Chapter 5
Newer Architectures for Clinical Decision Support

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Abstract In recent years, the general IT community has been moving from a monolithic-type of software architecture to a service-oriented architecture that involves developing systems using independent, well-defined software services that are then coordinated to meet business needs. The main benefit of a service-oriented architecture is the ability to more easily and more rapidly implement needed business capabilities using independent software services. While lagging behind many industries, the healthcare industry has been moving towards a service-oriented architecture, including in the space of clinical decision support. In this chapter, we describe notable efforts in service-oriented clinical decision support and speculate on its potential evolution in the future.

Keywords Clinical decision support systems • Service oriented architecture • Software architecture • Service-oriented design • Service oriented computing • Medical information systems

Clinical decision support Systems (CDSS) were originally based on a stand-alone architecture, in which the system was fully self-contained and required direct user input for obtaining data. A number of early CDSS were built using this architectural style, for example MYCIN (1975). MYCIN provided advice on antimicrobial therapy for patients with bacterial infections after the physician answered a set of yes-no questions [1]. Similarly, the INTERNIST-I (1982) [2] and DXplain (1987) [3] systems accepted a wide variety of patient findings (e.g., history, physical, laboratory data) as the input and returned a ranked list of possible diagnoses, also known as a differential diagnosis. DXplain is still available and is in continuous development [4]. Although this approach provides a straight-forward mechanism for obtaining the required CDS functionality, it relies on manual entry of the input data to obtain the desired results. Using these systems can therefore be time consuming. For example, entering the relevant data for a complex patient case in the INTERNIST-I system can take about an hour [5].

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As electronic health record (EHR) systems matured, CDS capabilities began to be integrated with EHR systems and other health information technology (IT) systems. This was typically done in a system-specific manner. One of the first integrations between clinical data and CDS capabilities was implemented in 1967 at the LDS Hospital in Salt Lake City, Utah. This EHR system was named HELP, and it was first introduced in the cardiac catheterization laboratory. Since then, the HELP system has been extended to various other clinical areas such as respiratory therapy, intensive care, and pharmacy, to name a few [6]. Subsequently, other similar integrated CDS systems have been developed by different research groups and hospitals [7, 8]. Chapters 13, 14, and 15 describe the HELP system and some of the other systems. However, it soon became clear that a major challenge with these integrated CDS solutions was the difficulty of sharing CDS content developed for one EHR system with another EHR system.

Over the years, as the evidence of CDS effectiveness and the scope of CDS implementations increased, there was a desire to scale CDS across systems and institutions. However, stand-alone CDS architectures were limited by their need for extensive manual data entry, and integrated CDS architectures were limited in their ability to be scaled. At the same time, there was a growing trend in the general IT industry to move towards software architectures that allowed for more reusable components that could be scaled across institutions. In particular, of these so-called component-based architectures, service-oriented architectures (SOA) quickly became predominant. The CDS space has also started to adopt this approach. In this chapter, we aim to address some of the fundamental questions related to the use of Service Oriented Architecture for CDSS, namely:

- What is a service-oriented architecture?
- Is SOA a preferred architecture for enabling scalable CDSS?
- What are notable efforts in the space of service-oriented CDS?

5.1 Service-Oriented Architecture: Definition, Benefits, Challenges, History

Before SOA became the preferred approach for the design, development and integration of distributed systems, most distributed software solutions were based on Remote Procedure Calls (RPC). The most important RPC models were the Common Object Request Broker Architecture (CORBA) and the Distributed Computing Object Model (DCOM). For various reasons, the use of CORBA and DCOM over the Internet proved to be problematic, and none of these technologies took control of the market. With the widespread adoption of the Internet and more specifically the use of the Hypertext Transfer Protocol (HTTP), the notion of SOA started to materialize. In the field of software architecture, the concept of SOA can be defined as a "paradigm for organizing and utilizing distributed capabilities that may be under control of different ownership domains" [9]. The needs of a distributed

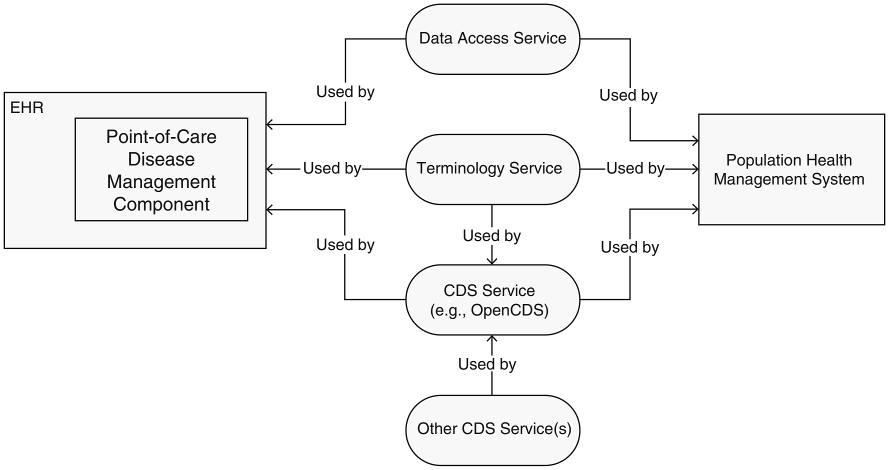

Fig. 5.1 Sample CDS system architecture [10]

computer program may be met by the capabilities of another program that is maintained by a different owner. These needs may be satisfied by combining multiple capabilities, and these capabilities may be designed to address various needs. In the context of SOA, services are the "mechanism by which needs and capabilities are brought together" [9]. The access to these capabilities is provided through well-defined services interfaces. While not required, SOA is commonly implemented using Web services that are accessible over the Internet.

An important feature of SOA is that distributed capabilities can be used without having to know the implementation details. For example, a CDSS that exposes its functionality through a Web service can be used without the client system having to know which technology or platform is being used to implement the service. Figure 5.1 provides an overview of an example SOA-based CDS environment [10]. In this example, a CDS service is used by the point-of-care disease management component of an EHR system and by a population health management system. Figure 5.1 also shows other services that facilitate CDS [10]. A data service that retrieves relevant clinical information from different databases, and other CDS services, such as commercial medication CDS services, are leveraged by the primary CDS service. A terminology service is also leveraged to map between vocabularies. For example, an EHR system may define patient problems in terms of ICD-10 [11] whereas a CDS system may only accept concepts in terms of ICD-9 [11] and SNOMED-CT [12]. In this case, a terminology service can be used by the CDS service to translate the EHR system's problem concepts from ICD-9 to SNOMED-CT to allow for processing.

SOA is well-suited for the development of low cost, large scale systems, as it allows various business functionalities to be implemented and maintained independently in a distributed manner. Additionally, SOA supports software component reusability, scalability and interoperability. Complex applications can be implemented by assembling reusable, self-contained units of functionality, thereby reducing the time and resources required for implementation. Applications scale as the computing infrastructure (e.g., Amazon Elastic Compute Cloud [13]) is grown or reduced according to the service demand. Usually, SOA applications are based on Web service standards (e.g., SOAP and REST), thereby enabling greater interoperability with other systems that use these standards.

SOA can present several challenges, however, with common challenges including security and service discovery [14]. Validating the security of a SOA-based system can be challenging due of the multi-tenant and distributed nature of its components. Discovering services that meet the requirements of the service consumer may also be challenging if there is limited support for the automatic discovery of service semantics.

A number of the key concepts of SOA are exercised at the Service Composition level, namely choreography and orchestration. In service choreography, each participating service defines its part in the interaction, with the details typically described using choreography languages such as the Web Services Choreography Description Language (WS-CDL). In service orchestration, the logic is defined by a single participant, which is referred to as the orchestrator. Service orchestration resembles a process (i.e., sequence of tasks), and it is commonly achieved through the use of process execution languages such as Business Process Management and Notation (BPMN) and Business Process Execution Language (BPEL). Both approaches can have associated challenges. For example, in service orchestration, all data passes through a centralized point (i.e., the orchestrator), which may result in unnecessary data transfer and the orchestrator becoming a bottleneck. On the other hand, choreography models can be harder to design and implement than orchestration models. The decentralized control logic in choreography can bring significant challenges resulting from issues such as control-flow (e.g., which interaction comes after another), time constraints, and asynchronous and concurrent interactions. In service choreography, it is necessary to design an agreement between a set of services in order to define roles and how the collaboration should take place while maintaining SOA principles including service reusability.

5.2 Benefits and Challenges of SOA for Health IT Systems in General and CDSS in Particular

The U.S. Department of Health and Human Services' (HHS) Office of the National Coordinator for Health IT (ONC) defines health IT (HIT) as "the application of information processing involving both computer hardware and software that deals with the storage, retrieval, sharing, and use of health care information, data, and knowledge for communication and decision making" [15]. Using the ONC definition, a variety of applications can be considered health IT including electronic health records, picture archiving and communication systems (PACS), laboratory information systems (LIS) as well as CDS systems [15].

Because healthcare delivery is often fragmented across systems and providers, SOA has been proposed as a promising solution for the integration of healthcare related data across these various types of health IT systems. The decomposition of functionalities or capabilities into relatively autonomous units (i.e., services) simplifies the design and implementation of software solutions to complex problems in health care. SOA supports the strategic reuse of legacy applications, while allowing adoption of new technologies. This enables healthcare organizations to adapt more quickly to the complexity and constant evolution of medical knowledge and health care. Healthcare organizations are also subject to regulations and supervision by authorities and government agencies. In combination with other technologies such as Business Process Management and Business Rules, SOA can enable the implementation of audit controls that allow healthcare organizations to demonstrate that their processes comply with regulations.

For the reasons mentioned above, SOA promises a significant reduction in the cost and time required for HIT implementation and maintenance. These advantages have been identified by governments and organizations worldwide, which strongly promote the adoption of SOA-based health care systems. For example, Canada Health Infoway, a non-profit organization funded by the Canadian government, defines an HIT implementation model based on SOA [16]. The Infoway model connects provincial networks of health care systems to form a national network where electronic health care records can be accessed from different places. Another important initiative is the Healthcare Services Specification Project (HSSP), which is a collaborative effort between Health Level 7 (HL7) and the Object Management Group (OMG). The HSSP focuses on the specification of HIT service standards based on SOA principles [17].

Because health data relevant for CDS may exist in multiple physical locations, SOA can serve as a useful architectural approach for integrating disparate data sources. Additionally, SOA can enable CDSS to be implemented through the assembly of various services providing required functionality, such as for data retrieval, terminology mapping, and patient data evaluation. For example, a SOA can be used to provide personalized care recommendations that combine whole genome sequence information with clinical data and a centralized knowledge repository [18].

Despite the potential benefits of using the SOA paradigm to implement CDS capabilities, Kawamoto et al. describe several challenges to the adoption of this approach to enabling CDS [10]. One of the important challenges they identify is that developing and maintaining generalized CDS services that can be used by multiple applications require considerably more effort than doing so for similar CDS services designed for specific systems [10]. There is also a need for CDS interfaces to be standardized in order to facilitate and encourage component reuse, and the CDS content may need to be customized to meet the unique needs of individual client organizations [10]. Furthermore, defining the optimal service granularity (i.e., scope of service function) can be challenging. Some of the problems that can arise

Table 5.1 Services and capabilities desired for scalable, standards-based, service-oriented CDSS as described by the HL-7 CDS Work Group [19]

Services hosted by CIS that enable a SOA for CDS	Capabilities provided by a CIS that enable a SOA for CDS
Event subscription and notification service	Use of appropriate, standard information models and terminologies
Cohort identification service	Ability to leverage a decision support service
Entity identification service/identity cross-reference service	Ability to leverage a terminology service
Clinical data query service	Ability to leverage a unit conversion service
Resource query service	Ability to leverage a data transformation service
Data acquisition service	Ability to leverage a data presentation service
Data addition/update service	Ability to populate a data warehouse in real-time
Order placement service	Maintenance of audit logs
User communication service	
Task management service	

from inappropriate service granularity include service duplication (several services for similar functions), a proliferation of services, and services that cannot be easily reused in different contexts [10]. In addition, the black-box nature of a CDS service may not be acceptable for some organizations that want to know exactly how a clinical decision has been reached [10]. Finally, healthcare organizations may insist on a CDS service to be locally hosted, which can make it more difficult to achieve economies of scale and enable real-time content updates [10].

5.3 SOA Services and Capabilities Needed for CDS

The HL7 CDS Work Group has identified and published key capabilities and requirements for a Clinical Information System (CIS) to provide SOA-based CDSS [19]. These capabilities and services are shown in Table 5.1.

An important requirement for interoperable, SOA-based CDSS is the development of standard definitions for required services, so that services can be re-leveraged in a scalable manner across organizations. Also needed are resources to facilitate the implementation of such standards-based, SOA-enabled CDS. Described below are notable efforts in this area with regard to service standardization and resource development.

5.4 Healthcare Services Specification Project

The HSSP is a collaboration effort between HL7 and OMG that addresses interoperability challenges by developing SOA service specifications [20]. The specifications focus on the functionality, semantics and technology needed to support interoperability between systems. The goal is to reduce the complexity of implementation, promote effective integration and lower implementation costs. Specifications developed by HSSP include the Retrieve, Locate, Update Service (RLUS) for data retrieval and update, the Decision Support Service (DSS) for evaluating patient data to generate patient-specific care assessments and recommendations, and the Common Terminology Services (CTS2) for providing commonly required terminology functions.

5.5 OpenCDS

OpenCDS is "a multi-institutional, collaborative effort to develop open-source, standards-based CDS tools and resources that can be widely adopted to enable CDS at scale" [21]. An important resource developed by this effort is a knowledge authoring, management, and execution platform that supports relevant HL7 standards including the HL7 Virtual Medical Record (vMR) and HL7 DSS standards. OpenCDS encapsulates knowledge into reusable components that can be shared with different medical systems. Some of the areas where OpenCDS has been leveraged include immunization forecasting, [22] CDS for whole genome sequence information, [18, 23] multimorbidity case management, [24] and CDS-based quality measurements, [25] among others.

5.6 CDS Consortium

The CDS Consortium (CDSC) was established by researchers from Brigham and Women's Hospital, Harvard Medical School, and Partners HealthCare Information System in partnership with the Regenstrief Institute, Kaiser Permanente Northwest Research Group, the Veterans Heath Administration, Masspro, GE Healthcare, Siemens Medical Solutions, and other organizations. The aim of the CDSC is "to asses, define, demonstrate, and evaluate best practices for knowledge management and clinical decision support in healthcare information technology at scale – across multiple ambulatory care settings and EHR technology platforms" [26]. CDSC focuses on several CDS areas such as the development of standards for CDS knowledge representation and demonstrations of CDS implementations at different sites across the United States.

5.7 Health eDecisions and Clinical Quality Framework

The Health eDecisions (HeD) project and the Clinical Quality Framework (CQF) project are part of the Standards & Interoperability framework (S&I) framework sponsored by the U.S. Office of the National Coordinator for Health Information

Technology (ONC) [27]. The goal of HeD was to define and validate standards that enable CDS sharing at scale [28]. The main achievements of HeD include the further development, refinement, and validation of the HL7 vMR data model standard for CDS; the development and validation of the HL7 CDS Knowledge Artifact Specification for representing standard rules, order sets, and documentation templates; and the HL7 DSS Implementation Guide. The CQF project is based on the work accomplished by the HeD, with a focus on harmonizing the standards for CDS and electronic clinical quality measurement [29].

5.8 Healthcare Services Platform Consortium

The Healthcare Services Platform Consortium (HSPC) is a nonprofit community of healthcare providers, software vendors, educational institutions and individuals committed to increasing the quality and reducing the costs of health care [30]. The HSPC's goal is to create a framework for, and facilitate the widespread adoption of, SOA-based architectures for health care that incorporate open data models and terminology standards. Some of the functions of HSPC include the selection of standards for the development of interoperable SOA-based services, as well as the evaluation, testing and certification of software solutions proposed by its members. Some of the standards that have been selected by HSPC include SNOMED CT, LOINC, and RxNorm for terminology; HL7 FHIR for data exchange; and SMART [31] for EHR integration.

5.9 Other Individual Efforts

Beyond these specific efforts, there are a number of other efforts completed or underway. In a systematic review of SOA for CDS, we found 44 studies on this topic [32]. For example, a prominent implementation standard for SOA is Service Component Architecture (SCA). SCA is a set of OASIS specifications designed for building distributed applications based on SOA, and it is the result of the collaboration of major software vendors such as IBM and Oracle [33]. SCA has been adopted by various industries in conjunction with Business Process Management tools and techniques, with a primary goal of addressing the complexity issues that arise with large scale SOA implementations. SCA has been successfully applied to provide guideline-based CDS to physicians within the context of EHR systems [34, 35]. Further details on this and other relevant individual efforts can be found in this aforementioned systematic review of SOA for CDS [32].

5.10 Future Directions

Here, we speculate on the future directions of CDS architectures based on previous and current efforts underway. First, we believe that the trend towards service-oriented CDS will continue. The pace at which it will do so is unclear, but keys to the facilitation of this movement include standardization and the availability of robust content and services to support the approach. Second, just as the general IT industry is moving towards more cutting-edge approaches to SOA and to approaches that go beyond SOA, we anticipate this trend will also start appearing in HIT and in CDS. An example of potential evolution includes movement towards use of SCAs and other advanced architectural approaches, such as the combination of SOA with event-driven and workflow-driven approaches such as Business Process Management. Finally, we anticipate that CDS architectures will also begin to incorporate other trends in the general industry, such as a focus on mobile devices (e.g., smart phones and tablets) and an increasing adoption of Cloud computing.

5.11 Conclusions

CDS implementations have been moving towards SOA, similar to other fields, with a particular focus on standards-based scalability. We anticipate that this movement will continue to gain momentum. Moreover, we anticipate that implementations in this area will continue to follow general trends in HIT and the broader IT marketplace, such as a focus on mobile technologies and Cloud computing.

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