OOSTT: a Resource for Analyzing the Organizational Structures of Trauma Centers and Trauma Systems

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***Abstract*—Organizational structures of healthcare organizations has increasingly become a focus of medical research. In the CAFÉ project we aim to provide a web-service enabling ontology-driven comparison of the organizational characteristics of trauma centers and trauma systems. Trauma remains one of the biggest challenges to healthcare systems worldwide. Research has demonstrated that coordinated efforts like trauma systems and trauma centers are key components of addressing this challenge. Evaluation and comparison of these organizations is essential. However, this research challenge is frequently compounded by the lack of a shared terminology and the lack of effective information technology solutions for assessing and comparing these organizations. In this paper we present the Ontology of Organizational Structures of Trauma systems and Trauma centers (OOSTT) that provides the ontological foundation to CAFÉ's web-based questionnaire infrastructure. We present the usage of the ontology in relation to the questionnaire and provide the methods that were used to create the ontology.**

Keywords—biomedical ontologies; trauma system; trauma center; organization

I. INTRODUCTION

The role of organizations and organizational structure has received increasing attention in the delivery of quality of health care. Biomedical research relies, for example, on research organizations, funding agencies, and research infrastructure such as biobanks. Healthcare and healthcare systems rely on healthcare providers, professional organizations, and insurance providers, among others. Over the last years, researchers have increasingly examined the representation of organizations and their structures in the biomedical ontologies community [1,2]. Some ontologies specifically aim to represent social and legal entities related to biomedicine (e.g. the Ontology of Medically Related Social Entities (OMRSE) [3], Document Act Ontology (d-acts) [4,5]). These ontologies provide the basis to represent more domain-specific social and legal aspects of organizations. In this paper, we report the development of the Ontology of Organizational Structures of Trauma systems and Trauma centers (OOSTT) and will report its current and intended future use in the services created by the CAFÉ project[2].

II. BACKGROUND

Injuries caused by traffic crashes, violence, and other mechanisms are a major public health issue worldwide and account for more than 5 million people dying each year [6]. In the United States, injury is the leading cause of death for persons below the age of forty-four and is the fourth leading cause of death overall [7]. The cost of fatal injury and violence in the US was $671 billion in 2013 [8,9]. This situation poses a challenge to healthcare organizations and healthcare providers that must be answered in order to improve the delivery of health care service and to improve the overall population health. The evolution of the trauma center, as an individual hospital with commitment, resources, and expertise dedicated to the care of the injured, has been one approach to addressing the problem. A broader understanding of injury as a public health issue suggests that the optimal approach involves systems of care that address the entire spectrum from prevention through rehabilitation. A trauma system forms a single cohesive operating unit that brings together many facets of health care (e.g., injury epidemiology, regional communication cen-

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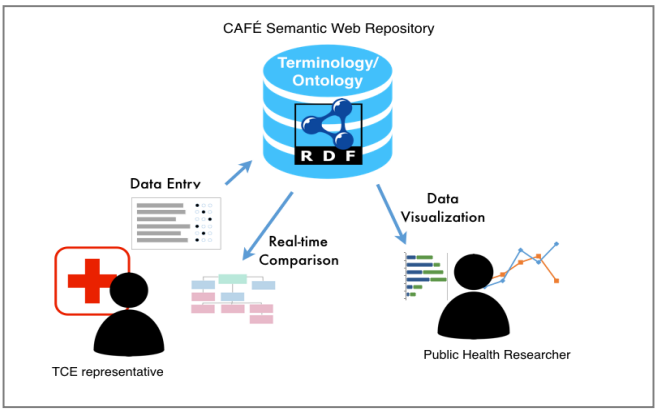
ters, prehospital care, hospital-based trauma care, and rehabilitation) and has been shown to both decrease mortality and improve quality of care [10,11]. Trauma centers, an integral component of trauma systems, have also been shown to improve patient outcomes without specific reference to system participation [11]. Development of future trauma systems will be positively impacted by examination and evaluation of existing trauma systems [12], and improvements in processes and outcomes at those centers often result from verifying trauma centers against published standards [13,14]. The sharing of best practices across trauma systems would be a major impetus to improving the delivery of trauma care.

Although the role of organizational structure in influencing performance of healthcare organizations is widely recognized [15], little is known about which organizational details may particularly influence patient care in trauma centers. The Donabedian structure-process-outcome (SPO) model suggests that good structures increase the likelihood of good processes, and good processes increase the likelihood of good outcomes; good structure can also directly improve outcomes [16]. As Hillmer et al. have argued, the health care outcomes are dictated by the 'interrelationship of structure and process, as well as individual patient characteristics.' even though the exact relationship between structure and process, and the outcome often remains unclear. Understanding these relationships and the interactive pathways is essential to improving the quality of healthcare in trauma centers in particular and in healthcare in general [17]. We aim to address this issue in the domain of trauma centers and trauma systems, by providing a web-based infrastructure to compare organizational structures of both trauma centers and trauma systems, and to collect data about their organizational characteristics.

CAFÉ (Comparative Assessment Framework for Environments of Trauma Care) is an NIH-funded project (1R01GM111324) that aims to develop a web service that allows representatives in interested institutions to pre-assess the organizational structure of their trauma center or trauma system and to learn about possible optimizations. Users will answer a number of questions about the leadership and governance structure of their trauma center or trauma system. Based on their answers, the service will create a graphical representation of the characteristics of the user's organization. One of the challenges we address is the fact that the role of, for instance, a trauma medical director can differ from one institution to another considerably. Hence, we cannot presume the set of rights and obligations that come with that specific role in a given institution. It will be possible for the users to compare their organizational structure to a typical trauma center or trauma system. This comparison will allow

Fig. 1. CAFÉ Framework Architecture.



the dissemination of the best organizational structures across trauma centers and trauma systems. Fig. 1 shows the planned workflows of the CAFÉ environment. In building this system, we will use semantic web technology to ensure semantic integration of data used in the comparative graphics.

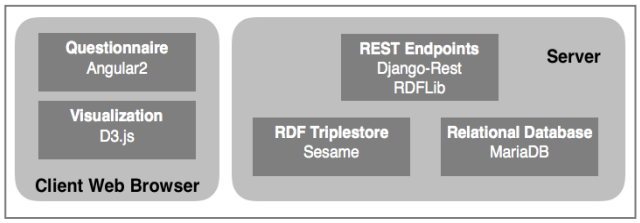
III. METHODS

A. *The CAFÉ architecture*

The CAFÉ application will be implemented on an open source questionnaire framework, which is being developed for the CAFÉ project. The goal of this framework is to capture user responses to a questionnaire in Resource Description Framework (RDF)[3] in real-time.

The architecture of the framework is broadly divided between the client and the server (s. Fig. 2). On the client side of the framework we are creating the questionnaire using Angular2[4], a JavaScript library for creating web applications. The visualizations on the client end are being rendered with the help of D3.js[5], a JavaScript library to help with real-time data visualization in HTML. The server hosts a series of REST endpoints, a SQL database, and an RDF Triplestore. The REST endpoints are implemented in Python using the

Fig. 2. CAFÉ Questionnaire Workflow.



[3] http://www.w3.org/TR/2014/REC-rdf-schema-20140225/

[4] https://angular.io/

[5] https://d3js.org/

Django-REST[6] library and RDFLib[7]. The data is stored in the SQL database MariaDB[8] and the RDF Triplestore Sesame[9].
Two separate data stores are used to keep user identifying information separate from the data we want to share with researchers. Additionally, this ensures the confidentiality of our users. When a question is answered a series of RDF statements is created in the Triplestore. This way, as the user works through the questionnaire a more complete RDF representation of their organization's characteristics are created. The visualization of the user's data will update in real time as they answer the questions.

B. *Domain Analysis*

To allow managing data about organizational structures of trauma centers and trauma systems, the targeted domain, using semantic web technologies and allowing automatic inferences, we decided to create a representation of the domain in an ontology coded in Web Ontology Language (OWL2)[10]. A crucial step in ontology development is the domain analysis [18]. In order to conduct a thorough domain analysis, the CAFÉ consortium includes a group of domain experts with extensive experience in trauma care, management and assessment of trauma programs, trauma centers and trauma systems. The inclusion of the American College of Surgeon's (ACS) Committee on Trauma (COT) in the CAFÉ consortium is essential to ensure that the CAFÉ ontology and the CAFÉ services in general fit the requirements of the trauma center and trauma system management community.

To create a preliminary overview of the number of domain specific terms we used natural language processing (NLP). In a first step we used TermoStat [19], a web-based NLP tool that was chosen for its ability to recognize domain-specific noun phrases that would confound a standard NLP part-of-speech tagger. We extracted a list of domain specific noun phrases (e.g. "trauma program manager") and verbs and ranked them according to their significance. To assess how those terms were related to each other we used WordNet [20,21], a large lexical database of English in which nouns, verbs, adjectives, and adverbs are grouped into sets of cognitive synonyms. We used the hypernym relation to achieve a preliminary understanding of the interrelations among the terms and explore the potential impact of these interrelations on the taxonomy underlying the ontology we planned to build.

Once the NIH project period started, we set up a weekly – in the later phase of the project bi-weekly – teleconference of all CAFÉ domain experts with the ontology experts, with the aim of providing a prioritization of the terms based on the requirements of the project and providing definitions for those terms. Prioritization was done based on the requirements of the service, which aims to graphically represent the organizational structures of trauma centers and trauma systems. To facilitate the collecting and editing of terms we created a Google sheet that captured term label, order of terms, genus-differentia definition, user-centered definition, references for the definition, date of approval of the definition by the domain expert group, examples of usage, comments, background information about alternative pre-existing definitions with source information, and the status of OWL implementation.

Previous work on domain expert language and definitions provided by ontologies strongly suggests that genus-differentia definitions —although instrumental in building the underlying taxonomy of an ontology— do not receive high approval rates from domain experts [22]. This may lead to situations where domain experts are unable to pick the right term, since they do not recognize the term based on its genus-differentia definition. To address this problem in cases where the genus-differentia definition is deemed not helpful by our domain experts, OOSTT provides both a genus-differentia definition and a user-centered description. For the latter we created a novel annotation property: "OOSTT user-centered description"[11]. Genus-differentia definitions are annotated using the Information Artifact Ontology's ontology metadata[12], in particular the annotation property "definition".

One utility of OOSTT is to provide definitions that are displayed to the user filling in a web-based questionnaire or using any other CAFÉ service. Hence, it is crucial that the definitions are recognized and understood by the potential users, most of whom we assume are domain experts. To ensure this we have created a survey requesting domain experts outside of CAFÉ to assess the definitions of the seventeen most relevant terms as identified by the CAFÉ domain experts. For terms that have both a genus-differentia and a user-centered definition, the survey asks for feedback on both. The survey will be distributed via the COT mailing list. Table 1 shows the example of six central terms for representing organizational structures of trauma centers and trauma systems that have been part of our domain expert survey and their genus-differentia definitions.

IV. RESULTS

A. *OOSTT*

[6] http://www.django-rest-framework.org/
[7] https://github.com/RDFLib/rdflib
[8] https://mariadb.org/
[9] http://rdf4j.org/
[10] http://www.w3.org/TR/owl2-overview/
[11] http://purl.obolibrary.org/obo/OOSTT_00000030
[12] http://purl.obolibrary.org/obo/iao/ontology-metadata.owl

The latest release version of OOSTT can be obtained from the OBO Foundry[13]. OOSTT is freely and openly available. It is implemented in Web Ontology Language (OWL) 2 and developed followed the OBO Foundry principles[14]. The community driven development is done using the open source code repository Github[15]. Issues and term requests can be communicated at the repository issue tracker[16]. OOSTT is based on Basic Formal Ontology (BFO), an upper ontology which is frequently used to represent the biological and biomedical domain [23]. In addition, we re-use representations from the Document Act Ontology (d-acts) [4,5] and the Ontology of Medically Related Social Entities (OMRSE) [3]. Currently, OOSTT contains 289 classes, 33 individuals, 68 object properties, and 584 logical axioms.

Table 1: List of six central OOSTT terms and their genus-differentia definition.

regional trauma system	An organization in a defined geographic area that ensures optimal trauma care, which includes injury prevention, access to care, pre-hospital care, acute hospital care, and rehabilitation.
trauma center role	A role that is borne by a hospital or clinic and, if realized, is realized by its bearer providing emergency trauma care through specially trained personnel. The role is the specified outcome of a trauma center designation.
trauma medical director role	A human health care role borne by a physician that, if realized, is realized by having the authority to direct and oversee the management all aspects of the trauma service.
trauma program manager role	A role borne by a human healthcare provider that, if realized is realized by managing the operation of the trauma service, including: supervision of trauma registry, trauma case managers, and support staff; coordination with hospital administration and medical staff; coordination of trauma quality improvement functions; preparation of trauma designation/verification applications, documentation and required reporting; and trauma-specific education and training.
trauma registrar role	A registrar role borne by a human being that, if realized, is realized by preparing, keeping, and overseeing records in a trauma registry.
trauma system	An organization of organizations and healthcare providers to facilitate and coordinate a multidisciplinary response to severe injury.

A key functionality of the ontology is to provide the basis for graphical representations of organizational characteristics of trauma centers and trauma systems and the specific of the institutional role therein. This functionality will be provided in the first half of the CAFÉ project duration by the development of the first set of CAFÉ tools, which center around an interactive questionnaire (s. Figure 3). While users fill in the questionnaire a graphical representation of their organization's structure will be built and compared to the organizational structure of other trauma centers or trauma systems. If the questions that are filled-in concern one of the central roles in a trauma center or trauma system (e.g. trauma medical director, trauma program manager) the system will show the rights and obligations the role bearer holds in the particular organization and compare it to other organizations of the same type.

With respect to the competency questions that guided our OWL development, this means that, at least for the first tier of tools, we have a fixed and pre-defined set of queries our system needs to be able to execute based on the ontology and the data. The range of competency questions is pre-defined by the questions we present the user with on the questionnaire[17]. In a first step an RDF representation of a specific organizational component of the user's organization is created. Then the Triplestore is queried to retrieve data about the same component of comparable organizations. In order to provide insight into the kind of competency questions the ontology is built to answer, we list some examples of them below. The entire scope of competency questions can be assessed best from the questions [18].

- Is there a resolution supporting the trauma program from the hospital governing body?
- Who does the trauma medical director (TMD) report to?

[13] http://purl.obolibrary.org/obo/oostt.owl
[14] http://www.obofoundry.org/principles/fp-000-summary.html
[15] https://github.com/OOSTT/OOSTT
[16] https://github.com/OOSTT/OOSTT/issues
[17] https://cafe-trauma.com/cafe
[18] https://cafe-trauma.com/cafe/questionnaire

- Does the trauma medical director participate in trauma call?
- Who does the trauma program manager report to?
- Does the TMD have the authority to contribute to the trauma program manager's performance evaluation?

Using an OWL representation provides us with the potential to use automatic inference over the data we create by this process. One way we plan to use it is to infer which institutions follow the ACS COT recommendations. For example, the COT's "Resources for Optimal Care of the Injured Patient" [24] specifies the recommended requirements for the trauma medical director depending on the which level trauma center they serve at. Besides the usual requirements regarding their medical training, it also lists requirements regarding their involvement in the trauma community and their ability to oversee and manage the procedures of their trauma program. Using the OWL representation we will be able to represent the role of a trauma medical director compliant with ACS recommendations as a subclass of 'trauma medical director role'. Reasoning over our triple store we will be able to infer which institutions already are fulfilling the requirements. While the institutions will be anonymized, this will still give an number of how many institutions are compliant. Creating those classes in OOSTT is still ongoing work and not described in detail in this paper.

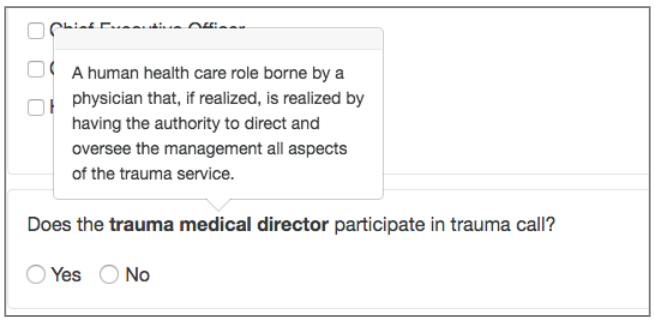
B. Current usage of OOSTT in the CAFÉ infrastructure

In what follows we describe how OOSTT is currently used in CAFÉ infrastructure. The usage of the ontology will evolve as the project progresses and additional tools are developed. At this point the basic CAFÉ infrastructure (Fig. 2) is completely set up.

With respect to the first tier of tools, we have finished the interactive questionnaire for trauma centers. The questions that are on the web-based questionnaire are based on a hospital pre-review questionnaire for Level I and Level II trauma centers developed and used by the Arkansas Department of Health. The web-based tool is used to capture data from representatives of trauma centers or trauma systems wishing to compare the organizational characteristics of their institution to those of user institutions of the same type.

Our goal is to provide users with a fast and seamless way to enter answers to a set of questions. In addition, we aim to prevent problems with data entry by ensuring the user has the ability to understand the meaning of terms as established by OOSTT. To achieve this, we added a feature to the web-based questionnaire that highlights highly domain relevant terms. Hovering over these opens a popover that displays the OOSTT user-centered description or, if none exists, the definition for that term (Figure 3).

Fig. 3. Example of definition popover in CAFÉ online questionnaire.



One of the REST endpoints implemented in the Django-REST component is a list of definitions of all classes currently in the Sesame triplestore. When the questionnaire page is loaded by the user the Angular2 client will make a request for all definitions and then add a popover text box to the relevant terms when the user hovers over them.

As we described above, when a user answers a question, one or more RDF triples will be created and stored in the Sesame triplestore. Some of the triples will create new instances that did not exist in the triplestore before, e.g., answering any questions about the trauma medical director will create an instance of a human with the role trauma medical director. In addition, the triples created will use pre-existing classes (e.g. "trauma program" from the ontology) or from previous question (e.g. the user's institution, which has been created as an instance before). RDF schemata have been created for all questions and are used to create actual RDF triples based on each answer in the questionnaire.

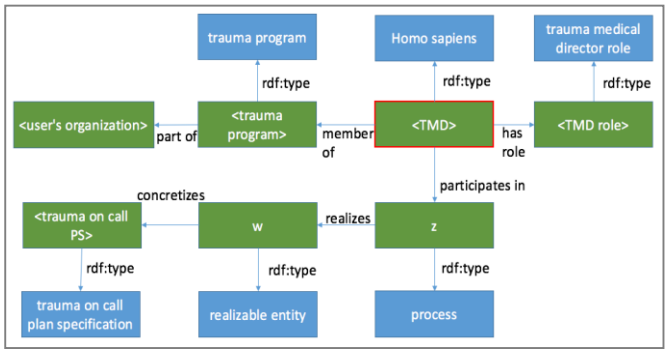
The triples are added to the Sesame triplestore by the Django-REST component. Each question has a series of dependencies on other questions and RDF triples that will be inserted when the question is answered. These triples will be added, with a context specific to that user and question, so that if the user changes an answer the triples can be removed along with any triples associated with questions that depended on that question (e.g. if a user decides they do not have a trauma program manager, all triples related to the trauma program manager will be removed from their institution).

Figure 4 shows an example of such an RDF schema as prepared before entering the information into the into the system.

V. NEXT STEPS

Our immediate next step is to build the questionnaire for entering trauma system information. This will be facilitated by

Fig. 4. RDF schema for question "Does the trauma medical director participate in trauma call?". Blue boxes represent OWL classes provided in OOSTT, green boxes represent individuals, arrows represent rdf:type or object properties. The red box represents the entity, which is created, if this particular question is answered with "Yes".



the fact that we have investigated and setup the entire framework of managing the questionnaires and the answers using OOSTT. Building the trauma system questionnaire will likely result in an extension of OOSTT, as we foresee additional classes and object properties to be required for creating RDF representation for the answers regarding trauma systems.

In the second phase of the project that will start in 2017 we will begin to develop tools for research from trauma research, public health and other related fields to access the data that we captured in our triplestore. This will involve providing query tools and allow graphical analysis of the data in the triplestore. Once the second phase starts we will work closely with domain experts from public health research on trauma centers and trauma systems to ensure that we meet their requirements.

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