

**Methods for Testing and Specification (MTS);  
Model-Based Testing (MBT);  
 Requirements for Modelling Notations**



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## Foreword

This ETSI Standard (ES) has been produced by ETSI Technical Committee Methods for Testing and Specification (MTS), and is now submitted for the ETSI standards Membership Approval Procedure.

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## Introduction

Based on the recent success and deployment of model-based automated test design in industry, TC MTS investigated work on model-based testing specifically in the context of standardized test specification development [i.1]. Contrary to other methods and approaches, which focus mainly on automation of test *execution*, this standard considers to use of model-based testing for the automation of test *design*.

Model-based testing facilitates a more thorough and earlier validation of standards as well as the efficient automatic generation of test specification artefacts, e.g., **MSC based test descriptions or TTCN-3 test suites**, which perform black-box functional testing of the external behaviour of a system. Due to its independence of the output format and its higher level of abstraction, model-based testing enables **a more direct review** of the requirements **imposed by a standard** compared to test specification artefacts. In addition, automation of test design **allows ETSI** as well as other organizations to more efficiently create test suites, coping with the ever-growing demand for interoperability and conformance testing in standardization.

The motivations for the development of this standard were:

 to collect in one document agreed terminology and concepts required for the specification of models specifically for testing for all interest groups that maybe be exposed to model-based testing technology such as **product vendors, tool makers**  test service providers, test engineers, government agencies, procurement personnel and researchers

to enable the specification of models for derivation of standardized conformance and interoperability tests

to facilitate the use of model-based testing for product certification

to create a basis for an open, competitive model-based testing tool market which process such models and where such models can be exchanged between different tools

to enable consumer accountability (including also for legal issues)

To ensure its success and quality, this standard has been developed by a group of experts from all types of stakeholders involved in test specification development, i.e., researchers, tool makers, industrial users, as well as testing experts of ETSI's Centre for Testing and Interoperability.

This document lays the foundation for the deployment of model-based testing in standardization since it specifies requirements for modelling notations to be suitable for the generation of tests in the context of standardization. Such

tests need to adhere to well established concepts defined and used in manual test specification [i.2, i.3., i.4]. In addition, this standard defines the criteria that need to be fulfilled by a model **in order to be included in a standardized ETSI test specification**, and the relation that models have to the generated tests.



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# 1 Scope

The present document identifies and collects all concepts of a modelling notation required for specifying behavioural models for the specific purpose of functional black box testing of communicating systems. Such models form the basis for generating abstract conformance or interoperability test cases which follow the principles of ISO 9646 [ref], e.g., TTCN-3 [core] test suites. Model-based testing presents an alternative to manual test specification, but does not eliminate the need for test systems [TRI] which execute abstract test cases. Model-based testing tools that use a modelling notation that complies with the requirements stated in this standard can be used to automatically generate abstract test cases suitable for standardization.

The concepts and requirements described in this standard have been developed mainly from the recommendations collected in ETSI TR 102 840 [i.1] and complement the theoretic foundation of modelling standard specifications specified in ITU-T Z.500 [Z500]. They are specified independent of a specific modelling notation or tool. Mapping of concepts to concrete modelling notations is intentionally not treated in this document and preserved for future standards.

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# 2 Informative References

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area. For non-specific references, the latest version of the referenced document (including any amendments) applies.

- [i.1] ETSI TR 102 840: "Methods for Testing and Specifications (MTS); Model driven testing in standardization".
- [i.2] ISO/IEC 9646-1: "Information technology - Open Systems; Interconnection - Conformance testing methodology and framework - Part 1: General concepts".
- [i.3] ETSI ES 201 873-1: "Methods for Testing and Specification (MTS); The Testing and Test Control Notation version 3; Parts 1: TTCN-3 Core Language" (also published as ITU-T Recommendation series Z.140).
- [i.4] UML reference needed 
- [Z500] ITU-T Recommendation Z.500: "Framework on formal methods in conformance testing".

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# 3 Definitions and abbreviations

## 3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

**abstract test case:** see ISO 9646-1 [i.2]. A complete and independent specification of the actions required to achieve a specific test purpose. An  atomic test case may be represented as a set of informal instructions or a formal specification like a TTCN-3 test case.

**abstract test suite:** see ISO 9646-1 [i.2]. A test suite composed of abstract test cases.

**action:** an atomic activity of the system triggered or observed via the system interface, consisting of an action name and a set of data parameters. Actions are partitioned into *input* and *output* actions.

**(functional) behaviour:** the functional behaviour of a system as specified by a set of requirements in a specification and given as a set of action sequences, where each sequence represents a legal scenario, and every sequence not in this set represents an illegal scenario.

**deterministic behaviour:** behaviour of a system in which for each input action sequence there exist no more than one possible output action sequence.

**input action:** an action stimulated by the environment **on**, representing a message, operation, or other kind of communication means. An input action may carry parameters.

**model-based testing:** an umbrella of approaches that generate tests from models. This standard addresses model-based testing with (functional) behavioural models.

**modelling notation:** a formal language used for the specification of models.

**non-deterministic behaviour:** behaviour of a system where for one input action sequence more than one possible output action sequences exist.

**offline test generation:** test generation ahead of test execution time (see test generation).

**online test generation:** dynamic test generation from a model during test execution.

**output action:** an action issued by the system or SUT on the environment as a reaction on input actions, or spontaneously. An output action may carry parameters.

**requirement:** a documented need of what a system should be or perform.

 **(system) model:** computer-readable behavioural model that describes the intended external operational characteristics of a system, i.e. how the system being modelled interacts with its environment, in terms of the system interface. Depending on the purpose, a system model may only capture aspects of real system behaviour, as determined by the abstraction level chosen by the system interface.

**system interface:** a model element that defines the input and output actions of the system on the level of abstraction selected for the given modelling and testing problem.

**(system) state:** a modality in which the SUT accepts certain input actions and/or issues certain output actions

**(system state) transition:** a transition in the SUT from one system state to the next, usually associated with an input or output action which causes the transition.

**system under test (SUT):** see ISO 9646-1 [i.2]. The real open system in which the implementation under test resides.

**test description:** systematic specification of the test steps that must be taken to reach a specific test verdict

**test generation:** the automatic **derivation of abstract test cases**  **test descriptions** from a model based on user defined test selection criteria.

**test purpose:** see ISO 9646-1 [i.2]. A prose description of a well defined objective of testing.

**test selection:** **the process**  **the result** of choosing a subset of tests from a larger or infinite set of tests which can be derived from a model.

**test selection criterion:** property that must be satisfied by a set of test cases generated from a model to be considered adequate.

## 3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

MBT	Model-Based Testing
MSC	Message Sequence Chart
SUT	System Under Test
TTCN-3	Testing and Test Control Notation version 3

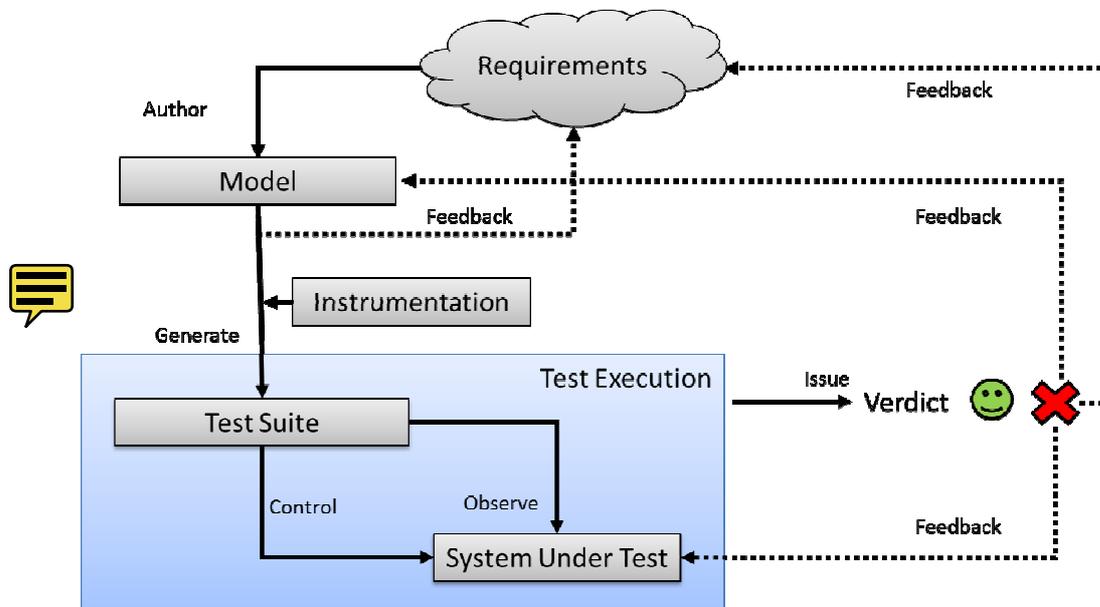
## 4 Model-based test development



In **model-based test development**, an engineer starts from a set of functional requirements of a system to be tested, usually given in a specification written in natural language. The engineer authors a model using a modelling notation which fulfils the requirements stated in this standard. The model encodes these requirements and describes the aspects of the functional behaviour which are to be tested.

The model is then instrumented for the purpose of test generation by adding or selecting test selection criteria, i.e., coverage goals or test purposes specifying what is to be covered, and heuristics specifying how these goals are to be covered. Test selection is necessary since from every non-trivial model, an infinite or huge amount of tests can be derived. A model-based testing tool then automatically generates an abstract test suite that complies with these criteria. This resulting abstract test suite may need to be adapted to enable test execution against the SUT.

In model-based testing, abstract tests may be generated offline in one or more different formats including informal test descriptions or instructions for manual test execution, graphical formats such as MSCs, programming languages such as Java, C#, or TTCN-3 [i.3]. In a second step, offline tests may then be compiled into executable tests and executed against the system under test. Input and output actions may also be generated online, i.e. the generated actions are immediately executed against the system under test and observations during test execution are directly fed back into the test generation engine. During test execution the test system finally issues a pass or fail test verdict based on the outcome of each generated test.



**Figure 1: Model-Based Test Development**

Model-based test development delivers feedback for the involved artefacts on multiple levels. First, the process of authoring a model which captures functional requirements provides feedback for the consistency of the system specification, potentially before any test is executed, or any part of the system is implemented. Second, the inspection of generated test cases and feedback from **mechanical** model analysis – like checking for deadlocks and safety conditions – can reveal issues in the system specification or the model. Third, when the tests are finally executed, issues in the SUT, in the system specification, or in the model can be discovered.

In the remainder of this standard, requirements for modelling notations which enables the described model-based test development are captured on a conceptual level. For an informative discussion of commonly used modelling notation styles fitting these requirements, see Annex A.

## 5 General modelling notation requirements

Models are well defined language artefacts which are used in engineering processes much similar to programming languages. They can become large for complex systems, are authored in teams, evolve in iterations, are reused in different versions, require documentation, and need lifecycle management. Moreover, functional models often require algorithmic descriptions for some of the aspects they describe. As such, a modelling notation shall support concepts to those common for programming languages in software engineering. These concepts are described in this section.

### 5.1 Modularization

An overall model may describe numerous complex aspects of a system, which can be best understood and maintained in isolation. A modelling notation should therefore support the software engineering principle of separation of concerns by providing means for modularization, allowing separating and recombining aspects of the system specification, such that they can be independently developed, understood, evolved, and composed into an overall system. Modularization should also support model reuse of individual components in different configurations or versions of one or more systems.

More specifically, the modelling notation should support the following:

- a) Provide a way to isolate aspects of the overall model in an independent artefact, like a document or set of documents.
- b) Provide a way to specify the dependencies of an isolated artefact from other artefacts
- c) Provide a way to specify aspects graphically in a hierarchical manner
- d) Have a well-defined semantics of the composition of isolated artefacts

Modularization concept can be achieved in a number of ways, details of which are beyond the scope of this standard. In general, modularization can be achieved in very similar ways as in programming languages by using concepts like components, modules, namespaces, and classes with well-defined interfaces. However, modularization can also be achieved by modelling-specific concepts, like model composition, model transformation, etc.

### 5.2 Algorithms

Nearly every non-trivial modelling problem requires the specification of algorithms which compute input from output data, compute the next system state, check for conditions, define constraints on data values, etc. Even if the modelling language is based on a diagrammatic notation, algorithmic language support is required for describing, for example, changes in the state of the SUT.

A modelling notation shall therefore provide basic means for algorithmic design and data manipulation, as described below:

- a) The notation shall be based on an unambiguous operational semantics
- b) The notation shall support at least the basic data domains integers and character strings as well as the user defined types records and arrays from conventional programming languages [ISO11404], together with their related operations.
- c) The notation should support more advanced data types, like floating point numbers and other user defined types such as enumerations and associative arrays.
- d) The notation should support unbounded data like arbitrary precision integers or arrays of non-fixed size.
- e) The notation shall support basic control constructs like variables, assignment, and conditional statements.
- f) The notation should support advanced control constructs like loops and quantifiers.
- g) The notation should support procedural abstraction, allowing a user to define procedures or functions which abstract the realization of a particular algorithm.

- h) The notation should support recursive procedural abstraction. 

While providing those features can be achieved in numerous ways, it is considered to be beneficial that these features are based on established notations instead of being defined from scratch for the particular modelling notation.

## 5.3 Documentation

While a model provides a precise formalized description of the system, in order to make it comprehensible for reviewers and other third parties, it needs to be accompanied by natural language documentation. Therefore the modelling notation shall support means to augment the formal definition of model elements with comments and more formal documentation, similar to that of many programming languages.

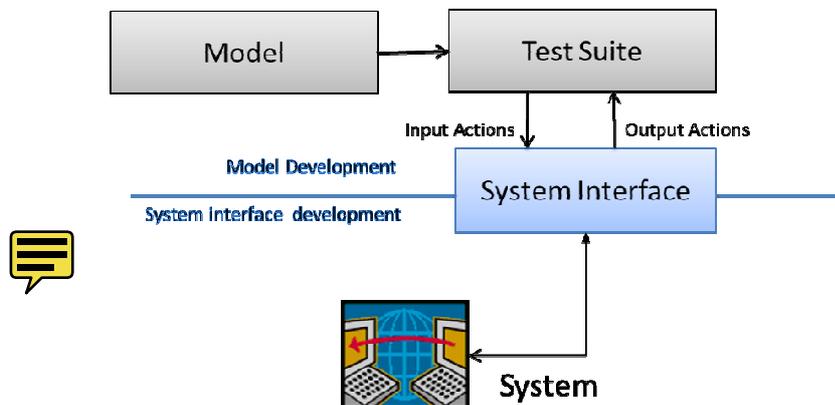
More specifically:

- A modelling notation shall support ways to attach informal comments to all relevant model element definitions
- A modelling notation should support ways to attach formal documentation to relevant model element definitions

Note that the difference between (a) and (b)  is the degree of formalization: an informal comment may appear in the original model artefact but its format **is free** and it **is not accessible** to a tool chain, whereas formal documentation has a well-defined format and can be processed by a tool chain; for example, can be validated for consistency, or used as input for model report generators. 

## 6 Modelling the system interface

In order to facilitate testing, a modelling notation for model-based testing shall provide ways  precisely define the interface available for testing the system. The system interface defines input and output actions  which allow to control and observe the system. The test suite generated from the model uses the input actions **to activate** functionality on the system, and observes the output actions which represent the system's responses, validating whether they conform to the modelled behaviour. Figure 2 illustrates the relations.



**Figure 2: The role of the system interface**

The system interface specified in modelling may only be a part and is often an abstraction of the real system interface. Abstraction results from focusing on testing specific aspects of a system while hiding others, or it may result from simplifying details, like for example low-level data representation of messages. For the model and the generated test suite the actual system is a black box; rather model and tests are defined in terms of the system interface abstraction. **A system interface abstraction can be seen as yet another system (with the properties derived from the original system via the abstraction process).** Therefore, this standard uses the notions of system and system abstraction, as accessible via the system interface, interchangeably. 

## 6.1 Actions

An action is an atomic activity of the system, triggered or observed via the system interface, consisting of an action name, a set of parameters, and directionality (input or output). Actions are used to represent messages, events, invocation of or return from operations, or other kinds of communication means.

A modelling notation shall support actions as described below:

- a) The modelling notation shall support the declaration of actions together with a name, whether they are input or output actions, and with parameter types.
- b) Parameter types shall include at least the basic types defined in Section 5.2 b), and should include advanced types defined in Section 5.2 c).

## 6.2 Operations

An operation is a set of actions where one action represents an input initiating either an operation (e.g., a “call” action) or a call-back operation (e.g., a “get call” action), and the other actions represent outputs for different ways of termination of the operation (e.g., a “return” or “exception” action) or call-back operation. In a domain where operation-oriented communication is dominant, it is beneficial if this concept is directly supported. For such domains, a modelling notation should support declaring operations as shorthand for declaring the basic constituting actions.

## 6.3 Ports

A port represents a collection of actions (or operations) which together constitute a particular viewpoint of the overall system. For example, a port may represent one of several logical access points or services provided by the system. Clustering actions in ports aids the structural clarity of the model. Ports may also exist in multiple instances, for example, to provide a similar service to different clients on request.

- a) A modelling notation should support ports or a similar concept (access point, endpoint of a communication channel, interface, contract etc.) as a way of grouping actions and operations.
- b) A modelling notation should support multiple instances of ports (or a similar concept). Alternatively to multiple instances, a modelling notation may use dedicated parameters of actions of a port to distinguish the instance of the port on which the action is operating.

## 6.4 Configurations

Often more complex systems are compromised by a configuration of entities which concurrently interact with each other using some form of communication channels. In some cases the topology of system components may be dynamically evolving, in other cases it may be statically defined for the lifetime of a system.

The modelling notation should support the specification of individual model components with concurrent activity and communication channels between them as well as the instantiation of static component configurations. Ideally, the specification of model component interfaces follows the same notion as that of the system interface between the SUT and the test suite derived from a model – i.e. it is given in terms of input and output actions or operations, clustered in one or more ports.




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# 7 Modelling the system behaviour

The specification of the functional behaviour of a system is the core modelling activity in model-based testing. Functional behaviour can be modelled in a variety of ways, using, for example, rule-oriented or process-oriented textual notations, or diagrammatic notations like state machines, state charts, sequence charts, and **flow charts**. This standard does not prescribe a particular notational style, but rather captures the requirements for behavioural modelling on a conceptual level.

## 7.1 System state

Modelling the abstract state of the SUT is a central aspect of behavioural modelling, as it identifies the situations in which certain actions are allowed or not.

- a) A modelling notation shall be able to model the system state by allowing at least one of the following :

The definition of a set of state variables where the current values assigned to these variables constitute the state of a system.



The definition of a program where the current program counter and program stack constitute the state of the system.

The definition of a diagram representing a state machine such as a UML state machine diagram [UML] or Harel statecharts [Harel], where every state in the diagram constitutes a state or part of the state of the system.



The definition of a diagram representing a flow chart such as UML activity diagrams [UML], where every arrow between two activities in the flow chart constitutes a state of the system.



The definition of a diagram representing a sequence chart such as a message sequence chart [MSC] or a UML sequence diagram [UML], where a given point on the life lines of all agents or instances related to the system represent a state of a system.

A combination of two or more of the approaches described above; in particular, combining combination of the first approach, describing state using state variables, with any of the other approaches. In a combination, the state of the system is represented by the product of the states of the combined approaches.

- b) In order to deal with realistic systems, a modelling notation should be able to model an unbounded number of system states. This is usually achieved by allowing state variables to range over domains which are not bounded at model design time. (Note that bounding the ranges at test selection time is not excluded by this requirement.)
- c) A modelling notation shall allow to identify initial and should allow to model final states of the system.

## 7.2 System state transitions

To assess that a given functionality is implemented according to a system specification, the SUT needs to be moved through a sequence of state transitions. System state transitions are triggered by providing input actions and may require the observation of one or more output actions. State transitions are often also closely related to informal requirements stated in system specification. Finally, timers play often a central role when handling communication with other systems.



- a) A modelling notation shall be able to describe a transition between two system states by allowing at least one of the following:

The definition of operational state transition rule, consisting of an enabling condition (a predicate over the state variables) and an algorithmic update of the state variables.

The definition of a declarative state transition rule, consisting of a pre-condition identifying the source state(s), and a post-condition identifying the target state(s), where both conditions are predicates over the state variables.

Receiving or sending a message from a port, or assigning new values to state variables in a program

Drawing an arc between two states in a state machine diagram such as a UML state machine diagram [UML]



Drawing an activity in a flowchart such as a UML activity diagram [UML]

Drawing an arrow between two life lines in a sequence chart such a UML sequence chart [UML] or message sequence chart [MSC]

Combining two or more of the approaches above

- b) A modelling notation shall be able to associate with a transition one input and one or more output actions including action parameters by allowing at least one of the following:

Associating the action name and parameters with a state transition rule, and relating the parameter symbols with the enabling condition, pre-condition or post-condition of the rule. 

Receiving or sending a particular message with parameters to a port in a program and initializing the parameters from the program state.

Associating an arc in a diagram with an action name and parameters.

Combining one or more of the approaches above.

- c) A modelling notation should be able to associate informal requirement references with state transitions by allowing at least one of the following:

Associating a special identifier with a rule, such that the identifier will be associated with each transition created from the rule, where the associating can be combined with a condition (predicate over the state variables and the parameter symbols). 

Supporting a special instruction in the rule update instructions.

Supporting a special instruction in a program.

Annotating an arc or activity in a diagram with a special identifier.

- d) A modelling notation should support a notion of time and be able to associate timing constraints with state transitions by allowing at least one of the following:

The definition of an admissible delay of the transition for the firing of a rule.



Supporting the concept a timer in a program.

Annotating an arc or life line in a diagram with an admissible delay.

## 7.3 Non-determinism

Non-determinism is a situation where in a given state where the SUT can produce for one sequence of input actions or state transitions more than one possible sequence of output actions. This can be further partitioned into cases where these different state transitions carry the same output actions (internal non-determinism) or carry different output actions (external non-determinism). In this standard, only the ability to model external non-determinism is required.

The concept of non-determinism is particularly important when modelling communicating systems, as those systems may be subject to environmental influences which cannot be predicted or controlled. Non-determinism may also result from model abstraction, where the modeller chooses not to commit to a specific behavioural aspect of the system.

A modelling notation should be capable of describing external non-determinism, i.e., enable the capability to model the possibility taking one of multiple system state transitions from a given state by allowing at least one of the following:

The definition of multiple state transition rules which are applicable to the same source state.

Supporting a non-deterministic choice statement which can send and receive from a port.

Supporting multiple threads of control in a program which can send and receive from a port.

Drawing of multiple arcs with the same trigger and different output actions from the same system state in a state machine diagram such as a UML statecharts [UML] or Harel statecharts [Harel]

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## Annex A Examples of modelling notation styles

This annex contains a short overview of some of the most common styles of modelling notations which satisfy the requirements specified in this standard.

### A.1 Rule-Based Notation

Rule-based notations are textual modelling notations where state transition rules describe the behaviour of the system. They are also referred to as extended finite state machines (EFSM) [EFSM], or abstract state machines (ASM) [ASM].

In a rule-based notation, the system's state is described by a set of state variables. A set of state transition rules is then provided in an operational style. Those transition rules consist of

- An action name with its parameters, which describes how the transition created by the rule is labelled when the rule fires.

- An enabling condition, which is a predicate over the state variables and action parameters, and describes in which state and with which action values the rule fires.

- A state update, which describes how the state variables are changed by the rule if it fires.

- Other information like references to informal requirements or timing constraints.

Rule-based notations usually have one distinguished initial state, which is given by an assignment to the state variables.

Non-determinism in rule-based notations can be easily expressed by enabling rules with different output actions in given states.

Rule-based modelling notations satisfy the requirements in this standard provided the underlying algorithmic support for data domains as is used in state variable and action parameter modelling is sufficiently supported.

Extended finite state machine are a variation of rule-based notations where the number of states and transitions is bounded. This is not a contradiction with this standard, as long as providing these bounds is methodologically part of slicing for test selection.

### A.2 Statechart Notation

Statecharts are a diagrammatic notation which exists in many variations in system modelling; they are, for example, part of UML [i.4]. Statecharts combine aspects of rule-based notations with graphical structure.

In general, a statechart is a diagram which contains nodes for states and directed arcs for state transitions. A statechart may be associated with a set of state variables. The arcs of the statechart usually contain the following information:

- An action name with its parameters, which describes how the transition created by the arc is labelled when it is taken.

- An enabling condition, which is a predicate over the state variables and action parameters, and describes in which state the arc can be taken.

- A state update, which describes how the state variables are changed if the arc is taken.

- Other information like references to informal requirements or timing constraints.

In addition to these basic elements, statecharts also support hierarchical grouping of states, as well as parallel composition of states. There are more constructs in statecharts which go beyond the scope of this standard.

Statechart based modelling notations satisfy the requirements in this standard provided the underlying algorithmic support for data domains as is used in state variable and action parameter modelling is sufficiently supported.

## A.3 Process-oriented notation



In process-oriented modelling, a system of components is specified by describing the activity of each component as an independent sequential process (or thread). The process is usually described using an imperative modelling or based on a programming language. Each process has its independent data state, comprised by a set of state variables. During its lifetime, the process actively listens to inputs from its environment and produces outputs, usually by using the concept of port or communication channels.

Timing constraints are described by programmatic delays and timeouts.



Process-oriented models satisfy the requirements in this standard provided the underlying algorithmic support is sufficient.

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## History

Document history		
0.0.1	May 2010	First draft
0.2.1	August 2010	Second draft
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