An Ontology for Clinical Laboratory Standard Operating Procedures

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Abstract. This paper reports on a knowledge representation model, OCL-SOP, that formally defines key entities pertinent to clinical laboratory procedures. OCL-SOP provides a formal description of laboratory experimental actions, biochemical entities involved, equipment used, input and output data, and the data processing actions. We developed OCL-SOP in collaboration with domain experts. We demonstrate the utility of this knowledge model through a mobile application, SmartSOP, which gives laboratory technicians access to digitized laboratory standard operating procedures (SOPs) and enables searching through the semantically annotated SOPs. OCL-SOP is available at: github.com/fatibaba/EXACT-med/blob/master/OCL-SOP.owl

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1. Introduction

Laboratory testing in hospitals is a crucial step in the diagnosis of diseases. It is, therefore important to ensure quality and reduce error rates in the laboratory testing process. Exchange of laboratory test results, which forms part of the testing process, is another important factor to consider in laboratories. The discrepancies in the measurement standards, terminologies, reporting formats, and interpretation of test results between different laboratories complicate the exchange and integration of clinical information [1].

Health organisations have come together to develop Standard Operating Procedures (SOP) in an attempt to standardise laboratory practices in hospitals. Laboratories use these SOPs for "correct test selection, sample collection and handling, while standardized test terminology, and units of traceability to ISO standard 17511 are required to ensure equivalency of measurement results" [2]. However, the availability of guidance documents does not guarantee their use in the laboratories [3]. One of the major problems faced by practitioners is the inconveniences of finding required information quickly in the SOP documents. These documents are provided as free text either in PDF or MS Word formats with pages ranging from 12 to more than 50. The laboratory technicians find navigating through such documents time consuming, and the search interferes with

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the actual testing process. Another problem is the representation of SOPs in free text using non-standardized terminology which leads to difficulties in the computational comparison of procedures and also in the reproducibility of the results [4].

We propose a knowledge representation model, OCL-SOP (an Ontology for Clinical Laboratory SOP), that formally defines laboratory procedures and the associated data. Ontologies have been useful for knowledge representation in different areas including healthcare [5-7] and are becoming popular for representing clinical practice guidelines [8]. We extensively analysed Standards for Microbiology Investigations (SMI), that are SOPs provided by the Nation Institute for Health and Care Excellence (NICE) [9], and also consulted with microbiology experts for the development of OCL-SOP.

OCL-SOP aims to facilitate clinical data exchange, support information retrieval and improve reproducibility of laboratory procedures. We demonstrate the utility of this knowledge model through a mobile application, SmartSOP. SmartSOP gives laboratory technicians access to digitised SOPs, enabling semantic information retrieval, recording test results in a standardized form and recording relevant activities in the lab.

2. Related Works

Several projects are focusing on the semantic representation of biomedical protocols. BioAssay Ontology (BAO) describes chemical biology screening assays and their results for the purpose of categorising assays [10]. Another example of standardized protocol representation is the Ontology for Biomedical Investigations (OBI) [11] which represents different phases and activities involved in biomedical investigations. "OBI broadly describes terms that are applicable to the biomedical and technological domain which address the need for a cross-disciple ontology" [11].

The ontology for experimental actions (EXACT) provides a generic semantic representation of experimental protocols to ensure their reproducibility by humans and machines [12]. EXACT describes such experimental actions as *'add'*, *'incubate'* along with their descriptors, e.g. *'temperature'*, *'biochemical entities'* involved, and *'period'*.

The described projects do not focus on protocols that are specific to hospital laboratories. In this paper, we present OCL-SOP which re-uses relevant representations, and principally extends EXACT by knowledge pertinent to clinical laboratory protocols.

3. OCL-SOP

We developed OCL-SOP to capture the descriptions of the laboratory experimental actions, biochemical entities involved, equipment used, input and output data, and also the data processing actions. We developed OCL-SOP in collaboration with domain experts; they were involved in the specification of requirements and validation of the descriptions of experimental actions. We focused on NICE SMIs, with a total of 47 currently available. We extracted from these SMIs all the terms used in the description of experimental actions and their descriptors.

All experimental actions defined in EXACT were present in the considered SMIs. Therefore, we used EXACT as the upper-level ontology for OCL-SOP and imported other suitable classes from other sources. The structure of OCL-SOP inherits the EXACT ontology structure, and has the following main branches:

- *'Process'* to model processual entities, e.g. *'experimental action'*.
- *'information content entity'* to model information about SOPs, e.g. *'date submitted'*.
- *'Descriptor of experimental action'* to model entities pertinent to the actions, e.g. an action *'incubate'* requires the description of a *'period'* of incubation, and what *'biochemical entity'* will be incubated.
- *'Optional descriptor of experimental action'* to model non-essential (but still useful) entities pertinent to actions, e.g. *'temperature'* may not be essential for the description of *'incubate'* since a default value of 30℃ may be used.

Figure 1 shows a fragment of the OCL-SOP classes and their hierarchy. The class names are prefixed with their source ontology name to show which ones are imported and which ones are OCL-SOP specific classes.

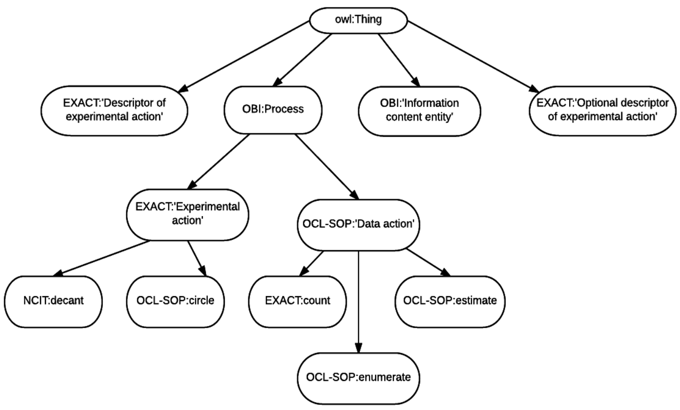
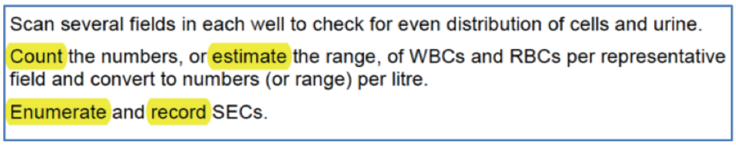


Figure 1. The upper-level of the OCL-SOP.

We refined the descriptors of several experimental actions. Our analysis shows that the NICE SMIs express '*temperature*' and '*period*' as ranges. To capture this, we created such descriptors as *'min temperature'*, *'max temperature'*, *'min period'*, and *'max period'*.

The analysis of NICE SMIs shows that there are many data-specific actions, see Figure 2 with a fragment of the urine investigation SMI document with data-specific actions *'estimate'* and *'record'*. To capture data-specific actions, we extended OCL-SOP by adding the *'data action'* sub-branch to the *'process'* branch. In EXACT, the actions *'record', 'measure', 'calculate'*, and *'count'* were defined as *'experimental actions'*. We re-modelled these actions as data-specific actions. We also added new *'data actions',* e.g. *'convert'* and *'estimate'*.



Scan several fields in each well to check for even distribution of cells and urine.

Count the numbers, or estimate the range, of WBCs and RBCs per representative field and convert to numbers (or range) per litre.

Enumerate and record SECs.

Figure 2. A fragment of urine analysis SMI showing data actions.

We identified 68 new experimental actions, i.e. actions that were not defined in any other knowledge representation resource. They were added to OCL-SOP as new classes, e.g. *'emulsify'* and *'double dilute'*. The semantic meaning of the classes in OCL-SOP is specific to the clinical laboratory domain. For example, *'double dilute'* means to do a serial dilution of a solution, and this differs from the conventional meaning in other areas: horses carrying a certain type of gene. Table 1 shows examples of new terms in OCL-SOP and their definitions.

Table 1. Examples of new terms and their definitions in OCL-SOP.

Term Name	OCL-SOP Branch	Definition
'double dilute'	Experimental Action	A dilution of a solution to reduce its concentration made twice.
estimate	Data Action	To give a range of probable values for a given entity.
tilt	Experimental Action	To slant a biochemical entity or equipment slightly to one side.
stain	Experimental Action	To use a colouring agent to enhance the structure of a 'biochemical entity', usually a specimen, for easy viewing, using equipment such as a microscope

The terminology in SMIs differs from the terminology used in biological protocols. To capture that, we added SMI-specific synonyms to terms previously defined in other resources. For example, the synonym '*agitate'* was added to the term *'shake'* via the relation *'has-synonym'*.

Many of these terms have been already defined in other knowledge models. For example, '*incubate*' and '*mix*' are defined in EXACT, and '*decant*' is defined in the National Cancer Institute Thesaurus (NCIT) [13]. Following the best practices in ontology development and the recommendations by OBO foundry [14], we re-used these definitions and imported the relevant classes to OCL-SOP. We used OntoMaton [15], an ontology search tool, to find ontologies in the BioPortal that have defined similar terms. Table 2 shows example re-used classes and the source ontologies.

Table 2. Examples of re-used terms in OCL-SOP.

Term Name	Ontology Source	Ontology Full Name
count	EXACT	An Ontology for Experimental Actions
decant	NCIT	National Cancer Institute Thesaurus
observe	BIOMO	Biological Observation Matrix Ontology
streak	EXACT	An Ontology for Experimental Actions
dispense	NCIT	National Cancer Institute Thesaurus

We developed OCL-SOP using Protégé, and it is freely available in OWL-DL format with all external import files at https://github.com/fatibaba/EXACT-med.

4. Use Case: SmartSOP

We used the terms defined in OCL-SOP ontology to represent Urine Investigation SMI and the Internal Quality Assurance (IQA) procedure of a particular microbiology laboratory from a hospital in London. This laboratory needs a simple representation of SOPs to encourage technicians to follow the guidance and allow them to retrieve the necessary procedural information quickly. We developed a mobile app SmartSOP that enables an easy access to the lab procedures. SmartSOP provides a user friendly semantically annotated versions of the Urine Investigation SMI and IQA.

The use of OCL-SOP ensures that all the terms are disambiguated (via globally unique identifiers) and have logically consistent definitions. The semantic search functionality enables users to find information about experimental actions easily, including by their synonyms. SmartSOP enables lab technicians to record the results of lab procedures in a dedicated MySQL database, and export these results to CSV files. This makes sharing of the results by different labs easier despite the differences in the platforms used. SmartSOP provides lab technicians with a secure login and keeps track of the activities of each technician. This is important for quality assurance management in the laboratory.

Clinical lab practitioners and biomedical scientists evaluated our SmartSOP positively. We conducted a user acceptance test; six laboratory technicians used the app and their feedback was captured through a questionnaire. The technicians agreed that it would make their work easier and more efficient. They suggested that such an app will be even more useful for the representation of more complex procedures. Such procedures require specialist knowledge in order for them to be performed due to the vast number of rules and conditions lab technicians must consider, and the complexity of interpreting results. A usability evaluation of the app in accordance with the usability principles provided by the Health Information Management Systems Society that measure effectiveness, efficiency and user satisfaction of medical applications, was also positive.

5. Conclusion and Future Work

In this paper, we report on the development of OCL-SOP, an ontology for the representation of hospital laboratory SOPs. OCL-SOP imports relevant terms from several knowledge models and defines 68 new terms required for the representation of NICE SMIs. We present a mobile application SmartSOP which utilises OCL-SOP for the visualisation of SOPs, semantic search, and recording clinical test results.

We plan to analyse more clinical laboratory SOPs to provide a better coverage of actions in OCL-SOP. We are working on aligning OCL-SOP with a newly emerging standard, the Robot Task Ontology [16] to support the development of autonomous robots which will carry out clinical laboratory procedures. We will add more complex laboratory procedures such as the detection of Carbapenemases to the SmartSOP application. This procedure includes complex algorithms which are more difficult to follow. We also plan to support automatic update of SOPs in SmartSOP whenever OCL-SOP is updated.

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