APAMI 2014 [Arden-Syntax-Based Clinical Decision Support]

Service-Oriented Fuzzy-Arden-Syntax-Based Clinical Decision Support

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Abstract

Objectives: To develop and bring into practice a scalable genuine technology platform for clinical decision support (CDS).
Methods: Arden Syntax is a widely recognized formal language for representing clinical and scientific knowledge in an executable format, maintained by Health Level Seven (HL7) International and approved by the American National Standards Institute (ANSI). Fuzzy set theory and logic permit the representation of knowledge and automated reasoning under linguistic and propositional uncertainty. These forms of uncertainty are a common feature of patients' medical data, the body of medical knowledge, deductive clinical reasoning, as well as practice and patient safety guidelines, health care quality, benchmarking, and reporting systems.
Results: A scalable production-ready software environment for authoring, testing, compiling, and processing clinical knowledge—defined by and written in Arden Syntax—was developed and implemented. Various forms of technical connection with, or integration into, external health information technology (IT) systems were added. This software is now in use at several production sites. Using the ANSI-audited, consensus-based standards development process of HL7, we created a new version of the Arden Syntax—version 2.9 (known as Fuzzy Arden Syntax)—to fully incorporate fuzzy methodologies.
Conclusion: By introducing service-oriented solutions for integrating and interconnecting Fuzzy-Arden-Syntax-based rule engine software into health IT systems, we put highly accepted scalable clinical decision support systems into practice.

Keywords: *Arden Syntax, fuzzy methodologies, clinical knowledge representation and processing, genuine technology platform, health IT integration*

Background

Arden Syntax is a medical knowledge representation and processing scheme for the development of clinical decision support (CDS) systems [1,2]. It originated in 1989 at a gathering of several medical informaticists from the USA, the Netherlands, and Sweden at the Arden Homestead Retreat in Orange County, NY (conference estates owned by the Columbia University). The intention was to write computer-based clinical reminders, diagnostic and therapeutic recommendations, and crucial alerts in a clear and human readable way and—one of the prime objectives—make them shareable with others.

The early versions of Arden Syntax were updated, extended, and then adopted by standards organizations. The American Society for Testing and Materials (ASTM) first approved the Arden Syntax as standard E-1460-92 in 1992. Ownership was transferred to Health Level Seven (HL7) and the American National Standards Institute (ANSI) in 1999, when version 2.0 of the standard was approved. The latest ANSI-certified release is Arden Syntax version 2.9, which was approved in March 2013 [3]. This version consists of a new Arden Syntax, completely extended by fuzzy methodologies, now known as Fuzzy Arden Syntax. However, HL7's Arden Syntax Work Group is preparing further improvements and extensions of this representation, also in association with HL7's Clinical Decision Support Work Group [4].

Methods

Arden Syntax is a formalism defining the arrangement of input data for processing, the condition and action parts of clinical rules to be written, and how and where to output the computed results. Medical logic modules (MLMs) are the basic representation and processing units in Arden Syntax. The syntax was designed such that each MLM may contain all knowledge for at least one decision. However, MLMs can call each other, be interconnected, even intertwined, and can thus form entire medical knowledge packages (MKPs) consisting of sets of MLMs [5].

To execute MLMs written in Arden Syntax, on arbitrary computers, one needs to write or develop in a programming language an interpreter or compiler for Arden Syntax, and an execution environment to have the MLMs being processed. In addition, an authoring tool containing an editor for writing MLMs—which possibly includes an execution engine for testing them before they become enacted—needs to be provided with such a suite of Arden Syntax software.

Following current software architectures and providing the Arden Syntax execution rule engine within a service-oriented architecture make it possible to offer interoperable CDS systems for a variety of tasks. These tasks have in common the fact that data sources such as clinical, laboratory, or intensive care information systems or the Web "itself" supply the data to be processed, and the MLM-processed results are returned to the connected information systems; alternatively, they are provided by separate web-based applications.

As mentioned earlier, this Arden Syntax [6] was thoroughly extended and enhanced by fuzzy methodologies [7]. Clinical linguistic uncertainty can now be modeled using fuzzy sets; propositional uncertainty can be introduced to model rule-associated truth values. The computed results are further propagated and possibly aggregated by fuzzy logic. This new version is referred to as Fuzzy Arden Syntax. An example of a fuzzy set defined to formally model the clinical concept of *increased C-reactive protein* is shown in Figure 1.

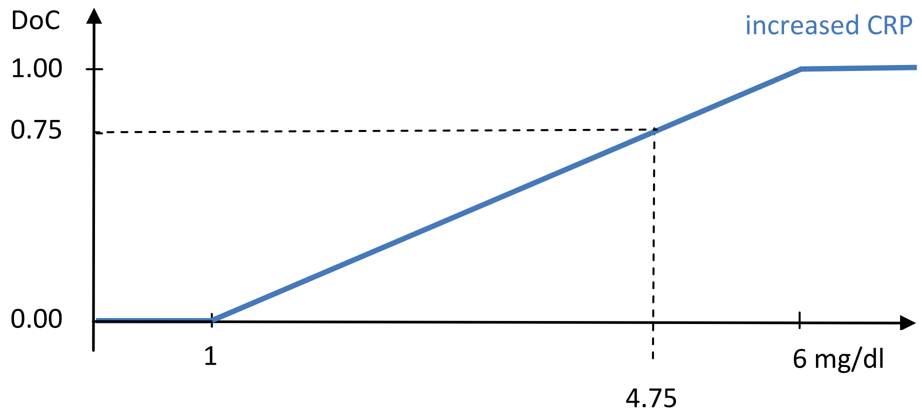

Fig. 1: Example of a fuzzy set definition. Increased C-reactive protein (CRP) is a label of a fuzzy set; it allows for the gradual transition from normal CRP levels (≤1 mg/dl) to definitely increased levels (≥6 mg/dl). DoC is the degree of compatibility *between a measured laboratory test result and the clinical concept under consideration.*

Results

Based on each of the approved Arden Syntax versions, authoring, testing, and processing software was developed, interfaced with or integrated into other health IT systems, and applied to a variety of small or large clinical CDS problems.

For this purpose, we developed an authoring and testing environment—including an Arden Syntax compiler—to write MLMs and compile and test them immediately. Based on the Arden Syntax rule engine, which executes the compiled MLMs, an Arden Syntax server is built around this engine to enable service-oriented access to and from arbitrary client applications. Additionally, the Arden Syntax server harbors compiled Arden Syntax MLMs and allow easy management of these MLMs, such as the activation or deactivation of MLMs in an application, or the management of different versions of MLMs.

To connect the server with host systems and data sources, three basic forms of technical integration into different health IT environments were established:

I. Web services for calling and data: Using the first form of integration, MLM and event calls are realized by SOAP or RESTful web services, with the respective service call also transferring the necessary data required for MLM processing. Examples are (a) the connection between the Arden Syntax server and Siemens' hospital information system i.s.h.med via SOAP web services [8], (b) the SOAP web service connection in a project for identifying adverse drug events [9], (c) the calling of and providing data for the iPhone and iPad App Hepaxpert via RESTful web services [10], and (d) a similar RESTful web service approach in a system to diagnose and treat Lyme borreliosis infection patients [11].

II. Web services for calling and server/database connector: The second form of interconnecting Arden Syntax software with external applications and patient data sources is to call MLMs and events through SOAP or RESTful web services, but to access patient data directly from data sources through a so-called server/database connector (being an add-on to the Arden Syntax server). The server connector can be used to query patient data through SOAP or RESTful web services offered by the host system to access its data; the database connector connects directly to a database to access data (e.g., SQL database). Examples are (a) the connection of the Arden Syntax server with the EPIC hospital information system, (b) with the VistA system by the Department of Veterans Affairs [12], and (c) accessing SQL databases through a database connector to obtain patient data from routine patient databases or from databases for research (and teaching). Figure 2 shows the overall architecture and interplay of this form of integration.

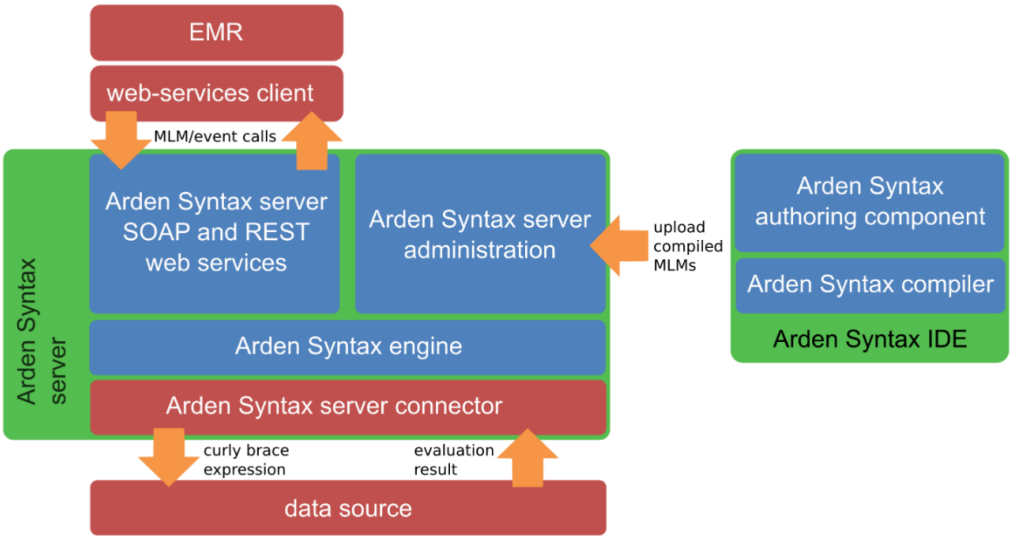

Fig. 2: Arden Syntax MLMs are written, compiled, tested, and then uploaded on the Arden Syntax server. In an application, MLMs are called by web services; the necessary medical data are accessed and transferred through a server or database connector. Note: EMR – electronic medical record; IDE – integrated development environment.

III. Data warehouse + rule engine = autonomous clinical decision support system: Here the Arden Syntax server—including its rule engine and database connector—accesses a project-specific data warehouse (which can be quite general and extensive). This data warehouse receives "raw" patient data through communication servers or import routines from any external data source (in HL7/XML/SQL or other formats). The received data triggers the rule engine (when appropriate), and the data warehouse makes data available for further processing in the Arden Syntax server. The data warehouse can, in turn, store the final or even intermediate results generated by rule processing. These results may subsequently be transferred back to the calling host application for presentation or—if the data warehouse is part of a separate solution—to the solution's presentation layer. The stored results may be used for reporting and benchmarking, or for data and knowledge mining. One example is the Moni system, which monitors and reports on hospital-acquired infections in intensive care units with adult and neonatal patients [13-16].

Discussion

Software for Arden Syntax was written, distributed, and has been incorporated into a number of hospitals and healthcare companies' information systems. It was implemented as a genuine technology platform for CDS and is equipped with service-oriented interoperability. This technical solution was shown to be deployable in connection with hospital and intensive care information systems, and proved useful in a number of clinical fields. Telemedical and mHealth systems also participate in this technological advance.

Conclusion

Thus, many forms of CDS in the diagnostic and therapeutic process are made possible: clinical reminders, alerts, recommendations, support for differential diagnosis, therapy selection, patient management according to guidelines and protocols, adverse event monitoring, health care quality, benchmarking, and reporting systems. Arden Syntax, or its extended form Fuzzy Arden Syntax, appears to be highly suitable for developing such clinically useful decision support systems.

Competing interests

Klaus-Peter Adlassnig is co-founder, CEO, and Scientific Head of Medexter Healthcare GmbH, Vienna, Austria. Medexter Healthcare GmbH has been established to develop and disseminate decision support systems with confirmed applicability in the clinical setting. Karsten Fehre is the project leader of the Arden Syntax software at this organization.

Acknowledgments

Our thanks are due to the members of HL7's Arden Syntax Work Group, who are committed to the ongoing development of Arden Syntax. We wish to acknowledge Andrea Rappelsberger for her excellent assistance in preparing this report.

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