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Advancing Healthcare Through Interoperability: Implementing Scalable Solutions for Patient Data Integration

Shramika GOUR[a], Ashley PEAKE[a], Chao TONG[a], James CHURM[a], Bilal AHMAD[a], Omid POURNIK[a] and Theodoros N. ARVANITIS [a,1]
[a] *Department of Electronic, Electrical and Systems Engineering, School of Engineering, University of Birmingham, Birmingham, UK*
ORCiD ID: Shramika Gour https://orcid.org/0009-0006-5585-5040, Ashley Peake https://orcid.org/0000-0001-6431-0778, Chao Tong https://orcid.org/0000-0002-8983-0638, James Churm https://orcid.org/0000-0003-0654-5960, Bilal Ahmad https://orcid.org/0000-0002-6328-1888 , Omid Pournik https://orcid.org/0000-0001-7938-0269, Theodoros N. Arvanitis https://orcid.org/0000-0001-5473-135X

Abstract. Healthcare faces significant challenges in exchanging and utilizing health information across diverse providers, necessitating innovative solutions for improved interoperability. This study presents a comprehensive exploration of scalable technical and semantic solutions for patient care integration, emphasizing the implementation of these solutions within the framework of the Fast Healthcare Interoperability Resources (FHIR) standard. Our approach revolves around the development and deployment of Technical Interoperability Suite (TIS) and Semantic Interoperability Suite (SIS) technology solutions to disparate health information systems, predominantly Electronic Health Records (EHRs) into a unified Patient Care Platform, fostering comprehensive data exchange and utilization. The integration process involves importing data from various EHR systems and transforming imported patient data into FHIR-standardized formats. The provided solution supports various functionalities, including automatic and manual importation of patient data, through standard computer-readable templates. The integration of TIS and SIS solutions is underpinned by a robust technological framework, incorporating technologies such as Typescript, Deno, and document-oriented databases such as MongoDB. The effectiveness of our interoperability solutions was validated through deployment in multinational EU projects: ADLIFE and CAREPATH. The scalability and generalizability of our approach underscore its potential for diverse healthcare settings.

Keywords. Technical and semantic Interoperability, Semantic Mapping, FHIR

1. Introduction

In the digital era, health information exchange across various providers are pressing challenges and recognized as fundamental to research, innovation, efficiency [1]. As we

[1] Corresponding Author: Professor Theodoros N. Arvanitis, Department of Electronic, Electrical and Systems Engineering, School of Engineering, College of Engineering and Physical Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom; E-mail: T.Arvanitis@bham.ac.uk.

move forward, traditional paper-based industries undergo a profound transformation into digital counterparts [2]. One such framework is Electronic Health Record (EHR) systems that store and manage a comprehensive set of patient data, including demographics, lab results, medications, and medical history [3]. By exchanging patients' records stored in organizations with other systems, repeated entries and medical errors can be reduced [4]. Technical and semantic interoperability plays a pivotal role in this exchange. Studies have highlighted the burden of errors during data transfer between systems [5-7]. By enabling the integration of disparate health information systems and data sources, interoperability lays the foundation for the development of comprehensive patient care platforms transcending geographical and institutional boundaries.

This paper proposes a framework for integrating healthcare data systems to promote interoperability and improve clinical decision-making. The framework utilizes the Fast Healthcare Interoperability Resources (FHIR) standard for consistent data exchange across various sources like EHRs and clinical observation systems. A Technical Interoperability Suite (TIS) facilitates patient registration, automates and allows for manual data import from EHRs, and maintains anonymity through designated identifiers. A Semantic Interoperability Suite (SIS) transforms data into a FHIR-compliant format, bridging the gap between incompatible terminologies and formats. The framework leverages technologies like Typescript, Deno, and MongoDB for scalability and adaptability in diverse healthcare settings. The solution is tested within two significant multinational and multicenter EU projects, namely ADLIFE [8] and CAREPATH [9].

2. Method

Existing EHRs generally lack a standardized approach for data export or integration via Application Programming Interfaces (APIs). To address this, we first established connections to provided APIs to retrieve patient data using local identifiers. Subsequently, we initiated mapping procedures based on internationally used nomenclatures and health standards such as ICD or SNOMED, ensuring alignment with the FHIR standard. Our platform facilitated data import via standard computer-readable templates, like CSV, triggered manually or at scheduled intervals (Figure 1).

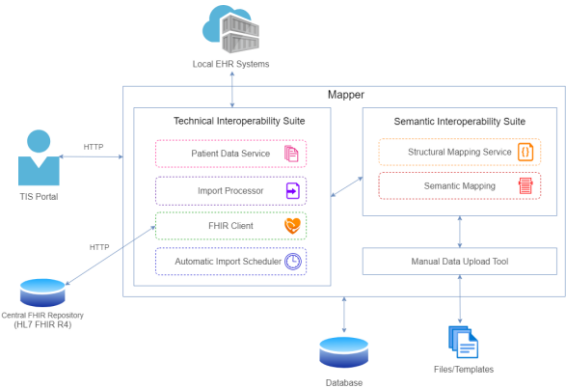

Figure 1. Architecture Diagram of TIS and SIS

After successful data import, the TIS employed the SIS to transform imported patient data into a FHIR standardized terminology and format before saving it into the central

FHIR repository. SIS was responsible for both structural and semantic mappings, transforming disparate terminologies and formats into platform-based terminology codes and ensuring correct target format alignment.

The TIS/SIS modules were developed using various technologies, primarily Oak, leveraging Deno's runtime JavaScript and Typescript middleware framework. Alongside document databases such as MongoDB aligned with Deno have also been used. Additionally, alternative technology stacks such as Nodejs and Typescript from Node Package Manager (NPM) were also explored enabling adaptability across various platforms. The easily accessible containerization for building, sharing, and running applications "docker" has been chosen. The mapper and mapper UI images are built and pushed to the docker hub which is further pulled and deployed at all sites (Table 1).

Table 1. Technology Stack in TIS/SIS

Technology	Usage Context	Methodological insights
Deno	A native TypeScript environment allowing good object-oriented practice and live parsing and bundling for mapping.	Enables the utilization of existing skills to create mappings, leveraging access to numerous libraries.
Mongo Database	Document oriented database system, JSON based, aligns well with Deno.	By directly saving JavaScript objects in db, reduces design overhead compared to SQL.
Bioportal API	Ontology system for mapping, use JSON standards.	Allows mapping unknown codes to other systems, saving time vs manual mapping and keeping the systems up to date.
NodeJS	An alternate JavaScript environment that can run the mapping scripts.	Allows running mapping scripts in a variety of environments, locally and on cloud platforms, written natively in JavaScript using the TypeScript application.
FHIR	Provide recognizable industry standards for handling records, manage and store ontology information.	FHIR, used as the target for all mapping systems, is a well-defined standard allowing for the stable rapid tool development.

In the flowchart shown in Figure 2, the following processes have been performed. To create a Structural Mapping template for interoperability, TypeScript interface files were generated to be compatible with mapping standards. Next, existing mock data files, regardless of their original format (such as XML or YAML), were converted to JSON for testing. Using an environment like Visual Studio Code, we employed an automated tool, such as typescript-JSON-schema, to convert the source and target TypeScript interfaces into JSON Schema, which provided validation for the test data. We then developed shared mapping functions, such as creating patient references in a common format. Later, we created structural mapping templates for each input type, compiled them into JavaScript, and tested them locally using the mapper testing suite. Successful tests confirmed that the templates accurately transformed mock input data into the expected output, ensuring stylistic elements like tabs and line spaces were disregarded. The verified templates were were uploaded into the TIS portal. For semantic mapping, the source information of centralized coding and target platform-based ontologies was reviewed. A semantic map was prepared and then uploaded into the TIS portal. Selected data can effortlessly be imported from the EHR manually via TIS portal, or by regular automatic schedule. The imported data interacts with the structural mapper to generate a FHIR mapping. The semantic mapper then scans the target data for codes, ensuring they are appropriately mapped. Once the transformation is complete, TIS places the data in the FHIR repository, or it can be directed to any HTTP-based API, given TIS's adaptability. The FHIR-transformed data remains accessible through any digital platform.

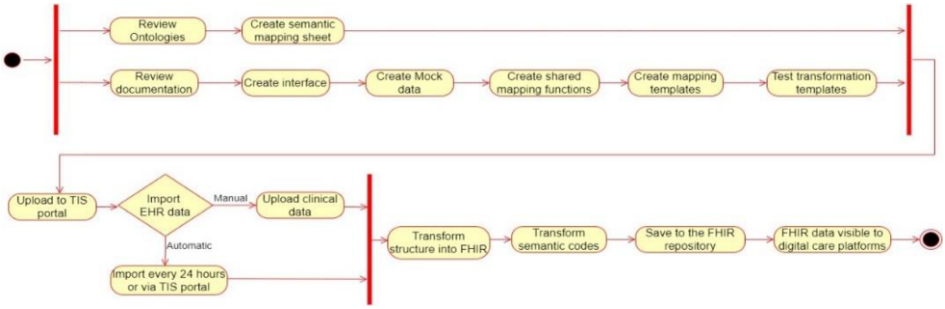

Figure 2. Workflow of TIS and SIS

3. Results

The interoperability solutions developed with TIS/SIS were effectively deployed in various projects. These solutions facilitated data transfer from local sites to the main platforms. The developed SIS module is technically unique and has not been previously used for this purpose. Existing systems often rely on bespoke scripts, introducing a learning curve barrier, restrictive functionality, and operating environment restrictions. Our approach, using a JavaScript mapper and JS transformation engine, makes the system easily scalable and enhances its functionality by leveraging existing libraries and modules. This architecture ensures full reproducibility and flexibility, allowing implementation in various environments using pre-made tools like NodeJS with Docker.

In ADLIFE, our TIS and SIS solutions were seamlessly integrated into the digital toolbox. Clinical research spanning six healthcare facilities across Israel, Germany, Denmark, Spain, and the UK [10] demonstrated successful display of data technically and semantically mapped to the FHIR standard. In the CAREPATH project our interoperability solution played a pivotal role. Utilizing Semantic and Structural Mapping approaches, our solution facilitated information sharing between CAREPATH components and local care systems in Germany, Romania, Spain, and the UK [11].

In the lab testing phase, tests were performed both with a series of records and outputs, and a synthetic dataset with more than 800 records, and semantic mapping was tested with circa 1000 records of codes. The successful function and reliability of the developed system, guided by the suggested architecture and concept, were demonstrated.

4. Discussion

The implementation of interoperability solutions with TIS/SIS represents a significant advancement in addressing the challenges of health information exchange and utilisation across different E-Health systems. The successful deployment in multinational projects underscores the effectiveness of our approach, demonstrating its scalability and generalisability across diverse healthcare settings with different standards and languages.

Our approach, centred on the utilization of the FHIR standard and leveraging technologies such as a document database system including MongoDB, Typescript, and Deno, offers a flexible framework that can be adapted to various situations and healthcare standards. This scalability and adaptability make it well-suited for use in numerous

contexts, rising above geographical and institutional limits with extended applicability in telehealth, telemonitoring, and Internet of Medical Things (IoMT) health projects (12).

5. Conclusions

The interoperability framework introduced not only addresses current challenges in health information exchange, but also paves the way for future advances in telehealth, telemonitoring, and IoMT projects. By facilitating data integration and empowering both clinicians and patients, our solutions enhance decision-making processes and ultimately improve patient care outcomes. This work signifies a remarkable leap towards a more connected and efficient healthcare ecosystem.

Acknowledgements

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