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Proposal of an integrated decision support system for Tuberculosis based on Semantic Web

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Abstract

Epidemiological surveillance of Tuberculosis (TB) requires a strong integration of different health services, programs and levels of care. The deepening and broadening of data management techniques must be constantly carried out to increase the integrality of healthcare. Otherwise, knowledge extraction and clinical and administrative decision-making processes are significantly hampered, directly affecting the management and quality of health services. Thus, this work aims to establish a computerized decision support system capable of collecting, integrating and sharing TB health data in Brazilian Unified Public Health System. Also, it will allow the monitoring of infected patients and the visualization of consolidated information of regular TB and its resistant variants for health professionals and managers. The data will be made available from heterogeneous, disconnected and unstructured sources by combining traditional web services, Semantic Web resources and security algorithms. A solid knowledge base applied to epidemiological surveillance, health information governance and clinical support will be enabled to integrate the multiple areas of TB patients care, as well as to support the creation of more accurate operational and diagnostics models.

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1. Introduction

Tuberculosis (TB) is a bacterial infectious disease that remains as a major public health problem in the world. It is estimated that in 2017 approximately 10.5 million people got infected with TB or with a variant rifampicin-resistant (RR-TB) or multidrug-resistant (MDR-TB). Brazil is part of the 30 high TB burden countries, with a best estimate of 93.000 TB cases, including drug-resistant TB [1].

The large number of heterogeneous and isolated data sources makes data integration management a big challenge [2]. To deliver a better support on decision-making processes for administrative and clinical demands, health systems must support functional and semantic interoperability, that is, systems must be able to exchange and recognize data with semantic value in a transparent way.

Decision support system (DSS) is a general term for any information system that enhances a person or group's ability to identify problems and to make decisions that could help to solve such problems. These systems can be categorized as one or more groups, such as data-driven, document-driven, knowledge-driven, and model-driven [3]. According to their category, systems will be able to bear out decisions through gathering and processing data, non-structured documents, inference rules/procedures and analyzing users' input/parameters, respectively.

Aligned with the The End TB Strategy, a global strategy for tuberculosis prevention, care and control designed by the World Health Organization (WHO) [4], the main goal of this work is the development of a secure computerized decision support system capable of collecting, integrating and sharing TB data. Also, it will allow the monitoring of infected patients and the visualization of consolidated information about regular TB and its resistant variants by health professionals and managers to underpin their decisions towards a better care. Data incompleteness, inconsistency and duplicity will be reduced. Information will be segmented and stratified to precisely represent a desired population and to be available to public and private domains. Security features, such as authentication mechanisms, cryptography and data access levels [5], will be added to the solution to allow the use of Semantic Web (SW) in a sensitive context. Finally, this proposal will improve existing work by compiling useful but isolated tools and researches in a robust integrated decision support system for Tuberculosis.

In the next section, related work will be presented. In the third section, the methodological approach and key concepts will be described. In the fourth section, the proposed decision support system will be showed. Finally, in the fifth section, expected contributions will be highlighted, as well as possible limitations and future work.

2. Related Work

Several researches regarding decision support system for Tuberculosis are available in literature. A primary search for related works was performed in the following databases: PubMed/MEDLINE, ACM Digital Library, IEEE Xplore Digital Library, Elsevier Scopus and Cochrane Database of Systematic Reviews, considering the time frame ranging from March 2006 until nowadays.

In general, these works cover clinical and managerial/epidemiological issues. Additionally, some studies address TB/HIV co-infection, latent TB and drug-resistant TB. However, in all cases, there is not any reference to SW technologies or concerns about safe data sharing.

Clinical decision support systems focus is, usually, TB diagnosis. Authors show that diagnosis can be enhanced through distinct methods, such as artificial neural networks [6]–[8], rule-based approaches [9]–[11] and guideline-based systems [12]–[15]. Furthermore, a clinical DSS for TB capable of producing insights and orientations for patients' treatment based on their historical data was not found.

Managerial/epidemiological decision support systems are used to guide policy makers, governmental agencies and non-governmental organizations in the development of new recommendations applied to TB diagnosis [16], [17] and treatments [18], patients' isolation [19] and to enable new decision-making tools [20], [21]. In general, this category of DSSs is able to provide crucial information to underpin right decisions about which new tools to implement and where in the diagnostic algorithm to apply them most effectively [16].

Aiming to tackle other TB related concerns, researchers are concentrating efforts to create support tools to help fighting TB/HIV co-infection, latent TB and drug-resistant TB. These issues require specific actions to avoid serious public health problems. Then, it is important to support diagnosis and prediction of latent TB [22], [23] and drug-resistant TB [24], as well as improving patient management and integration of TB/HIV services and decision-making capabilities [25]–[27].

3. Research Methods

The scientific methodology basis for this work is Action Research, which is a continuous search to create improvements within an observed context that simultaneously assists in practical problem-solving and expands scientific knowledge, as well as enhances the competencies of the respective actors [28][29].

The investigative and practical approach proposed by this methodology was considered the most appropriate, since the project, besides the theoretical development, has also a practical component. Through a sociotechnical perspective, key stakeholders will actively participate in the process of requirements survey and to effectively integrate several health information systems.

3.1. Semantic Web

The key concept of Semantic Web was introduced as a form to represent structured knowledge through a stack of several protocols, resources and definitions. The evolution of the current Web of Documents for a Programmable Web was proposed through the application of semantics to the data to facilitate their understanding and interoperability in a universe of heterogeneous information published in different formats. The SW makes it possible for both humans and machines to have the same understanding about things [30].

The World Wide Web Consortium (W3C) preconize specific protocols and resources for the SW, such as the Resource Description Framework (RDF) for data modelling, SPARQL Query Language for RDF for data querying and ontologies for formal knowledge specification [31]. According to W3C, structured and formalized knowledge improves the web usage experience by providing users with consistent and adequate information to the searched content [32].

The Semantic Web works like an extension of the current web [30] and enables considerable gains in the information treatment. Through its use it would be possible to connect and associate previously disconnected information, establishing a world-wide standard of communication based on existing knowledge on several domains. However, considering that it is usually applied to disseminate open public data for transparency goals, security standards must be added to protect sensitive information [33].

3.2. Tuberculosis Ecosystem

Tuberculosis Ecosystem is a computational health infrastructure that consists on a set of integrated systems that aims to do a better management and to allow exchange of TB related information in State of São Paulo, Brazil. This ecosystem has a functional and semantic interoperability architecture that enables relevant data exchange with authorized systems [34].

Several systems compose the ecosystem, each one designed to achieve a specific goal regarding the TB treatment and patient follow-up. The data is semantically tagged with personalized domain ontologies to provide meaning. Examples of these systems are: GuideTB, created to digitalize paper-based official manuals and guidelines [12]; WebDot, which enables the sending of video records by patients through a smartphone and allows its visualization and validation by a health professional through the Web platform [35]; SisTB, a web-based and mobile information system for monitoring patients' treatment following WHO-recommended DOTS strategy [36][37]; TB Knowledge Portal, a portal with semantic markup created as a tool to support health professionals and to publicly disseminate TB content and indicators [38].

3.3. Governmental Tuberculosis health information systems

In Brazilian Unified Public Health System (SUS), there are some platforms that store TB related data. At a national level, the Notification of Injury Information System (SINAN), for investigation of cases of compulsory notification diseases, and the Special Tuberculosis Treatment Information System (SITETB), for notification, follow-up and monitoring of TB special cases (e.g., drug-resistant TB) are used; Further, in the State of São Paulo, there is also the Notification and Monitoring System for Tuberculosis Cases (TBWEB), a software for epidemiologic vigilance.

These systems are widely used and represent relevant sources of TB information. By taking advantage of this, data will be gathered from these databases and integrated in the DSS proposed in this study. This will be achieved by establishing a protocol with governmental entities for data sharing through the provision of web services for interoperability purposes.

3.4. Other Tuberculosis decision support tools

In order to identify other valuable TB decision support tools that could be reused and integrated in a broader DSS, a literature scoping review will be conducted. The main goal is to select clinical and managerial/epidemiological free tools (and preferably, open-source) that could help, for instance, in TB diagnosis, patient isolation and policy makers decisions.

In a preliminary search, as presented in Section 2, very relevant tools were identified, such as: the TIME Impact, a user-friendly TB model that can be customized to different epidemiological settings [21]; a tool to enable local decision-makers to evaluate the impact of different diagnostic strategies for tuberculosis under the conditions specific to their region [39]; and the TB Consilium e-platform, that specifically provides evidence-based advice globally to national consilium bodies and individual clinicians on how to manage drug-resistant TB and other difficult-to-treat TB cases [40].

3.5. Development process

The process of surveying functional and visual requirements and mockups creation will be based on the sociotechnical approach. Key users actively participate in the process, keeping them motivated to use and improve the system [41]. After mockups validation, minimization of specification errors is expected during coding process. In addition, mockups can be reused as technical documentation, user manuals and training material.

Finally, for developing users' clients/interfaces, Java programming language was selected, along with other open-source tools and libraries that are compatible with Semantic Web resources, such as Apache Jena and Apache Any23. These tools permit operations with semantic data in RDF and others semantic formats and data extraction from semantically tagged web pages.

4. Decision Support System for Tuberculosis

In Brazil, there is a considerable amount of data related to TB patients' admission and treatment follow-up being continuously generated. Assistance to these patients is carried out at different levels and involves the use of several softwares that records data in non-shared databases. This scenario contains critical barriers for information retrieving due to lack of data standardization and controlled access, resulting in difficulties to produce strategic insights, clinical orientations and reports to support professionals in healthcare services and in the creation of new public policies to fight Tuberculosis.

The novelty of this work is the proposal of development of a secure Decision support System for Tuberculosis (DSS-TB) based on Semantic Web. This will be achieved by transforming the Tuberculosis Ecosystem, the governmental Tuberculosis health information systems and specific decision support tools identified in the literature in an integrated set of tools that will allow the combination and sharing of health TB. The system will be multi-driven, that is, at the same time, it will be categorized as a data-driven (data gathered from several sources), a document-driven (non-structured data from guidelines, manuals, etc.), a knowledge-driven (rules, procedures, etc.) and a model-driven (users' inputs) DSS. Figure 1 illustrates the DSS-TB conceptual model.

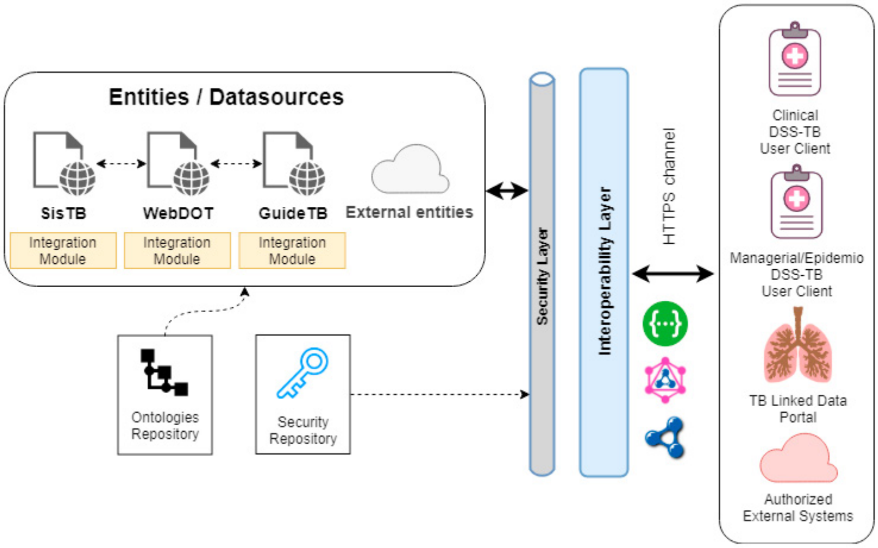

Fig 1. DSS-TB conceptual model

The DSS-TB will be composed of integrated modules segmented in clinical and managerial/epidemiological support. Each segment will deliver specific information for health professionals, managers and public policy makers. All modules will be able to contribute with TB related information for the DSS. However, they will remain available to be used separately for specific interventions. Additionally, for transparency, a TB Linked Data Portal will be available for public dissemination of consolidated TB information, as well as two DSS-TB User Clients for a visual interaction with integrated data, which will contain relevant features according to each target audience.

The interoperability layer will provide several endpoints, including APIs, called Semantic APIs due to the use of responses in semantic formats, a SPARQL endpoint and a HyperGraphQL endpoint (a GraphQL interface for querying and serving linked data on the Web - https://www.hypergraphql.org/). Also, each entity will be able to send and retrieve data through web services/APIs (integration modules) and all responses will necessarily include semantic metadata by using adequate formats such as JSON-LD and RDF.

The security layer will provide mechanisms to enable users' authentication and authorization (security keys and data access levels), data integrity check (hashing functions), confidentiality (cryptography) and availability. The security repository will store all metadata necessary in authentication, authorization and privacy controllers implemented by the security layer.

Finally, the ontologies repository will contain all vocabularies designed to address TB concepts that can be reused across every system. This ensures the semantics for all data available over the DSS-TB. Personalized ontologies will be designed fit the particularities of the Brazilian National Tuberculosis Control Program.

The development of an evaluation protocol is under discussion with the Health Department of the State of São Paulo and the Brazilian Ministry of Health. This protocol should include methods for assessing user's satisfaction on the following parameters: perceived ease of use, perceived usefulness and attitude towards using applications developed as decision-making tools

5. Final Considerations

Health data complexity and heterogeneity can contribute to devaluation of relevant information that is disconnected and spread across different databases. The low integration of information systems prevents information from being cross-checked, compared and used in the scope of operational and managerial activities. As a result, information retrieval and establishment of correlations from multiple data sources remains as a difficult task, making most of the data inaccessible [42].

The proposal of a multi-driven DSS for Tuberculosis is an innovative approach to integrate, combine, process and visualize TB related data. Besides of the inexistence of such kind of tool in Brazilian Unified Health System, the presented clinical and managerial/epidemiological decision support systems will be capable of integrating and processing data from several data sources, systems and applications in a safe way through Semantic Web resources. This will empower managers, policy makers and health professionals with critical information to bear out their decisions towards a better care of TB by gathering useful tools and researches in a robust integrated decision support system.

As a possible limitation, getting access authorization to other systems and databases can be a bureaucratic barrier to the development of this project, considering that it involves negotiation of security aspects and possible costs for systems' adaptations (due to lack of interoperability features). Although they are used by public entities, some of them are proprietary. However, for an initial version and validation of the proposed Decision Support System for TB, the databases and systems that are part of the Tuberculosis Ecosystem are enough.

As future work after the completion of this project, it is intended the adoption of a private and permissioned Blockchain technology in the DSS model to enhance security, accountability, transparency and to provide additional interoperability features to contribute with trustful Tuberculosis data. It is also planned to establish more solid system requirements for the DSS-TB User Clients in collaboration with potential users from health services, including health professional and managers. Finally, negotiations with governmental entities will be carried out to expand participant systems that will be part of the decision support system.

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