

Medication Interoperability: Improving Medical Integration Between Healthcare Systems

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Abstract—The fragmented nature of the U.S. healthcare system lacks medication interoperability, resulting in preventable Drug-to-Drug Interactions (DDIs) and Adverse Drug Reactions (ADRs). Discrepancies in medication history cause increased healthcare provider burden, higher medical costs, and reduced patient health. We argue that the characteristics of this problem are indicative of the Byzantine Generals problem. As such, it requires an exploration of consensus algorithms that are Byzantine Fault Tolerant such as RAFT for proper data synchronization. Exploration of this problem space could then inform a prototype solution that would be iterated upon based on community feedback. This prototype would then be used in turn to inform a standards-based solution for implementation across industry that would provide practitioners with a complete patient medication history, thereby mitigating unnecessary ADRs, DDIs, and the over prescription of medications.

Keywords—Medication, Interoperability, Healthcare, FHIR, Drug Interactions

I. INTRODUCTION

The highly decentralized and heterogeneous nature of the U.S. medication distribution system creates a vexing problem for patients and health care providers: how to minimize the likelihood that two or more conflicting drugs are prescribed to the same patient since many patients see multiple prescribers and/or have medications dispensed at numerous pharmacies. At present, prescribers, pharmacists, and patients often lack a quick accessible way to view current and past medications taken which can result in overprescribing, adverse medication interactions, or duplicate medication prescriptions.

Pharmacy and Electronic Health Record (EHR) systems will notify prescribers of possible adverse drug interactions as well as list out known medications that a patient is taking but lack proper cross communication to track all the medications for a patient. This issue arises because existing EHR and pharmacy systems are limited to only medications in that specific system and those self-reported by the patient. Often the burden is placed on a patient to remember and self-report all the medications they are taking, which is cumbersome and prone to error. Lack of comprehensive medication information and human error can result in prescribers not being aware of medications being prescribed to the patient by other providers, potentially resulting in complications arising during a patient's treatment. Figure 1 outlines the complex disjointed market share of EHR systems within the US [1]. The lack of interoperable exchange and communication of medication history between these EHR and pharmacy systems is not only a burden on prescribers and pharmacists but also an unnecessary health risk for the patient.

Estimates range, but research states that ADRs account for anywhere between 7,000 to 106,000 deaths annually. Additionally, drug-related morbidity and mortality costs are estimated to be between \$30.1 billion [2] to \$136 billion annually [3]. Moreover, further studies have demonstrated that a lack of medication reconciliation is responsible for 46% of all medication errors and >20% of ADRs in hospital settings [4]. The immense physical and financial toll of ADR's amount to unnecessary stress on the United States healthcare system. These consequences therefor necessitate the investigation of this complex problem and warrant an analysis of the intricate nature of its features that can then in turn be used to inform the development of a standards-based solution for medication interoperability across industry.

II. OBJECTIVE STATEMENT

The objective of this research is to fully understand the unique characteristics of this problem space and the related research. This work will explore the relationship of this problem to existing consensus algorithms and thereby inform the development of a prototype that models the workflow between prescribers, intermediary systems, pharmacies, and patients. Iterations upon this prototype would serve as a framework of investigation and inform a standards-based solution that could be implemented across the health care industry. This solution will focus primarily on enhancing stakeholders' ability to make informed decisions regarding potential adverse medication interactions by allowing for an accessible way to view the current and past medication history of a patient thereby minimizing the risks of ADRs and DDIs.

III. RESEARCH QUESTIONS

This research evaluates the state of patient medication history exchange. It further investigates related research in support of proposing methodologies and technologies that could be implemented to improve medication interoperability

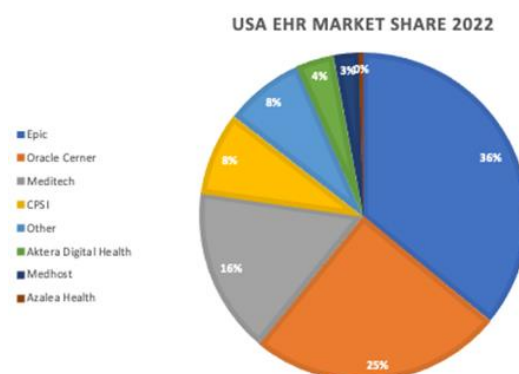


Fig. 1. Market Analysis of Current USA EHR Percentages [1]

in the United States. Our guiding questions for this research are as follows:

- 1) *How can an interoperable standard be designed such that it works with current industry systems to facilitate data exchange regarding a patient's medication history?*
- 2) *How can standards and existing algorithms be leveraged to reduce the burdens on healthcare practitioners with the goal of reducing medical error and improving overall patient care?*

IV. GENERALIZED PROBLEM SPACE

The problem space was reduced to a generalizable problem for comparison to work completed in other domains and industries. It was supposed that work in other fields could be leveraged to inform more efficient and effective solution development for this complex problem.

A. Defining the Problem Space

The medication history problem space consists of three main stakeholders: *Prescribers, Pharmacists, and Patients*.

Prescribers and pharmacists exist within EHR and Pharmacy information systems respectively. Both Pharmacy information systems and EHR systems contain records of patient medications. The prescribers and pharmacies can be thought of as individual nodes. These nodes each have their own records that will be referred to as *ledgers*. Lastly, the patient can be seen as a *trigger*, given a ledger is only updated when there is an interaction with the trigger (i.e. a patient goes to see the prescriber).

In a system of n ($n = 1...*$) nodes each containing their own ledger, how can all the ledgers be consistently updated to contain the same information after a trigger interacts with any given node?

The following constraints must also be taken into consideration:

- 1) *The trigger's interaction with any ledger may or may not result in an accurately updated ledger (Patient may provide a limited or inaccurate medication history to a provider).*
- 2) *As the event of a trigger interacting with a given node, communication with all other nodes must be assumed unreliable (In the event of difficulty establishing connection with external EHR systems and pharmacy management systems).*

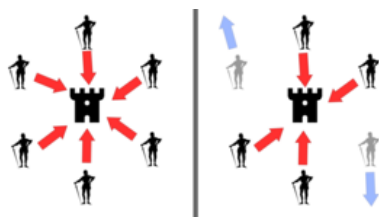


Fig 2. Generals Synchronizing Attack in the Byzantine Generals Problem [5]

B. The Consensus Problem

Consensus is a fundamental problem in fault-tolerant distributed systems. Consensus involves multiple servers agreeing on values. [6]. One such consensus problem is the *Byzantine Generals Problem (BGP)* in which a group of generals are attacking a fortress. They are attempting to synchronize an attack or retreat. The goal is that all generals agree on a common decision, to either attack or retreat (see Figure 2)[5]. The problem can be abstracted by viewing each of the individual generals as a node who each contain information that needs to be synchronized across all other nodes. Some nodes may be unreliable, and some may become compromised. Furthermore the Byzantine Generals Problem emphasizes a few key points:

- 1) *How can a list of trusted nodes be agreed upon? How can nodes be added or removed from this list?*
- 2) *How do a list of determined trusted nodes have reliable and secure communication?*
- 3) *How can communication be synchronized between trusted nodes?*
- 4) *What is done to prevent bad actors and malicious attacks from compromising the shared information?*

C. Raft Consensus Algorithm

One such algorithm designed to address the BGP is the Raft Consensus Algorithm. The Raft Consensus Algorithm provides a reliable solution to node synchronization by providing a method for defining consensus upon values within a system as well as determining trusted nodes. Raft has been implemented across industries and has proven to be reliable and accurate [7]. The algorithm separates the key elements of consensus, such as leader election, log replication, and safety, and it enforces a stronger degree of coherency to reduce the number of states that must be considered. It outlines a method for data synchronization across unreliable, disjointed systems. Furthermore, Raft provides a modern, easy to understand methodology compared to other Byzantine Fault Tolerant consensus algorithms [8].

D. Reconnecting the Generalized Problem Space

The Medication History Problem mirrors that of a consensus issue and further of the Byzantine Generals problem. The Raft Consensus Algorithm provides a tested methodology that would enable EHR systems to maintain congruency and accurate medication histories regardless of where a patient is being seen. Moreover, the large existing industry necessitates a modern methodology that is easily understood and simple to implement, which Raft emphasizes [7]. As such it stands out as a leader contender over other Byzantine Fault Tolerant consensus algorithm.

By design, Raft would provide a secure method for newly added or removed medications to be synchronized across EHR networks. A consistent and updated medication would allow for a provider to effectively treat a patient while mitigating the risks of ADR and DDIs. As such, this work proposes that the disjointed medication histories across EHRs and Pharmacy information systems could be ameliorated by implementing Raft.

V. TECHNICAL CONSIDERATIONS

The goal of this research is to inform a standard definition for patient medication interoperability. It is recommended that the standard specification be based in FHIR, which is supported by many modern day EHR systems and provides some standard data model definitions that are already used today by industry and can therefore be leveraged. Furthermore, the utilization of Clinical Decision Support Hooks (CDS-Hooks) for integrating directly with existing clinical workflows should be implemented. Additionally, SMART-on-FHIR applications can be leveraged to provide EHR systems that don't natively support CDS-Hooks with similar functionality.

While the primary focus is on building out a FHIR Implementation Guide to define a standard definition, it is also important to consider other standards used in industry. For instance, NCPDP Script is widely adopted by many pharmacy systems for conveying and storing medication prescription information. It is necessary that the standard specification would interface with NCPDP Script to facilitate communications between EHR and Pharmacy Systems. Thus, it is important to consider mappings between FHIR and NCPDP Script data elements when designing a standard such that adoption can be made easier, regardless of if translation between the two standard specifications occurs within the EHR or an intermediary system. Thus, it is important to consider mappings between FHIR and NCPDP Script data elements when designing a standard such that adoption can be made easier, regardless of if translation between the two standard specifications occurs within the EHR system itself or an intermediary system. For a more detailed depiction of the communication exchange between relevant stakeholders, see Figure 3.

VI. CONCLUSION

This paper discussed the Medication History problem in relation to other similar consensus problems with an in-depth comparison to the Byzantine General Problem and the corresponding Raft Consensus Algorithm. This research is in support of a prototype modeling the workflow between prescribers, intermediary systems, pharmacies, and patients. This model can then be used to inform an interoperable standards-based solution to the medication history exchange problem in FHIR that can then be implemented across industry.

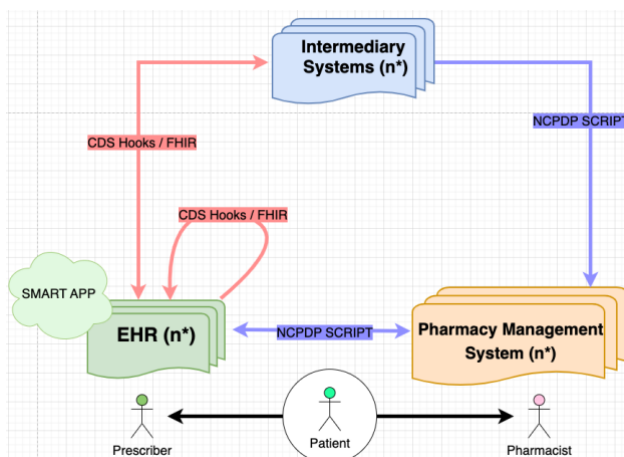


Fig. 3. Example Medication Interoperability Architecture

Future research, specifically collecting stakeholder feedback, is needed to refine the development of both the prototype and standard. Successful implementation of this standard would mitigate the high incidence of medication errors and adverse drug events that commonly occur in healthcare settings. This in turn would reduce stakeholder burden, mitigate risk, and improve overall patient health and healthcare literacy. Moreover, there would also be improvements to the cost burden on the healthcare system, which is something that insurance organizations would also greatly benefit from due to the reduction of medical claims and expenses.

Once a standard specification has been adopted by industry, the system would then also be able to generate large amounts of high-quality anonymized patient data through outcome reporting that could be utilized in further research applications revolving around medication interoperability. Additionally, there are other possible further expansions to explore with this system such as medication transition of care, artificial intelligence integration, data segmentation for security, and patient supplement reporting.

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