# Towards an Automated and Dynamically Adaptable Test System for Testing Healthcare Information Systems

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*Abstract*—Interoperability is one of the most important requirements for the next generation Healthcare Information Systems (HIS) that permits healthcare institutes to use heterogeneous solutions from different vendors. Introducing standards in eHealth domain, such as Health Level 7 (HL7) used for data representation, and Integrating Healthcare Enterprise (IHE) profiles for describing interactions between actors, is important to support interoperability of healthcare systems. This work addresses the challenges of interoperability testing of different HL7/IHE based HIS systems and introduces a testing methodology and its realization test framework based on TTCN-3 language.

*Keywords*-eHealth, HIS, HL7, Testing, TTCN-3

## I. MOTIVATION

As in many other domains, in the healthcare area, the *eHealth shift paradigm* [20] occured too, replacing the traditional paper based patient records with electronic based standardized data formats. Hence, the quality assurance became more challenging due to the complexity of the data records, products, processes, heterogeneous architectures, etc. We address this topic by developing a test methodology, including a test framework based on the standardized test technology TTCN-3 [2] to automate the testing process, for testing IHE [5]/HL7 [3] compliant systems in the healthcare area.

For system testing in healtcare domain, two aspects are especially important. Firstly, the test scenarios should be derived from real life usage scenarios. In this respect, we need to identify the most common scenarios in medical environments and, based on them, generate test drivers. Secondly, there is a need for reducing the test efforts especially when it comes to adapting the test configurations to selected test scenarios. The dynamic adaptation of test configurations is a great achievemnt to cope with various system setups (many actors, different protocols, various data formats) which are possible for the same IHE profile.

The feasability of the test methodology is evaluated in a case study from IHE Patient Care Device (PCD) [21] domain. Additionally, the investigated dynamic aspects of HIS test system and their realization within the TTCN-3

framework reduced the testing efforts and made the framework easily extendible to support further case studies.

## II. POSITIONING WITH RESPECT TO THE RELATED WORK

The major problem of Electronic Health Record (EHR) solutions, as stated in [10], is the lack of product interoperability. To address interoperability testing in a scientific way, the evaluation and selection of interoperability scenarios are necessary [11]. There is a wide range of standards concerning the integration and interoperability of medical applications to facilitate document exchangeability. HL7 messaging standard defines a common message structuring scheme for all messages used in medical systems. IHE introduces profiles enabling laboratories within healthcare institutions as well as standalone laboratories to share their patient data. These standards are the basis for the interoperability testing.

In our methodology the test system simulates the components that the SUT needs to interact with. This way, the interoperability is always tested against a reference implementation. This method states that the tested system can interoperate but it does not guarantee that. This method differs from previous approaches such as [12] and [13] where the input and output of EHR data are verified against standards and criteria identified by the Certification Commission for Healthcare Information Technology (CCHIT). However, we consider these approaches difficult to apply in the early stages of testing as they require complex setups and, especially, the presence of all interacting parties. Our method has the advantage that it can be used in the lab with no need for real components to interact with.

## III. MAIN ACHIEVEMENTS

The following problems and their solutions have already been investigated:

**Dynamic adaptation of the test configuration to a concrete HIS architecture**. Implementers of IHE standardized healthcare scenarios have a high degree of choice regarding the system configuration, with regard to the number of actors, interfaces, protocols, identifiers, etc., involved in an workflow. Therefore, the SUT architecture influences

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the design of the test system. It is very time consuming and effort demanding to adapt the test platform every time the system configuration changes. We worked on this problem by realizing a generic TTCN-3 framework [19], [22] whose adaptation layer is generic enough such that no manual changes are needed when the test configuration varies. This approach enables to generate automatically the test configurations from interaction scenarios described and adnotated in UML. The main benefit of this approach is that the adaptation layer does not require further changes and, consequently, the test scripts are ready to run against the SUT.

**Support for test data types from the HL7 messaging standard and IHE profiles**. There are many versions of HL7 data formats coexisting nowadays in healthcare information systems. To avoid incompatibilities between systems complying with different HL7 versions, IHE standardized various profiles that constrain the message structure irrespective of the HL7 version. To cope with both alternatives, a concept for mapping HL7 data types as well as IHE profile constraints to the test language has been introduced.

This concept has been realized in two steps. First, a generic mapping of the most used in practice HL7 version, v2.5, to a TTCN-3 type system has been defined. This type system allows testing for interoperability between HIS systems complying with this version. Second, to also support IHE profile constraints, a constrained TTCN-3 type system according to an IHE profile was derived out of the generic HL7/TTCN-3 type system.

**Enabling a test configuration to communicate to different SUT entities by using multiple protocols**. Many healthcare interaction scenarios allow interactions between the involved actors supporting many communication protocols and data format representation such as MLLP [4], SOAP and DICOM [6]. In practice, it is very useful that the tester focuses on the test logic while the communication layer between the test system (TS) and the system under test (SUT) is transparent. This need is addressed by a concept for test configuration design (components and test ports) that allows transparent switching of the adaptation layer according to the required communication protocol. Figure 1 illustrates this concept. Each TS actor is mappped to a PTC in the test configuration, for example, Actor1 translates into PTC1. In the example, the actors can communicate over two protocols.

**Generation of the test data out of existing databases collected from clinical and hospital environments**. The test system should make use of existent concrete data. Manually translating a data format in a target test language format is a very tedious task especially when data structure is very complex. HL7 defines very complex data structures. Hence an automation mechanism is required. But the work on such a generator from HL7 messages in test data instances requires different generation patterns from specific HL7
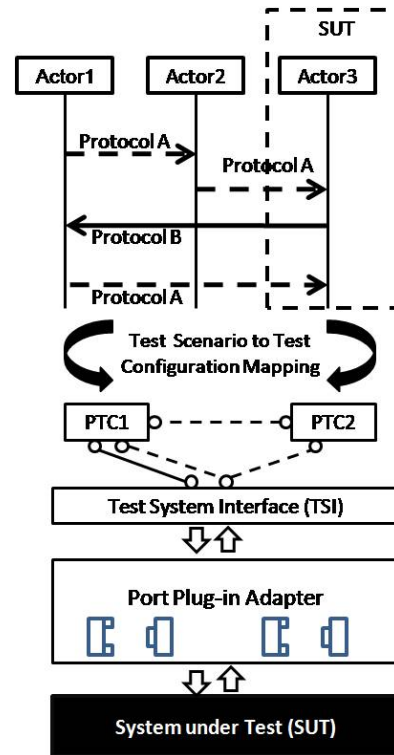


Figure 1.   Multi-Adaptation Layer

message databases to the target test language. To address this issue we proposed an architecture for a generic test data generator that makes use of a codec layer acting as a translator between the TS and the SUT. However, the problem of how to select the stimuli messages that assure a high coverage of the SUT interfaces remains still open.

**Dynamic identification of entities with a higher risk within an HL7 system and derivation of an efficient order of test cases such that faults with a higher impact on the system can be uncovered prior to other faults producing minor damages**. The risk is taken into consideration for test prioritization. The concept is to associate probabilities to the SUT entities or to the connectors between different SUT entities. We start with the identification of the SUT entities from an architectural level and the probabilities are obtained dynamically by computing complexity metrics from the SUT entity implementations. These metrics are then used to compute an heuristic risk factor [9] of a specific entity and its associated actions that a user or other adjacent components of the system can trigger. The prioritization of tests according to the risk factors is realized starting with a formal model of the system. On top of this model, a cumulated heuristic risk factor associated to a path in the graph of the system is computed. The last step is the derivation of ordered test sequences out of the paths indentified with a higher risk factor.
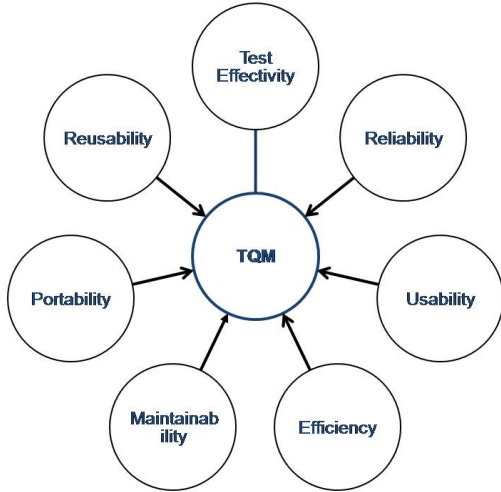
Figure 2.   Test Specification Quality Model

**Addressing the problem of assessing the quality of tests**. The size of the test specifications and the complexity level of test data increase with the complexity of the SUT interfaces and functionalities. Hence, it is difficult to evaluate and assess how good the tests are. To answer this question, we proposed a Test Quality Model (TQM) [14] (see Figure 2) derived from the standard ISO 9126 [7]. This model addresses the problematic of how the quality of a test specification can be approached. We achieved this by characterizing the test specifications by means of various test quality characteristics such as test effectivity, reliability, etc. Our focus was on the effectivity test characteristic and in particular on the fault-revealing capability subcharacteristic. To be able to assess the fault-revealing capability of a test specification we looked into test data stimuli set and we considered the test data variance metric [18]. Two methods [15], [16] of how this can be computed on TTCN-3 test suites have also been provided and implemented in a proof of concept tool.

A further aspect is to check the abstract test specification code for compliance with predefined guidelines. We selected a set of such rules and implemented a guideline checker for TTCN-3 test suites [17].

## IV. EVALUATION

The concepts and the implementation of the test framework have been been applied to the Patient Care Device (PCD) [21] IHE domain case study. For test specification and test execution, a commercial TTCN-3 IDE [8] has been used. The setup was realized within the context of the Test Automation for the Next Generation of Medical Systems (TestNGMed) [1] research project.

PCD standardises the communication scenarios and flows between medical devices directly connected to a monitored care unit (e.g., blood pressure sensors), and other units from the medical environment interested in receiving data from those medical devices.
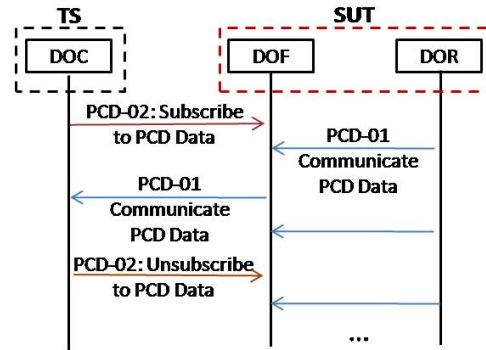


Figure 3.   A Scenario example from IHE PCD Domain

Figure 3 presents in a sequence diagram the PCD actors and the sequence of possible interactions between them. An instance of this diagram may involve an arbitrary number of actors. Multiple Device Observation Reporters (DOR) can be involved at the same time, while many Device Observation Consumers (DOC) may receive data in parallel. The Device Observation Filter (DOF) is responsible for handling all subscriptions and ensures that the DOCs receive the required data. The DOR has the role of monitoring medical devices from which data needs to be included into the system (ventilator, blood pressure sensor, etc.), and the role of converting that data into digital format, if necessary, acting as a data provider for the other actors of the PCD profile. The DOF is the entity responsible for handling a connection between a DOC of the medical data (laboratory, medical clinic, etc.) and the DOR, in charge of providing that data. The DOF manages subscriptions and offers to the DOC subscribers the possibility to receive a subset of the data stream, according to their needs and subscription predicates.

The actors communicate through transactions. PCD-02 is used by a DOC to subscribe/unsubscribe to a DOF for PCD data. The DOF receives the subscribe requests and sets the adequate filters. PCD-01 is used to communicate PCD data from a DOR to a DOC as filtered by DOF.

In our setup, the test system simulates the DOC component that in the real environments can be the medical clinic, the laboratory or any entity that requests data about patients. The test type specification only contains thousands of definitions spread over 10.000 TTCN-3 lines of code, it is extremely important to be consistent in writing TTCN-3 test definitions and in maintaining a clear test suite and module structure. To keep the test specifications consistent, readable, reusable and well structured, we developed and applied a set of guidelines for writing and structuring the TTCN-3 specifications.

The concepts presented in this paper were applied to the

PCD case study and their implementation integrated in the test framework. As result of the experiment, the test system proved its degree of automation with respect to type system derivation, generation of test configurations, handling of different protocols used in the communication transactions without any need for manual changes, only a minimal set of parameters need to be configured. Additionaly, it proves to be extendable as new IHE domains started to be regarded.

## V. CONCLUSIONS

Addressing the challenges of realizing an automated test system, this work contributes to the validation and further improvement of interoperability and conformance of HIS systems in the healthcare domain. It also opens the possibility to create reference tests which can be used for product validation and possible certification. The design of the test system allows for practicability, flexibility and extendability by dynamically adaptation to the test configuration changes. Finally, complementary aspects such as risk and test quality characteristics are explored.

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