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Commentary

Clinical decision support: Converging toward an integrated architecture

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1. Introduction

Multiple national initiatives [1], focus on cost cutting [2] and medical error reduction [3], and the need for healthcare quality improvement have given rise to the concept of Clinical Decision Support (CDS). The notion of CDS goes back to a concept called "medical data processing" in the 1960s [4], which for the first time entertained the idea that medical data processing by computers could make the physician's job easier. In order to utilize a computer program, the physician must learn how to communicate with it and how to correctly evaluate the information obtained from it. The medical data processing concept morphed into a concept called Clinical Medical Librarian (CML) in 1977 [5]. The objective of CML was to develop a librarian, called the informationist librarian [6], which acts as a clinical decision support consultant for patient care, identifying and addressing complex evidentiary needs of a clinical team. The CML services [7] were offered to provide information quickly to the physicians and other members of the healthcare team; to influence the information-seeking behavior of the clinicians; and to establish a special role of librarian in the clinical team. Guise et al. [6] point out that the current emphasis on cost-effective and high-quality care, with a strong focus on applying evidence-based guidance to decrease medical errors, has resulted in amplified interest in and demand for expert support to clinicians. Garg et al. ([2], p. 1223) found that "clinical decision support system improved practitioner performance in 62 (64%) of the 97 studies assessing this outcome, including 4 (40%) of 10 diagnostic systems, 16 (76%) of 21 reminder systems, 23 (62%) of 37 disease management systems, and 19 (66%) of 29 drug-dosing or prescribing systems".

Our analysis of review papers on clinical decision support, published over the last 20 years [8–15], reveals two things. First, there are too many definitions of CDS. Our review suggests that the literature has not provided a clear definition of CDS; rather, CDS has been defined in myriad ways [13,14]. For example, CDS has been defined as an Artificial Intelligence tool, an information retrieval mechanism, and a component of an Electronic Health Record (EHR) system. Second, there seems to be too many architectural frameworks in CDS. The issue is whether all these architectures are necessary, or whether they are converging toward a common, integrated architecture.

In this commentary, we present arguments in support of the architecture integration proposition. We emphasize that CDS borrows ideas and concepts from different fields, such as knowledge management; decision support systems (DSS); data warehousing and analytics; and Electronic Health Record (EHR) systems. We used extensive internet and library searches to collect journal articles on CDS going back to 1960s. CDS application information was collected from hospital web sites. EHR information was collected from vendor web sites, from our discussions with the vendor representatives, attending demonstrations of their EHR tools, and finally trying out several of them. Two of the authors acted as reviewers and analyzed articles in full text along with EHR tools and vendor web sites. The other authors evaluated the reviews to make sure that the articles are correctly represented in the paper. Such an exercise provided us with the information needed to evaluate the relevance of retrieved articles, and understand their main findings.

In Section 2, we review the CDS literature to identify the different CDS definitions. We argue that like DSS in Information Systems area, CDS evolution is dictated by the underlying tools and clinical decision support needs. In Section 3, we contend that the CDS architectural frameworks are converging toward integration by focusing on a representative sample of CDS architectures. We also argue that we need three essential components – information management, data analytics and knowledge management – for such an integrated architecture. In Section 4, we argue that an integrated architecture would provide an implementation mechanism to respond to the ten grand challenges posed in [13,14]. We conclude this commentary by summarizing our findings and outlining future directions in Section 5.

2. CDS definition: A moving target?

Ledley and Lusted [4] first introduced the notion of decision support in medical data processing:

> Medical data processing could aid certain aspects of medical diagnosis. The foundation of such effort rests on its use of AI

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tools with logical analysis on symptoms, or by using fast information retrieval of records for the biochemical and physiological indices or using statistical modeling techniques.

Johnston et al. [8] studied 793 citations from MEDLAR, EMBASE, SCISEARCH, and INSPEC databases in the period between 1974 and 1994, along with 28 controlled trials, and defined CDS as software that uses a knowledge base designed for use by a clinician involved in patient care as a direct aid to clinical decision making. Hunt et al. [9] used MEDLINE, EMBASE, INSPEC, SCISEARCH, and the Cochrane Library bibliographic databases from 1992 to March 1998 along with 68 controlled trials. They found that CDS could enhance clinical performance for drug dosing, preventive care, and other aspects of medical care. However, they did not find any convincing evidence for use of CDS in helping diagnosis. Hence, they defined CDS as a computer-based decision support system that could synthesize and integrate patient-specific information, perform complex evaluations, and present the results to clinicians in a timely fashion.

Osheroff et al. [17], on the other hand, defined CDS as a collection of support methods: documentation forms/templates, relevant data display, order creation facilitators, time-based checking and protocol/pathway support, reference information and guidance, and finally, reactive alerts and reminders. Garg et al. [2] examined MEDLINE, EMBASE, Evidence-Based Reviews databases (Cochrane Database of Systematic Reviews, ACP Journal Club, Database of Abstracts of Reviews of Effects, and Cochrane Central Register of Controlled Trials), and Inspec bibliographic databases from 1998 through September 2004. They defined CDS as an information system designed to improve clinical decision making, where characteristics of individual patients are matched to a computerized knowledge base, and software algorithms generate patient specific recommendations. Computer-generated recommendations are delivered to the clinician through electronic medical record, by pager, or through printouts placed in a patient's paper chart.

Chaudhry et al. [10] connected decision support with computerized reminders. They observed that the decision support functions were usually embedded in electronic health record systems frequently used in the outpatient setting or in computerized provider order-entry systems more often assessed in the inpatient setting. They looked at MEDLINE (1995 to 2004), Cochrane Central Register of Controlled Trials, the Cochrane Database of Abstracts of Reviews of Effects, and the Periodical Abstracts Database. They hand-searched personal libraries kept by content experts and project staff; and mined bibliographies of articles and systematic reviews for citations.

Berlin et al. [11] studied 58 randomized controlled trials from PubMed and the Cochrane Library from 1998 to 2003. They found that CDS systems can be decomposed into two groups: patient-directed systems and inpatient systems. A patient-directed system provides decision support for preventive care and health-related behaviors, while an inpatient system targets clinicians to provide online decision support and execution of recommendations. They define CDS as an information system that has a collection of features such as context, knowledge and data source, decision support, information delivery and workflow.

Following the style of creating taxonomy of features, Wright et al. [12] have described CDS as a collection of its decision support functionalities. They argue that the decision support features can be grouped into four categories: triggers, input data, interventions, and offered choices. Triggers are events that cause a decision support rule to be invoked. Input data are the data elements used by a decision support rule to make inferences. Interventions are possible actions that a decision support module can take, and offered choices are the choices that a clinician might have.

The definition of CDS, as is evident from above, has evolved from "medical data processing" to a collection of "decision support functionalities" that can be housed in any health care information system. However, we need to understand the reasons for the many changes in the definition of CDS. Note that the definition for decision support systems (DSSs) has also undergone several such changes, according to the information systems literature. We believe that the cause for the changes in the DSS definition is the evolution of the underlying tools. We support our argument by first describing a representative sample of DSS definitions from the literature.

The term "decision support system" was first introduced by Gorry and Scott Morton [18] 40 years ago. According to them, a DSS is a system that supports users/managers in unstructured decision-making situations. In their overview of the first DSS conference, Carlson and Scott Morton [19] state:

> The use of the term "decision support system" is relatively new and means different things to different people. For the purpose of this conference, it meant the flexible support of decision makers with computer-based information. In particular, we were interested in systems which provided useful support for problems with a lack of predefined structure. For all practical purposes, this type of computer support has not been available in the past (p. 2, [19]).

Keen and Scott Morton [20] extended the notion of generic operations and emphasized a need for the building blocks in a DSS. In their words:

> A DSS can be assembled selectively, drawing on those building blocks that offer the best combination of power, cost, turnaround time and suitability to the problem statement (p.13, [20]).

Several suggestions for these building blocks can be seen in the information systems literature. Haseman [19] and Donovan and Madnick [19] offered architectures, where the use of database management with analytical capabilities was shown to be useful for DSS. The idea of graphics as a component of DSS was introduced by Carlson and Sutton [21] in their GADS (Geodata Analysis and Display System) project. They argued that since decision makers have trouble describing a decision process, a DSS should use familiar representations to assist conceptualizations. Bonczek, Holsapple and Whinston [22] defined DSS as a collection of three interacting components: a language system to communicate between users and other components of DSS; a knowledge system acting as a repository of problem domain knowledge; and a problem-processing system linking the above two components with general problem manipulation capabilities required for decision support. Intelligent DSS [23] also employed artificial intelligence (AI) techniques to extend its capabilities to include knowledge system and problem processing system [22]. El-Najdawi and Stylianou [23] argued that an integration of the underlying tools is essential for an effective DSS.

Using a time line, we divide the history of DSS into seven eras: pre-Sixties, the Sixties, the Seventies, the Eighties, the Nineties, the 2000s and the 2010s (Fig. 1). The shaded boxes in brown depict important events in the DSS area. The shaded boxes in pink show its underlying tools, ranging from language development, modeling, database, web design to artificial intelligence. In the interest of space, we focus only on events that are relevant to our argument.

Even though DSS originated in the computer-aided models of pre-sixties needed for decision making and planning, much of the DSS activities were pushed by tool innovations in languages, data base systems, expert systems, statistical packages, web development, enterprise integration, etc. The concepts of data warehouses, online analytical processing (OLAP), and business