Towards Evidence-Based Ontology for Supporting Systematic Literature Review

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Abstract—[Background]: Systematic Literature Review (SLR) has become an important software engineering research method but costs tremendous efforts. [Aim]: This paper proposes an approach to leverage on empirically evolved ontology to support automating key SLR activities. [Method]: First, we propose an ontology, SLRONT, built on SLR experiences and best practices as a groundwork to capture common terminologies and their relationships during SLR processes; second, we present an extended version of SLRONT, the COSONT and instantiate it with the knowledge and concepts extracted from structured abstracts. Case studies illustrate the details of applying it for supporting SLR steps. [Results]: Results show that through using COSONT, we acquire the same conclusion compared with sheer manual works, but the efforts involved is significantly reduced. [Conclusions]: The approach of using ontology could effectively and efficiently support the conducting of systematic literature review.

Keywords—systematic literature review; ontology; structured abstract; software cost estimation

I. INTRODUCTION

Systematic Literature Review (SLR) aims at identifying, evaluating and interpreting all relevant materials to a specific research question [1]. The procedure of conducting SLR mainly consists of 5 steps: a) identification of Research; b) study selection; c) study quality assessment; d) data extraction; e) data synthesis. SLR typically requires much more efforts compared to traditional reviews [1]. To conduct SLR, researchers have to review a great number of literature collected from various sources, e.g. papers published on conferences and journals, technique reports, advices of authorities, and various other materials. Researchers have to review a great number of literature to achieve consistent understanding on its details. Though quick scanning may be helpful in making decisions, it tends to decrease the fairness and objectivity as well as increase the bias of the final results. Therefore, methods that could both reduce the involved effort and guarantee the quality of SLRs are in great need, which motivate the research work of this study.

There are numerous studies focusing on how to effectively and efficiently conduct SLR in software engineering field. Zhang et al. [2] employ a systematic and evidence-based approach to develop and execute optimal search strategies in SLR. However, every time of conducting a SLR, they have to construct the “standard” manually, which is quite an effort intensive task. Emam et al. [3] tried to apply visualization in support of the conducting of SLR. However, lots of human judgments are also indispensable to implement the SLR processes. This paper reconsiders the problem of using ontology to organize and manage knowledge needed for SLR.

Defined as “an explicit specification of a shared conceptualization.” by Gruber [4], ontology has many advantages in dealing with knowledge related work [5]. Ontology based approaches attract software engineering researchers’ attentions in various sub-fields. The whole lifecycle of software engineering could be greatly assisted due to a number of advantages of applying ontology techniques [6]. Zhang et al. [7] use ontology-based approach to reason security concerns of software. It can also be used to organize knowledge of a problem domain [8]. For knowledge centered tasks, ontology could be a great help. One of these tasks is systematic literature review in software engineering field. We try to model an ontology structure capable of supporting SLR.

In this paper, abstract is an important source for developing our ontology structure. According to Kitchenham et al. [1], current procedures suggest that a review of the title and abstract of a primary study should be sufficient to decide whether or not one study is relevant to a SLR. Budgen [9] has proved that structured abstracts are easier to read and contains more complete information. Kai Petersen [10] also claimed that structured abstracts may be a great help in conducting SLR. Though SLR could not be conducted by reviewing abstract only, abstract provide abundant and significant information that is in support of SLR steps, such as study selection. Therefore, abstracts are chosen as crucial research objective in this study.

The purpose of this study is to find an approach to build general empirical ontology, and specifically addresses its application on facilitating SLR in the software engineering field. The structure of abstracts is chose as an important evidence of building ontology. Protocol guiding the conducting of SLR is another important source. Based on these evidences, Systematic Literature Review ONTology (SLRONT) is
discussed and built. Then we propose a specification extension of SLRONT on cost estimation systematic review, and build the structure of Cost estimation Ontology (COSONT). Key concepts and knowledge are extracted and added to the ontology as instances to instantiate the knowledge base. Two case studies illustrate the usefulness of our approach.

The rest of this paper is organized as follows: section 2 presents the details of building SLRONT, extending it to more specific COSONT, instantiating COSONT with extracted knowledge from abstracts and how to use it to support SLR; section 3 describes case studies we conducted; section 4 offers detailed discussion and the limitations; and finally, we make conclusion in section 5.

II. METHODOLOGY OF BUILDING ONTOLOGIES

The overview of methodology is shown in Figure 1. First, we establish SLRONT, which work as groundwork for more specific ontologies. Then based on typical structure of review protocol of SLR and structure of typical domain abstracts, we extend SLRONT into more specific ontology, the COSONT. Working as a knowledge base, COSONT could support research query for concrete cost estimation questions. The retrieved knowledge and concepts provide support for SLR procedures.

A. Construction of SLRONT

Whether the structure of ontology is suitable enough is mainly depend on whether or not it could effectively support knowledge centered tasks in certain domain. In this study, we develop the hierarchy of SLRONT with the top-down method. The ontology models both the review protocols and the primary study. The relationship between these two sub-parts is a many-to-many mapping. That is, for a specific systematic literature review protocol, there are many primary studies relating to it and vice versa. The top level structure of ontology is designed in Figure 2:

1) Ontology structure of systematic literature review protocol: According to Kitchenham et al. [1], SLRs conform to strictly defined procedures. The top level procedure of SLR includes planning, conducting and reporting three phrases. In order to guarantee the overall quality of the whole procedures, review protocols should be defined at first. Researchers have to figure out what are the constraints and why the SLR should be conducted in that way. They are designed by the researchers according to specific requirements in the planning step (the early stage of SLR), so that the researcher bias would be furthest reduced [1].

Figure 1. Methodology

![Figure 1. Methodology](image)

A. Construction of SLRONT

As shown in Figure 3, researchers should build impartial, unbiased protocol based on their expert judgment. All of these aspects should be defined explicitly for a specific SLR at the planning stage of SLR. The protocol is helpful for researchers to understand the research question for the reason that once all these factors are designed, the scope of SLR is also clear constrained. After adding the review protocols, the ontology grows into the following form in Figure 4:

2) Ontology structure of primary study: This part of ontology is created to organize the knowledge contained in primary studies. Most primary studies are well written in consistent modern writing style. They are mainly organized as: title, author & affiliations, abstract, keyword, full-text and references. In SLR, almost all of these parts are needed to be reviewed to find the answer to the research question. While in this study, we investigate mainly on the abstract part.

In primary study, abstract plays a unique role in conducting SLRs. Though reviewing pure abstract could not fulfill SLR's requirement of "thoroughly survey every primary study", abstract is still effective enough for narrow down the scope of
candidate relevant studies. In SLR, the purpose of the study selection step is to identify primary studies that provide direct evidence to the research question [1], which is in fact mainly performed with the help of abstracts (Review the detail of full-text is still necessary if disagreement exists). What's more, data extraction in abstract could assist SLR tasks in more general level for the reason that usually the most crucial information is presented in abstract part.

The advocating of writing structured abstracts has been prevailing in recent years. Many studies have focused their survey on better clarity and completeness of structured abstracts compared to conventional abstracts [12] [13] [9]. Due to its key role in academic study, abstract has the advantage that its quality is assured by the authors “inborn”. But the majority of existing papers has only conventional abstract. Therefore, syntactical analysis could automatically transfer unstructured abstracts into structured ones, and extracts knowledge out of the segmented parts. This could save time for “high” level review in conducting SLR.

A standard structured abstract includes the following five parts: Background, Object, Method, Result and Conclusion. Structure of other parts of literature is out of the scope of this study, which will be surveyed in our future works. We develop the following structure to represent primary studies. Details are shown in Figure 5. The “structured abstracts” class is extended with five sub-classes. The dotted circle represents other parts of primary studies; we focus mainly on structured abstract in this study.

Since the quality of unstructured abstracts is not as good as structured ones, we make a simplification here so that unstructured abstracts could be converted structured abstracts with grammatical and syntactical analysis. We combine the “object” part of structured abstracts into the “method” part and combine the “result” part into the “conclusion” part. Therefore, five subclasses of structured abstracts are briefed into three subclasses: background, method and conclusion.

The main extending work lies in the method sub-class of structured abstracts. According to the cost estimation systematic review of Jorgensen et al. [14], the most common research topic is the introduction and evaluation of methods (with 61% of the papers). The methods are: regression, analogy, expert judgment, neural network and bayesian etc. Also metrics like size and uncertainty of effort are popular topics. Therefore, we concluded that the most widely concerns of this field are: a) what methods are used; b) what are the metrics adopted; c) in what context the study is launched. We extend the SLRONT into COSONT based on the above discussions. For the method class, we build three sub-classes: model, metric and SE feature. Due to the limitation of space, only subclasses of model class are presented. We also build a “simple conclusion” class as the subclass of “conclusion” class. Details are shown in Figure 6.

This is only an empty structure, COSONT needs to be instantiated. We use the Stanford Parser to parse the structure of abstract sentences. With the grammatical and syntactical rules, unstructured abstract is converted into structured ones. Then knowledge and concepts are extracted from the method and conclusion part of structured abstract. They are further added to COSONT. Please refer to our technical report [15] for the details.

C. Automated Query and Retrieval

When COSONT is built up, it works as a knowledge base for further SLR studies. Since key knowledge and concepts relevant to specific cost estimation research question is extracted from abstracts and is inserted into the ontology structure, researchers could use SPAROL queries to retrieval them. Then relevant analysis is conducted on the retrieved results. This will save many efforts than manually check each literature and extract information out of them. Next section will discuss the detail by two case studies.

III. CASE STUDY

In this section, we illustrate the application of our method through 2 example scenarios:

1) Research question for scenario 1: Find all cost estimation literatures discussing both regression and neural network methods.

2) Research question for scenario 2:
Is regression method considered “better” than neural network method?

Towards the researching area of software effort estimation, we use "effort prediction" as the primary search string. Four most popular digital libraries: IEEE Explorer, ACM Digital Library, Springer and Science Direct are searched with this string. As a raw set, we got 645 papers. Then, all parts of abstract are manually examined, with the help of title and keywords. If there are papers difficult to identified, we will go through the full text to make the advanced decision. Moreover, experts are invited to supervise the whole process and assure the quality of final results. After carefully selection, 347 papers are selected as the final dataset.

Then we instantiate the COSONT with extracted concepts and knowledge. Every paper is added to the primary class as an instance. Simple conclusions extracted from conclusion part are added to the conclusion class. All the noun phrases extracted from the method part are added to classes and subclasses of Model, Metric and SE-feature classes, according to its hierarchical categorization.

We invited 4 PhD students to participate in our case study; all of them have background of SLR. At first, we give them proper training to enable them to have an overview of the whole work.

A. Study 1: supporting study selection

In this step, each student is randomly assigned around 87 papers of the overall 347 papers. The main inclusion/exclusion criterion is that the paper should mention both regression and neural network models. They should go through the details of abstracts. Based on their personal judgment they filter out those irrelevant ones. They were also asked to record the efforts they used. As a comparison, we query COSONT to check the method part of abstracts automatically to find relevant paper. The SPARQL querying COSONT are listed in Figure 7. The results of manual work are showed in Table 1.

As shown in Table 1, 11 papers are identified at last. Manual selection is rather time consuming. The total time used is 35 Person Hours. However, using our COSONT, we select the same set of studies but the time used by COSONT could be ignored. Results show that it is rather convenient to use COSONT to accomplish this task. After this study selection step, we give answer to our SLR question: There are 11 papers in the dataset discussing both regression and neural network method.

B. Study 2: supporting data extraction

In this case study, 4 PhD students need to find whether regression method is better than neural network in cost estimation research area. They should further check abstracts of identified paper set to judge whether the topic of a paper is about the comparison between two models, and make their further judgment about which model is better. Meanwhile, we use COSONT to get simple conclusions extracted from each paper. And we make our decision based on the extracted information. The SPARQL sentences are listed in Figure 8. Results are shown in table 2. Note that R denotes regression and NN denotes neural network.

As shown in Table 2, of the total 11 papers, student 1 believes there are 5 papers about the comparison between two methods. Among them, 3 papers contend neural network is better, no paper said regression is better, and 2 papers said there is no big difference between them. So Student 1 reached the conclusion that neural network is better. The table shows that all of the 5 testers (including COSONT) reach the same conclusion. Time used by applying COSONT is much less than each of the 4 PhD students. After this data extraction step, we could give answer to our SLR question: Neural network is “better” than regression model in performing cost estimation.

In these studies, we reached the same conclusion using COSONT compared with sheer manual work. However, in each step of SLR, time used by COSONT is significantly less.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>No. of Abstracts about Comparison</th>
<th>Number of results</th>
<th>Which is Better</th>
<th>Time Used (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student 1</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Student 2</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Student 3</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Student 4</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>COSONT</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

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IV. DISCUSSION

In this study, one general purpose ontology, SLRONT, is built to support systematic literature review. To illustrate its usage and effectiveness, a specialization form, COSONT is built to extend it.

Firstly, ontology has multiple advantages in supporting knowledge intensive tasks, such as knowledge reuse, knowledge expansion and machine reasoning. Though extra efforts may be cost in building ontology, the benefits of
ontology are profound and will give positive effects to future researches.

Secondly, ontology structure enables sharing knowledge between different research groups, which helps to improve the development of software engineering subjects. Research groups in small scale may have problem in conducting SLR for lacking of the considerable amount of efforts. With the help of ontology, more researchers could conduct SLRs without the worrying of paying too many efforts.

Thirdly, using the automatic methodology, core contents of an abstract can be automatically identified and analyzed. Not all of the concepts and knowledge contained in abstract is useful, and some of them may even confuse the automatic searching behavior. For example, irrelevant concepts in background part of abstracts are quite confusing. Our method extracts knowledge from more relevant parts: the method and conclusion part of structured abstracts, and could quickly filter out irrelevant materials.

There are also some limitations of our work. First, more detailed ontology should firstly be configured to more specific applications in specific areas. Second, while converting unstructured abstract into structured ones for COSONT, we reduce the five sub-parts into three sub-parts. In this paper, we consider this level of granularity is detailed enough. However in other circumstances, more detailed structuralizing may still be needed. Thirdly, we only give an example of facilitating the second and fourth step of systematic literature review. Further studies are needed in proving the usefulness of ontology’s supporting of other conducting steps. The fourth but not the least, only abstracts are analyzed to instantiate ontology knowledge in our work. We will continue to survey using the full-text and other parts of primary studies in the future.

V. CONCLUSION

We propose a general purpose SLRONT to facilitate knowledge intensive researches, the systematic literature review. The review protocol of SLR is modeled into the ontology in order to better organize these concepts. Structured abstracts are also taking advantaged of in building SLRONT. To illustrate its effectiveness, we specify it into more detail structure, the COSONT. Then we use this out built COSONT to support the ponderous work involved in systematic literature review. We conduct case studies to account for the usefulness of our approach and receive exciting results. And therefore convince us that ontology is a good tool to support intensive efforts required in conducting systematic literature review.

REFERENCES