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Standards-Based Interoperability for Clinical Decision Support Systems

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Abstract. This paper presents a narrative analysis of standards-based interoperability approaches in clinical decision support systems, focusing on the ArdenSuite platform. We examine how both semantic and technical interoperability challenges are addressed through its modular architecture and support for multiple healthcare standards including HL7's Arden Syntax, FHIR, openEHR, and CDS Hooks. The platform's implementation at University Hospital Vienna demonstrates practical applications in automated guideline processing and pandemic alert services. Our findings suggest that standards-based interoperability solutions can effectively bridge the gap between disparate healthcare systems while enabling sophisticated clinical decision support capabilities. The approach presented offers insights for addressing the growing challenge of healthcare system fragmentation in an increasingly digitalized medical landscape.

Keywords. Clinical Decision Support Systems, Health Level Seven (HL7), Arden Syntax, FHIR, CDS Hooks, openEHR, BPMN, PMML, ArdenSuite

1. Introduction

Computerized clinical decision support (CDS) systems are information systems employed to apply generalized medical knowledge to individual patients with the aim of improving healthcare delivery. Despite rapid development during the last decades, many commercially available CDS systems still suffer from interoperability issues [1].

The challenge of achieving interoperability in CDS stems not only from the variety of data standards used in contemporary electronic health records (EHRs), but also from differing standards for knowledge representation [1]—such as Health Level Seven International (HL7)'s Arden Syntax [2, 3] and Clinical Quality Language (CQL) [3]. In this paper, we present the approach chosen by Medexter Healthcare to strive for widespread interoperability in their ArdenSuite CDS platform [4].

The European Interoperability Framework (EIF) highlights the critical role of interoperability in the ongoing process of digital transformation and divides it into four layers: legal, organizational, semantic and technical [5]. While legal and organizational

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interoperability mainly concern policymakers and organizational managers, the field of medical informatics deals with the lower levels of semantic and technical interoperability.

Technical interoperability pertains to the applications and infrastructures linking systems and services, while the goal of semantic interoperability is to ensure the format and meaning of data is preserved and understood throughout exchanges [5].

2. Methods

Our narrative analysis employed a thematic framework to examine the interoperability approaches within ArdenSuite, one of the leading clinical practice guideline-derived CDS systems according to a recent study [6]. It was chosen due to the comprehensive knowledge of the implementation process by Medexter Healthcare's engineers.

We conducted manual thematic coding, focusing on the interoperability layers and standards utilized. Identified themes were refined through an iterative review process and validated with expert input. To ensure rigor, we triangulated findings by cross-referencing data from peer-reviewed articles, official healthcare standards documentation, and practical use cases of ArdenSuite's deployment.

This approach not only provided a comprehensive understanding of current challenges but also revealed insights for advancing CDS system interoperability.

3. Results

ArdenSuite [4] is an extensible CDS platform, whose architecture is based on the dependency inversion principle of object-oriented design [7]. This allows the platform's high-level components, such as the core, to interact seamlessly with diverse data sources without being tightly coupled to specific implementations, leading to the highly extensible modular architecture of ArdenSuite, as depicted in Figure 1 and elaborated in the subsequent sections.

3.1. Core

The central component of the ArdenSuite CDS platform is the core, which serves as the engine responsible for storing and executing medical logic. Since ArdenSuite is built upon HL7's Arden Syntax, executable clinical knowledge is stored in the form of medical logic modules (MLMs): self-contained files, each responsible for a single calculation or medical decision [2].

With CQL, there exists another formalism by HL7 for the representation of clinical knowledge. While there is significant overlap in the capabilities of both standards, Arden Syntax is ultimately used for its higher versatility in complex CDS systems. We came to this conclusion, since it natively supports event triggering, iteration statements, and fuzzy sets as first-class citizens [3] while its main shortcoming compared to CQL—native support for data models—has been addressed in version 3 of Arden Syntax, now incorporating HL7 Fast Healthcare Interoperability Resources (FHIR) as standard data model [8, 9].

3.2. Communication

While the core comprises the heart of ArdenSuite, executable medical knowledge on its own is not yet CDS. To support clinical decisions, individual patients' data have to be communicated to the core while the results ought to be communicated back to the user to be displayed and eventually acted upon.

The simplest means of accessing external data from within an MLM is provided by ArdenSuite's Database Connector [4], allowing for connection of databases which can then be queried within MLMs using Structured Query Language (SQL). A similar way of accessing external data via specialized connectors is provided for openEHR- [10] and FHIR-based EHR systems. All three custom connectors follow the REST architectural style and allow for reading input data as well as writing results to the connected systems.

While interoperability is important for CDS to retrieve data for medical decisions to be based upon, another use case is the sharing of clinical knowledge itself. Arden Syntax MLMs strive to be as sharable as possible on their own [2]. This is enhanced by the specification of an XML-based markup language, ArdenML [8], which is fully supported by ArdenSuite. Furthermore, predictive models such as decision trees can be transformed into MLMs via a PMML extension [11].

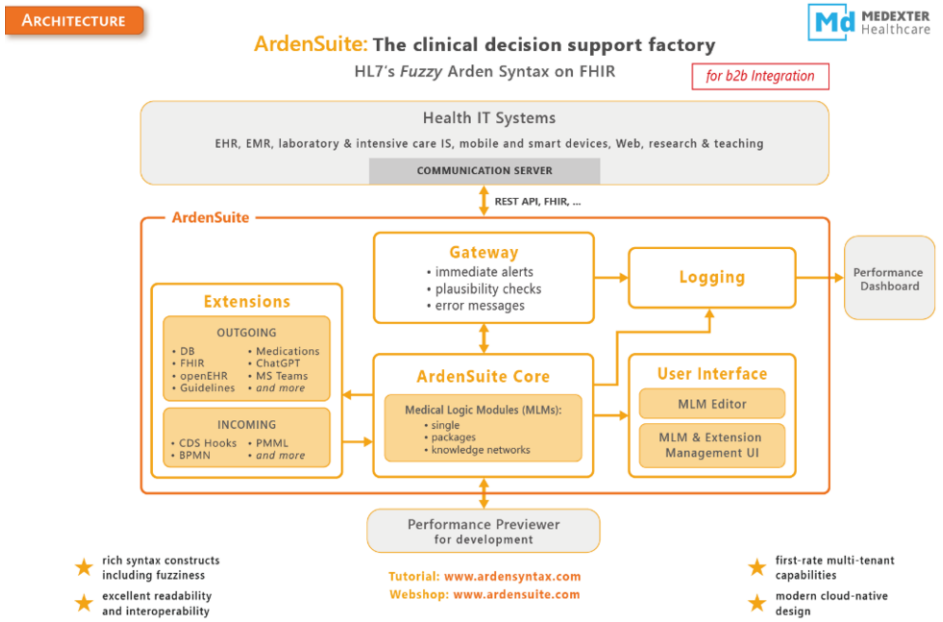

Figure 1. Architectural design of Medexter Healthcare's ArdenSuite clinical decision support platform [4].

3.3. Data Representation

The means of communication is an important part of interoperability—namely the technical layer—another important aspect is the way data are represented: the semantic layer of interoperability.

In order to allow seamless integration with EHR-based hospital information systems, ArdenSuite includes connectors for two of the most wide-spread data standards in

healthcare: openEHR and FHIR. While the openEHR connector had to be developed specifically for this purpose [10], the new version 3.0 of Arden Syntax [8] used in an upcoming version of ArdenSuite includes FHIR as standard data model [9]. This allows for native support of the FHIR Resources *Patient*, *Observation*, *Condition*, and *Encounter*, facilitating vendor-agnostic FHIR queries directly within each MLM.

3.4. External Events

Alerts are one of the most widely used type of CDS [1]. To allow for timely alerting of clinically relevant situations, execution of medical logic has to be triggered by external factors. The principal ability to handle external triggers is one of the key points distinguishing Arden Syntax from CQL [3]. ArdenSuite further enables EHR integration by supporting HL7's CDS Hooks [12] application programming interface (API) as a standardized means of evoking MLMs.

Another out-of-the-box feature of ArdenSuite is its Activiti Extension, allowing the Business Process Model and Notation (BPMN) 2.0 engine Activiti [13] to call MLMs. However, ArdenSuite's modular structure and adherence to industry standards like REST (cf. Figure 1) facilitate triggering of MLM execution by any platform such as Apache Kafka.

3.5. Summary and Practical Examples

The modular, standards-based architecture of ArdenSuite has enabled numerous extensions [10–13]. Together, these extensions enable ArdenSuite to act as a versatile CDS platform with practical utility in the clinical practice of an Austrian tertiary hospital, University Hospital Vienna (UHV). For example, the platform allows for automated processing of clinical guidelines [14] and serves as the foundation of an alert service for potentially pandemic-causing viruses [15]. Another feasible application leveraging the interoperability of ArdenSuite is the prototype of a Health Digital Twin presented in [16].

4. Discussion

Computerized CDS systems have played a crucial part in shaping contemporary healthcare delivery, and trends such as ageing populations as well as the unwavering process of digital transformation leading to ever-increasing amounts of health data stored in EHRs will in all likelihood lead to further increasing adoption around the world [1].

While opening up new possibilities in big data analytics, this rapidly evolving dynamic entails the risk of creating a fragmented landscape of so-called digital silos [5], i.e.,—in the extreme case—a variety of standalone applications which are unable to interact with each other. Hence, it is paramount to strive for maximum interoperability in healthcare to harness the potential of big data to revolutionize healthcare delivery and personalized medicine [17].

Through the example of ArdenSuite, we have demonstrated how a modular, standards-based architecture can integrate multiple healthcare data standards and communication protocols while maintaining the flexibility needed in modern healthcare environments. The platform's successful deployment at UHV validates the practical utility of this approach, particularly in critical applications such as automated guideline processing and pandemic surveillance.

5. Conclusions

Standards-based interoperability is essential to overcoming fragmentation in healthcare systems. ArdenSuite's modular architecture allows the platform to be adapted to emerging health care standards with ease, enabling seamless data sharing. Its deployment at UHV showcases the practical benefits of such solutions.

To advance interoperability in CDS, key priorities include continuously expanding support for emerging standards while ensuring backward compatibility, fostering collaborative standardization efforts, and promoting real-world implementations. These steps will drive broader adoption of interoperable systems, enabling better data sharing, personalized care, and robust healthcare delivery in an increasingly digitized society.

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