAStep, *runvcDelSteps*, *runvcHighlightAStep*,
runvcClearDisplay}

enum domain HISTORYMANAGER_COMMAND = {
historymanagercAddAStep, *historymanagercDelSteps*,
historymanagercClear}

The sending process for signals is specified as a rule, *signalingTo(aSignalPool : SignalPoolName, aSignal : GUI_Signal).*

```
rule signalingTo(aSignalPool : SignalPoolName, aSignal : GUI_Signal) =
    case aSignalPool of
        programv →
            add aSignal to programvSignalPool
        messagev →
            add aSignal to messagevSignalPool
        outputv →
            add aSignal to outputvSignalPool
        statev →
            add aSignal to statevSignalPool
        updatesetv →
            add aSignal to updatesetvSignalPool
        runv →
            add aSignal to runvSignalPool
        historymanager →
            add aSignal to historymanagerSignalPool
        vocabv →
            add aSignal to vocabvSignalPool
        controlpanel →
            add aSignal to controlpanelSignalPool
```

B.5 Interfaces in the GUI ASM model

There are three interfaces specified in the GUI ASM model. They are the GUI $\leftrightarrow$ User interface, the GUI $\leftrightarrow$ FileStorage interface, and the GUI $\leftrightarrow$ Engine interface.

B.5.1 The GUI $\leftrightarrow$ User interface

The GUI $\leftrightarrow$ User interface specified in the GUI ASM model consists of the commands to activate the activities and the operations of CASM_User on CASM_GUI.

```
rule getFileURIToLoad (aUser : CoreASM-User ,
                       aFileStorage : CoreASM-FileStorage)
rule getNumForwardStepsRequested (aUser : CoreASM-User)
rule getStateIdBackTo (aUser : CoreASM-User)
rule getStateIdViewInHistory (aUser : CoreASM-User)
rule getUpdateSetIdViewInHistory (aUser : CoreASM-User)
rule createAWatch (aUser : CoreASM-User , aVocab : GUI_VOCAB)
rule selectAWatchToDel (aUser : CoreASM-User)
```

B.5.2 The GUI $\leftrightarrow$ FileStorage interface

The GUI $\leftrightarrow$ FileStorage interface specified in the GUI ASM model provides an I/O channel to read a file stored on File Storage.

```
rule loadFile (aFileStorage : CoreASM-FileStorage , aUri : FileURI)
```

B.5.3 The GUI ↔ Engine interface

The GUI ↔ Engine interface consists of a *control* interface and an *access* interface.

The *control* interface of GUI ↔ Engine interface:

rule *checkSpecification* (*aEngine* : CoreASM-Engine , *aFile* : File)
rule *initSpecification* (*aEngine* : CoreASM-Engine)
rule *step* (*aEngine* : CoreASM-Engine , *anI* : Integer)
rule *rollback* (*aEngine* : CoreASM-Engine , *anId* : StateID)
rule *createEngine*
rule *killEngine* (*aEngine* : CoreASM-Engine)
controlled *interrupt* : CoreASM-Engine → Boolean
monitored *getEngineMode* : CoreASM-Engine → ENGINE-MODE

The *access* interface of GUI ↔ Engine interface:

monitored *getGUI_VOCAB* : CoreASM-Engine → GUI_VOCAB
monitored *getOutput* : CoreASM-Engine → GUI_Outputs
monitored *getCurrentGUI_State* : CoreASM-Engine → GUI_States
monitored *getLastUpdateSet* : CoreASM-Engine → GUI_UpdateSets
monitored *getPreviousGUI_State* : CoreASM-Engine
∗ GUI_Watch ∗ StateID
→ GUI_States
monitored *getPreviousUpdateSet* : CoreASM-Engine
∗ GUI_Watch ∗ UpdateSetID
→ GUI_UpdateSets
monitored *getSpec* : CoreASM-Engine → File

B.6 Activities of CASM_GUI

The activities in CASM_GUI are specified as ASM rules. And they are classified into two groups, synchronous activity and asynchronous activity.

B.6.1 Activities

The followings are the activities specified at the second abstraction level of the GUI ASM model. The details about the signals transferring among the internal components and the usage of the interfaces in each sub-activity are specified formally at the third and the fourth abstraction levels. The full version of the four abstraction levels of the GUI ASM model will be provided as required.

StartupActivity

```
rule StartupActivity
    createGUISA seq createLinkEngineSA
```

LoadFileActivity

```
rule LoadFileActivity
    getFileURIToLoadSA  seq  loadFileSA
```

CheckSpecActivity

```
rule CheckSpecActivity
    checkSpecSA(currentEngine, guiAFile) seq getCSFeedbackSA
```

InitActivity

```
rule InitActivity
    initSpecSA(currentEngine, guiAFile)
        seq getISFeedbackSA
```

ForwardRunActivity

```
rule ForwardRunActivity
    getNumForwardStepsRequestedSA seq forwardRunSA seq getFRFeedbackSA
```

RollbackActivity

```
rule RollbackActivity
    getStateIdBackToSA seq rollbackSA
```

StopActivity

```
rule StopActivity
```

InterruptActivity

```
rule InterruptActivity
    interrupt(currentEngine) := true
```

ViewProgramCodeActivity

rule *ViewProgramCodeActivity*

ViewLastOutputActivity

rule *ViewLastOutputActivity*

ViewOutputInHistoryActivity

rule *ViewOutputInHistoryActivity*

ViewLastMsgActivity

rule *ViewLastMsgActivity*

ViewMsgInHistoryActivity

```
rule $ViewMsgInHistoryActivity$
```

ViewLastUpdatesetActivity

```
rule $ViewLastUpdatesetActivity$
```

ViewLastStateActivity

```
rule $ViewLastStateActivity$
```

ViewUpdatesetInHistoryActivity

```
rule $ViewUpdatesetInHistoryActivity$
  $getUpdateSetIdViewInHistorySA$
    $seq$
      $viewUpdatesetInHistorySA(guiUpdateSetIdToViewInHistory)$
```

ViewStateInHistoryActivity

```
rule ViewStateInHistoryActivity
  getStateIdViewInHistorySA
     seq
       viewStateInHistorySA(guiStateIdToViewInHistory)
```

AddWatchActivity

```
rule AddWatchActivity
  createAWatch(currentUser, guiVocab)
```

DeleteWatchActivity

```
rule DeleteWatchActivity
  selectAWatchToDel(currentUser)
```

QuitActivity

```
rule QuitActivity
  killEngineSA(currentEngine) seq killGUISA
```

B.6.2 The function *isSynchronousActivityRunning( )*

The function is defined to check if a synchronous activity is currently processing in CASM_GUI.

```
isSynchronousActivityRunning( )
   if (guiSAMode_StarupA = undef)
         and (guiSAMode_LoadFileA = undef)
         and (guiSAMode_CheckSpecA = undef)
         and (guiSAMode_InitA = undef)
         and (guiSAMode_ForwardRunA = undef)
         and (guiSAMode_RollbackA = undef)
         and (guiSAMode_StopA = undef)
         and (guiSAMode_InterruptA = undef) then

      isSynchronousActivityRunning := true
```

Appendix C

ATM executable model

This appendix presents the ATM executable model.

```
asm    ATMmanager
vocabulary  :
    enum domain Mode = {idle, processing}
```

```
definitions :
  main rule $CoreASMGUIProgram$ =
    if $Idle$ and $ActivationEvent$ then
      $data := getCardData$
      $code := getPinCode$
      $amount := getAmount$
      $mode := processing$
    if $Processing$ and $IsAuthenticated(data, code)$ then
      if $IsValidTransaction(data, amount)$ then
        $ReleaseCash(amount)$
        $UpdateAccountBalance(data, amount)$
      else
        $OutputCancellationNotification$
      $mode := idle$
    if $Processing$ and ( $not$ ($IsAuthenticated(data, code)$) or $CancellationEvent$)
     then
      $OutputCancellationNotification$
      $mode := idle$
    where
      rule $Idle$
        $mode = idle$
      rule $Processing$
        $mode = processing$
      rule $ActivationEvent$
        $isActivated = true$
      rule $CancellationEvent$
        $isCancelled = true$
      rule $IsAuthenticated(data, code)$
        $isAuthenticated(data, code) = true$
```

```
where

    rule $IsValidTransaction(data, amount)$
        $isValidTransaction(data, amount) = true$
    rule $ReleaseCash(amount)$
        $print$ "$Releashcash.$"
    rule $UpdateAccountBalance(data, amount)$
        $print$ "$Updateaccountbalance.$"
    rule $OutputCancellationNotification$
        $print$ "$Theoperationiscancelled.$"
    $staticisAuthenticated(data, code) := true$
    $staticisValidTransaction(data, amount) := true$
    $getCardData :=$ "2345673242"
    $getPinCode :=$ "34520"
    $getAmount :=$ 400.00
    $data$ : String
    $code$ : String
    $amount$ : Double
    $mode$ : Mode
    $isActivated$ : Boolean
    $isCancelled$ : Boolean
```

Bibliography

[1] Spec# Home, http://research.microsoft.com/specsharp/.

[2] eXtensible Abstract State Machines, http://www.xasm.org/.

[3] G. Booch. *Object-Oriented Analysis and Design.* Redwood City, CA: Benjamin/Cummings, 1994.

[4] E. Börger, N. G. Fruja, V. Gervasi, and R. F. Stärk. A high-level modular definition of the semantics of C#. *Theoretical Computer Science*, 2004.

[5] E. Börger, U. Glässer, and W. Müller. Formal Definition of an Abstract VHDL'93 Simulator by EA-Machines. In C. Delgado Kloos and P. T. Breuer, editors, *Formal Semantics for VHDL*, pages 107–139. Kluwer Academic Publishers, 1995.

[6] E. Börger, E. Riccobene, and J. Schmid. Capturing requirements by abstract state machines: The light control case study. *Journal of Universal Computer Science*, 6(7):597–620, 2000.

[7] E. Börger and D. Rosenzweig. A mathematical definition of full Prolog. In *Science of Computer Programming*, volume 24, pages 249–286. North-Holland, 1994.

[8] Egon Börger. The ASM ground model method as a foundation for requirements engineering. In *Verification: Theory and Practice*, pages 145–160, 2003.

[9] Egon Börger and Robert Stärk. *Abstract State Machines: A Method for High-Level System Design and Analysis.* Springer-Verlag, 2003.

[10] J. Pac Coutaz. An object oriented model for dialog design. In H. J. Bullinger and B. Shackel, editors, *Human-Computer Interaction - INTERACT'87*, pages 431–6. Elsevier Science Publishers, North-Holland, Amsterdam, 1987.

[11] Paul Curzon and Ann Blandford. From a formal user model to design rules. In *DSV-IS '02: Proceedings of the 9th International Workshop on Interactive*

Systems. Design, Specification, and Verification, pages 1–15, London, UK, 2002. Springer-Verlag.

[12] Alan Dix, Janet Finlay, Gregory D. Abowd, and Russell Beale. *Human - Computer Interaction.* Pearson-Prentice Hall, third edition, 2004.

[13] Jacob Eisenstein and Charles Rich. Agents and GUIs from task models. In *IUI '02: Proceedings of the 7th International Conference on Intelligent User Interfaces*, pages 47–54, New York, NY, USA, 2002. ACM Press.

[14] Roozbeh Farahbod, Vincenzo Gervasi, and Uwe Glässer. Coreasm: An extensible ASM execution engine. In *Proc. of the 12th Intl Workshop on Abstract State Machines*, 2005.

[15] Uwe Glässer, Y. Gurevich, and M. Veanes. An abstract communication model. Technical Report MSR-TR-2002-55, Microsoft Research, Microsoft Corporation, May 2002.

[16] Uwe Glässer, Y. Gurevich, and M. Veanes. High-level executable specification of the universal plug and play architecture. In *Proc. of 35th Hawaii International Conference on System Sciences, Software Technology Track, Domain-Specific Languages for Software Engineering, IEEE*, 2002.

[17] Y. Gurevich. Logic and the Challenge of Computer Science. In E. Börger, editor, *Current Trends in Theoretical Computer Science*, pages 1–57. Computer Science Press, 1988.

[18] Y. Gurevich. Evolving algebras 1993: Lipari guide. In E. Börger, editor, *Specification and Validation Methods*, pages 9–36. Oxford University Press, 1995.

[19] ITU-T Recommendation Z.100 Annex F (11/00). *SDL Formal Semantics Definition.* International Telecommunication Union, 2001.

[20] I. Jacobson, M. Christerson, P. Jonsson, and G. Overgaard. *Object-Oriented Software Engineering: a Use Case Driven Approach.* Addison-Wesley, 1992.

[21] Bernard J. Jansen. *The Graphical User Interface: An Introduction*, pages 22–26. SIGCHI Bulletin, 1998.

[22] Atif M. Memon, Martha E. Pollack, and Mary Lou Soffa. Automated test oracles for GUIs. In *Proc. of the Eighth International Symposium on Foundations of Software Engineering*, pages 30–39, 2000.

[23] Brad A. Myers. Why are Human-Computer Interfaces Difficult to Design and Implement? Technical report, Pittsburgh, PA, USA, 1993.

[24] William M. Newman and Michael G. Lamming. *Interactive System Design.* Addison-Wesley Publishing Company, 1995.

[25] Fabio Paterno. Towards a UML for interactive systems. In G. Goos, J. Hartmanis, and J. van Leeuwen, editors, *Engineering for Human-Computer Interaction*, Lecture Notes in Computer Science. Springer, 2001.

[26] Dave Roberts, Dick Berry, Scott Isensee, and John Mullaly. *Designing for the User with OVID: Bridging User Interface Design and Software Engineering.* Software Engineering Series. Macmillan Technical Publishing, 1998.

[27] Meurig Sage and Chris Johnson. Pragmatic formal design: A case study in integrating formal methods into the HCI development cycle. In *Design, Specification and Verification of Interactive Systems'98*, pages 134–155, Abingdon, UK, 1998. Springer Verlag.

[28] R. Stärk, J. Schmid, and E. Börger. *Java and the Java Virtual Machine: Definition, Verification, Validation.* Springer-Verlag, 2001.

[29] Adriana-Mihaela Tarta. Task modeling in systems design. *Studia Univ. Babes-Bolyal, Inforasmtica*, XLIX(2), 2004.

[30] H. Tonino and J. Visser. Stepwise Refinement of an Abstract State Machine for WHNF-Reduction of λ-Terms. Technical Report 96-154, Faculty of Technical Mathematics and Informatics, Delft University of Technology, 1996.

[31] Roger Took. Putting design into practice: Formal specification and the user interface. In Michael Harrison and Harold Thimbleby, editors, *Formal Methods in Human-Computer Interaction*, Cambridge Series on Human-Computer Interaction, pages 63–96. Cambridge University Press, 1990.

[32] Hallvard Trætteberg. Using user interface models in design. In *CADUI'2002: Proceedings of 4th International Conference on Computer-Aided Design of User Interfaces*, 2002.