MODEL BASED STANDARDS FOR DIAGNOSTIC AND MAINTENANCE INFORMATION INTEGRATION

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Abstract—There is no doubt that system complexity is increasing. There are a number of ramifications of this increase in complexity, besides higher performance. On one hand conventional means of testing are being overwhelmed by the complexity. On the other there are more sources of information about the system. System data is fragmented by time and discipline. Early design data is not available during the operational phase. Design data is often segregated from test data. Even within a particular discipline, e.g. diagnostics, data is fragmented. Few diagnostic reasoners can exchange data. One approach to dealing with the complexity issues is to integrate these sources of information into a single picture of the state of the system. This is the approach taken by the SCC20 Diagnostic and Maintenance Control (DMC) subcommittee. The DMC is developing a family of standards that are product information exchange standards for test, diagnosis, and maintenance. This paper describes the current efforts by the DMC to integrate data from a wide range of sources into a "picture" of the diagnostic and maintenance state of a system.

INTRODUCTION

The complexity and cost of current systems, the inability to consistently diagnose and isolate faults in systems using conventional means, and advances in information exchange technology have fostered the development of standardized technologies in test and diagnosis. Design goals of such technologies often include notions of software component interoperability. The associated proliferation of diagnostic reasoners and related software components and systems necessitates establishing standard interfaces to these tools as well as formal data specifications to capture relevant diagnostic and maintenance information and facilitate information exchange. Existing test standards provide little guidance for integrating diagnostic and maintenance information in test applications.

The Institute for Electrical and Electronics Engineers (IEEE) Standards Coordinating Committee 20 (SCC20) Diagnostic and Maintenance Control (DMC) subcommittee focuses on standards that specify:

- Standard interfaces between diagnostic reasoners
- Formal data specifications to support the exchange of information relevant to test, maintenance and diagnosis.
- Information required for management and maturation of test, diagnostic, and maintenance processes.

The Artificial Intelligence Exchange and Service Tie to All Test Environments (AI-ESTATE) subcommittee (later to be renamed the DMC) developed the original standards, the 1232 series, providing a means of exchanging information between diagnostic reasoners. The complete 1232 standard, which was published in November 2002 as a full-use standard, contains several diagnostic information models and formally defines a set of standard software services to be provided by a diagnostic reasoner in an open-architecture test environment. Recent advances in diagnostic technology have resulted in the need to examine these technologies for expanding current work in diagnostic standards. Specifically, the use of Bayesian networks for system diagnosis is becoming more common, thus warranting consideration of a Bayesian model within 1232. Diagnostic models utilizing formal logic are also becoming more prevalent in the industry, and this has provided an impetus for including models supporting logic-based reasoners. As the information models for the 1232 standards were developed, it became apparent that these models could be used for standardizing testability and diagnosability metrics as well as diagnostic and maintenance history information.

As part of the effort to standardize testability and diagnosability metrics the DMC also developed a new standard focusing on expanding the work of the cancelled testability standard, MIL-STD 2165. The approach taken to develop this replacement standard involved defining testability and diagnosability metrics based on standard information models. Specifically, it was found that the AI-ESTATE models provided an excellent foundation for defining these metrics. AI-ESTATE provides formal definitions of the same information required for determining the testability and diagnosability of a system. With these formal definitions, the constraint language of EXPRESS can be applied directly to define metrics and characteristics of testability and diagnosability. This standard was published in 2004 by the IEEE Standards Association as a “trial use” standard.

Currently the DMC is developing a new family of standards focusing on the management of test , diagnostic, and maintenance history information in support of diagnostic maturation—the IEEE P1636 Software Interface for Maintenance Information Collection and Analysis (SIMICA) [9]. Currently, SIMICA consists of a base standard defining and conceptual information architecture for diagnostic maturation and two “component” standards—IEEE P1636.1 Test Results [10] and IEEE P1636.2 Maintenance Action Information [11]. The Test Results standard is intended to provide ontological information about the test process and provides a framework for capturing specific measurements and outcomes of actual tests The Maintenance Action Information standard provides ontological structure for gathering information that is typically recorded by providers of maintenance services.

In the following, we will provide a detailed, technical update on the work of the DMC in developing and maintaining these standards. We will explain the role of information models/ontologies for specifying the domains of fault diagnosis and system maintenance, and we will illustrate how the information models are being used to specify the information interfaces for maintenance and diagnostic applications.

INFORMATION MODELS

The purpose of an information model is to identify clearly the objects in a domain of discourse (e.g., diagnostics) to enable precise and unambiguous communication about that domain. Such a model comprises objects or entities, relationships between those objects, and constraints on the objects and their relationships. When taken together, these elements of an information model provide a complete, unambiguous, formal representation of the domain of discourse. In other words, they provide a formal language for communicating about the subject of interest or domain.

In any information intensive activity, like Integrated Diagnostics [3], it is crucial that information requirements be derived from the objectives of the activity to ensure that the required information can be obtained and effectively utilized. In disciplined setting, the information engineering process would proceed by first defining objectives, specifying a process for achieving those objectives, deriving performance requirements from the process, determining and specifying the information required to meet those requirements, and building the information system needed to satisfy the information requirements. To accomplish this, one must begin with a formal understanding of the process to be supported as well as an in-depth understanding of the semantics of the information supporting the process. One approach to defining the semantics of information for a component of a larger system is through an “information model.” An information model is “a formal description of types (classes) of ideas, facts, and processes that together form a model of a portion of interest of the real world” [16].

Using information models, information exchange can be executed in two ways. The first is through a set of exchange files. Specifically, information can be stored by one party in a file and read by a second party. The file format is derived directly from the information model and defines the syntax of the message contained within it. The semantics of the message (i.e., the interpretation of the information contained within the file) is derived from the semantics of the model.

The second means of information exchange is through a set of services defined for a hardware or a software component as accessed via some communications infrastructure. The interface definition for the component is derived from the information model and, once again, defines the syntax of the message. As before the interpretation of the message is derived from the semantics of the model.

Three advantages to using standard information models to define the communications mechanism are evident. First, since standards are published documents, a large audience has access to the standard. By specifying standards in procurement documents or design documents, the designers know the basis for communication before detailed design begins.

Second, the contract defined by a standard has been validated and legitimized by the fact that a community of experts in the domain have gathered and agreed upon the content of the standard. Consequently, users of the standard can trust that a) the standard is technically correct, and b) the community of those using the standard believes the standard is useful.

Third, standards are typically endorsed and accredited by an independent accrediting body. Such endorsement certifies that the standard was developed according to an open process designed to keep the best interests of the community in mind. Examples of such accrediting bodies include IEEE, the American National Standards Institute (ANSI), the International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC).

The EXPRESS information modeling language, standardized by ISO, was designed for formally defining information models in support of communication [13]. EXPRESS is object-oriented in flavor but focuses on defining the semantics of the information that is modeled. In addition, rules have been defined for deriving exchange files and services for information exchange directly from the EXPRESS models. The information models in the DMC standards use EXPRESS.

STANDARDS PROCESS

The IEEE is a "consensus" standards development organization accredited by ANSI. Because of its ANSI accreditation, the IEEE is required to apply several "imperative principles" to ensure the standard has been developed by in an open manner. According to the IEEE Standards Association [12], these imperative principles can be summarized as follows:

1. Due process:
2. Consensus:
3. Openness:
4. Balance:
5. Right of Appeal:

Additional details on the standards process are available in the *IEEE Standards Companion* [12].

Given these principles, the IEEE develops standards through a formal process of document development, balloting, revision, and reaffirmation.

The standards being discussed in this paper are being developed and maintained by the Standards Coordinating Committee 20 (SCC20) on Test and Diagnosis for Electronic Systems. All standards projects must be sponsored before the IEEE will approve the PAR for the project, and only IEEE societies or SCCs can serve as sponsors. Typically, an SCC is formed when more than one society has an interest in the standard to be developed. SCC20 is co-sponsored by the Aerospace Electronic Systems Society, the Computer Society, and the Instrumentation and Measurement Society, all societies of the IEEE.

SCC20 is made up of four different working groups responsible for developing and maintaining standards. The Diagnostic and Maintenance Control subcommittee (DMC) focuses on standards for diagnostics and maintenance information, and is the focus of this paper. The Hardware Interfaces subcommittee (HI) is developing standards related to test architectures and interface devices. The Test and ATS Description subcommittee (TADS), historically, was responsible for the ATLAS language and is now focusing on standards for signal definition, test descriptions, and instrument descriptions. Finally, the Test Information Infrastructure subcommittee (TII) is the parent working group for the Automatic Test Markup Language (ATML) standards and focuses on an information framework for automatic test systems.

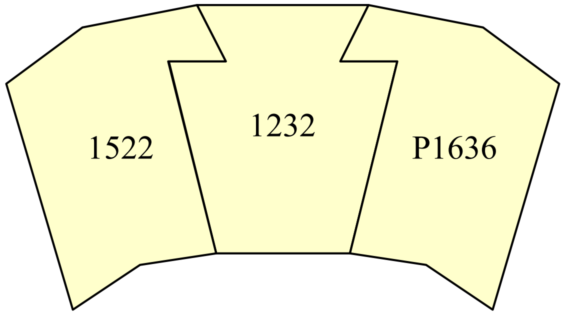

Figure 1. DMC Standards Family

DMC STANDARDS

As described above, several standards are currently being developed or maintained within the DMC. In this section, we provide a technical discussion of each of these standards. We conclude our discussion by explaining how the standards fit together into a cohesive family in support of maintenance and diagnostics.

IEEE 1232-2002 (AI-ESTATE)

IEEE 1232-2002 is the "keystone" standard of the DMC work. IEEE 1232 describes the information comprising the diagnostics domain, i.e., information related to system test and diagnosis (Figure 1). The description of the diagnostic domain enables the exchange of diagnostic information between applications. IEEE 1232 also supports modular diagnostic architectures and interoperability with other test-related software assets. The 1232 standard was developed using information modeling practices as described above, resulting in the definition of five models addressing static and dynamic aspects of the diagnostic domain. The AI-ESTATE information models are: the Common Element Model (CEM), the Bayesian Model (BM), the Fault Tree Model (FTM), the D-Matrix Inference Model (DIM), the Diagnostic Logic Model (DLM), and the Dynamic Context Model (DCM). This standard formally defines a set of standard software information services to be provided by a diagnostic reasoner in an open-architecture test environment. These five models and their associated services are used by the other standards in the DMC family.

Based on the formal information models, AI-ESTATE provides three different mechanisms for exchanging diagnostic information. The historical approach uses the STEP Physical File Format defined in [14]. This format specifies a simple ASCII, flat file utilizing tokens within an attribute-value structure and must be used in conjunction with the EXPRESS Schema. The DMC is also in the process of defining an XML schema consistent with the information model. Busch describes an approach to using XML, XSLTs, and Part 21 files to exchange data validated according to both the XML schema and the original information model [1].

Finally, in addition to the information models being developed, AI-ESTATE defines a set of software services to be used when integrating a diagnostic reasoner into a test system. The reasoner services are being specified using the Web Services Description Language (WSDL), arising mostly due to the increased emphasis on web services and XML for exchanging information.

Since its publication in 2002, the requirements for systems using AI-ESTATE have evolved and led to the need to revise the standard. A revision to AI-ESTATE is expected to be published in 2008. To summarize the key changes in the AI-ESTATE standard that will be reflected in this revision:

1. The information models have been revised to tighten semantic definitions and to correct errors in the 2002 standard.
2. A new information model supporting Bayesian diagnostics has been incorporated [17].
3. XML schemas are being defined to facilitate an alternative method in file exchange.
4. Service definitions are being re-defined to use WSDL and transaction processing [1].
5. The Diagnostic Inference Model has been revised to represent D-matrix based diagnostics in the DMatrix Inference Model.
6. The Enhanced Diagnostic Inference Model has been revised to represent general logic-based structures in the Diagnostic Logic Model.
7. The Dynamic Context Model has been simplified to emphasize the historical nature of the diagnostic information captured and to de-emphasize any suggestion that the model be used to track internal state of a reasoner.

IEEE Std 1522-2004. (Testability)

The purpose of IEEE 1522 Standard Testability and Diagnosability Characteristics and Metrics [8] is to provide formal, unambiguous definitions of testability and diagnosability metrics and characteristics. IEEE 1522 builds on the

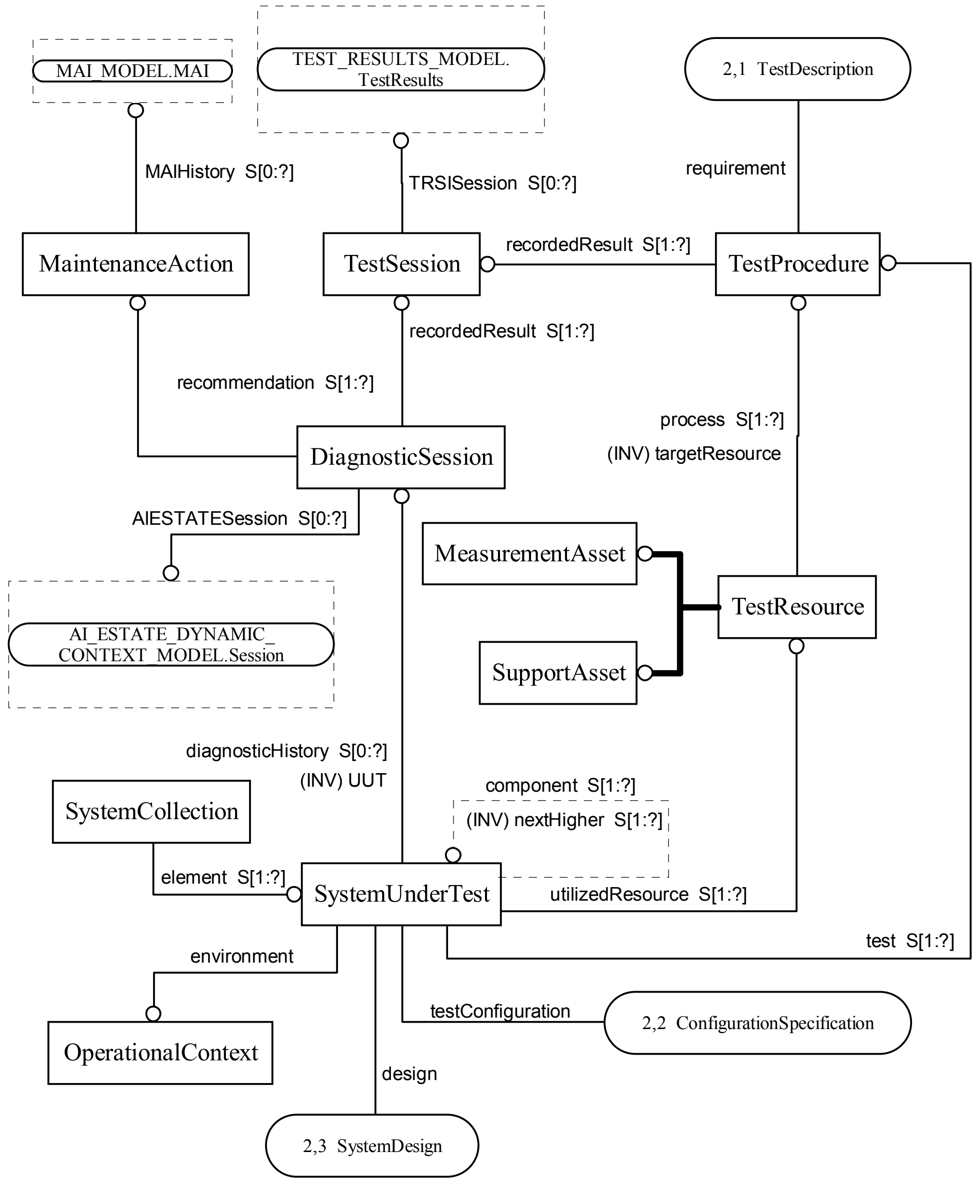

Figure 2. SIMICA Information Model (EXPRESS-G) [9]

fundamental definitions in standard information models related to test and diagnosis, drawing primarily from IEEE Std 1232.

The goals of the P1522 standard are to provide definitions of characteristics, metrics that are independent of specific test and diagnosis technologies and independent of specific system under test technologies; Another goal of IEEE 1522 is to assist procurement and support organizations in evaluating system testability and diagnosability. Because 1522 fundamentals are tied to definitions in standard models conceptual ambiguity is eliminated. 1522 metrics and characteristics are calculated from fundamentals derived from 1232 model entity definitions. Additionally 1522 allows for composition, extension, and expansion of the metrics and characteristics using the fundamentals. For example, 1232 provides the means to determine the total number of faults and the number of faults that are detectable. The EXPRESS within 1522 makes a query of the 1232 complaint reasoner and receives the total number of faults and the number to detectable faults. 1522 uses this information to calculate the percentage of faults detectable. Although many of the metrics in 1522 can stand alone, the maximum utility of the metrics is realized in conjunction with 1232, and calculation of metrics based on the formal information models of 1232 provides a pedigree that supports metric traceability.

In 2007. IEEE 1522 was "re-affirmed" by the DMC to elevate its status from a trial-use standard to a full-use standard. At the same time, the DMC has observed that the standard is currently not being used by its intended community. Conversations have begun with personnel in the US Department of Defense and the UK Ministry of Defense to determine if either department has interest or intent in using or specifying the standard. Since the DMC is entering a period where the standard will need to be revised and updated, the purpose of these conversations is to determine if there is a demand for the revision to occur and to determine how the revision may best support these agencies' efforts.

IEEE P1636 (SIMICA)

IEEE P1636 Software Interface for Maintenance Information Collection and Analysis (SIMICA) will be an information model that defines the information domain of system maintenance. SIMICA will support the capture of historical maintenance/diagnostic data, facilitate discovery/extraction of maintenance knowledge, and provide a foundation for diagnostic maturation. Like 1522, SIMICA also uses the models of 1232 to define maintenance related fundamentals.

Three standards are currently under development within the SIMICA framework:

1. IEEE P1636: A standard defining the conceptual information architecture necessary for diagnostic maturation and providing an overarching structure supporting the relationships across the P1636 component standards [9].
2. IEEE P1636.1: A standard for defining an XML schema to exchange historical test result information [10].
3. IEEE P1636.2: A standard for defining an XML schema to exchange maintenance action information, based on information contained in DoD-based "maintenance action forms" [11].

Each of the components includes an EXPRESS information model to define the semantics of the required concepts. At the same time each of the component standards are including XML schemata to make them compatible with other efforts sponsored by the DoD, such as the Automatic Test Markup Language (ATML) effort.

Perhaps the most significant element in SIMICA at this point is the conceptual information model being defined for P1636. This model is shown in Figure 2. Some of the key elements of this model identify essential relationships between various documentation or model sources within a system under test, placing the diagnostic session information at the conceptual center of the process for maturing diagnostic models. These sessions then provide entry points into test result data feeds and maintenance action information collected during the overall maintenance process. Details on how SIMICA is expected to function have been presented previously in [18].

DMC Standards and ATS Framework

Compared to many information-based standards, the approach taken to developing the standards with the DMC is unique. Drawing from a philosophical approach utilized by standards families such as Standards for the Exchange of Product model data (STEP)[1], the DMC standards begin with definitions of formal information models for the domain of diagnostics and maintenance. These models are designed specifically to support information exchange, either through flat file exchange or through software interfaces. Second, the standards are developed recognizing that, currently, the predominant approach to information integration and dissemination is through the use of web-based technologies. Thus, exchange formats based on XML and WSDL are emphasized. Finally, the standards are being developed with a look to how they can best fit in to the Department of Defense Automatic Test System (ATS) Framework [15]. The approach being taken is to identify components within the ATML architecture with requirements related to diagnostics (e.g., test results and diagnostic data) and specify the XML schemas to satisfy those requirements [4], [5].

[1] The STEP standards are based entirely on EXPRESS information models and specify the semantics for information to be exchanged in a product design and manufacturing environment.

SUMMARY

Current work within SCC20 is focusing on the next generation of automatic test for the military test community; however, the work of SCC20 has application in non-defense maintenance processes as well. Wherever maintenance information on a complex system passes between multiple organizations or involves multiple tools, that information must be handled in a standard way or the interoperating components may not function as intended with the result that maintenance effectiveness is lost. Therefore, the DMC standards have been designed to focus on both the structure and the semantics of the information to ensure the information can be exchanged and interpreted correctly.

Additional information on the DMC and its standards projects can be found at http://grouper.ieee.org/groups/scc20/dmc.

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