

Overture – Open-source Tools for Formal Modelling TR-2010-01
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Tutorial to 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 Overture; 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 UML models alone can be limited as many tools concentrate on just the structural view of classes.

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.



However, the combination of Enterprise Architect (EA) and Overture provides a significant number of benefits.

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

Section 3.2 describes how to obtain the tools and the license for EA. For those readers who would like to start using EA, 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 3.5 shows how to import EA UML class and sequence diagrams into Overture and export them back to UML again. 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. Section 3.6 describes the process of testing and debugging using Overture. Section 3.7 shows how parts of the test process can be automated using Overture's combinatorial testing feature. Section 3.8 demonstrates how it is possible automatically to generate the additional checks (called *proof obligations*) needed ensure that a model is consistent. Finally, Section 3.9 illustrates how parts of Overture's functionality can be accessed from a command line, including support for test coverage analysis which is not currently available from the Eclipse GUI.

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 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 SourceForge³. 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 Mac⁴.

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

`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 SourceForge under the `files/Examples` section using the URL⁵:

³`https://sourceforge.net/projects/overture/`

⁴It 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.

⁵The library files are created to be used with Eclipse, but can be opened with file compression programs like Winrar on Windows



<https://sf.net/projects/overture/files/Examples/>

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.

Note for VDMTools[®] users. Overture provides a new open source VDM tool set, but it can also work with VDMTools[®]. VDMTools, originally developed IFAD A/S, is now maintained and developed by CSK Systems (see <http://www.vdmttools.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 Enterprise Architect

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

The `alarmumlinit.eap` file can be found on the book's web site. 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 3.1.

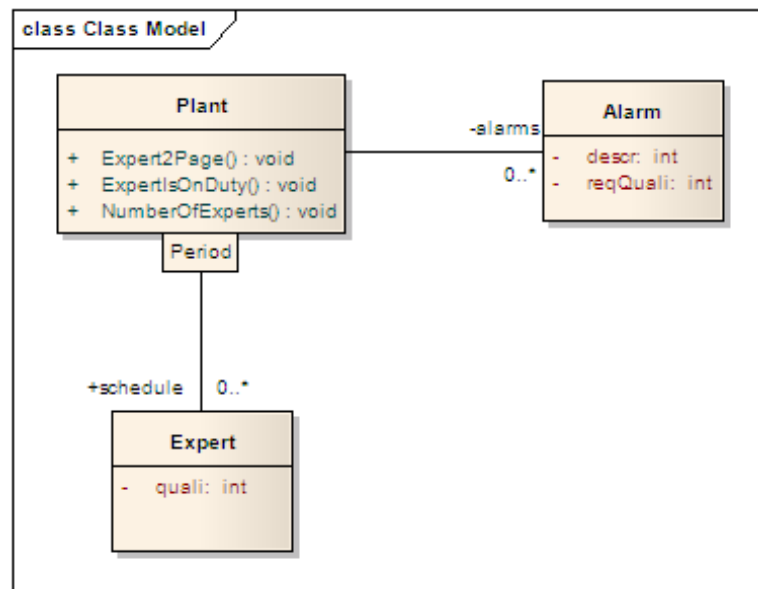


Figure 3.1: The initial UML class diagram.



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 to XMI format. This is then imported subsequently into Overture (see Figure 3.2).

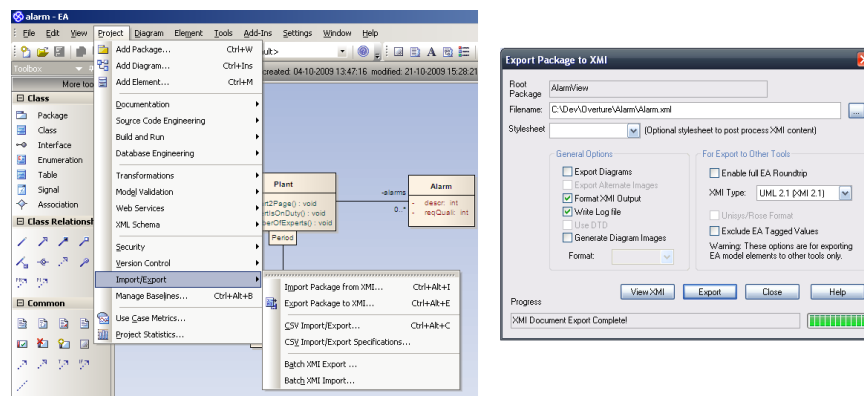


Figure 3.2: Exporting the UML model to XMI format.

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 Script Explorer view at the top left of Figure 3.3. A particular collection of panels designed to assist a specific activity is called a *perspective*. For example Figure 3.3 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.

The *Script 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 3.4⁶.

⁶You need both of these for carrying out different kinds of exercises throughout this chapter.

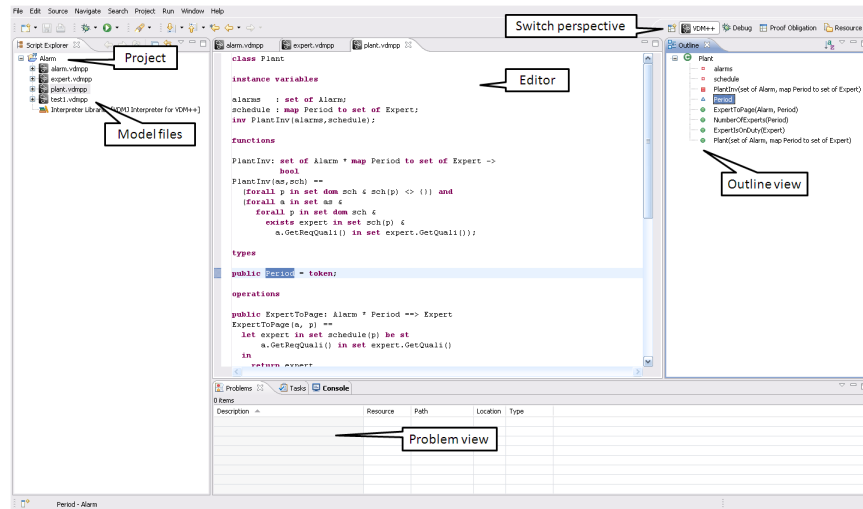


Figure 3.3: The Overture Perspective

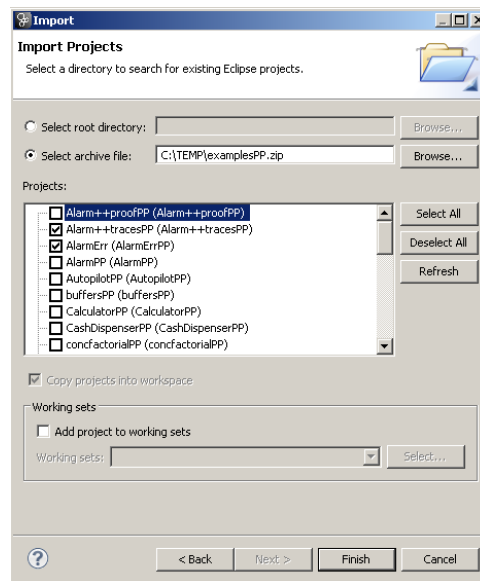


Figure 3.4: Importing the Alarm VDM++ Projects

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. A new VDM++ project is created by choosing *File* → *New* → *Project*. The dialog shown in Figure 3.5 will appear. Click *Next* and name the project.

The *Outline view*, to the right of the editor (see Figure 3.6) displays an outline of the file selected in the editor. It shows all declared classes, their instance variables, values, types, functions,

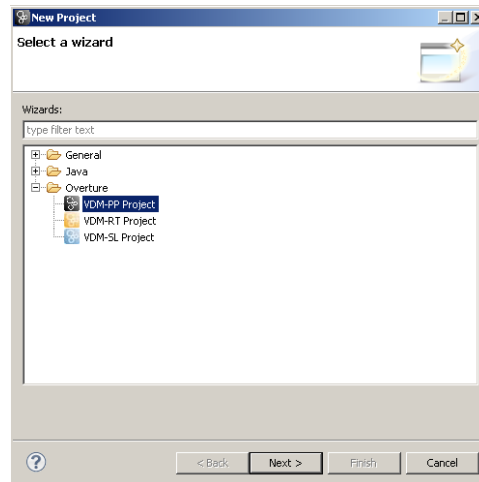


Figure 3.5: Creating a New VDM++ Project

operations and traces. Figure 3.3 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.

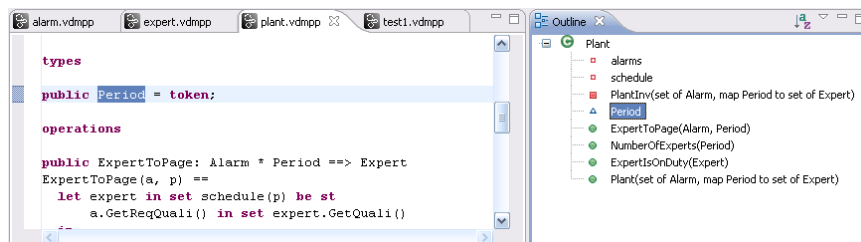


Figure 3.6: The Outline View

The *Problems* view presents information about all the open projects you are working on, such as warning and error messages. In Figure 3.3 the problems view is shown at the bottom.

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.

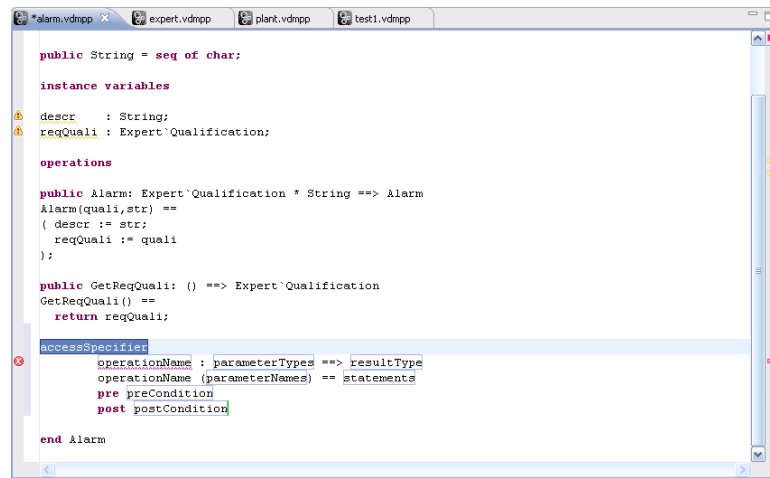


Figure 3.7: Explicit operation template

3.5 Mapping UML to VDM

In order to map the UML class diagram created in Enterprise Architect to VDM, a new project must be created in the Overture tool to receive it. This is done by right-clicking in the *Script Explorer* view, and creating a new VDM-PP project and for example naming it AlarmUML. By right-clicking the new project root in the *Script Explorer*, *UML Transformation* can be chosen, followed by *Import XML*. Now browse to the XMI/XML file exported from EA and open this.

The three classes from the Alarm system will be converted to VDM++ format (.vdmpp), one 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. When making corrections to the model, you can use the Overture IDE templates. When you hit the key combination *CTRL+space* after entering the initial characters of the template needed, Overture will offer possible completions. For example, if you type "op" followed by *CTRL+space*, Overture will propose the use of an implicit or explicit operation template.

The Overture IDE supports many templates for language constructs including cases statements, classes, quantified expressions, functions (explicit/implicit), operations (explicit/implicit) and many more. Further templates can easily be added in the future. The use of templates makes it more convenient to write VDM models without detailed prior knowledge of the language syntax.

Before proceeding, finish the model of the alarm system. Begin by deleting the alarm project in the Overture IDE, and import the alarm project from the book's web site. This can be done by right clicking the project view and selecting *Import*, followed by *Existing Projects into Workspace*.

When editing a VDM model, the Overture IDE parses the content of the editor buffer continuously as changes are made. Any parsing errors will be reported in the problems view, as well as



being highlighted in the editor (see the bottom of Figure 3.3). Each time a VDM model is saved the editor type checks the entire VDM++ model and reports any errors or warnings. Note also that the suggestions about missing characters 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.

The imported `AlarmErrPP` 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. □

3.5.1 Mapping VDM to UML

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, 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. □

3.6 Debugging

This section describes how to debug a model by testing it using the Overture IDE. The following test file (`Test1.vdmpp`) can be found in the alarm project.

```
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

```

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.

3.6.1 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*⁷. The debug configuration dialog requires the project name and the class and the operation/function used as the entry point of the test. Figure 3.8 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/operation⁸.

Once the debug configuration is ready, the model can be debugged. This will change the main perspective of the Overture IDE to the *Debug perspective* which contains the views needed for debugging in VDM. 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.

The Debug perspective is illustrated in Figure 3.9.

⁷Note that the *Run As* functionality existing Eclipse users are used to is not supported in the current version of Overture.

⁸Note that in the current version of Overture the error handling is not optimal if you type something that is not defined here. If you make mistakes here the current version will normally come with an error message like “Execution error 206: Unexpected token in expression” in the *Console* view

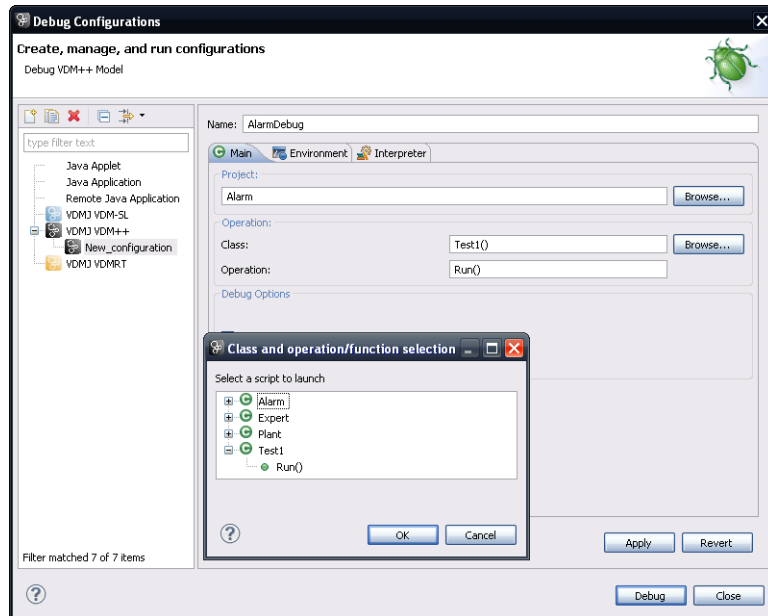


Figure 3.8: The debug configuration dialog

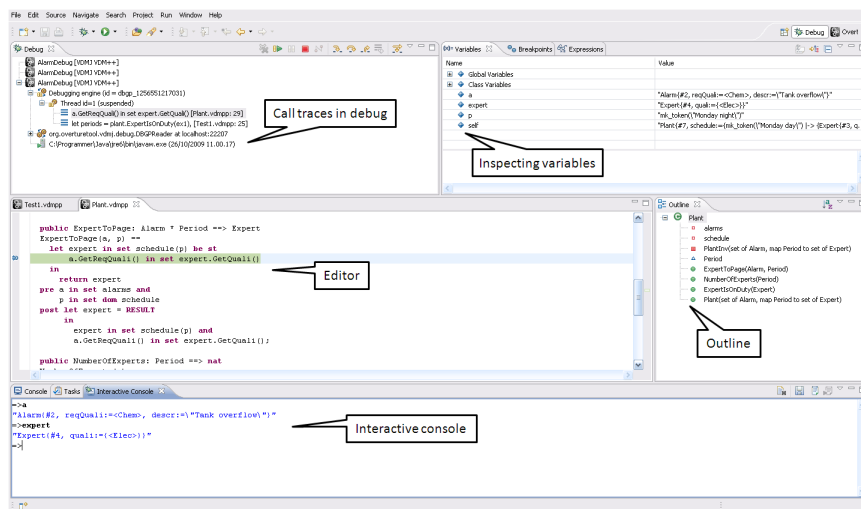


Figure 3.9: Debugging perspective



Table 3.1: Overture debugging buttons

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

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*⁹.

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.



Figure 3.10: Breakpoint View

The *Breakpoints view* gives an overview of all breakpoints set (see Figure 3.10). From this view you can easily navigate to the location of a given breakpoint, disable or delete them, or set their

⁹In the current version only the thread where the breakpoint is met is stopped, but in the future all threads will be stopped when a breakpoint is met and all will be enabled again once the user resume the execution.



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.

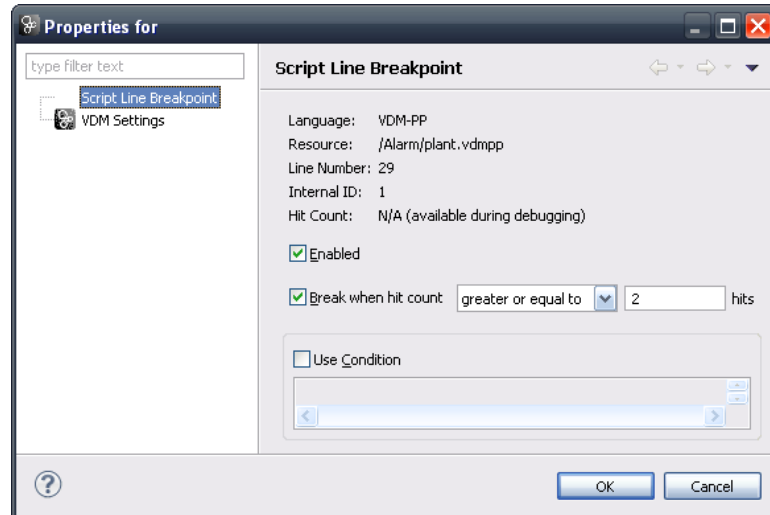


Figure 3.11: Conditional breakpoint options

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 3.11.

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 3.9.

While the Overture Expressions view allows you to inspect values, the functionality is somewhat limited. For more thorough inspections in Overture, the *Interactive Console* view is provided. Here commands can be executed in a given context, i.e. when the debugger is at a breakpoint. The Interactive Console keeps a command history, so that previously executed commands can be run again easily. The interactive console can be seen at the bottom of Figure 3.9.

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

□

3.7 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.

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) union {ex}
                 else {ex};
```

and the `RemoveExpertFromSchedule` operation can be expressed as:

```
public RemoveExpertFromSchedule: Period * Expert ==> ()
RemoveExpertFromSchedule(p,ex) ==
  let exs = schedule(p) in
    schedule := if card exs = 1
                 then {p} <-: schedule
                 else schedule ++ {p |-> exs \ {ex}}
pre p in set dom schedule;
```

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. 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. A full explanation of this can be found in [Larsen&09]. In our case, inside the `Test2` class one can write¹⁰:

```
traces
```

¹⁰Such *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.



```
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-such-that 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. If you select the Combinatorial Testing perspective you will see the **CT Overview** view. Inside this view you can select the alarm project, right click it and choose the **Run selected** option. 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 that the tests passed or failed respectively. See Figure 3.12. 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.

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)¹¹.

3.8 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*.

¹¹Note 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 work is underway for a feature that reduce the numbers of tests to be executed using various intelligent selection techniques. This will be released in a future version of Overture.

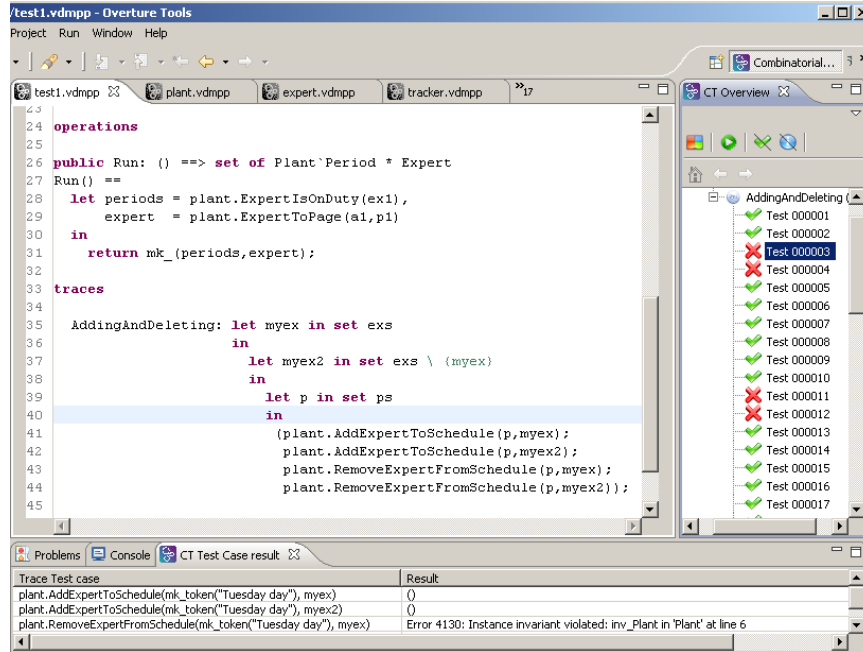


Figure 3.12: Using Combinatorial Testing for the Alarm VDM++ model

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 3.13.

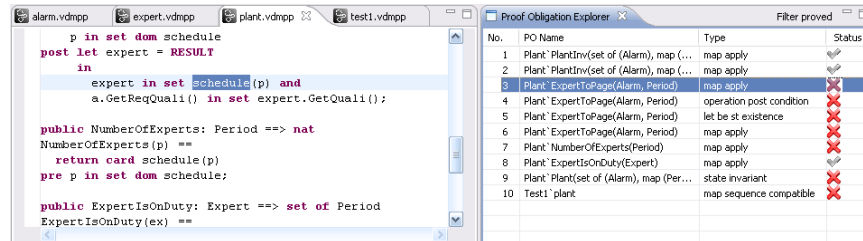


Figure 3.13: The Proof Obligation view for the Alarm VDM++ model

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.



3.9 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 ¹² should be executed with a Java JRE (version 5 or later):

```
java -jar vdmj-2.0.0.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 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-2.0.0.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-2.0.0.jar -vdmpp -q -e "new Test1().Run()"
AlarmPP
```

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

¹²See the Overture documentation at sourceforge.net/projects/overture for the location of the jar file.



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),  
[thread 1]> print plant.NumberOfExperts(  
    mk_token("Wednesday"))  
Runtime: Error 4071: Precondition failure:  
    pre_NumberOfExperts in  
    'Test1' (console) at line 1:1
```



```
[thread 1]> continue
= mk_({mk_token("Monday day")},
      Expert{#3, quali:={<Mech>, <Bio>}})
Executed in 91.014 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 Guide¹³.

When any evaluation is performed on a VDM model, VDMJ 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 single test does cause the majority of the VDM model to be executed, but the `NumberOfExperts` operation in `plant.vdmpp` remains unused. To display coverage, the `coverage <file>` command is used. Lines that have been executed are listed with a '+' prefix, while those that have not have a '-' prefix; lines that are not executable have no prefix. Alternatively, the coverage can be written to a `LaTeX` file using the `latex` command:

```
> coverage plant.vdmpp
Test coverage for plant.vdmpp:
...
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;
```

¹³Supplied with the Overture documentation.



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

Coverage = 87%
>

> latex AlarmPP/Plant.vdmpp
Latex coverage written to AlarmPP\Plant.vdmpp.tex
>
```

3.10 Summary

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

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

References

- [Fitzgerald&98] John Fitzgerald and Peter Gorm Larsen. *Modelling Systems – Practical Tools and Techniques in Software Development*. Cambridge University Press, 1998.
- [Larsen&09] Peter Gorm Larsen and Kenneth Lausdahl. *User Manual for the Overture Combinatorial Testing Plug-in*. Technical Report TR-2009-01, The Overture Initiative, www.overturetool.org, March 2009. 30 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.

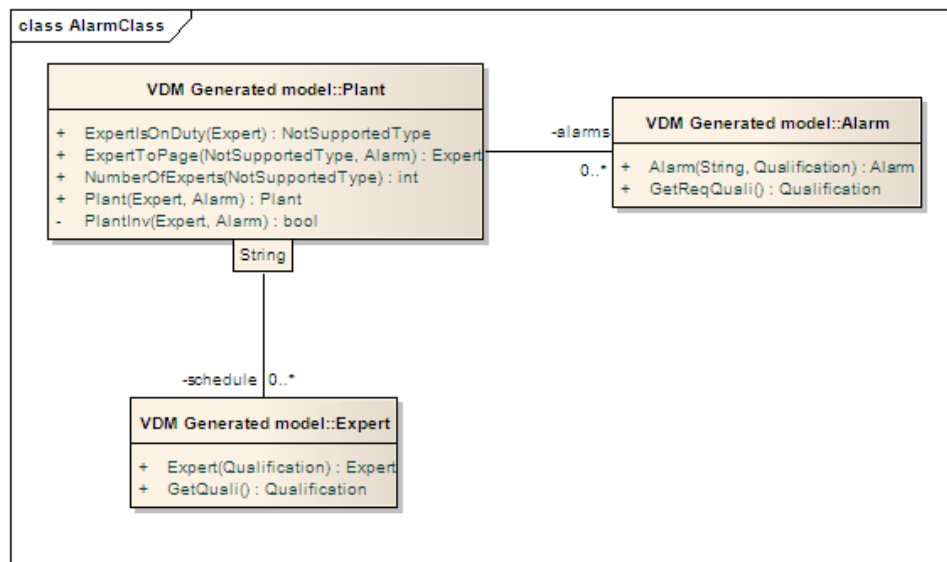


Figure A.1: UML diagram translated from VDM++ files



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
```