

VDMTools

VDM++ Test Automation:
VDMTestK

How to contact SCSK:

<http://www.vdmtools.jp/>
<http://www.vdmtools.jp/en/>

VDM information web site(in Japanese)
VDM information web site(in English)

<http://www.scsk.jp/>
http://www.scsk.jp/index_en.html

SCSK Corporation web site(in Japanese)
SCSK Corporation web site(in English)

vdm.sp@scsk.jp

Mail

VDM++ Test Automation: VDMTesK 2.0

— Revised for VDMTools v9.0.2

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1 Introduction

Testing is one of the necessary stages of the software development life cycle. It is applied at both the development and the maintenance stages. Testing appears especially important during the development and maintenance of critical software. In fact, only testing can demonstrate to the developers and customers that a software program does what is required, and does it as expected.

The size and the complexity of a test suite that provides a required test completeness is comparable with the size of the program under test, or even exceeds it. That is the reason why manufacturers often have to economize on testing, which, in turn, typically increases the cost of the maintenance stage.

To reduce the cost of testing during industrial software development to an acceptable value, it is necessary to organize industrial test development. In this case, the following are essential:

1. Elaborate a test suite architecture, i.e. to define a collection of test suite artifacts and relations between them.
2. Evolve invariant components, which are identical for different test suites.
3. For the specific components that depend on the target system, define ways of their generation based on compact and clear formal descriptions, and maximally increase reuse of such descriptions.

The VDM++TesK tool is an add-on feature that extends features of the VDM++ version of VDMTools. VDM++TesK provides the developer of VDM++ models with new features enabling automation of parts of test suite design and development, that allow to essentially increase the quality of the models and, thus, to contribute to increase reliability and other quality characteristics of the target software.

In the initial phase of getting acquainted with this feature, most users may be confused with certain technical solutions that may be uncommon. A number of basic concepts and constructs needed to master to obtain the full benefits from this technology. Complexity of the methodology, the following points should be kept in mind:

- VDM++TesK had been developed for constructing test suites for large and critical software.

- VDM++TesK is mostly aimed at the industrial process of systematic testing, where the essential tasks are: evaluation of the test suite completeness, reuse of all testing process artifacts, etc.
- The concepts of the VDM++TesK process is primarily based on the idea of a model's sequential complication. VDM++TesK potentially provides full support for this process. While solving problems of testing of models at each level and consistency of such levels, it is possible to achieve a high degree of test suite components reuse. It is also important for industrial projects that the test suite development and debugging activity can be started simultaneously with the prototype design and implementation.

VDM++TesK is an implementation of the UniTesK concept of software testing [BKPP02]. UniTesK is based on the experience of deployment of the advanced industrial testing technologies. The UniTesK concept has already been approved in companies such as Nortel Networks, Microsoft Research and Intel. In these projects, the target software was an operating system kernel and utilities, telecommunication protocol implementations and various components of compilers. UniTesK assumes that it is possible to implement its concepts using different languages (and on multilanguage) platforms. Several implementations already exist now (e.g. for extended dialects of Java and C). VDM++TesK is such an implementation for the VDM++ VDMTools platform.

First of all, the UniTesK concept proposes a novel view on the test production using generation as much as possible. The underlying idea is that it is not a test itself that is generated because this is unmanageable for the most real-life systems, but instead a framework for test suite is generated. This framework consists of three kinds of components. The first kind is the pre-built components that are common for all test suites of a certain kind. The second kind is the components that are generated automatically. Sources for such generation are pre- and postconditions and class invariants. The third kind is so-called handmade components of a test suite. Usually, the handmade components are operations of 2-3 lines in length, which interfaces and purposes are defined by the UniTesK test suite architecture. Notice, that a volume of handmade components in a test suite usually does not exceed 5-10% of the total amount.

The current version of VDM++TesK is the first one that is offered to VDM++ users. It has several limitations in comparison with other implementations of UniTesK. At first, in regards to the fact that both specification and executable model (that is the system under test) are related to the same level of abstraction. In general case, UniTesK allows data structures and even interfaces of a specification and an implementation to differ (they are related to different abstraction levels). The second limitation is the only criterion of the test coverage completeness. Both of these limitations are not fundamental and can be removed in future updates.

Reading guide for document

Terminological note. Below, the term "model" will be used often. For the VDM users, a model is a prototype written in VDM++. But in UniTesK/VDM++TesK, the following conventions are accepted:

- A model is a kind of presentation of the target system's functionality/behavior (e.g. specifications in the form of pre- and postconditions, or a finite state machine that establishes the correlation between stimuli and reactions of the target system). Often (but not always), a model is more abstract and simple than its implementation.
- Terms "implementation", "target system", "system under test" are synonyms in this document, all these terms denote usual VDM++ classes with explicit definition of their operations.

2 General VDM++TesK test suite architecture

The VDM++TesK test suite is built according to the UniTesK concept [BKKP02]. We begin describing its architecture with the description of the UniTesK test suite.

2.1 Terminology and General Principles

UniTesK/VDM++TesK follows the "Design-by-contract" concept. First of all, testing is aimed at verification of the correspondence between the real behavior of an explicit VDM++ model (will be referred to as an implementation below) and an implicitly defined VDM++ model (its software contract i.e. to be referred to as a specification below). The software contract is given in the form of pre- and postconditions and invariants of classes/types (so-called constraint specifications). The conformance testing is the main testing operation in UniTesK/VDM++TesK.

If pre- and postconditions are defined, the so-called oracle program can be automatically generated. An oracle assigns a verdict about correspondence between a result of each operation explicit definition execution and its formal implicit definition (its specification).

2.2 Partition Analysis and Partition Testing

A rational way of minimizing of the number of tests assumes that the space of all test input can be divided into a number of equivalence classes. Elements of this space corresponds to values of some variables or to sequences of events of some kind. The challenge of producing such a space division is called partition analysis. A partition can be build based on an implementation (e.g. basing on variables of an implementation) or a specification. In the UniTesK, first of all, the partitioning is created basing on the specification, since exactly this partition gives a clear way to determine equivalence classes for the conformance testing. Other kinds of the partitioning can also be used, but they are auxiliary in nature.

An approach to testing which, on the one hand, prescribes to test the target system in situations that as a whole cover all the equivalence classes obtained as a result of the partition analysis, and, on the other hand, postulates that such testing is sufficient, is called partition testing¹.

2.3 Test Coverage

Traditionally, a test coverage serves as a characteristic of the testing quality. In the presence of an automatic test generation and execution, a test completeness criteria serve as one of the basic factors that control test generation and execution.

In practice, a test completeness is measured in percents in some numerical measure, e.g. in the number of source lines of a target program. It is known that such characteristic is not sufficient. Moreover, from the conformance testing point of view, a measure is required that is concerned rather with specification than with implementation. UniTesK/VDM++TesK uses a family of nested testing completeness criteria that are built basing on the postcondition structure. The basic criterion (the weakest one) requires the coverage of all postcondition branches. The next criterion requires the coverage of all reachable combinations of logical terms that determine predicates of the corresponded branches. Furthermore, it is possible to refine the criteria in terms of the postconditions subbranches.

¹If we follow the partition testing ideology, and at the same time use partitioning of the specification space, it means that we suppose that the hypothesis of conformance of implementational and specification spaces is correct. In most cases it is just an assumption, and many counter-examples can be found. But industrial experience shows that a good partition testing based on specification space gives almost 100% of required % reliability.

2.4 Test sequences

When testing is performed over groups of functions/procedures with common variables or objects' operations, besides the problem of an input data generation we will have to solve the problem of getting the VDM model into desirable states enabling certain tests. This is called test sequence (TS) and this can be generated. There are two basic approaches to the TS generation. The first is based on use cases, or scenarios of the target system usage. The second is the test sequence generation according to the test coverage completeness. Sometimes this approach is erroneously called random testing. The term is not correct, because in this approach it is also possible to follow a purposeful strategy of choosing the best (in some sense) sequence. This can be called an exhaustive testing approach. The UniTesK supports both approaches, but in the current version of VDM++TesK only the later approach is supported, so here focus will be on the exhaustive testing approach.

As a rule, in testing, the term “exhaustive” does not imply an examination of all possible test situations as this is typically too large or even infinite. Thus, an exhaustive test is constructed within a certain set of equivalence classes or (which is the same) accurate within a criterion of the test coverage completeness.

UniTesK/VDM++TesK has a ready-for-use base of the test coverage criteria – the coverage of postconditions branches and/or term combinations. But in general case it is not enough for constructing a TS. Pre- and postconditions provide information used for division of the input data space into equivalence classes, and an information for building oracles. However, it is often difficult or even impossible to build test sequence based on this information, due to the implicit nature of specifications. At the same time, executable models are good for test sequence generation.

3 Details of UniTesK Test Suite Architecture

3.1 Intercation between Test Engine and Test Sequence Iterator

The core of UniTesK test suite is the traversal mechanism for a finite automata. To provide additional flexibility it is divided into two parts:

- A test engine component encapsulating an algorithm of traversal of a finite automaton from a class, and
- A test sequence iterator component, which embodies all the details of particular

automaton.

The test engine and the test sequence iterator interact through well defined interface consisting of the following three operations defined in test sequence iterator.

State **getState()** This operation returns the identifier of the current state of the automaton. State identifiers can be stored by a test engine to facilitate a traversal, but the only thing it can do with them is comparison, which shows whether two identifiers designate one state of the automaton under traversal or two different states.

Input **next()** This operation search for the next input symbol in the current state, which has not yet been applied during this traversal. If there exists any, it returns anyone of such symbols, else it returns `nil`. The objects of `Input` type are identifiers of input symbols. As state identifiers, they may also be stored by the test engine and can be compared with each other.

() call(param : Input) This operation applies the input symbol identified by the `param` object in the current state. It actually performs the corresponding transition in the automaton under traversal.

Notice, that the interface specified requires that the algorithm of automata traversal implemented by test engine component does its work only on base of data provided by these operations, that is, identifiers of states, able to be compared, the next input symbol not yet applied in the current state, and the possibility to apply it. This means, in particular, that the test engine has no description of the automaton under traversal except for the structure that already have been traversed. Algorithms of automata traversal that does not require more information to work are called “undemanding”.

Why is the use of undemanding automata traversal algorithms justified? It may seem that more traditional automata testing based on a complete description of the state transition graph is more appropriate. However, notice, that undemanding traversal algorithms require only the information on applicable input symbols in each state, whereas traditional approaches need additionally to know the end of each transition (for nondeterministic automata – all possible ends). Our experience shows that the first way to describe an automaton is much simpler and more scalable on the size of the automaton under test. To obtain the information on all possible ends of each transition we need to examine the specifications deeply – so, along with additional data full description of an automaton requires much more manual work, because such an analysis can hardly be automated in most cases. However, if we already have the specifications, why do not describe only applicable input and let oracles, generated

from these specifications, check the correctness automatically, instead of hard manual work?

It may seem that specifications contain enough information to generate inputs too, but it is true only for very simple software components, because specifications are often given in an implicit form – they describe only properties of admissible input. In general case it takes less effort to specify the necessary input by hand than to derive it from such specifications (see below the discussion of the structure of test sequence iterator component).

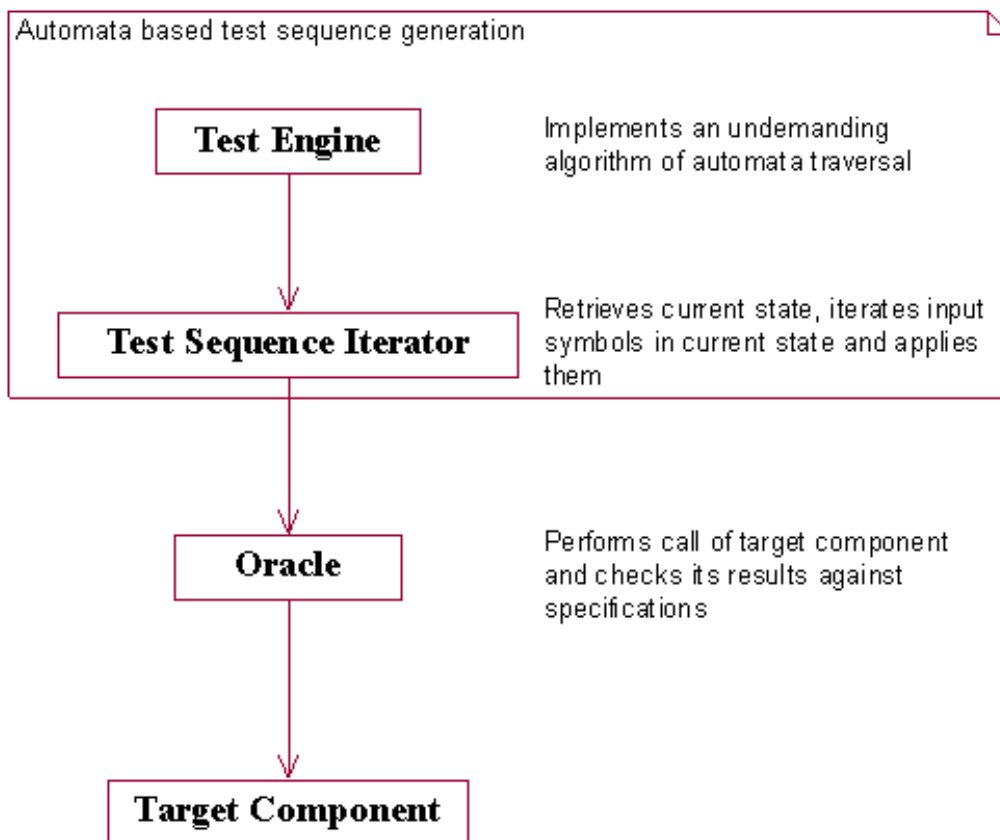


Figure 1: Basic architecture of UniTesK test suite

So, the main idea of UniTesK testing technique is separation between test sequence generation and behavior verification tasks. Test engine and test sequence iterator are responsible for test sequence generation and require only a part of description of an automaton under test – the set of states and applicable input symbols for each state.

Oracles of target components are called during the work of test sequence iterator's `call()` operation and, in turn, call the corresponding target operations and perform the verification of the behavior of these operations against their specifications.

Figure 1 shows the basic architecture of UniTesK test suite. We do not consider here auxiliary components responsible for trace gathering and run-time test support, because they have no any UniTesK specifics.

The test engine component is a predefined part of a test suite. There are several such components, but the test developer do not need to write them manually; an existing one shall be used. Oracles are supposed to be generated automatically from specifications, which in turn are always developed by hand.

The test sequence iterator shall provide all possible input symbols for each state of the automaton under traversal. Remember, that this automaton is constructed from the behavior of the system under test and some coverage criterion, or coverage of all possible test situations. Input symbol of the automaton under traversal corresponds to some class of possible inputs for the system under test.

3.2 Test Coverage Criteria

An arbitrary coverage criteria can be described by a number of predicates depending on the target operation identifier and a list of its input parameters. Each of these predicates determines one element of the coverage. The set of predicates, describing the coverage based on the structure of implementation or specification could be extracted from them, but it is not easy task in the common case. To facilitate this work the UniTesK technology requires the specification designer to emphasize the basic partition of the specified operation domain by means of special constructs, branch function. The elements of this basic partition correspond to subdomains where the specified operation has substantially different functionality.

But how can the predicates describing coverage be used? In most simple cases the corresponding boolean predicates can be solved to produce automatically the set of test cases that ensures the test coverage needed. Unfortunately, it is impossible in general – because the predicates obtained can be unsolvable by any algorithm, or, if we remember that all the data in real computers are from some finite sets, they are practically unsolvable due to enormous amount of time needed for that.

Thus, the general case solution should allow the test designer to facilitate test case generation with some handmade components of test system, which are called iterators in UniTesK. However the predicates defined above do remain useful. They can be

used to filter the test cases provided by iterators, and, so, iterators need not to be very precise – it is enough, if an iterator used for some component under test provides a wide range of possible inputs, including at least one representative of each coverage class. In UniTesK test development technology the predicates describing the target coverage, for example, the coverage extracted from the structure of specifications, are used to generate a special kind of test system components called coverage trackers.

Such a coverage tracker is used as a part of test sequence iterator component. It determines the element of the target coverage corresponding to a call of the target operation generated by iterator and checks whether this element has been covered before during the test. If not, this call is considered as the next unapplied input symbol, and the tracker marks the corresponding coverage element as covered (because the test engine actually performs this call later), otherwise the coverage tracker calls the iterator for the next call. When all the elements of the coverage are covered, the coverage tracker reports that there are no unapplied input symbols and the test can be completed.

3.3 The Test Sequence Iterator

Other functionality of test system iterator is represented by operations `getState()` and `call()`. When we consider the coverage criteria based only on coverages of component's operations domains, the latter operation can be generated in general case. For most testing tasks it is enough, but sometimes, when we need to cover some specific sequences of calls of target operations, we should write part of the second operation by hands, and for this reason this possibility exists in UniTesK technology.

Figure 2 shows the structure of mechanism iterating applicable input symbols used in UniTesK.

As illustrated above, test sequence iterators have a complex structure. The bulk of which is usually generated automatically – target coverage trackers and caller implementing `call()` operation. Sometimes callers need a bit of manual code and sometimes the state converter component and iterators can also be generated. To provide a coherent description of all the parts of test sequence iterator UniTesK operation proposes a form of test scenario, which partially generated and partially written by hand. Test scenario serves as a source for test sequence iterator generation. For more detailed description of the structure of test scenarios see below. Our experience shows that the ratio of generated code size to manual code size in test sequence iterator component is usually more than 4:1.

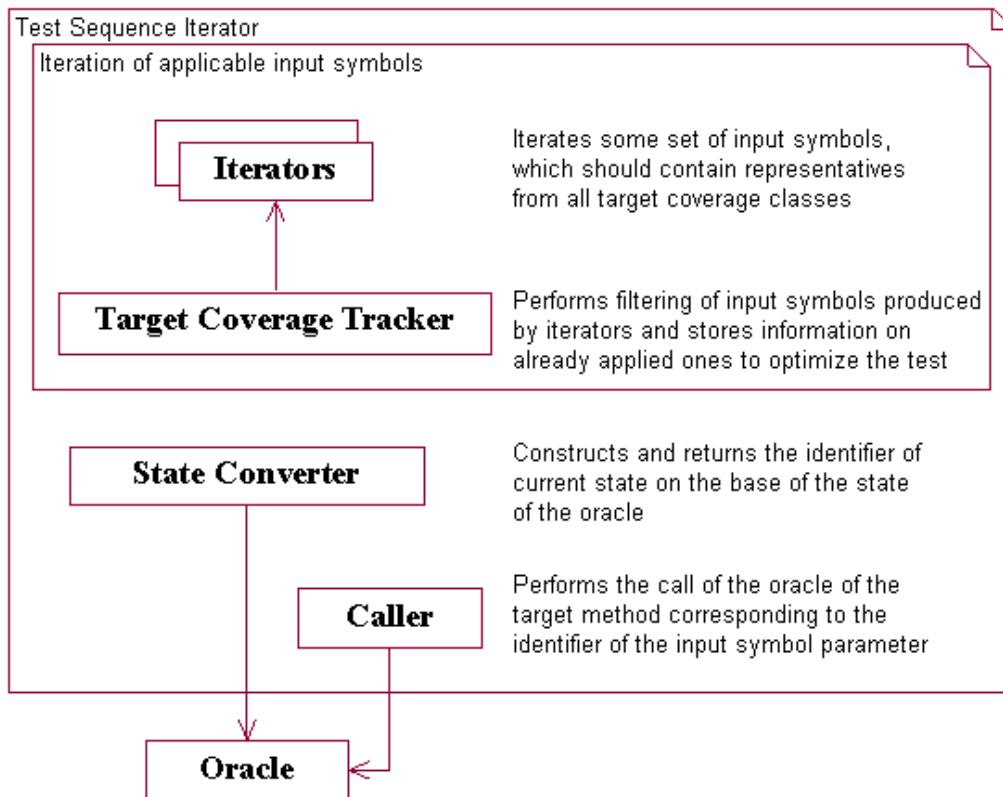


Figure 2: Typical structure of test sequence iterator component

3.4 Use of Design Patterns

One more important point of UniTesK test suite architecture is the use of adapter pattern to bind specification and implementation of the target component. For historical reasons we call adapters, which have specification interface and implement it on the base of the implementation under test, mediators.

To be able to produce reusable and repeatable tests is crucial for industrial test development technology. UniTesK supports reusability of tests and specifications by using more abstract specifications, which can be applicable to several versions of the target component. To perform a test in such a situation we should have something to bind the immutable specification with a changing implementation. One of the simplest and at the same time most flexible solutions is to use a mediator component having the interface of specification and implementing it with the help of implementation. Such

an approach allows us to change the level of abstraction of specifications and tests developed with the help of UniTesK technology in almost arbitrary way.

Along with implementation of the specification interface, a mediator is responsible for synchronization of its state as it is defined in specifications with the state of the implementation, which can have an entirely different form. This is important to support open state testing, which assumes that on every step (between two calls of target operations) we can determine exactly what the current state of the component is.

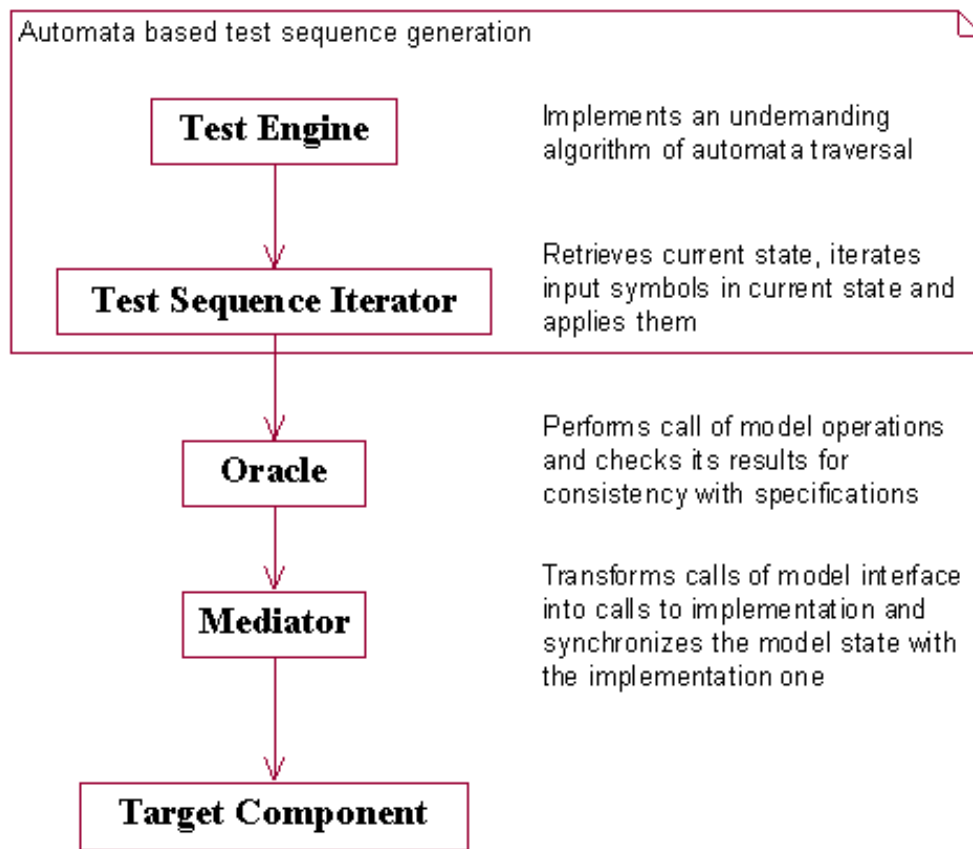


Figure 3: Complete architecture of UniTesK test suite

Figure 2 demonstrates the complete set of the main components of UniTesK test suite architecture. However auxiliary components of test suite responsible for tracing and run-time test support have been left out.

Mediator components are usually written by hand. This fact increases the total size of manual work, but in return we have the possibility to develop really reusable specifications and tests, sometimes comprising the complete and ready-to-use suite for regression testing.

4 VDM++TesK Test Suite Architecture

4.1 Relating UniTesK to VDM++TesK

This section will demonstrate how the VDM++TesK test suite architecture corresponds to that of UniTesK described above.

The VDM++TesK test suite architecture is implemented as a collection of classes with well-defined functionality. Each component of the UniTesK test suite presented on Figure 1 and Figure 2 corresponds to a class or a group of classes (or even to parts of classes). Each class of the VDM++TesK test suite belongs to one of three kinds depending on its origin. Such kinds are:

- hand-made;
- pre-built; and
- generated.

Abstracting from a few details, a class diagram of the VDM++TesK test suite is as shown in Figure 4.

For each of the components in the UniTesK framework the classes in the VDM++TesK solution will be explained below:

Target Component in VDM++TesK is presented by one or more VDM++ classes, which functionality should be tested. On the class diagram it is presented by the **Target Class**.

Oracle component corresponds to the class of the VDM++TesK test suite called **Oracle class**. It is aimed at checking conformance of behavior of the target operations (operations of the target class(es)) with their specifications. In the **Oracle class**, for each target operation, a operation with identical signature is defined

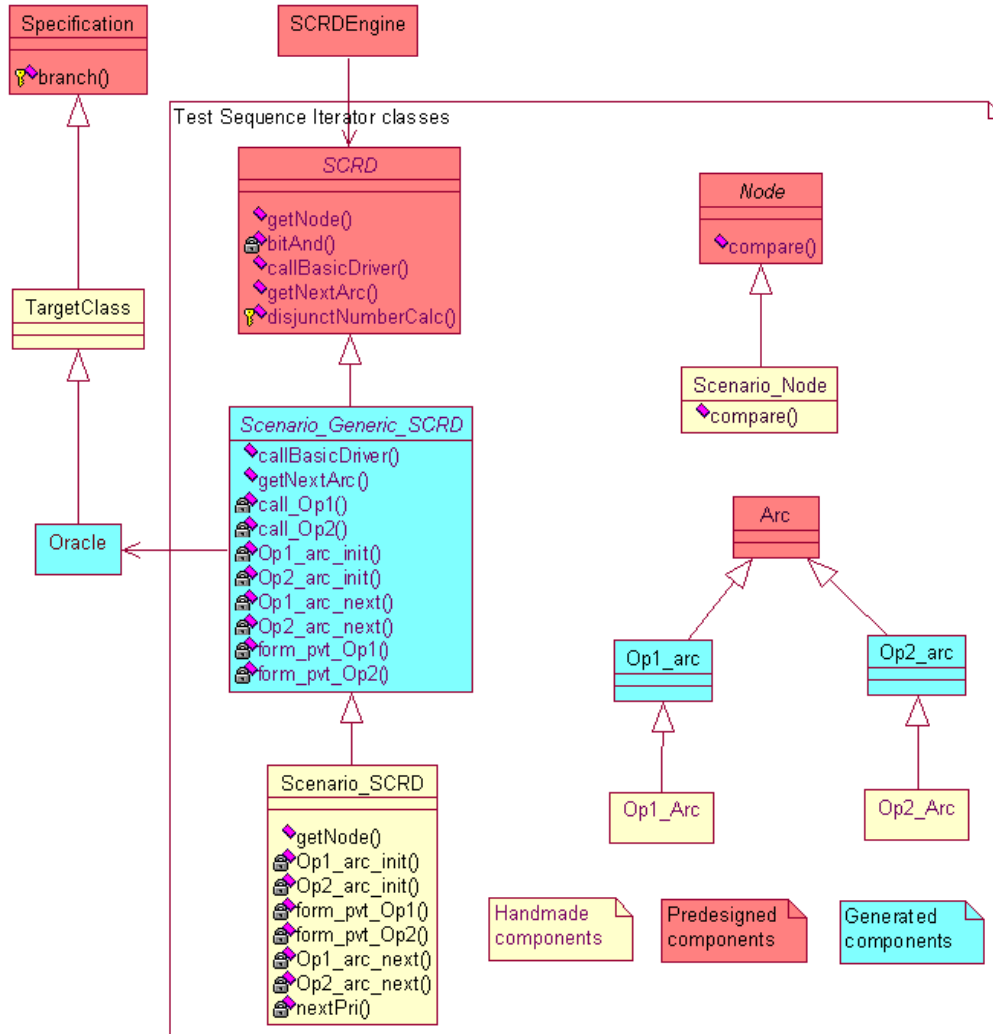


Figure 4: VDM++TesK Test Suite Class Diagram

(as it is seen on the class diagram, the **Oracle** class is inherited from the target class, so oracle operations override the target ones). In case of correct behavior of the corresponding target operation (i.e. if conformance is held), the result of the oracle operation (i.e. its return values and values of object instance variables) coincides with the target operation result. Otherwise, the oracle operation raises an exception depending on the kind of a discrepancy (e.g. if class invariant or pre- or postcondition is violated).

The **Oracle** class is automatically generated basing on the target class formal specification written in VDM++.

Test Engine component is implemented by the **Test Engine** class of the VDM++TesK test suite. This class implements an algorithm of the FSM traversal. In VDM++TesK, such an algorithm is intended for deterministic mutual connected automata traversal. The **Test Engine** class is pre-built and uses the interface described above for automata traversal.

Test Sequence Iterator component is implemented by several classes that are combined into a group called **Test Sequence Iterator** classes in Figure 4. Below this component will be examined in more detail.

4.2 Test Sequence Iterators

The architecture of the test sequence iterators in UniTesK is presented in Figure 2. The class diagram of the test sequence iterators in VDMTesK is presented in Figure 5.

The classes in the VDM++TesK solution are explained below:

SCRD: Pre-built class that contains data and operations for test sequence iteration that do not depend on a concrete collection of operations to be tested.

Scenario Generic SCRd: Class that is generated for concrete operations testing and aimed at test sequence iteration.

Scenario SCRd: Hand-made class that contains data and operations for test sequence iteration that cannot be generated automatically and must be written manually.

Node: Base class for FSM state identifier that is pre-built.

Scenario Node: Handmade class for FSM state identifier for concrete test scenario.

Arc: Base class for FSM input symbols that is pre-build.

op1_arc, op2_arc: FSM input symbols classes that are generated for each operation tested by this scenario.

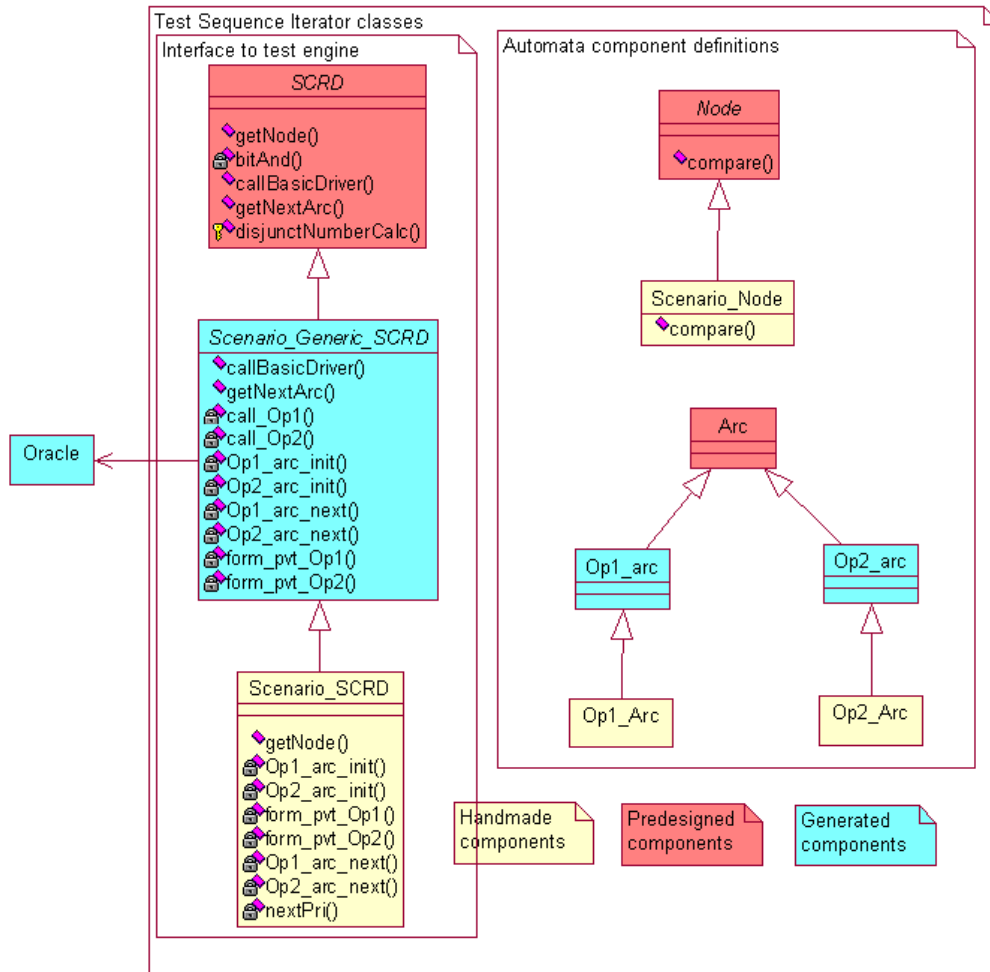


Figure 5: Test sequence iterator class diagram

op1_Arc, op2_Arc: Hand-made FSM input symbols classes. Such class is defined only if the input symbol for the corresponding tested operation should contain additional information (see below).

Classes of the Test Sequence Iterator can be grouped in the following manner:

- The SCRD, Scenario Generic SCRD, Scenario SCRD classes provide interface required for automata traversal by Test Engine that, in fact, performs testing.

- The `Node`, `Scenario Node`, `Arc`, `op1_arc`, `op2_arc`, `op1_Arc`, `op2_Arc` classes provide definitions of automata components (see above), namely nodes and arcs.

4.3 Test Iteration and Test Coverage

The function of the Iteration of applicable input symbols group is to deliver the next input symbol in the current state, which has not been applied yet during this traversal. This task can be divided into two parts:

- iteration of input symbols (this task is solved by components of Iterators group) and
- its filtration based on test coverage that is already performed (Test Coverage Tracker component).

The input symbols iteration is implemented by `<op name>_init()` and `<op name>_next()` operations that are defined in the hand-made class `Scenario SRC`D for each tested operation.

Operations for the input symbols filtering are generated automatically and defined in the generated class `Scenario Generic SRC`D. Moreover, these operations use information about test coverage criteria that is automatically obtained from the specification and is defined in the oracle class (see above). These operations use a conversion of input symbols to input parameters of the corresponding target operation. Operations for such conversions are developed manually and defined in the `Scenario SRC`D class.

When the `Test Engine` requests the next input symbol, it calls `getNextArc()` operation of the `Scenario Generic SRC`D class, and this operation, in turn, uses `<op name>_init()` and `<op name>_next()` operations described above.

The state converter component is implemented by the `getNode()` operation defined in the hand-made class `Scenario SRC`D. Its responsibility is to construct the FSM state identifier based on the current state of the target system. This state can be obtained from an object (or objects) of the oracle class (or classes).

The caller component is intended to impact the FSM under traversal with an input symbol, what corresponds to the a call to the operation of the oracle class with parameters defined by this input symbol. In the VDM++TesK test suite, this component is presented with the `callBasicDriver()` operation, which is generated automatically

and defined in the `Scenario Generic SCRD` class. This operation uses operations named `call_...()` that are generated for each tested operation. These operations convert an input symbols to parameters of the corresponding target operation and call that operation for the object of oracle class. Operations for such conversion are manually defined in the `Scenario SCRD` class and called the `form_pvt_...()` operation. In most cases, this collection of actions performed by generated operations `call_...()` is sufficient for testing, however, test designer can redefine it if necessary.

Detailed description of test suite classes interfaces can be found in Appendix C.

Notice that the mediator component shown on Figure 3 is not implemented in the VDM++TesK test suite. As it was mentioned above, mediators are used for binding between the target system and its model. In VDM++TesK, it is assumed that the target system structurally coincides with its model. In this case, mediators are not needed. In case when it is necessary to separate a system and a model, test designer can use mediators. However, description of the mediators development is out of scope in this document.

In the part of the UniTesK technology description dedicated to the test coverage, it was said that a designer can use nonstandard test coverage criteria. However, this possibility is absent in VDM++TesK. Moreover, the only coverage criterion supported is the criterion based on postcondition branches coverage.

5 Test Development

In this section a description of the test development process is provided. A small example will be used to explain the steps of the development, and a test suite for a class implementing a priority queue will be used. The full list of the VDM++ files composing this test suite can be found in Appendix C.

The VDM++TesK test development process has the following steps:

1. constraints are developed for the target classes and operations, i.e. their formal specifications are written;
2. groups of the operations are selected to be tested simultaneously, and for each such group a test scenario is developed.

5.1 Specification Development

Constraints of the target class are defined in the same class. A specification class (i.e. target class with constraints defined in it) should be a subclass of the pre-built class called `Specification`, where function branch is defined.

In VDM++TesK, the following constraints are used:

1. Class invariants (constraints on the instance variables that are common for all operations of this class)
2. Constraints for each operation
 - (a) Instance variables access description
 - (b) Operation preconditions
 - (c) Operation postcondition

VDM++TesK does not support semantics of the specification classes inheritance. The inheritance from a specification class implies only explicit definitions inheritance (i.e. data and explicit operations definitions). Base class constraints are ignored.

See for example the `PriorityQueue` class on page 87.

5.2 Class invariants

For the invariants definition, the standard VDM++ expressions is used after instance variables.

All expressions used in the invariant definition should be executable by the VDM++ interpreter.

5.3 Constraints for each operation

Operations for which postcondition is required should be defined using the VDM++-computable "extended explicit operation definition". This is the only way to combine both its explicit implementation and access to instance variables in the single operation declaration.

5.3.1 Instance variables access definition

The instance variables access definition describes how the operation uses the class's instance variables.

For an access definition, the standard VDM++ construct "externals" is used.

See access definitions for operations `PriorityQueue`enqp` (page 88), `PriorityQueue`enq` (page 90), `PriorityQueue`deq` (page 90), `PriorityQueue`size` (page 90) and `PriorityQueue`isEmpty` (page 91).

5.3.2 Operation preconditions

A precondition describes the operation's condition of applicability according to its input values and the object's state.

A precondition is defined using a predicate after the VDM++ keyword "pre".

An expression used as the precondition should be executable by the VDM++ interpreter.

See the precondition definition for the operation `PriorityQueue`enqp` on page 88.

5.3.3 Operation postcondition

A postcondition defines a relation between the operation's input parameters and the object's pre-state (the values of instance variables before the operation invocation), and the operation's output values and the object's post-state (the values of the instance variables after the operation's completion).

A postcondition is defined using a predicate after the VDM++ keyword "post".

In VDM++TesK, the so-called branch coverage is used as a coverage criterion. To enable VDM++TesK to elicit test coverage criteria, so-called branches should be denoted in the postcondition. Each branch describes one of the alternative behaviors of the operation.

To denote each branch, the postcondition must be defined using the VDM++ "if expression". Each branch must be marked with a name that is unique for the given operation.

```
if p1 then branch("branch #1") and post1
elseif p2 then branch("branch #2") and post2
...
elseif pn-1 then branch("branch #n-1") and postn-1
else branch("branch #n") and postn
```

The predicates $p_1 \dots p_{n-1}$ determine the partitioning of the input parameters space. In such predicates, only the pre-values should be used – the operation’s input parameters and the object’s instance variables in the pre-state. The constraints $post_1 \dots post_n$ determine the operation’s behavior correctness in each of the alternatives.

If the postcondition can’t be divided into more than one branch, it should be written in the following manner:

```
branch("single branch") and post
```

An expression used for the postcondition definition should be executable by the VDM++ interpreter.

See the postconditions for the operations `PriorityQueue`enq` (page 88), `PriorityQueue`enq` (page 90), `PriorityQueue`deq` (page 90), `PriorityQueue`size` (page 90) and `PriorityQueue`isEmpty` (page 91).

5.4 Test scenario development

A test scenario development starts with the definition of a group of operations which will be tested by it. In most cases, all operations of a class naturally form such group. However, sometimes this approach of grouping makes test execution time-consuming. In this case, operations may be grouped according to such considerations as use cases. In any approach, a group should be complete in the following sense. There should not be "irreversible" impacts to the tested system, i.e. the system can be returned to its initial (the particular) state from any state using only operations from this group.

The operations group is described by the list of their qualified named (`<class name>`<op name>`). Based on its description, the VDM++TesK tools generate the classes required for test sequence iteration (about these classes, see VDM++TesK test suite architecture). Then test developer should write the following handmade classes:

1. FSM state identifier;
2. Classes that describe FSM input symbols; and
3. Test sequence iterator class.

5.4.1 FSM state identifier

As mentioned above, a set of target system states can be divided into equivalence classes. A state identifier determines the membership of the corresponding system state in a particular equivalence class, or, in terms of FSM, in its particular state. A FSM state (and, hence, state identifier) may correspond to several target system states.

Class describing state identifier is derived from the pre-built class called `Node`. In this class test developer should define data that determines state of the tested FSM. For example, for the priority queue, such state is described as a mapping from priorities existing in the queue to the number of elements with such priority.

Moreover, in this class, an operation `compare` should be defined as:

```
compare : Node ==> bool
```

`n1.compare(n2)` returns `true` if and only if `n1` and `n2` are identifiers of the same automaton state (i.e. they correspond to target system states belonging to the same equivalence class).

See class `PQueue_Node` on page 94.

5.4.2 Classes that describe FSM input symbols

An impact on the FSM by an input symbol is a call to the corresponding target operation. For each operation under test, an empty class (declaring no data) is automatically generated. Such class corresponding to a operation `<op name>` is called `<op name>_arc`. During the test execution, the input symbol's membership in one of such classes determines the operation to be called, and parameters of this operation are determined using the corresponding conversion operation (see below). Thus, in a class describing a FSM input symbol, the test developer should declare data required for such conversion. This data should be defined in class inherited from the generated class.

For example, consider the handmade input symbol class corresponding to the `enqp` queue operation (`PriorityQueue_enqp_Arc`). In this case, different input symbols correspond to the enqueueing items with different priorities.

In case when it is not necessary to test with certain parameters of a operation, the test developer does not need to define such classes. Notice, that the `form_pvt_<op name> ()` operations still should be defined for such operations.

It should be noticed that in VDM++TesK FSM should be deterministic, i.e. any input symbol applied in the particular state should lead the FSM to the same state regardless of the previous transitions.

5.4.3 Test sequence iterator

In this class, the following should be defined:

1. Oracle objects initialization;
2. Acquisition of the FSM state identifier;
3. Operations for the input symbols iteration (for each target operation);
4. Operations for conversion of input symbol into operation's parameters; and
5. Operations for calling the oracle.

See class `SCRD_PQueue` on page 95.

Oracle objects initialization

In the class-iterator, objects of tested classes oracles are defined. If any initialization for oracles is needed, a operation for such initialization should be defined in the class-iterator.

This operation should be called `<scenario name>_init` and can have parameters required for the initialization.

Acquisition of FSM state identifier

The test developer should declare operation for state identifier construction basing on the target system's current state. Values of the tested class instance variables can be obtained from the corresponding oracle object (references to such objects are stored in the variables called `oracle_of_<class name>`).

See operation `SCRD_PQueue`getNode` on page 96.

Operations for the input symbols iteration

For each tested operation, a pair of operations must be defined – an operation that constructs a first input symbol to be applied in the current state and a operation that constructs a next input symbol based on the previous one.

<class name>_<op name>_arc_init: This operation yields a pair where the first component is the first input symbol for the current state. A false value in the second component means that the given target operation should not be invoked in this state.

<class name>_<op name>_arc_next: This operation computes the next input symbol according to the previous one. A false value of the second return component means that the iteration of operation's input symbols for the current state is completed.

For operations with no input parameters, these operations shall not be defined.

See operations `PriorityQueue_enq_arc_init` (page 96), `PriorityQueue_enqp_arc_init` (page 97), `PriorityQueue_enq_arc_next` (page 97) and `PriorityQueue_enqp_arc_next` (page 97).

Operations for conversion of input symbol into operation's parameters

For each tested operation, an operation shall be defined that converts an input symbol into this operation's input parameters.

For each tested operation, a structure is defined that holds values of this operation's input parameters, and an operation that converts the input symbol into such a structure.

Type of such structure is named `pvt_<class name>_<op name>`. Types and names of its fields and their order are equal to types and names of the corresponding operation's formal parameters.

See types `pvt_PriorityQueue_enq` and `pvt_PriorityQueue_enqp` (page 63).

The conversion operations has the following signature:

```
form_pvt_<class name>_<op name>:  
    <class name>_<op name>_arc ==>  
    pvt_<class name>_<op name>
```

Notice, that these operations and types are not defined for tested operations without input parameters.

See `form_pvt_PriorityQueue_enq` and `form_pvt_PriorityQueue_enqp` (page 96).

Operations for oracle calling

In the most cases, these operations can be generated automatically. However, sometimes for parameter iteration, output of target operations is required, or sequence of operations should be called as a reaction on a single input symbol. In such cases, these operations shall be defined manually.

```
call_<class name>_<op name>:  
    <class name>_<op name>_arc ==> bool
```

These operations return a boolean value that indicates successful oracle invocation (i.e. that the oracle had found no errors).

In the given example, these operations are generated automatically. See `call_PriorityQueue_enqp`, `call_PriorityQueue_enq`, `call_PriorityQueue_deq`, `call_PriorityQueue_size` and `call_PriorityQueue_isEmpty` (page 84).

6 Test execution and analysis

Now, when the test suite is developed, the test suite can be executed.

6.1 Test execution

To run the test, the FSM traversal algorithm should be executed with the FSM described by the test scenario.

An object of the `SCRDEngine` class shall be created and initialized with test sequence iterator class using its constructor, and subsequently its main operation shall be invoked.

The following will run the test developed for the priority queue example.

```
new SCRDEngine(new SCRDPQueue()).main() }
```

6.2 Test trace and its analysis

During an oracle execution, it traces information about the test coverage. After the test is executed, this information serves as a base for determining the test results – what test coverage has been performed and whether there were any errors. In addition the test trace can be used for exploring errors.

For the present time, test trace analysis must be done manually.

See example of test trace in Appendix [D](#).

References

- [BK KP02] Igor B. Bourdonov, Alexander S. Kossatchev, Victor V. Kuli Amin, and Alexander K. Petrenko. Unitesk test suite architecture. In *FME 2002: Formal Methods – Getting IT Right*, Copenhagen, July 2002. FME, Springer-Verlag.

A Setting up VDMTesK

A.1 Software requirements

- vdmtesk package
- [j2sdk1.4.2_16](#)
- [Eclipse Classic](#)
- [The VDM++ or VICE version of VDMTools](#)
- [Ant](#)
- VDMTesK source files

A.2 Installation

A.2.1 Installing J2SDK

The j2sdk package is an executable file. Double click on the installation file, and follow the instructions.

A.2.2 Installing Eclipse

After download the eclipse classic version, unpack it to a folder (e.g. eclipse).

A.2.3 Installing VDMTools

The VDM version needed is the VDM++ toolbox. After download it, double click on the executable and follow the instructions.

A.2.4 Installing Ant

After doing the download and unpack it, follow these steps:

1. Click **Start**. Click with the right bottom of the mouse in **My Computer**.

2. Click Properties → Advanced → **Environment variables**.
3. The user should have the following environmental variables:

Variable: ANT_HOME

Value: the path to the directory ant

Variable: ANT_OPTS

Value: -Dhttp.proxyHost=<proxy_settings> -Dhttp.proxyPort=<port>

Variable: JAVA_HOME

Value: the path to jdk1.5.0_13

The system variable (Path) should have the following paths:

Path to \ant\bin

Path to jdk1.5.0_13\bin

If any problem appear, please see the installation notes in the ant INSTALL file.

A.2.5 Installing VDMTesK

1. Unzip the `vdmtesk.zip` file. In this tutorial, it is assumed that the folder will be called `vdmtesk`.
2. Install all the software referred above.
3. Run '`ant setup`' (from `vdmtesk` directory) to download `javacc`, using the Windows command prompt.
4. Run '`ant distr.jar`' (from `vdmtesk` directory) using the Windows command prompt to generate Java code for `javacc` parsers (`*.jj`), AST abstract syntax tree (`*.ast`), compile Java and pack classes to jar.
If you need to perform individual steps, run the following commands sequentially:

- `ant AST.jj`
- `ant VDM.jj`
- `ant compile.ast.java`
- `ant VDM.ast`

- `ant compile.java`

If any command fails, besides the last one, they were not installed properly or it is being used another Operating System besides Windows. If that is the case, note that the operating system can be case sensitive; maybe it is necessary to run these commands without capital letters. If the last one fails, it means that the Java code has errors: probably there are some dependencies missing (e.g. JMK or ToolBoxAPI) which will be solved in the next steps.

5. Open the file `.tasktool` and change the variables `toolbox.path` and `user.dir`. The `toolbox.path` must have the path to the VDM++ gde executable and the `user.dir` must have the path to the `vdmtesk` home directory. Here it is an example:

```
toolbox.path C:\\The VDM++ Toolbox v8.3\\bin\\vppgde.EXE
user.dir C:\\vdmtesk
```

6. Open Eclipse and create a new java project. Note that the workspace must have a different path from where is the `vdmtesk`. Give a name to the project and choose "Create project from existing source". Browse the directory `vdmtesk`. Click Next. Click in the check box to "Allow output folders for source folders". Click Finish.

7. It is necessary to insert 2 new libraries:

- (a) Inserting the library JMK

Click Build path → Add libraries → User Library → Next → User libraries → New

Give the name JMK

Click Add JARs and browse `vdmtesk/jar/jmk.jar`

- (b) Inserting the library ToolBoxAPI

Similar process:

Click New

Give the name ToolBoxAPI

Click Add JARs and browse `vdmtesk/jar/ToolBoxAPI.jar`

If the standard library is different from the `j2sdk` mentioned in the Installation section, it must be changed. To do that, follow the following steps:

- Click with the right bottom of the mouse over the name of the project and click Build Path → Configure Build Path

- Select the System Library and click Edit. Then, click **alternate jre** and choose the right jre system library. At the end click Finish → Ok.
8. There should be no errors in the project, now. Assuming that, click with the right bottom of the mouse over vdmtesk (or the name of the project) and click Source → Clean up → Next → Finish
 9. Click Run → Open Run Dialog → Java Application. Complete the form like this:

Project: The name given to the project
Main class: ru.ispras.redverst.vdmtesk.Main
 10. Click run

B VDM++TesK test suite classes

B.1 Target class

The target class is the VDM++ class which functionality that shall be tested.

B.2 Oracle

Based on a formal specification an Oracle class is generated.

The Oracle class is inherited from the Specification class.

In an oracle, the following members are defined:

- Operations for checking of specification and implementation conformance
 - Operation for invariants checking ;
 - Operations for precondition checking;
 - Operation-oracles that check postcondition; and
 - Flags that determine whether to call oracle operation or not.
- Test coverage support
 - Filter operations; and
 - Values that hold the number of branches in postconditions.

Functionality of these components is described further below.

An Oracle class has the same interface as the corresponding class under test.

B.2.1 Operations for checking of invariants (`checkInv_<class name>`)

The operation for invariants checking (`checkInv_<class name>`) This operation checks invariants of the class under test. It evaluates all expressions marked as class invariants, and throws an exception if one of them evaluates to false.

See `checkInv_PriorityQueue` on page 54.

B.2.2 Operations for precondition checking (<op name>_pre)

For each the target operation, the oracle class declares operation that checks this operation's precondition.

See `enqp_pre` (page 58), `enq_pre` (page 61), `deq_pre` (page 56), `isEmpty_pre` (page 60) and `size_pre` (page 55).

B.2.3 Operation-oracles that check postconditions (<op name>_post)

For each target operation, the oracle class declares an operation-oracle. This operation is aimed at checking of a postcondition of the corresponding target operation. The signature of such operation is equivalent to the target operation signature. If the postcondition is false, this operation throws an exception.

In order to check a postcondition, an oracle saves values of instance variables that marked in signature as “written” by the target operation, before the target operation execution.

See `enqp_post` (page 58), `enq_post` (page 61), `deq_post` (page 56), `isEmpty_post` (page 60) and `size_post` (page 55).

Flags that determine whether to call oracle operation or not can be defined. For each target operation, oracle class declares a flag – a boolean variable that determines whether to call the oracle operation (to check postcondition) or not.

See `test_conf_var` (page 63) and `test_conf_all` (page 53).

B.2.4 Filter operations (<op name>_bnc)

On basis of the coverage criteria information taken from the specification, operations and data are defined in the oracle.

For each target operation, the Oracle class declares a filtering operation. Its input parameters are identical to the parameters of the target operation. As a result, this operation returns information about the test coverage equivalence class that the current object state and input parameters corresponds to. In particular, this operation returns an ordinary number of a postcondition branch which will be covered.

See `enqp_bnc` (page 58), `enq_bnc` (page 61), `deq_bnc` (page 56), `isEmpty_bnc`

(page 60) and `size_bnc` (page 55).

The `max_bn_<op name>` instance variable holds the number of branches in postconditions. To measure test coverage performed based on postcondition branches, the information about number of such branches is required. In an oracle, values that holds a branch number of corresponded operation are declared.

See `max_bn_enqp`, `max_bn_enq`, `max_bn_deq`, `max_bn_isEmpty` and `max_bn_size` (page 53).

B.2.5 Execution of oracle interface operations

As a result of an oracle interface operation call, the following actions are performed.

1. target operation precondition is checked;
2. if the flag of oracle invocation for corresponded operation is turned on, then the oracle operation is called. Otherwise, the parent operation is called (i.e. operation's implementation); and
3. invariant checking is performed.

The work of the oracle operation consists of the following actions:

1. values of instance variables marked as “written” by operation are saved in local variables;
2. the operation under test is called;
3. postcondition checking is performed (in postcondition, instance variables in pre-state replaced with its saved values).

See `enqp` (page 58), `enq` (page 61), `deq` (page 56), `isEmpty` (page 60) and `size` (page 55).

B.3 Test sequence iterator

The VDM++TesK test suite describes an FSM that tests operations of the target classes.

The following components are parts of the test sequence iterator:

1. The class that describes automaton state identifier;
2. The classes that describe input symbols of FSM; and
3. The class-iterator of test sequence.

This components are partially generated and partially developed manually.

B.3.1 Automaton state identifier

The class that describes automaton state identifier defines the single operation – the `compare` operation.

This class is derived from the pre-build abstract class called `Node` on page 38.

B.3.2 FSM input symbols

For each tested operation included in a test scenario, a class that describes the FSM input symbols must be defined.

Each such class is derived from the pre-build class named `Arc`.

B.4 Test sequence iterator

This class represents, in fact, a description of the FSM.

Its interface is described by the abstract class `SCRD`. It defines the following operations:

1. Acquisition of current FSM state identifier (`getNode`);
2. Acquisition of next FSM input symbol (`getNextArc`); and
3. Applying input symbol to FSM in its current state (`callBasicDriver`).

Acquisition of current FSM state identifier

This operation constructs an FSM state identifier corresponding to the target system's current state. It returns an object of the class inherited from the class named `Node`.

Acquisition of next FSM input symbol

A test sequence iterator shall produce a next FSM input symbol based on previous one that was applied to a FSM in the current state.

As an input parameter, this operation gets an object of a class inherited from the class `ARC`. This operation returns an object of class inherited from class `ARC`.

Applying input symbol to FSM in its current state

This operation takes a parameter that is a subclass of the `ARC` class. Applying the input symbol to FSM is just invocation of the operation corresponded to this symbol with parameters determined by it.

B.5 Test engine

In VDM++TesK, the algorithm of a FSM states traversal is implemented by the pre-build class called `SCRDEngine`.

The given algorithm intended only for determined FSM's traversal.

An object of the `SCRDEngine` class should be initialized by an object of a `SCRD` class inheritor – an object that represents a test scenario. Such initialization is performed using the `SCRDEngine` constructor.

```
SCRDEngine: SCRD ==> SCRDEngine
```

The traversal algorithm is launched using the `main` operation.

```
main: () ==> ()
```

The launch of an entire test scenario can be combined in a single expression:

```
new SCRDEngine(scrd).Main()
```

B.6 Test trace support

A test execution trace is supported by the class `Tracer`. This class allows to put a trace both into a file and to the VDMTools console.

Besides the standard trace support operations used by generated test suite components, this class declares the `putTraceMessage` operation that can be used for test scenario debugging.

```
putTraceMessage : seq1 of char ==> ()
```

To make a test trace to be put into a certain file, the operation `setOutFile` can be used:

```
setOutFile : seq of char ==> ()
```

If this operation is called with empty string as a parameter, a test trace will be put to the VDMTools console.

C Example of VDM++TesK technology application

Class implemented priority queue has been chosen as example of VDM++TesK application.

priority_queue.vpp: Manually developed. Implementation and specification of target class

queue_item.vpp: Manually developed. Base class for queue items

priority_queue_oracle.vpp: Generated file. Oracle class

pqueue_scrd_gen.vpp: Generated file. Generated parts of test scenario

pqueue_scrd.vpp: Hand-made parts of test scenario

scrd_engine.vpp: Test engine

scrd.vpp: Pre-build (system) file. Base and auxiliary classes for test scenarios

specification.vpp: Pre-build (system) file. Specification base class

io.vpp: VDM++ library for I/O

tracer.vpp: Pre-build (system) file. Class that provide support for test execution tracing

testgens.vpp: Pre-build (system) file. Definitions for test coverage support

Each of these classes are presented in the subsections below divided into the categories:

1. Predesigned components;
2. Generated components; and
3. Handmade components.

C.1 Predesigned Components

C.1.1 The Arc and EmptyArc Classes

```
-- Abstract class for script driver arc of graph
class Arc
end Arc

-- Class for presentation of empty arc
class EmptyArc is subclass of Arc
end EmptyArc
```

C.1.2 The Node Class

```
-- Abstract class for script driver node presentation
class Node

operations

public compare: Node ==> bool
compare(node) == is subclass responsibility;

end Node
```

C.1.3 The Specification Class

```
class Specification

functions

protected branch : seq1 of char +> bool
branch(-) == true;

end Specification
```

C.1.4 The SCRD Class

```

-- Abstract class for script driver
class SCRD

types

-- Script driver option types
public finish_mode = <until_error> | <until_end>;

public tcp_test_mode = <for_each_prt> | <for_each_ec>;

public
pvt_test_mode =    <for_each_pvt>
                  | <for_each_branch>
                  | <for_each_disjunct>
                  | <for_each_disjunct_with_conc_if_opti>;

public pvt_estimation =    <pre_condition_is_false>
                          | <do_not_test>
                          | <imperatively_test>
                          | <see_ECI>;

/*                                                    */
/* Possible returned pvt_estimation depended          */
/* on pvt_test_mode                                  */
/* -----                                           */
/*                                                    */
/*    pvt_test_mode = for_each_pvt                    */
/* =>                                                    */
/*    pvt_estimation = pre_condition_is_false          */
/*    \/\ pvt_estimation = imperatively_test          */
/*                                                    */
/*    pvt_test_mode = for_each_branch                  */
/* =>                                                    */
/*    pvt_estimation = pre_condition_is_false          */
/*    \/\ pvt_estimation = imperatively_test          */
/*    \/\ pvt_estimation = see_ECI                    */
/*                                                    */
/*    pvt_test_mode = for_each_disjunct                */

```

```

/*  =>                                                                    */
/*      pvt_estimation = pre_condition_is_false                          */
/*      \/\ pvt_estimation = imperatively_test                          */
/*      \/\ pvt_estimation = see_ECI                                    */
/*                                                                    */
/*      pvt_test_mode =                                                */
/*      for_each_disjunct_with_con_if_opti                              */
/*  =>                                                                    */
/*      pvt_estimation = pre_condition_is_false                          */
/*      \/\ pvt_estimation = do_not_test                                */
/*      \/\ pvt_estimation = imperatively_test                          */
/*      \/\ pvt_estimation = see_ECI                                    */
/*                                                                    */

```

```

-- TYPE FOR BC_PROC
public disTableType = map nat to nat;

instance variables
-- Test mode
public testMode: pvt_test_mode := <for_each_branch>;

-- Initialize tracer
public tracer: Tracer := Tracer`tracer;

operations

-- Evaluate node
public getNode: () ==> Node
getNode() == is subclass responsibility;

-- Get next arc
public getNextArc: ArcPrt*pvt_test_mode ==> ArcPrt * bool
getNextArc(in_arcprt, tm) == is subclass responsibility;

-- For given basic arc call basic driver
-- and returns next node, back-operation and verdict
public callBasicDriver: Arc ==> Node * Arc * bool
callBasicDriver(arc) == is subclass responsibility;

-- OPERATIONS FOR BC_PROC

```

```

bitAnd: nat*nat ==> nat
bitAnd(a, b) ==
  if (a <> 0) and (b <> 0)
  then return (a mod 2) * (b mod 2) +
               bitAnd(a mod 2, b mod 2) * 2
  else return 0;

protected disjunctNumberCalc:
  disTableType * seq of TESTGENS'KnownTermValue ==>
  disTableType * pvt_estimation * nat
disjunctNumberCalc(dis_table, termlist) ==
(dcl cur_disjunct: nat := 0;
 dcl cur_disjnum : nat;
 dcl dis_tbl      : disTableType := dis_table;

 for i = 1 to len termlist by +1 do (
   cur_disjnum := if termlist(i).termValue
                   then 2
                   else 1;
   cur_disjnum := cur_disjnum * (2 ** (2 *
                                     termlist(i).termNumber));
   if bitAnd(cur_disjunct, cur_disjnum) = 0
   then cur_disjunct := cur_disjunct + cur_disjnum
 );
 if cur_disjunct not in set dom dis_tbl
 then dis_tbl := dis_table ++
               {cur_disjunct |-> card dom dis_tbl + 1};
 return mk_(dis_tbl, <see_ECI>, dis_tbl(cur_disjunct))
)

end SCRd

```

C.1.5 The SCRdEngine Class

```

-- Basic engine of script drivers
class SCRdEngine

instance variables

```

```
-- Script driver
public scrd : SCRD;

-- List of tested states of object
public testedNodes : seq of TestedNode;

-- Path in graph - list of states of object under testing
public path : seq of PathNode;

operations

public SCRDEngine: SCRD ==> SCRDEngine
SCRDEngine(s) ==
  (scrd := s;

   testedNodes :=
     [new TestedNode().mkTestedNode(scrd.getNode(),
                                     new EmptyArc(),0,1)];

   path := [new PathNode().mkPathNode(1,new ArcPrt(),1)];
  );

-- Delete last node from path
delLastPathNode: () ==> ()
delLastPathNode () ==
  path := [path(i) | i in set{1,...,len path - 1}];

-- Make call basic driver
orientedCall: Arc ==> Node*Arc
orientedCall(cur_arc) ==
  let mk_(new_node,back_arc,verdict) =
    scrd.callBasicDriver(cur_arc)
  in (if not verdict then
    scrd.tracer.scriptTracerSuicide(
      "Oriented_call_:call_ returns bad verdict");
    return mk_(new_node,back_arc)
  );
```



```

-- Is the arrived node new?
isItNewNode: Node ==> nat
isItNewNode (n_node) ==
  (dcl tn_id: nat := 1;
   while (tn_id <= len testedNodes and
          not n_node.compare(testedNodes(tn_id).node))
   do tn_id := tn_id + 1;
   return tn_id
  );

```

```

-- Update lists (testedNodes AND path):
-- add new node to path and tested list
updateLists: Node * Arc ==> ()
updateLists (new_node, back_arc) ==
  (dcl lastPathNode: PathNode := path(len path);
   dcl backArcNum: nat;
   dcl backNodeNum: nat;

   backArcNum := if not isofclass(EmptyArc, back_arc)
                 then lastPathNode.testedNodeId
                 else 0;
   testedNodes := testedNodes ^
     [new TestedNode().mkTestedNode
      (new_node, back_arc,
       backArcNum, len path + 1
      )
    ];
   backNodeNum := if not isofclass(EmptyArc, back_arc)
                  then len path
                  else len path + 1;
   path := path ^
     [new PathNode().mkPathNode
      (len testedNodes,
       new ArcPrt(),
       backNodeNum
      )
    ]
  );

```

```

-- Go along back-arcs to path
goBackToPath: nat ==> nat
goBackToPath (tn_id) ==
  (dcl tested_node: TestedNode := testedNodes(tn_id);

  while -- go along back-arcs to path
    tested_node.pathNodeId = 0
  do
    if -- does back-arc exist?
      tested_node.backArcEndId = 0
    then (-- back-arc does not exist
      scrd.tracer.scriptTracerSuicide(
        "MAIN_oriented_with_abstract_state:" ^
        "no back-arc in tested node");
      return tn_id
    )
    else -- back-arc exists
      let -- movement along back-arc
        newTestedNodeId = tested_node.backArcEndId,
        mk_(newNode, -) = orientedCall
          (tested_node.backArc)
      in (if -- is the result of movement
        -- along back-arc right
        not newNode.compare(testedNodes(
          newTestedNodeId).node)
        then (-- the result of movement
          -- along back-arc is wrong
          scrd.tracer.scriptTracerSuicide(
            "MAIN_oriented_with_abstract_" ^
            "state_:back-operation faults");
          return tn_id
        )
        ;
        tested_node := testedNodes(newTestedNodeId);
      ); -- End let - movement along back-arc
    -- End if - does back-arc exist
  -- End while - go along back-arcs to path

  -- Return index in path node list of first node
  -- along back-arcs which in path node list
  return tested_node.pathNodeId

```

```
);
```

```
-- Some node at path arrived this node index in path-list
-- is newPathNodeId. newBackNodeId is index of back-node
-- of newPathNodeId node in path list.
-- if newBackNodeId is smaller than index of back-node of
-- last node of path then correct back-arcs and back-node
-- indexes of each node at path-list where point of
-- returning to path is greater then newBackNodeId from
-- end of path to newPathNodeId + 1
correctBackArcs: nat * nat ==> ()
correctBackArcs(newPathNodeId, testedLastArcEndId) == (
  (dcl newBackNodeId: nat :=
    path(newPathNodeId).backNodeId;

  if -- is newBackNodeId smaller than index of back-node
    -- of last node of path
    newBackNodeId < path(len path).backNodeId
  then (dcl pn: PathNode;
        dcl tn: TestedNode;
        dcl tn_id: nat;
        dcl pn_id: nat := len path - 1;

        -- correct back-arcs and back-node indexes for
        -- each node at path-list where point of
        -- returning to path is greater then
        -- newBackNodeId from end of path to
        -- newPathNodeId + 1
        while pn_id > newPathNodeId and
          newBackNodeId < path(pn_id).backNodeId
        do (pn := path(pn_id);
            tn_id := pn.testedNodeId;
            tn := testedNodes(tn_id);
            pn.setBackNodeId(newBackNodeId);
            tn.setBackArc(pn.pathArcPrt.arc);
            tn.setBackArcEndId(
              path(pn_id + 1).testedNodeId);
            pn_id := pn_id - 1
          ); -- End while correct back-arcs
        pn_id := len path;
```

```

    pn      := path(pn_id);
    tn_id := pn.testedNodeId;
    tn      := testedNodes(tn_id);
    pn.setBackNodeId(newBackNodeId);
    tn.setBackArc(pn.pathArcPrt.arc);
    tn.setBackArcEndId(testedLastArcEndId);
  ) -- End if - is newBackNodeId less than index
    -- of back-node of last node of path
);

```

```

-- go along path from arrived node to the end of path
goToPathEnd: nat ==> ()
goToPathEnd(path_node_id) ==
  (dcl pn_id: nat := path_node_id;

  while pn_id < len path do
    let mk_(newNode, -) = orientedCall(
      path(pn_id).pathArcPrt.arc)
    in
      if -- is the result of movement
        -- along path-arc right
        not newNode.compare
          (testedNodes(path(pn_id + 1).
            testedNodeId).node)
        then -- the result is wrong
          scrd.tracer.scriptTracerSuicide(
            "MAIN_oriented_with_abstract_state:" ^
            "call path-arc faults")
        else -- the result is right
          pn_id := pn_id + 1
  );

```

```

-- oriented graph browsing
public main: () ==> ()
main () ==
  (dcl needBack : bool;
    -- needback is true if it needs to go back
    dcl tested_NodeId : nat;

```

```

    -- index in list of tested nodes
dcl testedLastArcEndId : nat;
    -- index of the last arc end in list of tested nodes

while len path <> 0 do -- main cycle
  (needBack := false;
   let lastPathNode = path(len path),
       lastTestedNode =
         testedNodes(lastPathNode.testedNodeId),
       mk_(newArcPrt, isNext) =
         scrd.getNextArc(lastPathNode.pathArcPrt,
                        scrd.testMode)
   in (if isNext -- does untested arc exist at path end?
       then (-- yes, untested arc exists at the path end
            -- store this arc
            lastPathNode.setPathArcPrt(newArcPrt);
            -- go along untested arc
            let mk_(newNode, backArc) =
              orientedCall(newArcPrt.arc)
            in -- verdict of basic driver is positive
            -- after movement along untested arc
            if -- is the arc not a loop
              not newNode.compare(lastTestedNode.
                                node)
            then (-- the arc is not a loop
                  -- is the arrived node new
                  -- to know that browse all
                  -- tested nodes
                  tested_NodeId :=
                    isItNewNode(newNode);
                  testedLastArcEndId :=
                    tested_NodeId;

                  if tested_NodeId <= len testedNodes
                  then -- the node is not new (tested)
                    if -- does back-operation exist?
                      not isofclass(EmptyArc,
                                    backArc)
                    then -- back-operation exists
                      let mk_(newNode, -) =
                        orientedCall(backArc)

```

```

        in (if -- is the result of
            -- performing back-
            -- operation right?
            not newNode.compare(
                lastTestedNode.
                node)
            then -- the result of
                -- performing
                -- back operation
                -- is wrong
                scrd.tracer.
                scriptTracerSuicide(
                    "MAIN_oriented_" ^
                    "with_abstract_" ^
                    "state_:back-" ^
                    "operation faults")
                -- End if is the
                -- result of
                -- performing
                -- back-operation
                -- is right
            ) -- End let
        else -- back-operation does
            -- not exist
            needBack := true
        -- End if
    else (-- the node is new (untested)
        -- add it to path
        -- and tested list
        updateLists(newNode, backArc)
    ) -- End if
) -- End if - Is the arc a loop?
-- End let - go along untested arc
) -- End
else (-- no - all arcs at the path end are tested
    -- delete last node of path
    tested_NodeId := lastPathNode.testedNodeId;
    testedNodes(tested_NodeId).setPathNodeId(0);
    delLastPathNode();
    needBack := true
); -- End if

```

```

if needBack and len path <> 0
then (-- we need come back
      dcl pathNode_Id: nat;

      -- go along back-arcs to path
      pathNode_Id := goBackToPath(tested_NodeId);

      -- some node at path arrived. if its
      -- back-node index is less than index of
      -- back-node of last node of path then
      -- correct back-arcs and back-node indexes
      -- of each node at path-list where point of
      -- returning to path is greater then back-
      -- node index of arrived node from end of
      -- path to arrived node index + 1
      correctBackArcs(pathNode_Id,
                      testedLastArcEndId);

      -- go along path from arrived node
      -- to the end of path
      goToPathEnd(pathNode_Id)
    ) -- End if - need we come back?
  ) -- End let lastPathNode
); -- End of main cycle
scrd.tracer.putTraceMessage(
  "Script driver succefully finished.\n");
skip
); -- End of main

end SCRDEngine

```

C.1.6 The TESTGENS Class

```

class TESTGENS

types
/** Type for function bnc_OpName **/

```

```
public
KnownTermValue :: termNumber : nat
                  termValue   : bool;

end TESTGENS
```

C.1.7 The Tracer Class

```
class Tracer

values
public tracer: Tracer = new Tracer();

instance variables
private out_file: seq of char := "";

operations

public setOutFile : seq of char ==> ()
setOutFile( file_name ) ==
    out_file := file_name;

public putTraceOracleStart : seq1 of char ==> ()
putTraceOracleStart( oracle_name ) ==
    traceMessage("Oracle started: " ^ oracle_name ^ "\n" );

public
putTraceOracleFinish: seq1 of char * seq1 of char ==> ()
putTraceOracleFinish( oracle_name, verdict ) ==
    traceMessage("Oracle finished: " ^ oracle_name ^
        ". verdict: " ^ verdict ^ "\n" );

public putTraceBranch : bool * seq1 of char ==> bool
putTraceBranch( condition, branch_name ) ==
    (traceMessage( "Branch: " ^ branch_name ^ "\n" );
    return condition; )
```



```

public scriptTracerSuicide : seq of char ==> ()
scriptTracerSuicide( message ) ==
  (traceMessage("Scrd finished: " ^ message ^ "\n" );
   error;
  );

public putTraceMessage : seq1 of char ==> ()
putTraceMessage( message ) ==
  traceMessage("Message: " ^ message ^ "\n" );

-- implementation

values

private io : IO = new IO();

operations

private traceMessage : seq of char ==> ()
traceMessage( text ) ==
  let - = io.fecho( out_file
                    , text
                    , if len out_file = 0 then nil
                    else <append>
                    )

    in skip;

end Tracer

```

C.2 Generated Components

C.2.1 The PriorityQueueOp_arc Classes

```

-- Class PriorityQueue'deq_arc is inherited from Arc and
-- used in generation code only as type identification.
--
-- It must be refined manually by inheritance.

```

```
--  
-- Inherited from it manually developed class with  
-- appropriate object under test must specify  
-- parameter set for operation PriorityQueue'deq,  
-- i.e. test case for this operation.  
  
class PriorityQueue_deq_arc is subclass of Arc  
end PriorityQueue_deq_arc  
  
-- Class PriorityQueue'enq_arc is inherited from Arc and  
-- used in generation code only as type identification.  
--  
-- It must be refined manually by inheritance.  
--  
-- Inherited from it manually developed class with  
-- appropriate object under test must specify  
-- parameter set for operation PriorityQueue'enq,  
-- i.e. test case for this operation.  
  
class PriorityQueue_enq_arc is subclass of Arc  
end PriorityQueue_enq_arc  
  
-- Class PriorityQueue'enqp_arc is inherited from Arc  
-- and used in generation code only as type  
-- identification.  
--  
-- It must be refined manually by inheritance.  
--  
-- Inherited from it manually developed class with  
-- appropriate object under test must specify  
-- parameter set for operation PriorityQueue'enqp,  
-- i.e. test case for this operation.  
  
class PriorityQueue_enqp_arc is subclass of Arc  
end PriorityQueue_enqp_arc  
  
-- Class PriorityQueue'isEmpty_arc is inherited from Arc  
-- and used in generation code only as type  
-- identification.  
--  
-- It must be refined manually by inheritance.
```

```
--  
-- Inherited from it manually developed class with  
-- appropriate object under test must specify  
-- parameter set for operation PriorityQueue'isEmpty,  
-- i.e. test case for this operation.  
  
class PriorityQueue_isEmpty_arc is subclass of Arc  
end PriorityQueue_isEmpty_arc  
  
-- Class PriorityQueue'size_arc is inherited from Arc and  
-- used in generation code only as type identification.  
--  
-- It must be refined manually by inheritance.  
--  
-- Inherited from it manually developed class with  
-- appropriate object under test must specify  
-- parameter set for operation PriorityQueue'size,  
-- i.e. test case for this operation.  
  
class PriorityQueue_size_arc is subclass of Arc  
end PriorityQueue_size_arc
```

C.2.2 The PriorityQueueOracle Class

```
class PriorityQueueOracle is subclass of PriorityQueue  
  
  values  
  
    public  
      max_bn_size = 1;  
  
    public  
      max_dnf_size = 0;  
  
    public  
      max_bn_deq = 2;  
  
    public
```

```
    max_dnf_deq = 0;

    public
        max_bn_enqp = 3;

    public
        max_dnf_enqp = 0;

    public
        max_bn_isEmpty = 1;

    public
        max_dnf_isEmpty = 0;

    public
        max_bn_enq = 1;

    public
        max_dnf_enq = 0;

    public
        test_conf_all : set of seq1 of char = {"size",
                                                "deq",
                                                "enqp",
                                                "isEmpty",
                                                "enq"
                                                };

operations

    public setup : set of seq1 of char ==> ()
    setup( test_conf ) ==
        test_conf_var := test_conf;
```

```
protected checkInv_PriorityQueue : () ==> ()
checkInv_PriorityQueue() ==
    if ( forall i in set inds priorities &
        priorities( i ) >= MIN_PRIORITY and
        priorities( i ) <= MAX_PRIORITY
    ) and
```

```

    ( len priorities = len queue ) and
    ( forall i in set { 2 , ... , len priorities } &
      priorities( i ) <= priorities( i - 1 )
    )
  then skip
  else exit <INV_FAIL>;

```

```

public size : () ==> nat
size() ==
  trap verdict with
    ( cases verdict :
      <PRE_COND_FAIL>->
        tracer.putTraceOracleFinish("PriorityQueue`size",
                                     "pre_cond_fails"),
      <POST_COND_FAIL>->
        tracer.putTraceOracleFinish("PriorityQueue`size",
                                     "post_cond_fails"),
      <INV_FAIL>->
        tracer.putTraceOracleFinish("PriorityQueue`size",
                                     "invariant_fails"),
      others ->
        tracer.putTraceOracleFinish("PriorityQueue`size",
                                     "exception in implementation")
    )
  end;
  exit verdict;
)
in (dcl res : nat;
    tracer.putTraceOracleStart( "PriorityQueue`size" );
    size_pre();
    if true then res := size_post()
    else res := PriorityQueue`size();
    checkInv_PriorityQueue();
    tracer.putTraceOracleFinish("PriorityQueue`size",
                                "Ok" );

    return res;
);

public size_bnc: () ==> bool * nat *
      seq of TESTGENS`KnownTermValue
size_bnc() ==

```

```
    if true
    then return mk_( true, 1, [] )
    else return mk_( false, -1, [] );

protected size_pre : () ==> ()
size_pre() ==
    if true then skip else exit <PRE_COND_FAIL>;

protected size_post : () ==> nat
size_post() ==
    let res = PriorityQueue`size()
    in (if tracer.putTraceBranch(res = len queue,
                                "single branch" )

        then skip
        else exit <POST_COND_FAIL>;
        return res;
    );
```

```
public deq : () ==> [ QueueItem ]
deq() ==
    trap verdict
    with (cases verdict :
        <PRE_COND_FAIL>->
            tracer.putTraceOracleFinish("PriorityQueue`deq",
                                         "pre_cond_fails"),

        <POST_COND_FAIL>->
            tracer.putTraceOracleFinish("PriorityQueue`deq",
                                         "post_cond_fails"),

        <INV_FAIL>->
            tracer.putTraceOracleFinish("PriorityQueue`deq",
                                         "invariant_fails"),

        others ->
            tracer.putTraceOracleFinish("PriorityQueue`deq",
                                         "exception in implementation")

    end;
    exit verdict;
)
in (dcl res : [ QueueItem ];
    tracer.putTraceOracleStart( "PriorityQueue`deq" );
```

```

    deq_pre();
    if true
    then res := deq_post()
    else res := PriorityQueue`deq();
    checkInv_PriorityQueue();
    tracer.putTraceOracleFinish("PriorityQueue`deq",
                                "Ok" );

    return res;
);

public deq_bnc: () ==> bool * nat *
    seq of TESTGENS`KnownTermValue
deq_bnc() ==
    if true
    then if len queue > 0
        then return mk_( true, 1, [] )
        else return mk_( true, 2, [] )
    else return mk_( false, -1, [] );

protected deq_pre : () ==> ()
deq_pre() ==
    if true then skip else exit <PRE_COND_FAIL>;

protected deq_post : () ==> [ QueueItem ]
deq_post() ==
    let old_priorities = priorities, old_queue = queue
    in let item = PriorityQueue`deq()
    in (if len old_queue > 0
        then if tracer.putTraceBranch(
            priorities = tl old_priorities and
            queue = tl old_queue and
            item = hd old_queue,
            "non-empty queue")
        then skip
        else exit <POST_COND_FAIL>
    else if tracer.putTraceBranch(
        priorities = old_priorities and
        queue = old_queue and
        item = nil,
        "empty queue")
    then skip

```

```

        else exit <POST_COND_FAIL>;
    return item);

```

```

public enqp : QueueItem * int ==> ()
enqp(item, pri) ==
    trap verdict
    with (cases verdict:
        <PRE_COND_FAIL>->
            tracer.putTraceOracleFinish("PriorityQueue`enqp",
                                         "pre_cond_fails"),

        <POST_COND_FAIL>->
            tracer.putTraceOracleFinish("PriorityQueue`enqp",
                                         "post_cond_fails"),

        <INV_FAIL>->
            tracer.putTraceOracleFinish("PriorityQueue`enqp",
                                         "invariant_fails")

        others ->
            tracer.putTraceOracleFinish("PriorityQueue`enqp",
                                         "exception in implementation")

    end;
    exit verdict;
    )
in (tracer.putTraceOracleStart("PriorityQueue`enqp");
    enqp_pre(item, pri);
    if true then enqp_post( item, pri )
    else PriorityQueue`enqp( item, pri );
    checkInv_PriorityQueue();
    tracer.putTraceOracleFinish("PriorityQueue`enqp",
                                "Ok" );
    );

public enqp_bnc: QueueItem * int ==> bool * nat *
    seq of TESTGENS`KnownTermValue
enqp_bnc( item, pri ) ==
    if pri >= MIN_PRIORITY and pri <= MAX_PRIORITY
    then if priorities = [] then return mk_( true, 1, [] )
    elseif pri not in set elems priorities
    then return mk_( true, 2, [] )
    else return mk_( true, 3, [] )
    else return mk_( false, -1, [] );

```



```

protected enqp_pre : QueueItem * int ==> ()
enqp_pre( item, pri ) ==
  if pri >= MIN_PRIORITY and pri <= MAX_PRIORITY
  then skip
  else exit <PRE_COND_FAIL>;

protected enqp_post : QueueItem * int ==> ()
enqp_post( item, pri ) ==
  let old_priorities = priorities, old_queue = queue
  in (PriorityQueue`enqp( item, pri );
    if old_priorities = []
    then if tracer.putTraceBranch(
      priorities = [ pri ] and
      queue = [ item ],
      "Empty queue")
      then skip
      else exit <POST_COND_FAIL>
    elseif pri not in set elems old_priorities
    then if tracer.putTraceBranch(
      pri in set elems priorities and
      exists1 i in set inds priorities &
        priorities( i ) = pri and
        queue( i ) = item and
        [priorities( k )
         |k in set inds priorities
         &k <> i
        ] = old_priorities and
        [queue( k )
         |k in set inds queue
         &k <> i
        ] = old_queue,
      "Priority not in queue")
      then skip
      else exit <POST_COND_FAIL>
    else if tracer.putTraceBranch(
      pri in set elems priorities and
      exists1 i in set inds priorities &
        priorities( i ) = pri and
        queue( i ) = item and
        [priorities( k )

```

```

|k in set inds priorities
& k <> i
] = old_priorities and
[queue( k )
| k in set inds queue
& k <> i
] = old_queue and
forall k in set
  elems [k
        |k in set inds priorities
        & priorities( k ) = pri
        ] &
        k <= i,
    "Priority in queue")
then skip
else exit <POST_COND_FAIL>;
);

```

```

public isEmpty : () ==> bool
isEmpty() ==
  trap verdict
  with (cases verdict :
    <PRE_COND_FAIL>->
    tracer.putTraceOracleFinish(
      "PriorityQueue`isEmpty",
      "pre_cond_fails"),

    <POST_COND_FAIL>->
    tracer.putTraceOracleFinish(
      "PriorityQueue`isEmpty",
      "post_cond_fails"),

    <INV_FAIL>->
    tracer.putTraceOracleFinish(
      "PriorityQueue`isEmpty",
      "invariant_fails"),

    others ->
    tracer.putTraceOracleFinish(
      "PriorityQueue`isEmpty",
      "exception in implementation")
  end;

```

```

        exit verdict;
    )
in (dcl res : bool;
    tracer.putTraceOracleStart("PriorityQueue`isEmpty");
    isEmpty_pre();
    if true then res := isEmpty_post()
    else res := PriorityQueue`isEmpty();
    checkInv_PriorityQueue();
    tracer.putTraceOracleFinish("PriorityQueue`isEmpty",
                                "Ok" );

    return res;
);

public isEmpty_bnc: () ==> bool * nat *
    seq of TESTGENS`KnownTermValue
isEmpty_bnc() ==
    if true then return mk_( true, 1, [] )
    else return mk_( false, -1, [] );

protected isEmpty_pre : () ==> ()
isEmpty_pre() ==
    if true then skip else exit <PRE_COND_FAIL>;

protected isEmpty_post : () ==> bool
isEmpty_post() ==
    let res = PriorityQueue`isEmpty()
    in (if tracer.putTraceBranch(res = ( len queue = 0 ),
                                "single branch")

        then skip
        else exit <POST_COND_FAIL>;
    return res;
);

```

```

public enq: QueueItem ==> ()
enq( item ) ==
    trap verdict
    with (cases verdict :
        <PRE_COND_FAIL>->
        tracer.putTraceOracleFinish("PriorityQueue`enq",
                                    "pre_cond_fails"),
    )

```

```

    <POST_COND_FAIL>->
    tracer.putTraceOracleFinish("PriorityQueue`enq",
                                "post_cond_fails"),

    <INV_FAIL>->
    tracer.putTraceOracleFinish("PriorityQueue`enq",
                                "invariant_fails"),

    others ->
    tracer.putTraceOracleFinish("PriorityQueue`enq",
                                "exception in implementation")

    end;
    exit verdict;
  )
in (tracer.putTraceOracleStart( "PriorityQueue`enq" );
    enq_pre( item );
    if true
    then enq_post( item )
    else PriorityQueue`enq( item );
    checkInv_PriorityQueue();
    tracer.putTraceOracleFinish("PriorityQueue`enq",
                                "Ok" );
  );

public enq_bnc: QueueItem ==> bool * nat *
    seq of TESTGENS`KnownTermValue
enq_bnc( item ) ==
  if true then return mk_( true, 1, [] )
  else return mk_( false, -1, [] );

protected enq_pre : QueueItem ==> ()
enq_pre( item ) ==
  if true then skip else exit <PRE_COND_FAIL>;

protected enq_post : QueueItem ==> ()
enq_post( item ) ==
  let old_priorities = priorities, old_queue = queue
  in (PriorityQueue`enq( item );
    if tracer.putTraceBranch(
      priorities = old_priorities ^
        [MIN_PRIORITY] and
      queue = old_queue ^ [ item ],
      "single branch")

```

```

    then skip
    else exit <POST_COND_FAIL>;
);

```

```

instance variables

private
    test_conf_var: set of seq1 of char := test_conf_all;

private
    tracer : Tracer := Tracer`tracer;

end PriorityQueueOracle

```

C.2.3 The SCRD_PQueue_generic Class

```

class SCRD_PQueue_generic is subclass of SCRD

types
    --    Types for coverage estimation.

public pvt_PriorityQueue_enq ::
    item:           QueueItem;

public pvt_PriorityQueue_enqp ::
    item:           QueueItem
    pri:            int;

instance variables
    --    Oracles for classes.

protected
    oracle_of_PriorityQueue: PriorityQueueOracle
                           := new PriorityQueueOracle();

    --    Variables for coverage estimation.

```

```

Max_ECI_PriorityQueue_deq: map pvt_test_mode to nat
  := {<for_each_pvt> |-> 0,
      <for_each_branch> |->
        PriorityQueueOracle`max_bn_deq,
      <for_each_disjunct> |->
        PriorityQueueOracle`max_dnf_deq,
      <for_each_disjunct_with_conc_if_opti> |->
        PriorityQueueOracle`max_dnf_deq
    };

Max_ECI_PriorityQueue_enq: map pvt_test_mode to nat
  := {<for_each_pvt> |-> 0,
      <for_each_branch> |->
        PriorityQueueOracle`max_bn_enq,
      <for_each_disjunct> |->
        PriorityQueueOracle`max_dnf_enq,
      <for_each_disjunct_with_conc_if_opti> |->
        PriorityQueueOracle`max_dnf_enq
    };

Max_ECI_PriorityQueue_enqp: map pvt_test_mode to nat
  := {<for_each_pvt> |-> 0,
      <for_each_branch> |->
        PriorityQueueOracle`max_bn_enqp,
      <for_each_disjunct> |->
        PriorityQueueOracle`max_dnf_enqp,
      <for_each_disjunct_with_conc_if_opti> |->
        PriorityQueueOracle`max_dnf_enqp
    };

Max_ECI_PriorityQueue_isEmpty: map pvt_test_mode to nat
  := {<for_each_pvt> |-> 0,
      <for_each_branch> |->
        PriorityQueueOracle`max_bn_isEmpty,
      <for_each_disjunct> |->
        PriorityQueueOracle`max_dnf_isEmpty,
      <for_each_disjunct_with_conc_if_opti> |->
        PriorityQueueOracle`max_dnf_isEmpty
    };

Max_ECI_PriorityQueue_size: map pvt_test_mode to nat

```

```

:= {<for_each_pvt> |-> 0,
    <for_each_branch> |->
        PriorityQueueOracle`max_bn_size,
    <for_each_disjunct> |->
        PriorityQueueOracle`max_dnf_size,
    <for_each_disjunct_with_conc_if_opti> |->
        PriorityQueueOracle`max_dnf_size
};

dis_table_PriorityQueue_deq : disTableType := {|->};
dis_table_PriorityQueue_eng : disTableType := {|->};
dis_table_PriorityQueue_enqp : disTableType := {|->};
dis_table_PriorityQueue_isEmpty : disTableType := {|->};
dis_table_PriorityQueue_size : disTableType := {|->};

```

operations

-- COVERAGE ESTIMATION

```

bc_PriorityQueue_deq: pvt_test_mode ==>
    pvt_estimation * nat
bc_PriorityQueue_deq(tm) ==
    let mk_(pv,bn,termlist) =
        oracle_of_PriorityQueue.deq_bnc()
    in if pv then
        cases tm:
            (<for_each_pvt>) ->
                return mk_(<imperatively_test>, 0),
            (<for_each_branch>) -> return mk_(<see_ECI>, bn),
            (<for_each_disjunct>) ->
                let mk_(dis_tab,est,num) =
                    disjunctNumberCalc
                        (dis_table_PriorityQueue_deq, termlist)
                in (dis_table_PriorityQueue_deq := dis_tab;
                    return mk_(est,num)),
            (<for_each_disjunct_with_conc_if_opti>) ->
                let mk_(dis_tab,est,num) =

```

```

        disjunctNumberCalc
        (dis_table_PriorityQueue_deq, termlist)
    in (dis_table_PriorityQueue_deq := dis_tab;
        return mk_(est,num))
    end
else return mk_(<pre_condition_is_false>, 0);

```

```

bc_PriorityQueue_enq: pvt_test_mode *
    pvt_PriorityQueue_enq ==>
    pvt_estimation * nat
bc_PriorityQueue_enq(tm,pvt) ==
    let mk_(pv,bn,termlist) =
        oracle_of_PriorityQueue.enq_bnc(pvt.item)
    in if pv then
        cases tm:
        (<for_each_pvt>) ->
            return mk_(<imperatively_test>, 0),
        (<for_each_branch>) -> return mk_(<see_ECI>, bn),
        (<for_each_disjunct>) ->
            let mk_(dis_tab,est,num) =
                disjunctNumberCalc
                (dis_table_PriorityQueue_enq, termlist)
            in (dis_table_PriorityQueue_enq := dis_tab;
                return mk_(est,num)),
        (<for_each_disjunct_with_conc_if_opti>) ->
            let mk_(dis_tab,est,num) =
                disjunctNumberCalc
                (dis_table_PriorityQueue_enq, termlist)
            in (dis_table_PriorityQueue_enq := dis_tab;
                return mk_(est,num))
        end
    else return mk_(<pre_condition_is_false>, 0);

```

```

bc_PriorityQueue_enqp: pvt_test_mode *
    pvt_PriorityQueue_enqp ==>
    pvt_estimation * nat
bc_PriorityQueue_enqp(tm,pvt) ==
    let mk_(pv,bn,termlist) =

```



```

    oracle_of_PriorityQueue.enqp_bnc
      (pvt.item,
       pvt.pri)
  in if pv then
    cases tm:
      (<for_each_pvt>) ->
        return mk_(<imperatively_test>, 0),
      (<for_each_branch>) -> return mk_(<see_ECI>, bn),
      (<for_each_disjunct>) ->
        let mk_(dis_tab,est,num) =
          disjunctNumberCalc
            (dis_table_PriorityQueue_enqp, termlist)
        in (dis_table_PriorityQueue_enqp := dis_tab;
            return mk_(est,num)),
      (<for_each_disjunct_with_conc_if_opti>) ->
        let mk_(dis_tab,est,num) =
          disjunctNumberCalc
            (dis_table_PriorityQueue_enqp, termlist)
        in (dis_table_PriorityQueue_enqp := dis_tab;
            return mk_(est,num))

    end
  else return mk_(<pre_condition_is_false>, 0);

bc_PriorityQueue_isEmpty: pvt_test_mode ==>
  pvt_estimation * nat
bc_PriorityQueue_isEmpty(tm) ==
  let mk_(pv,bn,termlist) =
    oracle_of_PriorityQueue_isEmpty_bnc()
  in if pv then
    cases tm:
      (<for_each_pvt>) ->
        return mk_(<imperatively_test>, 0),
      (<for_each_branch>) -> return mk_(<see_ECI>, bn),
      (<for_each_disjunct>) ->
        let mk_(dis_tab,est,num) =
          disjunctNumberCalc
            (dis_table_PriorityQueue_isEmpty,
             termlist)
        in (dis_table_PriorityQueue_isEmpty := dis_tab;
            return mk_(est,num)),
      (<for_each_disjunct_with_conc_if_opti>) ->

```

```

        let mk_(dis_tab,est,num) =
            disjunctNumberCalc
                (dis_table_PriorityQueue_isEmpty,
                 termlist)
        in (dis_table_PriorityQueue_isEmpty := dis_tab;
            return mk_(est,num))
    end
else return mk_(<pre_condition_is_false>, 0);

bc_PriorityQueue_size: pvt_test_mode ==>
    pvt_estimation * nat
bc_PriorityQueue_size(tm) ==
    let mk_(pv,bn,termlist) =
        oracle_of_PriorityQueue.size_bnc()
    in if pv then
        cases tm:
        (<for_each_pvt>) ->
            return mk_(<imperatively_test>, 0),
        (<for_each_branch>) -> return mk_(<see_ECI>, bn),
        (<for_each_disjunct>) ->
            let mk_(dis_tab,est,num) =
                disjunctNumberCalc
                    (dis_table_PriorityQueue_size, termlist)
            in (dis_table_PriorityQueue_size := dis_tab;
                return mk_(est,num)),
        (<for_each_disjunct_with_conc_if_opti>) ->
            let mk_(dis_tab,est,num) =
                disjunctNumberCalc
                    (dis_table_PriorityQueue_size, termlist)
            in (dis_table_PriorityQueue_size := dis_tab;
                return mk_(est,num))
        end
    else return mk_(<pre_condition_is_false>, 0);

```

```

-- Calculation of actual parameters of operations.
--
-- It forms records of types pvt_'op name' which contains
-- parameters of 'op name' as their fields:
--
-- pvt_'op name' ::

```

```

--      'name of par1' : 'type of par1,'
--      ...
--      'name of parN' : 'type of parN';
--
-- Fields are calculated on base of current value of type
-- 'op name'_Arc and current value of appropriate object
-- under test.

form_pvt_PriorityQueue_enq: Arc ==> pvt_PriorityQueue_enq
form_pvt_PriorityQueue_enq(cur_par) ==
    is subclass responsibility;

form_pvt_PriorityQueue_enqp: Arc ==>
    pvt_PriorityQueue_enqp
form_pvt_PriorityQueue_enqp(cur_par) ==
    is subclass responsibility;

```

```

-- Calculation of initial browsed parameter set.
--
-- If initial browsed parameter set exists
-- operation returns initial browsed parameter set and
-- true.
--
-- If initial browsed parameter set does not exist
-- operation returns any value and false.
--
-- Operation depends on object under test
-- and script driver options which are stored in variables
--
-- If tested operation has not browsed parameters
-- operation returns empty set and true.

PriorityQueue_deq_arc_init: () ==>
    PriorityQueue_deq_arc * bool
PriorityQueue_deq_arc_init() ==
    return mk_(new PriorityQueue_deq_arc(),true);

PriorityQueue_enq_arc_init: () ==>
    PriorityQueue_enq_arc * bool
PriorityQueue_enq_arc_init() ==

```

```
    is subclass responsibility;

PriorityQueue_enqp_arc_init: () ==>
    PriorityQueue_enqp_arc * bool
PriorityQueue_enqp_arc_init() ==
    is subclass responsibility;

PriorityQueue_isEmpty_arc_init: () ==>
    PriorityQueue_isEmpty_arc * bool
PriorityQueue_isEmpty_arc_init() ==
    return mk_(new PriorityQueue_isEmpty_arc(),true);

PriorityQueue_size_arc_init: () ==>
    PriorityQueue_size_arc * bool
PriorityQueue_size_arc_init() ==
    return mk_(new PriorityQueue_size_arc(),true);

-- Calculation of next browsed parameter set.
--
-- If given value is not last value
-- operation returns next value and true.
--
-- If given value is last value
-- operation returns any value and false.
--
-- Operation depends on object under test
-- and script driver options which are stored in variables
--
-- If tested operation has not browsed parameters
-- operation returns any value nad false.

PriorityQueue_deq_arc_next:
    PriorityQueue_deq_arc ==>
    PriorityQueue_deq_arc * bool
PriorityQueue_deq_arc_next(cur_arc) ==
    return mk_(cur_arc,false);

PriorityQueue_enq_arc_next:
    PriorityQueue_enq_arc ==>
    PriorityQueue_enq_arc * bool
PriorityQueue_enq_arc_next(cur_arc) ==
```

```

is subclass responsibility;

PriorityQueue_enqp_arc_next:
    PriorityQueue_enqp_arc ==>
        PriorityQueue_enqp_arc * bool
PriorityQueue_enqp_arc_next(cur_arc) ==
    is subclass responsibility;

PriorityQueue_isEmpty_arc_next:
    PriorityQueue_isEmpty_arc ==>
        PriorityQueue_isEmpty_arc * bool
PriorityQueue_isEmpty_arc_next(cur_arc) ==
    return mk_(cur_arc,false);

PriorityQueue_size_arc_next:
    PriorityQueue_size_arc ==>
        PriorityQueue_size_arc * bool
PriorityQueue_size_arc_next(cur_arc) ==
    return mk_(cur_arc,false);

```

```

-- getNextArc()
--
-- For current states of objects under test
-- and current ARC (parameter set of specified operation
-- of some object among objects under test) finds
-- next ARC and if found returns new ARC and true
-- else returns any ARC and false.

getNextEmptyArc: bool * ArcPrt * pvt_test_mode ==>
    bool * ArcPrt
getNextEmptyArc(init_par,in_arcp,tm) ==
    return mk_(true,
        new ArcPrt().mkArcPrt
            (new PriorityQueue_deq_arc(),
              [ false
                | i in set {1,...,
                           Max_ECI_PriorityQueue_deq(tm)
                           }
              ]
            )

```

```
);
```

```
getNext_PriorityQueue_deq_arc: bool * ArcPrt *
                                pvt_test_mode ==>
                                bool * ArcPrt
getNext_PriorityQueue_deq_arc(init_par,in_arcprt,tm) ==
(dcl continue:    bool      := true;
 dcl isNew:      bool      := init_par;
 dcl cur_arcprt:  ArcPrt    := in_arcprt;
 dcl rest_of_prt: nat      := 0;

for all i in set {1,...,len in_arcprt.prt} do
  if not in_arcprt.prt(i) then
    rest_of_prt := rest_of_prt + 1;
  if len in_arcprt.prt <> 0 and rest_of_prt = 0 then
    isNew := true
  else
    while continue do (
      dcl new_arc:    PriorityQueue_deq_arc;
      dcl next_exist: bool;

      if isNew then
        let   mk_(new_arcl,next_existl)
              = PriorityQueue_deq_arc_init()
        in (
          new_arc    := new_arcl;
          next_exist := next_existl
        )
      else
        let cur_arc: PriorityQueue_deq_arc =
              cur_arcprt.arc,
          mk_(new_arcl,next_existl) =
              PriorityQueue_deq_arc_next(cur_arc)
        in (new_arc    := new_arcl;
          next_exist := next_existl);
      if not next_exist then (
        continue := false;
        isNew    := true
      )
    else (
```

```

cur_arcprt.setArc(new_arc);

let cur_arc: PriorityQueue_deq_arc =
    cur_arcprt.arc,
    mk_(est,eci) = bc_PriorityQueue_deq(tm)
in cases est:
    (<pre_condition_is_false>) -> (
        continue := true;
        isNew    := false
    ),
    (<do_not_test>) -> (
        continue := true;
        isNew    := false
    ),
    (<imperatively_test>) -> (
        continue := false;
        isNew    := false
    ),
    (<see_ECI>) -> (
        if cur_arcprt.prt(eci) then (
            continue := true;
            isNew    := false
        )
        else (
            cur_arcprt.setPrt
            ( [cur_arcprt.prt(i)
              | i in set {1,...,eci-1}]
              ^ [true]
              ^ [ cur_arcprt.prt(i)
                  | i in set {eci+1,...,
                               len cur_arcprt.prt}
                ]
            );
            continue := false;
            isNew    := false
        ) /** if prt(cur_arcprt)(eci) **/
    )
    end /** case est of **/
) -- end if not next_exist
); -- end while
if isNew then

```

```

        cur_arcprt
:= cur_arcprt.mkArcPrt(new PriorityQueue_enq_arc(),
    [ false
      | i in set
        {1,...,
         Max_ECI_PriorityQueue_enq(tm)}
      ]
    );
return mk_( isNew, cur_arcprt )
);

```

```

getNext_PriorityQueue_enq_arc: bool * ArcPrt *
                                pvt_test_mode ==> bool * ArcPrt
getNext_PriorityQueue_enq_arc(init_par,in_arcprt,tm) ==
(dcl continue:    bool      := true;
 dcl isNew:      bool      := init_par;
 dcl cur_arcprt: ArcPrt    := in_arcprt;
 dcl rest_of_prt: nat      := 0;

for all i in set {1,...,len in_arcprt.prt} do
  if not in_arcprt.prt(i) then
    rest_of_prt := rest_of_prt + 1;
  if len in_arcprt.prt <> 0 and rest_of_prt = 0 then
    isNew := true
  else
    while continue do (
      dcl new_arc:    PriorityQueue_enq_arc;
      dcl next_exist: bool;

      if isNew then
        let mk_(new_arcl,next_existl)
          = PriorityQueue_enq_arc_init()
        in (
          new_arc      := new_arcl;
          next_exist := next_existl
        )
      else
        let cur_arc: PriorityQueue_enq_arc =
          cur_arcprt.arc,
          mk_(new_arcl,next_existl)

```



```

    = PriorityQueue_enq_arc_next(cur_arc)
in (
    new_arc      := new_arc1;
    next_exist   := next_exist1
);
if not next_exist then (
    continue := false;
    isNew    := true
)
else (
    cur_arcprt.setArc(new_arc);

    let cur_arc: PriorityQueue_enq_arc =
        cur_arcprt.arc,
    pvt = form_pvt_PriorityQueue_enq(cur_arc),
    mk_(est,eci) = bc_PriorityQueue_enq(tm,pvt)
    in cases est:
        (<pre_condition_is_false>) -> (
            continue := true;
            isNew     := false
        ),
        (<do_not_test>) -> (
            continue := true;
            isNew     := false
        ),
        (<imperatively_test>) -> (
            continue := false;
            isNew     := false
        ),
        (<see_ECI>) -> (
            if cur_arcprt.prt(eci) then (
                continue := true;
                isNew     := false
            )
            else (
                cur_arcprt.setPrt
                ( [cur_arcprt.prt(i)
                  | i in set {1,...,eci-1}]
                  ^ [true]
                  ^ [ cur_arcprt.prt(i)
                      | i in set {eci+1,...,

```

```

len cur_arcprt.prt}

    ]
    );
    continue := false;
    isNew    := false
  ) /** if prt(cur_arcprt)(eci) **/
)
end /** case est of **/
) -- end if not next_exist
); -- end while
if isNew then
  cur_arcprt
:= cur_arcprt.mkArcPrt(
    new PriorityQueue_enqp_arc(),
    [false
    | i in set
      {1,...,
      Max_ECI_PriorityQueue_enqp(tm)}
    ]
    );
return mk_( isNew, cur_arcprt )
);

```

```

getNext_PriorityQueue_enqp_arc: bool * ArcPrt *
                                pvt_test_mode ==> bool * ArcPrt
getNext_PriorityQueue_enqp_arc(init_par,in_arcprt,tm) ==
(dcl continue:    bool      := true;
dcl isNew:      bool      := init_par;
dcl cur_arcprt:  ArcPrt    := in_arcprt;
dcl rest_of_prt: nat      := 0;

for all i in set {1,...,len in_arcprt.prt} do
  if not in_arcprt.prt(i) then
    rest_of_prt := rest_of_prt + 1;
  if len in_arcprt.prt <> 0 and rest_of_prt = 0 then
    isNew := true
  else
    while continue do (
      dcl new_arc:    PriorityQueue_enqp_arc;
      dcl next_exist: bool;

```

```

if isNew then
  let    mk_(new_arc1,next_exist1)
        = PriorityQueue_enqp_arc_init()
  in (
    new_arc    := new_arc1;
    next_exist := next_exist1
  )
else
  let cur_arc: PriorityQueue_enqp_arc =
        cur_arcpvt.arc,
    mk_(new_arc1,next_exist1)
    = PriorityQueue_enqp_arc_next(cur_arc)
  in (
    new_arc    := new_arc1;
    next_exist := next_exist1
  );
if not next_exist then (
  continue := false;
  isNew    := true
)
else (
  cur_arcpvt.setArc(new_arc);

  let cur_arc: PriorityQueue_enqp_arc =
        cur_arcpvt.arc,
    pvt = form_pvt_PriorityQueue_enqp(cur_arc),
    mk_(est,eci) = bc_PriorityQueue_enqp(tm,pvt)
  in cases est:
    (<pre_condition_is_false>) -> (
      continue := true;
      isNew    := false
    ),
    (<do_not_test>) -> (
      continue := true;
      isNew    := false
    ),
    (<imperatively_test>) -> (
      continue := false;
      isNew    := false
    ),

```

```

    (<see_ECI>) -> (
      if cur_arcprt.prt(eci) then (
        continue := true;
        isNew    := false
      )
      else (
        cur_arcprt.setPrt
          ( [cur_arcprt.prt(i)
            | i in set {1,...,eci-1}]
            ^ [true]
            ^ [ cur_arcprt.prt(i)
                | i in set {eci+1,...,
                           len cur_arcprt.prt}
              ]
          );
        continue := false;
        isNew    := false
      ) /** if prt(cur_arcprt)(eci) **/
    )
  end /** case est of **/
) -- end if not next_exist
); -- end while
if isNew then
  cur_arcprt
:= cur_arcprt.mkArcPrt(
    new PriorityQueue_isEmpty_arc(),
    [false
     | i in set {1,...,
                Max_ECI_PriorityQueue_isEmpty(tm)}
    ]
  );
return mk_( isNew, cur_arcprt )
);

```

```

getNext_PriorityQueue_isEmpty_arc: bool * ArcPrt *
                                   pvt_test_mode ==> bool * ArcPrt
getNext_PriorityQueue_isEmpty_arc(init_par,in_arcprt,tm)
==
(dcl continue:    bool    := true;
 dcl isNew:      bool    := init_par;

```

```

dcl cur_arcprt: ArcPrt      := in_arcprt;
dcl rest_of_prt: nat       := 0;

for all i in set {1,...,len in_arcprt.prt} do
  if not in_arcprt.prt(i) then
    rest_of_prt := rest_of_prt + 1;
  if len in_arcprt.prt <> 0 and rest_of_prt = 0 then
    isNew := true
  else
    while continue do (
      dcl new_arc:      PriorityQueue_isEmpty_arc;
      dcl next_exist: bool;

      if isNew then
        let   mk_(new_arcl,next_existl)
              = PriorityQueue_isEmpty_arc_init()
        in (
          new_arc      := new_arcl;
          next_exist   := next_existl
        )
      else
        let cur_arc: PriorityQueue_isEmpty_arc =
              cur_arcprt.arc,
              mk_(new_arcl,next_existl)
              = PriorityQueue_isEmpty_arc_next(cur_arc)
        in (
          new_arc      := new_arcl;
          next_exist   := next_existl
        );
      if not next_exist then (
        continue := false;
        isNew    := true
      )
      else (
        cur_arcprt.setArc(new_arc);

        let cur_arc: PriorityQueue_isEmpty_arc =
              cur_arcprt.arc,
              mk_(est,eci) = bc_PriorityQueue_isEmpty(tm)
        in cases est:
          (<pre_condition_is_false>) -> (

```

```

        continue := true;
        isNew    := false
    ),
    (<do_not_test>) -> (
        continue := true;
        isNew    := false
    ),
    (<imperatively_test>) -> (
        continue := false;
        isNew    := false
    ),
    (<see_ECI>) -> (
        if cur_arcprt.prt(eci) then (
            continue := true;
            isNew    := false
        )
        else (
            cur_arcprt.setPrt
            ( [cur_arcprt.prt(i)
              | i in set {1,...,eci-1}]
              ^ [true]
              ^ [ cur_arcprt.prt(i)
                  | i in set {eci+1,...,
                               len cur_arcprt.prt}
              ]
            );
            continue := false;
            isNew    := false
        ) /** if prt(cur_arcprt)(eci) **/
    )
    end /** case est of **/
) -- end if not next_exist
); -- end while
if isNew then
    cur_arcprt
:= cur_arcprt.mkArcPrt(
    new PriorityQueue_size_arc(),
    [false
     | i in set {1,...,
                 Max_ECI_PriorityQueue_size(tm)}
    ]

```

```

    );
    return mk_( isNew, cur_arcprt )
);

```

```

getNext_PriorityQueue_size_arc: bool * ArcPrt *
                                pvt_test_mode ==> bool * ArcPrt
getNext_PriorityQueue_size_arc(init_par,in_arcprt,tm) ==
(dcl continue:    bool      := true;
 dcl isNew:       bool      := init_par;
 dcl cur_arcprt:  ArcPrt    := in_arcprt;
 dcl rest_of_prt: nat       := 0;

for all i in set {1,...,len in_arcprt.prt} do
  if not in_arcprt.prt(i) then
    rest_of_prt := rest_of_prt + 1;
  if len in_arcprt.prt <> 0 and rest_of_prt = 0 then
    isNew := true
  else
    while continue do (
      dcl new_arc:    PriorityQueue_size_arc;
      dcl next_exist: bool;

      if isNew then
        let mk_(new_arcl,next_existl)
          = PriorityQueue_size_arc_init()
        in (
          new_arc      := new_arcl;
          next_exist   := next_existl
        )
      else
        let cur_arc: PriorityQueue_size_arc =
          cur_arcprt.arc,
          mk_(new_arcl,next_existl)
          = PriorityQueue_size_arc_next(cur_arc)
        in (
          new_arc      := new_arcl;
          next_exist   := next_existl
        );
      if not next_exist then (
        continue := false;

```

```

    isNew      := true
  )
else (
  cur_arcprt.setArc(new_arc);

  let cur_arc: PriorityQueue_size_arc =
    cur_arcprt.arc,
    mk_(est,eci) = bc_PriorityQueue_size(tm)
  in cases est:
    (<pre_condition_is_false>) -> (
      continue := true;
      isNew     := false
    ),
    (<do_not_test>) -> (
      continue := true;
      isNew     := false
    ),
    (<imperatively_test>) -> (
      continue := false;
      isNew     := false
    ),
    (<see_ECI>) -> (
      if cur_arcprt.prt(eci) then (
        continue := true;
        isNew     := false
      )
      else (
        cur_arcprt.setPrt
          ( [cur_arcprt.prt(i)
            | i in set {1,...,eci-1}]
            ^ [true]
            ^ [ cur_arcprt.prt(i)
                | i in set {eci+1,...,
                           len cur_arcprt.prt}
              ]
          );
        continue := false;
        isNew     := false
      ) /** if prt(cur_arcprt)(eci) **/
    )
end /** case est of **/

```



```

        ) -- end if not next_exist
    ); -- end while
    return mk_( isNew, cur_arcprt )
);

```

```

public
getNextArc: ArcPrt * pvt_test_mode ==> ArcPrt * bool
getNextArc(in_arcprt, tm) ==
  (dcl cur_arcprt: ArcPrt := in_arcprt;
   dcl verdict:    bool   := true;
   dcl init_par:   bool   := false;
   dcl first:      bool   := true;

   while init_par or first do (
     first := false;
     if (isofclass(EmptyArc, cur_arcprt.arc)) then
       let mk_(ini, cur) =
         getNextEmptyArc(init_par, cur_arcprt, tm)
       in (cur_arcprt := cur; init_par := ini)
     elseif (isofclass(PriorityQueue_deq_arc,
                       cur_arcprt.arc)) then
       let mk_(ini, cur) =
         getNext_PriorityQueue_deq_arc(init_par,
                                       cur_arcprt, tm)
       in (cur_arcprt := cur; init_par := ini)
     elseif (isofclass(PriorityQueue_enq_arc,
                       cur_arcprt.arc)) then
       let mk_(ini, cur) =
         getNext_PriorityQueue_enq_arc(init_par,
                                       cur_arcprt, tm)
       in (cur_arcprt := cur; init_par := ini)
     elseif (isofclass(PriorityQueue_enqp_arc,
                       cur_arcprt.arc)) then
       let mk_(ini, cur) =
         getNext_PriorityQueue_enqp_arc(init_par,
                                       cur_arcprt, tm)
       in (cur_arcprt := cur; init_par := ini)
     elseif (isofclass(PriorityQueue_isEmpty_arc,
                       cur_arcprt.arc)) then
       let mk_(ini, cur) =

```

```

        getNext_PriorityQueue_isEmpty_arc(init_par,
                                           cur_arcprt,
                                           tm)

    in (cur_arcprt := cur; init_par := ini)
elseif (isofclass(PriorityQueue_size_arc,
                 cur_arcprt.arc)) then
    let mk_(ini, cur) =
        getNext_PriorityQueue_size_arc(init_par,
                                       cur_arcprt, tm)

    in (cur_arcprt := cur;
        init_par := false;
        verdict := not ini)
);
return mk_(cur_arcprt, verdict)
);

```

```

-- Call basic drivers of tested procedures:
--
-- 1) forms parameters of basic driver:
--   - browsed parameters are fields of cur_par
--   - or are calculated from field values,
--   - object under test
-- 2) calls basic driver and obtains out-parameters;
--
-- 3) if basic driver returns verdict true
--   and one of out-parameters is object under test
--   then updates object under test
--
-- 4) returns verdict and back-operation
--   if back-operation is not exist
--   it is empty back-operation - getEmptyArc()

call_PriorityQueue_deq: PriorityQueue_deq_arc ==>
    Arc * bool
call_PriorityQueue_deq(cur_arc) ==
    trap - with return mk_(new EmptyArc(), false)
    in let - = oracle_of_PriorityQueue.deq()
        in return mk_(new EmptyArc(), true);

call_PriorityQueue_enq: PriorityQueue_enq_arc ==>

```

```

                                Arc * bool
call_PriorityQueue_enq(cur_arc) ==
  (let cur_pvt = form_pvt_PriorityQueue_enq(cur_arc)
   in trap - with return mk_(new EmptyArc(), false)
     in oracle_of_PriorityQueue.enq( cur_pvt.item );
   return mk_(new EmptyArc(), true));

call_PriorityQueue_enqp: PriorityQueue_enqp_arc ==>
                                Arc * bool
call_PriorityQueue_enqp(cur_arc) ==
  (let cur_pvt = form_pvt_PriorityQueue_enqp(cur_arc)
   in trap - with return mk_(new EmptyArc(), false)
     in oracle_of_PriorityQueue.enqp(cur_pvt.item,
                                     cur_pvt.pri );
   return mk_(new EmptyArc(), true));

call_PriorityQueue_isEmpty: PriorityQueue_isEmpty_arc ==>
                                Arc * bool
call_PriorityQueue_isEmpty(cur_arc) ==
  trap - with return mk_(new EmptyArc(), false)
    in let - = oracle_of_PriorityQueue.isEmpty()
      in return mk_(new EmptyArc(), true);

call_PriorityQueue_size: PriorityQueue_size_arc ==>
                                Arc * bool
call_PriorityQueue_size(cur_arc) ==
  trap - with return mk_(new EmptyArc(), false)
    in let - = oracle_of_PriorityQueue.size()
      in return mk_(new EmptyArc(), true);

```

```

-- For given basic arc call basic driver
-- and returns next node, back-operation and verdict
public
callBasicDriver: Arc ==> Node * Arc * bool
callBasicDriver(cur_arc) ==
  (dcl back_arc : Arc;
   dcl verdict  : bool;

   if (isofclass(EmptyArc,cur_arc)) then (
     tracer.scriptTracerSuicide(

```

```
        "PQueue:call_:empty arc in call");
    back_arc := new EmptyArc();
    verdict := false
)
elseif(isofclass(PriorityQueue_deq_arc,cur_arc))
then (
    let mk_(back_arc1,verdict1)
        = call_PriorityQueue_deq(cur_arc)
    in (
        back_arc := back_arc1;
        verdict := verdict1
    )
)
elseif(isofclass(PriorityQueue_enq_arc,cur_arc))
then (
    let mk_(back_arc1,verdict1)
        = call_PriorityQueue_enq(cur_arc)
    in (
        back_arc := back_arc1;
        verdict := verdict1
    )
)
elseif(isofclass(PriorityQueue_enqp_arc,cur_arc))
then (
    let mk_(back_arc1,verdict1)
        = call_PriorityQueue_enqp(cur_arc)
    in (
        back_arc := back_arc1;
        verdict := verdict1
    )
)
elseif(isofclass(PriorityQueue_isEmpty_arc,cur_arc))
then (
    let mk_(back_arc1,verdict1)
        = call_PriorityQueue_isEmpty(cur_arc)
    in (
        back_arc := back_arc1;
        verdict := verdict1
    )
)
elseif(isofclass(PriorityQueue_size_arc,cur_arc))
```

```

then (
  let   mk_(back_arc1, verdict1)
        = call_PriorityQueue_size(cur_arc)
  in (
    back_arc := back_arc1;
    verdict  := verdict1
  )
);
if verdict then
  return mk_(getNode(), back_arc, true)
else (
  tracer.scriptTracerSuicide(
    "PQueue:call_:call_ returns bad verdict");
  return mk_(getNode(), back_arc, false)
)
);
end SCRD_PQueue_generic

```

C.3 Handmade Components

C.3.1 The PriorityQueue Class

```

class PriorityQueue is subclass of Specification
values

  public
    MIN_PRIORITY : int = 0;

  public
    MAX_PRIORITY : int = 255;

instance variables

  public
    -- sequence of priorities
    priorities : seq of int := [];

```

```

public
  -- sequence of sequence of queue items
  -- queue(i) is item with priority priorities(i)
  queue      : seq of QueueItem := [];

  inv forall i in set inds priorities &
    priorities(i) >= MIN_PRIORITY
    and priorities(i) <= MAX_PRIORITY;
  inv len priorities = len queue;
  inv forall i in set {2, ..., len priorities} &
    priorities(i) <= priorities(i-1);

```

functions

```

protected
  insertBefore[@item]: seq of @item * @item * nat +>
    seq1 of @item
  insertBefore(list, elem, idx) ==
    [list(i) | i in set {1, ..., idx-1} ]
    ^ [elem]
    ^ [list(i) | i in set {idx, ..., len list} ];

protected
  branch : seq1 of char +> bool
  branch(-) == true;

```

operations

```

public
  enqp(item: QueueItem, pri: int)
  == ( dcl i : int := 1;
    while i <= len priorities and
      priorities(i) >= pri do i := i+1;
    priorities := insertBefore[int]
      (priorities, pri, i);
    queue := insertBefore[QueueItem]
      (queue, item, i);
  )
  ext wr priorities, queue

```

```

pre pri >= MIN_PRIORITY and pri <= MAX_PRIORITY
post if priorities~ = []
    then
        branch("Empty queue")
        and priorities = [pri]
        and queue = [item]
    elseif pri not in set elems priorities~
    then
        branch("Priority not in queue")
        and pri in set elems priorities
        and exists1 i in set inds priorities
        & priorities(i) = pri
        and queue(i) = item
        and [priorities(k)
            | k in set inds priorities
            & k <> i]
            = priorities~
        and [queue(k)
            | k in set inds queue
            & k <> i]
            = queue~
    else
        branch("Priority in queue")
        and pri in set elems priorities
        and exists1 i in set inds priorities
        & priorities(i) = pri
        and queue(i) = item
        and [priorities(k)
            | k in set inds priorities
            & k <> i]
            = priorities~
        and [queue(k)
            | k in set inds queue
            & k <> i]
            = queue~
        and forall k in set elems
            [ k
              | k in set inds priorities
              & priorities(k) = pri
            ]
            & k <= i;

```

```

public
  enq(item: QueueItem)
  == ( priorities := insertBefore[int]
      (priorities,
       MIN_PRIORITY,
       len priorities + 1);
      queue := insertBefore[QueueItem]
      (queue, item, len queue + 1);
  )
ext wr priorities, queue
pre true
post    branch("single branch")
        and priorities = priorities~ ^ [MIN_PRIORITY]
        and queue = queue~ ^ [item];

```

```

public
  deq() item: [QueueItem]
  == if len queue > 0
    then ( dcl item : QueueItem := hd queue;
          priorities := tl priorities;
          queue      := tl queue;
          return item;
        )
    else return nil
ext wr priorities, queue
pre true
post if len queue~ > 0
  then    branch("non-empty queue")
        and priorities = tl priorities~
        and queue = tl queue~
        and item = hd queue~
  else    branch("empty queue")
        and priorities = priorities~
        and queue = queue~
        and item = nil;

```

```

public
  size() res: nat

```



```

== return len queue
ext rd queue
pre true
post      branch("single branch")
          and res = len queue;

```

```

public
  isEmpty() res: bool
  == return size() = 0
  ext rd queue
  pre true
  post      branch("single branch")
            and res = (len queue = 0);
end PriorityQueue

```

C.3.2 The QueueItem Class

```

class QueueItem
end QueueItem

```

C.3.3 The TestedNode Class

```

-- Node in that we were at least once
class TestedNode

instance variables

-- State of node
public node : Node;

-- The way along back-arcs finishes at path
public backArc : Arc;

```

```
-- Index of the end of back-arc in list of tested nodes
public backArcEndId : nat;

-- Index of the node in list of path nodes
-- (if the node is not in the path then index is 0)
public pathNodeId : nat;

operations

-- READ/WRITE OPERATIONS

public
mkTestedNode: Node * Arc * nat * nat ==> TestedNode
mkTestedNode (n, a, bnum, pnum) ==
  (node := n;
   backArc := a;
   backArcEndId := bnum;
   pathNodeId := pnum;
   return self
  );

public setNode: Node ==> ()
setNode (n) == node := n;

public setBackArc: Arc ==> ()
setBackArc (a) == backArc := a;

public setBackArcEndId: nat ==> ()
setBackArcEndId (i) == backArcEndId := i;

public setPathNodeId: nat ==> ()
setPathNodeId (i) == pathNodeId := i;

end TestedNode
```

C.3.4 The PathNode Class

```
class PathNode

instance variables

-- node index in list of tested nodes
public testedNodeId : nat;

-- path arc
public pathArcPrt : ArcPrt;

-- index of the node at the end of the way along back-arcs
public backNodeId : nat;

operations

-- read/write operations

public mkPathNode: nat * ArcPrt * nat ==> PathNode
mkPathNode (tnum, parc, nb) ==
  (testedNodeId := tnum;
   pathArcPrt := parc;
   backNodeId := nb;
   return self
  );

public setTestedNodeId: nat ==> ()
setTestedNodeId (tnum) == testedNodeId := tnum;

public setPathArcPrt: ArcPrt ==> ()
setPathArcPrt (parc) == pathArcPrt := parc;

public setBackNodeId: nat ==> ()
setBackNodeId (nb) == backNodeId := nb;

end PathNode
```

C.3.5 The ArcPrt Class

```
-- Class for presentation of graph arc with prt
-- (coverage estimation list)
class ArcPrt

instance variables

public arc: Arc := new EmptyArc();
public prt: seq of bool := [];

operations

public mkArcPrt: Arc * seq of bool ==> ArcPrt
mkArcPrt(a, p) ==
  (arc := a;
   prt := p;
   return self
  );

public setArc: Arc ==> ()
setArc(a) == arc := a;

public setPrt: seq of bool ==> ()
setPrt(p) == prt := p;
end ArcPrt
```

C.3.6 The PQueue_Node Class

```
class PQueue_Node is subclass of Node

instance variables

  pris : map int to nat := {|->};

operations

public
PQueue_Node : map int to nat ==> PQueue_Node
PQueue_Node(p_pris) ==
```

```

    pris := p_pris;

public
compare: Node ==> bool
compare(node) ==
    return if isofclass(PQueue_Node, node)
        then let n : PQueue_Node = node
            in n.pris = pris
        else false;

end PQueue_Node

```

C.3.7 The PriorityQueue_enqp_Arc Class

```

class PriorityQueue_enqp_Arc
is subclass of PriorityQueue_enqp_arc

instance variables
    public pri : int;
operations
    public
        PriorityQueue_enqp_Arc : int ==> PriorityQueue_enqp_Arc
        PriorityQueue_enqp_Arc(p_pri) ==
            pri := p_pri;

end PriorityQueue_enqp_Arc

```

C.3.8 The SCRD_PQueue Class

```

class SCRD_PQueue is subclass of SCRD_PQueue_generic
    -- Below must be manual code

functions
    nextPri : int +> int * bool
    nextPri(pri)
    == if pri = PriorityQueue`MIN_PRIORITY

```

```

    then mk_((PriorityQueue`MIN_PRIORITY+
              PriorityQueue`MAX_PRIORITY) div 2,
              true
            )
    elseif pri = PriorityQueue`MAX_PRIORITY
    then mk_ ( PriorityQueue`MIN_PRIORITY,
              false
            )
    else mk_ ( PriorityQueue`MAX_PRIORITY,
              true
            );

```

operations

```

public
getNode: () ==> Node
getNode() ==
    return new PQueue_Node(
        {p |-> len [oracle_of_PriorityQueue.priorities(i)
                  | i in set inds
                  oracle_of_PriorityQueue.priorities
                  & oracle_of_PriorityQueue.priorities(i) = p
                ]
        | p in set elems oracle_of_PriorityQueue.priorities
    });

```

```

form_pvt_PriorityQueue_enq: Arc ==> pvt_PriorityQueue_enq
form_pvt_PriorityQueue_enq(cur_par)
== return mk_pvt_PriorityQueue_enq(new QueueItem());

form_pvt_PriorityQueue_enqp: Arc ==>
    pvt_PriorityQueue_enqp
form_pvt_PriorityQueue_enqp(cur_par) == (
    dcl curArc: PriorityQueue_enqp_Arc := cur_par;
    return mk_pvt_PriorityQueue_enqp(new QueueItem(),
                                     curArc.pri);
);

```

```

PriorityQueue_enq_arc_init: () ==>
    PriorityQueue_enq_arc * bool
PriorityQueue_enq_arc_init() ==
    return mk_(new PriorityQueue_enq_arc(),
        len oracle_of_PriorityQueue.priorities < 10);

```

```

PriorityQueue_enqp_arc_init: () ==>
    PriorityQueue_enqp_arc * bool
PriorityQueue_enqp_arc_init() ==
    return mk_(new PriorityQueue_enqp_Arc(
        PriorityQueue'MIN_PRIORITY),
        len oracle_of_PriorityQueue.priorities < 10
    );

```

```

PriorityQueue_enq_arc_next: PriorityQueue_enq_arc ==>
    PriorityQueue_enq_arc * bool
PriorityQueue_enq_arc_next(cur_arc) ==
    return mk_(new PriorityQueue_enq_arc(), false);

```

```

PriorityQueue_enqp_arc_next: PriorityQueue_enqp_arc ==>
    PriorityQueue_enqp_arc * bool
PriorityQueue_enqp_arc_next(cur_arc) ==
    let curArc : PriorityQueue_enqp_Arc = cur_arc,
        mk_(p,v) = nextPri(curArc.pri)
    in return mk_( new PriorityQueue_enqp_Arc(p), v);

end SCRD_PQueue

```

D Test Trace for PQUEUE Example

Oracle started: PriorityQueue'deq
 Branch: empty queue
 Oracle finished: PriorityQueue'deq. verdict: Ok

Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch

Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enq

Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch

Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue

Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size

Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
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Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue

Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enq
Branch: single branch
Oracle finished: PriorityQueue`enq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enqp

Branch: Priority in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Priority not in queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch

```
Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`enqp
Branch: Empty queue
Oracle finished: PriorityQueue`enqp. verdict: Ok
Oracle started: PriorityQueue`deq
Branch: non-empty queue
Oracle finished: PriorityQueue`deq. verdict: Ok
Oracle started: PriorityQueue`isEmpty
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Branch: single branch
Oracle finished: PriorityQueue`isEmpty. verdict: Ok
Oracle started: PriorityQueue`size
Branch: single branch
Oracle finished: PriorityQueue`size. verdict: Ok
Message: Script driver succefully finished.
```