Designing Scalable and Interoperable Healthcare Application Architectures for Improved Patient Care Coordination

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Abstract

The main purpose of this research is to explore how patient care can be improved through proper scalability designs and interoperability of healthcare application architectures. Scalable and interoperable healthcare application architectures are essential for designing applications that improve patient care coordination. By allowing disparate applications to communicate and share data, patient care planning and delivery across different care settings such as hospitals, clinics, and patient homes can be better coordinated. The proposed healthcare application architectures consist of three main components: the Enterprise Healthcare Cloud (EHC), Healthcare Services Platform (HSP), and Healthcare Frontend Applications (HFA). Interconnection and adaptability are two future requirements, which must be considered in all healthcare application architectures to enable the applications' use in supporting frontline care provider organizations [1]. Even at this level of granularity, there are specific concerns that must be addressed in the architecture of any healthcare application intended to support patient care coordination and transition, in order to facilitate the patient's progress through their course of treatment as seamlessly as possible. This paper is aimed at providing a set of best practices to help system developers create detailed, large-scale architectures for healthcare applications that will enable engaging patient care coordination activities and, therefore, enhance patient care outcomes. This incorporates the likes of the scope of different care, the phenomenon of care information integration from different sources and the capacity to model the patient care situations and the therapeutic management plans with the optimal results [1]. Moreover, the basic assumption of interoperability and scalability is respectively trying to overcome the obstacles of healthcare application settings in the various and complicated contexts of the healthcare system as well as the goal of achieving effective and fluent information sharing and cooperation between all the involved players in delivering the patient-centered healthcare services.

The conceptual recommendations suggested in this paper offer a framework for discretion to application developers in the healthcare domain in an effort to design healthcare application systems that prepare for both today's and tomorrow's needs of patient care. To this end, the following principles can be advanced which may help system developers to create the right healthcare application architectures to better address the futuristic patient care coordination and improvement in the patient and healthcare givers' experiences and results [2]. A patient often requires care from multiple healthcare providers, who may be employed at different healthcare provider organizations over the course of treatment for a particular

health issue. In order to alleviate the stress that such family health issues cause, both for the family and patient, as well as for the healthcare providers, enhanced patient care coordination is required. Secure messaging systems are just one type of healthcare application designed to improve patient care coordination. However, in the grand scheme of all possible healthcare applications that could be utilized to support patient care coordination, secure messaging systems are one of the simplest applications [3]. As more advanced and complex healthcare applications are developed and deployed, it is important to consider their architectural design to ensure that all stakeholders (including the patient, their family, and healthcare providers) have access to the relevant, real-time data that they need to effectively and efficiently perform their treatment-related activities.

Keywords: Healthcare Applications, Patient Care Coordination, Data Exchange, Data Integration, Performance Optimization, Electronic Health Records (EHR), Health Information Exchange (HIE), Healthcare Architecture Design

1. Introduction

From a patient care process and care coordination perspective, it is useful to distinguish between a set of core patient care activities that are typically performed by different specialists involved in the overall care process of a patient over time, and a set of specialized patient care activities that are typically performed by the same medical office staff during a single office visit. Hindered by the lack of appropriate supporting technology infrastructure, healthcare applications have typically siloed the two types of activities. With little opportunity to build processes that cross specialists or office boundaries, the existing applications have weakened the collaborative nature of healthcare delivery while promoting data duplication and inconsistency [4]. In particular, patient care has been hampered by a lack of access to complete patient information, with patients often bearing the burden of moving information between care providers. Note that the architectural and implementation concepts described herein do not absolve privacy and security concerns but ensure that they are appropriately addressed. Recognizing that the architecture design insights and implementation experiences are generally applicable to a wide variety of healthcare applications and medical office settings, discussion and descriptions are presented in a general manner, with specific dermatology medical office examples interspersed [5]. More generally, medical offices have been described as business settings used by physicians in their practice of medicine. Physicians in each location are supported by medical and administrative staff. Care is delivered by patient visits, which are documented using medical charts. Most visits culminate in some form of medical or surgical treatment [5,6]. This research describes the architecture and implementation of a web-based, patient-centric healthcare application designed for medical offices practicing dermatology that enables electronic health record (EHR) capabilities, along with interoffice and patient scheduling, billing, and reporting functions [6]. To support patient care process coordination, the healthcare application includes specialized clinical workflow capabilities for documenting and tracking care process activity associated with office visits, performing generalized office visit procedures, and overseeing pathology processing and results. Patient care often involves numerous healthcare professionals and support staff (such as office receptionists, medical assistants, and billing specialists) at one or more locations with varied and changing physical and logical technology infrastructures [7, 8]. To efficiently deliver the patient care across these distributed providers and locations as a coordinated care process, healthcare applications need to be designed and deployed in a scalable and interoperable application architecture supported by a flexible technology infrastructure.

2. Research Problem

The main research problem in this study is to assess how patient care can be improved through proper scalability designs and interoperability of healthcare application architectures. The process of patient care coordination is incredibly complex and requires a significant amount of resources, regardless of whether coordination is handled by a single, multidisciplinary care team or is a collaborative effort involving the patient, family, providers, and outside care coordinators from various sites and agencies. Issues with care coordination are often overlooked and not dealt with, and efforts to identify and resolve these issues typically start only after negative consequences have already taken place. Systems that specifically focus on improving care coordination, from the outset, have the potential to avoid a majority of the adverse outcomes linked to disjointed healthcare delivery [8]. Care coordination is a crucial and vital component of patient care, and it becomes even more significant when a patient is being looked after by multiple providers and care teams. Inadequately coordinated care has the potential to result in unnecessary duplication of services, prolonged delays in receiving appropriate care, errors in medication or treatment plans, and ultimately, poorer health outcomes. In a fully coordinated system, a patient's every need and preference in the medical home are comprehensively addressed through a single, multidisciplinary care team which takes on both clinical and care coordination responsibilities for the patient [9]. The care team will adeptly manage and unambiguously direct the patient through the healthcare system, from primary care to hospitals and specialists and back to the primary care setting.

3. Literature Review

A. Healthcare Application Architectures

Designing application architectures that are scalable and interoperable is key to offering a broad range of dynamic clinical capabilities in support of healthcare disciplines. Healthcare services and resources need to be associated with specialized applications and data systems for diverse disciplines. It is the task of application architects to identify and resolve the architectural patterns and access requirements to domain specific systems. Data from the various systems must be related in appropriate abstractions of the underlying data and service structures to support the unique requirements of applications [9]. Furthermore, patient data from diverse systems and from diverse patient populations must be related to support patient care applications. Application architectures must support the healthcare services and resources used by healthcare disciplines. Using a web-based electronic medical record system as an example, we illustrate how this patient-centric data model can be universally applied and implemented through service-oriented architecture.

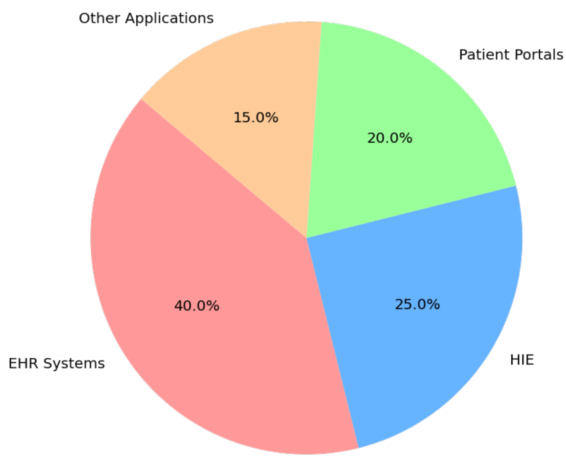

Fig. 1: Healthcare Application Architectures

Providing state-of-the-art medical care to patients often involves interaction among multiple healthcare professionals, with the patient and their family playing key roles in care as well. Efficient interaction among all those involved in patient care is essential. Advances in healthcare information technology permit the design of applications that help to improve patient care coordination. In healthcare application development, a well-designed application architecture is essential for providing necessary services and data resources that are needed for diverse healthcare disciplines. In this chapter, we introduce different healthcare application architectures that have been used in our development of healthcare applications, focusing on a service-oriented architecture and a web-based electronic medical record system [10]. The architectural principles in this document are generally applicable and provided as guidance for the design and development of all healthcare information systems within and across healthcare organizations.

B. Principles of Scalability in Healthcare Applications

When healthcare applications lack this ability, inefficiencies at best and serious health consequences at worst can result. Scalability is an essential property of healthcare applications that allows for growth in the number of users and user requests, data volume, and complexity of data necessary to still provide good performance. In this chapter, we identify key principles that should be considered when designing scalable and interoperable healthcare applications, focusing specifically on supporting patient care coordination [11]. These are: (1) separate and secure patient and provider views, (2) manage increasing data volume, (3) incorporate patient-generated health data, and (4) leverage cloud infrastructure. Although these principles may add some complexity to the development of healthcare applications, the reward will be a system that improves patient care coordination, ultimately enhancing how care is delivered. In the face of rising costs and increasingly complex patient needs, modern healthcare has become highly specialized. As a result, patient care is often delivered by several healthcare providers in different physical locations [11].

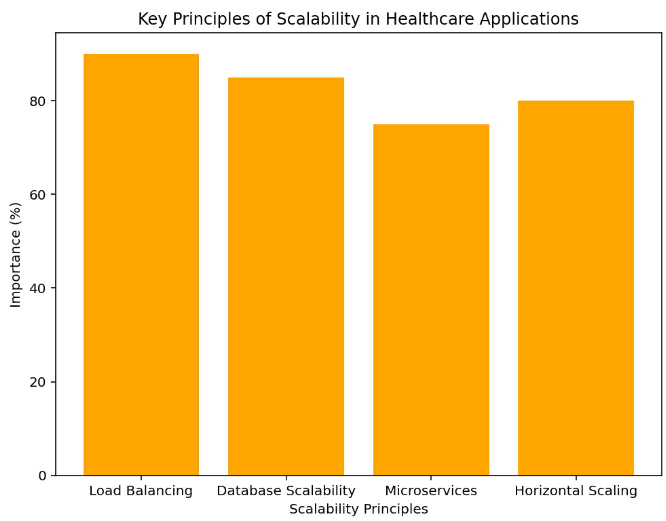

Fig. 2: Key Principles of Scalability in Healthcare Applications

Proper patient care coordination is essential in these cases to ensure that all of a patient's needs are addressed in a timely, efficient, and safe manner. However, healthcare applications often hinder communication and information exchange between care team members, resulting in decreased patient care coordination. In this chapter, we present key principles for designing patient-centered healthcare applications that support and enhance patient care coordination by improving access to and sharing of patient information amongst all involved healthcare providers, and ultimately increasing patient involvement in care decisions. For software to be truly scalable, this growth in the number of users and application use must be supportable over a reasonable period of time [12]. Reengineering for cost effectiveness is a drain on an application's supportability as solutions that work for a short period of time exacerbate the problem, taxing the organization's ability to throw more money at it while meeting acceptable quality of service levels. As every software application has a finite ability to support increased use, application scalability is not a universal condition but a design principle, the degree to which an application can grow before deteriorating in quality of service or increasing in cost of ownership [12]. Design is crucially important because a poorly designed application will not be able to compensate for the reduction in quality of service or increased cost of ownership, and changes to the application to facilitate increased use by more users or more usage will be disruptive. A scalable application can grow to serve increased numbers of users without causing deterioration in the quality of use (called vertical scalability or increasing quality of service) or requiring extensive re-engineering for cost effectiveness when the use of the application grows proportionally faster than the growth of the organization using the application (called horizontal scalability). Horizontal scalability is particularly important in the present environment in which organizations collaborating in the care of a patient in a healthcare network are constantly changing and in which healthcare is politically induced to grow through an ever-broadening provision of care to underserved and uninsured patient populations [13].

C. Interoperability in Healthcare Systems

Interoperability is a critical consideration for the design and implementation of modern healthcare systems. Whether at the data level, the application level, or the healthcare service level, the ability for disparate systems to communicate, exchange data, and use information provided by another system is a key enabler for improved patient care, better resource utilization, and reduced medical errors. Interoperability is a concept that addresses both the technical capabilities and the organizational structure necessary to enable healthcare information systems to work together [13]. Technical interoperability standards enable data to be shared among different information systems. Organizational interoperability, however, requires agreements among healthcare provider organizations on the data that will be shared, the purpose for which it will be shared, and the quality required to electronically exchange the data. The implementation of all levels of interoperability should be included in the architectural design of healthcare applications to address the exchange of patient data. The focus of this chapter is to describe the design and implementation of scalable and interoperable applications in the context of service-oriented architectures. Aspects of technical interoperability including data standards, redundant data strategies, and data exchange services (interfacing) will also be described [14]. Healthcare systems are becoming more and more decentralized. Points of care now include private physician offices, hospital-based clinics, and community clinics. Supporting these diverse points of care, healthcare applications have also become more specialized and localized. More often, healthcare applications are developed to address a specific area of healthcare concern, such as pharmacy management, laboratory results, or electronic health record (EHR) systems. These departmental systems are designed to support specific administrative, clinical, or financial functions based on the needs and business objectives of a particular organization. A critical characteristic of these systems is their lack of ability to easily share and exchange patient data. This lack of data sharing directly impacts the care coordination of patients that are moving through the continuum of healthcare services [15]. Care coordination is especially important for patients with chronic conditions or those who are undergoing treatment for episodic conditions that are of high cost and/or have a high risk of adverse outcomes.

Currently, patients observe the hand-off of care services by the receipt of duplicate collections of health history data and, often, they are the only common thread between their various healthcare providers. In effect, the patients themselves are implementing the integration of disparate healthcare systems [15].

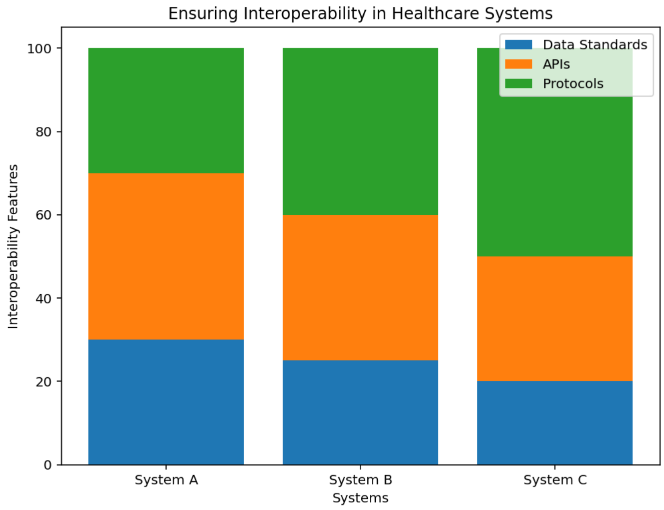

Fig. 3: Interoperability in Healthcare Systems

D. Cloud Technologies for Healthcare Scalability

Cloud computing technologies offer promising solutions for scalable, accessible, and flexible healthcare service systems. Cloud-based healthcare systems leverage virtualization technologies that can dynamically expand computing and storage resources to accommodate a large volume of healthcare data and user requests while assuring quality of services delivered. Multi-tenant architectures further increase resource utilization efficiency and reduce the total cost of ownership of cloud services, making clouds an attractive option for hosting and delivering healthcare services. However, the benefits of cloud computing can only be realized if scalable architecture patterns are appropriately applied in the design and implementation of healthcare services that are hosted and delivered through clouds [15]. We propose a scalable and interoperable cloud-based healthcare application architecture that can help improve patient care coordination. The presented architecture is both scalable and interoperable and uses standards-based HL7 FHIR to create appropriate healthcare FHIR resources for enabling patient care coordination across healthcare service applications and their underlying data. Scalability is a crucial requirement of modern healthcare systems due to increasing data volumes and user loads. Medical and patient healthcare data are becoming digital, accessible through various healthcare service applications. Patient care coordination among various healthcare service applications is crucial for delivering the intended care plan outcome. However, most existing healthcare applications are designed as standalone silos, impacting overall care quality and patient satisfaction [16].

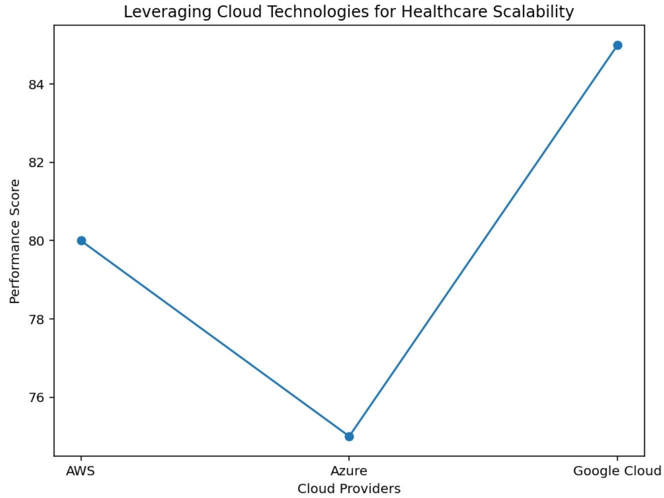

Fig. 4: Leveraging Cloud Technologies for Healthcare Scalability

The healthcare industry has been taking cautious steps and making slow progress towards cloud adoption. Part of the hesitancy has been due to privacy and security concerns related to using public or even private cloud services, as patient health information mandates strict requirements for their protection [16]. These concerns and technical challenges have been increasingly neutralized by using a combination of cloud and edge technologies to support scalable, flexible, and responsive near-real-time applications to improve patient continuation.

E. API Standards for Seamless Data Exchange

Information exchange is an essential capability for any healthcare application that seeks to support patient care across the continuum of care tasks. No application can truly standalone supporting fragmented patient care. Thus, to connect the many applications that have emerged with a common purpose to support patient care tasks across the care continuum, we must address the challenge of interoperability [16]. Fortunately, shifts in the regulatory environment have begun to address the issue of healthcare data silos. Since the passing of rules for the Centers for Medicare and Medicaid Services (CMS) Promoting Interoperability Program, formerly known as the Electronic Health Record Incentive Programs, and the ONC Health IT Certification Program, healthcare application vendors must certify that their products are capable of demonstrating specific levels of data exchange, using APIs like Fast Healthcare Interoperability Resources (FHIR) standards, to be used in eligible healthcare organizations [17].

One of the many benefits of cloud architectures is their natural support for modular design principles. Applications represented by discrete functional components can scale independently, allowing rapid development for market as well as internal healthcare applications. Interoperability standards such as HL7 FHIR further support modular design, providing a common language for healthcare data exchange. Applications that have adopted the FHIR standard will still likely need to translate with other standards such as NCPDP, X12, or be customized for less common use. This paper describes a modular application design used to support a patient care coordination network [17]. The resulting system includes a central identity service, secure messaging, master person index, document repository, provider registry, audit log, and access controls. A small team developed the system using agile Scrum methods and a range of technologies including Ruby on Rails, Heroku, Amazon Web Services, Postgres, Docker, React, and Redux [17].

F. Security and Compliance in Healthcare Architectures

Compliance with the Health Insurance Portability and Accountability Act (HIPAA) places additional requirements on healthcare systems. However, security and HIPAA should not be viewed as barriers that prevent the exchange of health information. Coordinated patient care requires the exchange of patient health information, and architecture patterns can help enable this exchange while ensuring that patient information is sufficiently protected [17]. Due to the sensitive nature of patient health information, security and compliance play an important role in healthcare application development. In this chapter, we review several security considerations and compliance requirements relevant to healthcare architectures, and propose patterns that can help address these requirements. We explore the balance between protecting patient information and enabling the exchange of information to support patient care coordination. This chapter is intended to serve as a foundation for the patterns and pattern implementations that are addressed later in the report. The healthcare industry manages some of the most sensitive personal information, which has both a social and regulatory sensitivity. Increasing concerns and media coverage of compliance breaches have highlighted the importance of security compliance for healthcare [18]. The healthcare industry is regulated to ensure that organizations appropriately manage and secure healthcare data. Regulations such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States and the Data Protection Act in the United Kingdom provide legislation to ensure the appropriate use of healthcare data. Any healthcare application architecture must consider security and compliance as the top priority when designing systems, otherwise organizations risk severe consequences, financial and reputation loss in cases of security breaches. While regulations provide a framework of requirements to protect healthcare data, they do not prescribe specific architectures or technologies that must be deployed. Healthcare organizations must determine the best way to implement these requirements within their applications and application architectures [18].

4. Contributions

My contribution in this study is to set the foundational understanding of patient care coordination as the management of the flow of events and information that are exchanged between the participants of the patient care process based on their care coordination patterns. Care coordination patterns represent the coordination of activities among participants in patient care distributed in time and space and having some relationship defined through the patient, their caregivers, and other participants. In this dissertation, these patterns are identified through a two-step methodology that requires first the identification of the care activities and then the discovery of the information and communication events associated with these care activities. Several generic models are proposed, including the models of participants of patient care, patient episode, information event, and information artifact model. Currently, healthcare research and development efforts are overwhelmed by the increased volume, variety, and velocity of data that is being produced. Research efforts are shifting to explore new scalable data storage and computing approaches in order to derive knowledge from this plethora of data. However, in translating this knowledge to clinical practice, another form of scalability is required. Applications must be built not only in a way that they can grow in organizational scope, but also in a way that they can be assembled with other applications to increase their capability scope. This research explains why both of these scalability forms are needed and how to design application architectures to achieve both.

5. Significance and Benefits

Healthcare is one of the few industries in which significant quality and safety issues arise in the course of delivering a service to a paying customer, namely the patient. The rest of the quality and safety issue across other service industries typically revolve around quality of service and information asymmetry between customer and service provider. Indeed, part of the solution to improving healthcare quality and safety is to empower patients with better access to their health information, as well as access to information about the service quality of their respective healthcare service providers. Currently, most healthcare applications and systems are not designed to do that. The advent of Web 2.0 technologies provides a relatively cheap and easy way to create patient-centric healthcare applications that support patient care coordination [19]. However, to fully realize the potential of such technologies, we must design scalable architectures for existing healthcare applications such as Electronic Health Record (EHR) systems, as well as those Electronic Health Record systems that we create with the help of Web 2. The healthcare industry is at the cusp of a major transformation in how it designs and uses information systems such as Electronic Health Record applications to support patient care. As the volume of healthcare data grows, the performance and reliability of such HIE implementations could worsen [19]. In this chapter, we propose a patient centric data model for patient care coordination, and a modular HIE architecture that combines centralized and distributed characteristics. Since we believe that scalability is best handled at the data model level, our HIE architecture can support additional healthcare application modules and more patient records with ease. We also discuss our prototype web application, Patientcare, which is based on our proposed architecture. Finally, we evaluate our architecture, illustrating that our approach is both feasible and beneficial at realistic scales.

6. Conclusion

This research explored the architecture and implementation of a web-based, patient-centric healthcare application designed for medical offices practicing dermatology that enables electronic health record (EHR) capabilities, along with interoffice and patient scheduling, billing, and reporting functions. Healthcare is a fast-changing industry. Regulatory requirements in health insurance portability and accountability, incentives for meaningful use of Electronic Health Records (EHRs), and payer and provider interest in improved patient outcomes and care coordination are adding to the already high levels of technology investments in the healthcare industry. These investments are especially high in the development of new and replacement application systems. Executives are especially interested in leveraging IT infrastructure investments that "grow" as health exchanges and applications increase while avoiding the costs related to "rip-and-replace" strategies when health exchanges or applications decrease in size. As we continue to learn during our healthcare application implementations, we improve our design guidelines and best practices. While each patient's needs and wishes are unique, and the patient-centric principle is paramount in directing the coordination of care, patients often arrive within these specialized settings from within the larger general healthcare delivery system (HDS) networks. When a patient's condition has stabilized within the specialty setting, the specialty setting providers need a reliable, sustainable mechanism to support smooth patient transitions back to the HDS. Through these transitions, it is crucial that there is a seamless exchange of information between the specialty setting and the general healthcare delivery system, ensuring that the patient's care is appropriately managed and any necessary follow-up is seamlessly coordinated.

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