Code Generation from an Abstract State Machine into Contracted C#

Supervisor:	Joseph R. Kiniry
Thesis by:	Asger Jensen
Date of birth:	10-11-82
Email:	asje@itu.dk
Thesis start:	01-12-11
Thesis end:	01-06-12

Abstract

In computer science designing systems, whether it is hardware or software, using an abstract state machine diagram to model the system is a common approach. When using the diagram as a blueprint for programming, it is possible to lose the equality between the diagram and the actual code, not to mention the time that was spent creating the code.

Having a tool which generates skeleton code from a state machine is not a new idea. In 2003 Engelbert Hubbers and Martijn Oostdijk created the AutoJML tool, which derives Java Modeling Language specifications from UML state diagrams.

The same kind of tool does not exist in the .NET environment. Visual Studio 2010 does offer the possibilities of creating state machine diagrams, but it is not possible to generate code from the diagram. This thesis is about creating such a tool, based on Hubbers and Oostdijk work, where the user can create their abstract state machine diagram and generate contracted skeleton C# code from it.

To accomplice this, a Domain Specific Language has been created, with an added feature to generate code. The user can create their state machine by adding states and transitions, specify what states should be initial-, normal- and final state, fill out the transition properties and initiate the validation and generation of the code. Code Contracts is used in the generated code to keep the constraints of the abstract state machine diagram.

The result of this thesis is a Visual Studio extension, which makes it possible to get generated contracted C# code from an abstract state machine diagram.

Table of Contents

1 INTRODUCTION 5

2 ABSTRACT STATE MACHINES 5

2.1 CONTROL STATE ASMS 6
2.2 LINK BETWEEN ASM AND FSM 6
2.3 DFA AND NFA DEFINITION 7

3 HUBBERS AND OOSTDJIKS PAPER 8

3.1 THE THESIS COMPARED TO THE PAPER 9

4 THE ASM EXTENSION 10

4.1 CURRENT FEATURES 10
4.2 FUTURE WORK 11

5 EXTENSION WALKTHROUGH 11

6 CODE CONTRACTS 14

6.1 PRECONDITION, POSTCONDITION AND INVARIANT 15
6.2 ISSUES WITH CODE CONTRACTS AND SOLUTIONS 15

7 BUILDING THE DSL 17

7.1 THE META-MODEL 17
7.1.1 Embedding and Reference Relations 18
7.1.2 Allow Duplications 19
7.2 THE GRAPHICAL NOTATION 20

8 THE BUTTON 20

8.1 DECLARING THE BUTTON AND FUNCTIONALITY 20

9 VALIDATION 21

9.1 CHOSEN RULES 21
9.2 CONSIDERED RULES 22
9.3 THE CODE 22

10 GENERATING C# CODE 23

10.1 THE GENERATED CODE 24

11 TEST 24

11.1 VALIDATION TEST 24
11.2 GENERATION TEST 25

12 CONCLUSION 26

13 LITERATURE LIST 27

14 SOFTWARE 28

Appendices

APPENDIX A........29

APPENDIX B........30

APPENDIX C........31

APPENDIX D........32

APPENDIX E........34

APPENDIX F........36

APPENDIX G........45

APPENDIX H........47

1 Introduction

Over the last 10 years there has been more interest in developing a way of using a state machine model and generating a skeleton code from it. Engelbert Hubbers and Martijn Oostdijk from the University of Nijmegen created AutoJML tool which automatically derives Java Modeling Language (JML) specifications from UML[1] state diagrams. This thesis is based on the paper *"Generating JML Specifications from UML State Diagrams"* by Engelberg Hubbers and Martijn Oostdijk [1].

A way of achieving the goal of replicating Hubbers and Oostdijk's earlier experiment in a new programming language is to define a domain specific language (DSL), where it is possible for users to create an Abstract State Machine (ASM) diagram. The DSL will also have a functionality to generate code from the created state machine model, with a validation check of the model before the generation. The final product of the thesis will be an extension containing the DSL to Visual Studio 2010 (VS2010).

VS2010 does contain a UML Activity Diagram extension to create ASMs it is not possible to generate any code from the ASM. The possibility to generate skeleton code would boost production speed of software development considerably. Also one can lose similarity between the ASM and the written code if there is not a regular comparison, known as architecture drift [8]. So by generating skeleton code from an ASM, one is sure that the code is equivalent to the ASM.

This report will cover topics, ASMs and how they link to Finite State Machines[2] (FSMs), the paper by Hubbers and Oostdijk, Code Contracts, a use case describing the extension, the meta-model of the extension, the validation of ASMs, the code generation and the tests of the extension.

2 Abstract State Machines

Designing a system is difficult and can be the most error prone part of the system development [2]. Creating the system requirements is based on what the customer wants, but the customer does not have the same insight into system design as the developers. This leads to a system description from the customer that is perhaps incomplete, has misleading details or somewhat ambiguous. The ASM method is machine- and programming language independent, which makes it a valid method for designing hardware and software systems. This offers a way for customers and developers to design a system together, which is precise enough to meet the customer's wishes, but also abstract enough for the developer's creative thinking.

When the customer and developer create an ASM of a system, it is known as a ground model ASM for the system. The ground model is based on the system description and requirements, and serves as a blueprint for the project. Since the ground model is created by the customer together with the developer, it can serve as the basis for the software contract, a documentation which binds the two involved parties.

Having a ground model of the system, it is possible to define a test plan for the system before the actual coding starts. Furthermore it is also possible to create test cases for the actual ground model, to prevent

[1] Unified Modeling Language

[2] Finite State Machines are also known as Finite Automata (FA)

any major mishaps. These possibilities lower some of the project expenses, since the actual testing is designed, and some also performed, before the later stages of the development.

The ground model is used as an overview of the entire system, but for the actual development more specific ASMs are needed. Taking the ground model, a hierarchy of intermediate models can be designed. The intermediate models, known as stepwise refining ASMs, are a deeper view into the different states in the ground model ASM. Look at the stepwise refining ASMs as pieces of a bigger puzzle, seen in Fig. 2-1.

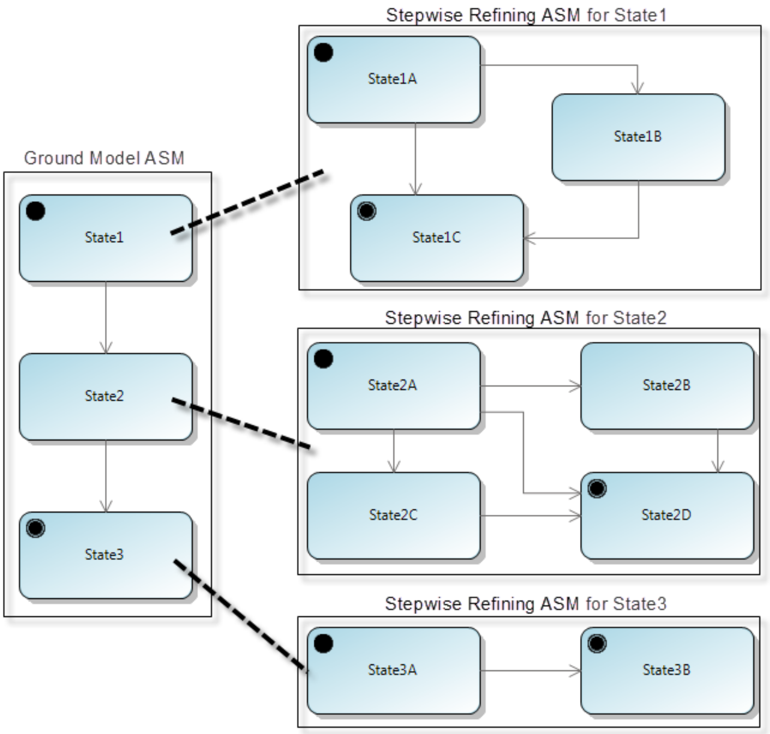


Fig. 2-1: Stepwise Refining ASMs from a Ground Model ASM

Using the stepwise refining ASMs the individual person responsible for the code has something more specific to work with, without having to think about the entire system, just the one piece of the puzzle.

2.1 Control State ASMs

In this thesis a version of ASMs called control state ASM is used. The control state machine uses the notation of the UML activity diagram, together with the structure of FSM to allow the possibility of manipulating data structures.

The control state ASM contains finitely many control states, which resembles the internal states of FSM. The states can be used to describe different modes of a system, example shown in Fig. 3-1. As with FSMs, control state ASMs can be deterministic and non-deterministic. The non-deterministic can be used to resolve possible conflicting updates of a state.

2.2 Link between ASM and FSM

FSM only holds the states or data structures which is within the boundary of the modeled machine, and does not contain any variables which can be changed during a transition. The label of the transitions in a

FSM only holds a symbol or a letter from a set of inputs for the FSM, and it is not possible to use arbitrary expressions as a label. The ASM takes the FSM as a foundation and builds upon it. The ASM has the same notation of states and transitions, but one can attach variables to the ASM, which can be updated based on the rules of the transitions. The definition of an ASM [2] is as follows

> *Basic ASMs are a finite set of so-called transition rules of the form*
>
> > ***if*** *Condition* ***then*** *Updates*
>
> *which transform abstract states…*

With the control state ASM used in this thesis a transition has a label with the form

> *Event(arguments)[Condition] /Action*

The event is the trigger to update the current state, which can be thought of as a method call with possible arguments. The condition[3] for the transition determines whether or not the transition occurs, and the action is what is going to happen, if the condition is true. The action can be an exception thrown or a variable changing value.

2.3 DFA and NFA Definition

As written above, ASMs as well as FSMs can be deterministic and non-deterministic. Deterministic means that there is one transition from a state for each possible input, whereas the input for a non-deterministic can lead to one, more than one or no transitions from a state.

Hopcroft et al. [3] defines deterministic as

1. *A finite set of states, often denoted with Q*
2. *A finite set of input symbols, often denoted Σ*
3. *A transition function that takes as arguments a state and an input symbol and returns a state. The transition function will commonly be denoted δ*
4. *A start state, one of the states in Q*
5. *A set of final or accepting states F. The set F is a subset of Q*

Furthermore Hopcroft et al. defines non-deterministic as

1. *Q is a finite set of states*
2. *Σ is a finite set of input symbols*
3. *q_0, a member of Q, is the start state*
4. *F, a subset of Q, is the set of final (or accepting) states*
5. *δ, the transitions function is a function that takes a state in Q and an input symbol from Σ as arguments and returns a subset of Q. Notice that the only difference between NFA[4] and DFA[5] is in*

[3] A condition in an ASM is also known as a *guard*
[4] *Non-deterministic Finite Automata* a.k.a. *Non-deterministic State Machine*
[5] *Deterministic Finite Automata* a.k.a. *Deterministic State Machine*

the type of value the δ returns: a set of states in the case of an NFA and a single state in the case of a DFA

These definitions will be used to build the arguments for the class that generates the skeleton C# code from the ASM. This will be addressed in section 10.

3 Hubbers and Oostdjiks Paper

Hubbers and Oostdijk created a prototype tool, AutoJML, which automatically derives JML specifications from UML state diagrams.

The AutoJML tool accepts UML state diagrams as input and generates skeleton Java code with JML specifications. The JML adds the invariants, pre- and postconditions for each method, class wide. Using the generated code the software engineer still has to create the actual program, but the program can be verified against the generated specification.

Hubbers and Oostdijk use the following state diagram, Fig. 3-1, as an example to test their tool with.

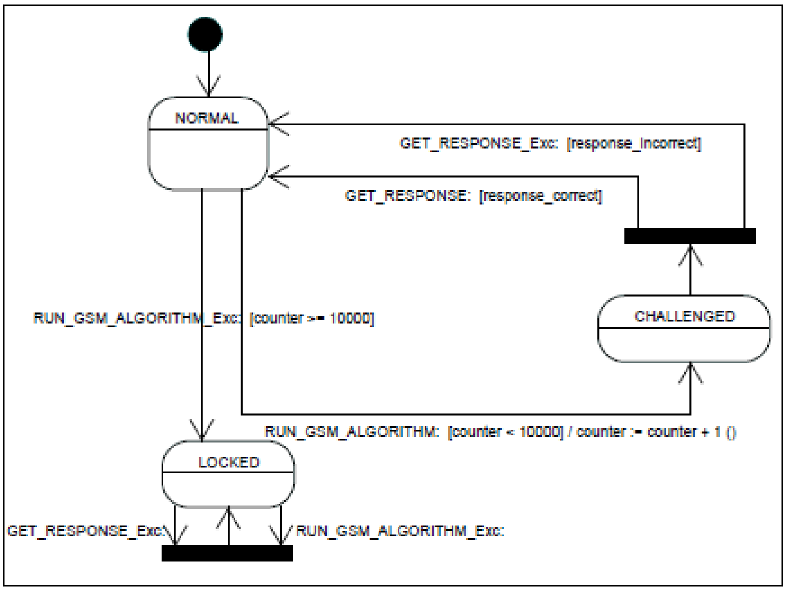


Fig. 3-1: GSM authentication state diagram

The example is taken from the world of the Global System for Mobile communication (GSM). Hubbers and Oostdijk describe the example as follows:

> *"GSM uses a cryptographic protocol to authenticate the Subscriber Identity Module (SIM), which is embedded in the cell phone, to the network service provider…*
>
> *… On a more concrete level the standard describes the protocol using two commands which can be sent to the SIM: **RUN_GSM_ALGORITHM** and **GET_RESPONSE**. The key $\boldsymbol{K_I}$ is a 16-byte number stored in the SIM, the challenge **RAND** is a 16-byte number sent to the SIM in the data field of the byte sequence representing the **RUN_GSM_ALGORITHM** command. The response (SRES, $\boldsymbol{K_C}$), a 12-byte number (4 for SRES, 8 for $\boldsymbol{K_C}$) is the result of running the Comp128 algorithm with key $\boldsymbol{K_I}$ and input*

***RAND**. This is sent back in the data field of the response byte sequence after sending the **GET_RESPONSE** command. The **RUN_GSM_ALGORITHM** command should be followed by a **GET_RESPONSE** command."*

Using the AutoJML they produced the following code:

```
/*@ invariant
    mode==LOCKED || mode==CHALLENGED || mode==NORMAL;
*/

/*@ constraint
    (mode==LOCKED ==> \old(mode)==NORMAL || \old(mode)==LOCKED) &&
    (mode==CHALLENGED ==> \old(mode)==NORMAL) &&
    (mode==NORMAL ==> \old(mode)==CHALLENGED) &&
    (\old(mode)==LOCKED ==> mode == LOCKED) &&
    (\old(mode)==CHALLENGED ==> mode==NORMAL) &&
    (\old(mode)==NORMAL ==> mode==CHALLENGED || mode==LOCKED);
*/

/*@
    requires true;
    modifies mode, counter;
    ensures
        \old(mode)==NORMAL && counter < 10000 ==> mode==CHALLENGED;
    exsures (ISOException)
        \old(mode)==LOCKED ==> mode==LOCKED;
    exsures (ISOException)
        \old(mode)==NORMAL && counter >= 10000 ==> mode==LOCKED;
*/

private void processRUN_GSM_ALGORITHM(APDU apdu)
throws ISOException {
    if (mode==LOCKED) {
        mode = LOCKED;
        ISOException.throwIt(SW_UNKNOWN);
    } else if (mode==NORMAL && counter < 10000) {
        counter = (short)(counter + 1);
        mode = CHALLENGED;
    } else if (mode==NORMAL && counter >= 10000) {
        mode = LOCKED;
    ISOException.throwIt(SW_UNKNOWN);
    }
}
```

The postconditions are indicated with ensures and exsures. The exsures is similar to ensures but only handles exceptions.

3.1 The Thesis compared to the Paper

At the current time there is no tool for the .NET environment which has the same functionality as the AutoJML tool. There are extensions in VS2010 where it is possible to create ASM diagrams, but it is not possible to generate code based on the model.

So the idea for the thesis is to create an extension/tool, where users can create an ASM diagram and generate skeleton C# code. Clearly the JML is not part of .NET environment, so another way of adding the pre- and postconditions, invariants, and the constraints has to be resolved. One solution is Code Contracts, an overview of Code Contracts can be read in section 6.

The example state diagram that from Hubbers and Oostdijk, Fig. 3-1, and their generated code is going to be used in this thesis as a base for testing the extension. The diagram has the needed elements for testing, and their generated code is used for comparison with the ASM extensions generated code. Furthermore their generated code is used for the Code Contracts section of this paper, to solve the issues regarding the functionalities that JML has, but Code Contracts do not have.

4 The ASM Extension

Fig. 4-1 shows a use case, which explains how the user interacts with the ASM extension and the functionality of it. The iterative process square is an indication that the users can do those processes over and over before the validation of the ASM. The generated code file is placed on the user's desktop on the computer.

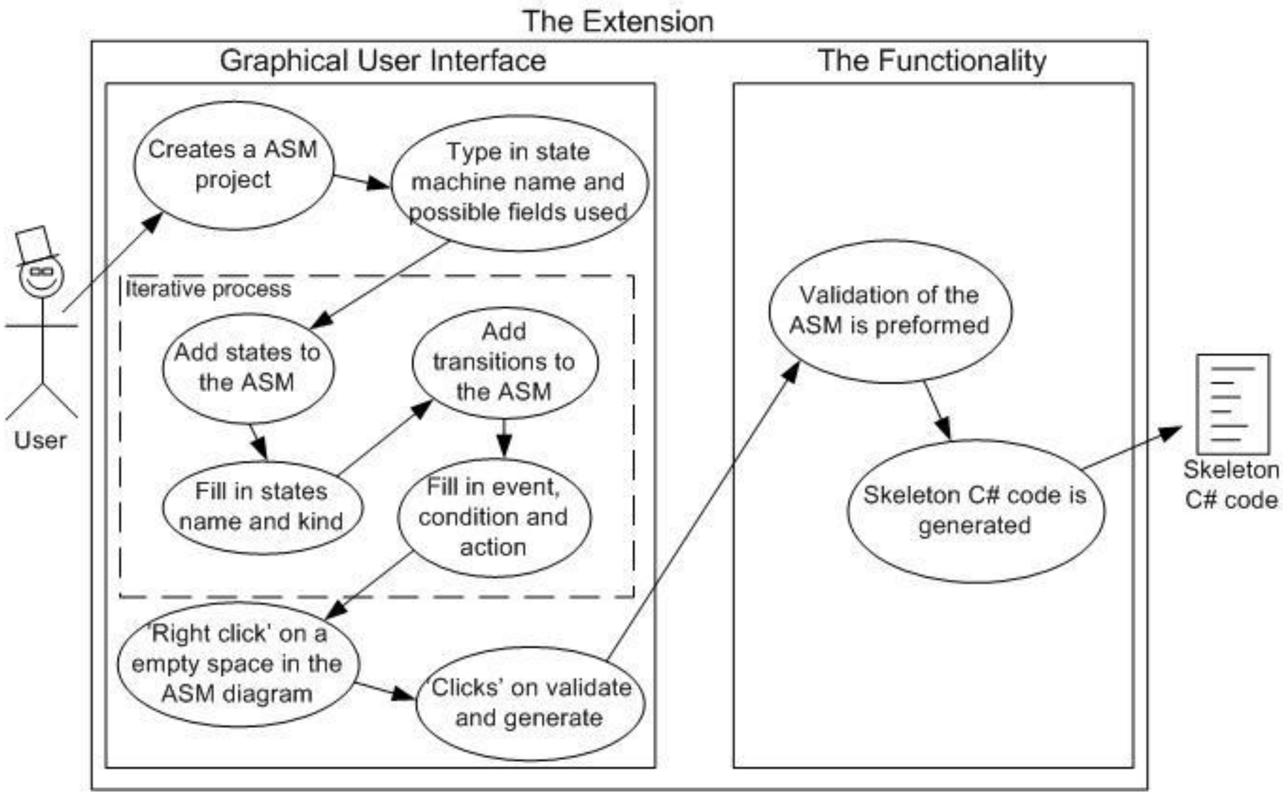


Fig. 4-1: Use Case for the ASM extension

4.1 Current Features

States can be set to different kinds of states, such as *initial*, *normal* or *final*, where normal is the default kind. The transitions can be set to *normal* or *epsilon* kind. The epsilon transitions make it possible to create NFAs. Bear in mind that setting the kind to *epsilon* means that no code is going to be generated based on the info in the transition.

At the current time, with the ASM extension, it is only possible to generate skeleton C# code with added Code Contracts. The Code Contracts contain postconditions, invariants and constraints for the code.

4.2 Future Work

Future work could be to add hard constraints to the transition property fields. The constraints add an additional feature to the extension, making the property field's dependant on each other. The fields *Event*, *Condition* and *Action* generates the *Label* in the form of *Event(possible argument) [Condition] / Action*. Furthermore the user can fill in the label, and the other three properties will be filled out based on the label. The constraint on the actual label is that it has to be filled out in the form described above.

Prompting the user in case of an infinite loop in the ASM, could be a valid addition to features in the extension. The prompt should be information about an infinite loop in the ASM, where the user can acknowledge with pressing "OK" or "Cancel".

Another possible feature could be to implement ASM generation from C# code, where the user can add an existing .cs file to the ASM project, right click on it, select *"Generate ASM"*, and a .asm file will be created. The DSL can show files in different formats, e.g. the .asm file can be shown as an ASM diagram but also as a XML file, so the generated code would be in the form of XML language. The XML code for the GSM authentication ASM diagram can be seen in appendix A. With this feature the user can see if the ASM is still the same after they modified the generated code.

Another item which could be implemented is XML code generation for UPPAAL, a model-checking tool. The UPPAAL tool can, among other things, check invariants and reachability properties of an ASM. The generate button would be placed in the same group as the *"Validate and Generate"*–button is placed, when the user right clicks on an empty space in the ASM diagram.

5 Extension Walkthrough

Installing the extension is done by 'double clicking' on the file *AsgerJensen.ASM.DslPackage* in the *ASM\DslPackage\bin\Debug* directory and accepting to install it, when the installation window shows. To use the extension the user needs to open up their VS2010 and create a standard project, seen in Fig. 5-1.

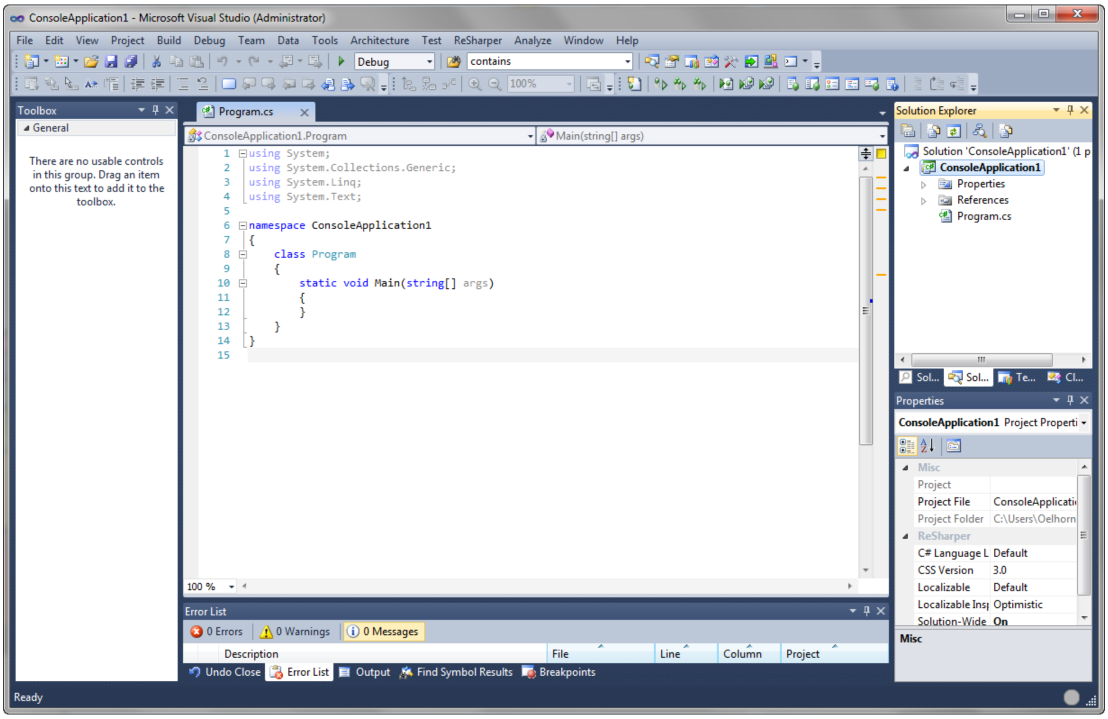


Fig. 5-1: Screenshot of a VS2010 project

From here the user has to 'right click' the project folder, choose Add -> New Item, pick an *ASM* file, name it and 'click' *Add*. In this example the .asm file is named *LightSwitch*, shown in Fig. 5-2.

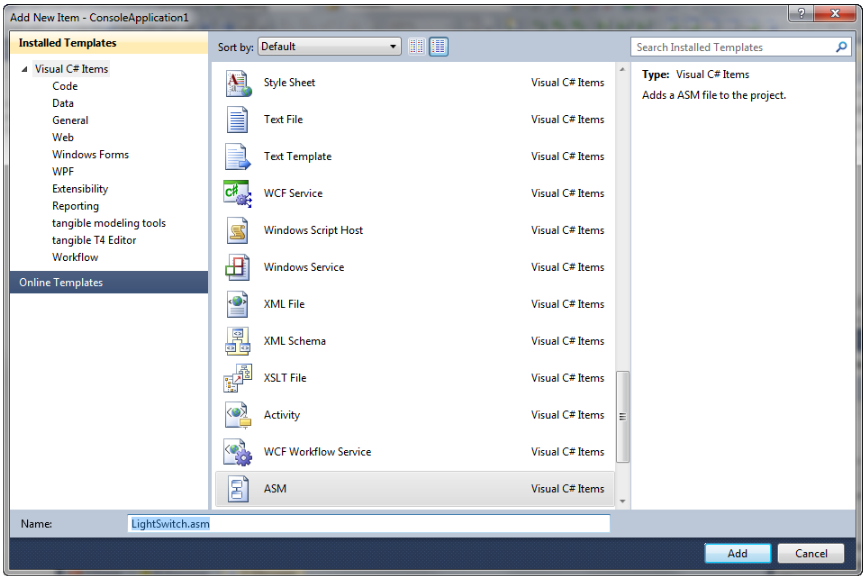


Fig. 5-2: Screenshot of a *Add Item* window

The newly added .asm file is now added to the project and opened up. Fig. 5-3 shows the opened .asm file. To the right, is the toolbox containing the state- and transition tool. Here the user should fill in the name of the ASM diagram, which is done in the properties window, in the lower right corner, that is displayed when they 'click' on an empty space in the ASM diagram.

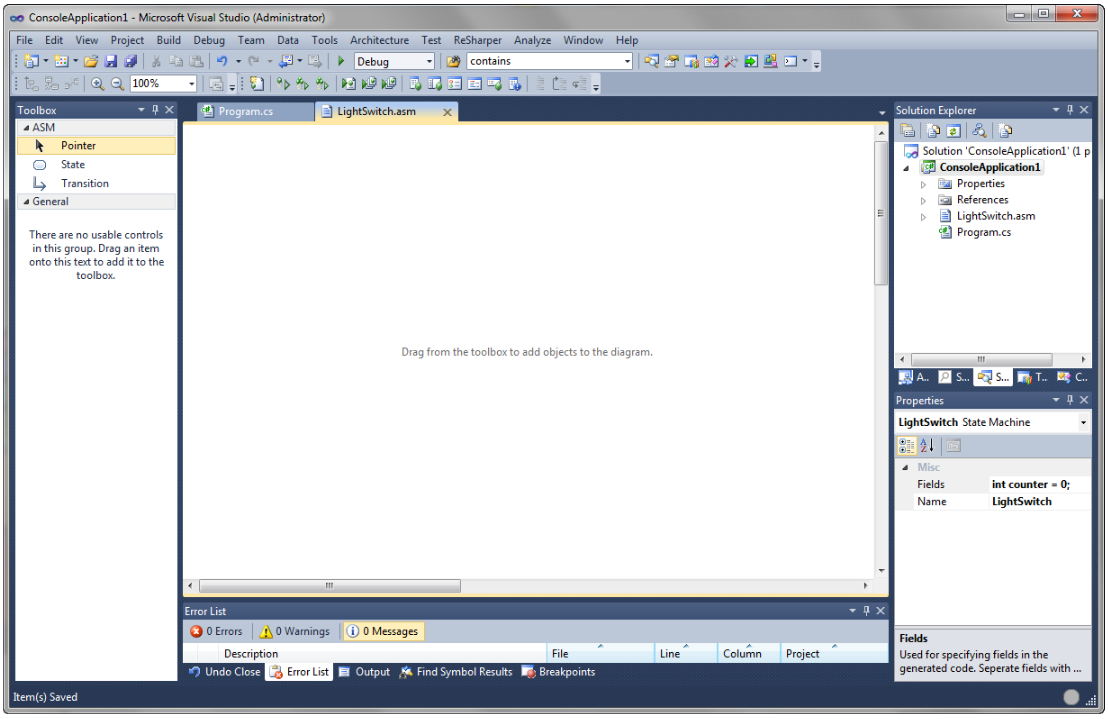


Fig. 5-3: Screenshot of the opened .asm file

Now the user can add states to the diagram by ‘clicking’ on the state tool and dragging it into the diagram. In this example two states have been added *Off* and *On*, shown in Fig. 5-4. The properties for the state are shown in the properties window in the lower right corner, which is shown when the user ‘clicks’ on a state. Here the kind of the state can be set. *Off* is set to *Initial* and *On* is set to *Final*.

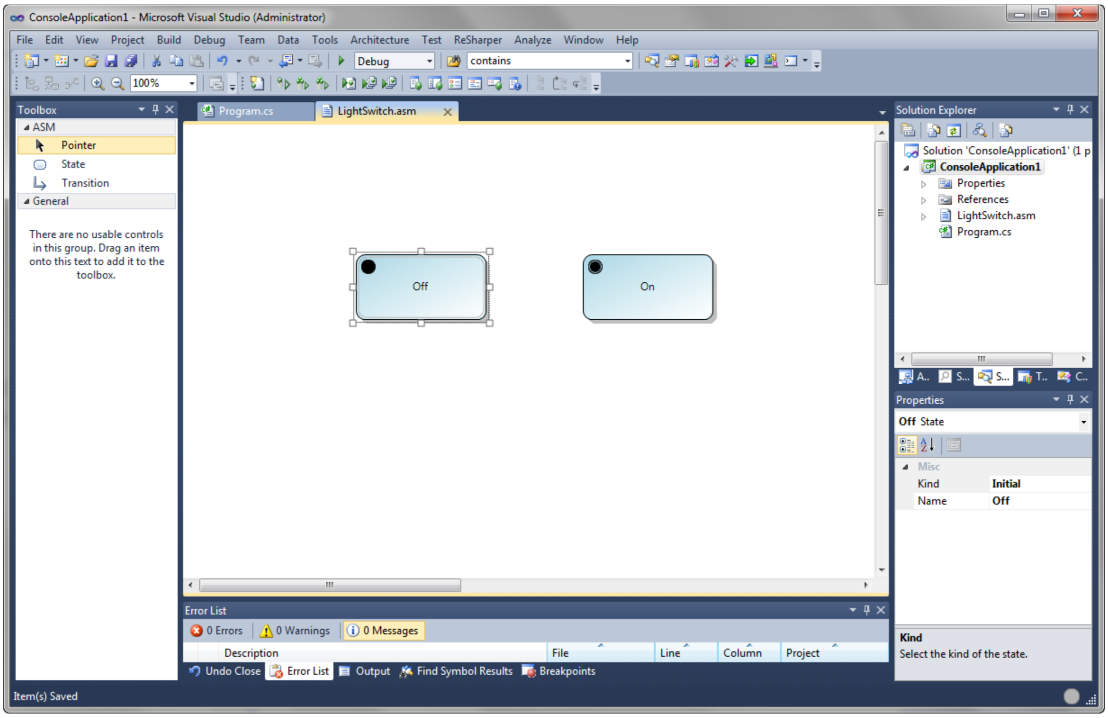


Fig. 5-4: Screenshot of two added states

Transitions between the states are added by ‘clicking’ on the transition tool, then ‘click’ on the state it should go from, and then ‘click’ on the state it should go to. Fig. 5-5 shows the added transition between the states. Its properties are also filled out in the lower right corner, when the user has selected the transition. In the example the transition as the event/method call *Switch*, the condition *counter >= 0* and the action *counter++*.

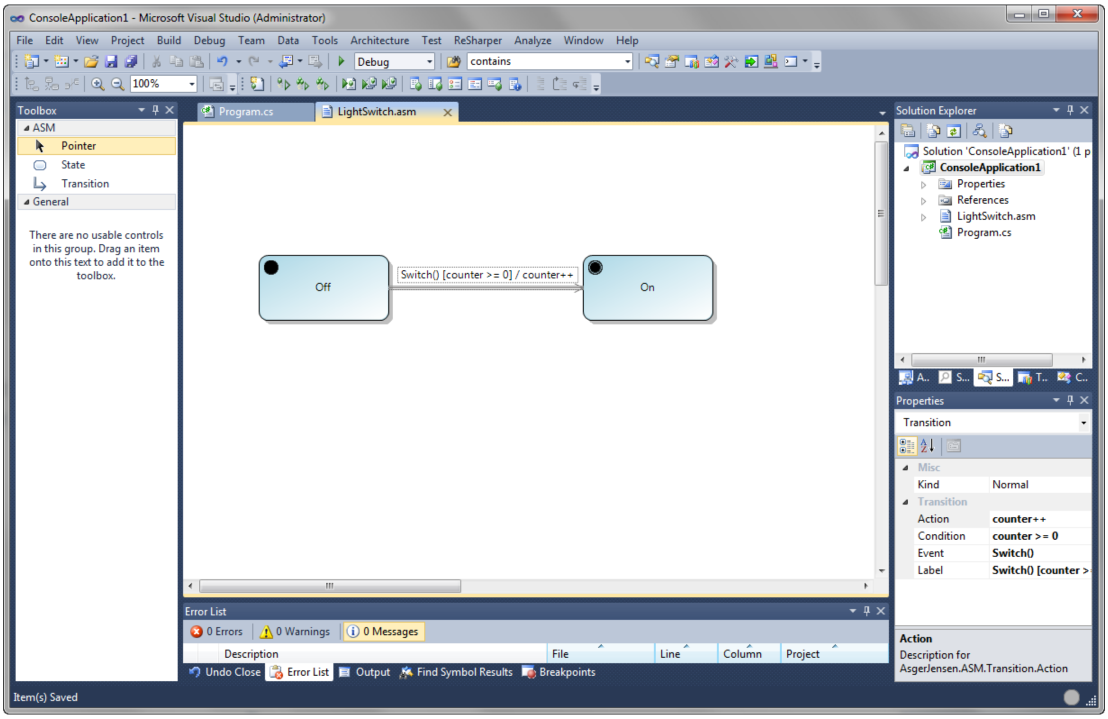


Fig. 5-5: Screenshot of the added transition

To generate the C# skeleton code, the user ‘right clicks’ an empty space in the diagram and selects *Validate and Generate*. The file can be found on the user’s desktop and can easily be shown in VS2010 by ‘double clicking’ it. The generated code from the *LightSwitch* example can be seen in appendix B.

6 Code Contracts

Code Contracts is an extension to Visual Studio (VS) which brings the advantages of design-by-contract[6] programming to all .NET languages. With Code Contracts it is possible to add preconditions, postconditions and invariants to ones code. *The contract is used to improve testing via runtime checking, enables static contract verification, and documentation generation* [7].

Using Code Contracts one restricts, in a good way, how the code can possibly behave. Other than helping out the author of the code, the contract also helps other users of the code, whether they are working with the actual code or working with a subclass of the code, since Code Contracts are inherited.

[6] “*An approach for designing software. It prescribes that software designers should define formal, precise and verifiable interface specifications for software components, which extend the ordinary definition of abstract data types with preconditions, postconditions and invariants.*” Ref. Wikipedia

6.1 Precondition, Postcondition and Invariant

Code Contracts contains a lot of functionalities, so will only address some of the functionalities of precondition, postcondition and invariant, which were part of the solution to the issue with not having the possibility of using JML.

Preconditions, expressed by *Contract.Require(…)*, for methods are conditions that have to be valid when the method is invoked. All the variables used in the preconditions have to be of same accessibility as the method itself or the condition cannot be satisfied by the method callers.

Postconditions, on the other hand, are conditions that have to be valid just before exiting the method, and is expressed by *Contract.Ensures(…)*. If a particular exception should be thrown in the postcondition, the *Contract.EnsuresOnThrow<T>* should be used. It is **not** recommended to use the type *Exception* for *T*, since *Exception* is to "superficial". The exception thrown will not address what the actual exception is, like stack overflow or some other exception. *T* should be what a caller expects as part of the application programming interface (API), e.g. *FileNotFoundException*. The last postcondition functionality that will be addressed is *OldValue*. *OldValue* makes it possible to refer to the old value of an expression, expressed by *Contract.OldValue<T>(e)* where *T* is the type of *e*.

Invariants[7] are also conditions. Invariants hold the terms for which an object of the class is in a "good" state. So when an object of the class is visible to a client, these terms need to hold. Compared to the conditions, the Invariants are declared in their own private void method. The method is identified with the attribute *[ContractInvariantMethod]*, and the individual invariants are specified with *Contract.Invariant*.

6.2 Issues with Code Contracts and Solutions

Comparing the generated JML specification from the paper [1] with the Code Contracts functionalities, some issues occurred. The following example from the paper will be used to state the issues and solution.

```
(mode==LOCKED ==> \old(mode)==NORMAL || \old(mode)==LOCKED)
```

Firstly, code Contracts does not have a way of modeling constraints as JML does. The solution is to model the JML constraints as Code Contracts invariants, since the constraint is an expression that returns *true* or *false*, which is what invariant expressions also should do.

The next issue was to figure out how to get the previous value of the state. The postconditions in Code Contracts have the *OldValue* method, but that is only available in postconditions. The states from the ASM are modeled in the generated code by declaring an enumeration with the *Enum* keyword, as follows.

```
Enum State
{
    State1,
    State2,
    …
};
```

[7] Known as *Object Invariants* in Code Contracts, but will refer to them as *Invariants* in this paper

Using an enumeration like this, it is possible to hardcode[8] two fields that contain the value of the current state and the previous state in the generated code, named *_curState* and *_preState*. These two fields are used throughout the generated code to symbolize the state changes and to handle postconditions, conditions in the methods and also the invariants/constraints. The *_preState* field solved the issue with not having an *OldValue* method in the invariants.

The *Enum State* cannot be a value other than what is declared in the enumeration, which means that the actual invariant in the paper [1], declared

mode==LOCKED || mode==CHALLENGED || mode==NORMAL

is not needed in the C# generated code. But since the current state and the previous state have to be one of those three, what is the previous state of the initial state in the ASM? Hardcode an additional state, named *InvalidState*, to the *Enum State* was the answer. So when an object of the class is created, the previous state has the default value *InvalidState*. However, this means that one additional invariant needed to be hardcoded, since the current state can possibly end up being *InvalidState*. Furthermore when the current state is the initial state, the previous state can also be *InvalidState* or a valid state leading to the initial state. The hardcoded invariants and the added *InvalidState* to initial state constraint are shown below.

```
Contract.Invariant(_curState != State.InvalidState);

Contract.Invariant(_curState == State.Normal ? (_preState == State.Challenged |
                  _preState == State.InvalidState) : true);
```
[9]

The last issue was to model the "*implies*" notation ==>, since Code Contracts does not have that functionality. Looking at the example at the beginning of this section, and using *states* instead of *modes*, the constraint is "*if the state is LOCKED, that implies that the old value of the state was NORMAL or LOCKED*". The conditional operator "*?:*" in C#, also known as the ternary operator, is used to solve the predicament. The ternary operator is expressed as *condition ? expression_1 : expression_2* and returns one of the two expressions depending on outcome of the Boolean condition. In other words, the condition decides what expressions will be evaluated and the expressions determine the outcome of the entire ternary expression, which is *true* or *false*. So the conditions can be used to check what the current state is, the first part of the JML constraint example. If the second expression is set to default *true*, then the first expression can be used to define what should be implied, the last part of the JML constraint example. Leading to a ternary expression looking like this

```
_curState == State.Locked ? (_preState == State.Normal | _preState == State.Locked) : true
```

If current state is *Locked*, then the first expression will be evaluated, which states "*Is the previous state Normal or Locked?*". If the current state is not *Locked* then the second expression of the ternary will be evaluated, which is *true*, hence the invariant will be not throw an error and move on to the next invariant in the method.

[8] Meaning that the specific code will always be in the generated code, no matter how the ASM is designed
[9] This example code is from the generated code from the GSM authentication ASM

7 Building the DSL

When faced with a specific problem that occurs over and over e.g. designing an ASM, starting to code and losing similarity between the code and the ASM. A way of solving the issue is to build a Domain Specific Language (DSL) and add code generation to it.

The created extension contains two projects, Dsl and DslPackage. The Dsl contains the meta-model of the extension, customized code by the use of the partial class mechanism and generated code. The DslPackage contains; customized code, code that enables the DSL to be hosted and to interact with VS2010, where part of the code is generated from the DslDefinition.dsl, which is the meta-model. Since there is a lot of generated code, there will only be a walkthrough of the meta-model and a description of key points in the customized code.

7.1 The Meta-model

The meta-model is shown in the DslDefinition.dsl in the Dsl project. The DslDefinition.dsl is in sense a "DSL to create DSL's". There are two parts to it, shown in two *"Swimlanes"*, the meta-model[10] in the left section called "Classes and Relations", and the graphical notation in the right section called "Diagram Elements".

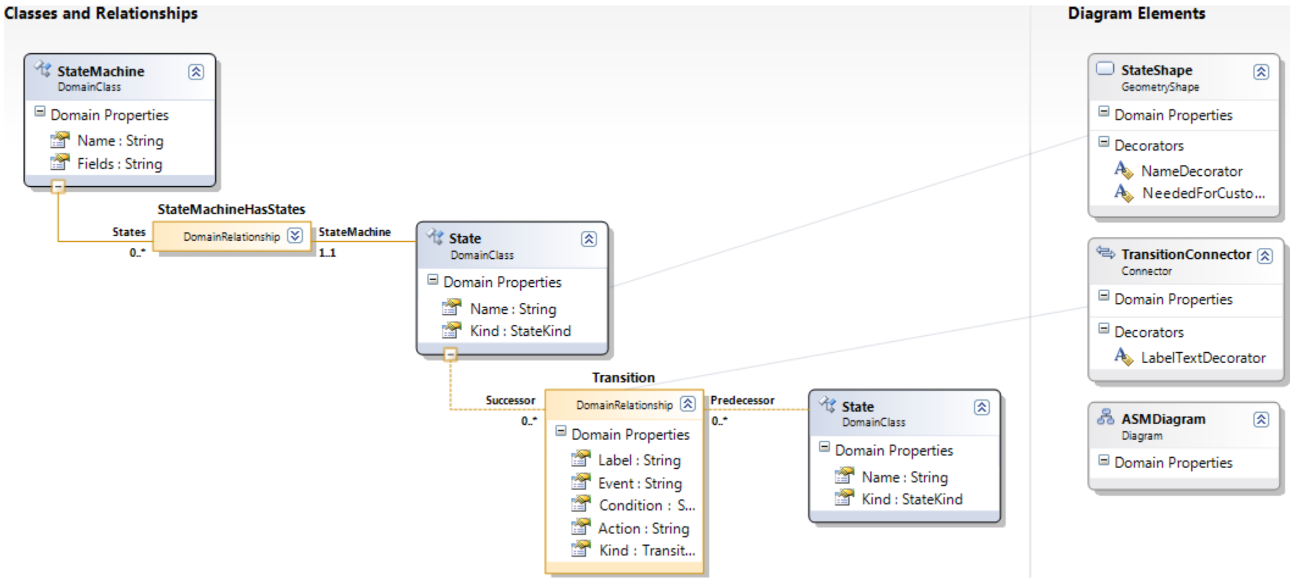


Fig. 7-1: Meta-model of the ASM extension

Fig. 7-1 shows the meta-model and graphical notation for the extension. The meta-model has two concepts; *StateMachine* and *State*, and two domain relationships; *StateMachineHasStates* and *Transition*. The link between the meta-model and the graphical notation is displayed by two connection lines from *State* to *StateShape* and from *Transition* to *TransitionConnector*.

The *StateMachine* is the root concept, meaning that it is never really shown when the user designs an ASM, since the root concept is the actual diagram. *StateMachine* has two domain properties, shown in Fig. 7-2. *Name* for naming ones ASM which will be the name of the generated class, and *Fields* which are for adding fields to the generated class.

---

[10] Also referred to as Domain Model

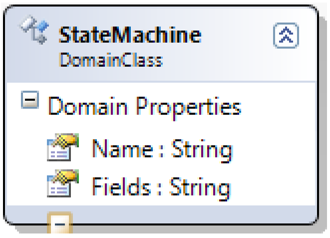


Fig. 7-2: The StateMachine element

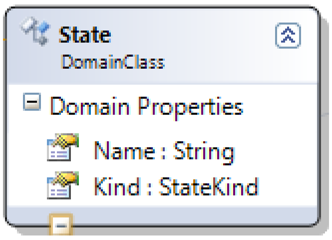


Fig. 7-3: The State element

The *State* is the only true concept the user really works with within the extension. *State* also has two domain properties, shown in Fig. 7-3. *Name* for naming the states, and *Kind* to specify what kind of state it is *Normal*, *Initial* or *Final*.

StateMachineHasStates, shown in Fig. 7-4, is an embedding relationship that links *State* to *State*, which are the elements in *StateMachine*. An explanation to embedded relationships can be seen in section 7.1.1 below.

Fig. 7-4: The StateMachineHasStates relation

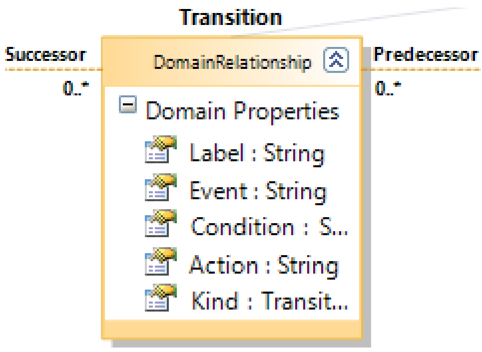


Fig. 7-5: The Transition relation

Transition is a reference relationship that links two *State* classes, shown in Fig. 7-5. The *Transition* relationship has several domain properties, since it is from the transitions most of the generated code comes from.

Label is the shown label on the transition which should be in the form *Event(possible argument) [Condition] / Action*. At the current time it is not a hard constraint but can be added in future version of the extension, explained in 4.2. *Event* can be viewed as the method call which changes the current state from one state to another state. *Condition* should contain the condition which needs to be met before moving from one state to another state. *Action* is a possible action that can happen in the transition from one state to another, e.g. exception thrown. *Kind* works the same way as for *State*, except there are only two kinds of transition *Normal*- and *Epsilon* transition.

An important aspect of the properties of *Transition* is that the *"Allow duplications"* field is set to *true*, since it should be possible to have more than one transition between two states.

7.1.1 Embedding and Reference Relations

In a meta-model every domain class, except the root, must be in relationship with at least one embedding relationship. Without the embedding it will not be possible to see the model explorer, serialization would not work and it would not be possible to create a tree of model elements. In other words, embeddings provide a path to navigate through the meta-model as a tree, where every element has exactly one parent element.

With the embedding relationship some constraints follow. The multiplicity on the target role must be *1* or *0..1*, because a model element can only be embedded once. Another constraint is, e.g. the root has several embeddings to several targets, the targets have to have the multiplicity *0..1* because only one model element can be embedded by one of those relationships at a time. Having one of the targets multiplicity as *1* would render all the other relationships impossible to instantiate. Furthermore the default deletion of a parent of an embedding, deletes also the child of the embedding.

Reference relationships, on the other hand, represents any kind of relationship which is not embedded and does not have constraints like embedded relationships. Generally a reference relationship can refer from any model element to any other model element, and the multiplicity is often *0..** on the roles. It is even possible to make a reference relation between two relationships, since links are themselves model elements. By deletion of a parent of a reference relation, it is only the parent and the reference link that gets deleted not the child of the relationship.

7.1.2 Allow Duplications

The transition allows duplications in the properties of *Transition* in the meta-model. Keeping this in mind, one needs to be aware, when using the *Successor* and *Predecessor* methods for states. For example, having two states with two transitions between them, shown in Fig. 7-6, gives the successor list from *State 1* *"State 2, State 2"*, even though there is only *State 2* as the successor.

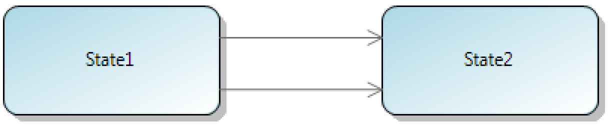


Fig. 7-6: Two states with to transitions

If not aware of this, then the generated code will contain the double amount of constraints for the two states in Fig. 2-1. When asking for the "link" between a state and a successor, another issue occurs. Below is C# code for getting the "link" between each state in the ASM and each of their successors.

```
foreach (var state in sm.States)
{
    foreach (var successor in state.Successor)
    {
        ReadOnlyCollection<Transition> transitions = Transition.GetLinks(state, successor);
    }
}
```

If using the example of the two states in Fig. 2-1, then you will get two transitions for each successor, meaning you will get four transitions in total, since there are two *State2* in the successor list. This means, that there will be double as many methods, conditions and postconditions in the generated code. Hence there will be N^2 as many methods with conditions and postconditions in the generated code, where *N* is the number of transitions. These issues have been take care of in the extension.

7.2 The Graphical Notation

The graphical notation of the ASM is designed after the principle of a control state ASM. States are squares with round corners. The initial and final state is indicated with an icon, in the upper left corner of the state. The initial icon is a fully black colored circle, and the final icon is a fully black colored circle with a ring around it, equivalent to how an initial- and final state looks in a FA. Transition is an arrow from one state to another. The epsilon transition is marked with an epsilon icon at the state, where the transition starts. The notations can be seen in Fig. 7-7.

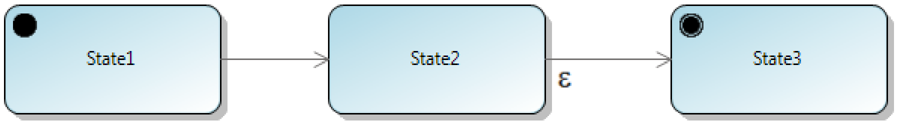


Fig. 7-7: Example of the ASM notation for the ASM extension

8 The Button

To activate the validation and code generation, a menu command has been added to the DSL. The menu command is found in the context menu when the user right clicks on an empty space in their ASM diagram. The menu command is named *Validate and Generate*.

The menu command can be defined so it is visible in the context menu in specific circumstances, or be visible but grayed out. For example, the menu command can be visible but grayed out when they right click an object in their ASM.

The reasoning for making the menu command only visible, when the user right clicks on an empty space in the diagram, is that the validation and the generation should be done for the entire ASM not for selected objects.

8.1 Declaring the Button and Functionality

The command is declared in the *Commmand.vsct* by adding a section/group in the menu and adding a button to that section/group. To be sure that the command is only loaded in the DSL, a visibility constraint is added. The *GUID*s and *ID*s for the group and the button are defined in the *Symbol* section at the end of the *Command.vsct* file. Several sections/groups and buttons can have the same *GUID*, but must have different *ID*s. For a more detailed view of the code, look in appendix C.

The DSL already has some commands in the generated partial class *CommandSet.cs*, so to add the behavior of the command a new partial class[11] was added. The added partial class contains two methods to handle the visibility of the command and the functionality.

The *OnMenuMyContextMenuCommand* method handles the functionality of the command button. It builds the needed sets for the validation and code generation, explained in section 2.3. Furthermore the method creates an object of the validation- and the code generator class, and calls the methods that validate the ASM and generate the code. For a more detailed view of the code, look in appendix D.

[11] Can be found in *DslPackage\CustomCode*

A set of final states and a set of input symbols have been created, based on the definition of an FA, but these sets are not used in the validation or the generation, since the transitions functions set holds the same information. These are still kept in the code for the possibility of future work on the extension.

9 Validation

To generate the skeleton C# code, some validation rules have to be created to make it possible to generate valid code. These rules are chosen by the author of the VS 2010 extension, because the Abstract State Machine has to be more concrete to generate code from. Even though a state machine with one state is in theory a valid state machine, it does not generate more code than a class with two fields and an enumerator.

9.1 Chosen Rules

The validation rules are as follows;

1. The state machine has to have states
2. There has to be one initial state, and only one
3. States have to have a name
4. States cannot have the same name
5. Every state, except initial state, has to have a predecessor
6. Every state, except final state, has to have a successor
7. Every transition, except epsilon transition, has to have a label
8. Transitions with the kind *Normal* cannot have the exact same event, condition and action

The rules have been created on the assumptions that the user actually wants to generate code, 1st rule. There has to be an initial state, and only one, in state machines, 2nd rule. Without a name on states and filled in properties on a normal transitions it is not possible to generate methods or the Code Contracts, 3rd and 7th rule. States could have the same name, but to keep the user from making the ASM to confusing with too many states with the same name the 4th rule was created. The 8th rule is in essence the definition of a deterministic state machine, which is described in section 2.3.

The 5th and 6th rule makes sure that all the states in the ASM are connected, so it is not possible for the user to create two ASMs in the same diagram. Furthermore the rules also say, together with 1st and 2nd rule, that there **has** to be an initial state and a transition to one other state, shown in Fig. 9-1, which means that the user **has** to create this as a minimum if they want to generate code.

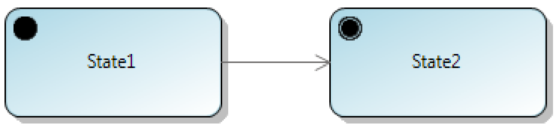


Fig. 9-1: ASM diagram containing the minimum about of states and transitions

Also if the ASM's last state is not a final state, there have to be a transition leading to itself, else it breaks the 6th rule and an exception is thrown, example shown in Fig. 9-2.

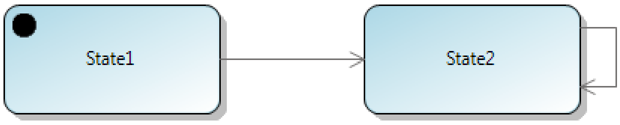


Fig. 9-2: ASM diagram with accepted last state, not marked as final

9.2 Considered Rules

In the process of choosing the right rules for the ASM other rules have come up in discussions. Rules such as;

- Must the ASM contain one final state?
- Should the ASM only have one final state?
- Should infinite loops be allowed in the ASM?

When designing state machines it is good practice to have an initial state and a final state, but sometimes it is needed to design a system which should not stop running at any point, e.g. the state machine in the Hubbers and Martijn paper [1], where the state *Locked* is the “final state” but it doesn’t shut down the system. Therefore it should not be mandatory to have a final state.

With regards to having more than one final state, it is a matter of design and overview of the system. One could argue that several final states would make the ASM look cluttered, but having transitions running from several states to the final state through all the other transitions would cause the same issue. So, it is possible to have more than one final state.

Most often infinite loops in systems, algorithms etc. are considered a bug. But there are situations where users want to model a system, where there should be an infinite loop, such as reactive systems like websites. So having the possibility of modelling an infinite loop in the ASM extension seems reasonable, but there should be a prompt about an existing infinite loop. This feature can be implemented in future versions of the extension, also written in section 4.2.

9.3 The Code

For validating the ASM the class *Validation*[12] has been created, which takes three arguments; *states*, *inputSymbols* and *startState*. They are all of type *HashSet*, since the same arguments are used in the code generator. The code generating class takes arguments sets because of the DFA and NFA definition, described in section 2.3.

One could argue against having the *startState* of type *HashSet* since there is only supposed to be one initial state, but keeping all the validation together in one file, rather than several places trough out the DSL, was the only reason for it.

Since the validation is based on the rules written in section 9.1, the solution for the validation are if-statements where an exception is thrown, when the ASM does not adhere to the rules.

For a more in depth view of the code, see appendix E.

[12] Can be found in *DslPackage\CustomCode*

10 Generating C# Code

The C# code is generated in the *CodeGenerator.cs*[13] class. The class uses the argument sets containing the ASM states, the ASM name, the ASM fields, the transition function from the ASM and the initial state.

The process of generating the code is sequential where each bit of code is created in a "builder" method, added to a *StringBuilder* and gets written to the .cs file with the name of the ASM. The sequence of how the code is built and written to the file can be seen in Fig. 10-1. The sequence does not show the formatting methods for the generated code.

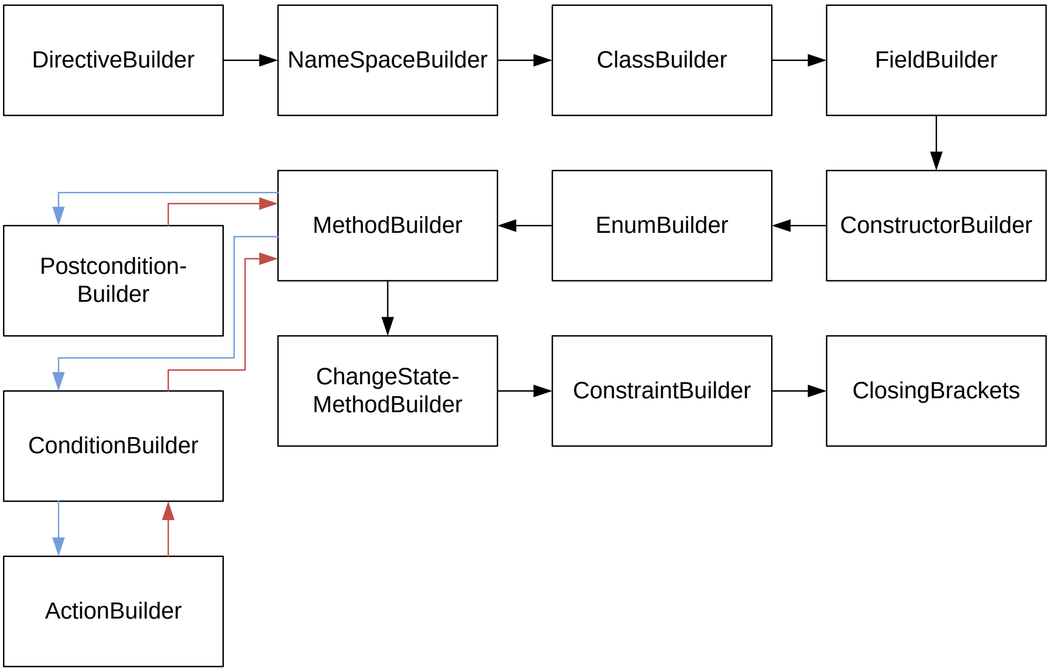


Fig. 10-1: The sequential flow of code generation

In Fig. 10-1 the black arrows symbolizes what is written to the file. The *PostconditionBuilder*, *Condition-Builder* and *ActionBuilder* are not written directly to the file, but are part of what the *MethodBuilder* creates, shown with light blue- and red arrows.

The idea of only using one *String* as the container for the created code was thought of, but since there is no limitation to the size of the ASM, it could be possible to go over the maximum amount of bits a *String* has. As a precaution a *StringBuilder* was chosen as a container instead, where at the beginning of each "build method" the *StringBuilder* is cleared, since the code from the previous "build method" have already been written to the .cs file.

While the code is being generated, formatting is added to it, so the code looks like standard C# code. To do this some formatting methods were created, named *Tab, StartBracket* and *EndBracket*. These three methods work together with the *bracketCounter* to keep track of how many tabs are in front of each line of code. This is done by incrementing the *bracketCounter* each time a start bracket '{' is added to the code, and decrementing the *bracketCounter* when an end bracket '}' is added. Since the generated code is

[13] Can be found in *DslPackage\CustomCode*

written to the file as it gets build, there are a lack of end brackets at the end of the file. The *ClosingBracket* method takes care of this together with the formatting methods and the *bracketCounter*.

The source code for *CodeGenerator.cs* can be seen in appendix F.

10.1 The Generated Code

An equivalent ASM to the GSM authentication state diagram, have been created to show what the *CodeGenerator* class generates. The GSM authentication state diagram can be seen in section 3, where as the equivalent ASM using the ASM extension, is shown in Fig. 10-2.

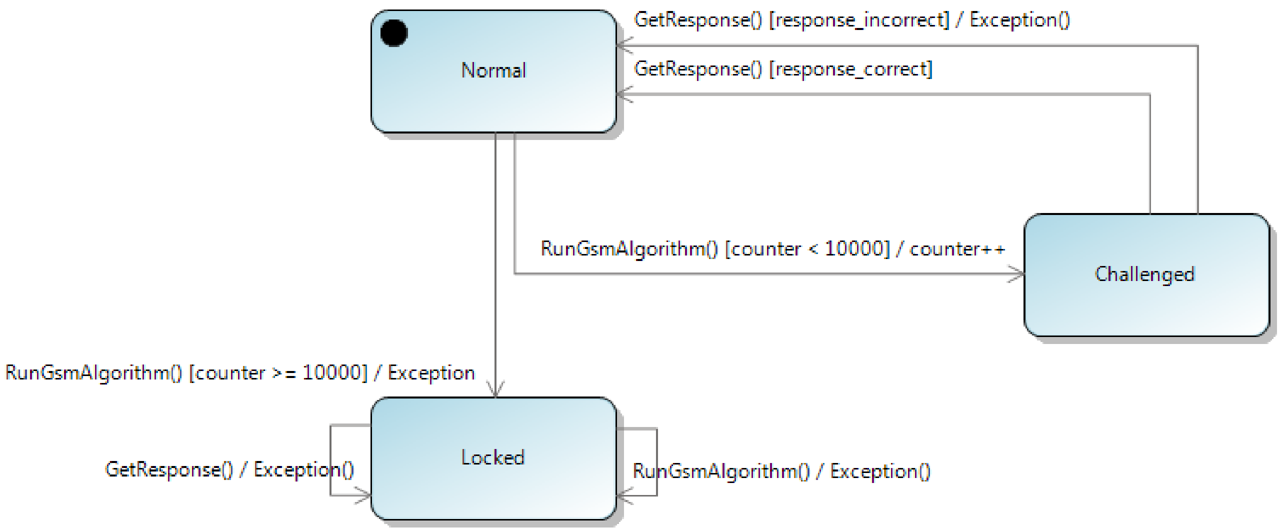


Fig. 10-2: GSM authentication ASM

The generated code from the ASM can be seen in appendix G.

In the generated code, one can see that transition *Event* is equivalent to a method call with the same name. The transition *Condition* is an if-statement containing what the current state should be and what conditions needs be met for the state change. The transition *Action* is what happens in the if-statement if it is *true*, hence the conditions are met.

The accessibility of the class and the different methods are not written, which means that they are *Private* by default in C#. It is up to the user of the code to add the appropriate accessibility.

11 Test

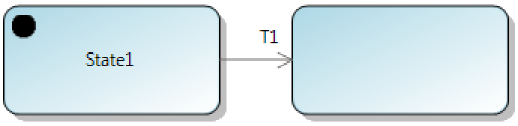
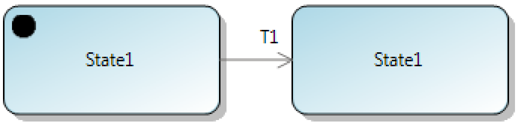
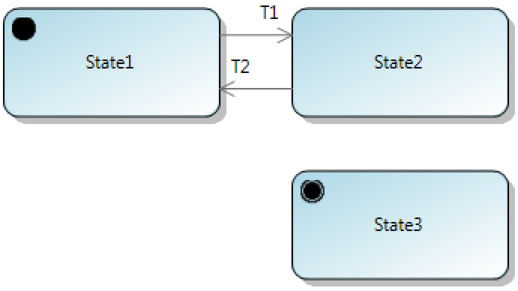
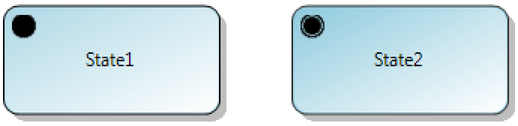
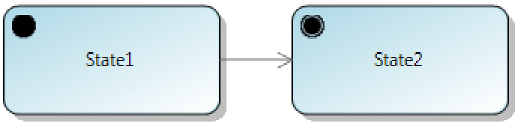
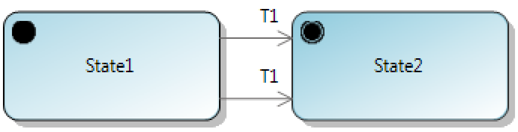
The test will be divided up into two, one that covers validation and one that covers code generation. The validation test will be done with test cases, whereas test of the code generation will be done by creating an ASM that has 100% code generation coverage.

11.1 Validation test

To test the validation code, test cases have been created to trigger the exception handlers. The test cases are black box testing, so they are bases on the validation rules, described in the validation paragraph, and **not** derived from the code.

Preconditions for the test cases are; operation system is Windows, using VS 2010 Ultimate and ASM extension installed.

Postcondition for the test cases is; an exception is thrown.

Test Case	Input	Output
1	(Empty ASM)	Exception thrown: *"The ASM has to have states"*
2		Exception thrown: *"There have to be one initial state, and only one"*
3		Exception thrown: *"States have to have a name"*
4		Exception thrown: *"States can't have the same name"*
5		Exception thrown: *"Every state, except initial state, has to have a predecessor"*
6		Exception thrown: *"Every state, except final state, has to have a successor"*
7		Exception thrown: *"Every transition, except epsilon transition, has to have a label"*
8		Exception thrown: *"Transitions cannot have same event and condition and action"*

11.2 Generation test

Test of the generation code is done with an ASM which will give 100% code coverage. To display the 100% code coverage a Boolean array, with the length of the number of methods in the generation code, has been created. A method called *CheckMark* have been created which changes the Boolean value in the array, at a specific index, from 0 to 1 if it is not 1 already.

Each index in the array is equivalent to a method in the generation code, so when the method is called, the *CheckMark* method is called. The *CheckMark* method takes the *method number* as an argument and changes the value at the index number in the array.

The used ASM for the test is the ASM shown in Fig. 10-2, above.

Below is the result of the test coverage.

```
Test Coverage Results:
True True True True True True True True True True True True True True True True True True True True
True True
```

12 Conclusion

The outcome of this thesis is a VS2010 extension, where users have the possibility to create an ASM and generate contracted C# skeleton code from it. The generated code uses Code Contracts to keep the constraints of the ASM diagram.

ASMs are used to describe hardware and software systems. They help contractors and developers to create a common view of how the system should be put together and what it should contain. The ground model of the ASM can be split up into stepwise refining ASMs, which describes more in-depth how a state in the ground model should work.

Programming the stepwise refining ASM is a time consuming process for programmers and they can easily lose the equality between the ASM and the code they have created. The created extension would solve this problem.

Using Code Contracts did raise some issues since it does not have the same features as JML specifications. The issue with “implies” from the JML specifications was solved with the ternary operator. Constraints are modeled as invariants with the ternary operator. The *OldValue* functionality cannot be used in other places than postconditions, so hardcoding a previous state field in the code was necessary.

Future versions of the extension could hold features such as hard constraints to the transition properties, a feature where the user gets prompted about an infinite loop in the created ASM, the possibility of generating an ASM diagram from C# code, and the feature to generate XML code for third party software like UPPAAL.

13 Literature List

[1] Engelbert Hubbers, Martijn Oostdijk. *Generating JML Specification from UML State Diagrams*. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.183.4351&rep=rep1&type=pdf

[2] Egon Börger, Robert Stärk. *Abstract State Machines: A Method for High-Level System Design and Analysis*. ISBN 3-540-00702-4

[3] John E. Hobcroft, Rajeev Motwani, Jeffrey D. Ullman. *Introduction to Automata Theory, Languages, and Computation*. Second Edition. ISBN 0-201-44124-1

[4] Steve Cook, Gareth Jones, Stuart Kent, Alan Cameron Wills. *Domain-Specific Development with Visual Studio DSL Tools*. ISBN-13: 978-0-321-39820-8

[5] Microsoft Corporation. *Code Contracts User Manual*. January 8, 2012

[6] Egon Börger. *The Abstract State Machine Method for High-Level System Design and Analysis*. http://www.di.unipi.it/~boerger/Papers/Methodology/BcsFacs07.pdf

[7] Microsoft Research/Microsoft Corporation. *Code Contracts*. http://research.microsoft.com/en-us/projects/contracts/

[8] R. N. Taylor, N. Medvidovic, E. M. Dashofy. *Software Architecture: Foundations, Theory, and Practice*. ISBN-10: 0470167742

[9] Martin Fowler. *UML Distilled: A Brief Guide to the Standard Object Modeling Language*. Third Edition. ISBN 0-321-19368-7

14 Software

Product name: *Microsoft Visual Studio 2010 Ultimate*. Version: *10.0.30319.1 RTMRel*.

Product name: *Microsoft Code Contracts (academic) 1.4.40602.0 for .NET*. Filename: *Contracts.msr9.msi*. Authors: *Microsoft Corporation*. Revision number: *{22366D81-6B52-4B5C-AD79-153DEFD6641D}*

Product name: *Visualization and Modeling SDK*. Filename: *vs_vmsdk.exe*. Authors: *Microsoft Corporation*. File version: *10.0.30319.2*.

Product name: *Visual Studio SDK*. Filename: *VsSDK_sfx.exe*. Authors: *Microsoft Corporation*. File version: *10.0.30319.1*.

Appendix A

XML code for the GSM authentication ASM

```xml
<?xml version="1.0" encoding="utf-8"?>
<stateMachine xmlns:dm0="http://schemas.microsoft.com/VisualStudio/2008/DslTools/Core" dslVersion="1.0.0.0"
Id="c01cec70-761c-4951-a22f-8e313498a675" name="GsmAuthenticator" fields="int counter = 0;"
xmlns="http://schemas.microsoft.com/dsltools/ASM">
  <states>
    <state Id="d557fb93-ef08-4aaf-b99e-c521c189967d" name="Normal" kind="Initial">
      <successor>
        <transition Id="a156ab27-b62d-4b08-b212-6c5a50dd590c" label="RunGsmAlgorithm() [counter &lt; 10000] /
counter++" event="RunGsmAlgorithm()" condition="counter &lt; 10000" action="counter++">
          <stateMoniker name="/c01cec70-761c-4951-a22f-8e313498a675/Challenged" />
        </transition>
        <transition Id="8d10e2dc-da3a-4d9c-9cc3-8808947339fc" label="RunGsmAlgorithm() [counter &gt;= 10000]
/ Exception" event="RunGsmAlgorithm()" condition="counter &gt;= 10000" action="Exception()">
          <stateMoniker name="/c01cec70-761c-4951-a22f-8e313498a675/Locked" />
        </transition>
      </successor>
    </state>
    <state Id="9b6c2a22-a768-43fd-81a4-02e46f166a00" name="Challenged" kind="Normal">
      <successor>
        <transition Id="4b39a648-9dcd-4eb5-91e9-a7a9d002996a" label="GetResponse() [response_incorrect] /
Exception()" event="GetResponse()" condition="response_incorrect" action="Exception()">
          <stateMoniker name="/c01cec70-761c-4951-a22f-8e313498a675/Normal" />
        </transition>
        <transition Id="59848c74-0d4f-43fa-b257-896e346f546f" label="GetResponse() [response_correct]"
event="GetResponse()" condition="response_correct">
          <stateMoniker name="/c01cec70-761c-4951-a22f-8e313498a675/Normal" />
        </transition>
      </successor>
    </state>
    <state Id="1c6e3594-0f98-40d4-a3de-edc1e254858b" name="Locked" kind="Normal">
      <successor>
        <transition Id="c992a49e-c99b-4c95-8558-34d0cf3f557b" label="RunGsmAlgorithm() / Exception()"
event="RunGsmAlgorithm()" action="Exception()">
          <stateMoniker name="/c01cec70-761c-4951-a22f-8e313498a675/Locked" />
        </transition>
        <transition Id="d57945c2-4979-43aa-9101-6045b6f2000b" label="GetResponse() / Exception()"
event="GetResponse()" action="Exception()">
          <stateMoniker name="/c01cec70-761c-4951-a22f-8e313498a675/Locked" />
        </transition>
      </successor>
    </state>
  </states>
</stateMachine>
```

Appendix B

Generated C# Code from Light Switch ASM

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Diagnostics.Contracts;

namespace LightSwitch
{
   class LightSwitch
   {
      State _curState;
      State _preState;
      int counter = 0;

      LightSwitch()
      {
         _curState = State.Off;
         _preState = State.InvalidState;
      }

      enum State
      {
         InvalidState,       // Do NOT remove this state, used in Code Contracts
         Off,
         On
      }

      void Switch()
      {
         Contract.Ensures((_preState == State.Off & counter >= 0) ? _curState == State.On : true);

         if (_curState == State.Off & counter >= 0)
         {
            StateChange(State.On);
            counter++;
         }
      }

      private void StateChange(State name)
      {
         _preState = _curState;
         _curState = name;
      }

      [ContractInvariantMethod]
      private void ObjectInvariantsAndConstraints()
      {
         Contract.Invariant(_curState != State.InvalidState);

         Contract.Invariant(_curState == State.Off ? _preState == State.InvalidState : true);
         Contract.Invariant(_curState == State.On ? _preState == State.Off : true);
         Contract.Invariant(_preState == State.Off ? _curState == State.On : true);
      }
   }
}
```

Appendix C

The *Commands.vsct* Code

```xml
<?xml version="1.0" encoding="utf-8"?>
<CommandTable xmlns="http://schemas.microsoft.com/VisualStudio/2005-10-
18/CommandTable" xmlns:xs="http://www.w3.org/2001/XMLSchema">
  <!-- -->
  <!-- This file contains custom command definitions. -->
  <!-- -->
  <!-- NOTE: Each time commands are added or changed, the "version" parameter to the -->
  <!-- ProvideMenuResource attribute in Shell\Package.tt should be incremented. -->
  <!-- This causes Visual Studio to re-merge the menu definitions for the package. -->
  <!-- Otherwise, changes won't take effect until the next time devenv /setup is run. -->
  <!-- -->
  <Extern href="stdidcmd.h"/>
  <Extern href="vsshlids.h"/>
  <Extern href="msobtnid.h"/>
  <Extern href="virtkeys.h"/>
  <Extern href="DSLToolsCmdID.h"/>
  <Include href="GeneratedCode\GeneratedVsct.vsct"/>
  <Commands package="guidPkg">

    <!-- Define a group - a section in the menu -->
    <Groups>
      <Group guid="guidCustomMenuCmdSet" id="grpidMyMenuGroup" priority="0x0100">
        <!-- These symbols are defined in GeneratedVSCT.vsct -->
        <Parent guid="guidCmdSet" id="menuidContext" />
      </Group>
    </Groups>
    <!-- Define a button - a menu item - inside the Group -->
    <Buttons>
      <Button guid="guidCustomMenuCmdSet" id="cmdidMyContextMenuCommand"
        priority="0x0100" type="Button">
        <Parent guid="guidCustomMenuCmdSet" id="grpidMyMenuGroup"/>
        <!-- If you do not want to place the command in your own Group,
         use Parent guid="guidCmdSet" id="grpidContextMain".
         These symbols are defined in GeneratedVSCT.vsct -->
        <CommandFlag>DynamicVisibility</CommandFlag>
        <Strings>
          <ButtonText>Validate and Generate</ButtonText>
        </Strings>
      </Button>
    </Buttons>

  </Commands>

  <VisibilityConstraints>
    <!-- Ensures the command is only loaded for this DSL -->
    <VisibilityItem guid="guidCustomMenuCmdSet" id="cmdidMyContextMenuCommand"
      context="guidEditor"/>
  </VisibilityConstraints>

  <Symbols>
    <!-- Substitute a unique GUID for the placeholder: -->
    <GuidSymbol name="guidCustomMenuCmdSet"
      value="{3B0B0E1E-A694-4CAF-BF50-2DE073E7BC36}" >
      <IDSymbol name="grpidMyMenuGroup" value="0x01001"/>
      <IDSymbol name="cmdidMyContextMenuCommand" value="0x00001"/>
    </GuidSymbol>
  </Symbols>

</CommandTable>
```

Appendix D

The Partial *ASMCommandSet* Class

```
using System;
using System.Collections.Generic;
using System.Collections.ObjectModel;
using System.ComponentModel.Design;
using System.Linq;
using AsgerJensen.ASM.Custom_Code;
using Microsoft.VisualStudio.Modeling;
using Microsoft.VisualStudio.Modeling.Shell;

namespace AsgerJensen.ASM
{
    /// <summary>
    /// Partial class, which add the command menu and functionality to the button
    /// </summary>
    internal partial class ASMCommandSet
    {
        // Declaration of the GUID and ID
        private Guid guidCustomMenuCmdSet = new Guid("3B0B0E1E-A694-4CAF-BF50-2DE073E7BC36");
        private const int grpidMyMenuGroup = 0x01001;
        private const int cmdidMyContextMenuCommand = 0x00001;


        // For each command define a OnStatus... method
        private void OnStatusMyContextMenuCommand(object sender, EventArgs e)
        {
            // The command is not visible all the time
            var command = sender as MenuCommand;
            command.Visible = command.Enabled = false;

            // If the diagram, itself, is selected, then the command is visible
            if (IsDiagramSelected())
                command.Visible = command.Enabled = true;
        }

        // For each command define a OnMenu... method
        private void OnMenuMyContextMenuCommand(object sender, EventArgs e)
        {
            var command = sender as MenuCommand;
            Store store = this.CurrentDocData.Store;

            // State machine variable to get hold of the different elements in the current diagram
            var sm = (StateMachine) CurrentDocView.DocData.RootElement;

            // smInitStates is only a set because the validation check is in another class
            var smInitStates = new HashSet<State>();
            var smFinalStates = new HashSet<State>();       // For future work
            var smInputSymbols = new HashSet<String>();     // For future work
            var smTransitionsFunctions = new HashSet<Pair<Pair<State, Transition>, State>>();
            var smStates = new HashSet<State>();

            // Used for validation
            var smTransitions = new HashSet<Transition>();

            foreach (var state in sm.States)
            {
                // Adds the states to a hashset
                smStates.Add(state);

                // Adds initial states to a hashset
                if (state.Kind == StateKind.Initial)
                    smInitStates.Add(state);

                // Adds final states to a hashset
                if (state.Kind == StateKind.Final)
                    smFinalStates.Add(state);
```

```
                // Used to prevent duplicate states, which can occur
                // when using "successor" and "predecessor" method on a state
                var preventDuplicateList = new List<State>();

                if (state.Successor.Any())
                {
                    foreach (var successor in state.Successor)
                    {
                        ReadOnlyCollection<Transition> transitions = Transition.GetLinks(state, successor);

                        if (!preventDuplicateList.Contains(successor))
                        {
                            preventDuplicateList.Add(successor);

                            foreach (var transition in transitions)
                            {
                                // Temp variables to help build the hashset of transition functions
                                var tempSet = new Pair<State, Transition>(state, transition);
                                var transitionFunction = new Pair<Pair<State, Transition>, State>(tempSet, su
ccessor);

                                if (!smTransitions.Contains(transition))
                                {
                                    smTransitions.Add(transition);

                                    // Adds input symbols to a hashset
                                    smInputSymbols.Add(transition.Event);
                                }

                                // Adds to the hashset the transition function in the form of ((StateA, input
), StateB)
                                if (!smTransitionsFunctions.Contains(transitionFunction))
                                    smTransitionsFunctions.Add(transitionFunction);
                            }
                        }
                    }
                }
            }

            // Initializes the validation checker and does the validation check
            var valid = new Validation(smStates, smTransitions, smInitStates);
            valid.Check();

            // Initializes the code generator and generates the file
            var code = new CodeGenerator(smStates, sm.Name, sm.Fields, smTransitionsFunctions, smInitStates.F
irst());
            code.GenerateFile();
        }

        protected override IList<MenuCommand> GetMenuCommands()
        {
            // Get the list of generated commands.
            IList<MenuCommand> commands = base.GetMenuCommands();
            // Add a custom command:
            var myContextMenuCommand =
              new DynamicStatusMenuCommand(
                new EventHandler(OnStatusMyContextMenuCommand),
                new EventHandler(OnMenuMyContextMenuCommand),
                new CommandID(guidCustomMenuCmdSet, cmdidMyContextMenuCommand));
            commands.Add(myContextMenuCommand);
            // Add more commands here.
            return commands;
        }
    }
}
```

Appendix E

The *Validation* Class

```
using System;
using System.Collections.Generic;
using System.Linq;

namespace AsgerJensen.ASM
{
    /// <summary>
    /// Class intended for validation of a state machine before code generation
    /// </summary>
    public class Validation
    {
        // State machine fields to hold of the different elements in the current diagram
        private readonly HashSet<State> _states;
        private readonly HashSet<Transition> _transitions;
        private readonly HashSet<State> _startState;

        /// <summary>
        /// The contructor
        /// </summary>
        /// <param name="states"></param>
        /// <param name="transitions"></param>
        /// <param name="startState"></param>
        public Validation(HashSet<State> states, HashSet<Transition> transitions, HashSet<State> startState)
        {
            _states = states;
            _transitions = transitions;
            _startState = startState;
        }

        /// <summary>
        /// Validation method, used for the ASM to see if it passes the validation rules
        /// </summary>
        public void Check()
        {
            // Temporary list - default string
            var temp = new List<String>();

            // Rule: The ASM must contain states
            if (!_states.Any())
                throw new Exception("Your ASM must contain states.");

            // Rule: There have to be one initial state, and only one
            if (_startState.Count() != 1)
                throw new Exception("There have to be one initial state, and only one.");


            foreach (var state in _states)
            {
                // Rule: States must have a name
                if (!state.Name.Any())
                    throw new Exception("States have to have a name.");

                // Rule: States can not have the same name
                if (!temp.Contains(state.Name))
                    temp.Add(state.Name);
                else
                    throw new Exception("States can not have same name.");

                // Rule: All states, except end state, must have a successor
                if (state.Successor.Count == 0 && state.Kind != StateKind.Final)
                    throw new Exception("Every state, except final state, has to have a successor.");

                // Rule: All states, except start state, must have a predecessor
                if (state.Predecessor.Count == 0 && state.Kind != StateKind.Initial)
                    throw new Exception("Every state, except initial state, has to have a predecessor.");
            }
```

```
            // Cleares temp list for use later on
            temp.Clear();

            foreach (var transition in _transitions)
            {
                if (transition.Kind != TransitionKind.Epsilon)
                {
                    // Rule: Transitions must have a label, except epsilon
                    if (!transition.Label.Any())
                        throw new Exception("Every transition, except epsilon transition, has to have a label
.");
                }
            }

            // Used to check for transitions which has the same Event, Condition and Action
            IList<Transition> transitionList = _transitions.ToList();

            // Compares with the next transition
            for (int i = 0; i < transitionList.Count; i++)
            {
                if (transitionList[i].Kind != TransitionKind.Epsilon)
                {
                    for (int j = i + 1; j < transitionList.Count; j++)
                    {
                        if (transitionList[j].Kind != TransitionKind.Epsilon)
                        {
                            // Rule: There cannot be transitions with same Event, Condition and Action
                            if (transitionList[i].Event.Equals(transitionList[j].Event) &&
                                transitionList[i].Condition.Equals(transitionList[j].Condition) &&
                                transitionList[i].Action.Equals(transitionList[j].Action))
                                throw new Exception("Transitions with the kind Normal cannot have the exact s
ame Event, Condition and Action.");
                        }
                    }
                }
            }
        }
    }
}
```

Appendix F

The *CodeGenerator* Class

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.IO;

namespace AsgerJensen.ASM.Custom_Code
{
    /// <summary>
    /// Class for generating C# code from an ASM diagram build in the DSL environment
    /// </summary>
    public class CodeGenerator
    {
        private readonly HashSet<State> _states;
        private readonly String _stateMachineName;
        private readonly List<String> _fields;
        private readonly HashSet<Pair<Pair<State, Transition>,State>> _transitionsSet;
        private readonly State _initialState;
        private int _bracketCounter = 0;
        private StringBuilder _sb = new StringBuilder();

        // Used for displaying the test coverage
        private bool[] testCoverage = new bool[21];

        /// <summary>
        /// Contructor
        /// </summary>
        /// <param name="states"></param>
        /// <param name="stateMachineName"></param>
        /// <param name="fields"></param>
        /// <param name="transitionsSet"></param>
        /// <param name="initialState"></param>
        public CodeGenerator(HashSet<State> states, String stateMachineName, String fields, HashSet<Pair<Pair
<State, Transition>, State>> transitionsSet, State initialState)
        {
            CheckMark(0);    // For testing

            _states = states;
            _stateMachineName = stateMachineName;
            _fields = fields.Split(',').ToList();
            _transitionsSet = transitionsSet;
            _initialState = initialState;
        }

        /// <summary>
        /// Method which calls the write to the different creates items in the .cs file
        /// </summary>
        public void GenerateFile()
        {
            CheckMark(1);    // For testing

            string strPath = Environment.GetFolderPath(Environment.SpecialFolder.DesktopDirectory);

            using (StreamWriter w = File.AppendText(strPath + "\\" + _stateMachineName + ".cs"))
            {
                Write(DirectiveBuilder(), w);
                Write(NameSpaceBuilder(), w);
                Write(ClassBuilder(), w);
                Write(FieldBuilder(),w);
                Write(ConstructorBuilder(), w);
                Write(EnumBuilder(), w);
                Write(MethodBuilder(), w);
                Write(ChangeStateMethodBuilder(), w);
                Write(ConstraintBuilder(), w);
                Write(ClosingBrackets(),w);
                w.Close();
```

```
    }

    PrintTestCoverage();    // Shows the test coverage results
}

/// <summary>
/// Is the writer, who writes the creates code to the file
/// </summary>
/// <param name="s"></param>
/// <param name="w"></param>
private void Write(String s, TextWriter w)
{
    CheckMark(2);   // For testing

    w.Write(s);
    w.Flush();
}

/// <summary>
/// Creates the standard directives used, together with the ones needed
/// for Code Contracts
/// </summary>
/// <returns></returns>
private String DirectiveBuilder()
{
    CheckMark(3);   // For testing

    _sb.AppendLine("using System;\r\n" +
                   "using System.Collections.Generic;\r\n" +
                   "using System.Linq;\r\n" +
                   "using System.Text;\r\n" +
                   "using System.Diagnostics.Contracts;\r\n");
    return _sb.ToString();
}

/// <summary>
/// Creates the namespace
/// </summary>
/// <returns></returns>
private String NameSpaceBuilder()
{
    CheckMark(4);   // For testing

    _sb.Clear();
    _sb.AppendLine("namespace " + _stateMachineName);
    _sb.AppendLine(StartBracket());
    return _sb.ToString();
}

/// <summary>
/// Creates the class from the name of the ASM
/// </summary>
/// <returns></returns>
private String ClassBuilder()
{
    CheckMark(5);   // For testing

    _sb.Clear();
    _sb.AppendLine(Tab() + "class " + _stateMachineName);
    _sb.AppendLine(Tab() + StartBracket());
    return _sb.ToString();
}

/// <summary>
/// Creates the fields in the class
/// </summary>
/// <returns></returns>
private String FieldBuilder()
{
    CheckMark(6);   // For testing
```

```
            _sb.Clear();
            _sb.AppendLine(Tab() + "State _curState;");
            _sb.AppendLine(Tab() + "State _preState;");

            foreach (var field in _fields)
            {
                _sb.AppendLine(Tab() + field);
            }

            _sb.AppendLine();
            return _sb.ToString();
        }

        /// <summary>
        /// Creates the contructor in the class
        /// </summary>
        /// <returns></returns>
        private String ConstructorBuilder()
        {
            CheckMark(7);   // For testing

            _sb.Clear();
            _sb.AppendLine(Tab() + _stateMachineName + "()");
            _sb.AppendLine(Tab() + StartBracket());
            _sb.AppendLine(Tab() + "_curState = State." + _initialState.Name + ";");
            _sb.AppendLine(Tab() + "_preState = State.InvalidState;");
            _sb.AppendLine(EndBracket() + "\r\n");
            return _sb.ToString();
        }

        /// <summary>
        /// Creates the Enum containing the states of the ASM
        /// </summary>
        /// <returns></returns>
        private String EnumBuilder()
        {
            CheckMark(8);   // For testing

            _sb.Clear();
            _sb.AppendLine(Tab() + "enum State");
            _sb.AppendLine(Tab() + StartBracket());
            _sb.AppendLine(Tab() + "InvalidState," + "\t\t // Do NOT remove this state, used in Code Contract
s");

            var temp = _states.ToList();    //Casting it to List to remove "," after last state
            foreach (var state in temp)
            {
                _sb.Append(Tab() + state.Name);
                if (!state.Equals(temp.Last()))
                    _sb.AppendLine(",");
                else
                    _sb.AppendLine();
            }
            _sb.AppendLine(EndBracket() + "\r\n");
            return _sb.ToString();
        }

        /// <summary>
        /// Creates the methods in the class
        /// </summary>
        /// <returns></returns>
        private String MethodBuilder()
        {
            CheckMark(9);   // For testing

            _sb.Clear();

            // Method is key value and value is a list of states and transition between them
            var methodsWithTransitionSets = new Dictionary<String, List<Pair<Pair<State, Transition>,State>>>
();
```

```
            foreach (var set in _transitionsSet)
            {
                // If the transition between two states is an epsilon transition
                // then there will not be created any code for it
                if (set.First.Second.Kind != TransitionKind.Epsilon)
                {
                    if (!methodsWithTransitionSets.ContainsKey(set.First.Second.Event))
                    {
                        var conditionList = new List<Pair<Pair<State, Transition>,State>>();
                        conditionList.Add(set);
                        methodsWithTransitionSets.Add(set.First.Second.Event, conditionList);
                    }
                    else
                        methodsWithTransitionSets[set.First.Second.Event].Add(set);
                }
            }

            // Builds the postcondition(s) and condition(s) for each method
            foreach (var method in methodsWithTransitionSets)
            {
                _sb.AppendLine(Tab() + "void " + method.Key);
                _sb.AppendLine(Tab() + StartBracket());

                _sb.AppendLine(PostconditionBuilder(method.Value));

                _sb.AppendLine(ConditionBuilder(method.Value));

                _sb.AppendLine(EndBracket() + "\r\n");
            }
            return _sb.ToString();
        }

        /// <summary>
        /// Creates the postconditions in each method
        /// </summary>
        /// <param name="list"></param>
        /// <returns></returns>
        private String PostconditionBuilder(List<Pair<Pair<State, Transition>, State>> list)
        {
            CheckMark(10);    // For testing

            var tempSb = new StringBuilder();

            foreach (var transition in list)
            {
                if (!Contains(transition.First.Second.Action, "exception", StringComparison.CurrentCultureIgn
oreCase))
                {
                    if (transition.First.Second.Condition.Any())
                    {
                        tempSb.Append(Tab() + "Contract.Ensures((_preState == State." + transition.First.Firs
t.Name);
                        tempSb.Append(" & " + transition.First.Second.Condition + ")");
                    } else
                        tempSb.Append(Tab() + "Contract.Ensures(_preState == State." + transition.First.First
.Name);

                    tempSb.AppendLine(" ? _curState == State." + transition.Second.Name + " : true);");
                } else
                {
                    if (transition.First.Second.Condition.Any())
                    {
                        tempSb.Append(Tab() + "Contract.EnsuresOnThrow<" + transition.First.Second.Action);
                        tempSb.Append(">((_preState == State." + transition.First.First.Name);
                        tempSb.Append(" & " + transition.First.Second.Condition + ")");
                    } else
                    {
                        tempSb.Append(Tab() + "Contract.EnsuresOnThrow<" + transition.First.Second.Action);
                        tempSb.Append(">(_preState == State." + transition.First.First.Name);
                    }
```

```
                tempSb.AppendLine(" ? _curState == State." + transition.Second.Name + " : true);");
            }
        }

        return tempSb.ToString();
    }

    /// <summary>
    /// Creates the conditions for the state change in the methods
    /// </summary>
    /// <param name="conditionList"></param>
    /// <returns></returns>
    private String ConditionBuilder(List<Pair<Pair<State, Transition>, State>> conditionList)
    {
        CheckMark(11);   // For testing

        var tempSb = new StringBuilder();

        foreach (var condition in conditionList)
        {
            if (condition.Equals(conditionList.First()))
            {
                tempSb.Append(Tab() + "if (" + "_curState == State." + condition.First.First.Name);
                if (condition.First.Second.Condition.Any())
                    tempSb.Append(" & " + condition.First.Second.Condition);

                tempSb.AppendLine(")");
                tempSb.AppendLine(Tab() + StartBracket());
                tempSb.Append(ActionBuilder(condition));
                tempSb.Append(EndBracket());
            }

            if (!condition.Equals(conditionList.First()))
            {
                tempSb.AppendLine();
                tempSb.Append(Tab() + "else if (" + "_curState == State." + condition.First.First.Name);
                if (condition.First.Second.Condition.Any())
                    tempSb.Append(" & " + condition.First.Second.Condition);

                tempSb.AppendLine(")");
                tempSb.AppendLine(Tab() + StartBracket());
                tempSb.Append(ActionBuilder(condition));
                tempSb.Append(EndBracket());
            }
        }
        return tempSb.ToString();
    }

    /// <summary>
    /// Creates the actions upon state change in the methods
    /// </summary>
    /// <param name="transition"></param>
    /// <returns></returns>
    private String ActionBuilder(Pair<Pair<State, Transition>, State> transition)
    {
        CheckMark(12);   // For testing

        var tempSb = new StringBuilder();

        tempSb.AppendLine(Tab() + "StateChange(State." + transition.Second.Name + ");");

        if (Contains(transition.First.Second.Action, "exception", StringComparison.CurrentCultureIgnoreCa
se))
            tempSb.AppendLine(Tab() + "throw new " + transition.First.Second.Action + "();");
        else if (transition.First.Second.Action.Any())
            tempSb.AppendLine(Tab() + transition.First.Second.Action + ";");
        return tempSb.ToString();
    }

    /// <summary>
    /// Creates a hardcoded method for changing states in the
```

```
        /// generated code
        /// </summary>
        /// <returns></returns>
        private String ChangeStateMethodBuilder()
        {
            CheckMark(13);   // For testing

            _sb.Clear();
            _sb.AppendLine(Tab() + "private void StateChange(State name)");
            _sb.AppendLine(Tab() + StartBracket());
            _sb.AppendLine(Tab() + "_preState = _curState;");
            _sb.AppendLine(Tab() + "_curState = name;");
            _sb.AppendLine(EndBracket() + "\r\n");
            return _sb.ToString();
        }

        /// <summary>
        /// Creates the invariants and contraints for the Code Contracts
        /// </summary>
        /// <returns></returns>
        private String ConstraintBuilder()
        {
            CheckMark(14);   // For testing

            _sb.Clear();
            _sb.AppendLine(Tab() + "[ContractInvariantMethod]");
            _sb.AppendLine(Tab() + "private void ObjectInvariantsAndConstraints()");
            _sb.AppendLine(Tab() + StartBracket());
            _sb.AppendLine(Tab() + "Contract.Invariant(_curState != State.InvalidState);\r\n");

            // Creates all the constraints, current state => previous state
            foreach (var state in _states)
            {
                _sb.Append(Tab() + "Contract.Invariant(_curState == State." + state.Name + " ? ");

                if (state.Predecessor.Any())
                {
                    if (state.Predecessor.Count() == 1)
                    {
                        if (state.Kind == StateKind.Initial)
                        {
                            _sb.Append("(_preState == State." + state.Predecessor.First().Name);
                            _sb.AppendLine(" | _preState == State.InvalidState) : true);");
                        }
                        else
                            _sb.AppendLine("_preState == State." + state.Predecessor.First().Name + " : true)
;");
                    }
                    else if (state.Predecessor.Count() > 1)
                    {
                        var purgedList = new List<State>(DuplicationPurge(new List<State>(state.Predecessor))
);

                        if (purgedList.Count() == 1)
                        {
                            if (state.Kind == StateKind.Initial)
                            {
                                _sb.Append("(_preState == State." + state.Predecessor.First().Name);
                                _sb.AppendLine(" | _preState == State.InvalidState) : true);");
                            }
                            else
                                _sb.AppendLine("_preState == State." + state.Predecessor.First().Name + " : t
rue);");
                        }
                        else
                        {
                            _sb.Append("(");
                            foreach (var element in purgedList)
                            {
                                _sb.Append("_preState == State." + element.Name);
                                if (!element.Equals(purgedList.Last()))
```

```
                        _sb.Append(" | ");
                    }
                    if (state.Kind == StateKind.Initial)
                        _sb.Append(" | _preState == State.InvalidState");
                    _sb.AppendLine(") : true);");
                }
            }
        } else // Initial state does not have a predecessor
        {
            _sb.AppendLine("_preState == State.InvalidState : true);");
        }
    }

    // Creates all the constraints, previous state => current state
    foreach (var state in _states)
    {
        if (state.Successor.Any())
        {
            _sb.Append(Tab() + "Contract.Invariant(_preState == State." + state.Name + " ? ");

            if (state.Successor.Count() == 1)
                _sb.AppendLine("_curState == State." + state.Successor.First().Name + " : true);");
            else
            {
                var purgedList = new List<State>(DuplicationPurge(new List<State>(state.Successor)));

                if (purgedList.Count == 1)
                    _sb.AppendLine("_curState == State." + state.Successor.First().Name + " : true);"
);

                else
                {
                    _sb.Append("(");
                    foreach (var item in purgedList)
                    {
                        _sb.Append("_curState == State." + item.Name);
                        if (!item.Equals(purgedList.Last()))
                            _sb.Append(" | ");
                        else
                            _sb.AppendLine(") : true);");
                    }
                }
            }
        }
    }
    _sb.AppendLine(EndBracket());
    return _sb.ToString();
}

/// <summary>
/// Adds the last end brackets to the generated code,
/// based on the amount of start brackets used minus the
/// amount of end brackets used
/// </summary>
/// <returns></returns>
private String ClosingBrackets()
{
    CheckMark(15);    // For testing

    _sb.Clear();
    for (int i = 0; i <= _bracketCounter; i++)
    {
        _sb.AppendLine(EndBracket());
    }
    return _sb.ToString();
}

/// <summary>
/// Help method for formatting the generated code.
/// Keeps track of start brackets added in the generated code,
/// so there will be the same amount of end brackets
/// </summary>
```

```
/// <returns></returns>
private String StartBracket()
{
    CheckMark(16);    // For testing

    _bracketCounter++;
    return "{";
}

/// <summary>
/// Help method for formatting the generated code.
/// Keeps track of start- and end brackets used.
/// If an end bracket is used, then the overall bracket count is reduced
/// </summary>
/// <returns></returns>
private String EndBracket()
{
    CheckMark(17);    // For testing

    if (_bracketCounter != 0)
        _bracketCounter--;
    return Tab() + "}";
}

/// <summary>
/// Help method for formatting the generated code.
/// Keeps track of the amount of 'Tab' is needed on each line of
/// the generated code. The Tab method is dependent on the overall
/// bracket count
/// </summary>
/// <returns></returns>
private String Tab()
{
    CheckMark(18);    // For testing

    var sb = new StringBuilder();
    for (int i = 0; i < _bracketCounter; i++)
    {
        sb.Append("\t");
    }
    return sb.ToString();
}

/// <summary>
/// Removes equal items in the list,
/// e.g. removing 2 of the 3 equal states in a successor list,
/// if state 1 has three transitions to state 2
/// </summary>
/// <typeparam name="T"></typeparam>
/// <param name="list"></param>
/// <returns></returns>
private List<T> DuplicationPurge<T>(IEnumerable<T> list)
{
    CheckMark(19);    // For testing

    var purgedList = new List<T>();
    foreach (var element in list)
    {
        if (!purgedList.Contains(element))
            purgedList.Add(element);
    }
    return purgedList;
}

/// <summary>
/// Help method for seeing if a string contains another string, ignores case
/// </summary>
/// <param name="original"></param>
/// <param name="value"></param>
/// <param name="comparisionType"></param>
/// <returns></returns>
```

```
        private bool Contains(string original, string value, StringComparison comparisionType)
        {
            CheckMark(20);    // For testing

            return original.IndexOf(value, comparisionType) >= 0;
        }

        /// <summary>
        /// Used for testing, so display the test coverage
        /// of this code
        /// </summary>
        /// <param name="index"></param>
        private void CheckMark(int index)
        {
            if (!testCoverage[index].Equals(true))
                testCoverage[index] = true;
        }

        /// <summary>
        /// Prints out the result of the test coverage
        /// </summary>
        private void PrintTestCoverage()
        {
            Output.WriteLine("Test Coverage Results: ");
            for (int i = 0; i < testCoverage.Length; i++)
            {
                Output.Write(testCoverage[i] + " ");
            }
        }
    }
}
```

Appendix G

Generated C# Code from the GSM authentication ASM

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Diagnostics.Contracts;

namespace GsmAuthenticator
{
   class GsmAuthenticator
   {
      State _curState;
      State _preState;
      int counter = 0;

      GsmAuthenticator()
      {
         _curState = State.Normal;
         _preState = State.InvalidState;
      }

      enum State
      {
         InvalidState,       // Do NOT remove this state, used in Code Contracts
         Normal,
         Challenged,
         Locked
      }

      void RunGsmAlgorithm()
      {

         Contract.Ensures((_preState == State.Normal & counter < 10000) ? _curState == State.Challenged : tr
         ue);
         Contract.EnsuresOnThrow<Exception>((_preState == State.Normal & counter >= 10000) ? _curState == St
         ate.Locked : true);
         Contract.EnsuresOnThrow<Exception>(_preState == State.Locked ? _curState == State.Locked : true);

         if (_curState == State.Normal & counter < 10000)
         {
            StateChange(State.Challenged);
            counter++;
         }
         else if (_curState == State.Normal & counter >= 10000)
         {
            StateChange(State.Locked);
            throw new Exception();
         }
         else if (_curState == State.Locked)
         {
            StateChange(State.Locked);
            throw new Exception();
         }
      }

      void GetResponse()
      {

         Contract.EnsuresOnThrow<Exception>((_preState == State.Challenged & response_incorrect) ? _curState
          == State.Normal : true);
         Contract.Ensures((_preState == State.Challenged & response_correct) ? _curState == State.Normal : t
         rue);
         Contract.EnsuresOnThrow<Exception>(_preState == State.Locked ? _curState == State.Locked : true);

         if (_curState == State.Challenged & response_incorrect)
         {
            StateChange(State.Normal);
```

```
            throw new Exception();
         }
         else if (_curState == State.Challenged & response_correct)
         {
            StateChange(State.Normal);
         }
         else if (_curState == State.Locked)
         {
            StateChange(State.Locked);
            throw new Exception();
         }
      }

      private void StateChange(State name)
      {
         _preState = _curState;
         _curState = name;
      }

      [ContractInvariantMethod]
      private void ObjectInvariantsAndConstraints()
      {
         Contract.Invariant(_curState != State.InvalidState);

         Contract.Invariant(_curState == State.Normal ? (_preState == State.Challenged | _preState == State.
         InvalidState) : true);
         Contract.Invariant(_curState == State.Challenged ? _preState == State.Normal : true);
         Contract.Invariant(_curState == State.Locked ? (_preState == State.Normal | _preState == State.Lock
         ed) : true);
         Contract.Invariant(_preState == State.Normal ? (_curState == State.Challenged | _curState == State.
         Locked) : true);
         Contract.Invariant(_preState == State.Challenged ? _curState == State.Normal : true);
         Contract.Invariant(_preState == State.Locked ? _curState == State.Normal : true);
      }
   }
}
```

Appendix H

CD containing the DSL project and a PDF of the report