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Tutorial for Overture/VDM++

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Chapter 3

Overture Tool Support for VDM++: an Introductory Guide

Preamble

This is an introduction to the Overture Integrated Development Environment (IDE) and its facilities for supporting modelling and analysis in VDM++. It may be used as a substitute for Chapter 3 of “Validated Designs for Object-oriented Systems”¹ or as a free-standing guide. Additional material is available on the book’s web site². Throughout this guide we will refer to the textbook as “the book” and the book’s web site simply as “the web site”.

We use examples based on the *alarm* case study introduced in Chapter 2 of the book. For readers using this as a free-standing guide, an informal explanation of the case study and its VDM++ model are given in Appendix A. The model has been slightly extended from the original version in order to illustrate Overture’s test automation features.

We introduce the features of Overture that support the combination of formal modelling in VDM++ with object-oriented design using UML. This is done by providing a “hands-on” tour of Overture, providing enough detail to allow you to use Overture for serious applications, including the exercises in the book. However, this is by no means a complete guide to Overture³; more information can be obtained from www.overturetool.org.

3.1 Introduction

One of the main benefits of combining VDM++ and UML class diagrams and sequence diagrams is the ability to use software tools to assist in the analysis of the models. Often the analytic power of

¹John Fitzgerald, Peter Gorm Larsen, Paul Mukherjee, Nico Plat and Marcel Verhoef. *Validated Designs for Object-oriented Systems*, Springer, New York. 2005, ISBN 1-85233-881-4

²www.vdmbook.com.

³Note that the Overture tool suite support three different VDM dialects; VDM-SL (Specification Language), VDM++ and VDM-RT (Real Time) so although this tutorial illustrate how to use Overture with VDM++ models you will see multiple references to these dialects.



UML models alone can be limited as many tools concentrate on just the structural view of classes. However, the combination of either Modelio or Enterprise Architect (EA) and Overture provides a significant number of benefits.

This guide can be used to illustrate the combination of Modelio or Enterprise Architect and Overture support, or just Overture support if a UML tool is not available or desired.

Section 3.2 describes how to obtain the tools and the license for EA (not necessary if you use Modelio). For those readers who would like to start using EA or Modelio, Section 3.3 briefly explains how a first model can be built in UML. Section 3.4 provides an initial introduction to the terminology used by Eclipse tools like Overture. Section 3.6 shows how to import EA/Modelio UML class and sequence diagrams into Overture and export them back to UML again. Section 3.7 describes the process of testing and debugging using Overture. Section 3.8 describes how line coverage from using the debugger can be covered and displayed. Section 3.9 shows how parts of the test process can be automated using Overture's combinatorial testing feature. Section 3.10 demonstrates how it is possible to automatically generate the additional checks (called *proof obligations*) needed in order to ensure that a model is consistent. Finally, Section 3.11 illustrates how parts of Overture's functionality can be accessed from a command line.

3.2 Obtaining the Tools

In order to run the examples and exercises presented in the book, it is necessary to install two separate tools – Overture and Modelio or Enterprise Architect, the latter being license-controlled.

Overture: This is an open source tool developed by a community of volunteers and built on the Eclipse platform. The Overture development project is managed on SourceForge⁴. The best way to run Overture is to download a special version of Eclipse with the Overture functionality already pre-installed. If you go to

<http://sourceforge.net/projects/overture/files/>

you can find pre-installed versions of Overture for Windows, Linux and Mac⁵.

Modelio: This is a tool that is both available in a commercial version as well as in an open source setting from a company called Softeam. Just like Overture this tool is built on top of the Eclipse platform. The product can be obtained from

<http://www.modelio.org/>.

Enterprise Architect: This is a commercial tool from a company called SparxSystems. The product, and a free evaluation license, can be obtained from

⁴<https://sourceforge.net/projects/overture/>

⁵It is planned to develop an update facility, allowing updates to be applied directly from within the generic Eclipse platform without requiring a reinstallation. However, this can be a risky process because of the dependencies on non-Overture components and so is not yet supported.



`http://www.sparxsystems.com.au/`.

A large library of sample VDM++ models, including all those needed for the exercises in the book, is available and can be downloaded from the URL⁶:

`http://overture.sourceforge.net/examples/ExamplesVDM_PP.zip`

You can import the example library zip folder as described in Section 3.4. Finally, the web site `www.vdmbook.com` contains all the examples used in this book as plain text files but these are also all present in the above mentioned zip file. Finally, in order to make use of the test coverage feature described in Section 3.8 it is necessary to have the text processing system called \LaTeX and its `pdflatex` feature. This can for example be obtained from:

`http://miktex.org/2.8/`

Note for VDMTools[®] users. Overture provides a new open source VDM tool set, but it can also be used with VDMTools[®]. VDMTools, originally developed by IFAD A/S, is now maintained and developed by CSK Systems (see `http://www.vdmtools.jp/en/`). In the future Overture will be able to access VDMTools functionality via a remote API, but the integration will to some extent be limited by the API capabilities. However, the additional features of the Overture IDE make it worth considering as a front end to the VDMTools functionality.

3.3 Using Modelio or Enterprise Architect

This section describes the tool support available if you wish to start model construction using UML class diagrams.

3.3.1 Using Modelio

The `AlarmInitUML.uml` file can be found on the book's web site⁷. This UML class diagram model is identical to the initial class diagram from the previous chapter except that the `Plant` class has been updated with the three operations identified in Appendix A. Note that the operations have not yet been given signatures. Download this `.uml` file and import it using Modelio. When this model is open, the class diagram should look like that shown in Figure 3.1.

The small '+' next to the rôle name `schedule` indicates that this association is `public`. The '-' in front of the rôle name `alarms` indicates that it is `private`. You can change the visibility of the `schedule` association to `private` by selecting the association and changing the `Visibility` with the `To:Expert`.

⁶The library files are created to be used with Eclipse, but can be opened with file compression programs like Winrar on Windows.

⁷`http://www.vdmbook.com/twiki/bin/view/Main/BookExamples/AlarmInitUML.uml`.

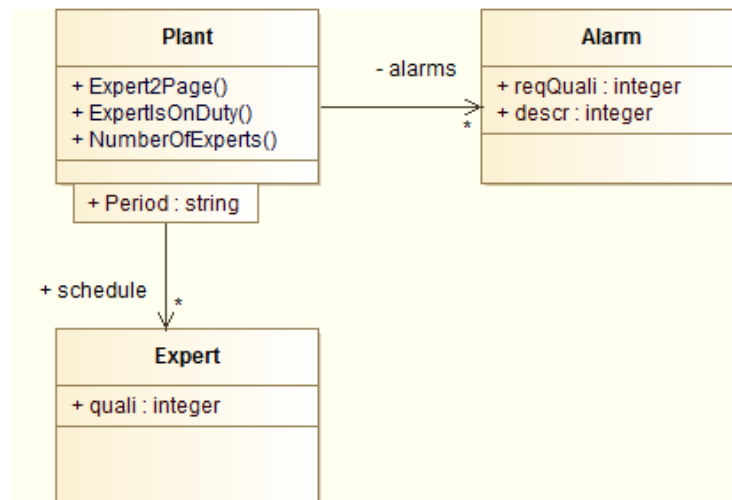


Figure 3.1: The initial UML class diagram in Modelio.

You can update the signatures for the operations in the `Plant` class. However, this is awkward and most developers prefer to use a text editor to perform such updates in the VDM++ text, then converting back to the UML model automatically.

To convert a UML class diagram model to a VDM++ model, you first need to export the UML model from Modelio to the Eclipse XMI format, called UML using the EMF UML3.0.0 format (see Figure 3.2). This is then subsequently imported into Overture as will be explained in Section 3.6.

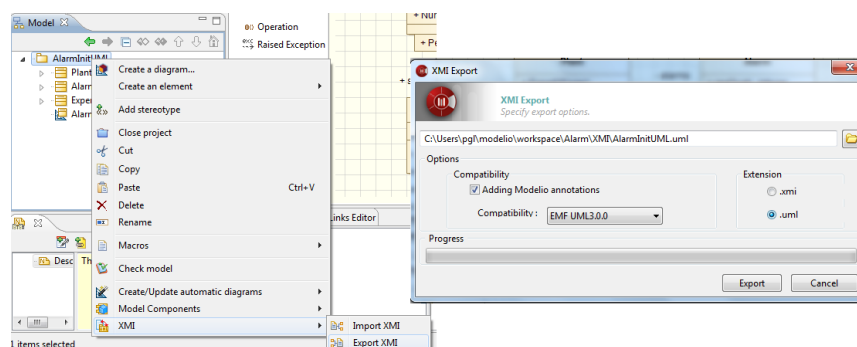


Figure 3.2: Exporting the UML model to XMI format in Modelio.



3.3.2 Using Enterprise Architect

The `alarmumlinit.eap` file can be found on the book's web site⁸. This UML class diagram model is identical to the initial class diagram from the previous chapter except that the `Plant` class has been updated with the three operations identified in Appendix A. Note that the operations have not yet been given signatures. Download this `.eap` file and open it using Enterprise Architect. When this model is open, the class diagram should look like that shown in Figure 3.3.

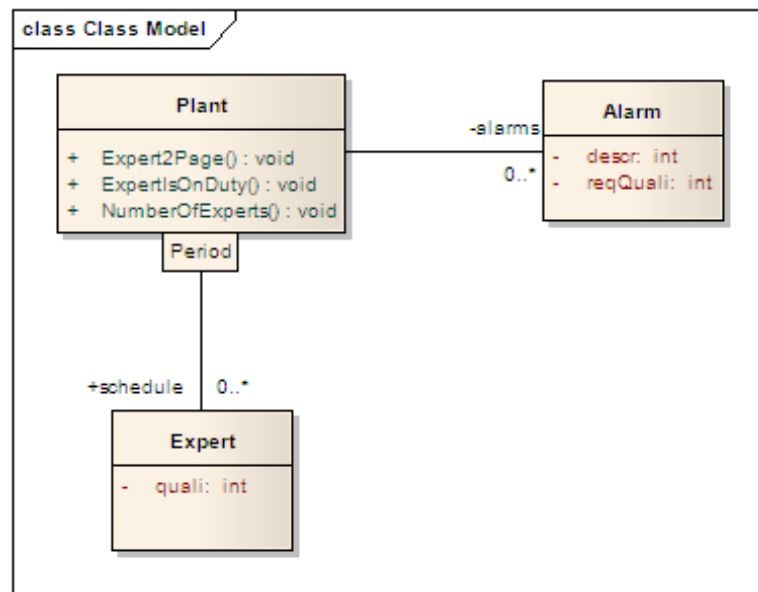


Figure 3.3: The initial UML class diagram in Enterprise Architect.

The small ‘+’ next to the rôle name `schedule` indicates that this association is `public`. The ‘-’ in front of the rôle name `alarms` indicates that it is `private`. You can change the visibility of the `schedule` association to `private` by double-clicking the association and changing the **Association properties** with the target **Role**, changing the **Access** field.

You can update the signatures for the operations in the `Plant` class. However, this is awkward and most developers prefer to use a text editor to perform such updates in the VDM++ text, then converting back to the UML model automatically.

To convert a UML class diagram model to a VDM++ model, you first need to export the UML model from EA/Modelio to XMI format (see Figure 3.4). This is then subsequently imported into Overture as will be explained in Section 3.6.

⁸<http://www.vdmbook.com/twiki/bin/view/Main/BookExamples/alarmumlinit.eap>.

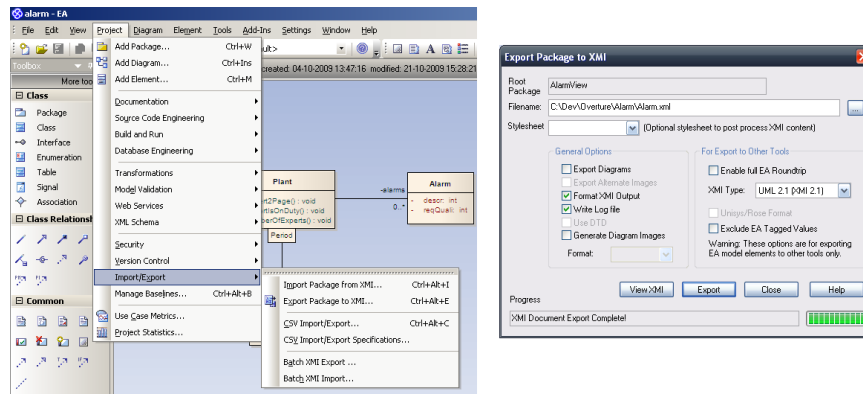


Figure 3.4: Exporting the UML model to XMI format in Enterprise Architect.

3.4 Using the Overture Perspective

Eclipse is an open source platform based on a *workbench* that provides a common look and feel to a large collection of extension products. Thus if a user is familiar with one Eclipse product, it will generally be easy to start using a different product on the same workbench. The Eclipse workbench consists of several panels known as *views*, such as the VDM Explorer view at the top left of Figure 3.5. A particular collection of panels designed to assist a specific activity is called a *perspective*. For example Figure 3.5 shows the standard Overture perspective which contains views for managing Overture projects, viewing and editing files. As we shall see later, several other perspectives are also available in Overture.

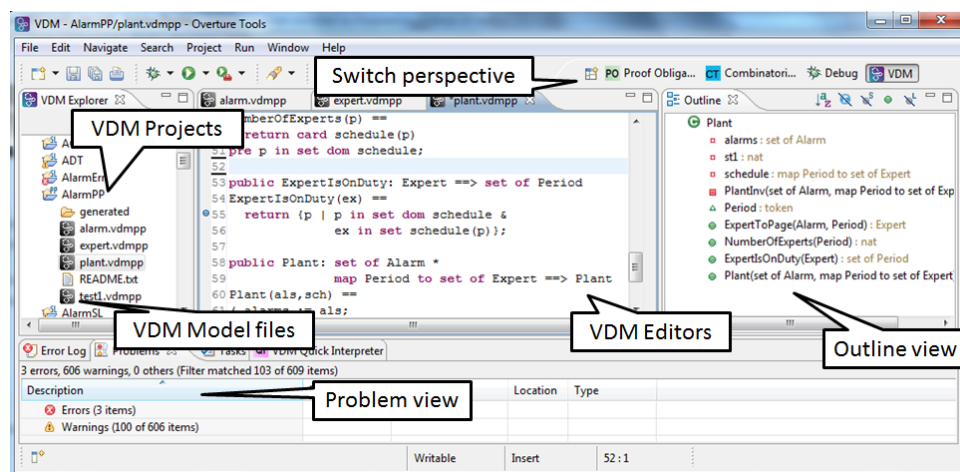


Figure 3.5: The Overture Perspective

The *VDM Explorer* view allows you to create, select, and delete Overture projects and navigate between the files in these projects. Start by importing the alarm project from zip file mentioned



above. This can be done by right clicking the project view and selecting *Import*, followed by *General* → *Existing Projects into Workspace*. In this way the projects from .zip file mentioned above can be imported easily. Initially it is recommended that you only import the `AlarmErrPP` and the `Alarm++tracesPP` projects as shown in Figure 3.6⁹.

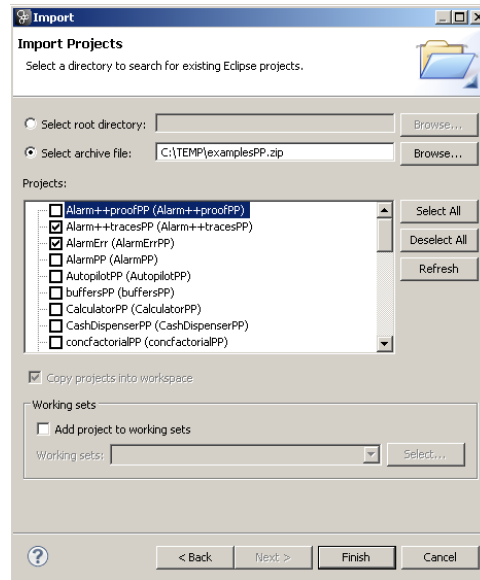


Figure 3.6: Importing the `Alarm` VDM++ Projects

An editor customised to the dialect of VDM being used in the project will appear when one of the imported files are selected in the *Explorer* view by double clicking. When the `AlarmErrPP` project has been imported one can right click on the project in the *Explorer* view and then select the *Properties* item in the menu and then Figure 3.7 will pop up. This includes the properties set for this project including specific VDM options. Note that there is a language version option that for the `AlarmErrPP` project set to `vdm10` which indicates that it include non-standard features such as **traces** which is explained in Section 3.9. In addition, options are gathered here for additional checks where the `AlarmErrPP` project simply follow the standard settings used for new projects.

The *Outline* view, to the right of the editor (see Figure 3.8) displays an outline of the file selected in the editor. It shows all declared classes, their instance variables, values, types, functions, operations and traces. Figure 3.5 shows the outline view on the right hand side. Clicking on an operation or function will move the cursor in the editor to the definition of that operation/function. At the top of the outline view there is a button to (optionally) order the elements of the outline view alphabetically.

The *Problems* view presents information about all the open projects you are working on, such as warning and error messages. In Figure 3.5 the problems view is shown at the bottom.

⁹You need both of these to carry out various exercises throughout this chapter.

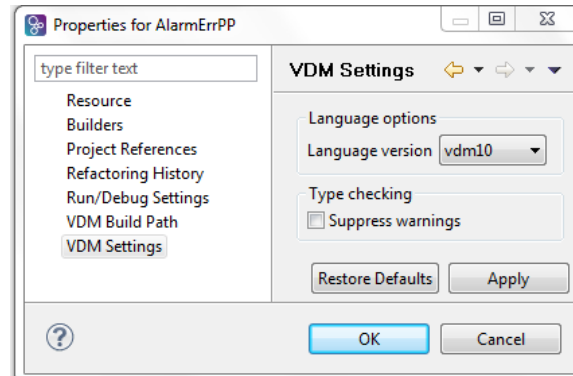


Figure 3.7: Properties for the AlarmErrPP Project

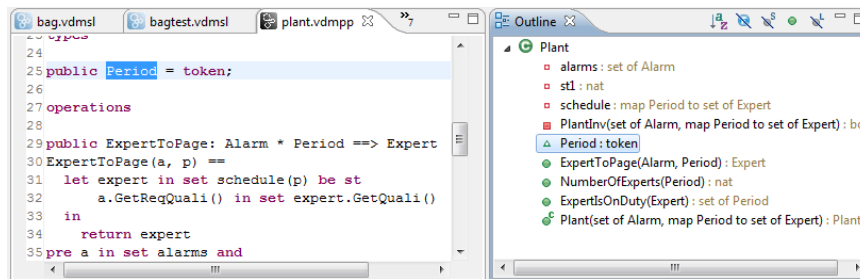


Figure 3.8: The Outline View

In the standard Overture perspective there is a *VDM Quick Interpreter* view in a pane in the same area as the problems view. This can be used for evaluation of standard VDM expressions independent of all VDM projects incorporated in your Overture IDE. This can be very convenient to gain understanding of the different VDM operators. In Figure 3.9 it is possible to see how a couple of expressions (typed in at the box at the bottom of the view) are evaluated¹⁰. Note that in order to get a console where you are able to make use of definitions you need to use the console launch mode as described in Section 3.7.1 below.

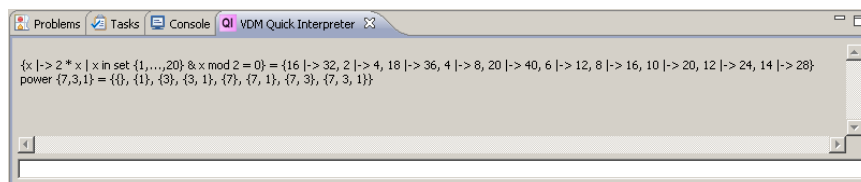


Figure 3.9: The VDM quick interpreter view

¹⁰If errors appear in this evaluation the current version of the Overture IDE simply yield a `Fatal` error where it is anticipated that later releases will provide more helpful run-time errors to the users.



Most of the other features of the workbench, such as the menus and toolbars, are similar to those used in other Eclipse applications, though it is worth noting that there is a special menu with Overture-specific functionality. One convenient feature is a toolbar that appears on the right side of the screen and allows the user to switch between perspectives; the particular perspectives on show here vary dynamically according to history.

3.5 Getting Started using Templates

Before proceeding, please make sure that you have imported both the `AlarmErrPP` and the `Alarm++tracesPP` projects as shown in Figure 3.6. When editing a VDM++ model, the Overture IDE parses the content of the editor buffer continuously as changes are made. Any parse errors will be reported in the problems view, as well as being highlighted in the editor. See the bottom of Figure 3.5. Each time a VDM++ model file is saved the editor type-checks the model and reports any errors or warnings. Note also that the suggestions made in the error messages may not always be entirely the action you may wish to take when correcting the source since the tool cannot guess what you intended to write.

Templates can be particularly useful when modifying VDM++ models. If you hit the key combination `CTRL+space` after the initial characters of the template needed, Overture triggers a proposal. For example, if you type "op" followed by `CTRL+space`, the Overture IDE will propose the use of an implicit or explicit operation template as shown in Figure 3.10. The Overture IDE supports several types of template: cases, quantifications, functions (explicit/implicit), operations (explicit/implicit) and many more¹¹. Additional templates can easily be added in the future. The use of templates makes it much easier for users lacking deep familiarity with VDM syntax to nevertheless construct models.

A new VDM++ project is created by choosing *File* → *New* → *Project*. The dialog box shown in Figure 3.11 will appear. Ensure that VDM++ is selected as the project type, click *Next* and then name the project `AlarmUML`. Following this it is possible to select standard libraries as shown in Figure 3.12. These standard libraries gives the possibility to get standard input/output, math and general utility functionality by selecting the appropriate standard libraries. In this `AlarmUML` project we can try to select the `IO` standard library. Afterwards one simply select *Finish*. Now you have an almost empty project (with the exception of the `IO.vdmpp` file in the `lib` directory) and you can then either add new VDM++ files to the project or simply paste in existing VDM++ source files from elsewhere. Adding a VDM++ file to a project you can rightclick on the project and then select *New* → *VDM-PP Class* and then give a meaning full name (e.g. `Test`) to the class you would like to start defining and press *Finish*. This will create a new class file with the selected name and with space for the different kinds of definitions you can make inside such a VDM++ class.

¹¹It is possible to see and enhance the complete list of these by selecting *Window* → *Preferences* → *Overture*.

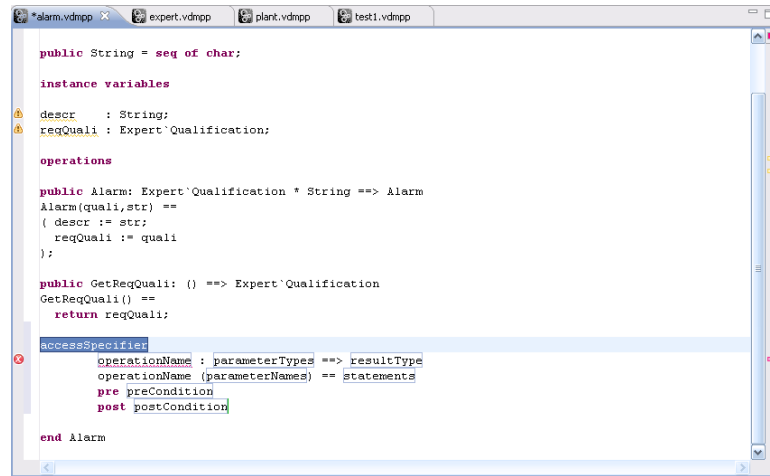


Figure 3.10: Explicit operation template

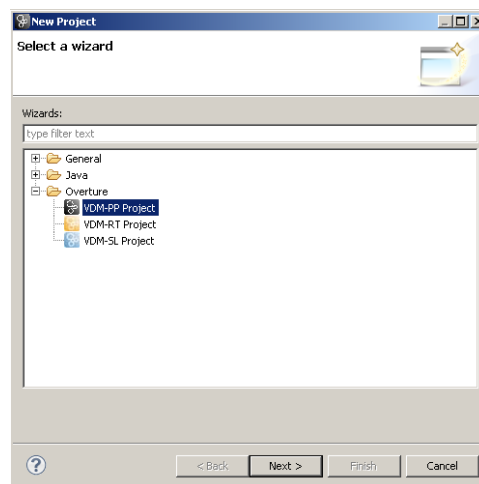


Figure 3.11: Creating a New VDM++ Project

3.6 Mapping Between UML and VDM

In order to map the UML class diagram created in Modelio or Enterprise Architect to VDM, use a new project inside the *VDM Explorer*. Paste the XMI/UML file exported from EA/Modelio into this new project. By right-clicking on the XMI/UML file in the *VDM Explorer* view, the *UML Transformation* can be chosen, followed by *Convert to VDM*. This will create a new `uml_import` directory with one `vdmpp` file per class from the UML model. The round-trip engineering abilities of this link however is still at a prototype stage so if you wish to use this you have to expect that this part is still not as automatic as we would like.

The three classes from the Alarm system will be converted to VDM++ format (`.vdmpp`), one

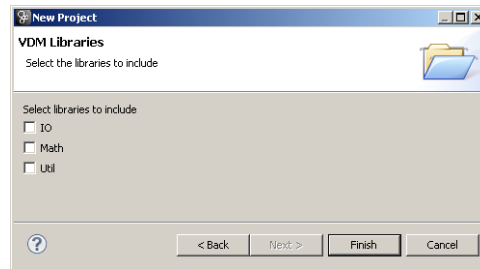


Figure 3.12: The VDM++ Standard Libraries

file per class.

The transformation from UML to VDM is not entirely automated in the current release. For example, any custom types are transformed to VDM++ definitions using machine-generated identifiers since custom types are not named in UML. As a result, you have to expect to make minor modifications to the generated VDM files.

Before proceeding, delete the `AlarmUML` project in the Overture IDE. For the following, the `AlarmErrPP` project is used. This project contains a number of VDM++ model files with a number of deliberate errors. The errors are common ones such as semicolons separating definitions that has been forgotten.

Exercise 3.1★ Correct all the errors discovered by the syntax and type checker from Overture and save the corrected files. Continue this process until no errors appear. **Hint:** Consult the model presented in Appendix A to see how values (note using “=” rather than “:=”), types and constructors should be defined and how access modifiers should be used. □

After correcting all the errors in the `AlarmErrPP` project, it is possible to map the complete VDM model to UML. To do this, simply right click the project root and choose *UML Transformation* → *Export XMI*. The XMI file can subsequently be imported in EA/Modelio, enabling the user to get an overview of the complete model.

Exercise 3.2 Add an instance variable to one of the other classes at the VDM++ level. Save it and it will automatically be syntax and type checked at the VDM++ level. Then export the model to XMI in order to see your changes in EA/Modelio. □

3.7 Debugging

This section describes how to debug a model by testing it using the Overture IDE. A test file (`Test1.vdmpp`) can be found in the alarm project and it is provided in Appendix A.2.

Using this test, it is possible to exercise the system informally in order to check if the correct expert is paged as a result of a given alarm.



3.7.1 The Debug Configuration

Before the debugging can begin in Overture, a debug configuration must be created by right clicking the project and choosing *Debug As* → *Debug configuration*. The debug configuration dialog have 3 different launch modes:

Entry Point: This is the standard Eclipse approach where one decides before debugging which operation/function to call.

Remote Console: This is an advanced option that enables remote control of the interpreter and this is described in the Overture user manual [Larsen&10].

Console: This will simply start up a console where the user interactive can debug different operations/functions defined in the selected project¹².

Here we will start with using the traditional Eclipse approach with an “Entry Point” launch configuration which requires the project name and the class and the operation/function used as the entry point of the test. Figure 3.13 shows the debug configuration for the alarm model. The class and operation/function name can be chosen from a Browse dialog; if the operation or function has arguments, these must be typed in manually between the brackets of the entry point function/operation.

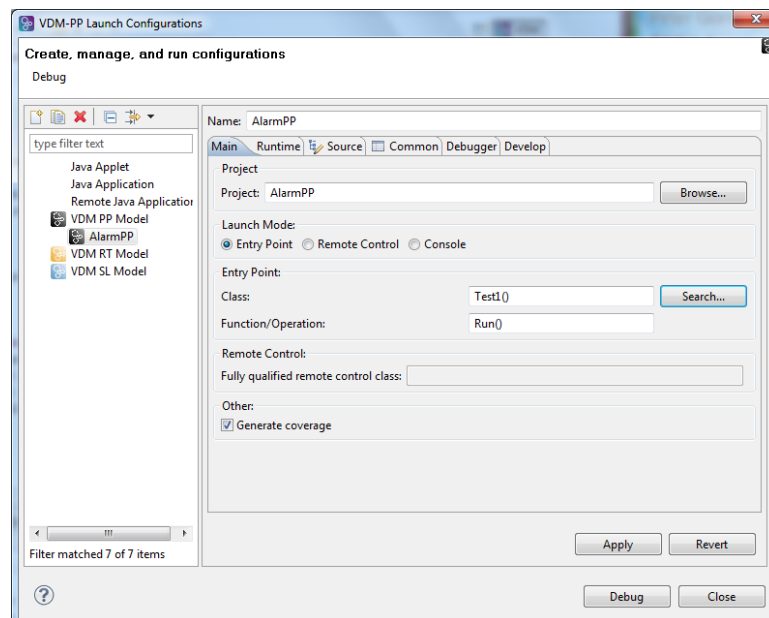


Figure 3.13: The debug configuration dialog

¹²For VDMTools users this will be a familiar console corresponding to a VDM model that has been initialised in VDMTools' interpreter.



Once the debug configuration is ready, the model can be debugged. If any breakpoints are set this will change the main perspective of the Overture IDE to the *Debug perspective* which contains the views needed for debugging in VDM. The Debug perspective is illustrated in Figure 3.14. Breakpoints can easily be set by double clicking in left margin in the editor view. When the debugger reaches the location of a breakpoint, evaluation suspends and you can inspect the values of different variables and step through the VDM model line by line.

3.7.2 The Debug Perspective

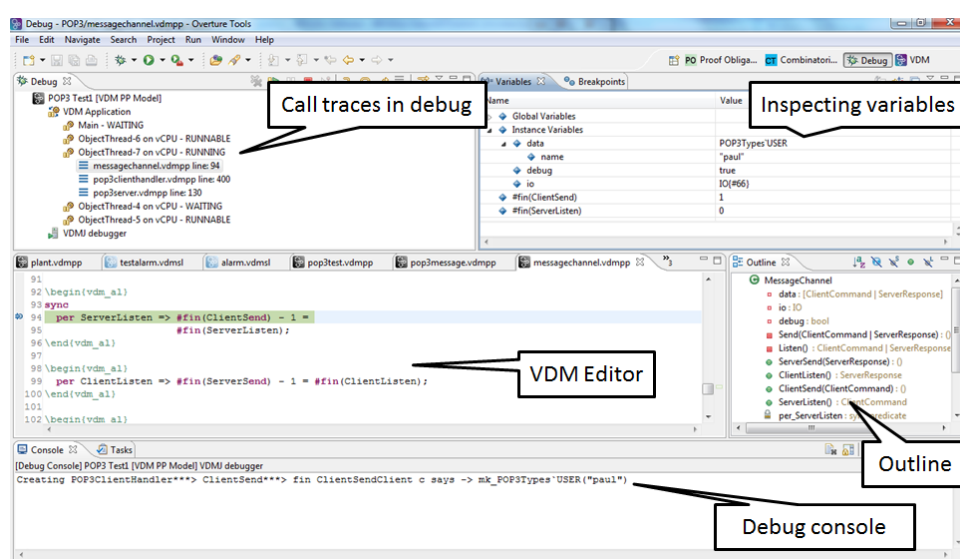


Figure 3.14: Debugging perspective

The *Debug view* in the upper left corner of the *Debug perspective* shows all running threads in the VDM++ model and their call stacks. It also shows whether a given model is stopped, suspended or running. All threads are also shown, along with their running status. It is possible to switch between threads from the *Debug view*.

At the top of the view are buttons for controlling debugging such as stop, step into, step over and resume. These are standard Eclipse debugging buttons (see Table 3.1).

The *Variables view* shows all the variables in a given context, when a breakpoint is reached. The variables and their displayed values are automatically updated when stepping through a model. The view is located in the upper right corner in the Debug perspective.

3.7.3 Breakpoints

The *Breakpoints view* gives an overview of all breakpoints set (see Figure 3.15). From this view you can easily navigate to the location of a given breakpoint, disable or delete them, or set their



Button	Explanation
	Resume debugging
	Suspend debugging
	Terminate debugging
	Step into
	Step over
	Step return
	Use step filters

Table 3.1: Overture debugging buttons

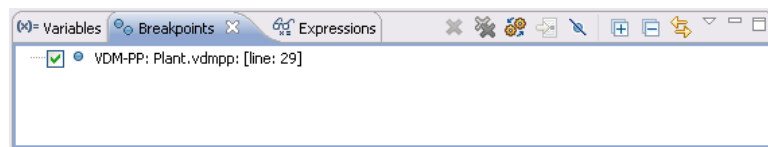


Figure 3.15: Breakpoint View

properties. Conditional breakpoints are supported. These are a powerful tool for the developer since they allow a condition to be specified which has to be true in order for the debugger to stop at the given breakpoint. The condition can either be a boolean expression using variables in scope at the breakpoint, or it can be a hit count after which the breakpoint should become active.

You can make a simple breakpoint conditional by right clicking on the breakpoint mark in the left margin of the editor and selecting the option *Breakpoint properties*. This opens a dialog shown in Figure 3.16.

The *Expressions view* allows the user to enter *watch* expressions whose values are automatically displayed and updated when stepping. Watch expressions can be added manually or created by selecting *create watch expression* from the *Variables view*. It is possible to edit existing expressions. Like the Breakpoints view, this view is hidden in the upper right hand corner in Figure 3.14.

Exercise 3.3 Use the interpreter to evaluate the following expression: `new Test1().Run()`.

□

3.8 Test coverage

It is often useful to know how much of a model has been exercised by a set of tests¹³. This gives some insight into the thoroughness of a test suite and may also help to identify parts of the model

¹³Note that this feature is not yet supported for models using unicode characters such as Japanese identifiers.

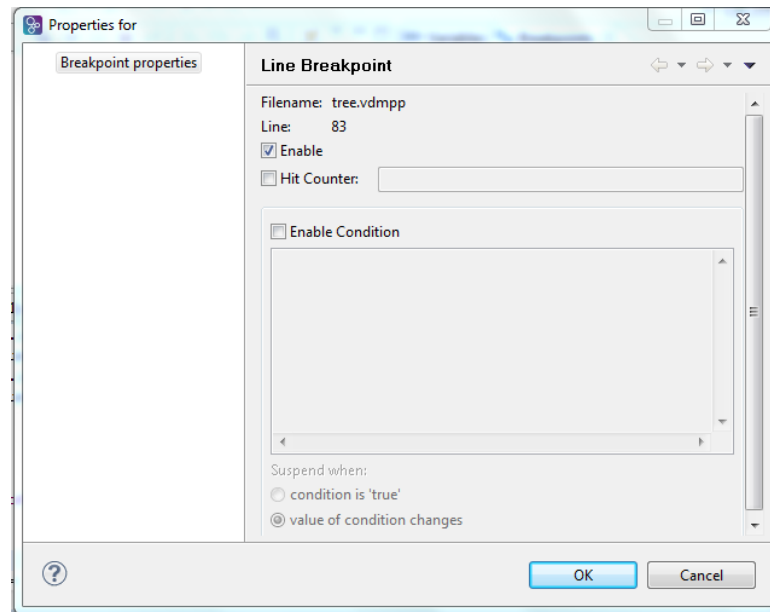


Figure 3.16: Conditional breakpoint options

that have not been assessed, allowing new tests to be devised to cover these. When any evaluation is performed on a VDM++ model, the interpreter records the lines of the VDM++ model that are executed. This permits the line coverage to be examined after a test to identify the parts of the VDM++ model that have not yet been exercised – coverage is cumulative, so a set of tests can be executed and their total coverage examined at the end.

In our simple example, the different tests in the exercise above does cause the majority of the VDM++ model to be executed, but for demonstration purposes let us start by cleaning the model (right click on the project and select *Clean*). If we simply take the *AlarmPP* debug launch configuration the *ExpertIsOnDuty* and *ExpertToPage* operations in *plant.vdmpp* are called by the *Run* function. Remember that whenever test coverage information is desired the *Generate Latex Coverage* option must be selected as shown in Figure 3.13. Once the debugger has completed and the result is written out in the *console* it is possible to right click on the *AlarmPP* project and select the *Latex* → *Latex coverage*. The coverage information that have been gathered in any expressions that have been debugged since the last change to a file have been saved or the project have been cleaned will be turned into a pdf file. The *AlarmPP.pdf* file is placed in the *generated/latex* directory as shown in Figure 3.17 and it includes the VDM definitions from all the files included in the project including coverage information. Note that whenever the model is adjusted or it is cleaned so it gets type checked again all the files in the *generated* directory are deleted.

The coverage information is provided in a way where uncovered expressions are shown in red in the generated pdf file. In addition to the content of each VDM++ source file a table with coverage overview is provided in tabular form. For the *plant.vdmpp* file this looks like:

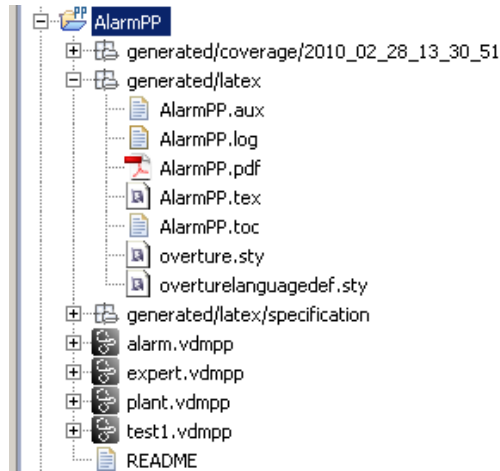


Figure 3.17: The generated pdf file with test coverage information

Function or operation	Coverage	Calls
ExpertIsOnDuty	100.0%	1
ExpertToPage	100.0%	1
NumberOfExperts	0.0%	0
Plant	100.0%	1
PlantInv	100.0%	2
plant.vdmpp	89.0%	5

where the `ExpertIsOnDuty` and `ExpertToPage` operations are fully covered by just one call (due to the fact that its body is simply one line) whereas the `PlantInv` operation is called twice¹⁴.

3.9 Combinatorial Testing

The previous sections have shown how to test and debug models manually. However, Overture also contains a feature enabling more automation in the testing process, making more comprehensive high-volume testing feasible. It is possible to write regular expressions, as *traces*, that one would like to expand into a large set of individual tests. When new traces are incorporated in a VDM project you may need to press the **Refresh** button (🔄) in the *CT Overview* view.

In order to illustrate how this can be used, we extend the `Plant` class with two additional operations for adding and removing experts from a given schedule. Both operations take a given `Period` and an `Expert` and then update the `schedule` instance variable from the `Plant` class. The `AddExpertToSchedule` operation can be defined as:

```
public AddExpertToSchedule: Period * Expert ==> ()
AddExpertToSchedule(p,ex) ==
    schedule(p) := if p in set dom schedule
                    then schedule(p)6 union {ex}
                    else {ex};
```

and the `RemoveExpertFromSchedule` operation can be expressed as:

```
public RemoveExpertFromSchedule: Period * Expert ==> ()
```



Note that `RemoveExpertFromSchedule` contains a deliberate error. It fails to take account of the invariant so the operation can leave the `Plant` in a state where it cannot be guaranteed that experts with the right qualifications are available in the periods that have been scheduled. `AddExpertToSchedule` has a similar error. If nobody is scheduled at the period provided as an argument, and the expert added for the schedule at this period does not have all the necessary qualifications, the invariant will again be violated. In fact this means that one would probably have to change the signature of this operation such that it instead of taking a simple expert would take a collection of experts. Instead of adding the two operations manually, use the `Alarm++tracesPP` project.

We could use the debugger presented above to test these two new operations manually, but we can also automate a part of this process. In order to do the automation, Overture needs to know about the combinations of operation calls that you would like to have carried out, so it is necessary to write a kind of regular expression called a *trace*. VDM++ has been extended such that traces can be written directly as a part of a VDM++ model. In our case, inside the `Test1` class one can write¹⁵:

traces

`AddingAndDeleting:`

```

let myex in set exs
in
    let myex2 in set exs \ {myex}
    in
        let p in set ps
        in
            (plant.AddExpertToSchedule(p,myex);
             plant.AddExpertToSchedule(p,myex2);
             plant.RemoveExpertFromSchedule(p,myex);
             plant.RemoveExpertFromSchedule(p,myex2));

```

The three nested `let-be` statements in the trace called `AddingAndDeleting` yield all possible combinations of their variable bindings whereas manual debugging will just select a few combinations. The cardinality of these sets determines the overall number of test cases, each being formed as a sequence of four operation calls, as shown. In this case, the cardinality of the three sets are respectively 4, 3 and 4. Multiplying these gives 48 tests in total. If you select the Combinatorial Testing perspective you will see the **CT Overview** view. Inside this combinatorial testing view you can select the `Alarm++tracesPP` project, right click it and choose the **Full Evaluation** option as shown in Figure 3.18. Now Overture expands and executes all 48 test cases one after another. The results of these executions are illustrated with green check marks and red crosses, meaning

¹⁵Such *traces* can actually also be represented as UML sequence diagrams and then automatically translated into the corresponding VDM++ textual form, but since this is still at a prototyping stage it is not explained further here.



that the tests passed or failed respectively. See Figure 3.19. Note that in the Combinatorial Testing perspective, the view in the lower region is able to show the individual steps of a selected test case, along with the corresponding results from its four operation calls.

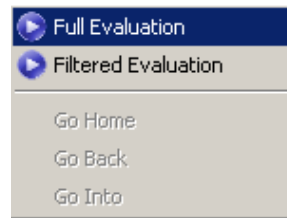


Figure 3.18: Invoking the combinatorial testing feature

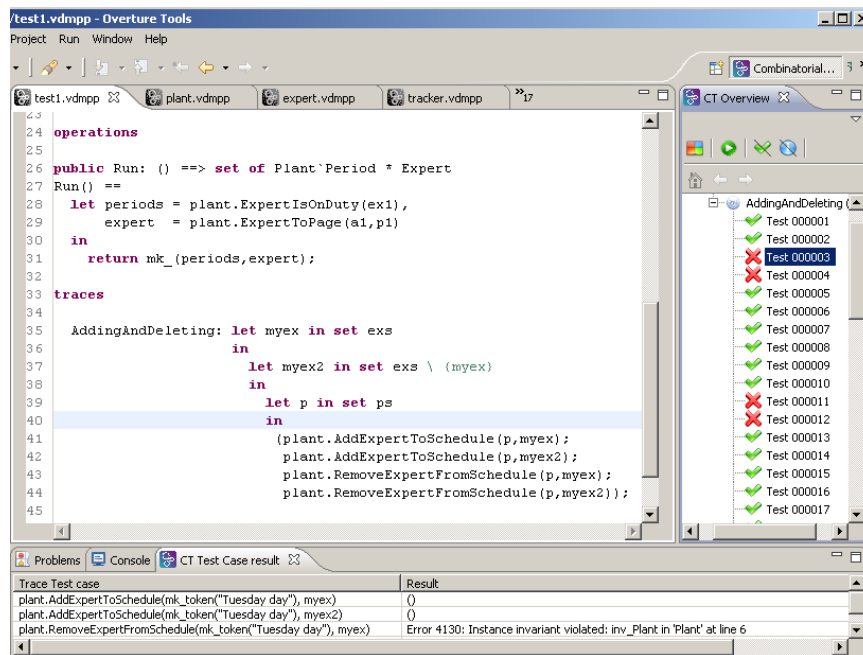


Figure 3.19: Using Combinatorial Testing for the Alarm VDM++ model

The syntax for traces also enables operation repetition and alternatives to be specified, but these were not needed for this simple case. Using the full power of traces, it is possible to efficiently generate and execute very large test suites. Naturally, this is most likely to find inconsistencies when the model attempts to define its essential predicates (invariants, pre and post-conditions)¹⁶.

¹⁶Note that when using repetitions and sequencing in combination it is easy to define traces that expands to hundreds of thousands of test cases and naturally their execution may then be very slow if one executes them all. Thus it is also possible to use a feature that reduce the numbers of tests to be executed.



3.10 Proof Obligations

The Overture tool is also able to generate *Proof Obligations* automatically for VDM++ models. Proof obligations are boolean expressions that describe constraints to be met at various points in the model in order to ensure that the model is internally consistent (i.e. no run-time errors will occur while debugging if these are all satisfied). Proof obligations are generated to ensure, for example, that operations will always respect invariants on instance variables. Each proof obligation generated from a model should evaluate to *true*.

The proof obligation generator is invoked by right clicking on the project in the *Explorer* view and then selecting the *Proof Obligations -> Generate Proof Obligations* entry. This will start up a proof obligation perspective with a special *PO* view. For the alarm example this view takes the form shown in Figure 3.20.

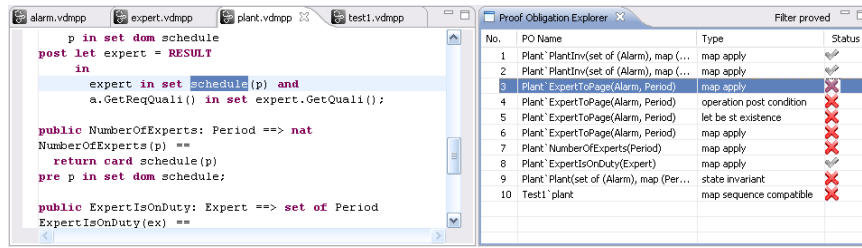


Figure 3.20: The Proof Obligation view for the Alarm VDM++ model

One of the first proof obligations listed for this example is related to the `PlantInv` function. Recall that the first part of the function's definition is as follows:

```
PlantInv: set of Alarm * map Period to set of Expert ->
    bool
PlantInv(as, sch) ==
    (forall p in set dom sch & sch(p) <> {}) and ...
```

The proof obligation records the constraint that the mapping application `sch(p)` should be valid (i.e. that the `p` is in the domain of the mapping `sch`). This is described as a proof obligation in the following form:

```
forall as:set of Alarm, sch:map Period to set of Expert &
    forall p in set (dom sch) &
        p in set dom sch
```

It is easy to see with simple pattern matching that this proof obligation is true and thus in the *Proof Obligation Explorer* view the status field the small checkmark indicates that indeed the proof obligation generation have been able to automatically determine this.



In general proof obligations represent checks that should be made on a model in order to gain confidence in its consistency. At present, proof obligations have to be checked by manual inspection of the model code. Proof tools are being developed for Overture to check as many as possible of the proof obligations automatically and with human assistance, but there are always likely to be some that have to be checked manually. If we for example instead consider the fifth proof obligation it is derived from the body of the `expertToPage` operation. That body looks like:

```
let expert in set schedule(p) be st
    a.GetReqQuali() in set expert.GetQuali()
in
    return expert
```

where an expert on duty with the right qualifications are being selected. The proof obligation here states:

```
exists expert in set schedule(p) &
    a.GetReqQuali() in set expert.GetQuali()
```

This is exactly describing that in order for this expression to be defined it is necessary to guarantee that there exists at least one such expert. Thus, without taking the pre-condition for the operation here into account it would not be possible to guarantee that. So it will never be possible to automatically to determine this using simple pattern matching because this is only guaranteed because of the invariant over the instance variables for the `Plant` class that has been defined.

3.11 A Command-Line Interface

So far only the graphical user interface of Overture has been presented but the engine underlying Overture, called VDMJ, also provides a simple command line interface. This is useful for the automatic batch execution of tests, though the command line also provides a full set of interactive execution and debugging commands which can be useful when examining batch tests. The command line also provides access to tool facilities that have not yet been included in the Overture IDE.

VDMJ is written in Java, and so to run it from the command line, the VDMJ jar file ¹⁷ should be executed with a Java JRE (version 5 or later):

```
java -jar vdmj-2.0.2.jar
```

If the jar file is executed with no further options like this, it will print a list of available options and exit. The most important option is the VDM dialect that the tool should use. In the case of

¹⁷ See the Overture documentation at sourceforge.net/projects/overture for the location of the jar file.



our alarm example, we want to use VDM++ for which the option is `-vdmpp`. After this, we can simply specify the names of the VDM model files to load, or the name of a directory from which all VDM model files will be loaded:

```
java -jar vdmj-2.0.2.jar -vdmpp AlarmPP
```

That will perform a syntax and type check of all the VDM model files in the `AlarmPP` directory, producing any errors and warning messages on the console, before terminating:

```
Parsed 4 classes in 0.561 secs. No syntax errors
Type checked 4 classes in 0.031 secs. No type errors
```

In the case of our alarm example, there are no syntax or type checking errors. Any warnings can be suppressed using the `-w` option.

If a VDM model has no type checking errors, it can either be given an expression to evaluate as an option on the command line, or the user can enter an interactive mode to evaluate expressions and debug their execution.

To evaluate an expression from the command line, the `-e` option is used, followed by a VDM expression to evaluate. You may also find the `-q` option useful, as this suppresses the informational messages about the parsing and type checking:

```
java -jar vdmj-2.0.2.jar -vdmpp -q -e "new Test1().Run()"
AlarmPP
```

This produces a single line of output for the evaluation, since the parsing and checking messages are suppressed:

```
mk_({mk_token("Monday day")},
    Expert{#3, quali:={<Mech>, <Bio>}})
```

Clearly a batch of test evaluations could be performed automatically by running a series of similar commands and saving the output results for comparison against expected results.

To run the command line interpreter interactively, the `-i` command line option must be given. Instead of terminating after the type check, this will cause VDMJ to enter its interactive mode, and give the interactive `>` prompt:

```
Parsed 4 classes in 0.468 secs. No syntax errors
Type checked 4 classes in 0.031 secs. No type errors
Initialized 4 classes in 0.031 secs.
Interpreter started
>
```




From this prompt, various interactive commands can be given to evaluate expressions, debug their evaluation, or examine the VDM model environment. The `help` command lists the commands available. The `quit` command leaves the interpreter.

For example, the following session illustrates the creation of a test object, followed by an evaluation (using a `print` command) of its `Run` operation, and a debug session with a breakpoint at the start of the same operation:

```
> create test := new Test1()
> print test.Run()
= mk_({mk_token("Monday day")},
      Expert{#3, quali:={<Mech>, <Bio>}})
Executed in 0.172 secs.

> break Test1`Run
Created break [1] in 'Test1' (test1.vdmpp) at line 26:3
26:    let periods = plant.ExpertIsOnDuty(ex1),

> print test.Run()
Stopped break [1] in 'Test1' (test1.vdmpp) at line 26:3
26:    let periods = plant.ExpertIsOnDuty(ex1),
[MainThread-10]> print plant.NumberOfExperts(
                    mk_token("Wednesday"))
Runtime: Error 4071: Precondition failure:
      pre_NumberOfExperts in
      'Test1' (console) at line 1:1
[MainThread-10]> continue
= mk_({mk_token("Monday day")},
      Expert{#3, quali:={<Mech>, <Bio>}})
Executed in 34.858 secs.
```

Notice that the `print` command is available at the breakpoint to examine the runtime state of the system. In the example, we attempt to evaluate an operation which fails its precondition (because the system is not yet initialized). The `help` command is context sensitive, and will list the extra debugging commands available at a breakpoint, such as `continue`, `step`, `stack`, `list` and so on. The full set of commands is described in the VDMJ User Guide¹⁸.

3.12 Summary

In this guide we have introduced the following major features of tool support for VDM++:

¹⁸Supplied with the Overture documentation.



- using Modelio or Enterprise Architect with class diagrams;
- mapping back and forth between Modelio or Enterprise Architect and Overture;
- syntax checking of VDM++ models;
- type checking of VDM++ models;
- executing and debugging VDM++ models;
- collecting and displaying test coverage information on VDM++ models;
- combinatorial testing enabling automation of parts of the testing process;
- proof obligation generation and
- a command-line interface.



References

- [Fitzgerald&98] John Fitzgerald and Peter Gorm Larsen. *Modelling Systems – Practical Tools and Techniques in Software Development*. Cambridge University Press, 1998.
- [Larsen&10] Peter Gorm Larsen and Kenneth Lausdahl and Augusto Ribeiro and Sune Wolff and Nick Battle. *Overture VDM-10 Tool Support: User Guide*. Technical Report TR-2010-02, The Overture Initiative, www.overturetool.org, May 2010. 103 pages.



Appendix A

A Chemical Plant Example

This appendix presents the requirements for a simple alarm system for a chemical plant. It forms a running example that serves to illustrate the process described earlier and to introduce elements of the VDM++ modelling language. Although the modelling process is described here as though it were a single-pass activity, a real development would usually be iterative.

A.1 An informal description

The example is inspired by a subcomponent of a large alarm system developed by IFAD A/S and introduced in [Fitzgerald&98]. A model of the system will be developed and validated using the facilities of Enterprise Architect and Overture enabling a graphical overview of the model in the form of UML class diagrams and sequence diagrams corresponding to traces. Chapter 3 provides an interactive and hands-on tour of the tools available for supporting the development of the model.

Imagine that you are developing a system that manages the calling out of experts to deal with operational faults discovered in a chemical plant. The plant is equipped with sensors that are able to raise alarms in response to conditions in the plant. When an alarm is raised, an expert must be called to the scene. Experts have different qualifications for coping with different kinds of alarms. It has been decided to produce a model to ensure that the rules concerning the duty schedule and the calling out of experts are correctly understood and implemented. The individual requirements are labelled R1, R8 for further reference:

- R1.** A computer-based system is to be developed to manage the alarms of this plant.
- R2.** Four kinds of qualifications are needed to cope with the alarms: electrical, mechanical, biological, and chemical.
- R3.** There must be experts on duty during all periods allocated in the system.
- R4.** Each expert can have a list of qualifications.
- R5.** Each alarm reported to the system has a qualification associated with it along with a description of the alarm that can be understood by the expert.



- R6.** Whenever an alarm is received by the system an expert with the right qualification should be found so that he or she can be paged.
- R7.** The experts should be able to use the system database to check when they will be on duty.
- R8.** It must be possible to assess the number of experts on duty.

In the next section the development of a model of an alarm system to meet these requirements is initiated. The purpose of the model is to clarify the rules governing the duty roster and calling out of experts to deal with alarms.

A.2 A VDM++ model of the Alarm example

This section presents the UML class diagram and the full VDM++ model of the alarm example. However, it does so without any explanatory text. That is placed in the VDM++ book so if you are a newcomer to VDM++ please read that there.

A.2.1 A UML Class Diagram

In Figure A.1 the final class diagram for the extended alarm example is shown from Enterprise Architect.

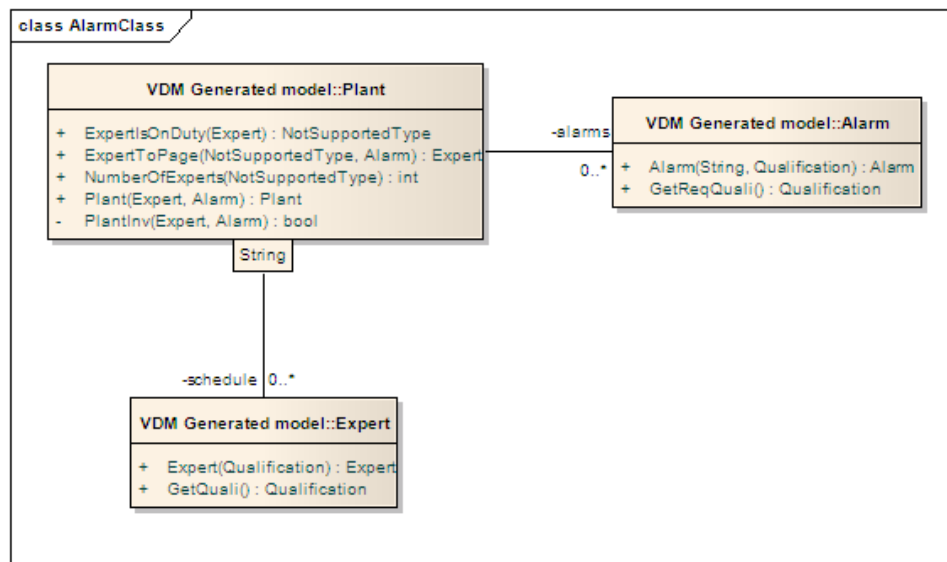


Figure A.1: UML diagram translated from VDM++ files



A.2.2 The Plant Class

The Plant class is the main class in this example.

```
class Plant
```

```
instance variables
```

```
alarms    : set of Alarm;
schedule  : map Period to set of Expert;
inv PlantInv(alarms,schedule);
```

```
functions
```

```
PlantInv: set of Alarm * map Period to set of Expert ->
        bool
```

```
PlantInv(as,sch) ==
  (forall p in set dom sch & sch(p) <> {}) and
  (forall a in set as &
    forall p in set dom sch &
      exists expert in set sch(p) &
        a.GetReqQuali() in set expert.GetQuali());
```

```
types
```

```
public Period = token;
```

```
operations
```

```
public ExpertToPage: Alarm * Period ==> Expert
```

```
ExpertToPage(a, p) ==
  let expert in set schedule(p) be st
    a.GetReqQuali() in set expert.GetQuali()
  in
    return expert
pre a in set alarms and
  p in set dom schedule
post let expert = RESULT
  in
    expert in set schedule(p) and
    a.GetReqQuali() in set expert.GetQuali();
```




```
public NumberOfExperts: Period ==> nat
NumberOfExperts(p) ==
    return card schedule(p)
pre p in set dom schedule;

public ExpertIsOnDuty: Expert ==> set of Period
ExpertIsOnDuty(ex) ==
    return {p | p in set dom schedule &
            ex in set schedule(p)};

public Plant: set of Alarm *
            map Period to set of Expert ==> Plant
Plant(als,sch) ==
    ( alarms := als;
      schedule := sch)
pre PlantInv(als,sch);

end Plant
```

A.2.3 The Expert Class

```
class Expert

instance variables

quali : set of Qualification;

types

public Qualification = <Mech> | <Chem> | <Bio> | <Elec>;

operations

public Expert: set of Qualification ==> Expert
Expert(qs) ==
    quali := qs;

public GetQuali: () ==> set of Qualification
GetQuali() ==
```



```
    return quali;  
  
end Expert
```

A.2.4 the Alarm Class

```
class Alarm  
types  
  
public String = seq of char;  
  
instance variables  
  
descr      : String;  
reqQuali   : Expert `Qualification;  
  
operations  
  
public Alarm: Expert `Qualification * String ==> Alarm  
Alarm(quali, str) ==  
( descr := str;  
  reqQuali := quali  
);
```

```
public GetReqQuali: () ==> Expert `Qualification  
GetReqQuali() ==  
    return reqQuali;  
  
end Alarm
```

A.2.5 A Test Class

```
class Test1  
  
instance variables
```



```
a1    : Alarm    := new Alarm(<Mech>, "Mechanical fault");
a2    : Alarm    := new Alarm(<Chem>, "Tank overflow");
ex1   : Expert   := new Expert({<Mech>, <Bio>});
ex2   : Expert   := new Expert({<Elec>});
ex3   : Expert   := new Expert({<Chem>, <Bio>, <Mech>});
ex4   : Expert   := new Expert({<Elec>, <Chem>});
plant: Plant     := new Plant({a1}, {p1 |-> {ex1, ex4},
                               p2 |-> {ex2, ex3}});
```

values

```
p1: Plant`Period = mk_token("Monday day");
p2: Plant`Period = mk_token("Monday night");
p3: Plant`Period = mk_token("Tuesday day");
p4: Plant`Period = mk_token("Tuesday night");
```

operations

```
public Run: () ==> set of Plant`Period * Expert
Run() ==
  let periods = plant.ExpertIsOnDuty(ex1),
      expert   = plant.ExpertToPage(a1, p1)
  in
    return mk_(periods, expert);

end Test1
```